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Review

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Author for correspondence:

Stephan Schwartzman
e-mail: steves@edf.org

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The natural and social history of the indigenous lands and protected areas corridor of the Xingu River basin

Stephan Schwartzman¹, André Villas Boas², Katia Yukari Ono², Marisa Gesteira Fonseca², Juan Doblas², Barbara Zimmerman¹, Paulo Junqueira², Adriano Jerolimski³, Marcelo Salazar², Rodrigo Prates Junqueira² and Maurício Torres²

¹Environmental Defense Fund, 1875 Connecticut Avenue, NW, Washington, DC 20009, USA

²Instituto Socioambiental, Av. Higienópolis, 901, Higienópolis, São Paulo 01238-001, Brazil

³Associação Floresta Protegida, Rua do Mogno, 240, Tucumã, PA 68385-000, Brazil

The 280 000 km² Xingu indigenous lands and protected areas (ILPAs) corridor, inhabited by 24 indigenous peoples and about 215 riverine (ribeirinho) families, lies across active agriculture frontiers in some of the historically highest-deforestation regions of the Amazon. Much of the Xingu is anthropogenic landscape, densely inhabited and managed by indigenous populations over the past millennium. Indigenous and riverine peoples' historical management and use of these landscapes have enabled their long-term occupation and ultimately their protection. The corridor vividly demonstrates how ILPAs halt deforestation and why they may account for a large part of the 70 per cent reduction in Amazon deforestation below the 1996–2005 average since 2005. However, ongoing and planned dams, road paving, logging and mining, together with increasing demand for agricultural commodities, continued degradation of upper headwaters outside ILPA borders and climate change impacts may render these gains ephemeral. Local peoples will need new, bottom-up, forms of governance to gain recognition for the high social and biological diversity of these territories in development policy and planning, and finance commensurate with the value of their ecosystem services. Indigenous groups' reports of changing fire and rainfall regimes may themselves evidence climate change impacts, a new and serious threat.

1. Introduction: indigenous lands, protected areas and Amazon deforestation

The 280 000 km² of indigenous lands and protected areas (ILPAs) of the Xingu River basin form a continuous forest corridor larger than the UK, inhabited by 25 indigenous peoples and about 215 riverine (*ribeirinho*) families. Directly adjacent to the arc of deforestation in Pará and Mato Grosso, the Xingu ILPAs are a clear example of how Brazilian government policy has worked to reduce Amazon deforestation rates over 70 per cent below the historic average since 2005 (<http://www.obt.inpe.br/prodes/index.php> accessed 21 February 2013) ([1]; figure 1). However, ongoing and planned infrastructure works (the Belo Monte dam, possible upstream dams on the Xingu, paving of the 163 highway), current and projected logging and mining, and emerging climate change impacts [5] suggest that these gains may prove ephemeral unless ILPAs and their socio-environmental value are recognized and incorporated into development strategies. In this study, we examine the history of the Xingu ILPAs in the context of modern Brazilian indigenous policy, contrasted to other tropical forest regions. We explore the conditions that enable and threaten the corridor's continued effectiveness against deforestation, and identify strategies to protect

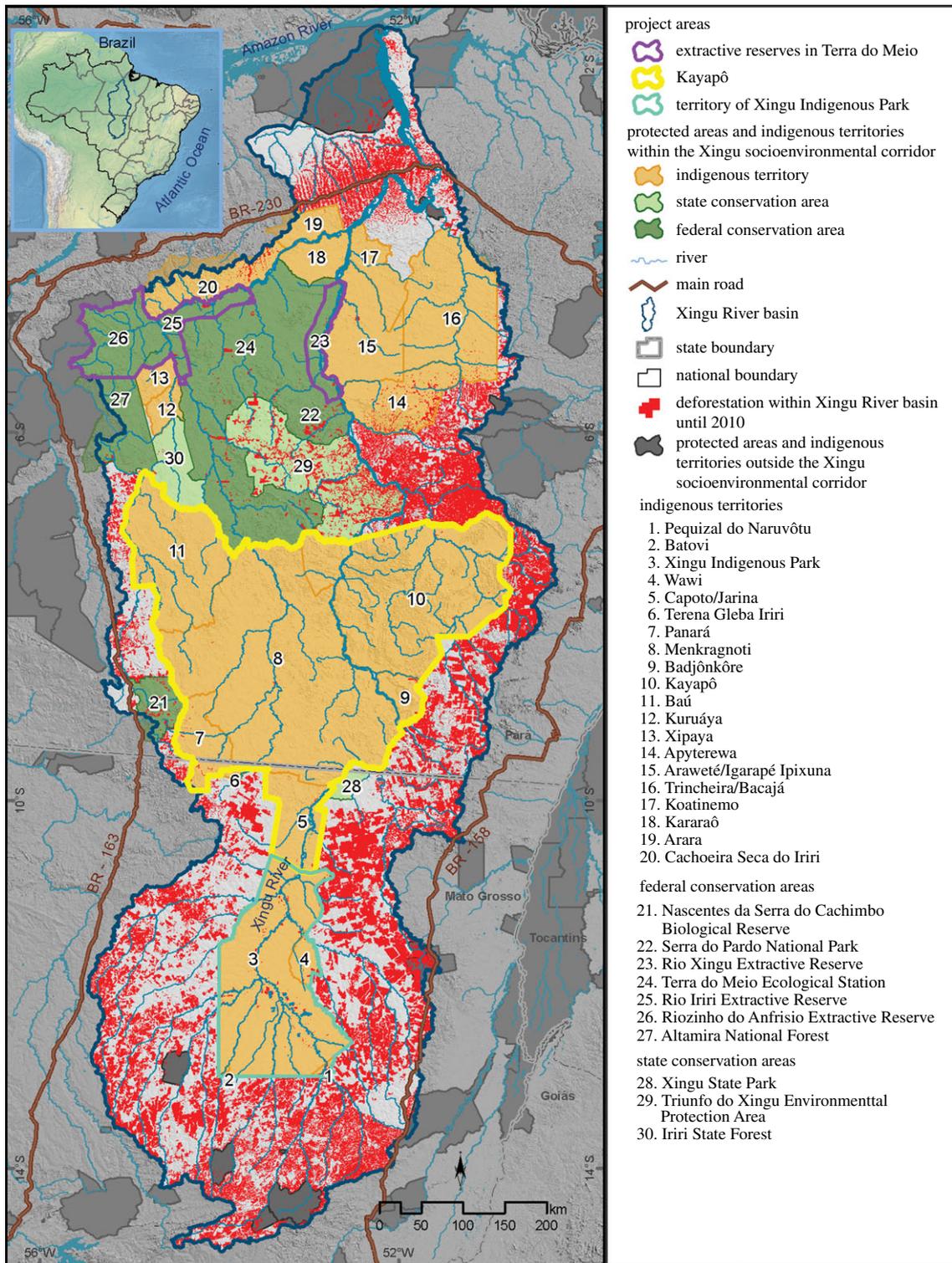


Figure 1. Xingu Basin indigenous lands and protected areas corridor. Data sources: rivers, state boundaries and national boundary [2]; Xingu River basin, indigenous territories and protected areas [3]; deforestation within the Amazonia biome [4]; deforestation within the *cerrado* biome [3].

and extend gains. We review the historical–ecological evidence that the territory of the corridor and present-day land uses are products of long term—in much of its extent, millennial—and dense occupation by ancient indigenous peoples. We show that present-day populations to a large extent inhabit anthropogenic landscapes, and that their historical management and use of the resources of these landscapes has enabled their long-term occupation of the territory and ultimately its protection.

Climate change impacts and degradation of upper headwaters appear to be increasing threats. We review ethnographic and archaeological descriptions of indigenous use of fire as a

management tool, and report Upper Xingu indigenous people's observations on changing fire and rainfall regimes. Because both use of fire and celestial timing of agricultural cycles are ancient practices, observed changes may themselves be indicators of climate change.

We find that NGO projects and government support for indigenous and traditional communities have, in some instances, launched innovative public policy (bilingual education in the Xingu Indigenous Park (PIX), and developed scalable resource management and income-generation projects within the ILPAs and in surrounding areas. They have, in some cases, materially improved small isolated populations' access to

healthcare, education and markets. NGOs have enabled local communities to organize their own institutions—critical to building capacity to manage their territories. However, larger-scale sustainable sources of finance will be needed to address current threats. Payment for ecosystem services, including reducing emissions from deforestation and forest degradation (REDD+), potentially including both public and private sources, could attain the scale needed.

Indigenous and traditional leaders call for better access to healthcare, education and markets—but also emphasize that territorial integrity from their perspective, depends on cultural identity and vice versa. Bilingual education, bicultural teacher and healthcare provider training, publications in indigenous languages, and mentoring indigenous filmmakers and inter-cultural researchers support indigenous peoples' self-reflexive examination and valuation of their own cultures as cultures that contrast to but are in parity with others. Critical perspectives on cultural difference may be an important condition for the sustainability of these territories.

2. Indigenous peoples: pre-colonial majorities to post-colonial minorities

Worldwide, much of the remaining tropical forest is also indigenous territory (i.e. occupied by social, cultural, linguistic and religious minorities, pre-dating European colonization and national governments) [6,7]. But this observation is only possible from a post-second world war, post-colonial vantage, through the lens of third- and fourth-world mobilizations and recent international law and accords [8,9]. 'Indigeneness' is, in the first instance, a relationship between colonizer and colonized. Indigenous policies in different regions were conditioned by differing strategies of colonial administration.

In nineteenth century Africa and Indonesia, colonial definitions of the 'native' as a political identity became the conceptual basis for indirect rule [10,11]. Identification of specific ethnic groups with fixed geographies and the attribution of a unique customary law and administrative 'native authority' to each tribe effectively divided colonized majorities into numerous, competing native minorities, in Africa in particular leading to intractable inter-ethnic conflicts. Colonial identification of specific ethnicities with fixed geographies produced a legacy of severe inter-ethnic tensions and conflict in Africa, and coloured regional and ethnic autonomy movements in colonial and post-colonial Indonesia. Identifying ethnicities with geographies in the Amazon in the twentieth century was a very different matter.

Modern Brazilian indigenous policy starting in the 1940s, based on existing evidence of demographic trends and prevailing ethnological theory, assumed that the story of the surviving descendants of pre-Columbian populations was winding to a close. Based on available census data and evidence of dwindling populations and indigenous assimilation, policy-makers and anthropologists alike concluded that indigenous peoples were a small minority destined, if not to altogether disappear, lose any vestiges of specific cultural identity [12,13]. Indigenous populations in the Amazon in the mid-twentieth century were probably approaching a historical nadir [14].

What were taken for the demographic facts on the ground at the end of the 1960s had a crucial influence on indigenous policy. Military government founders of the National Indian

Foundation (FUNAI) believed that they were dealing with a very small and diminishing population that could easily be accommodated on limited lands until such time as they became integrated into the national society. However, indigenous groups and anthropologists found that the land rights guaranteed in the 1973 Indian Statute applied to many more peoples than its framers anticipated. Fifteen years of public conflicts ensued between military leaders of FUNAI and anthropologists, indigenous rights activists and indigenous groups over who could be considered Indian [15–17]. The 1988 Constitution recognized the right of indigenous groups to maintain traditional cultures permanently, making indigenous land and resource rights permanent [18,19] and becoming the basis for large-scale demarcation of indigenous territories. In numerous local struggles and in the forum of national law and policy, indigenous peoples successfully gained recognition of their rights to specific geographies—and hence for control over 20 per cent of the Amazon. The indigenous population, while small (approx. 0.4% of the national total), is growing, and indigenous ethnicities, rather than disappearing, are proliferating [20].

3. Historical ecology and indigenous resource management: ancient populations and present-day resources

(a) Historical ecology

The Xingu River rises in the woodlands–savannah and transitional, semi-deciduous forest of northern Mato Grosso and flows north through the dense, moist forest of Pará for 2700 km to empty into the Amazon. A clear water river, it drains a landscape of ancient crystalline pre-Cambrian shield. The Xingu basin covers 51 million ha, of which approximately 20 million ha is officially recognized indigenous land, whereas another 8 million ha is protected areas [3].

Much of the Xingu was, and continues to be, an anthropogenic landscape [21], continuously occupied, managed and modified over at least the past 1200–1500 years. Many of the resources indigenous and riverine communities use are indicators or products of this earlier occupation (e.g. Brazil nuts, babassu palm, dark earths and vine forests). This includes, at least, the Upper Xingu, Kayapô and Panará territories, Assurini and Araweté indigenous lands, the Anfrízio, Xingu and Iriri rivers from the north to the south of the Terra do Meio [22–25].

Large parts of the middle Xingu (Arawete, Assurini, Kayapô and Panará indigenous lands, Anfrísio, Iriri and Xingu Extractive Reserves) are characterized by abundant deposits of Amazon dark earths (ADEs), archaeological remains and disturbance indicators including heavily used species such as Brazil nuts (*Bertholletia excelsa*), babassu palm (*Orbignya phalerata*) and liana forests [21,25]. Some 215 riverine families along several hundred kilometres of the middle Xingu, Iriri and Anfrízio rivers almost without exception inhabit and plant in dark earths, and regularly encounter potsherds, stone axes, ceramics and figurines. This is also the case for all the Kayapô communities in Pará [25,26]. Contemporary land use and resource management in the Xingu corridor is thus significantly conditioned or made possible by mostly little-studied prehistoric land-use practices.

Archaeological sites evidence ancient pre-Columbian occupation throughout the Xingu basin, although only the Upper Xingu has been the object of sustained archaeological research [22,23]. Occupation of the Xingu headwaters dates to about AD 800–900. Based on remains from the middle Xingu, similar to archaeological material dated to AD 1000 and AD 1580 on the Tocantins, Balée [21] suggests that two major indigenous societies occupied these regions in prehistoric times. Archaeology of the Xingu documents much larger populations than those registered by modern ethnology, as well as complex settlement patterns and large-scale transformation and management of forest cover and other landscape features [22,23]. In the Upper Xingu, in particular, large settlements surrounded by earthworks and palisades connected by extensive road networks from about AD 1250–1600 show marked cultural continuities with contemporary societies (ceramics, settlement location and patterns, and land use).

There are indications of sporadic incursions—with probably devastating demographic consequences—of Portuguese slavers and prospectors in the Upper Xingu in the mid-eighteenth century [27]. Kayapô and Yudja, fleeing colonists, gold miners, rubber tappers and missionaries occupied the still relatively isolated middle Xingu in the first half of the nineteenth century. Intensive occupation of the basin began only in the 1970s, with the opening of the Transamazon, BR 163 and BR 158 highways through the basin and the arrival of colonists from southern Brazil. The Xingu headwaters region has become one of the major cattle- and soya bean-producing regions in Mato Grosso, whereas the county of São Felix do Xingu in Pará has the largest cattle herd in Brazil of over two million head. There are currently some 610 000 people living in 35 counties in the basin [3].

(b) Fire and indigenous resource management

Ethnographic and archaeological data from the Xingu and other regions of the Amazon and the Americas suggest that fire was an important landscape and resource management tool dating to prehistoric times. This is significant in the light of Upper Xingu peoples' current observations on changes in fire regimes (see 4a(ii)). If fire has been used to manage landscapes for centuries—if not millennia—and only now is perceived as a threat in the region of the basin most vulnerable to climate change impacts, then these observations themselves may be taken as indicators of climate change.

The use of fire as a management tool in the pre-Columbian Americas is widely reported and evidenced in charcoal found in soil and lake sediment deposits that declines post-1500 [28–31]. Indeed, several authors propose that post-pandemic emissions reductions and carbon sequestration, as forest regenerated on previously fire-cleared and managed indigenous farmland, contributed significantly to the Little Ice Age of the sixteenth–eighteenth centuries [32,33]. Use of fire in swidden agriculture is ubiquitous in the Amazon [34, p. 191]. Repeated burning of plant materials is central to forming ADEs [35], such that ADE deposits evidence long-term use of fire as a management tool. Beyond this, Heckenberger reports that present-day Upper Xingu groups regularly burn floodplain savannah and scrub forest from June to September. Many tree and ground-cover species appear to be fire-resistant and quickly regenerate. Burning stimulates dense regrowth of sapé grass (*Imperata* spp.), used for housing thatch, and also renders clay soils friable and more easily worked (M. Heckenberger, personal

communication, 11 October 2012). Hecht argues that ethnographic observations of the use of fire and other management techniques among the Kayapô of the Xingu basin may shed light on the historical formation of ADEs. 'Burning is a low-level, relatively constant activity used to maintain *cerrado* formations; to favour certain vegetation in some areas, such as the *inaja* (*Attalea* sp.) and *tucumã* (*Astrocarym* sp.) palm groves which are important for attracting herds of pigs and for building materials; to clear for agriculture; for weeding; possibly to control plant pathogens and insects.' [36, pp. 363–364]. These observations of Kayapô are consistent with my observations of the Panará [37]. The Panará in the early 1980s, burned cleared forest for swiddens, regularly re-burned weeds and crop residue in gardens, and burned around the village and on paths to keep them clear. When on hunting, fishing or collecting expeditions in the forest they never put out cooking fires or fires set to collect honey, and even at the height of the dry season, these fires extinguished themselves. There is ample archaeological, historical and ethnographic evidence that indigenous groups routinely used fire as a management tool in a variety of ecological contexts over a very long period of time. It will be important to understand current Upper Xingu peoples' observations on fire regimes in the light of the evidence for the prevalence of fire in indigenous landscape and resource management.

4. Indigenous lands and protected area history

The official recognition of the Xingu Indigenous Lands and Protected Areas over more than 60 years, from the late 1940s to 2008, is a product of regional conflicts over land and natural resources and indigenous and local communities' strategies both to resist and accommodate successive frontiers. We will examine the histories of the PIX, Panará territory, the Kayapô Indigenous Lands and the Terra do Meio protected areas.

(a) Cultural continuity, land use and climate change: Xingu indigenous park

The current cultural geography of the Upper Xingu reflects both strategic trade-offs of its founders, the Villas Boas brothers, as well as occupation by traditional Upper Xingu groups showing strong cultural continuities over the past 1000 years. When the Villas Boas arrived in the Upper Xingu in the late 1940s, they found 11 peoples, soon reduced by diseases to about 569 (from 2500 to 3000 in the late nineteenth century [38]). They formulated a proposal for a Xingu National Park of about 20 million ha, comprising much of northern Mato Grosso from about 14° S to the Pará border, proposed in national legislation in 1952 [39]. Although the land was almost completely inaccessible, the Mato Grosso state government sold most of it to speculators, and opposed the Park. The area ultimately reserved for the Xingu Park in 1961, and ratified by Presidential decree in 1991, was little over 2 million ha.

The failure of this ambitious original vision of the PIX, along with events on the ground, no doubt coloured the Villas Boas' efforts to transform the Park as demarcated in 1961 into a sanctuary for the indigenous peoples of the region. From the 1950s through 1975, the Villas Boas relocated five indigenous groups to the Xingu Park. Several of

these groups had recently been devastated by disease and conflicts with invading miners and ranchers [40]. The implicit bargain of the contacts was trade goods and healthcare in exchange for ending raids on Brazilians and indigenous groups and settling near assistance posts. Most of the newcomers were traditional enemies of the Upper Xingu peoples, and the Villas Boas brothers heavily promoted their view of the Xinguano ethic of inter-tribal peace for the Park as a whole [41].

The Villas Boas' policy of contacting and relocating indigenous groups to the Xingu probably saved several groups from extinction, but it left their lands open for occupation by outsiders. Most of the traditional territory of the Panará, Kawaiweté, Ikpeng, Tapayuna and Kisedje was in fact appropriated by goldminers, ranchers and colonization projects once it had been vacated by the Indians. The last group relocated to the Park, the Panará, was the first to seek to recover their traditional land. Beginning in 1990, the Panará mobilized NGO support to return to, and ultimately reoccupy, the remainder of the traditional territory from which they were relocated in 1974 after the opening of the BR-163 [42,43]. Subsequently, Kisêdjê, Waura, Kawaiweté, Naruvotu and Ikpeng all made claims on parts of the traditional territories they left when they moved into the Xingu Park, and the Park boundaries were expanded in 1997 to include Batovi (Waura) and Wawi (Kisêdjê) Indigenous Lands, and in 2009, the Pequizal do Naruvotu (Naruvotu) [44].

(i) Non-governmental organizations and the state

From the later 1980s, Xingu groups' relations with the national society changed substantially. Although FUNAI had mediated and largely controlled all interactions with the outside world, with shrinking budgets and diminished capacity, FUNAI decentralized services and groups developed independent relations with outsiders [45, p. 39; 46, p. 53].

The Xingu peoples faced radically changed circumstances in the 1990s. The Xingu basin in Mato Grosso was rapidly becoming a major timber, soya bean- and cattle-producing region, surrounding the PIX with farms and ranches. Regional cities became accessible. Both pressure from outsiders on the natural resources of the Park as well as internal demand for industrialized goods and technology increased dramatically. Meanwhile, the indigenous populations grew far more rapidly than the national average, such that today the Xingu groups have reached or exceeded their pre-contact levels, totalling some 5000 in 2011 [3]. With increased dependence on outsiders' goods and healthcare, some groups became more sedentary, putting more pressure on land and natural resources key to subsistence and social and cultural reproduction.

The key pre-condition for launching the NGO Instituto Socioambiental (ISA) Xingu programme in 1995 was the founding of the Xingu Indigenous Land Association (ATIX) in 1994. This created the institutional basis for the 16 Xinguano member groups to enter into legal relationships independently, formulate project proposals and receive funds. Following the creation of ATIX, the Panará, Kisêdjê, Yudja, Kawaiwete, Ikpeng, Kuikuro and Waura have organized their own associations to develop projects in their respective communities.

The ISA Xingu programme has developed a long-term presence in the PIX, based on projects and activities jointly planned with indigenous organizations and leadership. Major programme focus has been on territorial monitoring

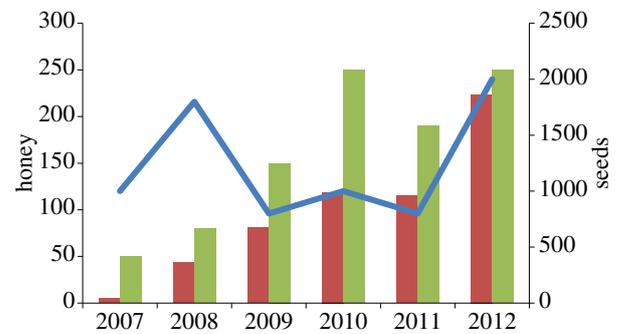


Figure 2. Honey and seed production in the Xingu Park and headwaters, 2007–2012. Annual totals of honey produced (blue, 100 kg), seeds sold (green, 100 kg) and seed revenues (red, \$1000s). Data source: Instituto Socioambiental Annual Activities Reports (2007–2011).

and control (mapping of deforestation and degradation, border patrols, reconnaissance flights, maintenance of demarcation signage and paths, reporting and halting invasions); bilingual and Portuguese education, teacher training and inter-cultural research; economic and income-generation alternatives (beekeeping, natural oils, handicrafts, native tree species seeds); supporting and strengthening local organizations (capacity building in project and organizational management, resource management and GIS); and strengthening traditional culture. Indicators of the results of specific activities or projects show consistent demand for the programme's services, increasing participation in projects, and substantial output (figure 2) but some results are difficult to evaluate, particularly in relation to the long-term goal of creating the conditions for the socio-environmental sustainability of the PIX. Qualitative factors—leadership, commitment, social and kinship networks—may be more important than easily quantifiable indicators.

Cultural issues may be of particular importance to future land use in the indigenous territories. Leaders frequently assert that indigenous territory, and cultural identity, values and knowledge are mutually interdependent. 'Indigenous land is important because within the reserve we preserve our wealth and the knowledge of our elders... If my people were like the whites and destroyed the forest, the forests would no longer exist in the indigenous reserve... ' Jemy Kaiabi [40, p. 154]. 'Here in the Park the forest is ours. This is our place. Our creator was born here, our ancestors, that is why we live here... This is why I am very concerned with the forest. Because it has the resources we use... ' Arifirá Matipu [40, p. 214]. 'Indigenous land is important for indigenous society, because we get the food we survive on from it... We indigenous peoples don't destroy, we don't deforest land where biodiversity is. We don't pollute the air or the rivers, where there are other living things that give us health' Karin Juruna [40, p. 215]. Ecological sustainability and traditional culture are in this view inseparable. ISA's Xingu programme has consequently focused on indigenous culture, language and knowledge. The education programme, between 1999 and 2005, trained some 47 bilingual teachers [40, p. 160]. Thirty-seven of these have gone on to college, and three have done postgraduate work. The programme's network of linguistic and anthropological collaborators has produced alphabets for 14 languages and published 20 readers and health manuals in 14 languages (i.e. all but one of the languages of the PIX). Another organization took on teacher

training, and trained an additional 50 teachers. Today, there are 50 schools and 120 teachers in the PIX, teaching children to read and write first in their native languages, then in Portuguese [40]. The ISA bilingual education project has become effective public policy in the PIX. The programme's other publications (including many joint efforts with ATIX), on agriculture, art, ritual, myths, music and oral histories evidence enduring concern with recording and preserving traditional knowledge and culture [47]. We will return to the issue of cultural values and sustainability in the following text.

(ii) Fire and degraded headwaters: new threats

Degradation of the riparian forests of the upper headwaters of the rivers that form the Xingu and changing, more destructive, fire regimes constitute new and serious, threats to the ecological integrity of the PIX and the livelihoods of the Xingu peoples. Xingu peoples traditionally use fires to burn cleared forest for new gardens, secondary burning in older gardens, to burn savannahs and keep village environs and pathways clear, to ward off bees when collecting honey, and for cooking fires on hunting, fishing and collecting trips in the forest [3,40] (M. Heckenberger, personal communication, 11 October 2012). Both older and younger Xinguanos themselves articulate perceived changes clearly.

I am concerned with the change, today I am very concerned with forest fires... because the savanna and forest are burning. Formerly, in the 1970s, these changes had not happened. Until 1980, everything was fine, we set fire to the savanna and it went out by itself, since it stopped right at the edge of the savanna. Starting in 2000, the fires don't put themselves out anymore... In my village a lot of forest burned. The fire happens because of the heat. We are in a new climate. Arifirá Matipu [40, p. 214].

Today our customs are changing. This is what my grandfather was saying, there didn't use to be this heat, there were not problems with water. Ausuki Kalapalo [40, p. 214].

Fire is different now. When I was little, people didn't burn like now. The sun didn't get as hot as it does now. It always burned and went out. Now, people set fire and it gets away and there's a big fire. Before it would burn the savanna but didn't burn the forest. Now, we say, 'I think the weather changed.' Lahussia Juruna [Interview with Lahussia Juruna, May 2007, Tuba-tuba village, Xingu Indigenous Park].

We know when it is time to clear gardens when we see a star (the Pleiades) that doesn't always come out, only when its time to make gardens... When the star comes out in the middle of the sky, it's the time to stop clearing for gardens... In the old days the forest was much more humid and because of this only the part cut down caught fire. Today, all the humidity of nature dries up and more places catch fire... The star still comes out, but the rain is very different. Last year we planted a community garden... and it didn't grow. The sun got very hot, because the rains were very late. The earth was very dry. The river is also changing a lot. Before, when the water level fell, it was nice. Now there are more beaches in the middle of the river and along the banks the level doesn't fall. Sadea Juruna [48].

If the little group of stars (the Pleiades) appears about at sunset and the *murici* (*Byrsonima crassifolia*) flowers, it's time to make gardens. They clear forest and wait. When its near time for the rains to start, there's another flowering and when it falls the rains come. The people get ready to burn. Then they plant. They know that when it rains, it won't stop, its the rainy season. We plant corn, sweet potatoes and more. They come up well. Before, it was like this. I and the older people notice the change... Another thing is when the rains stop. There's a vine that burns and when its flowers fall, its time for the rains to stop. The fruits are also changing the way they ripen. Some ripen in the summer when they used to ripen in September.

We ask ourselves why these changes are happening... The fall of the water level in the rivers is also different. Formerly the river got really small and then the rains would come, now it doesn't dry out as much and the rain already falls.' Ntôni Kisêdje [48] (see the electronic supplementary material).

Xingu indigenous groups' observations are consistent with both with remote-sensing observations of fire incidence and recent literature on the effects of climate change and deforestation on Amazonian ecosystems—forests that were historically too moist to burn are beginning, particularly in dry years, to catch fire [49–52].

Given long-term, widespread indigenous use of fire for landscape and resource management in the Xingu, indigenous people's observations of changed fire regimes may themselves be taken as early signs of climate change.

Traditional agriculturalists in the Xingu also observe changes in rainfall regimes that disrupt traditional agricultural cycles. Indigenous groups throughout lowland South America traditionally have timed their agricultural cycles to the appearance of the Pleiades in the early evening and their movement across the sky [53, p. 222 et passim]. As Sadea Juruna notes, the onset of the rains could be predicted by appearance of the Pleiades in the middle of the sky, but this is no longer a reliable indicator. Various Xingu leaders make this observation [48], and also note changes in river flow.

Waurá elders in a village meeting to discuss climate change observed that the water level of the rivers does not fall, the rains come late and may fail. In 2005, by their account, the river rose early, before turtle eggs had hatched and killed the hatchlings (Meeting with traditional leaders on climate change, Waurá village, PIX, 24 April 2011). In general, Xingu indigenous people's observations of changes in in-stream flows appear consistent with observations and predictions in the hydrology literature of increased flow in increasingly deforested catchments [54–56].

Indigenous observations of changing fire, rainfall and river flow regimes clearly merit more research, both because many indigenous people are intimately acquainted with the ecosystems they inhabit and are careful observers, and because much of their resource use and management is based in oral traditions spanning hundreds of years or more. Using the rising of the Pleiades as an indicator of the onset of the rainy season is observed across lowland South America and can thus be assumed to be a very ancient practice. If, in fact, it has become or is becoming an unreliable indicator, this—and other indigenous observations based in traditional agro-biological knowledge—may also be early signs of climate change.

The ISA, with ATIX, has since 2010 initiated a fire prevention and control project, initially with eight villages in the PIX, mobilizing FUNAI and IBAMA to participate in training courses and to draft a fire prevention plan for the region. While the IBAMA fire prevention programme, Prevfogo, has plans for protected areas, it lacks an approach to the problem in indigenous territories. Some years before the Xinguanos expressed concerns with fires and rainfall, many were already alarmed by changes in water quality.

(iii) Multi-stakeholder effort to restore degraded headwaters: the Xingu headwaters campaign

All of the upper headwaters of the rivers that form the Xingu lie outside of the PIX, and have since the 1990s increasingly been deforested for soya bean and cattle ranching. By the

late 1990s, Upper Xingu communities were voicing growing concern with water quality, turbidity, siltation of riverbeds and fish populations [40]. For cultural reasons, the traditional Upper Xingu groups prohibit hunting almost all mammals and thus depend on fish as their source of protein. A subsequent study of water quality identified increased turbidity, siltation and water temperature as effects of deforestation of riparian forest in the upper headwaters [57] that if unchecked, could compromise fish populations.

Discussion among indigenous leaders, country governments, landowners and NGO led in 2004, to the launch of the Xingu headwaters campaign—Y'ikatu Xingu—in order to promote voluntary efforts to restore degraded headwaters. The campaign has engaged a wide array of regional organizations and governments and promoted some restoration of riparian forest. It also gave rise to the Seed Network, made up of indigenous and family farmer seed collectors, who collect native tree species seeds for sale to public and private restoration efforts, as well as developing mechanized direct planting of seeds, a lower-cost alternative to seedlings. Income from seed collection has grown substantially, but the cost of restoration and lack of effective incentives for landowners have constrained restoration to a small fraction of the area degraded [58,59].

The seed network is potentially a scalable form of income generation for indigenous people and small farmers, given the large amount of degraded lands that will, in principle, have to be restored under the new Forest Code. The headwaters experience suggests that building multi-stakeholder networks at a river basin, or sub-basin, level, linking ILPA and surrounding populations may be a necessary and critical step towards long-term protection and sustainability of the ILPAs—but also that restoration of degraded lands will require very significant investment, public or private, to come to fruition. The wording of law 12.651/12 (the Forest Code) authorizing payments for ecosystem services, and the National REDD+ Policy process (see the electronic supplementary material) offer important opportunities to create performance-based incentives for the large-scale restoration of degraded lands.

5. Warrior tradition in the frontier economy: the Mebêngôkre (Kayapô)

The approximately 10.5 million ha in five contiguous Kayapô territories comprises the largest expanse of forest occupied by a single ethnic group in the Xingu ILPA corridor. Through the 1980s and 1990s, the Kayapô repeatedly staged highly visible demonstrations, blocked roads and expelled goldminers from their territory, in the process of winning official recognition of their land rights. At the same time, nearly all of the Kayapô chiefs negotiated deals with illegal mahogany loggers and gold miners [60, pp. 115–122]. With the exhaustion of mahogany and NGO-organized alternative income projects in the late 1990s, virtually all of the Kayapô have stopped logging and mining in their territory [61]. However, with 2500 km of perimeter, in a newer and more lawless frontier region than the Upper Xingu, and limited government resources, the Kayapô face ongoing challenges.

The attraction of white people's goods drew indigenous groups into the PIX. Kayapô strategies to obtain others' goods worked in the opposite sense in the middle Xingu.

The Kayapô from mid-nineteenth century occupied the Xingu basin from about 7° S to 9° 40' S, and established the widely dispersed settlements where most Kayapô groups were contacted in the 1950s and 1960s in consequence of ongoing internal feuds among subgroups following different chiefs [62] and raiding (or at times trading with) regional Brazilian settlements for trade goods, particularly firearms and captives. While many subgroups were decimated by epidemics, 'contact' with the surrounding society reflected Kayapô strategies to access outsiders' goods for their own social and cultural ends at least as much as any externally driven process [63]. The Kayapô have developed a self-reflexive, strategic sense of the value and symbolic power of their own culture and its representation in securing recognition of their territory and defending it from invasions [61] (see §7). There are now some 9000 Kayapô in about 40 villages [64].

At the highly publicized Kayapô protest against the Belo Monte dam in Altamira in 1989, some environmentalist visitors were alarmed when they learned of Kayapô logging and mining. Anthropologist Terry Turner argues that while the Kayapô readily extract and even deplete forest resources, they regard the total ecosystem destruction entailed in clear-cutting as morally and aesthetically repugnant [65]. From this perspective, selective logging or localized gold mining is not necessarily inconsistent with forest protection. Selective logging for mahogany in the Kayapô lands, where they control access, has limited ecological impacts.

In 1992, at the request of Kayapô leaders, NGOs created a biological research station as an income alternative. A'Ukre village declared 10000 ha off limits to hunting and logging, in exchange for researchers' payments and training Kayapô assistants, with benefits distributed evenly across the community—unlike timber and gold payments controlled by chiefs.

The relative success of the research station—and depletion of mahogany stocks—led leaders of nearly all of the Kayapô villages to create the Protected Forest Association (AFP) in 2002, to support border control and develop alternatives across the territories. Western and southern communities founded the Raoni Institute (IR) in 2001, and the Kabu Institute (IK) in 2008.

The Kayapô organizations, in collaboration with chiefs and FUNAI, organize regular border patrols and have been highly successful in preventing or halting attempted ranching and gold mining invasions [61], but the recurrent costs of these activities are far beyond current FUNAI budgets and depend at present on philanthropy.

In the absence of outside support, the Kayapô, like other forest communities, face stark choices in the current regional economy between unsustainable, typically illegal but high-value activities and low-value non-timber forest products and handicrafts. AFP and IK have over the past 5 years developed Brazil nut marketing in seven communities, a venture that has sold on average about 150 tonnes of Brazil nuts over the past 3 years and generated some \$160 000 annually—at a price well above the government-set minimum [66]. Handicrafts, collection of natural essences and oils, and a field course on conservation and development are under development. In addition, NGOs and the Amazon Fund have granted the Kayapô an \$8 million endowment, which will generate about \$400 000 per year, both for project support and part of the administrative costs of their three associations. The value of loggers' and goldminers' payments to Kayapô chiefs in the 1980s and 1990s are

unknown, but were probably an order of magnitude greater than project income or more.

Kayapô groups have adopted a series of strategies to access Western goods and technology—raiding, ‘contact’, logging and mining, and alternative projects—with considerable success, while maintaining an independent stance in relation to the surrounding society. The Kayapô emphatically reject the naive but still widespread assumption that ‘real’ Indians neither have nor need white people’s goods and technology; cash poverty is not an option they entertain. Their organizations have prioritized territorial protection and economic alternatives, but if economic alternatives cannot be scaled to meet increasing demand, their market access strategies could change. While the Belo Monte dam is currently the only proposed hydroelectric project on the Xingu, the prospect of upstream dams is of great concern, even as regional power company Eletronorte has begun funding Kayapô projects. Kayapô and Panará now access conditional cash transfers (CCT) such as the ‘family grant’ (*bolsa família*). These programmes may have unintended social and health effects in indigenous groups (see the electronic supplementary material). Substantial external funds will be needed to maintain territorial control projects and bring commensurate income generation through activities that the Kayapô control. The Kayapô NGOs provide the basis for the institutions needed to administer them.

6. Closing the gap in the Xingu-protected areas corridor: Anfrízio River, Iriri and middle Xingu Extractive Reserves (Resex)

The government’s creation of the Terra do Meio Reserves Mosaic from 2004 to 2008 completed the 28 million-ha Xingu-protected areas corridor, halted rampant illegal occupation of public lands and deforestation, and guaranteed the land rights of some 215 riverine families [67], many of whom were previously threatened with imminent expulsion by land-grabbers. Originally proposed by the Transamazon social movement [26,67], creating the mosaic and attendant legal action largely resolved major land tenure issues—in 2006, for example, the Federal Attorney General’s Office (MPF) won a lawsuit extinguishing claims by one individual to between 4.7 and 7 million ha [3, p. 32] in the region.

Providing basic healthcare and education in the Extractive Reserves (Resex)—in principle, the responsibility of the county—is an ongoing issue. Resex communities are up to a week away by boat from the county seat and nearest town, Altamira. NGOs and the reserve residents’ associations, with some government support, have built 10 schools and three health posts in the three reserves, as well as equipping the associations with shortwave radios and boats. The NGOs, responding to community demand, brokered agreements with companies to purchase native rubber (abandoned since the 1980s because of low prices) and copaiba (*Copaifera* spp.) oil from the reserves at premium prices, and introduced processing technology for oils extracted from other forest products.

Deforestation in the ILPAs of the Terra do Meio declined after reserve creation (see the electronic supplementary material). Deforestation in the Triunfo do Xingu Environmentally Protected Area (APA), where ranchers retain property rights, began to decline after its creation in 2006. It was probably also affected by the post-2008 credit freeze imposed the

Environment Ministry and National Monetary Council on the highest-deforestation municipalities in the Amazon (<http://climatepolicyinitiative.org/riodejaneiro/files/2013/01/Does-Credit-Affect-Deforestation-Evidence-from-a-Rural-Credit-Policy-in-the-Brazilian-Amazon-Technical-Paper-English.pdf> accessed 16 February 2013). Because nearly all of the approximately 8 million ha Terra do Mosaic was *terra devoluta*, or unclassified public land subject to widespread land grabs [25,26], the legal creation of the ILPAs probably accounts for much of the decline in deforestation, as elsewhere [68,69].

Localized illegal logging has, however, increased in some areas of the Terra do Meio. Residents of the Anfrízio Resex reported an invasion in 2010 and while ICMBio seized timber and equipment, logging continues. Remote-sensing analysis of the Terra do Meio (for methodology, see the electronic supplementary material) showed an increase in logging roads in the Anfrízio Resex from 2005 to 2011 (see the electronic supplementary material). A 2005–2011 comparison of endogenous roads shows a decrease for the ILPAs overall of roughly 3500 km to about 1000 km—substantial, although numerical values are uncertain. In addition, an analysis of the historically deforested areas detected by PRODES showed that nearly half of the Terra do Meio deforestation patches detected from 1997 were regenerating (NDFI > 186) in 2011, suggesting that land-grabbers had abandoned previous clearings in the newly created protected areas.

7. Discussion: indigenous lands and protected areas—effective management and sustainability

A considerable literature supports the view that ILPAs and indigenous territories in particular are effective barriers to frontier expansion and deforestation [69–71]. Data from the Xingu ILPAs support this conclusion. Deforestation in the Xingu basin is heavily concentrated outside the ILPAs. Of the approximately 10 million ha deforested in the basin through 2010, 91 per cent was outside protected areas, 3 per cent was in indigenous lands, 1.4 per cent in federal protected areas and 4 per cent in state protected areas [3, pp. 49,50] (see the electronic supplementary material). Fires are also apparently much less frequent inside reserves than outside [70]. A more difficult question is what this tells us about the prospects and conditions for the long-term sustainability of these territories.

Reserve histories suggest that the most degraded of the ILPAs are those in which invasion began before legal recognition or creation of the territory. About 55 per cent of the deforestation in the indigenous lands in the ILPA corridor is concentrated in the Cachoeira Seca and Apyterewa lands, in both of which invasion began before or in the early stages of demarcation [3, p. 15]. Maraiwatsede, partially within the Xingu basin but not contiguous with the corridor, was heavily invaded before the Xavante subgroup, removed from the area in the late 1960s, returned to the territory in early 1990s. The area is currently the most deforested indigenous territory in the Amazon (<http://maraiwatsede.org.br/tags/maraiwatsede-0> accessed 17 February 2013). The Panará, by contrast, removed from their territory at around the same time, returned, called on FUNAI to begin demarcation and removed invaders before large-scale deforestation began. The most heavily deforested area in the Xingu corridor, the APA Triunfo do Xingu,

was proposed as an APA because deforestation and occupation by the time of the initial survey were too advanced for a more restrictive type of protected area.

Increasing local participation and production in NGO-led economic projects (figure 2) demonstrates strong local demand for income and market access. It is indicative that only two of the 40 Kayapô villages, Gorotire and Kriny, have decided not to work with the NGOs and allow gold mining and logging in their territory. This may suggest that the majority of the Kayapô expect a greater return from alternative projects than they could obtain from logging for low value tree species (*Madeira branca*) and dwindling superficial gold deposits, or that NGO project benefits are more equitably distributed [61]. It may also be rooted in historical inter-village factional disputes [62,64]. There is, however, good reason to believe that more is at issue here, and not only in the Kayapô territories. Indigenous and traditional communities consistently affirm that cultural identities and territories depend on one another.

A recent study shows that Iriiri Resex of community members' motives for wanting to live in the reserve [72] were not restricted to material concerns with access to resources or income, but were also based on a strong sense of place informing riverine people's (*ribeirinhos*) identities. Ribeirinhos value their productive activities and environment for both economic and affective reasons; their support for the reserve has more than just political-economic motivation. Similarly, indigenous peoples repeatedly assert a fundamental interdependence between culture and identity and territory [73]. Indigenous 'traditional knowledge' of forest ecologies and resources, and grounding of culture and identity in territory, are based in culturally distinct cosmologies and world views that differ fundamentally from Western science. While Western science draws a sharp distinction between a natural world ruled by material forces and a cultural realm of values, conventions and concepts, indigenous peoples, Amerindian societies in particular, include animals, plants and other 'natural' phenomena in the domain of culture and society [74–76]. Amerindian resource knowledge arises from mutual recognition, active communication and exchanges amongst people, animals, plants, geographical features, spirits and the dead conceived as actors in the same socio-cosmological networks. The full statement of Ntôni Kisêdjê to the Cuiabá Seminar on Climate Change and Agriculture [48], cited in part above on climate change impacts, illustrates this (see the electronic supplementary material). This has several implications. First, environmentalists, but who wish to develop conservation projects with indigenous communities, but who ignore or fail to understand these differences, risk serious miscommunications and limited project results [77]. But also, this encounter of epistemologies creates the possibility for inter-cultural dialogue and exchange particularly relevant to the sustainability of Amazon indigenous territories.

Turner argues that the Kayapô's successes in influencing national and regional development policy, in particular in winning control of their territories, was predicated on the transformation of Kayapô social consciousness from the 1960s to the 1980s [78]. At the beginning of this period, the Kayapô regarded their social organization, ceremonies, arts and traditional economy simply as 'the way they had always done things' [78, p. 293], or part of the 'natural' order. Developing a self-reflexive view of their own culture as distinct, and as the product of their actions, allowed the Kayapô to unify politically and mobilize to contest threats to their territory, conceived as the basis of their existence as a distinct ethnicity. The Kayapô, in fact, repeatedly

and successfully staged dramatic public events featuring prominent representations of Kayapô culture and warrior ethos, generating national and international attention to their issues. The use of video technology to document confrontations with the surrounding society as well as their traditional culture became a central part of this process of self-empowerment. Conceiving, and recording, themselves as a separate culture allowed the Kayapô to assert the value of their culture, in contrast to and parity with the surrounding society, and consequently to take political action on their own behalf.

This sort of self-reflexive understanding of indigenous culture and knowledge, and their value in relation to other cultures and knowledge systems, are necessary conditions for dialogue between Western science and indigenous knowledge on terms of epistemological, if not political-economic, equality. Indigenous knowledge of itself is typically not sufficient to deal with Western diseases or meet market needs. But, as indigenous leaders consistently affirm, identity with their territories is grounded in traditional culture and knowledge, and losing this will lead them to behave as white people always have. Bilingual education, and teacher training [40], training bi-cultural health monitors, training filmmakers and producing indigenous videos (video in the villages, see <http://www.videonasaldeias.org.br/2009/> accessed 22 February 2013; Caititu Institute village in action, see <http://www.institutocaititu.org/en/> accessed 22 February 2013) enable young people in particular, to view their own distinct cultures and value them, while engaging modern technology and the surrounding society. Further examples are provided by more than 40 publications in indigenous languages of ISA's Xingu and Upper Rio Negro programmes [44] (http://www.socioambiental.org/inst/pub/cartilhas_html accessed 21 February 2013). Various experiences of collaborative, inter-cultural research between scientists and indigenous and traditional partners, including several in the Xingu [22,73,79, 80] may suggest a particularly productive approach. In short, sustainability in ILPAs, including the Xingu, cannot be conceived or measured in purely ecological or economic terms. As leaders such as Ntôni constantly reiterate, it is also a question of the viability and vitality of cultures.

Clearly, however, the sustainability of ILPAs also depends on sustainable sources of finance. REDD+ and payment for ecosystem services, whether from public or private sources, have often been proposed as options. A rough estimate, based on modelling of the gradual, bottom-up development of carbon markets from 2015 to 2030 suggests that the value of the Xingu ILPAs under a national emissions trading system might approximate \$42 million per year (see the electronic supplementary material). Recent proposed and existing legislation and policies could contribute significantly to maintaining the ILPAs and increasing headwaters restoration (see the electronic supplementary material). There are also, however, proposals to introduce industrial agriculture and mining in indigenous lands.

8. Conclusion

The Xingu ILPAs corridor is a highly socio-environmentally diverse landscape, continuously inhabited over at least the last millennium, and a critical source of ecosystem services—biodiversity conservation, carbon sequestration, watershed protection, maintenance of rainfall regimes—themselves the

historical products of, and largely dependent upon, ancient, historical and contemporary socio-culturally highly diverse populations. Creation of protected natural reserves and legal recognition of indigenous territories has, so far, halted frontier expansion and deforestation, although localized illegal logging continues. NGO work in the ILPAs has been effective in enabling the PIX, Panará and Kayapô peoples to control the boundaries of their territories, as well as in supporting the creation of local institutions—indigenous and extractive reserve residents' associations—necessary for community control and management of the territories. The ISA's bilingual education programme in the PIX, started as an NGO initiative, has become effective public policy and could serve as a template for other indigenous territories. Economic alternative projects have clearly generated increasing participation and production, but are far from meeting community demand for income and market access. These projects can be scaled up, but with the possible exception of the Seeds Network, will, at least in the near term, require continued outside investment and support to grow, as well as continued capacity building for community members to manage local enterprises effectively.

Indigenous leaders in the PIX report changes in fire and rainfall regimes that may be early indicators of climate change. Because both the use of fire as a management tool, and timing of the agricultural cycle according to the appearance of the Pleiades are widespread and ancient practices, Xingu people's recent reports of changes in forest flammability, in-stream water flows and timing of rains are significant.

Michael Heckenberger's observation that '... the unique and highly constructed landscapes of the Xingu... over the

past one thousand years have changed as much because of political as ecological factors' [24, p. 5] applies as much to the future of the Xingu as to its past. To the political and ecological, we would add cultural factors. Xingu—and many other—indigenous leaders clearly and consistently affirm that from their perspective, territory, cultural identity and traditional knowledge are mutually interdependent. Self-reflexive understanding and valuing of traditional culture and knowledge as distinct from Western values and science, including dialogue between Western science and traditional knowledge, are key conditions for the sustainability of these territories.

Sustainability—ecological, economic, political and socio-cultural—in the Xingu corridor will also require new governance structures and processes. Currently, no one speaks for the Xingu ILPAs in development policy debates. Given the lack of any legal structure to govern territories of these dimensions and diversity, and historical antipathy between indigenous and environmental agencies, the evolution of new forms of governance for such territories will be from the bottom up, with the development of networks, coalitions, forums and associations that can represent the shared concerns, interests and aspirations of highly diverse populations for the future of their territories and landscapes.

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