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Opinion

Co-conserving Indigenous and local knowledge systems with seeds

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Indigenous and local knowledge (ILK) holders have deep ecological, horticultural, and practical knowledge of plants, but this knowledge is not routinely considered and supported along with seed collections conserved *ex situ*. In this opinion, conceived collaboratively by a team of botanists, ecologists, ethnobiologists, and practitioners in biodiversity and ILK systems conservation, we propose seven actions towards the co-conservation of seeds and associated knowledge to overcome obstacles and encourage *ex situ* conservation institutions to support knowledge holders in multiple ways. Success depends on simultaneous changes in conservation practices, new collaborative relationships, and shifts in policy to share and conserve biocultural diversity. Failure to act will witness the continued erosion of ILK and depreciation of *ex situ* plant collections.

Highlights

A sustainable future requires securing of the fundamental relationship between humans and biodiversity. This includes not only the conservation of biodiversity, but also the Indigenous and local knowledge (ILK) associated with it.

Indigenous peoples and local communities (IPLCs) hold wide-ranging knowledge about plants and their ecology, properties, propagation, and cultivation from seed. ILK is globally threatened but rarely considered and conserved alongside *ex situ* seed collections, despite being key to the success of these collections.

Co-conservation of biodiversity with ILK through support of IPLCs enhances conservation success and improves the prospects for the future uses of *ex situ* collections in worst-case scenarios such as extinction or in mitigating the negative impacts of climate change.

The essential relationship between knowledge holders and nature

ILK (see Glossary) encompasses the knowledge, skills, practices, and innovations related to all aspects of human life, including food, healthcare, fuel, shelter provision, and environmental management, and is a fundamental aspect of cultural expression and identity [1,2]. ILK is embedded into multiple-value systems that can artificially be distinguished in instrumental, intrinsic, and **relational values** [3,4], hereafter named biocultural values. ILK describes the ecology, management, harvest, preparation, and use of plants and, in the case of crops and other plants in cultivation, storage, germination of seeds, planting, and maintenance. All of these knowledge domains are integrated in place-based worldviews. ILK systems underpin not only the domestication of crops, cultivars, and varieties through centuries of experimentation and the selection and diversification, transportation, and care of plants by knowledge holders [5–10], but also the shaping and conservation of wild plant diversity [11]. However, rapid socioeconomic, ecological, and climatic changes weaken the relationships between **Indigenous peoples and local communities (IPLCs)** and their environments, threatening their ILK systems [12]. Since ILK systems inherently develop with cumulative, place-based experiences of social–ecological inter- and transgenerational interactions [13], knowledge holders are particularly compromised by loss of language and biological diversity, IPLC rights, access to biological resources, and knowledge transmission pathways [14–17]. Such loss changes their livelihoods, institutions, religions, and beliefs and risks environmental degradation [14–17]. In parallel, ILK is increasingly recognised as essential for effective biological conservation, sustainable use, and fair and equitable sharing of benefits from the use of genetic resources [18–20]. While knowledge holders are increasingly considered and their knowledge incorporated in conservation approaches, this is far from routine.

ILK systems are important for seed conservation

Transformation or loss of traditional common-based seed systems threatens agrobiodiversity and the associated ILK, but only the former has been subject to systematic collecting and

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conservation efforts. This is also the case for natural and seminatural social–ecological systems involving culturally important wild plants. Farmers maintain multifunctional landscapes with a multitude of plants adapted to forests, hedges, fallows, gardens, meadows, or fields to ensure a diversity of uses taking into account species characteristics and seasonality [21]. Multiple-value systems generating the diversity and the dynamism of ILK coexist with these multifunctional landscapes and together they sustain a diversity of plants [22,23].

Farmers' seed systems circulating seeds (and other planting material; e.g., cuttings, stems, tubers) outside the commercial seed sector and formal regulation manage and conserve seed diversity locally thanks to complex, dynamic, and open networks that combine short- and long-distance exchanges [24]. They facilitate the exchange of both seeds and associated knowledge between farmers [25]. Local management systems are driven by local communities, including farmers, gardeners, and biodiversity knowledge holders, who are sometimes organised more formally around **community seed banks** and **seed-saving networks**, as well as foraging associations. These organisations are often grounded on relational values associated with pragmatic knowledge related to plants [26–28].

Both **botanic gardens** and **genebanks** store domesticated and non-domesticated plant diversity that is of cultural as well as ecological value [29]. However, securing the fundamental relationship between humans and biodiversity necessitates the future availability of genetic material as well as the associated dynamic ILK systems. While much material biological diversity today is being conserved in preserved and *ex situ* living collections, failure to support knowledge holders in the co-conservation of ILK systems together with both agrobiodiversity and wild biodiversity weakens humanity's resilience to the worst-case scenarios of *in situ* extinction and climate change impacts on humans, nature, and their relationship [12,30,31]. Supporting ILK holders alongside biodiversity is key to achieving the Sustainable Development Goals[i,ii] [32,33]. Global loss of ILK [12,31] and lack of recognition of ILK holders [76] is a concern for *in situ* conservation and dynamic management of plant genetic resources, but even more so for the meaningful conservation of seeds and plants *ex situ*, in the living collections of botanic gardens and genebanks.

A shift in seed conservation

Active seed exchange and seed-saving networks are highly effective in conserving ILK along with agrobiodiversity's genetic resources *in situ* [9,34–36], but they are vulnerable because of their dependence on a critical number of passionate members [37,38]. Farmers interested in organic farming and other agroecological practices have a growing interest in heirloom crops and wild foraged species, but associated ILK has been lost, is difficult to find, or is no longer adapted to current growing conditions. Seed saver and seed exchange networks, including farmer led, face similar difficulties, with ILK disappearing alongside seed varieties. In addition, migration of both people and plants further overwhelms ILK systems and requires enhanced access to new seeds and knowledge [39]. Genebanks, one source of biodiverse seeds for farmers [40], are registering an increased interest from farmer groups, seed saver associations, and non-governmental organisations (NGOs), in addition to researchers and plant breeders for whom they were originally developed. Data from the international Consultative Group on International Agricultural Research (CGIAR) genebanks show an increase in the share of accessions sent to group farmers, farmer organisations, and NGOs, from 8% in 2015 [40] to 15% in 2019 [41]. This signals a shift in their purpose and target audience that requires new information flows and closer relationships among the users and conservators [42]. Living collections in botanic gardens, and even viable seed preserved with specimens in herbaria, are also key sources of plant biodiversity to support local dynamic management and knowledge systems, reintroducing lost species or varieties or contributing to local adaptation to global change by sharing species and varieties new to specific local seed

Glossary

Botanic gardens: educational, academic, and conservation institutions, custodians of *ex situ* living plant collections. The aim of most botanic gardens is to conserve rare and threatened plants, fulfil sustainability goals, battle plant awareness disparity, and inform and inspire their visitors.
Community seed banks: institutionalised common-based seed systems, often funded by NGOs and sometimes in collaboration with national genebanks and research institutions. In community seed banks, organised groups manage and govern seeds (including selection, conservation, multiplication, exchange, and improvement).
Genebanks: *ex situ* conservation programmes that store biological material (often seeds for plants) and should promote the availability of these genetic resources for research, breeding, education, agriculture, and repatriation.
Indigenous and local knowledge (ILK): a cumulative body of inter- and transgenerational place-based knowledge that includes worldviews, institutions, practices, techniques and technologies, and innovations produced by Indigenous peoples and/or local communities. It is underpinned by multiple relational values with nature and humans, in addition to intrinsic and instrumental values. ILK is held by individuals, customary institutions, and communities.
Indigenous peoples and local communities (IPLCs): there are no universally agreed definitions for IPLCs. Indigenous peoples are recognised by the UN based on a range of criteria including diverse cultural features (language, material culture, cosmology, etc.), origin, and residence. Local communities have historical relationships to place and natural resources that have resulted in ecological knowledge, customary and formal institutions, and dynamic resource management practices.
Relational values: entail reciprocity and refer to the diversity of material and non-material relationships that people and communities nurture with nature, and among people through nature.
Seed-saving networks: farmer-led, place-based, customary or informal communities of growers selecting, sharing, and saving seeds.

systems. However, at present they rarely fulfil this role. Here we argue that *ex situ* seed conservation efforts of whatever kind should explicitly co-conserve local knowledge systems and dynamic seed management with knowledge holders to address the vulnerability of both plant biodiversity and ILK.

Actions to support co-conservation of ILK with seeds

ILK conservation strategies are grounded on fair collaborations and typically either 'store' or 'share' ILK to preserve it or undertake a combination of the two [37]. ILK remains vastly underdocumented [43], and 'storing' strategies for ILK conservation such as written documentation of ILK and policy/legislation efforts are the most common. Guided by FAIR and CARE best-practice protocols [44] and respecting Indigenous and local data sovereignty [45], 'storing' strategies can play a key role in claiming rights and benefits from biodiversity [37]. Nonetheless, and as ILK is also tacit, dynamic, and adaptive, documentation strategies can never fully preserve it. Self-directed visual documentation of complex knowledge systems in video format and subsequent sharing are a better documentation format [46]. Participatory videos, for instance, can document oral history [47] and capture at least some nonverbal knowledge [48]. However, while audiovisual media can honour culturally significant modes of knowledge dissemination in ways not achievable by written formats, books continue to be a welcome means of documentation by many communities. 'Storing' strategies may be helpful for sharing beyond local networks, but as ILK relies on knowledge holders' direct relationship with the environment, its conservation should always include initiatives that support knowledge holders [37,49]. 'Sharing' approaches can be tailored to local contexts and needs and lend themselves more easily to allowing learning, adaptation, and strengthening of networks of cultural transmission [38].

Supporting ILK holders to preserve their knowledge systems would generate mutual benefits to be shared between multiple actors, including fulfilling the ultimate goals of genebanks, to make biodiversity accessible for sustainable use and development in a fair and equitable way, and of botanic gardens, to conserve biodiversity, support research, and engage the general public (Figure 1) [40,42], taking into account nutritional security, social justice, climate change, and pollution [50]. Here we propose an integrated set of storage, sharing, and support actions for the co-conservation of ILK systems and *ex situ* plant material.

Action 1: facilitate access to plant material

Dynamic ILK systems are dependent on both individual and community knowledge as well as access to material plant diversity. A more flexible system for seeds and ILK going into, and out of, genebanks and botanic gardens would support grassroots associations and individuals to maintain *in situ* dynamic management and (re)introduce lost and new diversity [40] with associated knowhow. This is especially important in strategies for adaptation to changing social–ecological and climatic conditions where new biodiversity may be adopted (Box 1) as well as in contexts of ILK systems revival.

Action 2: support policy for customary seed exchange

Easy seed exchange is imperative to sustain ILK systems and multiple biocultural values of seed for the future. Variable legislation makes seed exchange bureaucratically burdensome if not illegal. The legal regimes affecting such customary practices include intellectual property rights and seed laws, but also the Access and Benefit Sharing provisions in the international biodiversity agreements of the Convention on Biological Diversity (CBD) and the Plant Treaty [51]. Restrictive legislation affects grassroots associations and botanic gardens alike. While grassroots associations are engaged in creating and maintaining the legal mechanisms for customary non-commercial seed exchange (Box 2), Botanic Gardens Conservation International has developed an alternative

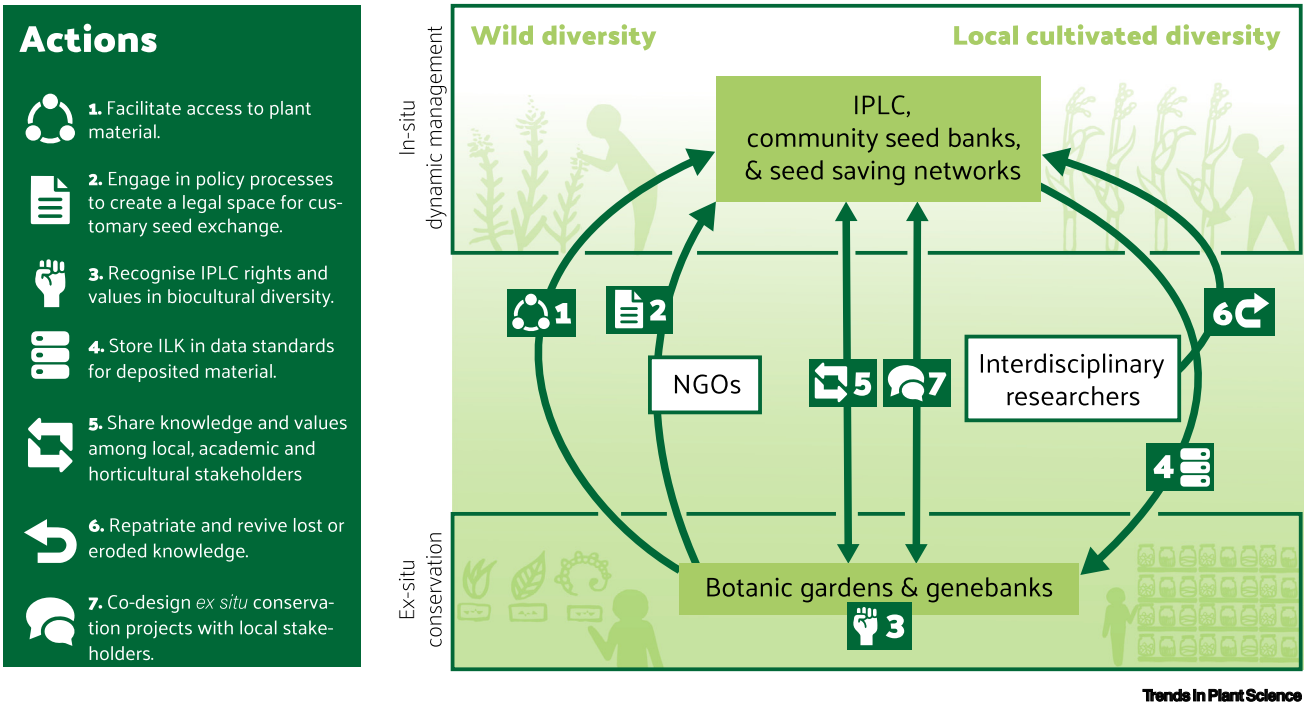

Figure 1. Actions to co-conserve knowledge and seeds linking stakeholders across scales. Abbreviations: IPLC, Indigenous peoples and local communities; NGO, non-governmental organisation.

platform and a certification system to facilitate seed exchange, if only between botanic gardens[iii] [52]. Such initiatives could be expanded to include local organisations, and *ex situ* conservation institutions should support and acknowledge grassroots efforts.

Action 3: recognise ILK holders rights and values in *ex situ* collections

IPLC rights and values regarding plant diversity should be recognised in existing *ex situ* collections, as they are explicitly acknowledged biocultural collections [53]. In practice, a first step could be to recognise their contribution to biodiversity stewardship by indicating the local names and languages of biodiversity conserved in *ex situ* collections[i], including herbaria [54]. A record of the IPLCs who have domesticated, selected, cultivated, and continue to cultivate the taxon could also be added to genebank accession passport data, for example, and linked to published literature where available. Community researchers with or without the support of ethnobiologists are best placed to inform and guide this process. This would provide evidence

Box 1. Shetland kale: transnational seed sourcing from genebanks and historical documentation to revive a local landrace

The Norwegian Seed Savers (KVANN) are a grassroots association for seed stewardship and exchange based in Norway. As part of their mission, they search for hardy plants adapted to northern climates. KVANN divides the stewardship into guilds based on plant families so members can specialise in the knowledge of each group, together forming a network for the conservation of biodiversity and cultural heritage. Varieties adapted to northern climates in seed exchange networks or genebanks are not necessarily easy to grow. This is the case for Shetland kale. Seeds of Shetland kale were sourced from a local Shetlander and from the Science and Advice for Scottish Agriculture genebank. By combining detailed historical, ethnographic, and archaeological evidence of past growing techniques in the Shetlands [71], for which the oral knowledge is no longer available, with an experimental approach, a KVANN member succeeded in reproducing past horticultural knowledge, reviving a forgotten kale variety, and sharing this knowledge within their community.

Box 2. Open-access knowledge for grassroots seed dynamic management

The European Coordination Let's Liberate Diversity! (EC-LLD) is a non-profit organisation comprising 19 seed saver organisations, seed exchange networks, NGOs, and national organic associations representing 18 European countries. All members share the same concern: food systems are too uniform and the promotion of biodiversity is key to achieving food sovereignty and security for future generations. The three pillars of EC-LLD's activities are: (i) capacity building on seed policy and legislation and (ii) community seed bank management; and (iii) being an exchange platform facilitating knowledge exchange between agrobiodiversity stakeholders. Some members share knowledge and practices through national online open-access platforms. This complements knowledge exchange during the many regular international meetings between farmers, researchers, and professionals in the sector who can then discuss theoretical and practical aspects of agrobiodiversity, including seed exchange, 'on site'. The EC-LLD is looking towards sister initiatives such as the Fundus Agricultura Alpina to implement an online open database for ILK.

for intellectual property right claims against expropriation and patenting [9,37,38] and help curb past power biases.

Action 4: storing ILK in data standards

While several examples of collaborations between genebanks and Indigenous communities leading to the *ex situ* conservation of IPLC-owned seed diversity are described in media reports [55–57], ILK remains invisible in open-access genebank databases such as Genesys PGR[iv]. Genebank and botanic garden open-access databases could serve as storage platforms for the long-term preservation of aspects of ILK. While we recognise that ILK holders may choose not to preserve their intellectual property in this way, we urge genebanks to reach out to ILK holders directly or through 'local–global scale' brokers (e.g., NGOs, researchers) to promote co-conservation of written or audiovisual ILK with seeds. The CBD and its Nagoya Protocol provide a robust ethical and legal framework for genebanks and botanical gardens to act as custodians of their collections and associated knowledge. Furthermore, the rights of IPLCs, the developers and stewards of biocultural diversity, are enshrined in the Farmers' Rights provision in the International Plant Treaty and as Peasants' Rights in the United Declaration on the Rights of Peasants and Other People Working in Rural Areas. Storing knowledge in public online platforms and encouraging open-access knowledge exchange, when this is desired by IPLCs, could amplify conservation success (Boxes 2 and 3). This has been acknowledged by the Kunming-Montreal Global Biodiversity Framework adopted at the 15th Conference of Parties to the CBD in December 2022, stating that a multilateral fund between providers and users of digital sequence information (DSI) shall be established for the equitable sharing of benefits[v]. The decision encourages the accompaniment of DSI with appropriate and relevant information and stresses that this system must 'take into account the rights of IPLCs, including with respect to the traditional knowledge associated with genetic resources that they hold' [58]. Nevertheless, we recognise that there is still a long way to go to gain trust from IPLCs in international organisations, a trust that can be built through free and facilitated material and knowledge exchange (Actions 1 and 5).

Box 3. Association of community seed banks facilitates knowledge exchange between communities and with *ex situ* conservation organisations

The Community Seed Banks Association of Nepal is a federation of community seed banks conceptualised in 2013 and registered in 2019, which aggregates 23 community seed banks to facilitate effective learning, sharing, and peer support beyond the community level and with governmental and international institutions [72]. The association supports on-farm conservation of seed diversity and the revival of local seed varieties and associated knowledge to maintain and harness Nepal's rich agricultural biodiversity for human health and well-being. The NGO mediates between community seed banks and governmental institutions including the National Genebank, which has committed to provide technical support to the community seed banks. The association also facilitates seed and knowledge exchange between communities through an app with a digital catalogue of seeds conserved by the community seed banks and associated knowledge as well as seed exchange festivals where seed exhibits serve as the basis for sharing seed and information on local varieties along with associated traditional knowledge.

Action 5: sharing knowledge and values

ILK systems are grounded on the relational values of ILK holders that steward nature. Relational values are manifested through reciprocal contributions between people and nature – interactions and experiences resulting in positive coevolutionary feedback loops [59–61]. Respecting and integrating ILK holders for knowledge co-production and in actions to build resilience and ensure the sustainability of food systems is acknowledged by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [62] and the Food and Agriculture Organization of the UN [10], for example. As ILK systems are dynamic, they can benefit from exchange between communities facilitated by institutions and organisations operating at larger scales [39,53]. For example, they can benefit from the experiences of IPLCs in similar environmental contexts, horticultural knowledge from gardeners in botanic gardens, plant breeders using genebanks, and academic knowledge from researchers across the natural sciences and the humanities (Boxes 1, 3, and 4). This is especially important in contexts where, due to climate and social change (including migrations), knowledge and seed diversity held by a community no longer suffice to ensure food security and community health and well-being [50]. Climate change is already stimulating a diversification of local knowledge systems [63], highlighting the urgent need to support traditions that are continuously reinventing themselves as well as emergent uses of biodiversity. Scenarios might include sharing horticultural information for wild plant cultivation, alternative uses of local species, knowledge of the domestication of local wild plants to support sustainable use, or the repatriation of knowledge that has been locally lost (Action 6).

Action 6: knowledge repatriation

It is essential that ILK preserved *ex situ* in written format is repatriated to owner communities. The first co-created repatriation projects are emerging [64], but in light of ILK loss, the potential scope of revival and repatriation projects is enormous and remain at an early stage. Repatriation can occur through researchers or NGO partners acting as brokers between the *in situ* and *ex situ* systems (Box 3) and by facilitating community exchanges between local seed management systems that are disconnected geographically or otherwise (Box 4). For example, in Europe researchers have supported farmers in re-appropriating lost seed diversity and the horticultural knowledge associated with it, and facilitated cross-community exchanges of knowledge and seed material [65].

Box 4. Conserving plant diversity and sharing knowledge with local communities: the Millennium Seed Bank (MSB) and the conservation of useful plants in Mexico

The MSB of the Royal Botanic Gardens, Kew, UK, was established in 2000 with the mission of safeguarding wild plant diversity and enabling its sustainable utilisation through global partnership. To date, more than 97 countries and territories and over 250 organisations have been involved [73]. Mexico is one of the main partner countries of the MSB. The long-term partnership with the Universidad Nacional Autónoma de México has focused on the study, conservation, and sustainable utilisation of important wild plant species to support people's livelihoods [74,75]. Overall, 150 wild plant species used as medicines, food, and materials were selected and prioritised through a participatory process in three partner communities from the Tehuacán-Cuicatlán Valley as part of the Project MGU – Useful Plants Project in Mexico. Seeds were collected, tested, and stored in the country and duplicated at the MSB. Seed conservation and propagation protocols were developed and the knowledge transferred to the source communities through training workshops and *ad hoc* technical support [75]. Local facilities were improved to enable the conservation and cultivation of these plants in the surrounding areas and included the building of a community-managed rural greenhouse. Species were planted in home and school gardens for local use, conservation, and education purposes. Undergraduate and postgraduate students were involved in documenting and preserving the local knowledge associated with these plants, studied their seed biology and germination ecology to inform the cultivation, and characterised bio- and phytochemical plant properties. Findings were published in the academic literature, shared with the local communities, and compiled in technical information sheets to inform practitioners involved in agriculture and forestry projects [29].

Action 7: conservation co-design

Connecting different institutional and spatial levels through the involvement of multiple stakeholders is the most promising way to tackle ILK as well as seed diversity loss [17]. We recommend that conservation projects of any kind, *in situ* or *ex situ*, should always partner with local actors and knowledge holders. The science and policy of seed diversity conservation needs to learn from the decolonial turn in conservation biology and ecology [66,67]. The future of seed diversity must be co-designed with IPLC farmers and growers, allowing the different knowledge value systems to shape practice and policy [62,68].

Together, the recommended actions link the biological and cultural diversity of seeds and lead to their co-conservation. These actions also encourage *ex situ* conservation institutions to invest in overcoming common obstacles to co-conservation. IPLCs have long been marginalised and misrepresented in science and policymaking [69,76], partly due to the striking paradigm differences with Western science [1]. Building trust relations with IPLCs demands personal and institutional long-term investment that is at odds with current scientific and practitioner modes of working and that is not supported by administrative frameworks or funding initiatives. However, long-term relations are key to establish meaningful collaborations and ensure respect of property rights.

Concluding remarks

Preserving genetic resources without supporting their associated ILK systems and knowledge holders undermines *ex situ* biodiversity conservation efforts and the value of *ex situ* genebanks in tackling local to global challenges. Integrated *ex situ–in situ* seed-knowledge conservation requires rethinking of current practices in at least five areas of seed conservation: (i) co-conservation of ILK and seeds (including relational values); (ii) selection of species for conservation; (iii) development of inclusive policy; (iv) use of seed collections to support ILK and farmers' seed systems, including food and health systems and local livelihoods; and (v) resource allocation to mainstream the co-conservation of plant diversity.

There is no 'one size fits all' solution [42], but context-specific actions to support the co-conservation and sustainable use of stored seed collections and ILK in *ex situ* and *in situ* conservation strategies should emerge from a participatory conservation process involving knowledge holders. Such a multistakeholder process starts with the recognition of the diversity of the concerns and needs of the actors using and maintaining biodiversity [42] and can be achieved through the engagement of conservation institutions and programs with local biocultural values of biodiversity [70]. Through engaged, transdisciplinary research, sharing of knowledge and seeds has a huge potential to support ILK systems, IPLC livelihoods, and *ex situ* conservation alike (see Outstanding questions).

Outstanding questions

How can we conserve a dynamic and adapted diversity of living plants and seeds in botanical gardens and genebanks when facing climate change and widespread biodiversity loss? How do we ensure that these collections can be used effectively when needed to restore biodiversity?

What policy actions are needed to both protect ILK holders and facilitate knowledge and seed exchange at larger scales (regional, international)?

What training is needed for leaders and members in community seed banks, seed-saving networks, botanic gardens, and genebanks, including academic and other staff, to implement co-conservation projects?

Does co-conservation of ILK and seeds require novel approaches for the selection of species for conservation? What is the role of NGOs and researchers in achieving this?

How can we ensure that resources are allocated in such a way that they contribute optimally to encourage and achieve co-conservation of ILK and *ex situ* collections?

Author contributions

All coauthors contributed to discussions leading to this article. T.U., A.M., M.L., and P.S. contributed with case studies. I.T-T., A.K., O.W., O.G., and T.U. wrote the article. All coauthors revised and edited the article.

Declaration of interests

No interests are declared.

Resources

[i] www.cbd.int/abs/

[ii] www.cbd.int/traditional/

[iii] www.bgci.org/our-work/projects-and-case-studies/responsible-exchange-of-plant-genetic-resources-for-research-and-development/

[iv]www.genesys-pgr.org/

[v]www.cbd.int/article/cop15-cbd-press-release-final-19dec2022

References

1. Tengö, M. *et al.* (2014) Connecting diverse knowledge systems for enhanced ecosystem governance: the multiple evidence base approach. *Ambio* 43, 579–591
2. Agrawal, A. (1995) Dismantling the divide between Indigenous and scientific knowledge. *Dev. Change* 26, 413–439
3. Pascual, U. *et al.* (2017) Valuing nature's contributions to people: the IPBES approach. *Curr. Opin. Environ. Sustain.* 26–27, 7–16
4. Arias-Arévalo, P. *et al.* (2017) Exploring intrinsic, instrumental, and relational values for sustainable management of social–ecological systems. *Ecol. Soc.* 22, 43
5. Delêtre, M. *et al.* (2011) Marriage exchanges, seed exchanges, and the dynamics of manioc diversity. *Proc. Natl. Acad. Sci. U. S. A.* 108, 18249–18254
6. Diamond, J. and Bellwood, P. (2003) Farmers and their languages: the first expansions. *Science* 300, 597–603
7. Westengen, O.T. *et al.* (2014) Ethnolinguistic structuring of sorghum genetic diversity in Africa and the role of local seed systems. *Proc. Natl. Acad. Sci. U. S. A.* 111, 14100–14105
8. Van Andel, T. *et al.* (2019) Hidden rice diversity in the Guianas. *Front. Plant Sci.* 10, 1161
9. Swiderska, K. *et al.* (2022) Indigenous peoples' food systems and biocultural heritage: addressing Indigenous priorities using decolonial and interdisciplinary research approaches. *Sustainability* 14, 11311
10. FAO (2019) *The state of the world's biodiversity for food and agriculture*, FAO
11. Brondízio, E.S. *et al.* (2021) Locally based, regionally manifested, and globally relevant: Indigenous and local knowledge, values, and practices for nature. *Annu. Rev. Environ. Resour.* 46, 481–509
12. Fernández-Llamazares, Á. *et al.* (2021) Scientists' warning to humanity on threats to Indigenous and local knowledge systems. *J. Ethnobiol.* 41, 144–169
13. Berkes, F. *et al.* (2000) Rediscovery of traditional ecological knowledge as adaptive management. *Ecol. Appl.* 10, 1251–1262
14. Aswani, S. *et al.* (2018) Global trends of local ecological knowledge and future implications. *PLoS One* 13, e0195440
15. Cámara-Leret, R. and Bascompte, J. (2021) Language extinction triggers the loss of unique medicinal knowledge. *Proc. Natl. Acad. Sci. U. S. A.* 118, e2103683118
16. Sutherland, W.J. (2003) Parallel extinction risk and global distribution of languages and species. *Nature* 423, 276–279
17. Tang, R. and Gavin, M. (2016) A classification of threats to traditional ecological knowledge and conservation responses. *Conserv. Soc.* 14, 57
18. Garnett, S.T. *et al.* (2018) A spatial overview of the global importance of Indigenous lands for conservation. *Nat. Sustain.* 1, 369–374
19. Reyes-García, V. *et al.* (2019) The contributions of Indigenous peoples and local communities to ecological restoration. *Restor. Ecol.* 27, 3–8
20. Antonelli, A. (2023) Indigenous knowledge is key to sustainable food systems. *Nature* 613, 239–242
21. Locqueville, J. *et al.* (2022) Semi-domesticated crops have unique functional roles in agroecosystems: perennial beans (*Phaseolus dumosus* and *P. coccineus*) and landscape ethnoecology in the Colombian Andes. *J. Ethnobiol.* 42, 198–216
22. Monroy-Sais, S. *et al.* (2022) Relational values and management of plant resources in two communities in a highly biodiverse area in western Mexico. *Agric. Human Values* 39, 1231–1244
23. Riechers, M. *et al.* (2021) Human–nature connectedness and other relational values are negatively affected by landscape simplification: insights from Lower Saxony, Germany. *Sustain. Sci.* 17, 865–877
24. Coomes, O.T. *et al.* (2015) Farmer seed networks make a limited contribution to agriculture? Four common misconceptions. *Food Policy* 56, 41–50
25. Pautasso, M. *et al.* (2013) Seed exchange networks for agrobiodiversity conservation. A review. *Agron. Sust. Dev.* 33, 151–175
26. Chan, K.M.A. *et al.* (2016) Opinion: Why protect nature? Rethinking values and the environment. *Proc. Natl. Acad. Sci. U. S. A.* 113, 1462–1465
27. Anderson, C.B. *et al.* (2022) *Conceptualizing the diverse values of nature and their contributions to people*, Zenodo
28. Allen, K.E. *et al.* (2018) Relational values in agroecosystem governance. *Curr. Opin. Environ. Sustain.* 35, 108–115
29. Ulian, T. *et al.* (2019) *Wild Plants for a Sustainable Future*, Royal Botanic Gardens, Kew
30. Díaz, S. *et al.* (2019) Pervasive human-driven decline of life on Earth points to the need for transformative change. *Science* 366, eaax3100
31. Reyes-García, V. *et al.* (2023) Biocultural vulnerability exposes threats of culturally important species. *Proc. Natl. Acad. Sci. U. S. A.* 120, e2217303120
32. Sterling, E.J. *et al.* (2017) Biocultural approaches to well-being and sustainability indicators across scales. *Nat. Ecol. Evol.* 1, 1798–1806
33. Reyers, B. and Selig, E.R. (2020) Global targets that reveal the social–ecological interdependencies of sustainable development. *Nat. Ecol. Evol.* 4, 1011–1019
34. Bellon, M.R. *et al.* (1994) Keepers of maize in Chiapas, Mexico. *Econ. Bot.* 48, 196–209
35. Bellon, M.R. *et al.* (2018) Evolutionary and food supply implications of ongoing maize domestication by Mexican campesinos. *Proc. Biol. Sci.* 285, 20181049
36. Argumedo, A. *et al.* (2021) Biocultural diversity for food system transformation under global environmental change. *Front. Sustain. Food Syst.* 5, 685299
37. Benyei, P. *et al.* (2020) Storing and sharing: a review of Indigenous and local knowledge conservation initiatives. *Ambio* 49, 218–230
38. McCarter, J. *et al.* (2014) The challenges of maintaining Indigenous ecological knowledge. *Ecol. Soc.* 19, 39
39. Rhoné, B. *et al.* (2020) Pearl millet genomic vulnerability to climate change in West Africa highlights the need for regional collaboration. *Nat. Commun.* 11, 5274
40. Westengen, O.T. *et al.* (2018) Access to genes: linkages between genebanks and farmers' seed systems. *Food Sec.* 10, 9–25
41. CGIAR (2021) CGIAR genebank platform annual report 2020. Published online August 2021. https://hdl.handle.net/10568/114811
42. Louafi, S. *et al.* (2021) Crop diversity management system commons: revisiting the role of genebanks in the network of crop diversity actors. *Agronomy* 11, 1893
43. Cámara-Leret, R. and Dennehy, Z. (2019) Information gaps in Indigenous and local knowledge for science-policy assessments. *Nat. Sustain.* 2, 736–741
44. Carroll, S.R. *et al.* (2021) Operationalizing the CARE and FAIR principles for Indigenous data futures. *Sci. Data* 8, 108
45. Reyes-García, V. *et al.* (2022) Data sovereignty in community-based environmental monitoring: toward equitable environmental data governance. *BioScience* 72, 714–717
46. Bali, A. and Kofinas, G.P. (2014) Voices of the Caribou People: a participatory videography method to document and share local knowledge from the North American human–*Rangifer* systems. *Ecol. Soc.* 19, 16
47. Cameron, L. *et al.* (2021) "A return to and of the land": Indigenous knowledge and climate change initiatives across the Canadian prairies. *J. Ethnobiol.* 41, 368–388
48. Ginsburg, F. (2011) Native intelligence: a short history of debates on Indigenous media and ethnographic film. In *Made to be Seen: Perspectives on the History of Visual Anthropology* (Banks, M. and Ruby, J., eds), University of Chicago Press
49. Agrawal, A. (2002) Indigenous knowledge and the politics of classification. *Int. Soc. Sci. J.* 54, 287–297
50. Zimmerer, K.S. *et al.* (2019) The biodiversity of food and agriculture (agrobiodiversity) in the Anthropocene: research advances and conceptual framework. *Anthropocene* 25, 100192

51. Wynberg, R. *et al.* (2021) Farmers' rights and digital sequence information: crisis or opportunity to reclaim stewardship over agrobiodiversity? *Front. Plant Sci.* 12, 686728
52. Havinga, R. *et al.* (2016) The *Index seminum*: seeds of change for seed exchange. *Taxon* 65, 333–336
53. Salik, J. *et al.* (2014) *Curating Biocultural Collections: A Handbook*, Royal Botanic Gardens, Kew
54. Park, D.S. *et al.* (2023) The colonial legacy of herbaria. *Nat. Hum. Behav.* Published online June 12, 2023. https://doi.org/10.1038/s41562-023-01616-7
55. Lakhani, N. (2020) Cherokee Nation to preserve culturally important seeds in Arctic vault. *The Guardian*
56. International Institute for Environment and Development (2017) Quechua farmers take their potato seeds to Svalbard. Published online September 11, 2017. https://biocultural.iied.org/film-quechua-farmers-take-their-potato-seeds-svalbard
57. Zanon, S. (2022) Seed banks catalog Brazil's food past to safeguard its future. *Mongabay* Published online May 26, 2022. https://news.mongabay.com/2022/05/seed-banks-catalog-brazils-food-past-to-safeguard-its-future/
58. Convention on Biological Diversity (2022) Digital sequence information on genetic resources. Draft decision submitted by the President. Published online December 18, 2022. https://www.cbd.int/doc/c/c181/12cf/d29ef8c3f6bd4ec701699d9d/cop-15-l-30-en.pdf
59. Díaz, S. *et al.* (2015) Assessing nature's contributions to people. *Science* 359, 270–272
60. Comberti, C. *et al.* (2015) Ecosystem services or services to ecosystems? Valuing cultivation and reciprocal relationships between humans and ecosystems. *Glob. Environ. Change* 34, 247–262
61. Ojeda, J. *et al.* (2022) Reciprocal contributions between people and nature: a conceptual intervention. *BioScience* 72, 952–962
62. Hill, R. *et al.* (2020) Working with Indigenous, local and scientific knowledge in assessments of nature and nature's linkages with people. *Curr. Opin. Environ. Sustain.* 43, 8–20
63. Savo, V. *et al.* (2016) Observations of climate change among subsistence-oriented communities around the world. *Nat. Clim. Chang.* 6, 462–473
64. Martins, L. (2021) Digital repatriation of biocultural collections: connecting scientific and Indigenous communities of knowledge in Amazonia. In *Mapping a New Museum: Politics and Practice of Latin American Research with the British Museum* (Sunnucks, L.O. and Cooper, J., eds), pp. 227–234, Routledge
65. Bocci, R. and Chable, V. (2009) Peasant seeds in Europe: stakes and prospects. *J. Agric. Environ. Int. Dev.* 103, 81–93
66. Curry, H.A. (2022) *Endangered Maize: Industrial Agriculture and the Crisis of Extinction*, University of California Press
67. Trisos, C.H. *et al.* (2021) Decoloniality and anti-oppressive practices for a more ethical ecology. *Nat. Ecol. Evol.* 5, 1205–1212
68. Durán, A.P. *et al.* (2023) Bringing the Nature Futures Framework to life: creating a set of illustrative narratives of nature futures. *Sustain. Sci.* Published online May 4, 2023. https://doi.org/10.1007/s11625-023-01316-1
69. FAO (2021) *The White/Wiphala paper on Indigenous peoples' food systems*, FAO
70. Wall, J. (2021) *Evaluating compatibility between the key biodiversity area proposal process and Indigenous peoples and local communities environmental priorities with evidence from Canada and Mi'kma'ki (Nova Scotia)*, Wildlife Conservation Society Canada
71. Lightfoot, A. (2006) *Fortidens drivhus* – dyrking av grønnkål til folk og fe på Shetland. *SPOR* 42, 16–19 (in Norwegian)
72. Shrestha, P. *et al.* (2020) *A level up: community seed banks in Nepal join forces*, Bioversity International
73. Breman, E. *et al.* (2021) Plant diversity conservation challenges and prospects – the perspective of botanic gardens and the Millennium Seed Bank. *Plants (Basel)* 10, 2371
74. Rodríguez-Arévalo, I. *et al.* (2017) Conserving seeds of useful wild plants in Mexico: main issues and recommendations. *Genet. Resour. Crop. Evol.* 64, 1141–1190
75. Ulian, T. *et al.* (2017) Conservation of Indigenous plants to support community livelihoods: the MGU – Useful Plants Project. *J. Environ. Plan. Manag.* 60, 668–683
76. Molnár, Z. *et al.* Social justice for traditional knowledge holders will help conserve Europe's nature. *Biol. Conserv.* (in press).