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COMMENTARY

Science in support of Amazonian conservation in the 21st century: the case of Brazil

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ABSTRACT

This article presents a 21st Century agenda for Amazonian conservation. The agenda calls for developing a *system of refugia* and a scientific methodology for predicting impacts of the infrastructure development vision for the region. It also calls for a collaborative approach to conservation planning, in the interest of fruitful engagement with decision-makers and stakeholders. The ideas explored here emerged from the collaboration of peers over a decade, which culminated in a panel presentation, *Scientific Analysis, and Simulation Models to Support Conservation and Development Decision-Making*, at the Tools and Strategies Workshop held at the University of Florida in October, 2017.

Abstract in Portuguese is available with online material.

Key words: Amazon Basin; biodiversity conservation; climate change; deforestation; economic globalization; industrialization and agricultural development; Initiative to Integrate the Regional Infrastructure of South America (IIRSA).

CURRENT EFFORTS TO DEVELOP AMAZONIA WITH LARGE-SCALE INFRASTRUCTURE PROJECTS HAVE REKINDLED PUBLIC INTEREST IN THE LONG-TERM STATUS OF THE REGION'S FORESTED BIOME. A key concern is the program of infrastructure development being undertaken by the South American nations. Recent declines in rates of deforestation have raised some hope that the Amazonian nations will be able to ensure the long-run integrity of the region's ecosystems (Nepstad *et al.* 2014). However, new infrastructure plans could reverse these promising trends (Killeen 2007, Laurance 2007, da Silva Soito & Freitas 2011, Walker & Simmons 2018). In addition, land clearing for agricultural development may soon be overshadowed by forest die-backs associated with global climate change (Davidson *et al.* 2012, Jiménez-Muñoz *et al.* 2016). Infrastructure development will bring economic opportunity to the residents of Amazonia, but the growth it stimulates will lead to environmental impacts.

In this article, we outline a conservation agenda capable of avoiding the massive environmental degradation often associated with new infrastructure in Amazonia, defined here as the entire basin. Our agenda comprises two analyses and an outreach program. The first analysis involves the design of a *system of refugia*

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capable of maintaining Amazonian biodiversity in the face of changing environmental conditions. The second analysis identifies infrastructure portfolios that promote sustainable development by maintaining the *system of refugia* designed in the first analysis. The outreach program engages decision-makers and stakeholders to translate analytical findings into policy action targeted at Amazonian conservation. Much of the article focuses on Brazil, given the extent of the Brazilian Amazon and the magnitude of environmental and economic change occurring there over the past several decades. Nevertheless, we find occasion to scale our discussion to more general considerations of Amazonia as a continental region. This is because the infrastructure program now underway involves a multi-national design in which Amazonia is key to continental integration. It is therefore not possible to address 21st century conservation in Brazilian Amazonia without a broad perspective.

THREATS TO CONSERVATION IN THE 21ST CENTURY

Amazonia is no stranger to infrastructure investment. For example, the building of roads and dams under Brazil's military regime (1964–1985) opened the region to colonization and development (Walker *et al.* 2009a). The current infrastructure plan represents a quantum leap in investment scale and development vision, one involving not just Brazil but all of South America. It seeks to industrialize the economies of the Amazonian nations (Brazil, Bolivia, Colombia, Ecuador, French Guiana, Guyana, Peru, Suriname, and Venezuela) and to dramatically expand the region's engagement in global commodity markets, during a time when climate change will intensify across the region (Laurance 2007). Here, we consider the implications of this development vision for the forest biome. At the outset, we note that environmental change is presently underway in parts of Brazilian Amazonia (Davidson *et al.* 2012). We focus on environmental change precipitated by infrastructure in this article due to the magnitude of the investment program now targeting the region.

THE DEVELOPMENT VISION AND IIRSA.—As indicated, the infrastructure program is a continental effort involving South America's twelve nations working together on an integrated development blueprint. This program comprises both: (1) the *Initiative to Integrate the Regional Infrastructure of South America* (IIRSA), adopted in 2000 and later managed by the Council of Infrastructure and Planning (COSIPLAN) of the United Nations of South America (UNASUR); and (2) projects undertaken independently by the individual South American nations but in coordination with IIRSA. Although Argentina, Brazil, Chile, Colombia, Paraguay, and Peru recently suspended UNASUR membership for a year over political disagreements, the IIRSA vision continues. In fact, most projects are national in scope and involve these six countries (Burges 2018).

National banks and treasuries have played a premier role in project financing, notably Brazil's National Development Bank (BNDES). Regional institutions contributing to the overall effort include the Inter-American Development Bank (IDB), the Development Bank of Latin America (CAF), and the Financial Fund for the Development of the Rio de la Plata Basin (FONPLATA). Extra-regional funding derives from institutions such as the World Bank, the China Development Bank (CDB), the Japan Bank for International Cooperation (JBIC), Kreditanstalt für Wiederaufbau (KfW), the Nordic Investment Bank (NIB), Agence Française de Développement (AFD), the Swedish Export Credit Corporation (SEK), and the Official Credit Institute (ICO; Frischtak *et al.* 2016). Development partners include Brazil's four largest construction companies (*e.g.*, Andrade Gutierrez, Camargo Corrêa, Odebrecht, Queiroz Galvão) and regional utilities (*e.g.*, Eletrobras), as well as corporate investors from overseas such as Bunge and Cargill from the USA, Louis Dreyfus Commodities from France, and China's Cianport (Monde *et al.* 2010, Aguiar 2017).

A key IIRSA objective is the transformation of Amazonia into a transportation hub, connecting the Atlantic and Pacific Oceans, as well as the Amazonian region with the rest of South America. This will be accomplished by the implementation of a logistical system of navigable waterways (20,000 km), a system of ports, a transcontinental railway with over 15,000 km of new tracks, and improvements to ~2 million km of roads (COSIPLAN n.d). The overall infrastructure program also includes hydropower projects undertaken by the individual South American nations sharing the basin. So far, 177 plants have been built (or are under construction), 241 planned, and 220 inventoried (International Rivers n.d.). The build-up in hydropower will make the region attractive to electricity-intensive industries across a wide range of goods including steel castings, aluminum sidings, basic chemicals, synthetic fibers, glass products, consumer electronics, and automobiles (Michielsen 2013). In addition to federal projects, state, and local governments are participating with their own complementary infrastructure initiatives.

The full extent of Amazonia's infrastructure program is obscured by its jurisdictional complexity and is not limited to IIRSA. In the case of Brazil, this is illustrated by Figure 1 showing IIRSA, federal, state, and municipal projects for the Tapajós River Valley (TRV). Brazil's national energy plan includes the Tapajós Hydroelectric Complex, with five dams projected to generate ~12,000 megawatts. The locks and reservoirs for three of them are also components of the Teles Pires-Tapajos waterway, outlined in COSIPLAN for IIRSA (São Luiz de Tapajós – Fig. 1A; Jatobá – Fig. 1B; Chacorão – Fig. 1C). Enhanced navigability will cost ~US $1.6 billion, with 300 km of rock demolition, dredging, and chanelization (Ministerio dos Transportes, Portos, e Aviação Civil 2013). Reservoirs will occupy another 380 km, directly impacting Munduruku tribal territories. Brazil will complement the IIRSA waterway by building five new ports, including a major transshipment facility at Cachoeira Rasteira (Fig. 1D), involving private investments of ~US$224 million, and a municipal level road project to connect it with state road MT 206 (at Apiacás) and an upgraded federal highway system (Fig. 1E). In addition, TRV infrastructure will ultimately include road improvements (BR-163; Fig. 1F) and a 600-mile railway (Fig. 1G) as part of the IIRSA portfolio, privately funded silos and wharfs near Itaituba, and a ~1,000 km rail line from Itaituba to Cuiabá, a project initiated by Pará State (Fig. 1H).

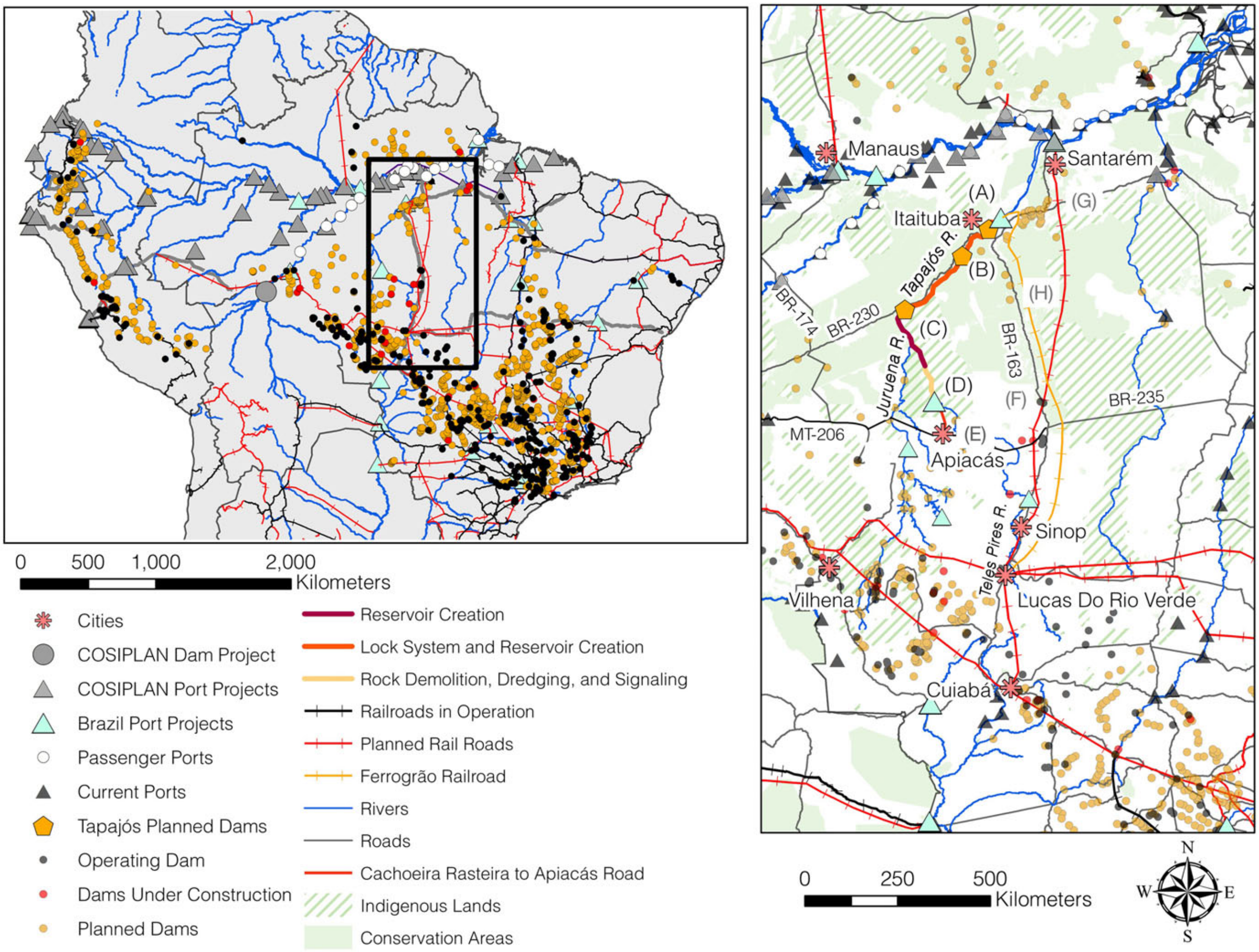

FIGURE 1. Blueprint of infrastructure projects for the Tapajós River Valley.

IMPLICATIONS FOR THE AMAZON FOREST BIOME.—Fully implemented, IIRSA and the independent projects will open Amazonia to a new array of global drivers that will stimulate deforestation directly via food demands of a growing urban workforce, and indirectly as expanding soybean production displaces old pasture further into forest frontiers (Laurance 2007, Arima *et al.* 2011). The extent of potential deforestation is massive, perhaps sufficient to precipitate a shift from forest to savanna due to declines in rainfall recycling (Lovejoy & Nobre 2018). Such a shift would be reinforced by external climate forcing that is projected to stress the forests of the lower and central basins (Hirota *et al.* 2011, Xu *et al.* 2016).

ANALYTICAL ACTIVITY 1: DESIGNING THE SYSTEM OF REFUGIA

Given the intensification of threats to Amazonia, a question arises as to whether current policies are adequate for successful conservation across the entire basin. Of concern are conservation policies based on *protected areas* (PAs), which to date have functioned as repositories of biodiversity, undisturbed ecosystems, and carbon (Soares-Filho *et al.* 2010). In Brazil, PAs are organized into the National System of Conservation Units (SNUC), including both (1) Integral Protection Units for biodiversity protection; and (2) Sustainable Use Units for use by traditional communities (Moore et al. 2007, Walker *et al.* 2009c). In general, biodiversity protection represents SNUC's primary objective, as indicated by Article 4 of Federal Law 9985/2000. That said, PAs tend to conserve ecosystems and their services. Together with indigenous reserves, Brazil's Amazonian PAs cover ~2.3 million km^2 or ~43 percent of the so-called Legal Amazon. Unfortunately, projections of future hydro-climatological conditions suggest that external climate forcing will significantly disturb a number of PAs, both in Brazil and in other Amazonian countries (Salazar *et al.* 2007, Lewis *et al.* 2011, Zemp *et al.* 2017).

Our conservation agenda calls for adapting all of Amazonia's PAs into a *system of refugia* (SR) enabling species mobility at local and regional scales (Hannah 2008, Walker *et al.* 2016). Conceptually, the SR integrates the identification of connected thermal corridors (McGuire *et al.* 2016) and 'cool' environments that can serve as refugia in the face of climate change (Shoo *et al.* 2011). It also accommodates the dynamics of land-cover change, which can limit the number of corridors and refugia that remain viable over time. As stated, the SR complements two existing Brazilian initiatives aimed at protecting biodiversity via the connection of conservation units by corridors. First, it complements Brazil's Ecological Corridors Project (Ministério do Meio Ambeinte [Ministry of the Environment - MMA] n.d.) by integrating PAs and dispersal pathways into a configuration that maximizes conservation by exploiting spatial variations in transpiration potential, which contributes to forest stability (Staal *et al.* 2018). Second, it also complements the Central Amazon Conservation Complex by contemplating a conservation design for the entire basin, not just the State of Amazonas (UNESCO World Heritage Centre n.d.). Although these two initiatives and Brazil's SNUC emphasize biodiversity protection, the SR we envision seeks conservation outcomes along multiple dimensions of diversity, spanning species, ecosystems, and ecosystem services.

An Amazonian SR consistent with our agenda has yet to be defined. Doing so would require identifying future useable habitats, as well as corridors offering pathways of least resistance (*e.g.*, Jantz *et al.* 2014). We define 'useable' habitat as an area or areas with environmental conditions capable of supporting the presence of a given species or assemblage, considering current land cover and climate, as well as potential future hydro-climatological disturbances. Monitoring of current environmental conditions coupled with future projections will help identify useable habitats that comprise the SR. Although this has not been done for the Amazon Basin, it is possible to outline a procedure. Specifically, presence-absence data can be collected and used to develop spatially explicit species distribution models (Boyce *et al.* 2002, Phillips *et al.* 2006, Phillips & Dudík 2008). Factors important to the identification of useable habitat at the basin-scale might include tree height, which provides thermal buffering of hot climates (Scheffers *et al.* 2014), as well as drought resistance (Giardina *et al.* 2018).

Regional Climate, land change, and hydrology models can be used to predict how environmental variables change. These predictions, together with information on permanent features such as topography, can then inform species models to find new useable habitats. With placement on a map and appropriate GIS software, the new usable habitats can reveal dispersal routes, thereby identifying corridors within and between current PAs. Presence-absence data might be obtained from such sources as IUCN 2017, Buckup *et al.* 2011, and Camargo *et al.* 2004. Other relevant variables can be drawn from existing datasets on rainfall and transpiration (Staal *et al.* 2018), and from land-use and land-cover maps (Hansen *et al.* 2013).

The SR as conceptualized represents a policy instrument dedicated to the conservation of Amazonian forests and ecosystem services across all the Amazonian countries. This leaves an important question about human populations residing in indigenous reserves, *quilombos*, and other traditional communities. The SR will likely depend on indigenous reserves and sustainable use areas, which are important PAs. As they are threatened, government assistance will be needed to facilitate mobility and identify new areas of habitation. We recognize the importance of accommodating human populations under stress, but considering policy responses lies beyond the scope of this paper (de Sherbinin *et al.* 2011). Some lands critical to the SR will probably reside in private hands; in the Brazilian case, applications of the Forest Code—which protects forests on private properties—may prove useful in organizing landscapes into dispersal corridors (Laurance 2007, Soares-Filho *et al.* 2010, Arima *et al.* 2013, Simmons *et al.* 2016). New PAs might also be needed, with appropriate compensation offered to individuals and communities thereby affected. Innovations in transportation infrastructure (*e.g.*, raised highways) might also enhance species mobility (Lovejoy & Nobre 2018).

ANALYTICAL ACTIVITY 2: IDENTIFYING SUSTAINABLE INFRASTRUCTURE PORTFOLIOS

The SR functions as a conservation tool only if environmental threats are sufficiently mitigated. For Amazonia, a key mitigation opportunity resides in managing the scale of infrastructure investment and associated impacts on regional climate, hydrology, and land cover. Infrastructure investments are responsive to short-term policy concerns, whereas the external forcing of Amazonia's climate (driven by global climate change) is locked in for the next several decades, despite the United Nations Framework Convention on Climate Change, following the Paris Accord (http://unfccc.int/paris_agreement/items/9485.php). Although we focus on a basin-scale conservation objective, it is important to note that local communities can act to mitigate the impacts of external climate forcing on their well-being (Adger *et al.* 2003, Keenan 2015, Ruiz-Mallén *et al.* 2017).

Infrastructure sets in motion the economic processes that underlie deforestation. But these same economic processes enhance the welfare of Amazonia's resident population by creating jobs, raising incomes, and improving education (VanWey *et al.* 2013). The key to balancing development and conservation is to identify portfolios—defined by combinations of projects (roads, waterways, dams, etc.) selected from the entire suite of potential investments—that do not stimulate a development outcome compromising the SR. This comprises the second analytical activity of our conservation agenda.

ENVIRONMENTAL IMPACT ASSESSMENT.—Governments predict impacts of public works by conducting environmental impact assessments (EIAs). As currently practiced, EIAs are incapable of assessing threats to the SR. For hydropower projects, analysis is typically limited to one or a small group of related projects, and to a sub-basin watershed (Santos & Hernandez 2009, Fearnside 2016, Millikan 2016). Such restrictions blind EIAs to spillovers across watersheds, and to synergies arising from multiple infrastructure types and projects. Moreover, EIA time horizons are too short to capture the full range of ecological disturbances. For reasons such as these, EIAs to date have failed to provide information on impacts arising from the dynamic implementation of basin-scale infrastructure (Santos & Hernandez 2009, Fearnside 2016, Millikan 2016). Thus, our second activity calls for an integrated modeling approach that is capable of providing this information in a timely and spatially explicit manner.

AMAZONIAN RESEARCH AND MODELING.—A substantial body of scientific research addresses how transportation infrastructure and agricultural development impact Amazonian forests (*e.g.*, Fearnside 1987; Pfaff 1999, Laurance *et al.* 2001, Fearnside 2005) and how derivative disturbances alter streamflow, cause biomass collapse, lower biodiversity (Fearnside 1989, 1995, 2001, 2002, Coe *et al.* 2011, Hayhoe *et al.* 2011), and degrade environmental services (Ferreira & Laurance 1997, Aldrich & Hamrick 1998, Cochrane & Laurance 2002, Davidson *et al.* 2012). Researchers have argued that deforestation contributes to global warming through greenhouse gas emissions and precipitates transcontinental teleconnections (Fearnside 2002, Avissar & Werth 2005). They have also shown that Amazonia can assume both wet and dry climate equilibria (Avissar *et al.* 2002, Oyama & Nobre 2003). Strong feedbacks link deforestation, forest fragmentation, fire regimes, and regional climate – all of which are likely to be exacerbated by global warming (Serrão *et al.* 1996, Laurance & Williamson 2001, Nepstad *et al.* 2008, Coe *et al.* 2013, Brando *et al.* 2014). Research has paid specific attention to hydropower infrastructure. Greenhouse gas emissions and impacts on local human populations have been addressed, as has the effect of deforestation on hydropower generation (Fearnside 1995, 2002, 2013, Stickler *et al.* 2013).

Researchers have also implemented models that project deforestation associated with alternative governance regimes, population growth, specific infrastructure programs, and global climate change (Laurance *et al.* 2001, Soares-Filho *et al.* 2004, 2006, Salazar *et al.* 2007, Fleck 2009). Although the methodologies employed have produced useful results, they do not provide all the information needed to evaluate infrastructure impacts on the SR for five reasons. First, they do not provide information on multiple infrastructure scenarios that can be assessed comparatively—a necessary prerequisite for choosing projects that minimize SR impacts. Second, they do not assess the cumulative and synergistic effects arising from multiple infrastructure projects and types (Fearnside 2016). Third, they do not consider how growth-induced deforestation—together with global climate change—affect regional hydro-climatology via breakdowns in rainfall recycling (Eltahir & Bras 1994, Laurance & Williamson 2001). Fourth, they do not model feedbacks on Amazonia's human system from natural disturbances caused by external forcing and infrastructure-induced development. Fifth, they do not accommodate the inherent uncertainty affecting climate and economic systems. All of these shortcomings must be rectified to provide information about the future needed to make good decisions today.

PROJECTING INFRASTRUCTURE IMPACTS.—The second analytical task of our conservation agenda involves the development of a methodology that overcomes these limitations. We suggest that this can be achieved by building a virtual representation that couples Amazonia's natural and human systems with an ensemble of economics, land change science, hydrology, climatology, and agronomy models. Such an ensemble can be designed to anticipate the environmental and socio-economic impacts of an infrastructure portfolio by tracing their pathways through the component systems. This is feasible through computational iteration, whereby the ensemble simulates future disturbances to the natural and human system (whether from infrastructure or external climate forcing) that are summarized as output variables of interest to decision-makers for a specific planning horizon (*e.g.*, annual precipitation, agricultural productivity).

Following is a brief description of how such simulations might unfold. In the initial time period, an econometric model predicts how infrastructure (hydropower generation, transportation) stimulates economic and population growth in addition to the demand for land (*e.g.*, Pfaff *et al.* 2007). A statistical land change model then uses information on the demand for land to generate basin-scale land cover maps (Moore *et al.* 2007). The maps are inputs to hydrology and regional climate models, producing streamflow for large Amazonian rivers and spatially distributed precipitation (Moore *et al.* 2007, Coe *et al.* 2008). Changes in streamflow affect hydropower generation, a variable in the econometric model (Stickler *et al.* 2013). Changes in precipitation affect agriculture, with impacts potentially captured by a spatially explicit crop model (Woli *et al.* 2013). The econometric model generates economic impacts to a specified planning horizon (*e.g.*, 2030; 2050), with site-specific infrastructure investments occurring over time. Projected economic and population data feed the land change model, so that inputs to the hydro-climatology are dynamic, as are feedbacks on the human system from reduced productivity and hydropower resulting from rainfall reduction. Global climate change can be accounted for by external forcing on the regional climate model (Moore et al. 2007, Walker *et al.* 2009c).

Figure 2 shows how the SR and such hypothetical projection outputs might be combined to produce conservation information. The figure provides a visualization of system effects out to 2050. Only one response variable is depicted, precipitation. The upper panel (2A) shows a 'tipping point' risk region resulting from heavy infrastructure investment and external forcing; the SR experiences high tipping point risk, with the potential for a new, lower-biomass vegetation equilibrium (Serrão *et al.* 1996, Laurance & Williamson 2001, Nepstad *et al.* 2008, Nobre & Borma 2009). The lower panel (2B) reflects a sustainable portfolio; the SR remains intact with corridors (depicted by arrows) providing for species mobility as climatic conditions change.

SCIENCE OUTREACH AND TRANSLATION FOR CONSERVATION

We have illustrated an analytical process for producing some of the science needed for conservation in the 21st Century. Little is gained if the information remains restricted to the scientific community. It needs to be made available to all stakeholders including

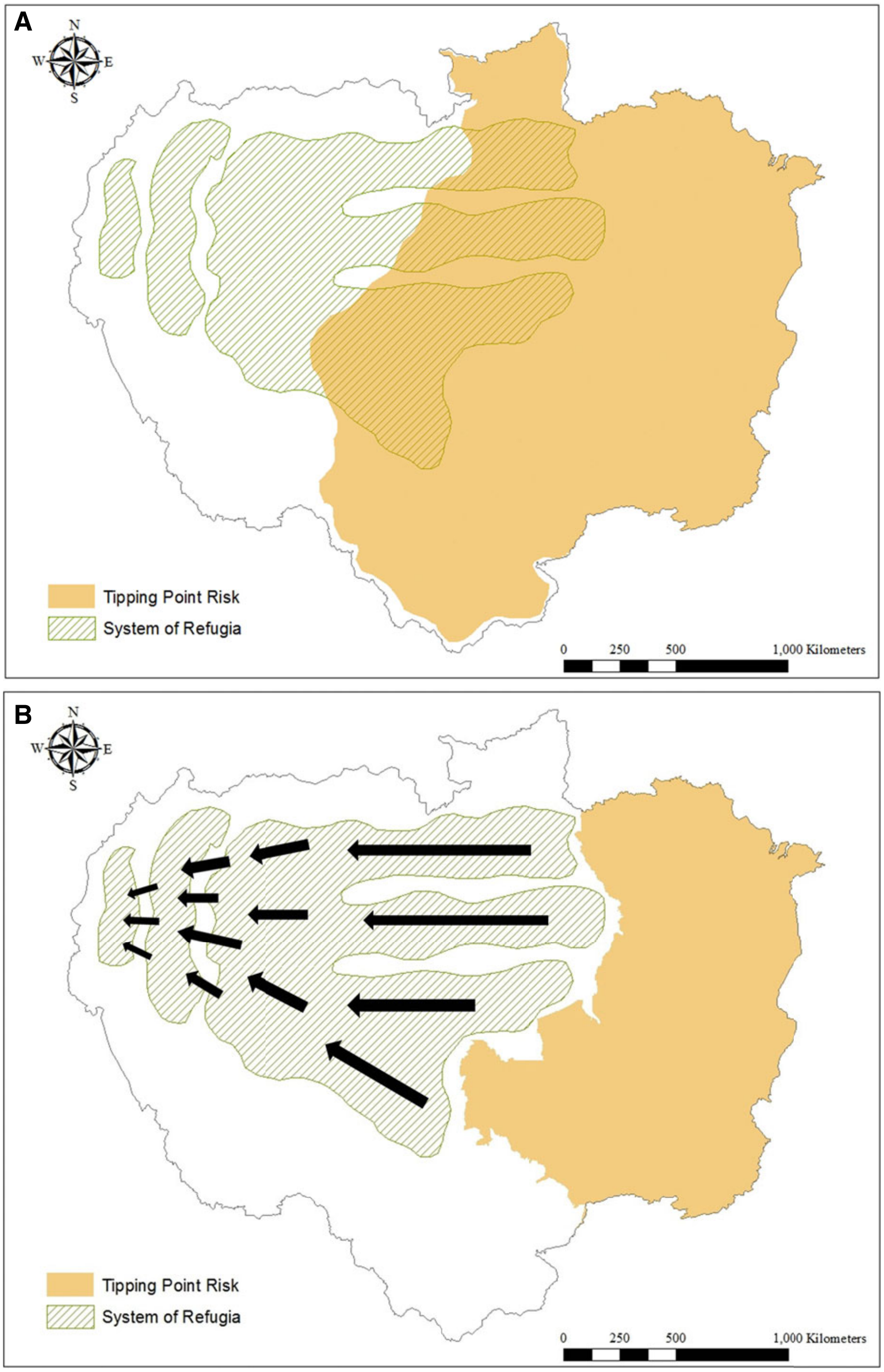

FIGURE 2. Amazonia's system of refugia. (A) Full infrastructure portfolio, 2050; (B) Sustainable infrastructure portfolio, 2050. Note: These panels illustrate a hypothetical visualization product; they are figurative and do not portray actual results. Only one impact is depicted, rainfall reductions that pose a significant tipping point risk (TPR), with high probability for conversions of tropical forest to savanna. The upper panel (A) shows the TPR area resulting from heavy infrastructure investment; here, the SR experiences high TPR with grave consequences for biodiversity due to diminished precipitation. The lower panel (B) is the sustainable portfolio case; the SR remains intact with corridors (depicted by the arrows) providing safe movement of species as climatic conditions change.

consortia of national planners (*e.g.*, COSIPLAN), governments (national, state, and local), financial interests (*e.g.*, IDB, BNDES, World Bank), corporations (*e.g.*, Andrade Gutierrez, Camargo Corrêa, Odebrecht), and local communities. Collaboration by an international science team is essential. Further, a 'boundary organization' should be created to facilitate communication; such a group should comprise a diversity of individuals, organizations, and stakeholders (Guston 2001). The article has focused primarily on Amazonian conservation and large-scale infrastructure development as a policy lever and driver of change. Local Amazonian communities will be affected by both infrastructure and global climate change, however. Declines in precipitation and streamflow will disrupt livelihoods in places and bring human misery. Conservation science has an obligation to create information germane not only to environmental concerns but also to individuals who will find it necessary to adapt to regional climate changes and mitigate derivative impacts on their well-being.

CONCLUSION

Infrastructure investments reflect a deliberate decision-making process subject to policy intervention. To date, decision-makers have lacked the information needed to 'choose' the best infrastructure portfolio for those who call Amazonia home, as well as the people of South America who desire continental integration and growth. One way to do this is with a projection methodology. Projection enables stakeholders to play a 'what if' game and visualize the outcomes of possible futures. For the case of Brazil, for example, what if the projected outcome of a particular infrastructure portfolio is the collapse of Mato Grosso's agricultural economy due to reduced precipitation and streamflow? This would probably stimulate the search for an alternative portfolio. Projection provides a picture of the future that can be used to inform infrastructure investments today, given likely intensities of external climate forcing. Combined with the SR, it would help identify a pathway to sustainability in Amazonia.

With IIRSA, the South American nations envision a breathtaking transformation of Amazonia into an economic powerhouse. This would raise incomes and spark population growth. However, development on a grand scale presents a challenge to Amazonian conservation, especially given the ecosystem stresses that will come with global climate change. The question we must all ask is this: Will the full IIRSA program—in coordination with the independent projects of the Amazonian nations—irrevocably degrade Amazonia's forest biome? If the answer is yes, then we must work together to find a way to make development choices without squandering a continental treasure of ecological resources and wild, tropical terrain. The conservation agenda we have outlined provides a pathway to address this question directly.

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