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Contributions of human cultures to biodiversity and ecosystem conservation

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The expansion of globalized industrial societies is causing global warming, ecosystem degradation, and species and language extinctions worldwide. Mainstream conservation efforts still focus on nature protection strategies to revert this crisis, often overlooking the essential roles of Indigenous Peoples and Local Communities (IP&LC) in protecting biodiversity and ecosystems globally. Here we assess the scientific literature to identify relationships between biodiversity (including ecosystem diversity) and cultural diversity, and investigate how these connections may affect conservation outcomes in tropical lowland South America. Our assessment reveals a network of interactions and feedbacks between biodiversity and diverse IP&LC, suggesting interconnectedness and interdependencies from which multiple benefits to nature and societies emerge. We illustrate our findings with five case studies of successful conservation models, described as consolidated or promising 'social–ecological hope spots', that show how engagement with IP&LC of various cultures may be the best hope for biodiversity and ecosystem conservation, particularly when aligned with science and technology. In light of these five inspiring cases, we argue that conservation science and policies need to recognize that protecting and promoting both biological and cultural diversities can provide additional co-benefits and solutions to maintain ecosystems resilient in the face of global changes.

As global industrial societies expand, concerns about how much space and ecological quality remain for nature are increasing[1,2]. Recent analyses of the human footprint in terrestrial ecosystems identified areas with very low to moderate impact of industrial societies (20–56% of terrestrial ecosystems) as targets for biodiversity conservation[3–5]. Although these low-impact areas are often called 'wildernesses' or 'intact ecosystems' in dominant global conservation science and policy[6,7], most terrestrial ecosystems have been modified by humans over the past millennia[8], including rainforests in Borneo, Central Africa[9], Amazonia[10], tropical Asia and Australia[11]. Today, more than one-third of such areas are within territories of Indigenous Peoples[12,13], and many areas are inhabited by local communities that use and manage their natural resources carefully[14]. Cultural diversity can be striking in so-called 'intact ecosystems'[15] inside and outside protected areas, due to the presence of IP&LC. The assumption of intactness therefore ignores that IP&LC rely on these ecosystems not only for cultural and spiritual practices, but also for their survival[16].

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BOX 1

Amerindian worldviews contrast with Western worldviews

We make a comparison between 'Amerindian' and 'Western' worldviews to highlight substantial differences that produce contrasting ways of relating to nature. Worldviews are ways of thinking and of acting based on concepts and practices that result in highly diverse ways of being in the world. For heuristic reasons, we compare Amerindian ways of perceiving biodiversity with the hegemonic Western scientific way of thinking that originated in the European Renaissance[167] and dominates the nature conservation agenda[6].

In general, Amerindian worldviews focus on the interconnectedness of all beings and emphasize the continuities among all elements of biodiversity, whereas Western worldviews are built upon a dichotomy between nature and culture, in which humans are superior to other beings[167]. These divergent worldviews originate from different cosmologies and ontologies. According to Indigenous ontologies all places and their inhabitants (all beings) possess social qualities, intentions and agency, similar to humans[168,169]. For humans to make their living, they must negotiate with other beings, because they share the same ecosphere, developing more or less conflicting relations[16,170]. Plants and animals are not seen as mere objects or resources to fulfil human needs (as in hegemonic Western thinking about nature), but as subjects with whom humans must deal to safely carry out their daily activities. Often, some of these beings appear condensed in the figures of 'masters' or 'owners'[59]. Each Indigenous People has its knowledge, rules and practices that help them to communicate and negotiate with owners–masters, for instance, to collect fruits and nuts, or to fish and hunt in a certain area[59].

These different worldviews are closely linked to biodiversity. Indigenous practices create diversified social–ecological systems, generally accumulating diversity over time, and tend to be more resilient to climatic fluctuations and stochasticity in the long term[163,171]. By contrast, Western practices can create highly productive social–ecological systems, such as large-scale monocultures that rely on substantial inputs of water, energy, nutrients and pesticides, which may result in relatively stable and predictable outcomes in the short term. However, by optimizing productivity, such systems become less diverse and less resilient to unexpected shocks in the long term[163,172].

Amerindian	Worldviews	Western
Interconnectedness Sense of continuity among everything Beings possess social quality and agency Beings are under the protection of 'owners'	**Ontologies/cosmologies**	Nature–culture dualism Sense of discontinuity Humans possess social quality and agency Nature should exist without humans
Intuitive and holistic Ancient, empirical and sacred Oral/intergenerational transmission	**Knowledge systems**	Analytical and reductionist Modern, rationalist and objective Literate transmission
Respectful relations and reciprocity Negotiation with the 'owners' Ecocentrism and precaution	**Rules/institutions**	Formal legal enforcement Governmental and top-down Anthropocentrism and remediation
Collective and ancestral Context-oriented Integrated and adaptive management	**Practices**	Individual and technological, Standardized, Fragmented and goal-oriented
Well-known, cared for, respected, transformed, managed, maintained	**Biodiversity**	Poorly known, threatened, degraded, restored, conserved, protected

Differences between Amerindian and Western worldviews and their consequences for biodiversity. Amerindian and Western worldviews are embedded in different ontologies and cosmologies, knowledge systems, rules and institutions, and practices that influence how Indigenous and Western societies relate to biodiversity. Biodiversity is often well known, cared for and respected by Amerindian worldviews, but poorly known, threatened and degraded by Western worldviews.

Current analysis suggests that over one billion people could be affected by nature conservation policies that intend to protect half of the Earth from humans[17]. Such conservation policies ignore the rights of Indigenous Peoples and work against the United Nations (UN) Declaration on the Rights of Indigenous Peoples[18], which acknowledges Indigenous self-determination and other territorial and cultural rights[19]. Yet, contrary to this common conservation vision that often focuses on detrimental human activities, Indigenous Peoples with their deep ecological knowledge maintain well-conserved ecosystems within their territories[12,13].

Thus, the diversity of IP&LC is essential to accomplish the UN Sustainable Development Goals (SDGs), which consider the economic, social and environmental dimensions of sustainable development[20]. However, worldviews grounded on the nature–culture dichotomy have largely dominated this agenda, and Indigenous worldviews are frequently excluded from decision-making[21] (see Box 1 for contrasting worldviews). Recently, the importance of Indigenous and traditional knowledge for achieving sustainable development was highlighted by the *Global Sustainable Development Report*[22], and the knowledge and rights of IP&LC were recognized and partly incorporated in the Global Biodiversity Framework[19] and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)[23]. Nonetheless, the full importance of Indigenous worldviews is still overlooked in mainstream conservation science and policies[24,25].

To address this gap and its potential consequences, this Review summarizes how IP&LC of various cultures contribute to the conservation of biodiversity and ecosystems in lowland South America. Based on evidence of multiple relations between biodiversity and cultural diversity, we identify interactions and potential feedbacks (interdependencies) that can amplify benefits to nature and human societies, maintaining ecosystems in a well-conserved state against global (socioeconomic, political and environmental) changes. We also provide examples of how IP&LC contribute to nature conservation in four tropical South American biomes (tropical rainforests

(Amazonia and Atlantic Forest); seasonally dry tropical forests (Caatinga); and tropical savannahs and grasslands (Cerrado))[26]. We discuss the main lessons from these successful conservation models and highlight why the promotion of biocultural diversity is essential to accomplish the 2030 Sustainable Development Agenda.

Multiple interconnections between biodiversity and cultural diversity

In this section, we discuss several examples of relations between biodiversity (including genes, species, communities and ecosystems) and cultural diversity of IP&LC that generate benefits to nature and human societies within tropical South American biomes (for details of the review, see Supplementary Methods). We focus on practices of IP&LC that directly transform, create or amplify biodiversity. The co-benefits that emerge from these relations are described in fluid categories of contributions to nature and people, such as regulating (for example, nutrient cycling), material (for example, food) and non-material (for example, inspirational experiences) contributions[23] (Box 2).

All human societies transform landscapes by socially manipulating, reorganizing and reassembling biological communities and ecosystems[27–29]. Since the beginning of human activities in South America at least 23,000 years ago, Indigenous societies developed diversified strategies of landscape management[30], particularly in transition zones between biomes, which have high ecosystem diversity[31]. With time, Indigenous Peoples created food production systems, such as horticulture, arboriculture, agroforestry and landscape management[30,32], creating new cultural niches[33], transforming environmental settings and ecosystem functions[34], and amplifying the benefits that people obtained from ecosystems[29,30,35]. Below we describe examples of how landscape management by IP&LC can transform or amplify ecosystem diversity and biodiversity in its various forms and at different scales, such as generating changes in alpha diversity (that is, local species diversity) and beta diversity of biological communities (that is, differences in species diversity across landscapes) (for instance, refs. 36,37).

Soils known as anthropogenic dark earths (or *terra preta*, anthropic soils) are examples of niches created by Indigenous practices, in which nutrient-poor soils are transformed into fertile and stable dark earths[38], influencing soil and plant communities, ecosystems[39–42] and landscapes[43,44]. Earthworks, such as forest islands[45], monumental mounds and raised fields in the seasonally flooded savannahs of Bolivia and French Guiana[46], are also remarkable examples of hydrological and soil niches created by Indigenous Peoples in pre-Columbian times[47]. In collaboration with soil invertebrates and woody plants, Indigenous practices improved water infiltration and reduced erosion, retaining organic matter and nutrients[46].

These managed soils provided multiple benefits to nature and societies for millennia, such as food provision and soil quality across forest[42,48,49] and savannah landscapes[50]. For instance, home gardens on anthropic soils formed by multiple pre-Columbian Indigenous occupations concentrate higher beta diversity of utilized plants than anthropic soils associated with a single occupation[43]. Anthropic soils have a similar local richness of microorganisms and macroinvertebrates as reference soils, but contrasting species compositions with bacterial, fungal and snail communities often found exclusively in these soils[51–54]. As a result, beta diversity of biological communities is significantly higher in landscapes growing on anthropic soils and earthworks than in adjacent landscapes, but alpha diversity does not differ[36]. By contrast, contemporary land use changes, mostly due to the expansion and intensification of pastures and agricultural lands, often result in biotic homogenization with soil and plant communities more similar across landscapes[55,56]. Contemporary Indigenous Peoples, however, still manage soils and biological communities around their villages, increasing environmental heterogeneity as a result of their daily practices and ecological knowledge, thus contributing to enhance beta diversity of biological communities[37,57].

The reason why Indigenous Peoples contribute to biodiversity lies in the way they relate with the environment (Box 1). Indigenous intergenerational knowledge and practices are based on empirical experiences and observations of the environment accumulated over millennia, which are embedded in respectful relationships of positive (sometimes negative) reciprocity between humans and other components of biodiversity, including immaterial ones[58]. For humans to access the material (for example, soil formation and food production) and non-material co-benefits (for example, spiritual experiences and inspirational values) of landscapes, they must negotiate with 'owners', who care for landscapes, avoiding their revenge, guaranteeing mutual benefits, and protecting the fertility of their territories[59]. For instance, the Zo'é people have social relations with other beings (animals and plants) in their territories. This perspective, commonly found in Amerindian worldviews (Box 1), influences their management practices that are based on an ethic of moderation[60]. If their actions become locally excessive, spider monkeys could send a disease to hunters, which causes the Zo'é to move, thus guaranteeing the existence of forest patches in different successional ages. Beta diversity of tree communities thus increases as a result of Indigenous forest management and their movement across their territories[37,57], a widespread process that is observed in other parts of Amazonia[32,36,61] and the Atlantic Forest[62].

Fire management is another classic example of how IP&LC influence ecosystems and biological communities, particularly in fire-prone ecosystems[63,64], such as the Cerrado savannahs and the Pampas grasslands[50,65,66]. Fire is managed for several reasons, such as preparing lands for cultivation and hunting, stimulating plant reproduction, and promoting ceremonies and rituals[67,68]. Indigenous and traditional management practices with controlled burning prevent large wildfires[69], amplifying and maintaining ecosystem diversity[50]. In southern South America, the combination of traditional fire management and small-scale cattle-based pastoralism has influenced the distribution of forests and grasslands, creating more complex and diverse landscape configurations[70,71]. The suppression of local cultures, with their traditional fire-management practices, increases grassland replacement by woody vegetation, impoverishing ecosystem diversity[71] and savannah species richness[72].

Across all tropical South America biomes, Indigenous Peoples developed profound ecological knowledge about how to use and manage populations of plants and animals[73]. At least 6,261 plant species across lowland South America have a documented utility, including food, medicine, raw materials, shelter and spiritual connections for human cultures[30]. Over thousands of years, Indigenous Peoples have enriched their landscapes with useful plants as local cultivators identified new allelic combinations that became cultivated varieties of plant species, amplifying alpha diversity of cultivated species[30]. Altogether, these traditional varieties, their associated wild populations, and other closely related species (agrobiodiversity) represent genetic resources that can be important for improving crops, ensuring food security[74] and adapting tropical food production to climate change[75]. With the intensification of Indigenous management practices, agrobiodiversity flourished across South America. Archaeobotanical records indicate an increase in agrobiodiversity throughout the Holocene that originated from diversified Indigenous management practices, such as protecting and caring for the best individuals, planting their seeds, removing competitors, and mulching soils around selected plants[76–79].

Often, a given species is used differently by different cultures[80,81], implying that biodiversity does not determine cultural outcomes, but that they are intrinsically linked[82]. This link created positive feedbacks between IP&LC and plants that keep tropical forests rich in food and medicine[83]. Ecological, palaeoecological and archaeobotanical data confirm this interpretation by showing that both forest enrichment and plant domestication occurred at numerous places across the continent[30,69,77–79,84]. For instance, Indigenous forest management increased the distribution, abundance and hyper-dominance of

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BOX 2

Definition of key concepts

Biodiversity and agrobiodiversity. "Biodiversity is the variety of life on Earth, it includes all organisms, species and populations; the genetic variation among these; and their complex assemblages of communities and ecosystems"[173]. Agrobiodiversity "includes all components of biological diversity of relevance to food and agriculture, and all components of biological diversity that constitute the agricultural ecosystems"[173], and results from interactions among cultural practices, biological resources and the environments of agroecological systems over millennia.

Cultural diversity. Can be defined as "interlinked components that contribute to an individual's identity by representing relationships with the surrounding environment"[93]. Individuals share language, symbols, artefacts, beliefs, values, knowledges, rules, institutions and practices considered distinctive of cultural groups with diffuse and fluid boundaries[174]. Each culture interprets and interacts with their environment in distinct ways[27] and has the capacity to change rapidly in response to internal processes or external drivers[93,174].

Cultural niche construction. The process by which human cultures modify the conditions of their living environment, creating new niches[34]. This process is mainly guided by cultural values and needs. By transforming the environment over human generations, cultures can promote changes in natural selection pressures of ecosystems that benefit their own survival and reproduction and also influence the niches of other species over time[35,175].

Biocultural diversity. The variety of life originated from the inter-relation and co-evolution of all biological, cultural and linguistic components of life on Earth[174]. Biocultural diversity is often analysed in the context of complex social–ecological systems with reciprocal interactions that result in interdependencies (feedbacks).

Social–ecological resilience. The capacity of integrated social and ecological systems to deal with external stressors and disturbances without losing their identities and functions, guaranteeing the supply of essential benefits that societies obtain from ecosystems[172]. This includes two abilities of the systems: (1) adaptability, which is the capacity to learn and adjust responses to changes; and (2) transformability, which is the capacity to reorganize in fundamental ways[172]. Biodiversity and cultural diversity contribute to the resilience of coupled social–ecological systems and "provide different options for responding to change and dealing with uncertainty and surprise", which increase the capacity of Indigenous and local management systems to cope with environmental change[73].

Co-benefits. Joint positive contributions of biodiversity and cultural diversity for humans and other species. These contributions are associated with the concepts of nature's contributions to people and people's contributions to nature. Nature's contributions to people are all the positive and negative contributions of nature to human well-being (IPBES)[23] and people´s contributions to nature are the contributions of human societies to nature[58]. Nature refers to the natural world in the context of Western worldviews. Nature's contributions to people is complementary to the concept of ecosystem services that refers to all benefits that people obtain from ecosystems[23].

Social–ecological hope spots. Areas that can meaningfully impact social–ecological resilience, where local communities and public engagement can be strategically combined with state-of-the-art science, engineering and technology, including geospatial, remote sensing and visualization tools, to provide the greatest impact for the conservation of vulnerable biodiversity. This concept was first introduced by the UN Environment Programme and popularized in marine conservation by Mission Blue[176], and was adapted here to terrestrial social–ecological systems.

edible tree species in Amazonia[10], as well as, the expansion of *Araucaria* forests in southern South America associated with Indigenous Jê linguistic trunk[84,85]. Today, *Araucaria* pines (*Araucaria angustifolia* and *Araucari araucana*) are keystone plant resources and culturally important species for many IP&LC[86]. *Araucaria* management facilitates other plant species and sustains biological communities, maintaining local tree and vertebrate diversities[87,88], and probably increased human food security[83]. In biomes with lower annual rainfall, such as the dry forests of the Caatinga, local management practices provide key food resources (for example, *Attalea speciosa* and *Spondias tuberosa*) for local communities in periods of extended drought[89–92].

However, the inseparable connection between biodiversity and cultural diversity is threatened[93]. Biodiversity degradation is causing consistent loss of Indigenous ecological knowledge, as culturally important species disappear from landscapes[94,95]. The loss of languages can further accelerate this process[82]. For instance, the majority of medicinal knowledge about plants is documented for only one language[82], implying that the extinction of a language causes the loss of unique medicinal knowledge. Although managed populations can persist in their wild forms, fully domesticated populations do not survive and reproduce without human care[96]. As a result of IP&LC exclusion from their ancestral territories, managed populations are in trouble due to ecosystem loss and cultural erosion[82], and domesticated plant populations are disappearing[83], jeopardizing agrobiodiversity and food security[97].

In some cases, however, IP&LC practices may result in negative outcomes for biodiversity. For example, gathering, hunting and fishing may locally decrease biodiversity if they are practiced in excess of the reproductive rates of the targeted species (see ref. 98 for contrasting hunting impacts). The interplay of human predation and climate change was probably responsible for megafauna extinctions across South America[99]. However, recent initiatives of collaborative management (co-management) of various culturally important species involving IP&LC and other stakeholders, such as scientists, governments and nongovernmental organizations (NGOs), led to positive ecological, socioeconomic and cultural outcomes[100]. For instance, Indigenous lands conserve equal-or-higher vertebrate diversity than protected areas[101] and these lands support viable populations of iconic species of primates[102]. One plausible explanation for this pattern is by enhancing the abundance of edible plants for humans at landscape scale[30,83], IP&LC also increased food availability for terrestrial vertebrates, particularly frugivores[32,88]. Indigenous practices are important for ensuring long-term hunting sustainability in comparison with non-Indigenous hunting practices[103]. Although modern Indigenous societies are incorporating Western practices (for example, adopting firearms), taboos and rituals of negotiation with game masters are still

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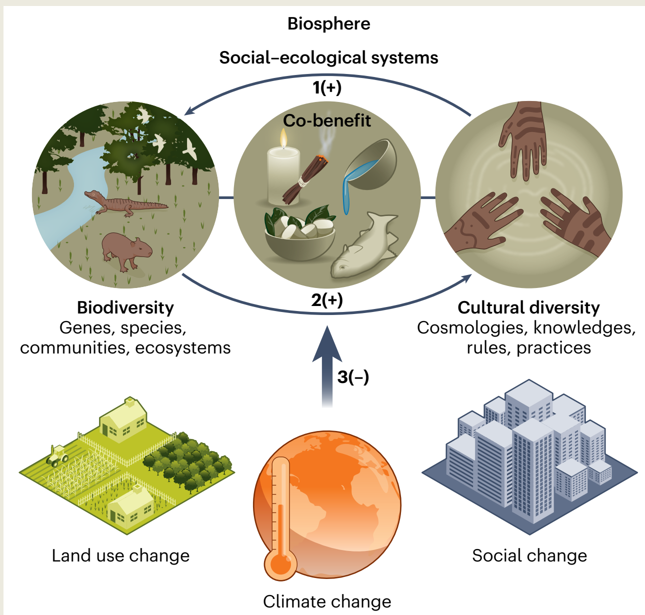
BOX 3

Feedbacks and interdependencies among biodiversity and cultural diversity

According to our Review, biodiversity and cultural diversity are interdependent[177], forming social–ecological systems that generate multiple co-benefits to nature and human societies. Another implication of this interconnectedness is that such integrated systems are exposed to the same drivers of change, that cause stress on the system[178], including climate change and associated hazards (for example, wildfires and extreme droughts), land-use change (for example, the expansion of agribusiness and illegal activities), and socioeconomic and political change (for example, privatization of lands and homogenization of conservation policies)[93]. With the intensification of these drivers, Indigenous Peoples have lost territories, memories and languages[179], and as a result, their cultural and ecological knowledge about how to use, and manage plants and landscapes has eroded over time[113], jeopardizing the provision of multiple benefits to local and global societies, such as fire management[69], agrobiodiversity[96,113] and medicinal plants[82]. Thus, the provisioning of a set of co-benefits, depends on the network functioning with all its interactions.

This notion of coupled systems proposes that positive feedbacks emerge from the interactions among any components of biodiversity and cultural diversity[180]. Interaction is a one-way relationship between two components of a system and a positive feedback can form by reciprocal cause-and-effect interactions that have the potential to amplify changes in the system[180]. These feedbacks are likely to be key mechanisms for the resilience of social–ecological systems[180], and consequently for amplifying the benefits that emerge from the interactions. They imply that degradation of one component of this network could lead to cascading effects and result in social–ecological systemic collapse[94].



Representation of interconnections among biodiversity and cultural diversity in a changing world. Conceptual model of interactions among the diversity of IP&LC with biodiversity (including ecosystem diversity) and the multiple material and non-material co-benefits that emerge from these interactions. Cultural diversity is shaped by a diversity of cosmologies, knowledge systems, rules and practices shared by IP&LC (Box 1). (1) IP&LC practices transform ecosystem functioning, change natural selection pressures on species via cultural niche construction, manage and maintain local ecosystems, promote small-scale intermediate disturbances, and create alpha and beta diversities of biological communities via management and domestication of populations of plants, animals, microorganisms and whole landscapes over time.
(2) Biodiversity provides a wide diversity of ecosystems, communities, species, genes with a range of resources and opportunities that different cultures interact with, depend on and benefit from. These interactions influence their responses to (3) external drivers of climate change, land use change and social (socioeconomic and political) change. Red arrows indicate mostly negative interactions and black arrows indicate mostly positive interactions. Based on an illustration by Letícia Lidia Voltolini.

widespread rules that influence hunting practices especially across Amazonia[104], reducing hunting pressure in places that are seen to be the *domus* of these masters[104,105].

In sum, despite the negative effects of overexploitation (for example, megafaunal extinction), the cumulative body of Indigenous and traditional knowledges and practices rooted in holistic and eco-centric worldviews (Box 1) has contributed to maintain and amplify the diversity of South American landscapes and plant communities and varieties, while attracting and sustaining vertebrate species in their territories. By applying intermediate levels of disturbances in the landscape[106], IP&LC manipulate the ecological dynamics of tropical ecosystems[27], increasing their heterogeneity. Some components of biodiversity (for example, domesticated and managed species and varieties) particularly depend on the cultures that created, transformed

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and maintained them[107,108]. All examples presented here support a major conclusion of the recent IPBES report about the Americas that IP&LC enhance biodiversity[97]. Hence, suppressing the interconnections among cultural diversity and biodiversity may cause loss of both cultures and ecosystems[94] and the co-benefits that they create and sustain (Box 3).

Social–ecological hope spots

Because modern human activities so frequently degrade ecosystems worldwide, nature conservation practices commonly exclude local people to give space to 'nature'[6]. However, IP&LC always claim their territorial rights, giving rise to social–environmental conflicts[6]. Even though diverse ecological knowledge systems are clearly a way to expand our capacity to deal with planetary sustainability issues[109], the inclusion of IP&LC in conservation practices is still trapped in this historical dilemma[110]. According to biocultural approaches for conservation, nature conservation actions would gain much more by expanding their principles and goals to protect both biological and cultural diversities, together with their co-benefits for nature and societies, as integrated social–ecological systems[111].

To encourage a paradigm shift in conservation initiatives, we present a case study of a well-developed Indigenous collaborative project from the Upper Xingu River inspired by the notion of hope spots (see Box 2 for definition), and four additional cases of promising hope spots in other South American regions with clear ecological, social, economic and cultural outcomes[112] (Fig. 1). 'Social–ecological hope spots' recognize the pronounced human influences on genetic[113], taxonomic[10], functional[36] and landscape diversity[46] over millennia, and contrasts with a focus on biodiversity 'hotspots'[114], areas of unusually high levels of endemic species (more than 1,500 species) and habitats reduced to less than 30% of their original size[115]. The following five cases illustrate how IP&LC can contribute to the conservation of biodiversity, ecosystems, and local cultures simultaneously by engaging them in nature conservation practices.

Case study 1: Xingu hope spot in Amazonia

The Xingu hope spot is in the most threatened ecoregion of Brazilian Amazonia, the 'arc of deforestation', which has already been reduced to less than 20% of its original extent. Due to deforestation, the remaining tracts of forest are mainly restricted to Indigenous Lands (Extended Data Fig. 1a). For millennia, Indigenous Peoples developed in this region urban systems with earthworks, cultural forests and many domesticated species[10,79,116], which demonstrate substantial Indigenous influence on biodiversity[117].

The Upper Xingu River basin is a clear example of a complex social–ecological system of land management and urbanized landscapes in moist forests that emerged approximately 1250–1350 CE (refs. 118,119) (Extended Data Fig. 1b). Participatory mapping and archaeological testing since 1992 with the Kuikuro descendant nation have documented diverse aspects of ancestral Indigenous populations within a cultural continuum that extends over two millennia and still flourishes within the *Território Indígena do Xingu* (TIX). They practised extensive landscape management, such as sophisticated techniques of creation and management of anthropic soils (locally known as *egepe*)[38], landscape burning and physical modifications, including extensive water- and fish-management technologies[120]. These practices converted native forest to cultural forest, creating highly differentiated successional forest mosaics[118].

They also domesticated several varieties of the Cerrado fruit tree pequi (*Caryocar brasiliense*), including one with a spineless endocarp[121], as well as a wide diversity of other crops, including over 35 varieties of manioc (*Manihot esculenta*), sweet potatoes (*Ipomoea batatas*), maize (*Zea mays*), and diverse food and medicinal crops, semi-domesticated palms and fruit trees[122]. They developed road and settlement earthworks, semi-intensive wetland-management systems, and fire- and soil-management techniques that enabled responses to the drier climate of the Medieval Warm Period[118]. This rich biocultural legacy is testimony to the cultural resilience of descendant communities that flourish today despite catastrophic population loss over the past five centuries that reduced an estimated 50,000 or more people in 1500 CE to just over 500 in the mid-1950s. Today, more than 7,000 Indigenous persons from 16 distinct ethnic groups live in the TIX (Extended Data Fig. 1c).

The notion of the Xingu hope spot was initially conceived in 2017 in discussions with Mission Blue and the Puente Institute, along with the creation of a cloud-based, GIS (geographic information system) enterprise for the Kuikuro Indigenous community in the TIX (Extended Data Fig. 1d). A geospatial Arc portal co-administered and copyrighted to the Kuikuro Indigenous Organization (AIKAX—*Associação Indígena Kuikuro do Alto Xingu*[123]) incorporates legacy data from participatory archaeological testing and GPS (Global Positioning System) cultural heritage mapping that documents a millennial record of social–ecological system dynamics[120,124]. The ArcGIS AIKAX Portal combines cutting-edge technology for social–ecological and cultural heritage mapping and monitoring by local communities, along with ethnographic and linguistic documentation programmes, including toponyms, natural and anthropogenic features, animal and plant surveys in relation to archaeological sites and local historical places. Hand-held real-time apps enable continuous data recovery and create a common language for collaboration.

Practical applications of technologies using the AIKAX Portal were adapted to map and monitor key social–ecological variables, such as fire occurrence and forest and river conditions, on the ground and remotely. This included a successful COVID-19 pandemic response, which redesigned apps to maintain remote connectivity in real-time by Kuikuro technicians to oversee medical supplies and personnel for communities in 2020 and 2021 (ref. 125). This case study shows how Indigenous knowledge and heritage, including learning from Indigenous technologies, when aligned with state-of-the-art science and technology, may be the best hope for beleaguered ecosystems and their people.

The Upper Xingu example underscores that, although the notion of governance should extend to all[21], in practice, Indigenous voices are often excluded from consideration in conservation and resource management (for example, ref. 126; compare with ref. 127). In this case, partnership between Western and Indigenous knowledges and practices depends on context-sensitive approaches, deep immersion and sustained dialogue between Western and Indigenous participants. It also requires a pragmatic orientation that links research, local communities and the public in finding solutions to common problems, such as health, food security and biodiversity conservation, to contribute to achieving the SDGs. The implementation of a hope spot promotes a 'pedagogy of hope'[128] that benefits from the interplay between Indigenous and Western knowledge systems, and recognizes the basic human rights of self-determination and representation, as well as intellectual property rights.

Case study 2: collaborative management of giant arapaima fish in Amazonia

The giant arapaima (*Arapaima gigas*) is the largest freshwater fish on Earth and represents one of the most emblematic fish resources in the Amazon basin due to its high cultural value since pre-Columbian times[129]. However, a long history of overfishing has led to the collapse of populations in many parts of the basin during the past decades[130]. To restore arapaima populations, rural communities, in close partnership with scientists, NGOs and government, established an innovative model of co-management of arapaima habitats in the Solimões River (Extended Data Fig. 2a). This model was established according to scientific and local knowledge of arapaima abundances estimated annually within management areas[131]. This allows accurate stock

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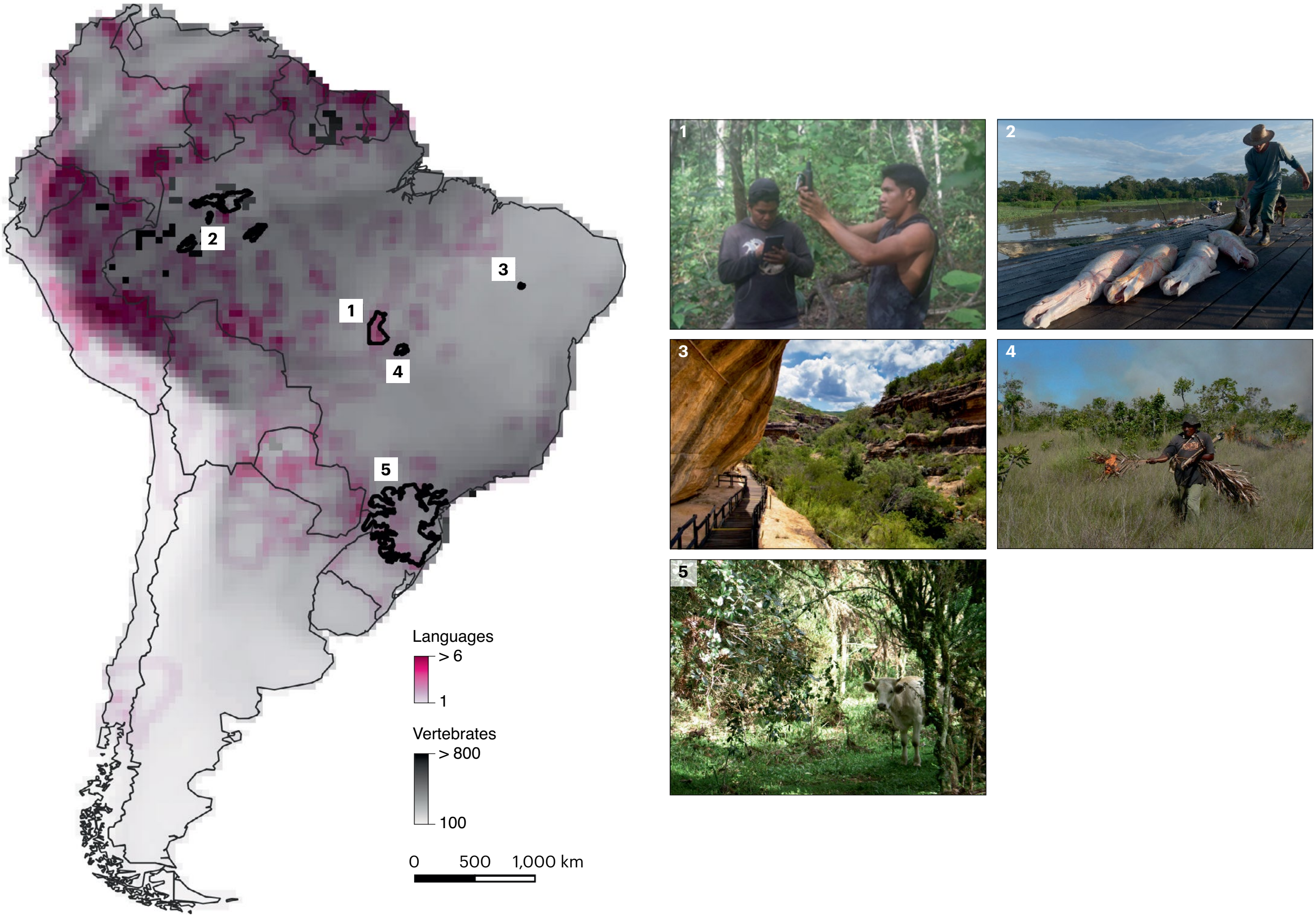

Fig. 1 | Variation of biocultural diversity across South America, with the locations of consolidated and promising social–ecological hope spots. Map shows spatial variation in terrestrial vertebrate richness (grey colour gradient) and language richness (purple colour gradient) across South America. (1) Hope spot in the Xingu Indigenous Territory, southern transitional forest of Amazonia. (2) Co-management of giant arapaima fish in freshwater ecosystems, central Amazonia. (3) Archaeological and ecological tourism of natural–cultural heritage in the Serra da Capivara National Park, Caatinga seasonally dry forest. (4) Indigenous fire management in the Xavante Indigenous Territory, Cerrado savannah. (5) Co-management of culturally important species in *Araucaria* forests, southern Atlantic Forest. These remarkable case studies may inspire other local and global initiatives for conserving biological and cultural diversity, and associated ecosystem services. Photograph credits: (1) AIKAX[123]; (2) Marcos Amend/Instituto Juruá; (3) Duda Menegassi; (4) reproduced with permission from ref. 164, Sage; (5) Nivaldo Peroni. Data from ref. 165 (language) and ref. 166 (terrestrial vertebrate). Map created in QGIS 2.18.25.

estimates, as the fish can be visually counted by trained fishers following a standardized protocol built from traditional knowledge[132]. Estimates of arapaima population size inform fishing quotas, which can reach up to 30% of adult individuals. This programme has already empowered more than 1,000 local villages to protect their territory against predatory commercial fisheries and poachers throughout Amazonian floodplains, allowing them to harvest fish resources according to their needs, which generates major socioeconomic benefits to the local people[100] (Extended Data Fig. 2b). Ecological outcomes of this programme include recovery of arapaima populations[131,133,134], which increased by 425% in protected lakes in the 11 years following the start of co-management[135], and of other aquatic species (for example, freshwater turtles, a wide range of vertebrate and invertebrate taxa), because their habitats (lakes and beaches) are protected by local communities[136]. Arapaima co-management also strongly improved the welfare and gender equality of IP&LC through enhanced annual income generation, investments in infrastructure, such as schools and health posts, social security and women's inclusion in decision-making via income generation[133,137] (Extended Data Fig. 2c). Testimonies from local leaders of IP&LC confirm food security, community pride, cultural maintenance and a more equitable distribution of profits from fisheries as important social outcomes. By aligning territorial protection, cultural maintenance and concrete socioeconomic outcomes, arapaima co-management emerges as a decentralized win–win conservation tool and a very promising hope spot for Amazonian freshwater ecosystems[138].

Case study 3: archaeological–ecological tourism in the Caatinga

The Serra da Capivara National Park (SCNP) is located within seasonally dry forests of the Caatinga, a region with high biodiversity and endemism, but poorly protected and critically endangered[139]. The SCNP is a UNESCO World Heritage Site and has over 900 archaeological sites with a diverse set of rock paintings, some of which have been dated to more than 20,000 years ago[140]. The rich iconography is a valuable source of archaeological and anthropological information, showing how local livelihoods and ceremonial rituals changed over time[140]. The SCNP can only be visited with the help of local inhabitants, which minimizes illegal activities, such as deforestation and vandalism of archaeological heritages, while providing socioeconomic benefits for local communities. However, the SCNP faces challenges that need to be dealt with before it can be consolidated as a social–ecological

Table 1 | Common principles for building social–ecological hope spots

Principles	Settings and supports	Case studies	Description
Respect for Indigenous and traditional knowledge systems, rules and practices	Local knowledge systems, rules and practices	All	Indigenous and traditional ecological knowledge systems and practices are the cornerstone of successful hope spots as local communities have primary responsibility for mapping and monitoring natural and anthropogenic features within their territories[123,133].
Endorse participatory mapping and monitoring and local surveillance	Local practices Species and ecosystem diversity	1 and 2	Participatory monitoring and local surveillance are also required for creating areas fully protected by Indigenous and local communities within well-defined boundaries, such as lakes protected from predatory fisheries or forest resources protected from fires. The first two principles[161] may also ensure the successful reproduction of managed populations of culturally important species and the replenishment of wild populations of keystone species within well-conserved habitats[135].
Manage culturally important species and keystone species	Local practices Species and ecosystem diversity	1, 2 and 5	The management of culturally important species and keystone species with economic value are also necessary to promote harvesting sustainability and income generation for local communities, which, in turn, ensure engagement in collaborative research and management[100,154].
Maintain biocultural diversity and diversified agroecosystems	Cultural diversity Biodiversity	All	Maintaining biocultural diversity and diversified agroecosystems increases the resilience of social–ecological systems to fluctuations in key resources[118].
Guarantee territorial rights and autonomy to IP&LC	External political support	1, 2, 4 and 5	Explicit internal rules and external support are also important to ensure transparency and regulation at local scales[162]. IP&LC can follow rules created by themselves, according with their needs and cosmologies, and governments have an important role in guaranteeing their territorial rights and autonomy.
Ensure financial support to IP&LC	External economic support	1, 2 and 3	Governmental and financial support is also necessary to regulate the management activities, such as Indigenous or traditional fire management[152] or authoring a quota system within protected areas[136].
Promote multiple partnerships among Western and Indigenous and local participants	External institutional support	All	Partnerships among IP&LC, researchers, NGOs and governmental institutions are also encouraged to promote autonomy and social organization of IP&LC[136,140]. The partnership with different institutions can bring complementary skills and capacities to obtain financial support in order to expand local practices and technical expertise.
Foster polycentric governance	External institutional support	1 and 2	Fostering polycentric governance (that is, multiple decision-making bodies interact to govern and co-manage a territory or location)[163] is another key principle, because it facilitates the participation of numerous actors, increasing the chance of incorporating Indigenous and traditional knowledges, and promoting opportunities for learning across cultures.

Multiple cultural and ecological settings as well as external political, economic and institutional support are described. We show which case studies are related to each principle and provide a brief description of all principles. A combination of principles can help to achieve successful hope spots. These principles may flourish in a particular site and potentially produce new 'seeds of a good Anthropocene' that may inspire other initiatives in new sites[112]. The principles were adapted from ref. 136 and are inspired by the principles for building resilience[163].

hope spot, particularly, inadequate financial support, ongoing cultural and environmental degradation and the need to strengthen the cultural value of archaeological and natural heritages for local and global societies[140]. Despite these issues, the SCNP provides a promising tourism-based model that combines the protection of archaeological, cultural, biological and educational heritages, strongly benefitting biodiversity conservation and poverty alleviation in the world's most threatened forest biome[139].

Case study 4: Indigenous fire management in the Cerrado

The Cerrado is a fire-prone savannah biodiversity hotspot, suffering from high rates of native vegetation loss to accommodate livestock and crop production[141], which, coupled with climate change, have increased the risk of large wildfires[142,143]. Although many species are ecologically adapted, tolerant or resistant to periodic burning[144], decades of fire-suppression policies have homogenized landscapes with high grass flammability and allowed trees and shrubs to encroach on open savannah vegetation, causing biodiversity loss and severe changes in ecosystem functions and services[72,143,145,146]. Indigenous Peoples inhabiting the Cerrado frequently burn the landscape for numerous purposes related to their livelihoods[147]. The Xavante, for example, have ancient knowledge associated with fire management that is rooted in their cultural activities[148]. Where the Xavante manage fire, the native savannah vegetation is better preserved and restored after abandonment by large-scale agriculture[149]. These fire-management practices have fundamental roles in the ecology of tropical savannahs by enhancing landscape complexity and biodiversity, and indirectly promoting ecosystem services and functions, such as food provision and recharge of groundwater reservoirs[143,150]. However, the Brazilian government has historically violated Xavante rights, which has resulted in social injustices, lack of territorial autonomy, and cultural shaming of subsistence practices[151]. By guaranteeing the rights of Indigenous populations, the Xavante case (together with other examples of Indigenous and traditional fire management in South America[50,152]) could represent a social–ecological hope spot for community-based fire management in the Cerrado[151,152].

Case study 5: collaborative management of *Araucaria* pine in the Atlantic Forest

Araucaria (*A. angustifolia*), a culturally important conifer species used for food and timber in the southern Atlantic Forest, was dispersed and managed by Indigenous Peoples for millennia[85]. Today, *Araucaria* forests are restricted to only 12% of their original distribution, mostly due to overexploitation and deforestation during the past two centuries[153]. Severe top-down regulations restrict the local use and management of araucaria populations with negative cultural, socioeconomic and ecological consequences for these ecosystems[154]. *Araucaria* forests are important for local smallholders that manage their resources in multi-species production systems[155]. This management system generates strong socioeconomic incentives for farmers involved, who reported that at least 50% of their annual gross income comes from araucaria seed markets[154]. Beyond the protection of native plant and animal species within *Araucaria* forests, traditional management by smallholders allows the conservation of other target species, ensuring the maintenance of genetic diversity of araucaria, yerba mate (*Ilex paraguariensis*), and other culturally important species within the production systems[155]. Because araucaria is also a keystone plant resource in these ecosystems, it has a fundamental role in the ecological processes that maintain ecosystem functions, such as seed dispersal[86], while being a central link for the persistence of these social–ecological systems in the southern Atlantic Forest under climate change[154,156]. By including local people in the decision-making process, a shift towards collaborative management of *Araucaria* forests can enhance the resilience of these forests and their peoples, thus representing a promising social–ecological hope spot.

Common principles for successful social–ecological hope spots

These five case studies (Fig. 1) illustrate how collaborative research and management of biodiversity with IP&LC engagement in territorial protection can produce better social and ecological conservation outcomes, when compared to strictly protected areas that in most cases either exclude IP&LC or restrict access to their ancestral lands[12,14]. All cases also show how local capacities and network partnerships that incorporate Indigenous or traditional knowledges and scientific knowledge can be transformed into better futures for common social–ecological problems[25,157]. From these case studies, we identify eight common principles that may help other conservation models to achieve successful outcomes (Table 1): (1) respect for Indigenous and traditional knowledge systems, rules and practices, (2) endorse participatory mapping and monitoring, and local surveillance, (3) manage culturally important species and keystone species, (4) maintain biocultural diversity and diversified agroecosystems, (5) guarantee territorial rights and autonomy to IP&LC, (6) ensure financial support to IP&LC, (7) promote multiple partnerships among Western, Indigenous and local participants, and (8) foster polycentric (multiple decision-making bodies) governance.

Conclusion

Our assessment reveals that by creating cultural niches; altering natural selection pressures; managing species, landscapes and ecosystems; and protecting their territories from the impact of global changes, IP&LC contribute to biodiversity conservation in South America and to the provision of multiple co-benefits to nature and societies. We also show how biodiversity and cultural diversity are interconnected as parts of a network of interactions and feedbacks that maintain social–ecological systems functioning. We present social–ecological hope spots as examples of such resilient systems emerging across tropical South American biomes, which may offer inspiration[112] for societies elsewhere[111]. Very often, biodiversity and ecosystem conservation are evaluated by conservationists, scientists and stakeholders as an outcome to be achieved. For IP&LC, healthy ecosystems are the basis of their existence, from which Western societies have much to learn. Without the recognition of the cultural dimension of our world's ecosystems[24], the most desired goals of global agreements for sustainable development, such as those related to the 'Decade of Action', are unlikely to be achieved.

The 2030 Agenda brings together several multilateral agreements to be reached by the end of this decade[158], such as the Paris Agreement and the Kunming–Montreal Global Biodiversity Framework. These agreements permeate the UN SDGs and recognize that the conservation of biodiversity and its associated benefits to societies underpin all dimensions of human well-being[20]. Although human cultures may contribute to the achievement of the SDGs and 79% of all targets[24], the inclusion of the full array of worldviews from Indigenous and local cultures in conservation policies is still emerging[25]. Our review and case studies demonstrate how the 2030 Agenda could be strengthened by recognizing the key roles of IP&LC in actions (including decision-making processes) necessary for fostering knowledge-based transformative changes towards sustainability[159]. By valuing and bringing together all human cultures, conservation policies can strengthen environmental governance, assist local development, promote social justice and alleviate conflicts[160]. Overall, our Review recognizes and summarizes how IP&LC with their diverse cultures are fundamental pillars of biodiversity and ecosystem conservation.

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Author contributions

C.L., B.M.F. and C.R.C. conceived the study. C.L., B.M.F., C.R.C. and N.P. conducted the literature review. J.V.C.-S. and C.L. were responsible for all promising case studies and M.H., W.D., H.L., C.F., B.F., J.W., B.M., M.S., T.W.K., H.K., K.W., K.K. and A.K. were responsible for the Xingu hope spot. C.L., B.M.F., C.R.C., N.P., J.V.C.-S., A.S., M.C.G.P., M.H., W.D., H.L., C.F., B.F., J.W., B.M., M.S., T.W.K., H.K., K.W., K.K. and A.K. interpreted the full literature review. C.L. led the writing of the article, and B.M.F., C.R.C., N.P., J.V.C.-S., A.S., M.C.G.P., M.H., H.L., J.W. and C.F. substantially revised it. All authors agreed to this version for submission.

Competing interests

The authors declare no competing interests.

Additional information

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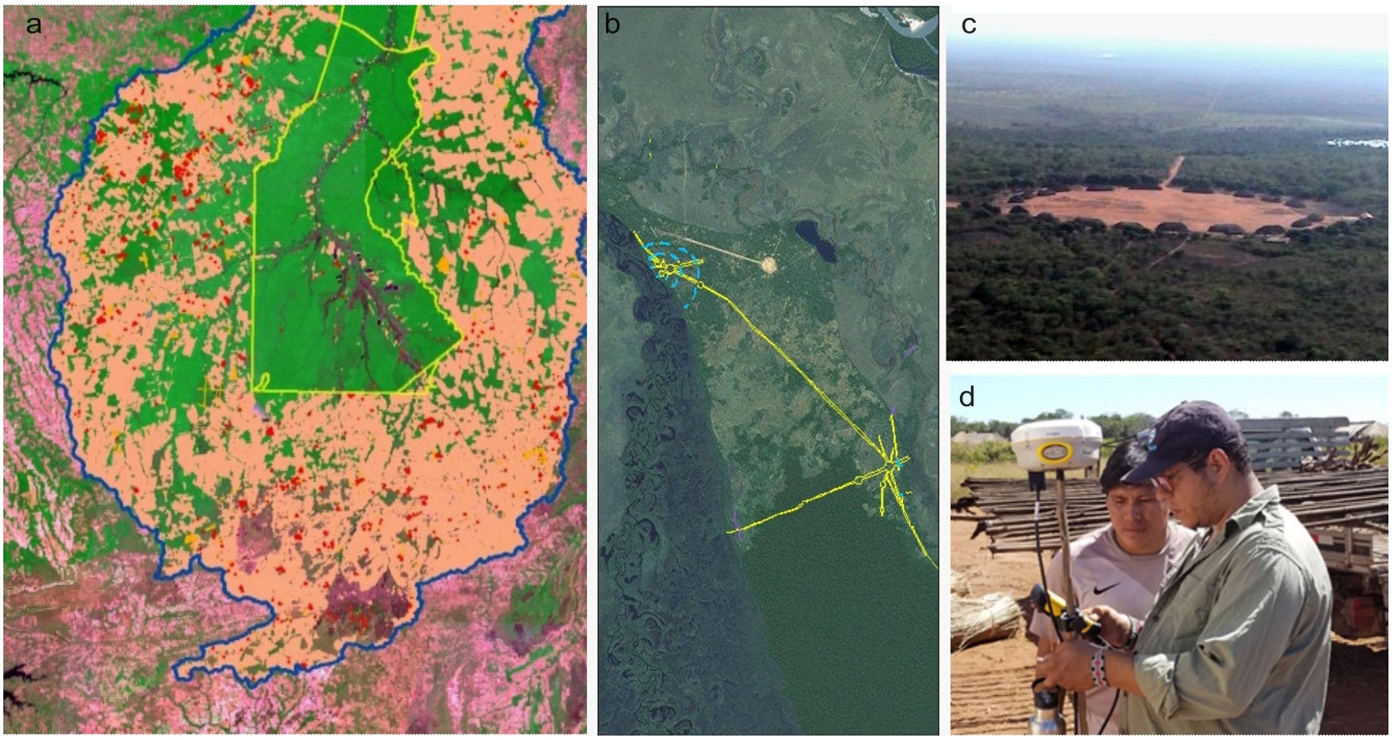

Extended Data Fig. 1 | Xingu Hope Spot in the Southern Transitional Forest of Brazilian Amazonia. (**a**) ArcGIS maps including the TIX and surroundings, archaeological sites and features and modern villages. (**b**) Pre-Columbian complex systems of land management and urbanized landscapes in the TIX. (**c**) Kuikuru modern village. (**d**) Indigenous participation in mapping and real-time data collection. Image credits: AIKAX[123].

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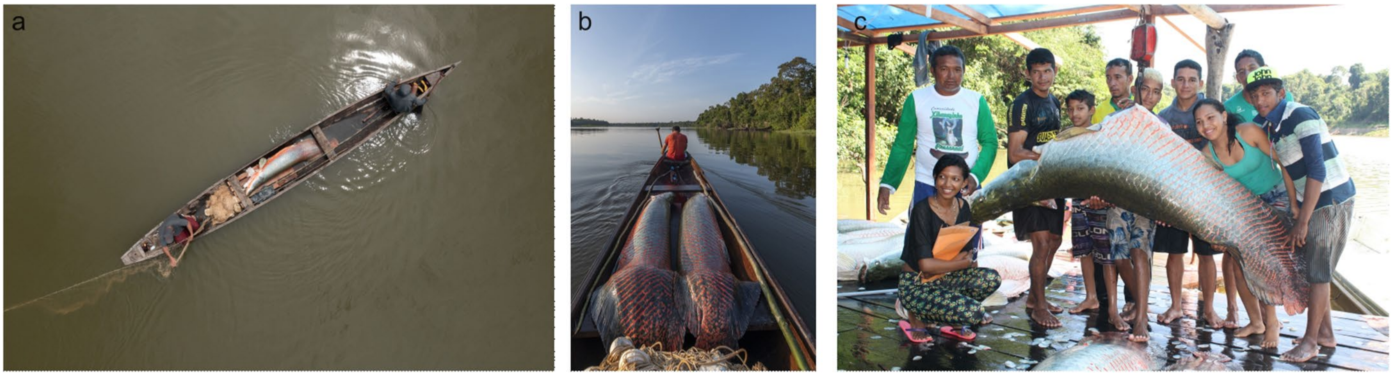

Extended Data Fig. 2 | Collaborative management of giant arapaima fish in Amazonian floodplains. (**a**) Co-management of arapaima habitats. (**b**) Harvesting arapaima fishes according to local needs. (**c**) Improving welfare and gender equality. Photos credits: Marcos Amend/Instituto Juruá and Andre Dib/Insituto Juruá.