Sustainable-use protected areas catalyze enhanced livelihoods in rural Amazonia

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Finding new pathways for reconciling socioeconomic well-being and nature sustainability is critically important for contemporary societies, especially in tropical developing countries where sustaining local livelihoods often clashes with biodiversity conservation. Many projects aimed at reconciling the goals of biodiversity conservation and social aspirations within protected areas (PAs) have failed on one or both counts. Here, we investigate the social consequences of living either inside or outside sustainable-use PAs in the Brazilian Amazon, using data from more than 100 local communities along a 2,000-km section of a major Amazonian river. The PAs in this region are now widely viewed as conservation triumphs, having implemented community comanagement of fisheries and recovery of overexploited wildlife populations. We document clear differences in social welfare in communities inside and outside PAs. Specifically, communities inside PAs enjoy better access to health care, education, electricity, basic sanitation, and communication infrastructure. Moreover, living within a PA was the strongest predictor of household wealth, followed by cash-transfer programs and the number of people per household. These collective cobenefits clearly influence life satisfaction, with only 5% of all adult residents inside PAs aspiring to move to urban centers, compared with 58% of adults in unprotected areas. Our results clearly demonstrate that large-scale "win–win" conservation solutions are possible in tropical countries with limited financial and human resources and reinforce the need to genuinely empower local people in integrated conservation-development programs.

community-based conservation | conservation bright spots | rural economics | sustainable development | tropical forest

Tropical deforestation worldwide is a major contributor to the loss of biodiversity, ecosystem services, and livelihoods (1, 2). Human activities, such as agricultural development, industrial logging, overhunting, and overfishing, have catalyzed rapid tropical forest degradation (3). Contemporary societies now face the intractable challenge of establishing new development pathways that align biodiversity conservation with enhanced local welfare. This is especially important in developing countries, which support most of the world's biota (4) and ethnocultural diversity but frequently suffer from high levels of poverty and social inequality (1).

Protected areas (PAs) arguably represent the most effective conservation policy tool for a more sustainable world (5). Although the primary goal of PAs is to maintain biodiversity, ecological processes and ecosystem services (6, 7), the ways in which PAs are created, managed and regulated continue to evolve (8). In tropical developing countries — where rural poverty is often a critical constraint — sustainable-use PAs are increasingly charged with the additional challenge of integrating mounting social aspirations (9, 10). The complex challenge of fulfilling seemingly opposing conservation and social goals has created an apparent conservation dilemma (11, 12), yet reconciling these two legitimate demands within human-occupied PAs remains largely unresolved (12).

There is considerable evidence that local people incur opportunity costs when a PA is established, including physical displacement and restricted access to natural resources (13–15). This can in turn lead to higher levels of poverty (13) and local resentment, if not social unrest (16). Nevertheless, depending on when, where and how PAs are implemented, they can also generate important benefits for local livelihoods. Most studies are focused on economic indicators (17) but PAs also catalyze wider improvements in well-being outcomes, including cultural maintenance, emotional and mental health, strengthening of local governance, ensuring social rights, land tenure, increased access to natural resources and greater food security and sovereignty for disenfranchised communities (17–20).

Global society has committed to decelerate biodiversity loss, increase PA coverage and halve rural poverty by 2030 through the Aichi Biodiversity targets and Sustainable Development Goals (21). Since PAs can have either negative or positive impacts on livelihoods, meeting these commitments will mean identifying scalable strategies that successfully reconcile conservation and social aspirations. Many studies have focused on the linkages between human well-being and ecosystem services to demonstrate the potential of PAs to provide positive social outcomes (6, 22). One such cultural service is tourism development within PAs, which has been shown to contribute to poverty alleviation in different countries (23, 24). Nevertheless, tourism is not always a

Significance

Sustainable-use protected areas (PAs) have contributed to tropical biodiversity conservation by deterring deforestation in multiple countries, yet their social and economic benefits to local stakeholders remain poorly understood. Amazonia hosts the largest tropical PA system on Earth, which is intended to safeguard its rich biological and cultural diversity. Aligning biodiversity protection with social aspirations is therefore imperative in this region. Our results demonstrate that sustainable-use PAs can catalyze a wide set of enablers, including multipartnerships, strong local associations, land tenure, comanagement, economic subsidies, strong leadership, public policies, and polycentric governance, resulting in marked improvements in local welfare beyond biodiversity protection. Such a rare conservation bright spot elucidates potential pathways that can foster social and ecological outcomes that are potentially scalable across lowland Amazonia.

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viable option, and other attempts to integrate nature conservation and local welfare in PAs have received far less attention. Empirical assessments of other mechanisms that can ensure the long-term goals of PAs, including the development of biodiversity value-chains and cultural practices, are thus urgently required to support conservation policy and practice (20, 25).

Community-based conservation initiatives within Amazonian sustainable-use PAs represent a promising window of opportunity to assess the degree to which biodiversity protection is compatible with local aspirations. In these arrangements, local communities are empowered to protect their own territories against illegal fishers, loggers, and poachers. Concomitantly, socioeconomic benefits can be obtained through biodiversity-based value chains, including Açaí palm fruits (*Euterpe precatoria* and *Euterpe oleracea*), Brazil nuts (*Bertholletia excelsa*), and wild-caught fish (19, 26–28). These schemes are often built by multiple partners under polycentric arrangements, including rural communities, local associations, nonprofit organizations, private companies, and government agencies (29), in which each partner makes a specific role to the same target but shares autonomous decision-making at different scales (27, 30). Although not a panacea, these participatory models represent a transformative approach in sustainable resource management accruing positive outcomes for both local welfare and biodiversity (30).

Here, we evaluate different elements of human well-being and their enablers both inside and outside a system of sustainable-use PAs in Brazilian Amazonia underpinned by strong local governance. This study covers more than 100 rural communities stretched across ∼2,000 km of the Juruá River, a major tributary of the Amazon River. Communities within PAs in our study area have been participating in a set of remarkably successful community-based conservation initiatives to sustainably manage commercially valuable aquatic and terrestrial resources, which have resulted in the population recovery of other wild species (19, 31, 32). We hypothesize that PAs create a wide range of opportunities that can induce local social changes resulting in enhanced socioeconomic profiles. We also discuss the role of sustainable-use PAs in megadiverse countries, arguing that some mechanisms ensuring social and ecological outcomes inside PAs can be largely rolled out beyond PA boundaries, thereby decentralizing biodiversity conservation and spreading transformative livelihood gains and biodiversity conservation at much larger scales.

Results

Community Level. There was a strong positive effect of PAs on local well-being. Specifically, there was a clear divergence between communities inside and outside PAs in terms of key services and commodities (Permutational Multivariate ANOVA [PERMANOVA]: F = 44.9, $P = 0.001$; *SI Appendix*, Fig. S1), such as digital communication, primary education, electrification, trade posts, and large cargo boats to transport local products. On average, communities inside PAs benefited from a greater number of key services and commodities (mean ± SD = 7.1 ± 3.5) than those outside (1.8 ± 3.5) (Fig. 1). Some critical infrastructure, including health posts and basic sanitation, were only found in communities within PAs. Our models show that living within a PA was the strongest predictor of access to key services and commodities, followed by community size, explaining 80.4% and 19.6% of the observed variation, respectively. Although present in the parsimonious models (*SI Appendix*, Table S1), travel distance to the nearest urban center was largely uninformative in explaining community key services and commodities, (Fig. 2*A*).

All communities within the PAs were empowered to harvest natural resources for subsistence and establish extractive natural capital value-chains through formal associations, whereas 67.2% of communities outside were not. The remaining 32.8% of communities outside PAs were in the process of being empowered, with wide access to natural resources but lacking the sociopolitical organization required to join existing value-chains. Most residents outside PAs therefore practiced subsistence livelihoods at the periphery of the market economy (Fig. 3).

Household Level. Living within a PA also contributed to a wealthier lifestyle. Household wealth was 1,253 USD (SD ± 834) inside PAs compared with USD 916 (SD ± 814) outside. Higher household wealth indicates that those families possessed typically unaffordable manufactured goods, such as fridge-freezers, gas stoves, other household appliances, and outboard motors, which enhance quality of life according to local perception. In our modeling approach, living inside PAs was again the strongest predictor of household wealth (Fig. 2*B*), explaining 65.5% of the overall variation. Income from cash-transfer programs and household size were also associated with higher wealth, respectively explaining 8.6% and 1.3% of the observed variation. A higher diversity of economic portfolios was negatively associated with household wealth, explaining 24.6% of the variation (Fig. 2*B*). In other words, households specialized in fewer economic activities including oilseed extraction, production of cold-pressed oils, or fisheries were more likely to have accumulated wealth compared with generalist households.

Individual Level. Living within a PA was strongly associated with a desire to remain within the community. Only 5% of adults living inside PAs expressed a desire to leave their communities in the future, thereby bucking long-held demographic trends. Conversely, this proportion increased to 58% for those living outside PAs (Fig. 4*A*). A similar, but weaker trend was observed among adolescents (13 to 17 y), for whom 31% living inside PAs and 58% living outside PAs expressed a yearning to move to an urban center to enhance their livelihood prospects (Fig. 4*B*). These findings show that the inclination to move from rural areas to urban centers has an opposite trend inside PAs compared with the historical pattern in riverine Amazonia (Fig. 4*C*). Our models show that living within a PA had the strongest (negative) effect and the strongest effect size on desire to move to urban areas, explaining 68.3% of the observed variation. This suggests that PAs in our study area positively influence regional scale demographics by reducing rural–urban mobility by local dwellers, which is typical of many hinterlands lacking economic opportunities. Distance to the nearest urban center and interviewee age were also important factors, explaining 27.6% and 4.1% of the variation, respectively (Fig. 2*C*). All parsimonious and full models can be seen in *SI Appendix*, Tables S1 and S2.

Well-Being Enablers. From our focus groups, we built a mental model (Fig. 5) linking enablers and their respective attributes ensuring a wide range of social and ecological outcomes that contribute to local well-being. Individual interviews with local leaders and stakeholders allowed us to identify the level of importance of each well-being enabler (*SI Appendix*, Fig. S2*A*), including multipartnership between actors from different backgrounds, strong local associations, land tenure, comanagement of natural resources, subsidies, strong leadership, public policies, and polycentric governance.

Discussion

PAs represent the central pillar of biodiversity conservation worldwide, yet their socioeconomic dividends to local residents remain controversial, generating both fortune and misfortune across the globe (33). Understanding the complex and frequently contrasting social and environmental consequences of PA creation and implementation is therefore essential to develop more successful strategies and interventions. Ultimately, a closer alignment of social and environmental objectives within PAs would be vital to ensure a more sustainable fate for threatened ecosystems, especially in tropical developing countries. Starting

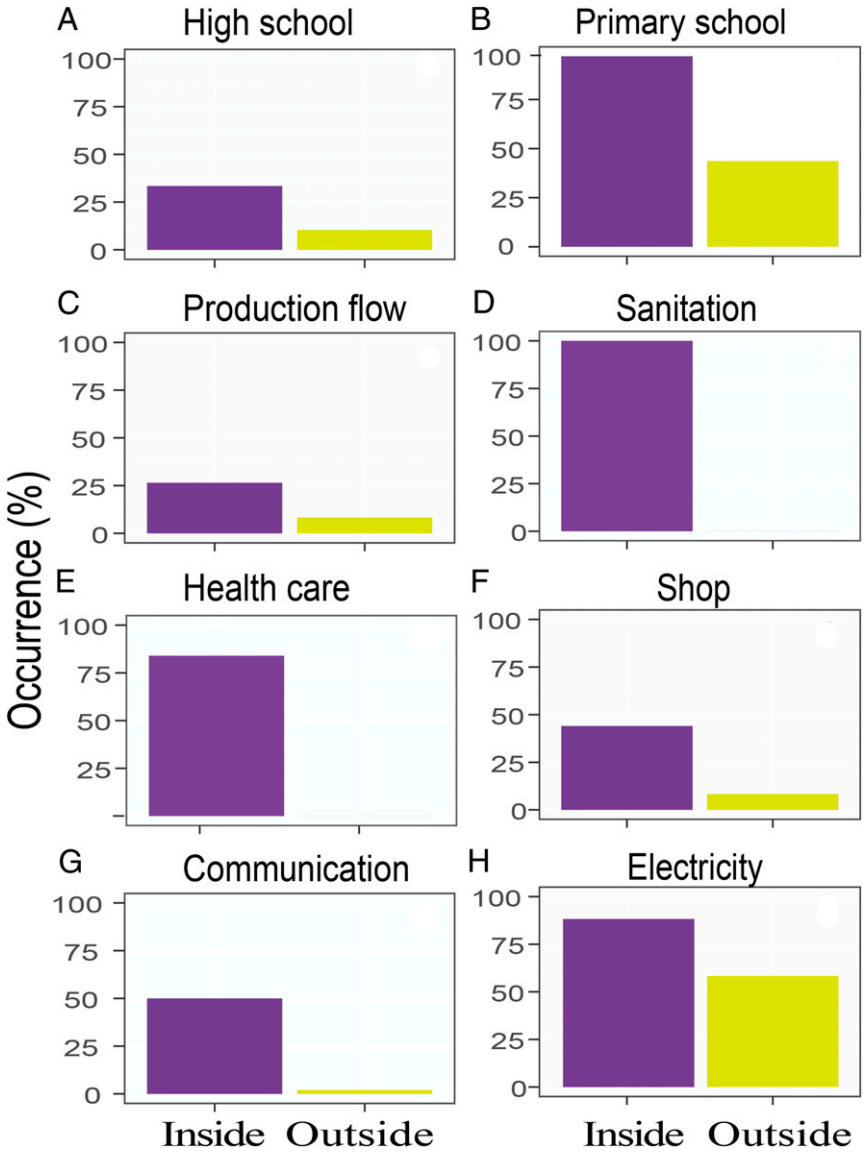

Fig. 1. The percentage of communities inside (purple, $n = 34$) and outside (yellow, $n = 48$) PAs with the following key services and commodities: (*A*) high school; (*B*) primary school; (*C*) production flow; (*D*) sanitation; (*E*) health care; (*F*) shop; (*G*) communication; and (*H*) electricity.

from a well-consolidated case study, our results clearly show that sustainable-use PAs in the Amazon under an organized resource comanagement structure, including high levels of participatory governance, can generate tangible social benefits. These PAs reshape the relationship between people and nature, which in turn increase the resilience and sustainability of PAs themselves (34) and reduce management costs. The wide range of benefits flowing from PAs includes better access to key services and commodities such as education, communication, electrification, shops to purchase food and basic equipment, and large boats to export local extractive and horticultural products. In addition, households inside PAs were also more likely to be associated with an affluent lifestyle, since they could afford highly prized durable goods that were perceived to enhance local well-being, including domestic appliances and boat motors.

Enablers of Social Benefits within Sustainable-Use PAs. Creation of sustainable-use PAs in Brazil is often motivated by strong local political will that usually involves grassroots environmental leadership (35). This is particularly important in Amazonia where transformational extractivists, such as Chico Mendes, played a central role in the political struggle to implement the "Alliance of Forest Dwellers." This eventually led to the sanctioning of Extractive Reserves, a formal PA category that seeks to reconcile the needs of local communities and biodiversity conservation (36). Sustainable-use PAs can therefore strengthen existing sociopolitical alliances, catalyzing steep social transitions that ultimately secure natural resource conservation through community-based stewardship in otherwise underfunded and understaffed PAs. Our landscape scale findings show that the creation of sustainable-use PAs consolidated incipient local organizations, which eventually attracted different stakeholders and promoted founding principles to achieve conservation success, including strong leadership (37), polycentric governance regime (38), and multipartnership among local organizations, government, NGOs, and the environmentally friendly private sector and academia (39). These combined principles stimulated the establishment resource comanagement rules of engagement leading to the development of different biodiversity value-chains, creating new jobs, enhancing infrastructure, key services, and commodities, attracting external

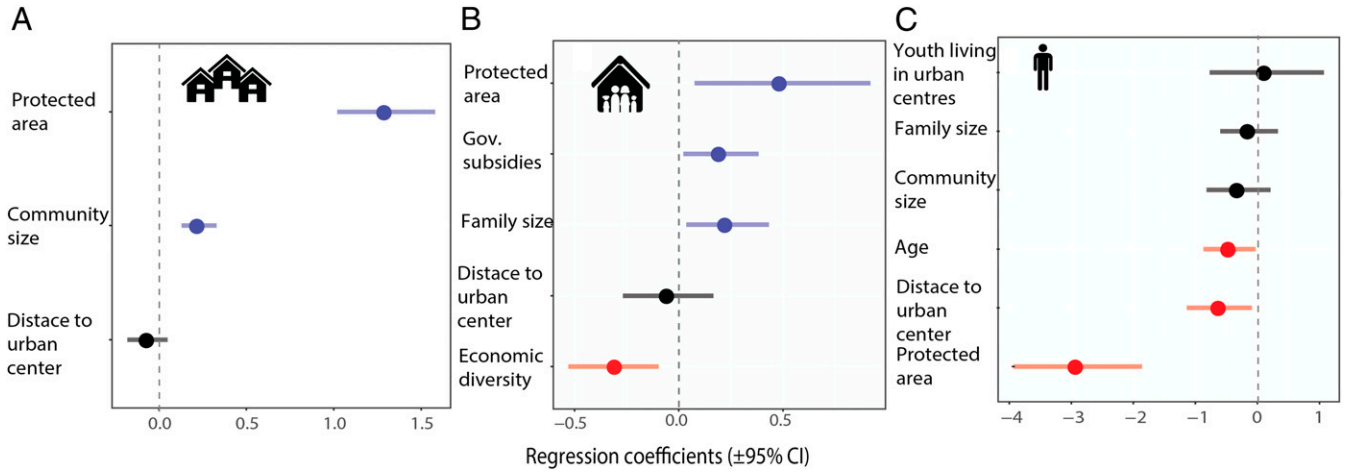

Fig. 2. Coefficient estimates (± 95% CIs) showing the magnitude and direction of effects of different predictors on the following: (*A*) community services, (*B*) household wealth, and (*C*) desire to move to urban centers. Blue and red symbols represent positive and negative effects, respectively; black symbols represent no effect.

incentives, and promoting capacity building, all of which paved the way to positive socioecological outcomes (27).

Development of value-chains based on biological resources has been widely used as a strategy to generate income for disenfranchised communities in tropical environments (40) and reduce income inequality (41). PAs can act as a platform, facilitating the development of new value-chains, including the commercialization of new products that provide communities with new income sources and improvements in community infrastructure and household wealth (19). The major challenge is to develop sustainable agro-extractivist communities toward this market-oriented solution (42). In our study area, a polycentric governance focusing on sustainable fishery comanagement and nontimber forest products facilitated regulated certification of offtakes ensuring a direct mechanism to deliver both conservation and social benefits, including population recovery of target and nontarget species, income generation, reinforcement of cultural heritage and pride, capacity building, and reduced gender inequality (27, 43–45).

Our data suggest that social benefits catalyzed by PA membership also contributed to reduced rural–urban mobility. Rural–urban migration in Amazonia is a complex issue that can be caused by a synergy of factors, including land scarcity, deprived access to public services, environmental degradation, large family

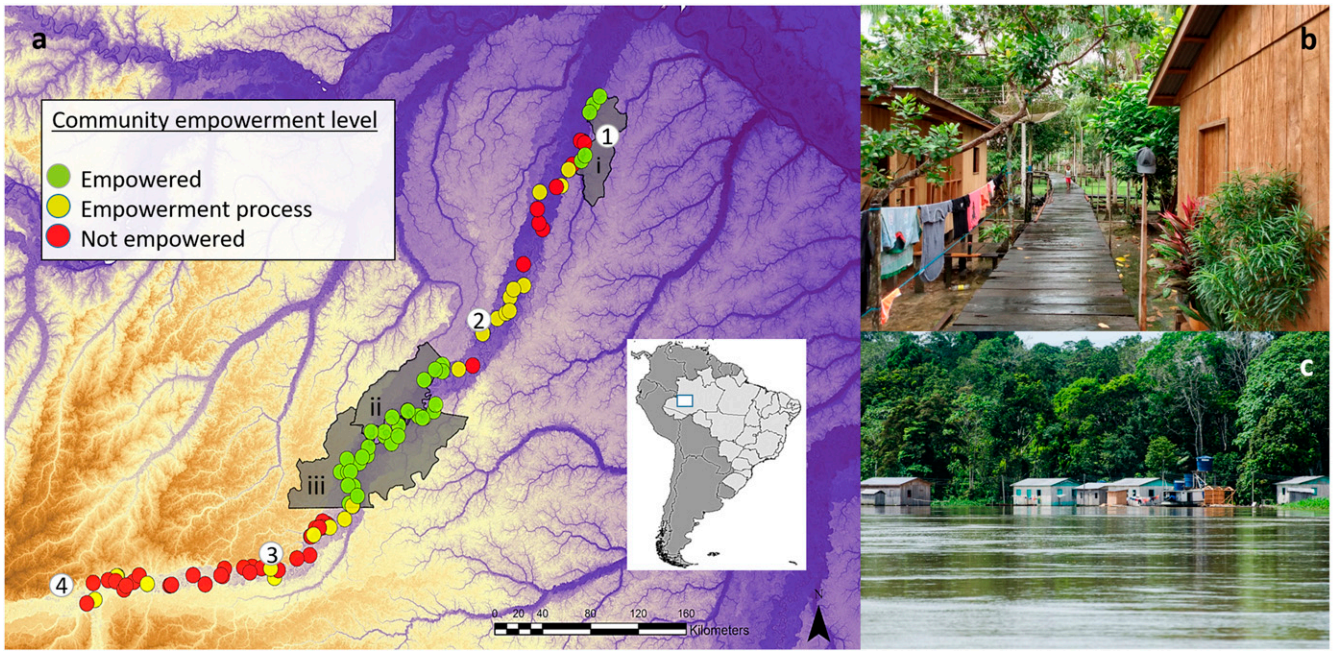

Fig. 3. Map of our study area, including (*A*) the spatial distribution of community empowerment, according to semistructured interviews with community leaders. Green circles indicate empowered communities, which are well-organized with full access to natural resources, and can commercialize their production through a collective cooperative. Yellow circles show communities in the process of empowerment, which have access to natural resources but not external value chains. Red circles represent nonempowered communities, which lack access to natural resources through restrictions imposed by the living descendants of past rubbers barons. Gray polygons represent three sustainable-use forest reserves: 1) ResEx Baixo Juruá; 2) ResEx Médio Juruá; and 3) RDS Uacari. White circles represent medium-sized towns along the Juruá River: (1) Juruá, (2) Carauari, (3) Itamarati, and (4) Eirunepé. Photos *B* and *C* show typical rural communities along the Juruá River. The color scale indicates the altitude variation, from uplands (brown) to lowland floodplains (blue).

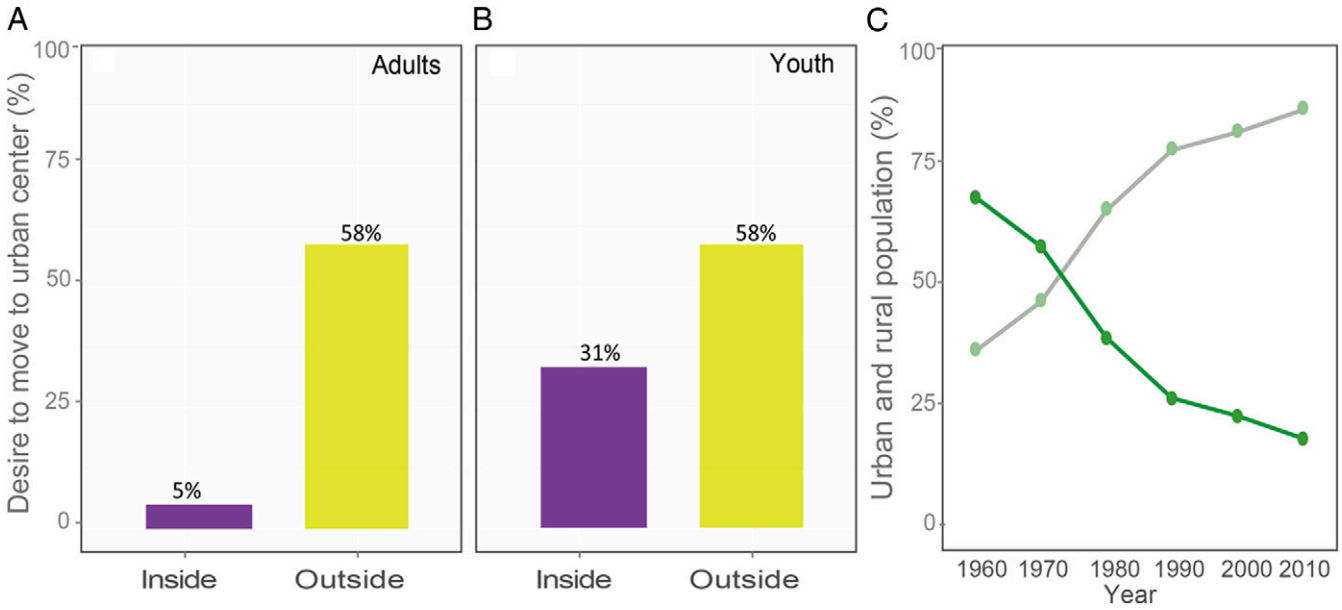

Fig. 4. Bar graph showing the individual inclination toward rural–urban migration. (*A*) The percentage of respondents among adults (n = 237), (*B*) young people (aged 13 through 17; n = 189) from communities inside (purple) and outside (yellow) PAs that expressed a desire for rural–urban migration, and (*C*) a general pattern of rural–urban migration within Amazonas State, where y-axis represent the percentage of urban (gray) and rural (green) population in relation of the entire population. Data were gathered from the Instituto Brasileiro de Geografia e Estatistica website (https://www.ibge.gov.br/).

sizes, lack of market access, and rural poverty (46). This demographic trend further leads to greater poverty and exposure to violence in overcrowded cities (47). However, rural–urban mobility does not always represent rural exodus, because rural families can maintain a perennial link between traditional territories and urban areas (48). This is particularly important for adolescents and young adults who aspire to move to urban environments to improve their livelihoods skills, redefining their social networks but also maintaining their links with their rural communities (49). There is an ongoing debate in world development about population stabilization in rural areas with proposals to strengthen central-government assistance to enhance education, health care, and employment (46, 50). In our study, young people living outside PAs were much more likely to express a desire to move away from their natal villages compared with those inside. Given appropriate conditions, sustainable-use PAs could therefore be used as an important tool to enhance local quality of life and stabilize rural demography. This is particularly critical in remote tropical forest regions, where access to health services, essential infrastructure, and wage labor incentivizes the prevailing out-migration (46, 51). Our results also show that the desire to move to an urban center is much higher among young people than adults, reflecting a generational abyss in youth engagement in PA functioning and highlighting the need to avoid complacency in future outlooks.

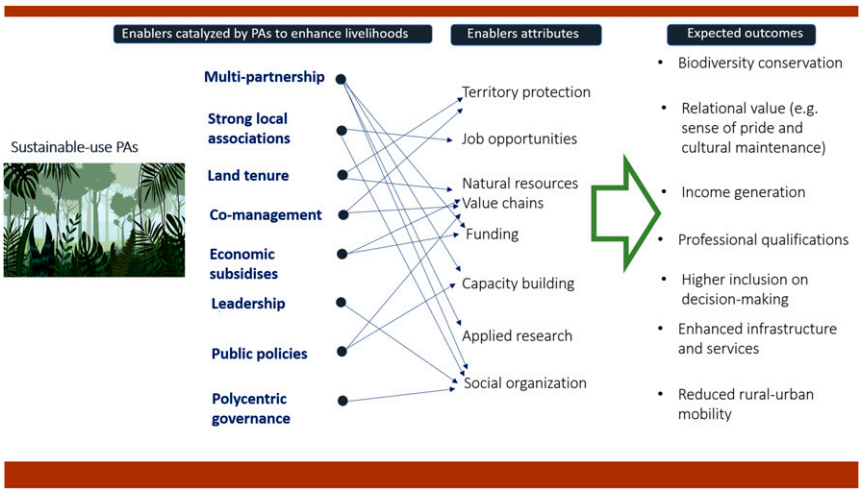

Fig. 5. Mental model built from our focus groups, elucidating the mechanisms through which sustainable-use PAs can achieve social and ecological outcomes. PAs can help strengthen enablers that enhance livelihoods, including multipartnerships, strong local associations, land tenure management, economic subsidizes, leadership, public policies, and polycentric governance. These enablers have a set of attributes such as territory protection, job opportunities, natural resources value-chains, funding, capacity building, applied research, and social organization. This fertile ground creates promising opportunities to catalyze biodiversity conservation, the strengthening of the immaterial values, income generation, professional qualification, the emergence of stronger leaders, enhanced infrastructure, and better access to services, inducing a social transformation that can improve the local quality of life and contribute to avoiding rural-urban mobility.

While youth-focused conservation initiatives have been successful in marine conservation, similar initiatives need further development in terrestrial and freshwater PAs (52).

Conditional cash-transfer programs (e.g., Bolsa Familia in Brazil) also have a significant impact on household wealth. Cash-transfer strategies have been widely used to curb inequality and poverty, especially in Latin America (53), with wide-reaching positive consequences, including improvements in health, education, nutrition, and reduced poverty and vulnerability (53, 54). However, the Bolsa Familia program in the Brazilian Amazon remains controversial, despite marked gains in living standards for rural populations (55, 56). This is largely because of difficulties in accessing monthly bank payments due to prohibitive travel time to the nearest urban center, thereby encouraging many families to leave their home villages permanently (57). In this context, PAs also counteract emigration incentives to access cash payments by providing better in situ government services through local organizations that help overcome complex bureaucracy, including signing up and corroborating social rights.

The diversification of rural economies increases the adaptive capacity of rural communities confronting global change (58) or greater environmental unpredictability (59). A diverse economic portfolio is a safe strategy in dealing with uncertainty, which typically marks extractive livelihoods relying on living resources, such as fish, crops, and fruit production that inevitably fluctuate seasonally to supra-annually (60), so that "bet-hedging" confers greater resilience against such variability (61, 62). Conversely, our results suggest that labor specialization can lead to higher income for rural households. Specialization typically increases labor efficiency, often generating higher profits (63). PAs may facilitate pathways for profitable specialization and, as long as resource exploitation can be defined as demographically sustainable, direct and indirect income will continue to be available to residents in times of plenty or scarcity (64).

Can Biodiversity Conservation and Social Aspirations Be Successfully Combined? Our study area along the Juruá River now hosts successful comanagement conservation arrangements that accrue critical benefits for floodplain conservation. These arrangements have resulted in the conservation and population recovery of emblematic Amazonian megafauna, including the arapaima (*Arapaima* spp.), the South American river turtle (*Podocnemis expansa*), and several other taxa inhabiting the floodplains (19, 32, 43). Within this model, rural communities are empowered to protect their own waterscapes, establishing well-defined no-take zones, where illegal fishers and poachers are effectively excluded (65), while communities outside PAs still experience limited access to natural resources mainly due to coercion by powerful local elites (mainly landowner descendants of 19th century rubber barons). The spatial zoning of harvesting activities can help maintain breeding and feeding grounds for target species, contributing to the replenishment of depleted neighborhoods via migration during the prolonged flood pulse when underharvested and overharvested zones become reconnected (45). In addition to these ecological outcomes, we show that there are also social gains observed through significant improvements in local living standards as an unusual example of "win–win" territorial governance. This effectively bypasses expectations of a Kuznets effect in at once delivering environmental benefits while shortcutting rural poverty.

Although our findings flag an optimistic scenario for lowland Amazonia, we also acknowledge that any participatory comanagement model is not a panacea, and successful cases could be described as an exception rather than the rule. First, Amazonian PAs face a dire shortage of funding and personnel, especially under Bolsonaro's government dismantling of environmental policies (66). There are also many examples of failures in participatory conservation. In general, resident populations often cannot serve the long-term interests of tropical forest biodiversity conservation, because escalating needs lead to runaway patterns of resource extraction and ever greater levels of anthropogenic disturbance (67). In this context, some conservation tools are imperative to ensure sustainable offtakes and avoid overexploitation that can result in the tragedy of commons, such as harvesting quotas and spatial zoning (27). Insufficient regulation and unfettered asymmetries of power at community level can also jeopardize participatory arrangements leading to negative conservation outcomes (68, 69). The alignment of different skills and capacities through multipartnership can help diversify the technical expertise and the profile of actors, which can strengthen local governance toward a more democratic system (30). Finally, remote areas of Amazonia often lack the necessary sanitary conditions to ensure profitable and far-reaching value-chains, a bottleneck that could be overcome with both government and private subsidies (30). In sum, many comparable initiatives may have failed because they lack the appropriate ingredients and implementation rather than induced by impracticality (27, 70).

Rethinking the Role of Sustainable-Use PAs. Rural tropical forest communities are typically trapped into perennial structural limitations of insolvent local economies. The cornerstone of social outcomes presented here is to foster local communal organization, enabling the establishment of successful comanagement of natural resources, which in turn can generate a wide spectrum of social and ecological benefits. Currently, PAs can play a very important role in this endeavor, serving as a platform to attract the "right ingredients" to achieve conservation success. However, human-occupied PAs are not a sine qua non condition to ensure social and ecological outcomes, which can be achieved through well-established comanagement conservation programs. A remarkable example is the comanagement of arapaima. Arapaima management, which was originally developed in a sustainable-use PA (71), has now been expanded to boost population recovery outside PAs. This expansion is possible through "Fishing Accords," a decentralized conservation tool that allows local communities to protect floodplain environments, generating local economic and food security while replenishing wild arapaima populations (45).

Sustainable-use PAs are critical in preventing deforestation, protecting biodiversity and livelihoods. However, if PAs are conceived as only biodiversity islands, always battling against external factors, then the ecological and socioeconomic asymmetry between communities inside and outside PAs will inevitably escalate into conflicts. Creating more integrated socioecological systems is an important objective for the Amazon, where the entire system is plagued by scarce financial and human resources (66, 72) that preclude effective surveillance against poaching and illegal logging (73). In this context, sustainable-use PAs could be conceived as "socioecological laboratories," in which sustainable comanagement of resource exploitation is developed, strengthened, and exported beyond PA boundaries. Implementation of such models in unprotected areas will require long-term public policies, decentralizing conservation and rolling out the ecological and socioeconomic benefits over regional scales.

Conclusion

Conservation science has long advocated that biodiversity conservation and human welfare improvements are at best difficult to deliver in the same package and at worst irreconcilable (74). Our findings challenge these assumptions by showing that successfully empowered local communities can decentralize top-down natural resource management, creating opportunities for self-development. Meanwhile ecological benefits are rekindled through the establishment of comanaged no-take zones following consensus negotiations. We recognize that most tropical PAs are poorly implemented, understaffed, and underfunded. However, highlighting conservation bright spots can boost optimism, a fundamental currency to address contemporary socioecological

challenges (75) that is often in short supply, particularly in megadiverse developing countries.

Materials and Methods

Study Area and Socioecological Context. This study was carried out across ~2,000 km of the Juruá River, a major whitewater tributary of the Amazon River (Fig. 4), including areas both inside and outside three large sustainable-use PAs. The Juruá River contains two main forest types: seasonally flooded ("várzea") forest along the wide floodplain and upland ("terra firme") forest, which is rarely, if ever, inundated. The wet and dry seasons coincide with periods of high (January to June) and low water levels (August to November), with the prolonged flood pulse often exceeding 10 m in amplitude (76).

The Juruá River was the scene of a silent social revolution that culminated in an unusually high level of sociopolitical organization among the rural communities. During the last century, natural latex exploitation by rubber tappers was an important economic activity in the Brazilian Amazonia. However, after the economic collapse of this activity, rubber extractivists typically succumbed to extreme rural poverty. This generated the need for further social self-organization, which fueled local demands for sustainable-use PAs to maintain and enhance livelihoods (35). In this context, the Médio Juruá Extractive Reserve (ResEx Médio Juruá) was created in 1997, covering 253,227 ha with 700 people living in 13 communities. In 2001, the Baixo Juruá Extractive Reserve (ResEx Baixo Juruá) was created, protecting an area of 187,980 ha with 748 people living in 15 communities. Finally, the Uacari Sustainable Development Reserve (RDS Uacari) with 632,949 ha was created in 2005, where 1,200 people live in 32 communities. There are also around 80 communities along the Juruá River that are outside any existing PAs. Extractive Reserves and Sustainable Development Reserves are PA categories that share similar attributes regarding the presence of people living within their limits who have the right to exploit natural resources sustainably.

Local governance along the Juruá River is represented by a polycentric arrangement, comprised of local associations, government agencies, private companies, environmental NGOs, and academia (refer to *SI Appendix* for further explanation of polycentric governance in our study landscape). The local economy is sustained by fisheries, small-scale, slash-and-burn agriculture, and nontimber forest products such as oil seeds and palm fruits (31), currently supported by Payments for Ecosystem Services schemes (77) and commercial arrangements with local associations and private cosmetic companies (67). The Juruá River also hosts emblematic cases of comanagement of natural resources, which have been generating strong ecological benefits. This approach has helped recover stocks of the highly sought fish arapaima (*Arapaima* sp.) (19) and freshwater turtles (*Podocnemis* spp.) (32). Both these examples of Community-Based Management target overexploited species of high commercial value but contribute to the wider conservation of Juruá floodplains and its aquatic biodiversity.

Data Collection.

Well-being assessments and response variables. Well-being is a multidimensional concept that can be understood, quantified, and evaluated in several ways. Many studies use a hedonic framework that is assessed through subjective approaches related to individual perception of pleasure and happiness (78), but objective indicators such as income, goods, and services are also often used to represent well-being (79). Here, we used an integrated approach at the community, household, and individual scale to assess the local well-being of rural communities. We quantified key services, commodities, and goods that can impact the individual and collective levels of autonomy, food security, and income. We also measured levels of community empowerment and inclination toward rural–urban mobility, which can be related to well-being (80).

First, we conducted preliminary semistructured interviews with 50 community residents and leaders from 18 communities between August and December of 2016 to understand the material items, infrastructure, and services that make the largest contribution to well-being at the community and household level in rural Amazonia (*SI Appendix*, Tables S3 and S4). To do that, we asked the following questions: 1) Which are the types of key services and commodities that are perceived to improve well-being in rural communities? and 2) Which are the household goods that are perceived to improve well-being for a family? At the community level, we identified eight collective key services and commodities, including primary and high school, health post, communication access (including telephone or internet), basic sanitation (presence of bathroom), small grocery shop, electricity, and large boats to transport products from biodiversity value-chains. At the household level, we identified nine important items that reflect family wealth, including having a boat, outboard motor, television, gas stove, mobile phone, fan, machine to process palm fruit, chainsaw, and freezer.

Second, we used the information from the preliminary survey to quantify our response variable using a combination of household surveys and semistructured interviews with community residents and leaders across 82 rural communities (34 inside PAs and 48 outside PAs), including 281 households and 426 individuals. At the community level, we quantified the existing infrastructure in terms of the number of collective key services and commodities, identified in the preliminary assessment. In this context, our response variable represents the total number of services operating in those communities. In addition, we quantified the level of empowerment of each community according to their natural resource stewardship (80). In this approach, we defined three categories of empowerment: 1) empowered, in which the residents had the power to regulate the local use of natural resources and were organized in local organizations and able to harvest natural resources and commercialize it through biodiversity value-chains; 2) in the process of empowerment, in which communities are still in the process of becoming empowered as those that have access to natural resources but do not have the level of social organization required (e.g., through formal organizations) to successfully trade their products in formal markets; and 3) nonempowered, in which communities are those that remain without access to natural resources in cases in which these are still controlled by the descendant families of old rubber barons. To quantify household wealth, we attribute a price for each of the material items identified in our preliminary assessment, considering the local market pricing. We sampled each household ($n = 281$), recording the items and assigning a total household wealth, which was the sum of the value of all reported items. All surveyed communities were randomly selected, and the community leader family was excluded from the sampling to avoid more affluent and networked households (48, 57, 81). Third, at the individual level, we conducted semistructured interviews with 237 adults (aged 18+) from 80 communities and 189 young people (aged 13 to 17) from 23 communities to assess their relative inclination toward rural–urban migration. This was the only hedonic measure of well-being, in which a desire to stay in the community could be related to subjective feelings of pleasure and happiness (82). We are aware that rural–urban mobility in Amazonia is complex and can often be understood from a multilocality perspective, in which local dwellers can sustain the management of natural resources connecting urban and rural environments in their social dynamic (48, 81). To avoid this dynamic, we explicitly asked whether the interviewee wished to eventually abandon his/her rural livelihood to find wage labor within an urban area. This research was authorized by the Ethics Committee (Comitê de Ética em Pesquisas com Seres Humanos, Universidade Federal do Rio Grande do Norte; Permit 2.013.825) according to Brazilian legislation involving research with traditional people, and all participants provided informed consent. It was also approved by the Departamento de Mudanças Climáticas e Gestão de Unidades de Conservação (DEMUC) and the Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) according to Brazilian legislation involving research in PAs.

Predictors. To understand the determinants of local well-being, we included predictors regarding governance status and landscape context, which were extracted for each community using ArcGIS (version 10.2). Our list of potential predictors of local well-being included the following: 1) governance status: whether the community was inside or outside a PA (binary variable); 2) distance to the nearest urban center: the nonlinear path distance by boat, which was measured using a Global Positioning System; 3) community size: the number of families living in the community; 4) family size: the number of adults in the family; 5) government subsidies: the amount of money received by each family from the government conditional cash transfer program; 6) (74) economic diversity: the number of economic activities conducted by each family; 7) young people living in urban centers: whether the family have members aged 13 to 17 living in urban centers; and 8) age: the age of each informant. The full dataset is available in *SI Appendix*.

Identifying enablers of social outcomes. To identify important operational mechanisms within PAs that can catalyze social outcomes, we conducted interviews with two focus groups including 52 people to build a stakeholder-based mental model to elucidate cause–effect relationships observed after the creation of these PAs (83, 84). First, we identified the enablers and their attributes that can ensure the social outcomes. Local stakeholders identified a wide set of social benefits that can be generated from the same enablers, going beyond the immediate social outcomes assessed in this study. We therefore decided to maintain the entire list of reported social outcomes to present a broader mental model that could be useful for future studies. Second, we conducted 40 interviews to quantify the level of importance of each enabler identified in the previous step using Likert scale responses. Interviewees were selected through snowball sampling to cover the most

prominent local leaders who have guided transformative activities along the Juruá River over the last 30 y (85).

Data Analysis. We tested the effect of PAs on community infrastructure through a Principal Component Analysis and a PERMANOVA, based on distance matrices of the infrastructure diversity at each site. For this analysis, we used the adonis function from the vegan package, which partitions distance matrices among potential sources of variation (86). We fitted a linear model to these distance matrices and evaluated the pseudo-F ratios with a permutation test. The number of permutations for all of these tests was set at 999.

To understand the variation in community key services and commodities, household wealth, and desire for rural–urban mobility, we performed Generalized Linear Models using different error structures and considering all potential predictors (*SI Appendix*). Models were fitted using the *lmer* function from the *lme4* package (87), and each model combination was examined using the *MuMIn* package (88). We selected the most parsimonious model with the lowest Akaike Information Criterion, correcting for small sample sizes (AICc). ΔAICc is calculated as the difference between each model's AICc and the lowest AICc, with a $\Delta AICc < 2$ interpreted as substantial support that the model belongs to the set of best models (89). After model selection, we calculated a model average, which considers the beta average of all variables included in parsimonious models; as the variables were standardized through z standardization, we compared the relative effect size of all variables. Finally, we calculated the hierarchical partitioning of each explanatory factor to understand the power of explanation of the observed variation. The dataset is available at *SI Appendix* (*SI Appendix*, Tables S6 and S7).

Data Availability. All study data are included in the article and/or *SI Appendix*.

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