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Avoiding Amazonian Catastrophes: Prospects for Conservation in the 21st Century

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A new threat now confronts the Amazon in the form of a massive infrastructure program, the Initiative for the Integration of the Regional Infrastructure of South America, or IIRSA. This article presents results of a projection analysis showing that IIRSA could push the Amazonian forest past a "tipping point," replacing it with tropical savanna. Such an event would degrade biodiversity, reduce carbon storage, and harm continental agriculture, dependent on moisture transport from forest-based rainfall recycling. The article considers environmental policy in Brazil and discusses its weakening over time. One short-term approach to conservation is provided by indigenous resistance to development forces. The article presents a case study of the Munduruku people, who recently stopped construction of a large dam on the Tapajós River in defending their territories. It argues that more research is needed to understand the impacts of IIRSA, which is proceeding in the dark.

Introduction

Recent headlines about the number of fires in Amazonia have renewed public concern for the future of the region's forest biome. This concern first arose in the early 1970s when Brazil decided to bring a "people without land to a land without people."[1] Soon after the bulldozers broke dirt on the Transamazon Highway in 1972, the rate of deforestation began a precipitous climb. For several decades it averaged nearly 20,000 km^2 $year^{-1}$ as the agricultural frontier converted ~800,000 km^2 of forest into fields and pastures, an area larger than Texas.[2] The Amazonian nations, in particular Brazil, implemented policies to stem the loss, and after the turn of the millennium deforestation rates fell below the historic average, where they now remain despite a recent uptick. Scholarship attributed the hopeful turnaround to environmental policy, the greening of agricultural supply chains, and a moratorium by soybean farmers on deforestation.[3] This kindled hope that a new era of sustainability had dawned on Amazonia, a hope that Brazilian President Bolsonaro has dampened with many public statements about his intentions for the region. Worries concerning what Bolsonaro might do are exacerbated by new threats to the forest looming on the horizon.[4]

Most worrisome is an infrastructure program, the Initiative for the Integration of the Regional Infrastructure of South America (IIRSA), which dwarfs all previous development efforts undertaken in Amazonia.[5,6] Given the established link between deforestation and infrastructure, especially for transportation, it is reasonable to question if a new wave of forest clearing will build, just as global warming begins to affect the region.[7–11] The present article addresses IIRSA in light of conservation concerns about a so-called "tipping point," a magnitude of deforestation that compromises rainfall recycling, inducing a biome shift from moist tropical forest to tropical savanna, with dire consequences for biodiversity, carbon sequestration, climate regulation, and dependent agricultural systems.[9,12–14] Because IIRSA is continental in scope, the article defines Amazonia as the river's entire watershed with an area of ~7,000,000 km^2, encompassing two biomes, the Amazonian Biome (tropical forest) and the Cerrado Biome (savanna). Although nine nations share the basin, we focus on Brazil, which occupies the largest portion and has experienced the most environmental change (Figure 1). Brazilian Amazonia is mostly coterminous with the planning region known as Amazonia Legal, or AML, which includes areas outside the watershed in the Tocantins River basin. To simplify the exposition, we will refer to Brazilian Amazonia as AML.

The purpose of this article is to address the possibility of an Amazonian tipping point catastrophe and how to avoid it. To this end, we present results of scenario projections out to 2050, showing that the possibility does exist. After this, we elaborate the main conservation strategies at play in AML, assessing their potential effectiveness in light of the challenges posed by IIRSA. We next consider how indigenous resistance can realize conservation outcomes, using a case study of the Munduruku people in the Tapajós River Valley (TRV) to demonstrate this. Finally, we look to the future and argue that IIRSA is moving forward in the dark, without full knowledge of its ultimate consequences. We suggest that support for indigenous territorial claims can provide a conservation stop-gap in the short-run, while the search continues for a long-run solution that guarantees the sustainability of Amazonia's economy and the conservation of its forest.

Flipping South America to an Amazonian Tipping Point

Before proceeding, we distinguish between the concept of a tipping point and forest dieback.[10,15,16] Both involve a

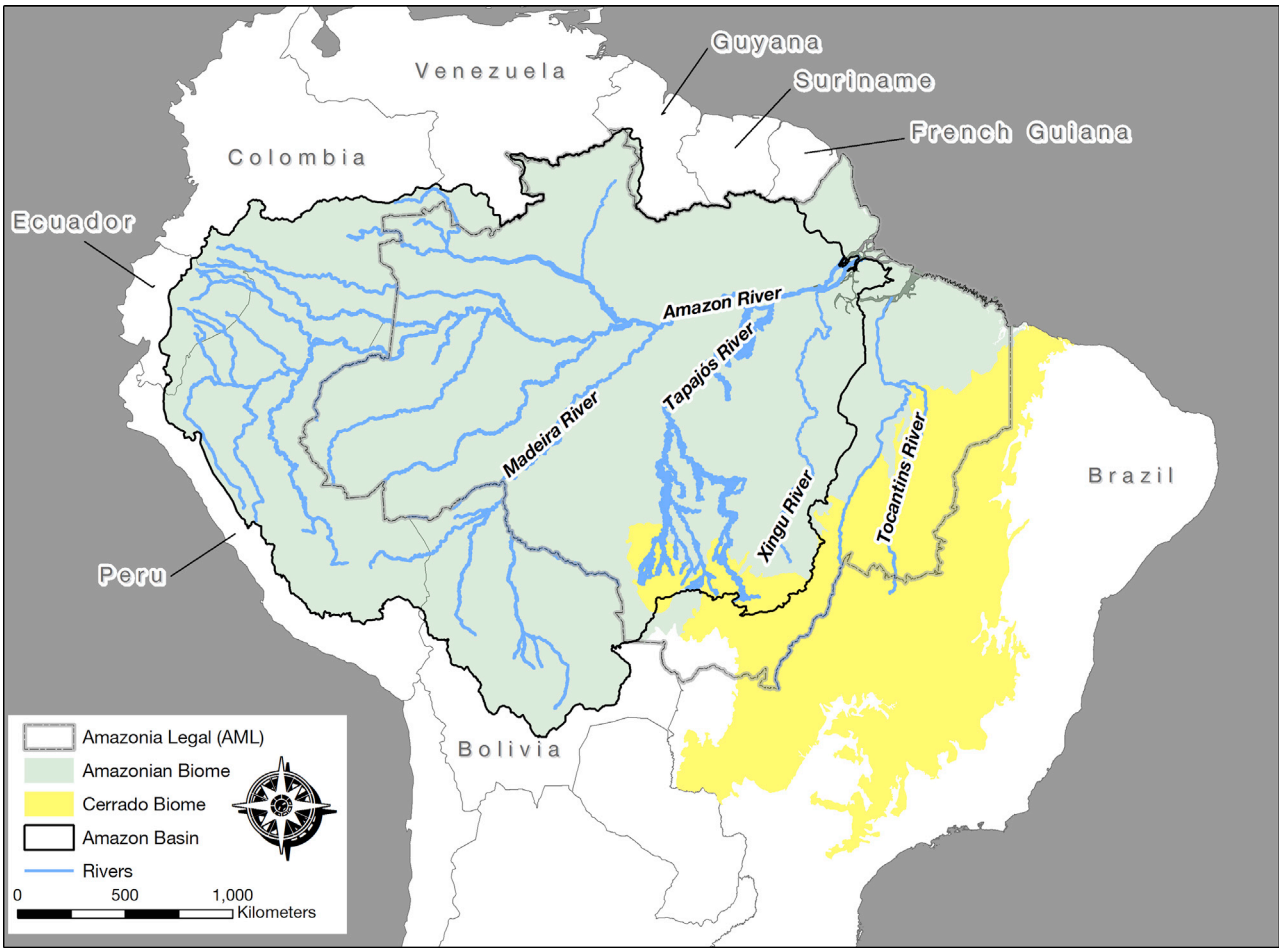

Figure 1. The Many Amazonias
This figure displays usage of the word "Amazonia," which can refer to a hydrologic basin, an ecological biome (the Amazonian Biome), or a planning unit, such as Amazonia Legal, the Brazilian Amazon. Here is shown the extent of the basin and the demarcation of the Brazilian Amazon. Also indicated are the two biomes that occupy the basin, namely the Amazonian Biome, which is forest, and the Cerrado, which is tropical savanna. Note that the Amazonian Biome occupies part of the Tocantins River watershed, which lies outside the Amazon basin.

catastrophic biome shift from forest to savanna, but their mechanisms differ. As defined here, the tipping point mechanism stems from the impact of deforestation on precipitation. In contrast, forest dieback occurs due to thermal stress associated with global warming (Supplemental Experimental Procedures, General Information, Tipping Point vs Forest Dieback). Acting in isolation, global warming is unlikely to cause a forest dieback through the 21st century, because increased atmospheric concentrations of CO_2 could stimulate tree growth.[10] On the other hand, a shifting thermal regime might intensify the effect of deforestation on rainfall, in which case Amazonia faces two primary threats: global climate change and IIRSA.[14] Addressing both in combination resides outside the scope of the article, in which case we focus our attention on IIRSA.

IIRSA comprises a set of South American infrastructure projects initiated in 2000 by former Brazilian President Fernando Henrique Cardoso. AML infrastructure investments began in earnest during Brazil's military government (1964–1985) and its enthusiasm for the ideas of Walt Rostow, Herman Kahn, and others, who theorized that development advanced in economic stages up to industrial "take-off," followed by sustained growth into the modern world.[17,18] Large-scale public works projects would initiate take-off by building roads and dams to create the necessary logistical platform, including a "Great Lakes System" of South America, in direct mimicry of the North American Great Lakes regarded as key to the emergence of the American industrial heartland.[19] Brazil's early infrastructure program was meant to secure national borders in a sparsely settled hinterland. It was also intended to promote national development by making the region's resources accessible to the Brazilian economy, which in turn would spark Amazonian development. In many respects, IIRSA represents a reincarnation of this earlier modernization quest, but one that forms part of a broader program of infrastructure projects being undertaken independently by South America's 12 nations at all levels of government including federal, state, and even municipal. To avoid ambiguity, we refer to the entire portfolio of multi-lateral, bilateral, and unilateral investments as IIRSA^{+}.

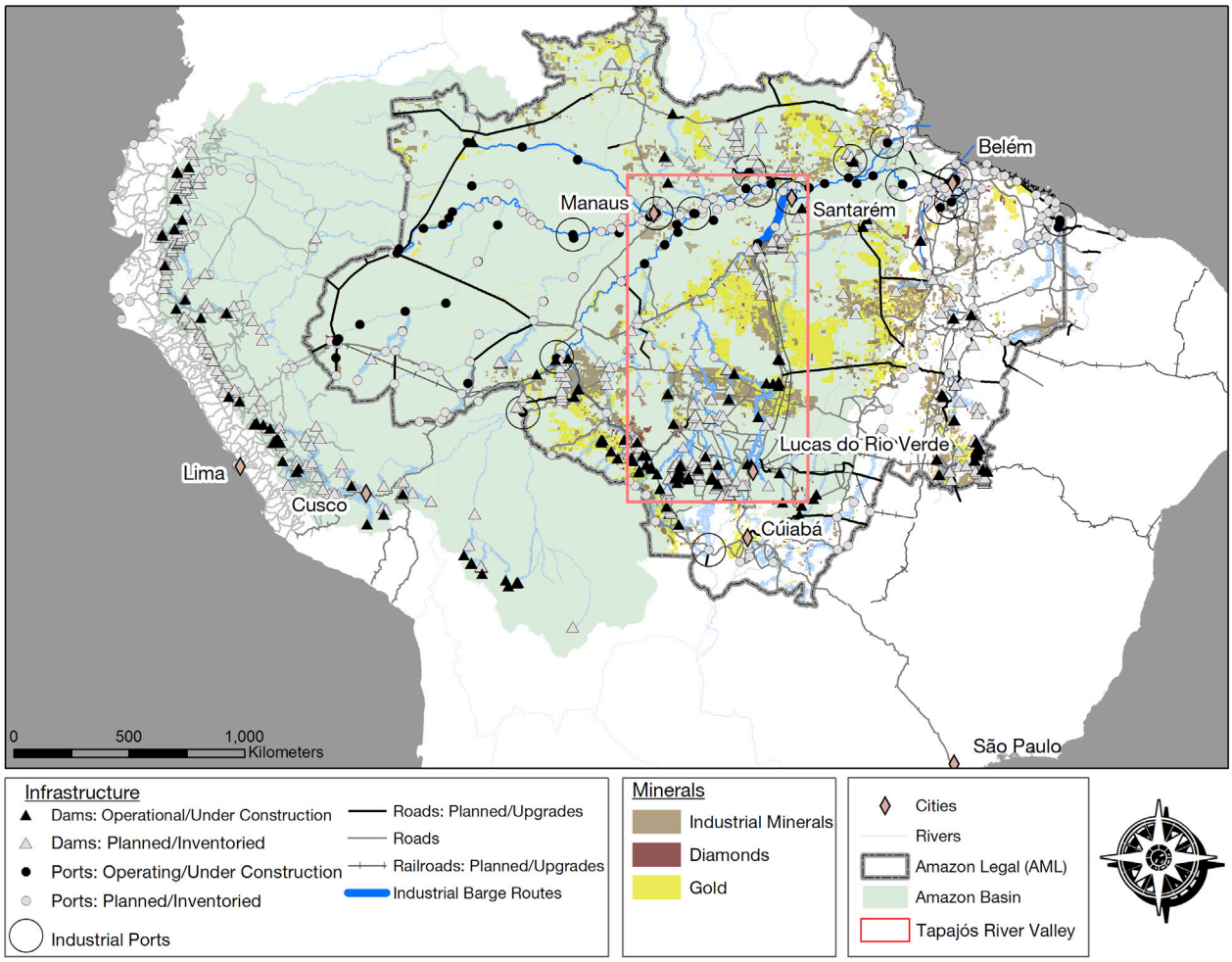

Figure 2. Basin-Scale Infrastructure Plan with Mineral Deposits

This figure shows the infrastructure plan known as the Initiative for the Integration of the Regional Infrastructure of South America, or IIRSA. These are the multi-lateral projects for the entire basin. Therefore, they do not necessarily reflect those being prosecuted under state and municipal auspices within the individual Amazonian nations. The figure also identifies known mineral deposits in Amazonia Legal. The large rectangle in the middle identifies the location of the Tapajós River Valley, subject of Figure 4.

The Plan

IIRSA^{+} seeks logistical integration of South America to enhance its competitiveness in a global economy. Fully implemented, it will transform Amazonia into a transportation hub with multi-modal capacity including highways, waterways, railways, and ports.[5] Furthermore, it will electrify the South American nations by developing the region's enormous hydropower potential.[20,21] The impact of IIRSA^{+} on Amazonia cannot but be dramatic. Its modernized transportation network will enable the export of grains from north-central Brazil to world markets. The buildup in hydropower will attract electricity-intensive manufacturing to the region, enabling the production of steel castings, aluminum sidings, basic chemicals, synthetic fibers, glass products, consumer electronics, and automobiles.[22,23] Subsidies and tax incentives in IIRSA-designated Export Processing Zones will stimulate existing industrial platforms and create new ones. Targeted are food and kindred product industries (e.g., meat packing, corn milling, and soybean meal and oil processing) as well as the smelting and refining of ferrous and non-ferrous metals (e.g., iron, steel, and aluminum). The development of heavy industry will be facilitated by Amazonia's abundant supplies of gold, diamonds, iron ore, manganese, chromium, vanadium, niobium, nickel, aluminum, copper, zinc, and tin. Figure 2 depicts the multi-lateral IIRSA program together with the basin's mineral deposits.[21,24–33]

Threshold Deforestation

IIRSA^{+} could hypothetically launch the region's industrial take-off, the goal of the development model adopted by Brazil's military government long ago but never realized.[17,18] If this were to happen, South America's spatial economy would "flip," with Amazonia becoming the continent's industrial core, and São Paulo and its hinterland, a rustbelt (Supplemental Experimental Procedures, Simulations, Conditions for a Spatial Flip).[34] Agriculture would push new croplands and pastures north onto cheap Amazonian land, and Brazil would begin capturing the value added it lost from decades of exporting raw materials rather than manufactured goods.[22,35–38] Even if IIRSA^{+} fails to launch the industrial transformation of Amazonia, some amount

of deforestation seems inevitable, an outcome that raises the specter of an Amazonian tipping point.[9,14]

Basin-scale deforestation of 40% of the forest biome's extent prior to development has been hypothesized as the tripwire for a tipping point catastrophe, although this could drop to 20%–25% with global climate change.[9,14,39] Such claims derive from climate models, which are subject to high uncertainty and do not always agree. Some suggest different tipping point thresholds, whereas others fail to predict a biome shift even with 100% deforestation.[15] There is also ambiguity in the geography of the effect. The western basin might retain its forest under any extreme while the eastern basin experiences savannization.[9] Then again, it might not.[40] Complicating the tipping point scenario is that the size of deforested areas influences the spatial and temporal distribution of rainfall as well as dry season hydro-climatology.[41–43] Additional research is necessary to resolve these modeling issues, which in any event lie outside the scope of the article. That said, conditions appear to be worsening with the intensification of drought and the lengthening of the dry season through the so-called Arc of Deforestation covering the eastern and southern parts of the basin.[14]

We suggest that the consequences of a tipping point catastrophe are sufficiently grave to warrant an assessment of the magnitude of deforestation likely to result from a fully implemented IIRSA^{+} plan. If the threshold is indeed 40%, how likely is it that the new infrastructure will push deforestation to this point and beyond? To provide a tentative answer we estimate the amount of Amazonian land that would be needed to accommodate Brazilian agriculture projected to 2050 and add it to the deforestation to date. Other modeling applications have projected Amazonian futures in the interest of conservation planning.[44–46] Our study differs by (1) considering deforestation magnitudes for both AML and the entire basin, and by (2) using the agricultural projections of government agencies, namely Brazil's Ministry of Agriculture, Livestock and Food Supply (MAPA)[47] and the Food and Agricultural Organization of the United Nations (FAO).[48] Furthermore, it implements a Bayesian probit model to present results spatially (Figure 3; Supplemental Experimental Procedures, Computational Methods, Deforestation Projections).

Our projections implicitly assume that deforestation over the next several decades will be dominated by the advancing agricultural frontier, as has often been the case when projecting Amazonian futures (Supplemental Experimental Procedures, Computational Methods, Deforestation Projections). Over the long run, out to 2099 as in many global climate projections, residential land use stemming from urbanization would probably begin adding deforestation pressures to those associated with agricultural development. Furthermore, tropical moist forest would probably give way to pine and eucalyptus plantations in some parts of the basin. To 2050, however, the model assumes that Brazil's expanding agricultural economy will constitute the primary proximate cause of deforestation. We consider a worst- and best-case scenario defined on assumptions about IIRSA development impacts, the strength of environmental governance, and agricultural intensification. This enables us to establish a range of deforestation that is likely to bracket the actual outcome.

MAPA and FAO both provide alternative projections of Brazilian agriculture to 2050, which we translate into deforestation under the assumptions of our two scenarios. For both, we add projected to current deforestation to produce values in 2050, then depict them spatially with the Bayesian probit model (Figure 3; Supplemental Experimental Procedures, Computational Methods, Deforestation Projections). We assume that IIRSA^{+} infrastructure provides the social overhead capital ultimately necessary for agricultural development, resource extraction, and industrialization. In turn, industrialization and resource extraction trigger positive feedbacks on agriculture through circular and cumulative causation, which builds the region's population and its food demands.[49,50] Such growth constitutes the distal driver of deforestation, given it sparks the demand for agricultural land use and funnels it to Amazonia.[51] Our model omits forest degradation from logging, edge effects, and fire regime, in which case the article neglects extinctions that are likely to result from forest fragmentation irrespective of a tipping point outcome.[44] IIRSA^{+}'s logistical system can be expected to significantly impact Amazonia's areas of endemism and complicate implementation of the mega-reserves deemed critical to the survival of top predators and other animals.[52,53]

Worst-Case Scenario. In the worst-case scenario, environmental governance is weak, agricultural intensification is stagnant, and IIRSA^{+} produces a spatial flip in the Brazilian economy (Supplemental Experimental Procedures, Simulations, Conditions for a Spatial Flip). The logistical network directs agricultural expansion to Amazonia, where manufacturing provides low cost inputs and transforms farm produce into value-added goods for export to the global marketplace. Population grows as industrialization—aided by abundant hydropower—creates jobs, adding regional to global food demands, further stimulating agriculture. To represent these conditions, we extrapolate from MAPA's[47] upper limit projection of Brazilian cropland to 2050. We take increase in cattle herds from the "business as usual model" of FAO[48] and calculate productivity (stocking density) using data on herd size and pasture areas.[32,54,55] Assuming projected crop expansion occurs entirely in Amazonia, another 680,000 km^2 of forest are converted after 2017. Likewise with cattle ranching, growth of the Brazilian herd occurs entirely in Amazonia, adding 53,000,000 animals by 2050. This requires an area of 375,000 km^2 if ranching does not intensify, in which case stocking density remains fixed at its 2017 value (1.41 head ha^{-1}). The worst-case scenario therefore generates 1,050,000 km^2 of deforestation. Adding to AML deforestation in 2017 ($\sim$792,000 km^2) yields the 2050 value of $\sim$1,800,000 km^2, or 43% of the original AML forest (4,200,000 km^2). Calculating as a percentage of the basin's Amazonian Biome presents difficulties given lack of basin-scale data comparable to Brazilian information. That said, we are able to estimate worst-case non-AML deforestation at 180,000 km^2 (Supplemental Experimental Procedures, Computational Methods, Deforestation Projections). Adding it to AML deforestation in 2050 gives 1,980,000 km^2, or 36% of the basin's forest. The increment of AML deforestation yields an average yearly deforestation rate of $\sim$32,000 km^2 year^{-1} (1,050,000 km^2/33 year) comparable with the maximum observed, 29,100 km^2 year^{-1} in 1995.[56]

Best-Case Scenario. In the best-case scenario, environmental governance mitigates deforestation and agriculture intensifies.

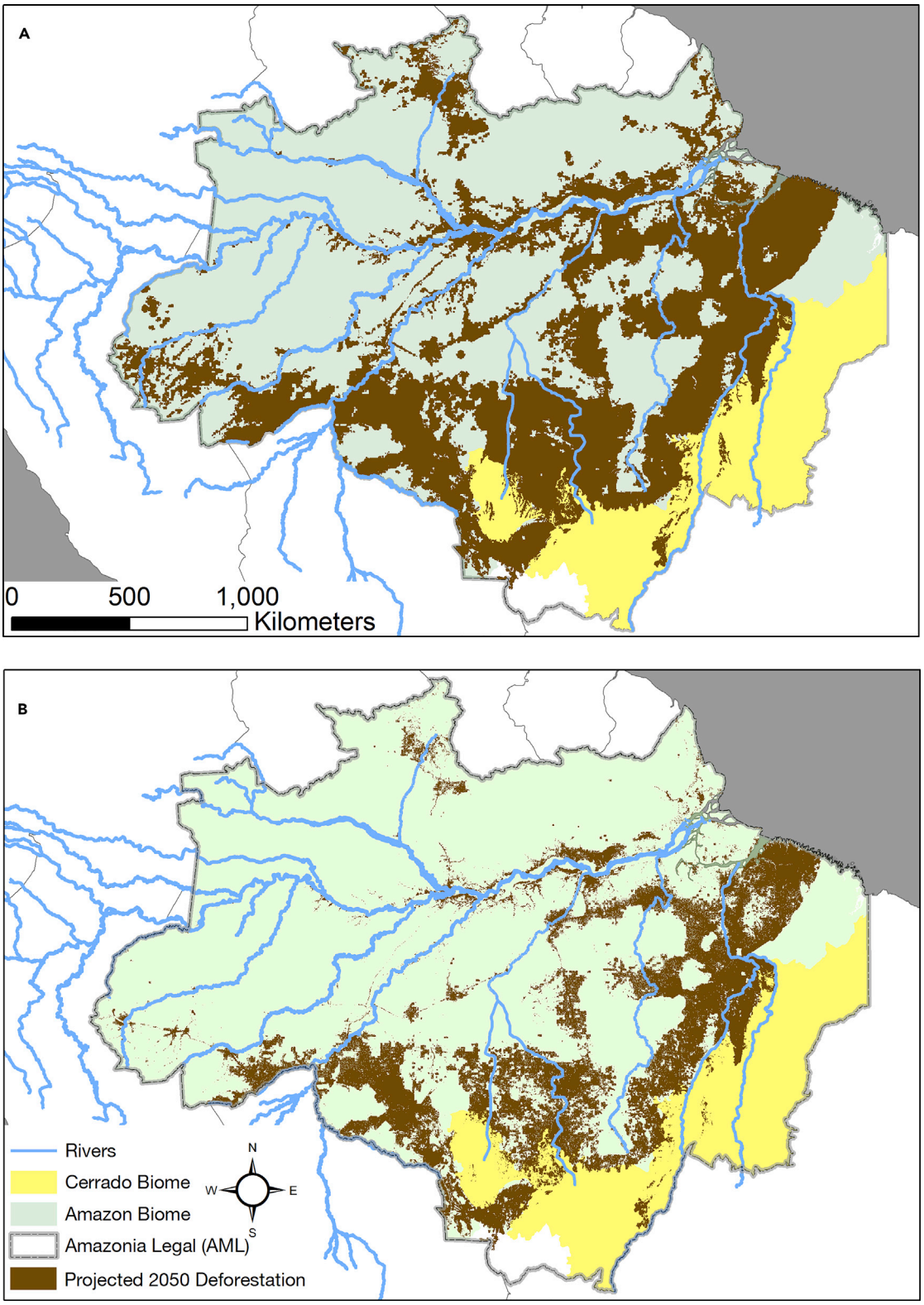

Figure 3. Outcomes for Worst and Base Case Scenarios
This figure portrays the deforestation generated by each of our scenarios in the year 2050. The worst-case (upper panel) spatially distributes a projected forest loss of 43% across the Brazilian Amazon, according to a Bayesian probit model. The lower panel does the same thing for the best case, with a 21% forest loss.

IIRSA+ infrastructure fails to trigger sustained growth in either agricultural or industrial sectors. Cropland expansion follows the average scenario of MAPA, which incorporates intensification effects.[47] The soybean moratorium holds and green supply chains dampen the export of agricultural commodities produced following deforestation. New fields occupy old pastures, displacing them to Amazonia and causing deforestation via indirect land use change.[57,58] For cattle, we use FAO's "toward sustainability" projection of the Brazilian herd in 2050, calculate its increment with respect to 2018, and allocate a portion to AML. The projected cropland increment is 294,000 km^2 by 2050, or 47.8% with respect to 2018. This yields 56,200 km^2 of deforestation via ILUC from across Brazil.[58] FAO projections show an addition to the Brazilian herd of 30,600,000 animals by 2050. With intensification in the cattle sector, we let stocking density double to 2.81 animals ha^{-1}, so the new animals require an additional 109,000 km^2 of pasture. If AML fails to increase its proportion of the Brazilian herd, which remains fixed at its current value of 33%, 36,300 km^2 of forest is converted to new pastures. Consequently, an additional 92,500 km^2 of forest will be cleared by 2050. This leads to a total forest loss of 885,000 km^2, or 21% of the AML forest, and implies an annual deforestation rate of ~2,800 km^2 $year^{-1}$ (92,500 km^2/33 year), comparable with the lowest observed historically. With best-case contributions of the other non-AML nations, we estimate total basin deforestation at 983,000 km^2, or 18% (Supplemental Experimental Procedures, Computational Procedures, Deforestation Projections).

In quantitative terms, the projection results are in broad agreement with previous modeling efforts. For example, Soares-Filho et al.[45] predict 40% deforestation of AML by 2050 under a "business as usual" scenario, close to our worst-case projection of 43%. Furthermore, projected rates of forest loss match results in Rochedo et al.[46] Worst-case deforestation, ~32,000 km^2 $year^{-1}$, is comparable with the 27,000 km^2 $year^{-1}$ in their "weak governance" scenario.[46] Alternatively, our best-case rate of 2,800 km^2 $year^{-1}$ is comparable with their "strong governance" scenario number of 3,920 km^2 $year^{-1}$. Figure 3 depicts the projection results spatially with a map showing the advance of deforestation from the south and east along the Arc of Deforestation.

We have used projection analysis to determine if a tipping point transgression will result from the IIRSA+ program. Given lack of agreement about thresholds of forest loss, results should be interpreted cautiously. Nevertheless, under the strong assumptions of our worst-case scenario, the catastrophic outcome seems possible, particularly with the onset of global warming.[14] We now turn to the question of how to avoid it.

A Trend Is Not a Law

Despite our worst-case projection, deforestation rates have recently tracked down, providing some hope that catastrophe can be averted. Unfortunately, trends by no means indicate immutable laws.[59] Forest loss could rebound with vigor, pushing the Amazonian Biome into the tipping point danger zone much sooner than expected. Brazilian environmental policy and other interventions helped mitigate deforestation drivers after the turn of the millennium, even in the face of problems endemic to the region involving land titling, grabbing, and speculation. But does previous success guarantee they will be able to manage the tectonic shock of IIRSA+ and keep us from the brink? It is too soon to know, but not too soon to point out several issues that underscore the importance of remaining vigilant despite the conservation achievements to date. To this end, we address public policies based on Brazil's protected areas program and forestry code, as well as efforts at developing sustainable land use and resource extraction. We also consider conservation by the private sector, ecosystem services, and global efforts to help Brazil reduce the rate of deforestation.

Policy Attrition and Amazonian Obsolescence

Brazil has long based its Amazonian environmental policy regime on a system of protected areas and a forestry code restricting the amount of land one can clear on private holdings. Both are credited with having helped reduce the rate of deforestation rates after 2004. At that time, the protected areas program experienced a significant increment in lands under some form of protection, expanding to ~43% of AML. Similarly, the forestry code was enhanced by enforcement procedures based on the satellite monitoring of individual holdings for compliance. Unfortunately, both policy instruments have degraded with time, a process that began shortly after they contributed to the historic decline in deforestation rates. Following the expansion of its system of protected areas, the Brazilian government began downsizing them to accommodate hydropower facilities and transmission lines.[60–62] Former President Rousseff even downsized Amazon National Park, the first in AML, to make way for dams on the Tapajós River, as discussed in the next section.[62,63] The current administration appears ready to continue in this direction given President Bolsonaro's public statements about the Amazonian environment. Nor is there much reason to believe he will pursue a rigorous enforcement of the Forestry Code. In fact, the so-called "Ruralist" political lobby in the Brazilian Congress succeeded this past February (2019) in fighting challenges to changes in the Code made in 2012 that weakened its environmental provisions[61,64] (Supplemental Experimental Procedures, General Information, the Forestry Code).

The political atmosphere also calls into question the longevity of private sector conservation practices such as supply chain greening and the soybean moratorium, a voluntary agreement among farmers to expand production on old pastures instead of primary forest.[65] In fact, the conservation effect of the moratorium has been overstated given deforestation occurs anyway due to indirect land use change.[57,58,66] Regarding green supply chains, they originate in response to consumers mostly resident in the global north, so their impact is limited when serving domestic markets. Furthermore, "green" certification provides no guarantee that the final product is "deforestation-free." Large-scale meatpackers often deal with independent brokers who collect animals of unknown origin from a wide variety of anonymous suppliers.[67] Such shortcomings are likely moot, since an energetic continuation of private sector engagement in the conservation quest appears unlikely under an administration intent on exploiting the resource potential of Amazonia.[64] Therefore, it is disappointing that a sustainable and economically viable alternative to cattle ranching has not been found, despite local successes with community-based forestry management, the extraction of non-timber forest products, and ecotourism.[68–70]

Many now argue that ecosystem services will provide conservation's long-sought magic bullet, both in Amazonia and elsewhere.[61,71] One way such services foster desirable environmental outcomes derives from placing dollar values on them to demonstrate their socio-economic importance.[72] For example, the Amazonian Biome's regulation of climate—via rainfall recycling and moisture transport by atmospheric rivers—underpins the agricultural economy within and beyond the region.[73,74] A conservation effect could arise if society, cognizant of the economic values at risk from declining rainfall, mitigates deforestation to ensure that the forest continues to provide its climate regulation service. A specific application relevant to the Amazonian case involves the payment for ecosystem services in a market exchange, as with the purchase of the carbon sequestration services provided by trees. In a similar vein, Amazonia's provision of biodiversity has recently inspired a proposal to restructure the region's economic base away from resource extraction to a green one that innovates biological technologies dependent on biodiversity inputs.[75] Conservation evidently results from the value of forested land in a manner analogous to selling sequestration services.

Unfortunately, Amazonian prices for carbon sequestration provide less income than earnings from agriculture at the present time, imposing an opportunity cost on property owners who opt to conserve trees.[63] The situation will only worsen as efficient carbon capture technologies come online and push prices down further, ultimately rendering Amazonia's "forest" technology obsolete.[76,77] Similarly with the provision of biodiversity services, these could soon be rendered obsolete by the rapid advances of synthetic biology.[63,78] Putting dollar values on aggregate service provision—for example, by calculating the value of Amazonian climate regulation to South American agriculture—could spark societal conservation responses if certain conditions are met. First, the public must be convinced of the mechanism translating anthropogenic activity (e.g., deforestation) into service impairment (e.g., rainfall decline); and second, they must also be convinced of the magnitude of the impending loss. Climate science skepticism by some, in both the world community and Brazil, complicates the fulfillment of these conditions.

Although the article focuses on the threat from IIRSA^{+}, global efforts to reduce greenhouse gas (GHG) emissions are relevant to the discussion, since many parties to the Paris Climate Treaty view forest policy as key to atmospheric GHG reduction. Tree-based carbon sequestration forms the foundational concept of the UN Programme for Reducing Emissions from Deforestation and Forest Degradation (UN-REDD, UN-REDD^{+}). Brazil's national REDD^{+} activities are guided by its Action Plan for Prevention and Control of Deforestation in the Legal Amazon (PPCDAm), established in 2004 and supported by the world community through multi-lateral and bilateral financial contributions.[79] In general, these are distributed through mechanisms such as the Amazon Fund, which Brazil has used in the past to strengthen its environmental policy applications. At present, most spending has supported its protected areas program and the Forestry Code, as for example by building monitoring capacity through the use of remote sensing (Supplemental Experimental Procedures, General Information, the Forestry Code). But PPCDAm can only be effective if the Brazilian government defends protected areas and enforces the forestry code, which is in doubt at the present time.

The "Mississippi" of Brazil and Ipereğ'Ayũ

Our consideration of policy and private sector engagement casts doubt on Brazil's ability to sustain low rates of deforestation in the near term, with the onset of IIRSA^{+}. Nor do global initiatives stemming from UN-REDD^{+} provide a sure substitute, given they must act through a weakening policy regime administered by a sovereign state. Luckily, there remains a societal action not expressly aimed at conservation but which fosters it. We refer here to indigenous resistance. This represents an assertion of sovereignty and therefore a political act. That said, successful resistance in Amazonia typically yields a conservation dividend of forest protection, as was recently demonstrated by the Munduruku Tribe in the TRV.[15,63,80–89] Indigenous reserves account for about half of Brazil's protected areas in Amazonia, a territory covering $\sim 1.06 \times 10^6$ km^2. Thus, Amerindian assertion of territorial claims could assure the potential conservation of ~20% of the Amazonian Biome in AML. Here we offer a case study of the Munduruku, and place their actions within the broader context of the conservation challenges that Amazonia now faces.

With a population of ~14,000, the Munduruku claim 60,000 km^2 in 14 reserves spread throughout TRV, once known as Mundurukania. TRV, a critical target of the IIRSA^{+} agenda, holds the key to opening the Central Amazon Basin to development (Figure 4; Sources[21,25–33]). This is because it provides a direct link between the agricultural regions of Mato Grosso and ports on the Amazon River, particularly at Santarém. Also, the Tapajós passes close to the intersection of the Transamazon Highway and BR-163, two major transportation arteries. It should come as no surprise that development planners envision the Tapajós River as the future "Mississippi of Brazil," a development lynchpin that will enable growth in South America the same way the Mississippi did in North America.[37] At the moment, the Tapajós remains undammed on its mainstem, one of the last large, right-bank tributaries in a natural state.[35,36] Its drainage reaches into Brazil's most important region of soybean agriculture, where farmers have long exported produce through the Port of Santos far to the south, a costly undertaking. The valley happens to be a region of great mineral wealth (Figure 4). In fact, Munduruku land harbors what may be the world's largest gold reserve, under state-sanctioned assessment as of January 2018 by Vale S.A., a major producer of iron ore and nickel, and a world leader in mining technology (Figure 4A). Besides gold, TRV is rich in the minerals necessary to the production of a variety of industrial metals. This has also attracted private interests, most notably Alcoa Corporation, the world's largest bauxite producer (Figure 4B).

At the heart of IIRSA^{+}'s design for TRV lies the Tapajós Hydroelectric Complex (THC), a Brazilian project consisting of five dams capable of generating 12,000 MW. The locks and reservoirs associated with three of them (São Luiz de Tapajós, Figure 4C; Jatobá, Figure 4D; Chacorão, Figure 4E) are components of IIRSA^{+}'s 1,400 km Tapajós Waterway, long sought by soybean farmers in Mato Grosso. Brazil's contribution includes 11 new and upgraded ports, one of them a major transshipment facility at Cachoeira Rasteira (Figure 4F) to be connected by a municipal road to state road MT 206 at Apiacás (Figure 4G). On the eastern margins of TRV, Brazil is now improving

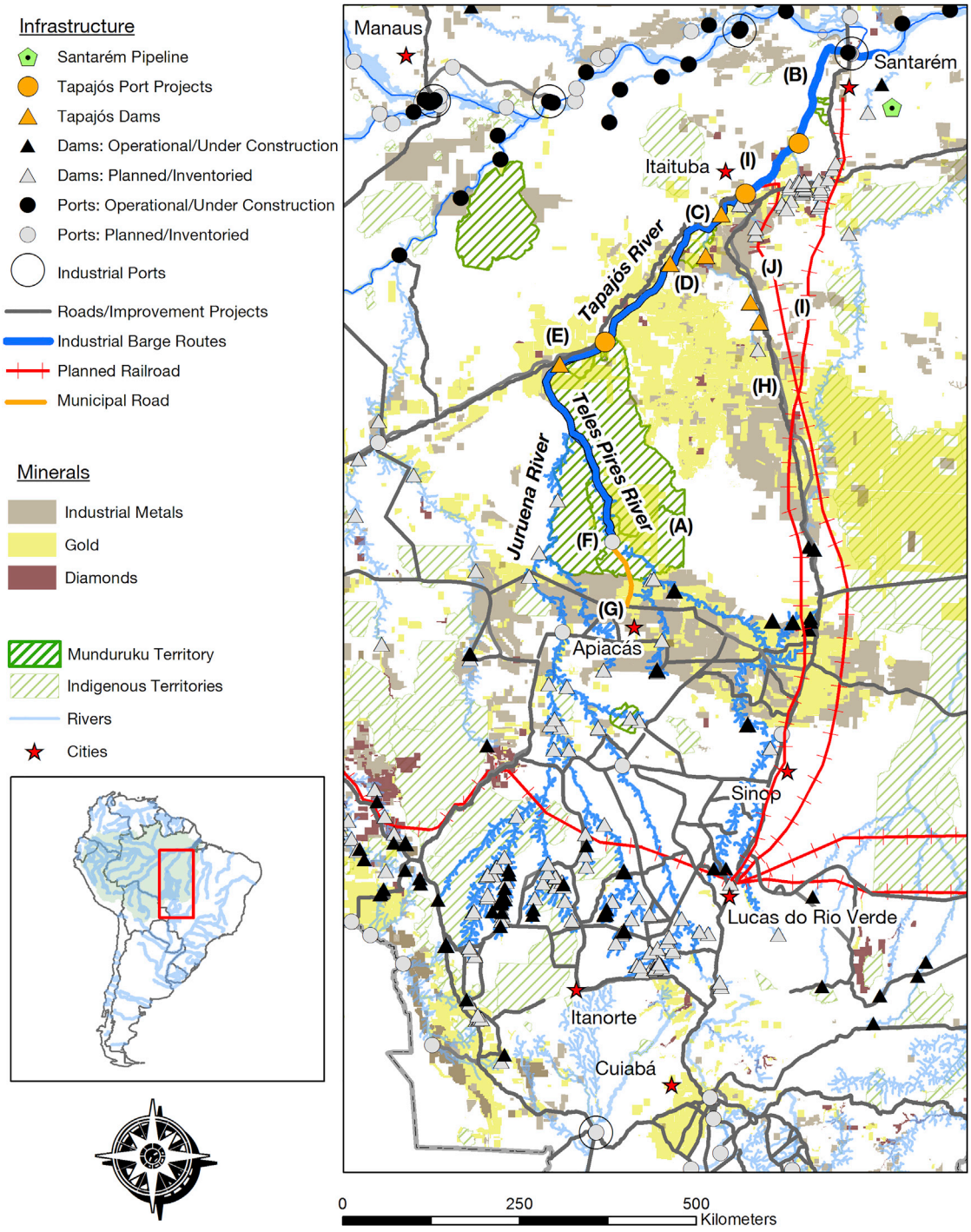

Figure 4. Infrastructure Plans for the Tapajós River Valley

This figure shows the combination of federal, state, and municipal infrastructure plans that together comprise IIRSA^{+} in the Tapajós River Valley, the home of the Munduruku People. It also shows the extent of indigenous lands and the abundance of industrial minerals, including gold (A) and bauxite (B). The locks and reservoirs of three project dams—São Luiz de Tapajós (C), Jatobá (D), Chacorão (E)—will facilitate implementation of the Tapajós Waterway, a multi-lateral project. This will be served by a transshipment facility (F) and connected to an existing state road by a municipal road (G). BR-163 (H), a federal highway, is to be improved and two railways are to be built, one of them by the State of Pará (I and J).

BR-163 (Figure 4H) and plans to construct a 965-km railway (Figure 4I), to be complemented by the State of Pará's 1,000-km track from Itaituba to Cuiabá (Figure 4J). The Bolsonaro government's first publicly announced development project, Plano Barão do Rio Branco, aims to extend Highway BR-163 to Suriname with a bridge across the Amazon River. In essence,

Figure 5. The Free-Flowing Tapajós River
This is a photo taken by Robert Walker on June 26, 2016, shot from the shore of the Tapajós River at the planned site for the São Luiz do Tapajós Dam (point 4C, Figure 4).

the Munduruku are surrounded by infrastructure projects in various phases of implementation.

At the turn of the millennium, IIRSA^{+} began breathing new life into Brazil's AML infrastructure agenda after years of economic difficulty. As the Belo Monte hydropower project got underway in the Xingu basin just east of TRV, the Munduruku joined other tribes in opposition. Despite widespread protest and acts of civil disobedience, construction began in 2011 with the first turbines going online in 2016. Before this, the Munduruku had grown suspicious of government intentions when small dams began sprouting in the headwaters of TRV close to lands they claimed. Infrastructure is not permitted to flood indigenous territories, so in October of 2014 they deliberately initiated the demarcation of a new one, Sawé Muyby, to interfere with THC scoping. The federal government moved forward with surveys anyway, neglecting territorial boundaries, much less standards of "Free, Informed, and Prior Consent" as outlined in the Brazilian Constitution and international labor law (Supplemental Experimental Procedures, General Information, Indigenous Territorial Rights).

Reacting to the homeland threat and the failure of the Belo Monte protests, the Munduruku looked to their past for strategic inspiration. In so doing they rediscovered a long-standing tribal posture known as Ipereğ'Ayũ, which served them well during 19th century conflicts with outsiders—the pariwat—intent on taking their land. Ipereğ'Ayũ means "We are strong. We know how to protect ourselves and all we believe in." For the Munduruku, it translates into a vigorous politics of direct action meant to stop the infrastructure projects that threaten them.[90,91] Not just a bold statement of intentions, Ipereğ'Ayũ is also a social force capable of conservation feats such as the victory of August 2016, when the Brazilian Institute of the Environment and Natural Resources canceled the installation license for the São Luiz do Tapajós (SLT) Dam, the centerpiece of THC, braking the momentum of the entire infrastructure plan (Figure 5). By way of explanation, the Brazilian government claimed that economic projections had failed to justify the infrastructure investment.[63] This is suspect given it contradicts IIRSA^{+}'s foundational principle, that infrastructure investment is what sparks growth in the first place. In any event, the Munduruku have staved off development of TRV for the time being. Although conservation of the Tapajós does not, in and of itself, put breaks on the slide to a tipping point catastrophe, such outcomes are necessary to ecological sustainability at basin scale. The SLT victory is notable given the general lack of success experienced by other conservation efforts in the region.[92–95]

21st Century Challenges

The Munduruku victory achieved a political objective at the same time as it made a significant contribution to Amazonian conservation. This is a welcome outcome for the Munduruku, who have blended politics with concepts of sustainability, viewed as essential to their long-run survival.[80] The cessation of the SLT project demonstrates the fundamental contradiction between sustainability and IIRSA-style development. The stalled SLT project was seen as a victory for the Munduruku and for Amazonian conservation, whereas most TRV residents presently

Figure 6. Munduruku Warriors
This is a photo taken by Maíra Irigaray on July 13, 2018, in the Patawazal community on the Cururu River, in the Tapajós watershed (point 4E, Figure 4). It shows a group of male warriors, guerreiros, holding a banner at the Munduruku Women's Gathering that was called to address Brazil's development plans and incursions by miners. The banner they hold proclaims SAWÉ, SAWÉ, SAWÉ, which roughly translates as, "We are united and determined."

feel as if something valuable has been taken from them. THC hydropower would have brought thousands of new electrical connections and tens of thousands of new jobs to the watershed. Regionally, the project would have contributed power to the national grid and agricultural growth in Mato Grosso. Extrapolating to basin scale, the cost of AML conservation is equivalent to the forfeited values that IIRSA$^+$ would create with a modernized economy based on industrialization and export-oriented agriculture.

Sustainable development remains a fanciful concept for the typical TRV resident, who would probably agree with Henry Ford that the only real development involves industrial development, which enriches investors with the serendipitous effect of creating jobs, raising per-capita incomes and expanding the tax base. That AML is Brazil's poorest region creates broad public support for this type of development, both in TRV and throughout the basin. From the perspective of the South American governments and public, IIRSA$^+$ represents an economic dream about to come true, even when taking environmental costs into consideration. This is because the standardized approaches to environmental cost-benefit analysis required by law consider only one project at a time and are therefore myopic in time and space. The implication is that they fail to capture the cumulative and synergistic impacts arising across multiple projects and infrastructure types.[96,97] Such impacts far exceed the sum of those generated by each individual project independently of the rest. Evidently, the implementation of IIRSA$^+$ is proceeding in the absence of complete information about possible basin-scale consequences. This means that a tipping point threshold could be passed unknowingly, with undesirable consequences for both environment and economy (Supplemental Experimental Procedures, General Information, Cumulative and Synergistic Effects).[5,63]

Avoiding Amazonian Catastrophes

Ironically, a tipping point catastrophe would undercut IIRSA's development objectives by disrupting the rainfall cycle, thereby reducing moisture transport through the South American continent. This would harm agriculture not just in Amazonia but also in Paraguay, Uruguay, Argentina, and possibly even the Mississippi Valley of the US.[14,74,98] Rainfall reductions would lower streamflow, imperiling waterway traffic and electricity generation, thereby wiping out Amazonia's industrial prospects.[10,74] As noted, Brazil's environmental policy regime, which is supposed to prevent this from happening, appears to be weakening and there is no guarantee that its prior successes will be sustained. One key to Amazonian conservation in the 21st century potentially resides in transforming indigenous resistance, such as the Munduruku's into a force that can confront state power, continental trading blocs, and international capital. This would by no means guarantee basin-scale conservation over the long run. But it would be a start (Figure 6).

The Brazilian Constitution of 1988 provides Brazil's indigenous peoples with "inalienable and indisposable" rights to their homelands, including control over water bodies, rivers, and subsoil resources. Unfortunately, it also grants Congress the authority to license mining and hydropower projects on indigenous reserves, which no doubt explains the routine violation of their boundaries by both government and private interests.[63] Thus, although the Constitution of 1988 has extended indigenous rights, contradictions with the statutory regime limit the ability of Amerindians to successfully argue their cases in a court of law, an important first defense against such violations.[99,100] Indigenous resistance such as that articulated by Ipereğ'Ayũ could be stiffened by strength in numbers, but more important is eliminating institutional ambiguities about indigenous rights and legal status. This would yield a strong foundation for the assertion of territorial claims, essential to effective resistance.[101]

Keeping their lands intact at the present time does not mean that the Munduruku, and Amazonia's indigenous peoples more generally, will choose to protect the region's environment over the long run, especially if the Brazilian government provides a judicious sharing of resource and development royalties.[102] This is to say that conservation may not always be in their best interests.[103] But at the present historical juncture, the stop-gap of resistance provides a critical conservation tool that needs buttressing. The SLT victory of today could vanish overnight, particularly with the new administration and the momentum of IIRSA$^+$.[104] Construction of the Belo Monte dam on the Xingu River occurred decades after indigenous peoples and environmentalists stopped initial efforts to build it in 1989. The conservation community has long failed to appreciate the persistence and continuity of South America's infrastructure quest, now visible in the form of IIRSA$^+$.

Our discussion has treated IIRSA$^+$ as comprising a predetermined number of infrastructure projects to be implemented in a set of fixed locations according to a construction schedule. This need not be. From our perspective, an important conceptual step toward sustainability involves rethinking the program as a collection of potential projects that can be assembled into any number of unique infrastructure portfolios, each with its own development outcome and conservation impact. The prospect for sustainable development is then enhanced by any one of these portfolios whose cumulative and synergistic impacts fall short of precipitating a tipping point catastrophe.

Until such time as a viable alternative to cattle ranching is discovered or the public decides to restore the environmental policies now in abeyance, sustainable development remains possible only by scaling back industrialization and agricultural modernization to keep environmental harms within a socially acceptable limit. What this limit might be remains to be seen. Nevertheless, we suggest that a tipping point catastrophe resides far beyond the limit because it would wreck the economy that IIRSA$^+$ is meant to build. If we come to learn that the entire IIRSA$^+$ portfolio is likely to lead to the catastrophic outcome, the quest for sustainability becomes an analytical search for a reduced subset of the full plan that creates jobs, raises income, and lowers export costs without pushing the region to an extreme. Such a combination of projects would not maximize economic benefits. Nor would it conserve all that could be conserved by putting an end to infrastructure investment forever. It would be a middle course, one allowing some measure of development without precipitating its most destructive environmental—and economic—consequences.

The Sustainability Pathway

Not so long ago, the Munduruku inhabited a world they recognized, which was mostly the same world their ancestors knew. Then, everything changed. In just a few decades, Amazonia metamorphosed into a region on the verge of industrial take-off, to use the modernistic term of development planners. The language that has been deployed in this regard is revealing. The Tapajós River is to become the Mississippi of Brazil, and the Amazon and its tributaries, the Great Lakes System of South America.[5,19] (Fearnside, 2019, AAG, conference) Given the momentum of IIRSA$^+$ and the political climate of the times, we should not discount these metaphors as figures of speech. They might well portend the future in the absence of decisive action. A difficulty arises immediately in knowing what action to take. In confronting this difficulty, we make three points.

Imperfect Information. Amazonian conservation efforts are stymied by a lack of information. We do not know if the entire IIRSA$^+$ plan, in combination with climate change, will produce a tipping point catastrophe. This is inherently problematic given that climate models to date do not agree about the deforestation threshold or even the existence of a tipping point. Nor did a decade's worth of research prosecuted under the auspices of the Large-Scale Biosphere-Atmosphere Experiment in Amazonia provide us with all the information we need to make informed decisions about the region's future.[105] Given these informational gaps we advocate as a first step a slow-down in the IIRSA$^+$ project schedule to accommodate a thorough assessment of how infrastructure development will affect the forest. More research is necessary to assess the cumulative and synergistic impacts of the infrastructure program so that the South American governments and public will be better informed about what is at stake. Modeling techniques capable of generating the necessary information are available.[5] Such techniques, although computationally intensive, could be used to assess alternative infrastructure portfolios in the interest of sustainability.

Indigenous Resistance. Indigenous resistance represents a mode of conservation even if this is not the tribal intention in any given case. The fact remains, however, that a politics of direct action has managed to stop the implementation of what is perhaps IIRSA$^+$'s most important infrastructure project, effectively saving the Tapajós River, whose watershed covers ~492,000 km^2, or 7% of the entire basin. But today's victory could become tomorrow's defeat given the hostility of Brazilian President Bolsonaro's government to Amazonia's indigenous peoples. Clearly, the environmental community must find ways to support the Munduruku and other tribal groups intent on defending their homelands. It could be argued that this is a duplicitous conservation strategy, as it presumes that Amazonia's indigenous peoples wish to keep their lands and resources in a natural state in the interest of sustainability. The Brazilian Constitution of 1988 expresses an expectation of environmental stewardship in its language regarding the creation of indigenous reserves. Over the long run, such stewardship may not be in the best interests of the Munduruku or Amazonia's other native peoples. Nevertheless, with a weakening environmental policy regime, indigenous resistance represents an effective conservation force, if only in the short-run.

Social Equity. Indigenous resistance, and conservation more generally, run into conflict with the aspirations of Amazonia's non-indigenous residents. On the order of 24 million of them live in AML, and 35 million throughout the entire basin. That the Amerindians possess ancestral claims is of little import to those who confront a daily struggle for survival. This is not to say that the plight of the majority trumps all considerations, but to point out the legitimate yearnings of those who came to the region seeking opportunity in the latter half of the 20th century. Infrastructure development is needed to create jobs and bring some measure of equity to the many who live in dire poverty. But must it be the entire IIRSA$^+$ portfolio? We suggest that before reaching its final destination, wherever that might be, the sustainability pathway must pass through a scaled back version of the original plan. The conservation community has waited decades for the appearance of sustainable alternatives to predatory resource use and cattle ranching. The wait continues as the environmental policy regime weakens. A green economy will someday be possible, but in the mean time decisions are made, the climate changes, and the Amazonian people long for a better life. It is imperative that a middle course be found, a combination of infrastructure investments that brings economic gain while avoiding the worst-case scenario of a tipping point transgression. In Amazonia, ecological and economic catastrophe are two sides of the same coin.

SUPPLEMENTAL INFORMATION

Supplemental Information can be found online at https://doi.org/10.1016/j.oneear.2019.09.009.

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