UNIVERSIDADE FEDERAL DE MINAS GERAIS`

Instituto de Geociências

Programa de Pós-graduação em Análise e Modelagem de Sistemas Ambientais

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(UN)SUSTAINABLE POLICY PARADIGM: Using Modeling to Address the Contradictory Faults of Brazil's Transportation Infrastructure – Socioenvironmental Conservation Nexus

Belo Horizonte

2019

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Versão Final

Dissertação apresentada ao Programa de Pós-Graduação em Análise e Modelagem de Sistemas Ambientais da Universidade Federal de Minas Gerais como requisito parcial para obtenção do título de Mestre em Análise e Modelagem de Sistemas Ambientais

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Belo Horizonte
2019

T613u 2019

Tisler, Trevor Ray.

(Un)sustainable policy paradigm [manuscrito] : using modeling to address the contradictory faults of Brazil’s transportation infrastructure – socioenvironmental conservation nexus / Trevor Ray Tisler. – 2019.

xviii, 209 f., enc.: il. (principalmente color.)

Orientador: Rodrigo Affonso de Albuquerque Nóbrega.

Coorientadora: Fernanda Zimmermann Teixeira.

Coorientadora: Sónia Maria Carvalho Ribeiro.

Dissertação (mestrado) – Universidade Federal de Minas Gerais, Departamento de Cartografia, 2019.

Inclui bibliografia.

Inclui anexos.

1. Modelagem de dados – Aspectos ambientais – Teses. 2. Política ambiental – Brasil – Teses. 3. Impacto ambiental – Transporte – Teses. 4. Desenvolvimento sustentável – Teses. 5. Sistemas de informação geográfica – Teses. I. Nóbrega, Rodrigo Affonso de Albuquerque. II. Teixeira, Fernanda Zimmermann. III. Carvalho-Ribeiro Sónia Maria. IV. Universidade Federal de Minas Gerais. Departamento de Cartografia. V. Título.

CDU: 911.2:519.6(81)

Ficha catalográfica elaborada por Graciane A. de Paula – CRB6 3404

FOLHA DE APROVAÇÃO

(Un)Sustainable Policy Paradigm: Using Modeling to Address the Contradictory Faults of Brazil's Transportation Infrastructure – Socioenvironmental Conservation Nexus

TREVOR RAY TISLER

Dissertação submetida à Banca Examinadora designada pelo Colegiado do Programa de Pós-Graduação em ANÁLISE E MODELAGEM DE SISTEMAS AMBIENTAIS, como requisito para obtenção do grau de Mestre em ANÁLISE E MODELAGEM DE SISTEMAS AMBIENTAIS, área de concentração ANÁLISE E MODELAGEM DE SISTEMAS AMBIENTAIS.

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Belo Horizonte, 10 de maio de 2019.

	UNIVERSIDADE FEDERAL DE MINAS GERAIS **Environmental Systems Analysis and Modeling Graduate Program**	

Approval

(Un)Sustainable Policy Paradigm: Using Modeling to Address the Contradictory Faults of Brazil's Transportation Infrastructure – Socioenvironmental Conservation Nexus

TREVOR RAY TISLER

Master's thesis submitted to the examination board designated by the governing council of Environmental Systems Analysis and Modeling Graduate Program, as a requisite for obtaining the title of Master of Science (MSc) in Environmental Systems Analysis and Modeling, with a concentration in Environmental Systems Analysis and Modeling.

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Belo Horizonte, May 10th, 2019

To future generations, so that you too may have a prosperous life and enjoy an ecologically balanced environment on this wonderful planet we call home.

Words of Gratitude

First and foremost, I would like to thank the people of Brazil for maintaining a free, open and inclusive federal university system and for allowing me, a foreigner, to take part in it. I would like to thank the UFMG community, to all those who make this place such a wonderful institution and feel like a second home. I would like to thank CAPES (*Coordenação de Aperfeiçoamento de Pessoal de Nível Superior*) for the financial support for the past two years through means of a scholarship which allowed me to fully dedicate to my studies.

To Mário Sérgio, for being my emotional support and rock, for giving words of encouragement and council, for cooking me dinner and making sure I ate it, for making me go to bed and preventing me from suffering from sleep deprivation, for keeping your cool when I was going crazy and stressed. Most importantly, thank you for always being there and giving me your love.

To my parents, Nancy and Andy. Thank you for instilling in me a sense of adventure and curiosity. For teaching me to work hard and always be tenacious. For allowing me to travel my own path, but always making sure that it was smooth journey.To my Brazilian family, thank you for your support, your acceptance, your love and your care. Angelica, thank you for being my second mom, Marco Antônio and Marcus Vinicius thank you for being 'big' brothers, Deborá and Uyara thank you for being fun and kind sisters. Mario Montoya, thank you for always giving council and advice, but most importantly thank you for the cold beer!

To my advisers. To Prof. Dr. Rodrigo A. A. Nóbrega, for seeing something in me and having confidence in me. For being willing to invest your time to help me succeed. And a serious thank you for sending me on the coolest road trip in the middle of the Amazon that I will ever have in my life! To Dr. Fernanda Z. Teixeira, words cannot express my gratitude. Thank you for reading, commenting, giving input, and reading again and again and again. Thank you for being a friend, for good conversation over a glass of beer, for encouraging me to pursue an idea, and for telling me I needed to sleep! To Prof. Dr. Sónia M. Carvalho-Ribeiro, for meeting with me to discuss ecosystem services and then allowing the conversation to move into various other areas and then having faith in me and my ideas.

The defense panel, Drs. Britaldo Soares-Filho, Raoni Rajão, and Francisco Vilella for agreeing to participate and read this thesis. An additional thank you is owed to Dr. André Naime for participating on my qualification panel and offering constructive feedback and advice.

To Prof. Dr. Aline S. Magalhães, thank for your wonderful environmental economics classes and for helping to make obscure economic concepts easier to understand.

To Kelly, thank you for becoming my unofficial adviser in the area of Brazilian law. For allowing me to go crazy and then us being crazy together! Also, thank you for the spontaneity and açaí! Coisa linda da tia!

To my PPG-AMSA colleagues. I could not have survived these past two years without your friendship. Studying in the salinha was the best with you guys! To Nina, Luciana, Luiza, Erika, Max, Rubem, Marcilla, Marlon, Mariana, Carolina, Daniel, Fernanda, Miluska, and Nunes. You guys are family now!

Finally, to Cora and Pâmela, thank you for being the most helpful secretaries and helping me navigate Brazilian bureaucracy! To Joana, thank you for helping to keep the study room clean, the laboratory in spick and span condition, and for lovely morning chats!

“We are just an advanced breed of monkeys on a minor planet of a very average star. But we can understand the Universe. That makes us something very special.”
Stephen Hawking

For the want of a nail, the shoe was lost; for the want of a shoe, the horse was lost; for the want of a horse, the message was lost; for the want of a message, the battle was lost; for the want of a battle, the kingdom was lost.
An old proverb

Abstract

In the quest for economic development Brazil's transportation infrastructure and socioenvironmental policies have become contradictory forces. The literature indicates that Brazil's socioenvironmental policies, protections, values and international commitments are commonly ignored or left out of the federal transportation planning process. On the ground legal and social conflict commonly only come to light at the environmental licensing and project implementation stages for large federally backed infrastructure projects. Yet, at least theoretically, large-scale impacts should have already been anticipated, considered, planned for and legally mitigated well before reaching these final stages of infrastructure development. However, this is rarely the case. In order to overcome this problem, and while focusing on transportation development, Brazil's infrastructure and socioenvironmental governance and policymaking processes were analyzed in an effort to investigate, where, why, and how their considerations fall through the cracks during infrastructure planning and if this can be corrected. The analysis identified entry points where key independent federal institutions and civil society actors could combine legally and scientifically backed spatially explicit models with legal and social pressure to potentially force socioenvironmental issues back into the planning process. As a result, this study aims to offer a toolset of spatially explicit models to allow for this to happen.

The methodological approach focuses on principal biodiversity conservation policy, international environmental commitments, and federal transportation planning in Brazil. Moreover, conservation opportunities were spatially modeled and identified as either needing mitigation or as needing to be geographically excluded from existing or future development of transportation infrastructure. This was done by combining a variety of key spatial environmental and legal variables which included: legally protected areas, remaining native vegetation, as well as considering the Brazilian Ministry of Environment's (MMA's) Priority Areas for Biodiversity Conservation (PABCs). Additionally, Brazil's Roadless and Railroad-less (RLRL) areas were modeled at distances of 1 and 5 kilometers away from all documented existing roads and railroads. Advanced GIS tools and massive official public available dataset were used to build the geographic-explicit model. The results indicate that Brazil's 1km and 5km RLRLs account for approximately 71.3% and 39.2% of the country's continental territory respectively. Moreover, 25.5% of MMA's PABCs overlap with 1km RLRLs (accounting for 18.2% of Brazil's continental territory) and 19.3% of MMA's PABCs overlap with 5km RLRLs (accounting for 7.5% of Brazil's continental territory). However, significant portions of Brazil's planned federal highway and railroad projects would impact these areas if built.

As Practical implications, these results show that if Brazil makes alternative infrastructure development plans and takes advantage of the ample conservation opportunities the country could potentially avoid conflict in infrastructure development and make significant progress in fulfilling its international commitments to the Convention on Biological Diversity and the United Nations Framework Convention on Climate Change Paris Agreement. Additionally, while focusing on Brazil's greatest environmental asset, the Amazon rainforest, the country's remaining Amazonian old growth forest and its carbon stock were calculated using a wide range of available spatially explicit data. Once tabulated, the Amazon's carbon stock estimates were novelly combined with two economic concepts to calculate the Social Cost of Carbon of the Brazilian Amazon's forest at a biome-wide and per hectare level. Moreover, this technique considers the damaging economic impacts that a possible ecosystem-tipping point would have on climate change from resulting high levels of greenhouse gas emissions, which are estimated to equate to $ 4.6 trillion to $243.1 trillion USD.

This thesis is original and logically involves key concepts of socioenvironmental analysis and transport planning, integrated into spatially explicit models in a geographic information system. Moreover, this thesis meets the standards set by the CAPES Committee on Environmental Sciences by promoting research and the social relevance of research in regions with a high index of social vulnerability, environmental vulnerability, and geographical isolation.

Key Words: Environmental Governance, Transportation's Environmental Impact, Roadless Areas, Ecosystem Services, Social Cost of Carbon, SCC, Deforestation, Economic Valuation

Resumo

No caminho por desenvolvimento econômico, a infraestrutura de transportes e as políticas socioambientais do Brasil tornaram-se forças contraditórias. A literatura indica que as políticas, proteções, valores e compromissos-internacionais socioambientais do Brasil estão regulamente ignorados ou deixados de fora do processo de planejamento do transporte federal. No terreno, os conflitos legais e sociais somente ficam reconhecidos para grandes projetos de infraestrutura apoiados pelo governo federal nas fases de licenciamento ambiental e implementação de projetos. No entanto, pelo menos teoricamente, os impactos socioambientais em grande escala já deveriam ter sido antecipados, considerados e legalmente mitigados bem antes de chegar esses estágios finais de desenvolvimento de infraestrutura. Contudo, isso raramente é o caso. De forma a solucionar tal problema, e com foco no desenvolvimento de transportes, os processos de governança e formulação de políticas públicas infraestruturais e socioambientais do Brasil foram analisados em um esforço para investigar onde, por que e como as considerações socioambientais caem pelas rachaduras durante o planejamento da infraestrutura e se isso pode ser corrigido. Esta análise identificou pontos de entrada onde instituições independentes federais e atores da sociedade civil poderiam combinar modelos espacialmente explícitos, que são legalmente e cientificamente apoiados, com pressão legal e social para tentar forçar as questões socioambientais a retornarem ao processo de planejamento. Como resultado, este estudo visa oferecer um conjunto de ferramentas de modelos espacialmente explícitos para permitir que isso aconteça.

A proposta metodológica do trabalho foca nas principais políticas públicas de conservação da biodiversidade, compromissos internacionais sobre o meio-ambiente e planejamento federal do transporte no Brasil, oportunidades de conservação foram modeladas e identificadas espacialmente como necessitando de mitigação ou como necessitando serem geograficamente excluídas de qualquer desenvolvimento de infraestrutura de transporte atual ou futuro. Isso foi feito pela combinação de uma variedade de variáveis chaves espaciais, ambos ambientais e legais, que incluíam: áreas com proteção legal federal, vegetação nativa remanescente, a com a consideração das Áreas Prioritárias para Conservação da Biodiversidade (PABCs) do Ministério do Meio Ambiente (MMA), e a modelagem de áreas sem estradas e ferrovias (RLRLs) a distâncias de 1 e 5 quilômetros de todas as estradas e ferrovias existentes e documentadas.

Os resultados da modelagem indicam que os RLRLs de 1km e 5km do Brasil representam aproximadamente 71,3% e 39,2% do território continental do país,

respectivamente. Além disso, 25,5% dos PABCs do MMA se sobrepõem com os RLRLs de 1 km (representando 18,2% do território continental do Brasil) e 19,3% dos PABCs do MMA se sobrepõem com os RLRLs de 5 km (representando 7,5% do território continental do Brasil). Contudo, uma quantidade grande dos projetos planejados de rodovias e ferrovias federais impactariam essas áreas identificadas se fossem construídas.

Como implicações prátcas, tais resultados mostram que se o Brasil fizer planos alternativos de desenvolvimento de infraestrutura e aproveitar as oportunidades de conservação, o país poderia potencialmente evitar conflitos no desenvolvimento de infraestrutura e alcançar progresso significativo no cumprimento de seus compromissos internacionais, tais como a Convenção sobre Diversidade Biológica (CBD), A Convenção-Quadro das Nações Unidas sobre Mudanças Climáticas (UNFCCC) e o Acordo de Paris. Adicionalmente, enquanto se concentra no maior patrimônio ambiental do Brasil, a floresta amazônica, as florestas remanescentes e seu estoque de carbono foram calculados usando uma ampla gama de dados espacialmente explícitos disponíveis. Uma vez que foram tabuladas, as estimativas de estoque de carbono da Amazônia foram combinadas com duas abordagens econômicos para calcular o custo social do carbono da floresta amazônica no nível do bioma e por hectare. Além disso, essa técnica considera os impactos econômicos prejudiciais que um possível ponto de inflexão do ecossistema teria sobre as alterações climáticas resultantes dos elevados níveis de emissões da gases de efeito de estufa devido à morte da floresta e os quais estão estimados para equivaler $ 4,6 trilhões a $ 243,1 trilhões USD.

A pesquisa desenvolvida nesta dissertação é original e combina, de forma lógica e estruturada, conceitos chave de análise socioambiental e de planejamento de transporte, integrados em um modelo espacialmente explícito desenvolvido em um sistema de informações geográficas. O trabalho vai ao encontro das necessidades apontadas pela Comissão de Área de Ciências Ambientais da CAPES ao promover a investigação e a inserção social da pesquisa em regiões com alto índice de vulnerabilidade social, vulnerabilidade ambiental e isolamento geográfico.

Palavras-chave: Governança Ambiental, Impacto Ambiental dos Transportes, Áreas sem Rodovias, Serviços Ecossistêmicos, Custo Social do Carbono, SCC, Desmatamento, Avaliação Econômica

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Abbreviations

ANTT – National Agency for Terrestrial Transport's (for *Agência Nacional de Transportes Terrestres*)

APPs – Areas of Permanent Protection (for *Áreas de Preservação Permanente*)

BC250 – 1:250,000 scaled Continuous Cartographic Database of Brazil (for *Base Cartográfica Contínua do Brasil 1:250.000*)

BIT – Transportation Information Database (for *Banco de Informações de Transportes*)

BoP – Balance of Payments

C169 – Indigenous and Tribal Peoples Convention, Convention n.169

CAR – Rural Environmental Registry (for *Cadastro Ambiental Rural*)

CBD – Convention on Biological Diversity

CF88 – 1988 Constitution of the Federal Republic of Brazil

CNUC – National Registry of Conservation Units (for *Cadastro Nacional de Unidades de Conservação*)

DNIT – National Department of Transportation Infrastructure (for *Departamento Nacional de Infraestrutura de Transportes*)

EIA – Environmental Impact Assessment

ES – Ecosystem Service(s)

EVTEA – Technical, Financial–Economic and Environmental Feasibility study (for *Estudo de Viabilidade Técnica, Econômico–Financeira e Ambiental*)

FBMC – Brazilian Forum on Climate Change's (for *Fórum Brasileiro de Mudança do Clima*)

FC – Forest Code (for *Codigo Florestal – Lei de Proteção da Vegetação Nativa*)

FCP – Palmares Cultural Foundation (for *Fundação Cultural de Palmares*)

FDI – Foreign Direct Investment

FPIC – Free, Prior and Informed Consent

FPICon – Free, Prior and Informed Conultation

FUNAI – National Foundation for Indigenous Peoples (for *Fundação Nacional do Índio*)

GHG – Greenhouse Gas

ha – Hectare(s)

IAM – Integrated Assessment Model

IBAMA – Brazilian Institute of the Environment and Renewable Natural Resources (for *Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis*)

IBGE – Brazilian Institute of Geography and Statistics (for *Instituto Brasileiro de Geografia e Estatística*)

ICMBio – Chico Mendes Institute for Biodiversity Conservation (for *Instituto Chico Mendes de Conservação da Biodiversidade*)

IEAs – Important Environmental Areas (RLRL areas; Conservation Units, Indigenous Territories, Quilombo Community Territories whether Regularized and Titled or Unregularized and Untitled; and Priority Areas for Biodiversity Conservation)

ILO C169 – International Labour Organization Convention 169

INCRA – National Institute for Colonization and Agrarian Reform (for *Instituto Nacional de Colonização e Reforma Agrária*)

INPE – National Institute of Space Research (for *Instituto Nacional de Pesquisas Espaciais*)

IUCN – International Union for Conservation of Nature

km – Kilometer(s)

LPAs – Legally Protected Areas (*which include Conservation Units, Regularized Indigenous Territories and Titled Quilombos*)

LULC change – Land Use Land Cover change

Mha – million hectars

MMA – Ministry of the Environment (for *Ministério do Meio Ambiente*)

MoI – Ministry of Infrastructure (for *Ministério da Infraestrutura*)

MP – Public Ministry (for *Ministério Público*)

MRE – Ministry of Foreign Affairs (for *Ministério de Relações Exteriores*).

MTPA – Ministry of Transportation, Ports and Aviation (for *Ministério dos Transportes, Portos e Aviação Civil*)

MTPA/MoI – Ministry of Transportation, Ports and Aviation / Ministry of Infrastructure

NBSAP – National Biodiversity Strategy and Action Plan (*Estratégia e Plano de Ação Nacionais para a Biodiversidade*)

NDC – Nationally Determined Contribution

NFEs – Non-Forest Ecosystems

NGOs – Non–Governmental Organizations

NTFPs – Non-Timber Forest Products

OSM – Open Street Map

P3s – Public–Private Partnerships

PABCs – Priority Areas for Biodiversity Conservation (*Áreas Prioritarias para a Conservação de Biodiversidade*)

PAC – Growth Acceleration Program (for *Programa de Aceleração de Cresimento*)

PCTs – Traditional Peoples and Communities (for *Povos e Communidades Tradicionais*)

PI – Full Protection (for *Proteção Integral*)

PIL – Logistics Investment Program (for *Programa de Investimento em Logística*)

PL – Preliminary Licensing

Plano ABC – Low Carbon Agriculture Plan (for *Plano de Agricultura de Baixa Emissão de Carbono*)

PNL – National Logistics Plan (for *Plano Nacional de Logística*)

PNLT – National Plant for Logistics and Transport (for *Plano Nacional de Logistica e Transportes*)

PNMA – National Environment Policy (for *Política Nacional do Meio Ambiente*)

PNT – National Transportation Policy (for *Política Nacional de Transportes*)

PNV – National Transportation Plan (for *Plano Nacional de Viação*)

PPI – Investment Partner Program (for *Programa de Parcerias de Investimentos*)

PPPs – Policies, Plans, and Programs

PROFAS – Environmentally Sustainable Federal Highways Program (for *Programa de Rodovias Federais Ambientalmente Sustentáveis*)

RIMA – Environmental Impact Statement (for *Relatório de Impacto ao Meio Ambiente*)

RLRL areas – Roadless and Railroad-less areas

RLs – Legal Reserves (for *Reservas Legais*)

SCC – Social Cost of Carbon

SEA – Strategic Environmental Assessment

SNV – National Transportation System (for *Sistema Nacional de Viação*)

SoyM – Brazil's Soy Moratorium

TCU – Federal Court of Accounts (for *Tribunal das Contas da União*)

TIs – Indigenous Territories (for *Terras Indígenas*)

UCs – Conservation Units (for *Unidades de Conservação*)

UNDRIP – United Nations Declaration on the Rights of Indigenous Peoples

UNFCCC – United Nations Framework Convention on Climate Change

US – Sustainable Use (for *Uso Sustentável*)

Figures

Figures presented in Chapter 1 – Policy and Governance Analysis

Figures Presented in Chapter 2 – Model 1 (Brazil's RLRLs)

Figures Presented in Chapter 3 – Model 3 (Social Cost of Carbon of the Brazilian Amazon)

Tables

Tables Presented in Chapter 2 – Model 1 (Brazil's RLRLs)

<u>Tables Presented in Chapter 3 – Model 2 (Social Cost of Carbon of the Brazilian Amazon)</u>

Section 1: Initial Considerations

This master's thesis is more than just two years in the making. The ideas and motivation behind this manuscript have roots that go all the way back to the early 2000s during my time in middle school and high school. It was during my teenage years that my interest in government and policy (thank you Mrs. Smith and Dr. Gray!) as well as the pursuit of a better world through scientific discovery (thank you Mrs. Bryan and Mrs. Kuhns!) were sparked.

This foundation set the course for my undergraduate studies in International Affairs and Geography at The George Washington University (GW) in Washington, D.C., USA and study abroad at L'Institut d'Études Politiques de Paris (Sciences Po) in Paris, France. At GW and Sciences Po my coursework further reinforced my pursuit to understand what makes good policy and good governance. Moreover, while at Sciences Po my coursework and a wonderful life event turned my attention to and sparked my interest in Brazil. As a complement to my coursework, during my final undergraduate year I undertook internships at the Brookings Institution's Metropolitan Policy Program and at the U.S. Department of State's Bureau of Oceans and International Environmental and Scientific Affairs (OES). These two internships contributed to my understanding of the multifaceted nature and complexities involved in the pursuit of sustainable development, economic development, transportation development and international environmental diplomacy. These experiences opened my eyes to the realities and challenges of a globalizing world and that humanity is likely facing its ultimate defining moment and will only successfully overcome this challenge through proactive stewardship of our planet's biosphere and atmosphere.

However, instead of being discouraged, I was encouraged to strive to make complex issues less complex through working towards finding holistic and simple solutions. After finishing my undergraduate studies in 2011, I undertook an internship at an environmental consulting firm, MDB, Inc., that provided support for the U.S. Environmental Protection Agency's Office of Water. It was at this point where I witnessed the necessity and positive contribution of public engagement in the policymaking and planning processes. Afterwards in 2012, I entered into the arena of wind energy infrastructure development and its impacts on wildlife, a field that I call "Wind Ecology," when I began working at the American Wind Wildlife Institute (AWWI). AWWI is an NGO which was jointly founded by environmental NGOs and wind energy companies to serve as a consortium of information sharing and forum for mediation and facilitation to encourage responsible wind energy development. It was at AWWI where I was introduced to multi-level and multi-actor governance that did not involve the government. I witnessed the engagement and cooperation of environmental NGOs and wind energy companies coming together with a common purpose of providing solutions for conservation in the face of ineffective government policy and ineffective government action.

After two years with AWWI, my partner Mário Sérgio and I decided to relocate to Mário's hometown of Belo Horizonte, Brazil. Knowing no Portuguese at the time, I left the U.S. for what would be a difficult but yet wonderful and eye-opening chapter of my life. After constructing a strong foundation for my personal life in Brazil, learning the language and culture, and building a social network, I felt that I was ready begin building the foundation for the next stage of my professional life. I had always planned on pursuing a master's degree, so I began searching for possible graduate programs to apply to in Belo Horizonte that are in the environmental field. It was during this search that I contacted Professor Rodrigo A.A. Nóbrega, who immediately responded to my inquiry and invited me to come meet with him at UFMG's Institute of Geosciences. After our conversation, I felt that I had found the program that would allow me to pursue research in the areas that interest me. The Graduate Program in Environmental Systems Analysis and Modeling, in my opinion, seemed like the perfect bridge between the world of environmental sciences and public policy. However, having missed the application deadline by a month I had to wait for the next year to apply to the program. In retrospect, what felt like a bump in the road was actually a helpful detour. Professor Rodrigo encouraged me to take elective courses (*disciplinas isoladas*) in the meantime to get accustomed to how a university in Brazil functions and frankly to learn more about Brazil. This year of elective coursework showed me that I was behind on the learning curve, and once I officially entered into the program, I took advantage of taking every single discipline that I felt would help me to understand the laws, norms, functions, actors and culture surrounding environmental conservation and sustainable development in Brazil.

Moreover, being an immigrant, I felt extreme gratitude that my adoptive country, Brazil, would be willing to offer me a free graduate level education and additionally that my adoptive country was willing to financially support me as I pursued this education. These are two opportunities that are very rare in my homeland. Realizing the privilege that I had in the fact that Brazil was willing to invest in me, I felt an extreme sense of responsibility to give Brazil a significant return on its investment.

Here we are, in 2019, writing my master's thesis, hoping to show Brazil that its investment in me was worth it. This thesis represents my appreciation of, gratitude to, and love for my adoptive home. As with all intimate relationships, love comes in many forms. Love comes in the form of care, in the form of celebration, and in the form of encouragement and compliments. However, love can also come in the form of tough love. This thesis contains all forms of love as well as the appreciation and gratitude that I hold for Brazil.

Understanding that Brazil is still in the pursuit of a sustainable pathway for development, the aim of this thesis is to celebrate with Brazil where it is doing well, to offer advice on where Brazil can improve, and to show Brazil where it is advisable to change. To do this, I am offering Brazil spatially explicit models and a systemic analysis of where Brazil is doing well, where Brazil has opportunities, and where Brazil has to improve its efforts to achieve a pathway to sustainable development that benefits all members of Brazilian society.

This is laid out in the following chapters. Specifically, the following section provides an analysis of Brazil's policymaking and governance system in relation to transportation infrastructure development and socioenvironmental protections and commitments. With a synthesized description of Brazil's policymaking and governance structures, systemic breakpoints where socioenvironmental considerations are often neglected during transportation infrastructure development are identified. Then, key institutional actors are highlighted that may be able to mend the identified breakpoints if Brazil's academic, scientific and legal communities as well as individuals and actors from civil society given them a helping hand. Finally, a call for the development of spatially explicit models is made to aid these identified actors to bring socioenvironmental considerations back into the process.

The third section analyzes the spatial distribution of Brazil's terrestrial transportation network and remaining roadless and railroad-less (RLRL) areas. Additionally, using the identified RLRL areas, potential synergies were identified to aid Brazil in implementing its national biodiversity conservation, environmental protection, and deforestation prevention policies as well as helping the country to achieve its commitments to international biodiversity and environmental agreements. Then Brazil's current federal terrestrial transportation infrastructure system and its future expansion plans were analyzed to identify were federal transportation policy impacts and contradicts federal environmental policy and its synergies with identified RLRL areas. Moreover, information was given to highlight how transportation policy impacts some of the country's constitutionally protected indigenous and tribal communities and cultures. Finally, existing highway infrastructure that still has not received any form of legally mandated federal environmental licensing was identified and impacts were analyzed in relation to federal environmental policy as well as indigenous and tribal peoples.

The fourth section provides a new approach for estimating the partial economic value and market impacts that result from the continued deforestation of Brazil's greatest ecological asset, the Amazon rainforest. This was done by implementing two advances in environmental economics, the first related to modeling the social cost of carbon (SCC) which resulted in a Nobel prize in economics, and the second involving an innovative approach to incorporating the consideration of a committed tipping point for an ecosystem into economic valuation calculations. These economic approaches were combined and used with a spatially explicit model which allowed for the calculation of above and below ground forest carbon stock and as well as a forest inventory estimate, to calculate overall value estimate of the Amazon's forest at a biome scale and per hectare scale.

The fifth section provides brief concluding remarks, highlighting how, where and who could implement the results from this thesis into Brazil's policymaking and governance structures. Finally, a proposed roadmap for future research related to the accomplishments outlined in this thesis and a call to action for Brazil's academic, scientific and civil society actors is proposed.

Section 2: Chapter 1 – Policy and Governance Analysis

Environmental and Social Governance: a reflection of the explicit and implicit contradictions in Brazil's Transportation and Sustainability Policy Nexus

Abstract: Brazil has an advanced legal framework for environmental and social rights protection. However, in the quest for economic development Brazil's transportation infrastructure and socioenvironmental policies have commonly come into conflict. The literature indicates that Brazil's socioenvironmental policies, protections, values and international commitments are commonly ignored or left out of the federal transportation planning process. On the ground, legal and social conflict commonly only come to light at the environmental licensing and project implementation stages for large federally backed infrastructure projects. This is despite the fact that large-scale socioenvironmental impacts should have already been anticipated, considered, planned for and legally mitigated well before reaching these final project development stages. In order to understand why this happens and with a focus on transportation development, a governance analytical framework was employed to identify the norms, actors, nodal points and processes in Brazil's federal infrastructure planning and environmental governance framework to recognize why delayed consideration occurs. We identified two policy breakdown points that occur before the Environmental Licensing stage where key federal institutions and civil society actors could act to potentially force socioenvironmental issues back into the planning process with the aid of legally and scientifically backed spatially explicit models.

2.1 – Introduction

Brazil is a country of contrasts. Its biodiverse, culturally diverse, and at the regional scale is developmentally diverse. Brazil is the most biodiverse tropical country in the world aided by its continental size (BRANDON et al., 2005; STRASSBURG et al., 2014). It is a melting pot of cultures, today's Brazilians include the diversity of indigenous and traditional peoples (HANNA et al., 2014) as well as descendants of immigrants coming from all around of the globe, yet the country is still affected by racial divides (KELLMAN, 2002). Brazil is home to two of Latin America's largest metropolitan regions (OECD, 2019) and also home to vast remote and highly inaccessible places. Brazil is the 8th largest economy in the (THE WORLD BANK, 2018) yet is a country of extreme income inequality (KELLMAN, 2002). Falling among these contrasts is Brazil's constitutional protection of its natural capital and human rights of indigenous and traditional peoples and the actual treatment they receive on the ground.

Brazil has one of the most advanced legal systems for environmental protections (DE OLIVEIRA; ANDREOLI; DA MATA CAVALCANTE, 2019; MAGNUSSON et al., 2018), with a rigorous environmental licensing legal framework (BRAGAGNOLO et al., 2017). Yet in reality the enforcement of environmental protections and licensing procedures is lackluster, flawed and in some cases nonexistent (DE OLIVEIRA; ANDREOLI; DA MATA CAVALCANTE, 2019; MAGNUSSON et al., 2018). Deforestation and Land Use Land Cover change (LULC change), combined with its resulting degradation to biodiversity and greenhouse gas (GHG) emissions, are some of Brazil's most pressing environmental issues (MAGNUSSON et al., 2018; ROCHEDO et al., 2018) even though the country's legal framework and its voluntary international commitments very much cover and call for prevention of deforestation and LULC change, biodiversity protection, and limits to GHG emissions.

The same is true in relation to Brazil and its protection of its indigenous peoples, maroon communities (quilombos)[1], and other traditional peoples and communities (henceforth PCTs, for *Povos e Communidades Tradicionais*). These groups have significant legal protections granted in the 1988 Constitution of the Federal Republic of Brazil (henceforth CF88) (BRAZIL, 1988, Ch. 3, Sec. 2, Arts. 215 & 216; Ch. 8, Arts. 231 & 232; and, Act of Transitional Constitutional Provisions, Arts. 67 & 68) and by Brazil being a signatory to and ratifying key international human rights treaties, declarations and conventions (HANNA et al., 2014; VALENTA, 2003). However, gross human rights abuses, discrimination, violence and a lack of enforcing constitutional protections have continued for indigenous communities since 1988 (BERARDINELLI, 2017; VALENTA, 2003) and there are still 236 indigenous lands that have not been regularized (ISA, 2019). Moreover, Free, Prior and Informed Consent (FPIC), a key procedural element for ensuring the protection of the rights of all tribal communities[2] and their land from any potential impacts resulting from proposed legislation, or administrative, development or economic policies, plans or programs (PPPs)[3], frequently falls short in practice in Brazil (BRATMAN; DIAS, 2018; HANNA; JEAN; VANCLAY, 2016; HANNA; VANCLAY, 2013).

To understand why the two aforementioned phenomena – the infringements on environmental and indigenous and tribal communities' rights – regularly occur in Brazil, it was necessary to deconstruct and then reconstruct the structural processes that lead up to these shortfalls. To do this we developed an investigative approach based on Hufty's (2011) Governance Analytical Framework to aid in our analysis. As proposed by Hufty (2011), our analytical framework identifies the problem, norms, actors, nodal points and relevant processes in Brazil's overall federal governance process. Moreover, we added a contextualization of Brazil's economic and political structural factors to the investigation of the aforementioned variables into our analytical framework.

Therefore, the principal problem under analysis is: Why are environmental and social legal protections – being explicitly defined as fundamental rights by Brazil's constitution and supported by secondary laws and ratifications of international conventions – regularly diminished, infringed upon or ignored during and throughout the development of large transportation infrastructure development projects in Brazil?

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[1] Quilombos refer to the geographic territory of Brazil's Afro-descendent Maroon communities (descendants of escaped slaves, known as Quilombolas) (HANNA et al., 2014, p. 59).

[2] As defined by ILO C169 Articles 1 and 2: 1. (**a**) *Tribal peoples* in independent countries whose social, cultural and economic conditions distinguish them from other sections of the national community, and whose status is regulated wholly or partially by their own customs or traditions or by special laws or regulations; (**b**) peoples in independent countries who are regarded as *Indigenous* on account of their descent from the populations which inhabited the country, or a geographical region to which the country belongs, at the time of conquest or colonization or the establishment of present state boundaries and who, irrespective of their legal status, retain some or all of their own social, economic, cultural and political institutions. 2. Self-identification as indigenous or tribal shall be regarded as a fundamental criterion for determining the groups to which the provisions of this Convention apply (ILO, 1989, Arts. 1 & 2).

[3] Policies, Plans, and Programs (PPPs) is a term used to highlight the strategic decision-making levels which occur prior to or above the project specific level (FISCHER, 2002).

To guide our investigation, the ordered flow of our analytical framework included investigating and understanding the key factors in the context of these structural elements:

(i) Brazil's economic reality and development paradigm (*relevant processes and economic context*);

(ii) The Brazilian State, its system of government and key institutions (*relevant processes, norms, actors, and political structure*);

(iii) Brazil's policy making process and how actors and mechanisms involved in policy making interact (*norms, actors, nodal points, processes, and political structure*);

(iv) Diagraming the relationships and connections of Brazil's State institutions, government actors, non-state actors, and their place in the public policymaking process and, moreover, in the overall governance system related to socioenvironmental protections and transportation development (*nodal points and actors*); and

(v) Identifying points where socioenvironmental considerations are ignored in the transportation development process and proposing support tools at these points that could aid in strengthening and reinforcing socioenvironmental considerations (*nodal points and processes*).

2.1.2 – Starting Definitions

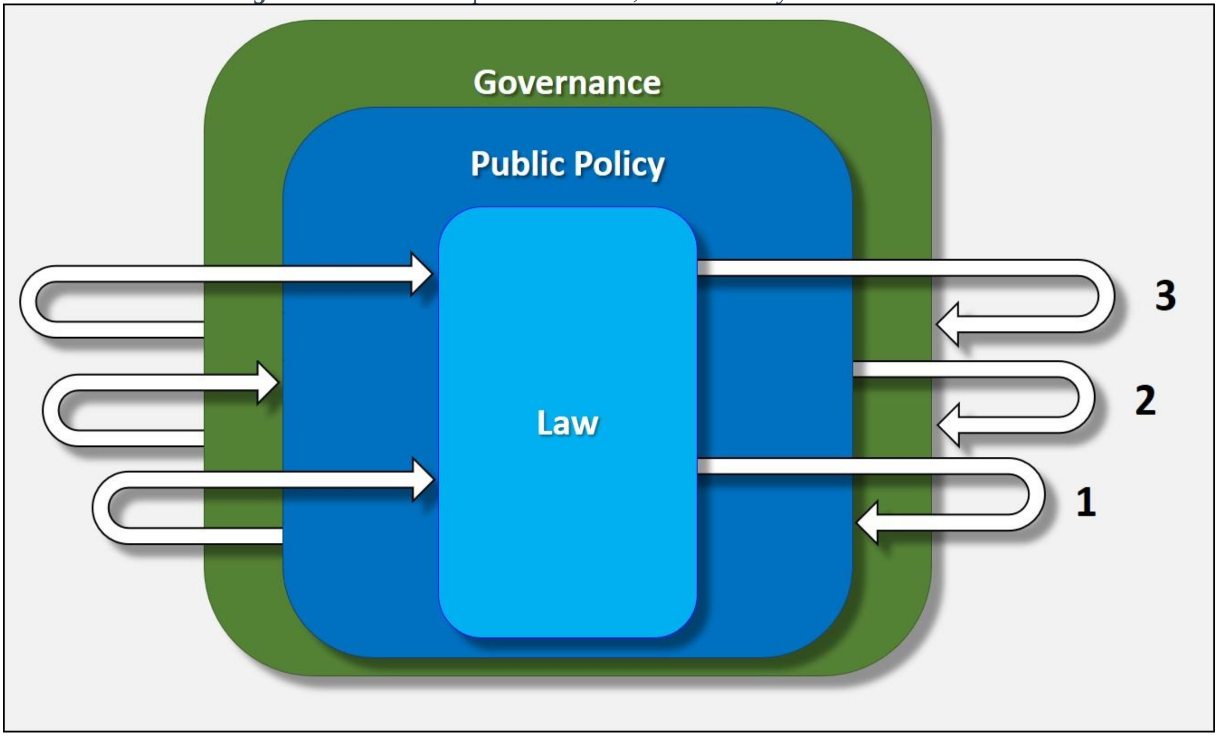
To begin, it is important to define three related terms that will be used throughout this analysis: laws, public policies, and governance. These terms will be analyzed in a deeper context in the following section. However, at this point it is important to understand that although these concepts are very much related, they are not the same thing. Firstly, for the purpose of maintaining a general understanding, **laws** are documented rules that are created, and enforced by the State[4], and they are supposed to be followed by all members of society and by government institutions and officials (FIUZA, 2013; HART, 2012; OAS, 2007; POUND, 1944). Secondly, **public policies** are bound by laws, sometimes they result in new laws; however, policies are broader than laws. Birkland (2011, p. 9) defines policy as "a statement by government – at whatever level, in whatever form – of what it intends to do about a public problem. Such statements can be found in the constitution, statutes, regulations, case law, agency or leadership decisions, or even in changes in the behavior of government officials at all levels." Finally, **governance** is related to the results and outcomes of implementing public policy, enforcing adherence to the law, and societal factors. Governance usually involves government; however, it does not necessarily need to. Moreover, governance can involve many different types of non-state actors and can occur across multiple scales. For a basic understanding, Hufty (2011, p. 405) states that governance refers to:

> "the processes of interaction and decision-making among the actors involved in a collective problem that lead to the creation, reinforcement, or reproduction of social

[4] As defined by Pound (1944, p. 1210), a State is "the political organization of a society legally supreme within and independent of legal control from without."

norms and institutions. Each society develops its own ways of making decisions and resolving conflicts. This is what governance is about. Therefore, as a social fact, governance is neither normative nor prescriptive: it refers to an observable phenomenon. Nor is it limited to any time or space, as it is observable in any human society."

***Figure 1** – Relationship between Law, Public Policy and Governance..*



The Law, Public Policy and Governance are interconnected and influence one another in the form of feedback loops. Feedback loops 1, 2, and 3 show that the concepts are interconnected yet also differ from being specific to broader. 1) Law is more specific than Public Policy. 2) Public Policy is broader than the law and is commonly influenced by non-state actors; however, the final course of Public Policy is still set by the government. 3) Governance is related to the results of implementing Public Policy, however it can also be related to the response of non-state actors to a lack of a government's policy stance on an issue or displeasure with the stance a government has adopted. While Governance is still usually associated with government, it can be completely related to non-state actors. Finally, Governance can force a change in Law.

2.2 – Brazil's Economic Reality and Developmental Paradigms

Brazil's federal government has traditionally been involved in guiding the country's "key" economic sectors to achieve 'maintained' economic growth, which has subsequently been geared towards export-oriented commodities (EBENAU; LIBERATORE, 2013; SAUER; BALESTRO; SCHNEIDER, 2018). Historically, the Brazilian State has been a Developmentalist State, even in the guise of past market reform and privatization policies (RICZ, 2019). As a result of Brazil's economic growth perspectives in recent decades, the federal government and its bureaucratic institutions grew to operate within and subscribed to a policy paradigm[5] titled neo-developmentalism (CARVALHO;

[5] "Policy paradigms are defined as frameworks embodying linguistic, normative, and epistemic dimensions, among others, that govern the policy process" (O'SULLIVAN, 1993). A paradigm is a distinct set of concepts or thought

SENNA; MATOS, 2018; RICZ, 2019). Neo-developmentalism is a form of state capitalism which involves, the State not only playing a strong role in key market sectors but also steering the economy through a national capitalist development program (DÖRING; SANTOS; POCHER, 2017; EBENAU; LIBERATORE, 2013; RICZ, 2019). In the past, Brazil's Growth Acceleration Program (henceforth PAC, for *Programa de Aceleração do Crescimento*) as well as the transportation specific Logistics Investment Program (henceforth PIL, for *Programa de Investimento em Logística*) both served this role (DÖRING; SANTOS; POCHER, 2017; EBENAU; LIBERATORE, 2013; FERNANDES, 2017).

Since the 2016 impeachment of President Dilma Rousseff (2011-16), former President Michel Temer (2016-18) and current President Jair Bolsonaro (2019 - Current) have been redirecting public policies to a more 'neo-liberal' policy approach. However, developmentalism is still very much present in the newly emerging 'neo-liberal' public policies that strongly echo sharp tones of economic nationalism and state interventionism (HIDALGO, 2018). So far, the emerging policies indicate that the State is still going to be actively involved in development policy that will support Brazil's 'key industries' (agricultural and mineral commodities) and to ensure that their export competitiveness grows. The principal divergence of the emerging 'neo-liberal' developmentalist paradigm from the previous Keynesian neo-developmentalist paradigm under former Presidents Lula (2003 - 10) and Rousseff are the social and education austerity measures occurring in national budgeting and a public management move towards promoting Public-Private Partnerships (P3s) via concessionary lease auctions of state-owned infrastructure as opposed to previous higher levels of direct state management (RICZ, 2019).

Currently, the Investment Partner Program (henceforth PPI, for *Programa de Parcerias de Investimentos*) is serving the role of a "national capitalist development program" using P3s to finance the implementation of the Ministry of Transportation, Ports and Aviation's (MTPA/MoI[6]) National Logistics Plan (henceforth PNL, for *Plano Nacional de Logística*) (BRAZIL, 2016a; MTPA, 2018). PAC, PIL, PPI, and PNL all reflect one of the main challenges that *status quo* economic development PPPs – which are usually related to export commodities – often face, which is the reality that Brazil's current infrastructure matrix is insufficient for achieving set economic growth goals (ARMIJO; RHODES, 2017, p. 232; GONÇALVES et al., 2017, p. 23).

Moreover, the country's dependence on commodity exports in helping to maintain a positive current account balance and thus an overall positive balance of payments (BoP) (SAUER; BALESTRO;

patterns, including theories, research methods, postulates, and standards for what constitutes legitimate contributions to a field.

[6] At the time of this writing President Jair Bolsonaro has proposed a reorganization of executive agencies which includes renaming the Ministry of Transportation, Ports and Aviation (MTPA) to the Ministry of Infrastructure (MoI) (BRAZIL, 2019). However, they should be synonymously interpreted as being the same federal ministry. Due to the ministerial restructuring and renaming occurring in the Bolsonaro administration, Brazil's federal laws are still being changed to account for the change in names of the executive ministries. Therefore, most current transportation laws and PPPs still reference MTPA, but are now allocated to MoI as MTPA's successor ministry (BRAZIL, 2019). Therefore, throughout this text MTPA and MoI should be understood as being synonymous.

SCHNEIDER, 2018) has increased significantly (IORIS, 2017) since the commodities boom in the 2000s and the reinforced process of continued deindustrialization of Brazil's economy (BRESSER-PEREIRA, 2012; BRESSER-PEREIRA; MARCONI, 2009; IORIS, 2017). For Brazil, and many other countries whose domestic currency is not an internationally accepted reserve currency, the BoP is a key tool used by the federal government to maintain or increase its foreign currency reserves (OREIRO, 2012). Brazil's BoP is of significant concern for macroeconomic stability as it is an important tool for: (i) sustaining internal economic growth and employment (OREIRO, 2012); (ii) indirectly helping to finance the country's discretionary spending (SAUER; BALESTRO; SCHNEIDER, 2018), especially on its national development programs (CARVALHO; SENNA; MATOS, 2018; SAUER; BALESTRO; SCHNEIDER, 2018); and, (iii) general economic stability to avoid a BoP crisis (KRUGMAN, 1979), so that Brazil can continue buying the goods and services from the international market that the country does not produce domestically.

Concurrently, many infrastructure development PPPs enacted under the neo-developmentalist paradigm have shown a documented track record of environmental and social costs (DÖRING; SANTOS; POCHER, 2017). Given the development push under the developmentalist paradigm, economic concerns are normally given priority consideration over environmental and social concerns (HOCHSTETLER, 2017), which themselves are often seen as barriers to development (BRAGAGNOLO et al., 2017, p. 87; LIMA; MAGRINI, 2010, p. 110; ZHOURI, 2008, p. 98). This situation is reflected by the reality that, using Brazil's recent federal level transportation infrastructure PPPs as an example, environmental and social considerations are usually not adequately taken into account at the early stages of the PPP process, and if they are considered they are usually considered too late in the process to effectively influence decisions (MALVESTIO; FISCHER; MONTAÑO, 2018).

2.3 – The Brazilian State, its Government, and Key Institutions

In the context of export-oriented growth paradigm via commodities, both mineral and agricultural, it is important to understand Brazil's economic reality in the context of the Brazilian State and its government. According to Sarlet and Fensterseifer (2009, p. 249) the State's purpose lies in its duties of respecting, protecting and promoting its citizens' dignity. This is a continuous undertaking that the State must work towards; and moreover, it is an undertaking that the whole of society should also strive to help fulfill. Protection duties are connected to the State's constitutional commitment to secure and ensure fundamental rights as well as removing any barriers to these fundamental rights. This means that the State has both a proactive and reactive role in removing any economic, social or cultural barriers to fundamental rights (SARLET; FENSTERSEIFER, 2009, p. 249). The State's authority, including the mandates of State institutions, is exercised by an acting government that is supposed to operate within the legal confines of the constitution. In Brazil, the CF88 is the supreme law of the land and outlines various fundamental rights and state duties that must be respected by and upheld by a government at any point in time.

One of the CF88's fundamental rights is the right to "[…] an ecologically balanced environment, which is a public good and essential for a healthy quality of life, the duty to defend and preserve it for current and future generations rests on the public power and society at large" (BRAZIL, 1988, Ch. 6, Art. 225, author translation). Therefore, any barrier to attaining or securing the right to an ecologically balanced environment for current or future generations, whether by conduct or omission from an individual, government authority or state institution, must be controlled and eliminated from the State (SARLET; FENSTERSEIFER, 2009, p. 250). All state institutions are bound to both proactively and reactively realize citizens' fundamental rights as efficiently as possible, including the outlined right to an ecologically balanced environment, within their constitutional mandates (SARLET; FENSTERSEIFER, 2009, p. 250). Environmental protection is therefore one of the fundamental goals of the Brazilian State. However, the State is not the sole guardian of the environment, all of Brazilian society, individuals and community share the responsibility of environmental protection with the State. This shared responsibility gives citizens, either individuals or as a collective group, the right to approach a court to require adjudication on environmental matters (SARLET; FENSTERSEIFER, 2009, pp. 252–253).

In this same context, the Brazilian State's protection duties of fundamental rights also include the protection of social and cultural rights (BRAGATO; BIGOLIN-NETO, 2017). Some of the CF88's fundamental rights consequentially include protected social and cultural rights relevant to Brazil's indigenous populations, quilombo communities, and other PCTs (BRAZIL, 1988, Ch. 3, Sec. 2, Arts. 215 & 216; Ch. 8, Arts. 231 & 232; and, Act of Transitional Constitutional Provisions, Arts. 67 & 68;, 2016b). Thus, following the same logic of Sarlet and Fensterseifer (2009, p. 250), all state institutions should work to realize these fundamental rights within their constitutional mandates. Moreover, Brazil has ratified and promulgated the International Labour Organization's (ILO) Indigenous and Tribal Peoples Convention, Convention n.169 (C169) (BRAZIL, 2002, 2004; ILO, 1989) which and also falls under the jurisdiction of the International Criminal Court as outlined by the CF88 (BRAZIL, 1988, Ch. 1, Art. 5, §s 2, 3, & 4). The ILO C169 specifically established that indigenous and tribal communities have the right to be consulted before any legislative or administrative measure is conducted that could affect them directly, they have the right to directly participate in the formulation of any national or regional plans or programs that could affect them directly, and moreover they shall not be removed from the lands they occupy (ILO, 1989, Arts. 6, 7, & 16).

The constitution is the ultimate law of the land and forms the framework of boundaries, responsibilities and duties of the different branches of government. Brazil's federal government is divided into three independent but harmoniously co-existing, interacting and balanced branches of government (a configuration typical of federalist systems and commonly referred to as a system of checks and balances) which include the legislative, executive, and judicial branches (BRAZIL, 1988, Art. 2). For a basic definition, the primary function (but not the only one) of each branch of government is as follows: the legislative branch makes laws, the executive branch enforces and implements laws, and the judicial branch interprets the constitutionality and intent of laws (BIRKLAND, 2011, p. 94)

It is incumbent on the legislative branch of government, i.e. Congress (including both senate and the representative assembly), to draft bills, reconcile the bills between both houses in Congress, and then vote on the reconciled bills. These bills must be within the confines of and not contradict the constitution and the fundamental rights it guarantees. For a passed unified bill to become law, the executive branch, i.e. the President, reviews the bill and decides whether the bill is constitutional or unconstitutional, and whether to sign bill into law, or to veto parts of or the entire bill if the President does not agree with it. In the case of a presidential veto Congress can overrule it with an absolute majority vote (BRAZIL, 1988, Art. 66, § 4). In the case of the legislative branch, where the environment, social, and cultural indigenous and tribal rights are concerned, Congress has already passed bills and ratified treaties which were signed into law that cover fundamental human rights within the constitutional boundaries of the CF88.

The executive is primarily charged with signing legislative bills into law, enforcing and implementing laws. However, in Brazil the President does have some “legislative” powers in the form of issuing decrees (ALSTON; MUELLER, 2006) that will be discussed later in more detail. An additional important role of the executive is to propose a legislative agenda to Congress. Through this last role the executive and his or her administration aim to set policy. Executive branch institutions strongly influence the direction of public policy and governance mechanisms (NEVES, 2016). In concern of the executive, where the environment, social, and cultural indigenous and tribal rights are concerned, a positive (proactive) duty rests on the executive to preserve, protect and secure a core of environmental protections and services for current and future generations as well as indigenous and tribal social and cultural rights, as mandated by Brazil’s CF88 and within the stipulations set by ratified international treaties (BRAZIL, 1988 Ch.1, Art. 5, §s 2, 3, & 4; Ch. 3, Sec. 2, Arts. 215 & 216; Ch. 8, Arts. 231 & 232; and, Act of Transitional Constitutional Provisions, Arts. 67 & 68;, 2002, 2004). However, Brazil’s Congress continues to pass bills that the President continues to sign into law, as well as make national security declarations, that arguably undermine and violate constitutional socioenvironmental and indigenous and tribal cultural rights (FEARNSIDE, 2018).

An independent judiciary fulfills essential functions in a democratic state. These functions include a role in: (i) ensuring that the actions of the other two branches remain within constitutional bounds, (ii) providing the continued legal protection of minorities (TAYLOR, 2007), and (iii) serving the necessary legal function aimed at applying and interpreting the law for resolving disputes and criminality (SANTISO, 2004). For the judiciary to effectively ensure the rule of law, it must be able to interpret the law impartially, consistently, and without the influence of political power (SANTISO, 2004, p. 162). Moreover, the judiciary acts when it is provoked or called on by public civil action or by popular action (TAYLOR, 2007, p. 231). Once called on, the judiciary has the power to interpret the intent of the law and if legislative or executive action or inaction is unconstitutional and infringes on fundamental rights (BIRKLAND, 2011; TAYLOR, 2007).

In Brazil, the constitutional supremacy of the right to an ecologically balanced environment means that the courts can be called on by either public civil action or popular action to judge and determine if environmental rights are being infringed on. These fundamental constitutional rights are shielded from being diminished in the form of ecological retreat resulting from state action (SARLET; FENSTERSEIFER, 2009, pp. 254–255). Due to the constitutionality of environmental rights, it is generally accepted that the delivery of successful enforcement of environmental rights is not dependent on the support of secondary environmental laws (SARLET; FENSTERSEIFER, 2009, p. 255), which therefore does not excuse any inaction to uphold environmental rights based on the absence of a relevant secondary law nor does it excuse infringement on environmental rights based on an unconstitutional secondary law or an unconstitutional enforcement of a secondary law.

Various authorities are empowered by the CF88 to institute civil action against citizens who damage natural heritage, such as: the Public Ministry (henceforth MP, for *Ministério Público*), Brazil's federal agency charged with the administration of protected areas called the Chico Mendes Institute for Biodiversity Conservation (henceforth ICMBio, for *Instituto Chico Mendes de Conservação da Biodiversidade*), the Brazilian Institute of the Environment and Renewable Natural Resources (henceforth IBAMA, for *Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis*), and the Brazilian Public Defender. Moreover, these authorities may be assisted by non-governmental organizations (NGOs) and other private actors, individually or constituting a group (SARLET; FENSTERSEIFER, 2009, p. 256). In regard to making claims against the State, where its procedures, actions or omission cause environmental damage and an infringement on the right to an ecologically balanced environment, the constitutionally granted right to popular action empowers citizens to institute claims. In the instance of criminal liability of the State, the legal standing for filing suits rests solely with the MP (SARLET; FENSTERSEIFER, 2009, p. 255); however, the public and civil society actors are allowed to inform the MP of alleged violations and provide evidence. In such cases the State is defended by the Federal Prosecutor's Office (*Advocacia-Geral da União*) (BRAZIL, 1988, Art. 131).

These processes are similar in terms of social and cultural rights for tribal and indigenous peoples, in which the MP, the National Foundation for Indigenous Peoples (henceforth FUNAI, for *Fundação Nacional do Índio*) and the Palmares Cultural Foundation (henceforth FCP, for *Fundação Cultural de Palmares*) represented by the Federal Attorney General (AGU, 2010; PGF, 2003), are empowered by the CF88 to institute civil action against citizens who damage cultural heritage. In criminal action against the State the MP is responsible for filling suits (BRAZIL, 1988, Art. 129); however, the public and civil society actors are allowed to inform and provide evidence to the MP of the alleged violations (SARLET; FENSTERSEIFER, 2009, p. 256). In such cases the State is defended by the Federal Prosecutor's Office (BRAZIL, 1988, Art. 131).

Another state actor that is important to mention is the Brazilian Federal Court of Accounts (henceforth TCU, for *Tribunal das Contas da União*) which is an important independent institution (TCU, 2019) that has a wide-reaching role and established jurisprudence in financial auditing and external control of the Brazilian government's operations (ZYMLER, 2004). One of the main responsibilities of the TCU is to evaluate public policies and the level of benefit that they bring to society and therefore protecting and ensuring the appropriate use of the country's national patrimony (BUGARIN, 1998; FERRAZ et al., 2015; LIMA, 2016; ZYMLER, 2004). The natural environment is identified and defined by the CF88 as being national patrimony that must be protected for current and future generations. In this context the TCU itself has acknowledge that it has the constitutional duty to take account of the environment and social impacts in its external control roles (LIMA, 2009). The agency officially adopted an internal policy for "controlling environmental management" established by Ministerial Order (*Portaria*) n. 383, of August 5, 1998 (TCU, 1998).

2.4 – The Policy Making Process

In the last section we were able to outline the role of the State, and its key institutions, and the government in the law and public policymaking process. However, there may still be some ambiguity on what the exact difference is between law and public policy. The term public policy does not have a uniform definition even in the fields of political science or public administration. That said, as outlined by Birkland (2011, p. 8) the following attributes should be attached to our understanding of public policy:

- Policy is made in response to some sort of problem that requires attention;
- Policy is made on the "public's" behalf;
- Policy is oriented towards a goal or desired state, such as the solution of a problem;
- Policy is ultimately made by governments, even if the ideas come from outside government or through the interaction of government and nongovernmental actors;
- Policy is interpreted and implemented by public and private actors who have different interpretations of problems, solutions, and their own motivations;

- Policy is what the government chooses to do or not to do.

From this, we can discern that public policy is a matter that is primarily linked to government. The public policymaking process has various stages, but firstly an issue must emerge for public policy to address. Once an issue is identified the policy process generally involves the following five steps: Agenda Setting, Policy Formulation, Policy Adoption or Decision Making, Policy Implementation, and Policy Evaluation (BIRKLAND, 2011, p. 28) (**Figure 2**). Using a systems thinking approach, i.e. the process of understanding how things influence one another with a whole, the public policymaking process can be thought of as a combination of continuous feedback cycles (BIRKLAND, 2011, p. 29) given that public policymaking is a continuous and repetitious process (**Figure 3**).

Figure 2 *- Stages of the Public Policymaking Process (Ideal Structure)*

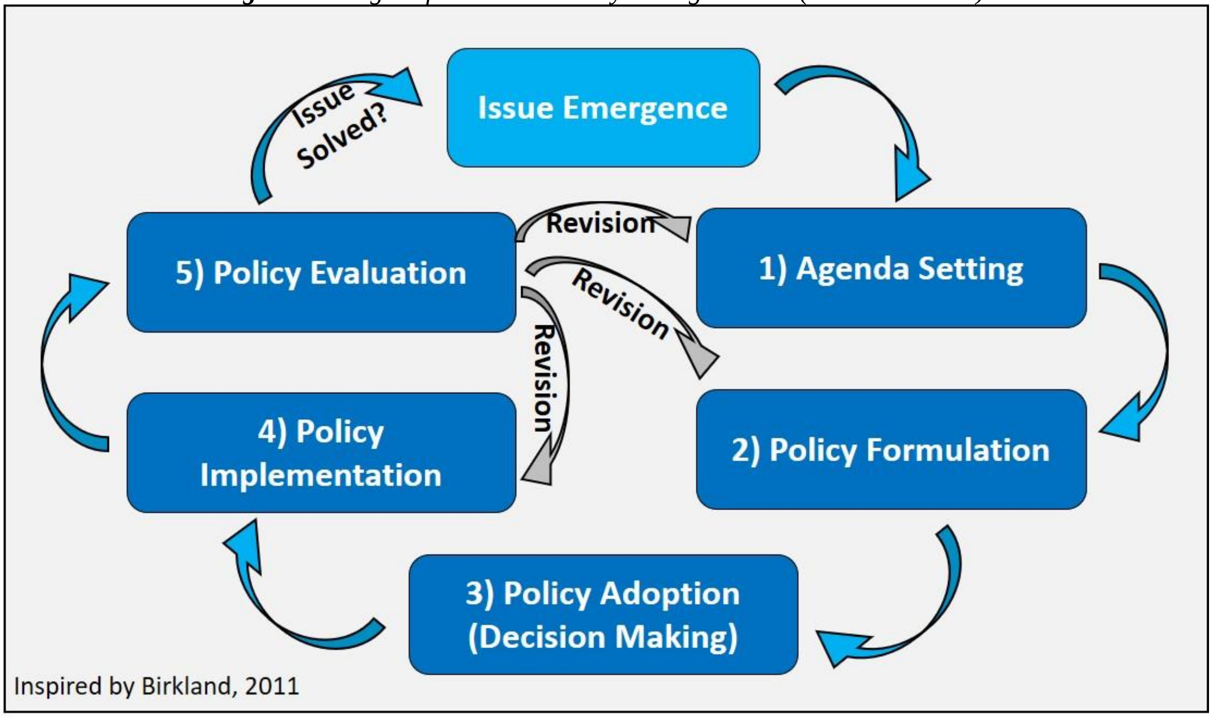
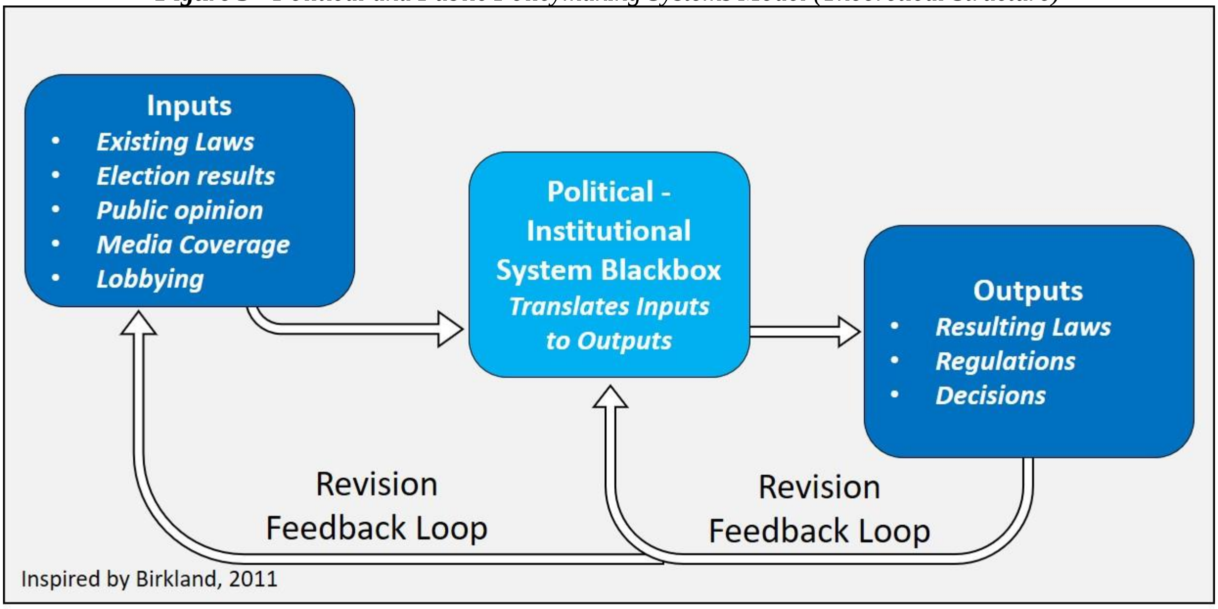
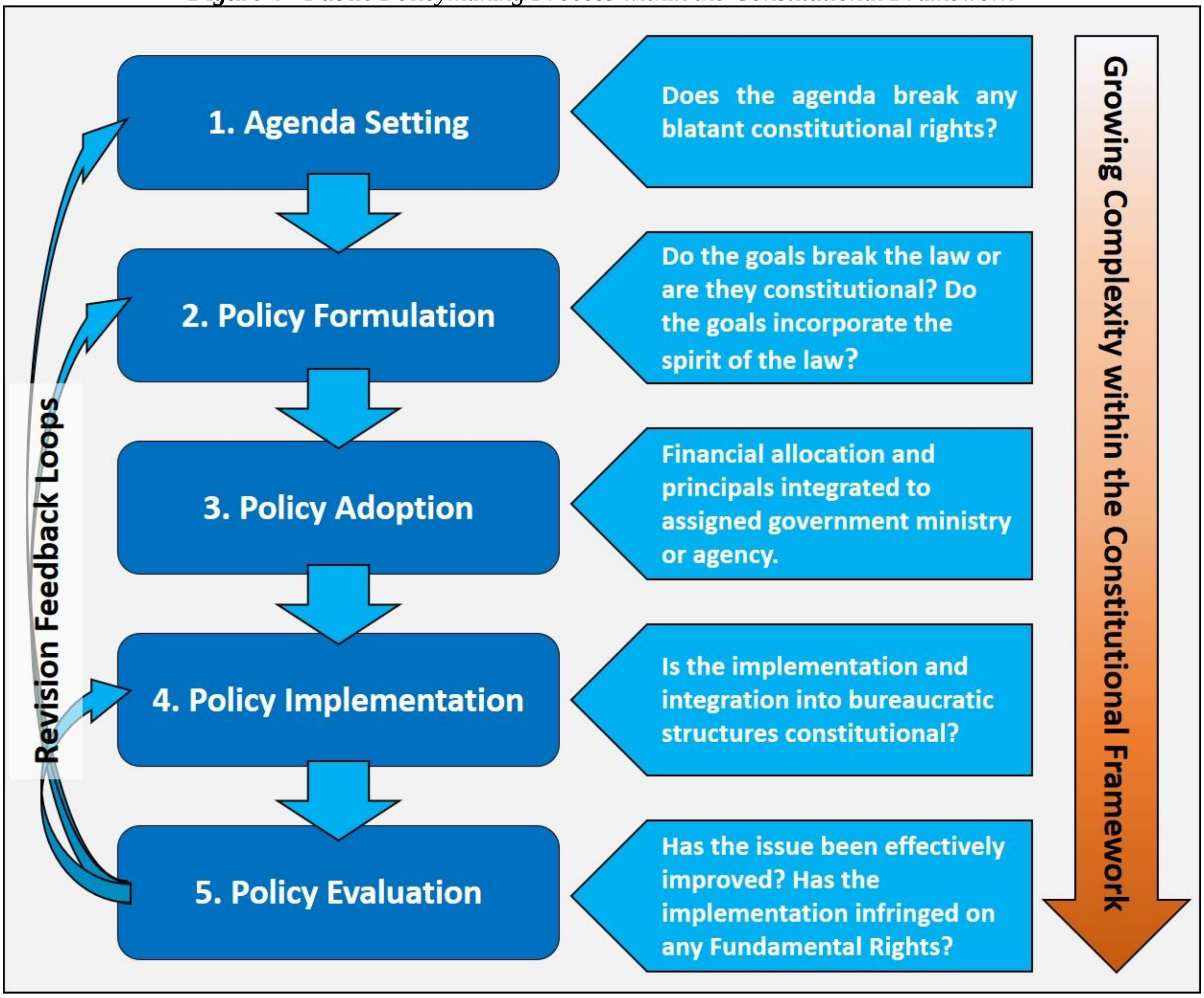


Figure 3 *- Political and Public Policymaking Systems Model (Theoretical Structure)*



Public policy and the law are connected and dependent on each other. Laws correspond to officially registered rules that are inputs to and resulting outputs from public policymaking. Policy is broader than law, and whether policy is registered or not, it aims to achieve broader societal goals and objectives that may or may not yet be covered by law (BIRKLAND, 2011, p. 8). Law stipulates what is supposed to be accomplished but the executive may have discretion on how to accomplish those legal stipulations, and policy forms the approach for accomplishing those stipulations. Another commonality, however, is that both public policy and law must obey and fall within the constitutional framework. In this context it is helpful to think of public policymaking as a top-down process (**Figure 4**), but still with revision feedback loops climbing back up to earlier steps.

Figure 4 - *Public Policymaking Process within the Constitutional Framework*



At this point it is important to discuss that Brazil's multi-party and bicameral federalism have generated a political governing system, which directly affects policymaking, that is commonly referred to as coalition presidentialism (LIMONGI, 2006). In order to effectively govern, the President needs Congress to support his or her policy objectives and to write and approve secondary input laws that may be needed to support policy and thus governing. However, given the multi-party nature of Brazil's political system, the President and his or her party must usually take part in a larger coalition of fragmented parties in Congress (SILVEIRA, 2014). For the President to achieve his or her policy objectives, which are dependent on the maintained existence of the governing coalition, the President must commonly answer to *quid pro quo*[7] demands from his or her congressional coalition partners (FENWICK; BURGES; POWER, 2017; MELLO; SPEKTOR, 2018). Under presidential coalitionism Brazil's federal public policy agenda is steered by the executive but commonly amended and altered by the legislative coalition partners in the form of *quid pro quo* patronage compensation (MELLO; SPEKTOR, 2018).

This commonly occurs in the context of the Brazilian President's 'legislative' powers which include his or her ability to issue presidential decrees and exclusive constitutional rights to initiate administrative and discretionary budgetary legislation (ALSTON; MUELLER, 2006; KATZ, 2018). Budgetary legislation includes the elaboration and changes to the executive budget. Administrative legislation includes laws that create new ministries, agencies, public corporations, new positions in the public sector, the mandates of public entities; and setting wages in public entities, however only within executive branch and excluding the legislature and the judiciary branches (ALSTON; MUELLER, 2006).

These powers are fundamental mechanisms for the Brazilian President in implementing his or her policy goals (FENWICK; BURGES; POWER, 2017). However, these executive laws are sent to Congress for its approval, and at this stage Congress commonly makes amendments to the President's administrative and discretionary budgetary proposals in the form of *quid pro quo* support. This commonly results in 'pork barrel projects', commonly for infrastructure, being added to presidential policy proposals (FENWICK; BURGES; POWER, 2017; MELLO; SPEKTOR, 2018).

At this point conflict commonly begins (but is still not necessarily evident) between the proposed pork barrel infrastructure projects and the environmental regulations that "stand in their way" (FENWICK; BURGES; POWER, 2017). Moreover, in the wake of various past corruption scandals, it has become clear that political players from private industry and other levels of government also provide influential pressure during the agenda setting stage. Pork barrel demands have been used as political currency to ensure survival but have come at the expense and disregard of socioenvironmental protections (FEARNSIDE, 2018; MELLO; SPEKTOR, 2018).

The judiciary, given its passive nature, does not set public policy per say; however, it can have an influence on public policy implementation (SARLET; FENSTERSEIFER, 2009, p. 261). Political actors commonly seek the institutional venues that best suit their goals, and given that the judiciary can impose its decisions on the other branches of government, it is one venue that influences if or how policy can be carried out (TAYLOR, 2007) as directed by judicial decisions. Non-state actors such as the public at large, constituency groups, NGOs, the private sector, and the media could have an influence in instigating popular action which may help trigger legal action to be undertaken by the MP. If this

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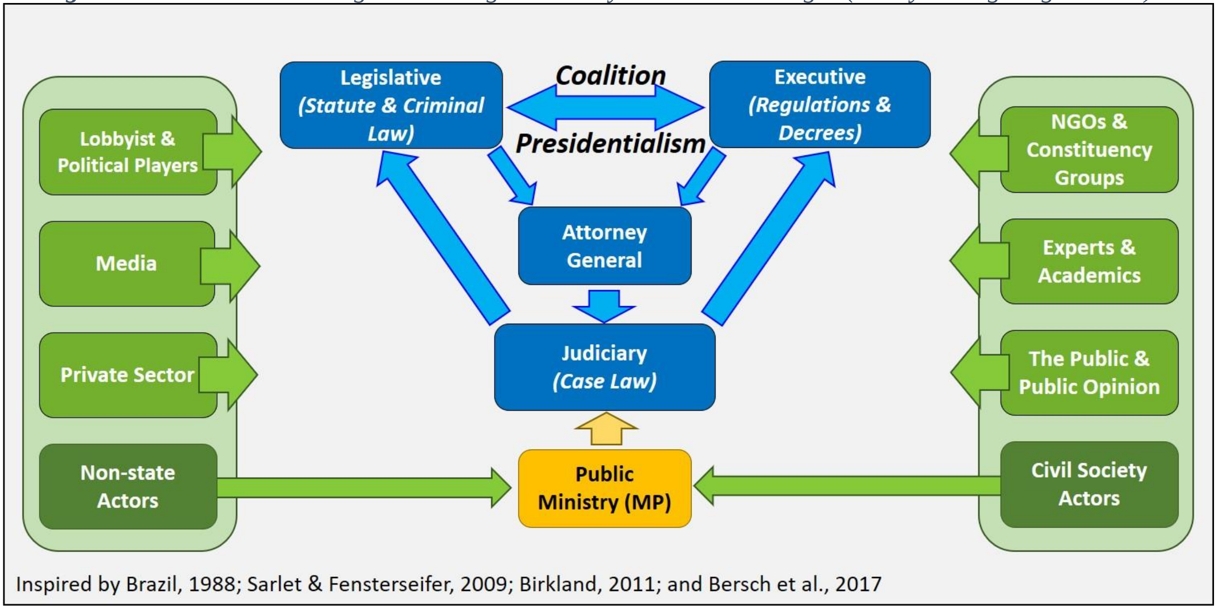
[7] a favor for a favor

happens the judiciary could be engaged and rule on legal decisions that could determine the direction of public policy. Additionally, in the specific context of Brazil and in light of corruption scandals, the role of Brazil's judiciary in mediating national politics has influence over shaping policy (KATZ, 2018).

In Brazil, the role of litigation in the context of environmental and social protections is important. For example, 67.5% of environmental public civil actions are successful in Brazil (BOYD, 2012). In the context of proactive action, there are success stories in Brazil where litigation has resulted in rulings requiring the protection of the environment and provision of basic environmental services (BOYD, 2012). Moreover, the role of the MP as an independent institution not falling under the direct control of any of Brazil's three branches of government, is important for ensuring that Brazilian citizen's fundamental rights are upheld in the case that the State infringes on those rights. Individuals and civil society actors can report and call on the MP to investigate alleged violations of constitutional rights (SARLET; FENSTERSEIFER, 2009, p. 256). However, the most vulnerable communities commonly have the most difficulty in fighting back against infringements on their fundamental rights. For the communities most affected by environmental degradation, it is often difficult for them to actually influence the legal or policy process or take advantage of their constitutional rights to a healthy environment. This is because these communities commonly lack: awareness of their rights, financial resources, and general access to legal assistance, and additionally they sometimes hold distrust of the judicial system (BOYD, 2012). **Figure 5** represents the interactions between the federal branches and MP during the first two of five public policymaking stages: (i) the agenda setting and (ii) policy formulation stages. Note that the passive character of the judiciary and reactionary nature of popular action can result in the executive and legislative branches having to reformulate policy that is already being implemented.

Figure 5 - Brazil's Federal Agenda Setting and Policy Formulation Stages (Policymaking Stages 1 & 2)



Blue blocks correspond to state institutions and factors in the public policymaking process which include the three branches of government and the Federal Attorney General (which is a key institution in the executive branch). **Light blue arrows** show the direction that each branch (or the Attorney General) may exert influence on one another in the policymaking process. **Yellow blocks** represent key independent state institutions that are completely separated from the three branches of government, such as the Public Ministry (MP). **Light yellow arrows** show the direction of interaction and influence that independent institutions have on other state institutions or factors. In this case the MP directly interacts with the judiciary. **Green blocks** represent non-state actors that may influence agenda setting or and policy formulation. **Light green arrows** show the direction of influence that non-state actors exert on state institutions, either on agencies connected to one of the three branches of government or by directly engaging with an independent institution, in this case the MP.

Once policy is formulated and has legislative and executive support, and any necessary supporting secondary laws are drafted and passed, policy is officially adopted by the government. Adopted policy is sent to relevant ministries and agencies, usually in the executive branch, that are tasked with implementing the policy. During the policy implementation stage there are various factors that can affect successful implementation. However, it is during the final policy evaluation stage where policy outcomes and effectiveness are assessed to determine if changes need to be made. It is at this final stage that ultimately governance can be assessed.

Focusing only on 'traditional' state governance, Fukuyama (2013, p. 350) defines governance as, "government's ability to make and enforce rules, and to deliver services", and indicates that good governance results from a variety of influences that can be boiled down to two principal variables, the government bureaucracy's autonomy and capacity. In the context of Brazil and in light of coalition presidentialism, Bersch et al. (2017a) indicate the importance of an additional variable which is the level of partisan dominance held by executive appointees in Brazil's ministries and agencies. They found that low bureaucratic capacity is correlated with higher amounts of partisan domination by political appointees, i.e. having appointees primarily from one dominant party versus appointees from a plurality of coalition parties in the same agency. Moreover, partisan domination is associated with higher reports of corruption; however, the institution's bureaucratic autonomy appears to influence to what degree corruption is reported. Their results overwhelmingly show that lower capacity and lower autonomy institutions have higher partisan dominance. All things equal, increased levels of politicization of the bureaucracy have detrimental impacts on governance (BERSCH; PRAÇA; TAYLOR, 2017a), and partisan dominance significantly explains which of Brazil's federal ministries and agencies are among regularly underperforming institutions while others are included in Brazil's so called 'islands of excellence' (BERSCH; PRAÇA; TAYLOR, 2017a; THE WORLD BANK, 2016). Moreover, based on the results presented by Bersch et al. (2017a, p. 113), none of the relevant executive ministries and agencies involved in transportation development or environmental and social protections[8] fall among Brazil's 'islands of excellence', i.e. those agencies that are predominantly associated with high capacity, moderate to high autonomy and low to moderate partisan domination.

In light of Bersch et al.'s (2017a) analysis, it is important to note that in Brazil the federal executive bureaucracy (not taking into account the military or publicly owned companies) is predominantly staffed by highly educated civil servants (*concursados*) who must pass competitive and demanding civil service exams to obtain their positions (BERSCH; PRAÇA; TAYLOR, 2017b). However, the Brazilian executive still controls between 22,000 to 40,000 political appointment positions throughout Brazil (ALSTON; MUELLER, 2006; BERSCH; PRAÇA; TAYLOR, 2017b) and it is through these positions that the patronage resulting from coalition presidentialism is conducted. In the context of overall partisan dominance as outlined by Bersch et al. (2017a) these patronage appointments can have eroding effects on policy outcomes. Additionally, the appointees do not necessarily have technical expertise in the policy area of their appointment position. Finally, it is not uncommon for desired infrastructure ministries and agencies to be used patronage tools as these agencies can help appointees achieve individual goals (BERSCH; PRAÇA; TAYLOR, 2017a).

Finally, two additional actors may impact federal policy implementation in Brazil. Firstly, non-state actors may have some influence in policy implementation, via information sharing with ministries and agencies, through special interest connections, or potentially being an official partner in policy implementation. Secondly, at the policy adoption and in review of policy implementation stages where the TCU's constitutional mandate of external control is constitutionally applicable, the TCU has authority to analyze whether the use of national resources and patrimony (financial and in other forms) is a legal, legitimate and economically efficient use of those resources by carrying out cost-benefit analyses and performing audits. In instances for adopted but not yet implemented PPPs, the TCU's cost-benefit analysis and feasibility study review has the legal power to determine that an adopted PPP should not even be implemented (GONÇALVES et al., 2017).

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[8] These include the National Department of Transportation Infrastructure (DNIT), the Palmares Cultural Foundation (FCP), the National Indigenous Peoples' Foundation (FUNAI), the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA), Chico Mendes Institute for Biodiversity Conservation (ICMBio), the National Institute for Colonization and Agrarian Reform (INCRA), the Ministry of the Environment (MMA), the Ministry of Transportation, Ports and Aviation/Ministry of Infrastructure (MTPA/MoI).

Moreover, there has been a small but growing amount of literature investigating the TCU's role as an independent external control agency in the field of environmental protection and regulation[9]. In the context of infrastructure development and for the focus of this study, highways and railroads considered to be of 'significant importance' (with budgets above R$ 20 million) and all federal infrastructure involved in P3s, which includes the PPI program, fall within the external review scope of the TCU (DNIT, 2010; TCU, 2006, 2018). This auditory review must be undertaken before the planned infrastructure project can be implemented by the State or sold in a concessionary auction. For highways and railroads the National Department of Transportation Infrastructure (henceforth DNIT, for *Departamento Nacional de Infraestrutura de Transportes*) must provide the TCU with a Technical, Financial-Economic and Environmental Feasibility study (henceforth EVTEA, for *Estudo de Viabilidade Técnica, Econômico-Financeira e Ambiental*). EVTEAs must outline the costs, benefits, and risks of the project and must also investigate the economic, technical, social and environmental feasibility and sustainability of the infrastructure project and impact to the surrounding region (DNIT, 2010; NÓBREGA et al., 2016). However, the TCU has only been able to incorporate environmental valuations into its analysis based on the price of implementing command and control environmental regulations and legally established fines for its environmental impact value assessments (LIMA, 2016). Although these estimates are still important, unfortunately the TCU still has not incorporated any additional market value estimates that environmental impacts may cause into its cost-benefit analyses (BOCANEGRA, 2017; LIMA, 2016). Furthermore, even though there are academically established economic methodologies for estimating the market value of environmental and even some social impacts from infrastructure development[10], DNIT guidelines fail to mention that these methodologies can be nor require that they be utilized in EVTEAs. Moreover, the third-party consulting firms that undertake EVTEAs regularly justify not implementing such calculations due to time and resource constraints (BOCANEGRA, 2017). **Figure 6** highlights the interaction of the mentioned actors at the final three stages of public policymaking.

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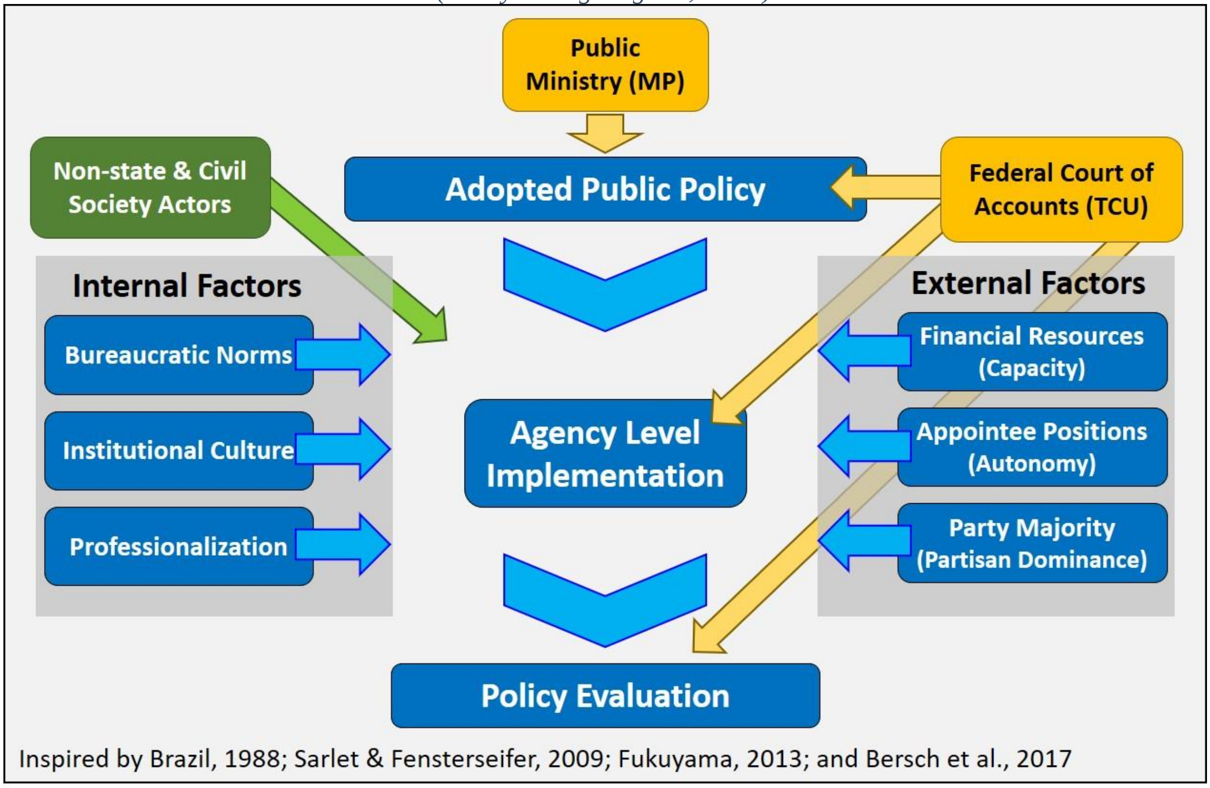
9 A significant portion of this research has been conducted by Luiz Henrique Lima, see: LIMA, 2009, 2000, 2005, 2011, 2016; LIMA; MAGRINI, 2010

10 These include using: Direct and Indirect Evidence from Markets, Market Demands and Prices, Travel-Cost Methods, Hedonic Price Analysis, Evidence from Self-Reports, Contingent Valuation, among others.

Figure 6 *- Brazil's Public Policymaking Adoption, Implementation and Evaluation Stages (Policymaking Stages 3, 4 & 5)*



Large light blue chevrons indicate transitions between policymaking stages. **Blue blocks** correspond to state institutions and factors in the final policymaking stages which are usually connected to the executive branch of government. Internal factors represent inherent variables in any bureaucratic institution that develop internally within a specific ministry or agency, i.e. the developed internal culture of the institution. External factors represent state and political forces coming from within the government system but 'outside' of the Weberian bureaucratic system inherent in each ministry or agency. These external factors are affiliate with presidential control over ministry budgeting and organization, political appointees within the ministries and agencies, and the level of legal or political autonomy that a ministry or agency enjoys from the executive branch. **Light blue arrows** show the direction of influence that one state factor may exert on another in the policymaking process. **Yellow blocks** represent key independent state agencies that are completely separated from the three branches of government, such as the Public Ministry (MP) and the Federal Court of Accounts (TCU). **Light yellow arrows** show the direction of interaction, influence, and jurisdiction that independent institutions have on other state institutions or factors. Note that the MP and TCU have jurisdiction to act at all three of the above policymaking stages (adoption, implementation, evaluation). The MP has the legal mandate to challenge executive action at these stages by engaging the judiciary, either through public civil action or popular action. The TCU has constitutional jurisdiction to perform external control on executive branch spending and determine the legality, legitimacy, and economic efficiency of policy at these stages. The TCU can also receive information from civil society which may prompt them to perform external control audits. **Green blocks** represent non-state actors, form civil society or the private sector, that may influence policy adoption, implementation, or the public discourse surrounding policy evaluation. **Light green arrows** show the direction of influence that non-state actors exert on state institutions.

2.5 – Brazil's Governance Structure

So far, the primary focus of this analysis has been given to the state institutions involved in the law and public policymaking processes, as well as some reference to non-state actors. Within the Brazilian State the principal duty to execute environmental governance lies with the executive and to a lesser extent with the legislature (SARLET; FENSTERSEIFER, 2009, p. 263) through policymaking and drafting laws. Additionally, as noted, the judiciary can impact if and how law or policy can be fully implemented (TAYLOR, 2007). However, law and policy are part of the larger process of governance[11].

In recent decades, non-state actors have become important agents in the overall socioenvironmental governance process throughout the world, including groups from civil society or the private sector. Moreover, information networks, community engagement, and market mechanisms have come to light in the emerging new governance systems (BAKER, 2018; JORDAN; BENSON, 2018). Moreover, governance occurs at multiple levels, from global to local, giving rise to the concept of multi-level governance (JORDAN; BENSON, 2018). Non-state governance actors may establish formal or informal relationships with the State, or among one another and not even involve the State. These types of arrangements and players have also become important in the realm of environmental governance.

According to Newig and Fritsch (2009, p. 199) multi-level governance has been defined as

> "[…] political structures and processes that transgress the borders of administrative jurisdictions, aiming to cope with interdependencies in societal development and political decision-making which exist among territorial units. Systems of governance at different levels are typically assumed not to be hierarchical in a chain-of-command sense, but rather to comprise formally independent, yet mutually interacting governance levels, which can be distributed either 'vertically' or 'horizontally'."

According to Lemos and Agrawal (2006, p. 298) environmental governance refers to

> "[…] the set of regulatory processes, mechanisms and organizations through which political actors influence environmental actions and outcomes. Governance is not the same as government. It includes the actions of the State and, in addition, encompasses actors such as communities, businesses, and NGOs. Key to different forms of environmental governance are the political-economic relationships that institutions embody and how these relationships shape identities, actions, and outcomes."

In Brazil, non-state actors, networks and market tools have emerged in the context of environmental governance. A relevant example is Brazil's Soy Moratorium (SoyM), originally brokered

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[11] Government does not necessarily have to be present for governance to exist. As explained by Hufty (2011, p. 405), "Decision-making processes, social norms, and institutions are inherent to social life, allowing members of any society to live together and cooperate, even without a state. It is now widely acknowledged that there are political processes at work in non-state societies as well."

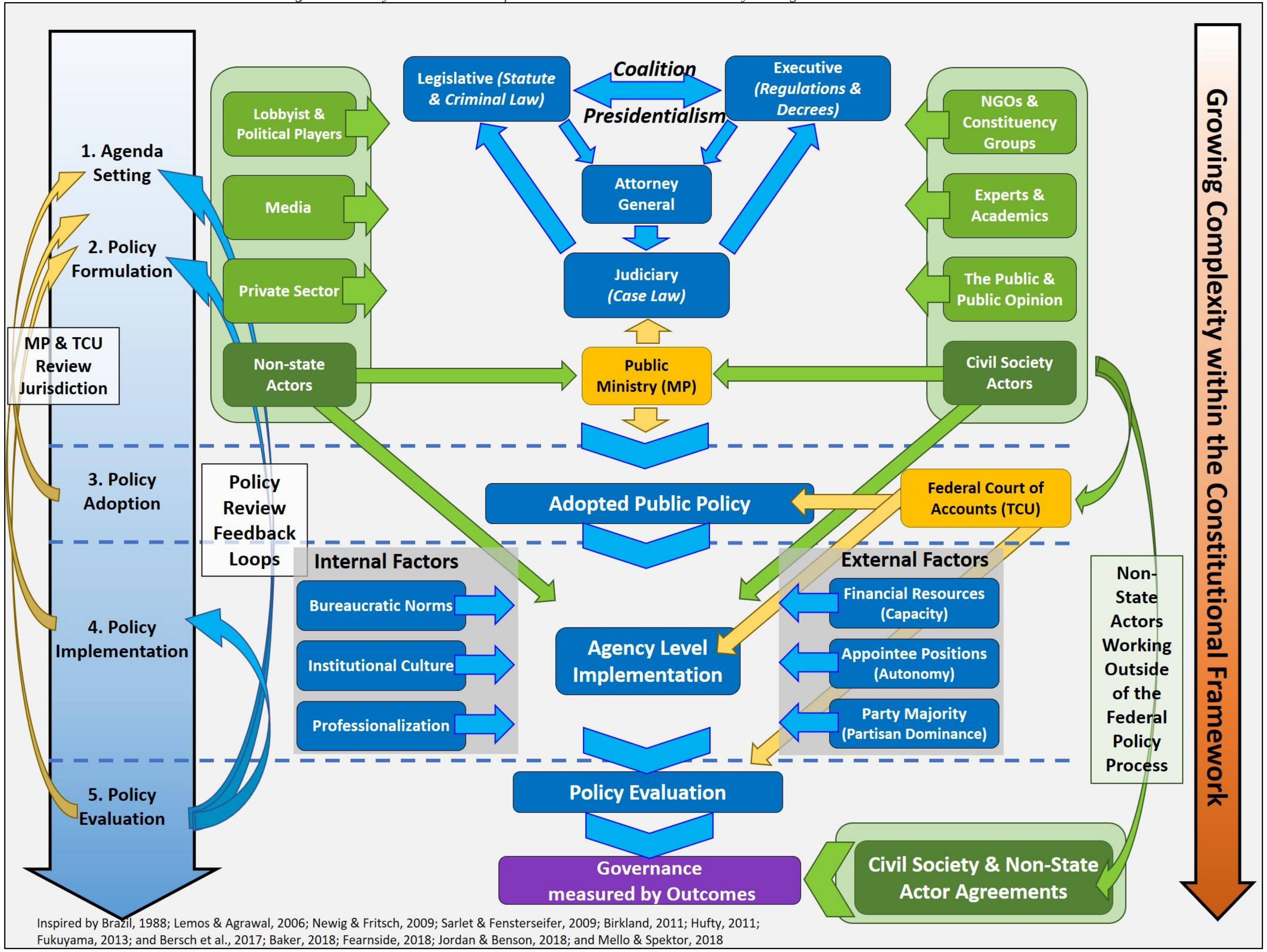
between environmental NGOs and soy traders in Brazil (GIBBS et al., 2015). NGO actors and purchasing retailers higher up in the soy supply chain asserted enough pressure on soy traders that all parties entered into a voluntary zero-deforestation agreement in 2006. This agreement did not originally involve the Brazilian government. However, in 2008 Brazil's Ministry of the Environment (henceforth MMA, for *Ministério do Meio Ambiente*) joined the SoyM and Brazil's Institute of Space Research (henceforth INPE, for *Instituto Nacional de Pesquisas Espaciais*) in providing deforestation monitoring support for the SoyM (GIBBS et al., 2015). In consideration of all the identified actors and points of interaction during the federal policymaking process, **Figure 7** shows the general governance structure that likely occurs for most public policy at Brazil's Federal level based on our analytical framework analysis.

In order to gauge how socioenvironmental governance is performing in Brazil we propose that good socioenvironmental governance would equate to positive environmental and social outcomes which include:

(i) Maintaining current levels or, enhancing tangible environmental and biodiversity protections and conservation;
(ii) A reduction in net GHG emissions;
(iii) A reduction in other types of pollution;
(iv) Enhanced energy efficiency and a net expansion of renewable energy generation in the national system, that is also developed in a low impact manner; and
(v) Effective protection of the fundamental human and territorial rights of Brazil's indigenous, quilombo and other traditional peoples, which would include a significant portion of Brazil's remaining tribes and quilombos that still do not have secure land rights receiving full legal recognition to their land and reduced instances of violence and suppression of FPIC rights.

Unfortunately, an overwhelming majority of the relevant literature indicates that Brazil, while acknowledging that there was a period of moderate progress, is not meeting the above criteria (FEARNSIDE, 2018; FERNANDES et al., 2017; HANNA, 2016; ROCHEDO et al., 2018; SOARES-FILHO; RAJÃO, 2018), and moreover that the recent positive progress towards reaching the mentioned criteria has actually backtracked in recent years.

Figure 7 - *Analytical Framework for Brazil's Theoretical Public Policymaking and Governance Structures*



Brazil's policymaking structure and processes in the context of governance. Incorporating Figures 5 and 6, all previously outlined public policy actors and factors (branches of government and state institutions, independent state institutions, and non-state actors) are located in the five policymaking stages as indicated by the large top-down blue arrow on the left-hand side of the graphic and horizontal dashed blue lines crossing the graphic. Additionally, on the left-hand side of the graphic there are two feedback cycles represented by the curved yellow and light blue arrows. The yellow feedback cycles represent the influence that Brazil's key independent institutions, the MP and TCU, can exert on the policymaking process either through engaging the judiciary to set legal jurisprudence in relevant matters or through establishing external control norms that reinforce set standards to be met at the policymaking stages that fall into their jurisdiction of external control. The blue feedback cycles represent the theoretical policy review processes that the executive and legislative branch would normally undertake to evaluate whether their implemented policies solved the identified issues that policy was created for. On the right-hand side of the graphic, a green curved arrow connects non-state actors at the policy formulation stage to the policy evaluation stage. In emerging multi-level environmental governance non-state actors may engage one another and not involve state actors to come to a mutual or contractual agreement. However, when the outcomes of these non-state actor agreements are combined with the outcomes of the government's public policymaking process, we have an overall measurement of governance. Finally, the arrow to the extreme right-hand side of the graphic represents constitutional complexity. As policy and non-state actors work throughout the policymaking process, keeping policy within the bounds of the constitution usually becomes more difficult. For example, policy goals may be constitutional, the established implementation process on paper may appear to be constitutional; however, when policy is evaluated infringements on constitutional rights may emerge.

2.6 – Identifying Breakdown Points in the Governance Structure

Corruption has historically played a part in Brazil's infrastructure development; however, it is important to note that this is the common reality in many other countries (ARMIJO; RHODES, 2017). Nevertheless, in the wake of continued corruption scandals it has become clear that political players from private industry or other levels of government also provide influential pressure throughout the policymaking process (MELLO; SPEKTOR, 2018). Brazil's established political culture of pay-to-play incentives in the form of bribery, also referred to as crony capitalism (AMANN; BARRIENTOS, 2016; ARMIJO; RHODES, 2017; FRONZAGLIA et al., 2014), is likely reinforced by coalition presidentialism and the political environment that it fosters (BERSCH; PRAÇA; TAYLOR, 2017a). This is highlighted by corruption during the first stage of PAC, in that if the estimated financial losses due to corruption were prevented, correct use of project funds could have resulted in 124% more built roads and 525% more built railroads (AMANN et al., 2016).

Moreover, greenfield investment is not the most desirable form of foreign direct investment (FDI), especially in Brazil due to the associate high transactional costs i.e. the "Brazil Cost"[12] (*Portuguese – "Custo Brasil")*. Part of the "Brazil Cost" can be attributed to the fact that doing business in Brazil, especially in the infrastructure and utilities sectors often involves high levels of regulatory risk[13] which dissuades private sector investment in these markets (AMANN et al., 2016). This environment explains why FDI in Brazil is overwhelmingly carried out by joint-ventures (foreign-domestic partnerships), acquisitions, and mergers. Due to this high cost and risk, the only source of FDI that appears to be willing to actively participate in Greenfield investments are Chinese firms (BERNARDI; FLOYD, 2018).

The existing literature indicates that, in Brazil, environmental and social consideration are frequently, if not almost always, inadequately considered or are not considered at all during the initial stages of transportation PPP making processes (DO NASCIMENTO NADRUZ et al., 2018; MALVESTIO; FISCHER; MONTAÑO, 2018; SÁNCHEZ, 2017). This is likely the result of: (i) the influence of *quid pro quo* political patronage in the federal budgeting process, (ii) delegated patronage positions in many of Brazil's infrastructure ministries and agencies resulting from coalition presidentialism, (iii) Brazil's continued economic dependence on commodities exportation due to the omnipresent developmentalist paradigm, and (iv) prevalence of investment risk and corruption. This reality not only includes a lack of social and environmental considerations in transportation PPPs (MALVESTIO; FISCHER; MONTAÑO, 2018) but also extends to many other federal infrastructure

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[12] "'Brazil Cost' is a general term used to describe the structural, bureaucratic and economic difficulties that increase the cost of investing in Brazil, hindering national development, causing rises in unemployment, informal labor and tax evasion. For this reason, it is known as a set of factors that compromise the competitiveness and efficiency of Brazilian industry" (MYSZCZUK; SOUZA, 2016, p. 308).

[13] Regulatory Risk is the risk of having the 'license' or 'permission' to partake in or operate business activities withdrawn by a regulator, or having conditions applied (retrospectively or prospectively) that negatively impact the economic returns of a business enterprise (INVESTOPEDIA, 2018).

PPPs such as energy, large industry and agriculture (DO NASCIMENTO NADRUZ et al., 2018; SÁNCHEZ, 2017). Thus, the decision-making occurring at the federal level prioritizes ecologically damaging ‘development’ projects that in practice do not consider alternatives (FEARNSIDE, 2018).

Unfortunately, this negligence has even commonly occurred in cases where Strategic Environmental Assessment (SEA) has been implemented (DO NASCIMENTO NADRUZ et al., 2018; MALVESTIO; FISCHER; MONTAÑO, 2018; SÁNCHEZ, 2017; ZIONI; FREITAS, 2015). SEA is described as a policy level environmental impact assessment (EIA) mechanism specifically designed and intended to incorporate socioenvironmental issues and considerations into the initial PPP stages to avoid possible negative impacts once a project is constructed (FISCHER, 2002). This is concerning for a variety of reasons, but in specifically because SEA has already been proposed by the TCU to be implemented by federal government ministries at the PPP making stage to aid in resolving significant environmental lapses that regularly occur later at the implementation stage and thus result in uneconomic use of national resources (LIMA, 2005). However, given the short-sighted and economic focused approach of transportation PPP making in Brazil (EBENAU; LIBERATORE, 2013), serious consideration of environmental and social issues is usually passed on further down the line to the project specific level, i.e. after the transportation PPP making stage (MALVESTIO; FISCHER; MONTAÑO, 2018).

The second point along Brazil’s governance structure where environmental and social impacts are supposed to be accounted for, in order to identify all possible viable alternatives (MALVESTIO; FISCHER; MONTAÑO, 2018), is the EVTEA stage. The role that EVTEAs play in ensuring that decision-makers are well informed is paramount. Even so, the EVTEA process may be in need of reform as the same negative environmental and social impacts are still being repeated regularly in Brazil (NÓBREGA et al., 2016). Federal level actors are aware that the EVTEA process may be in need of modernization, but due to limited resources federal agencies report that they lack the appropriate mechanisms and human resources to bring about the necessary change (NÓBREGA et al., 2016).

The problems that seem to emerge during the EVTEA come from the highly fragmented decision-making at the federal level, which is vulnerable to political pressures (AMANN et al., 2016). Information across ministries and agencies is often times conflicting and can hinder integrated planning of the national transport network at large scales (GONÇALVES et al., 2017). Moreover, this appears to indicate that siloed public policymaking (top-down within agencies but low horizontal interagency communication) is common in Brazil’s federal institutions (GONÇALVES et al., 2017). As a result, pertinent information falls through the cracks due to the fragmented communication and information sharing. Additionally, this means that the information shared between government agencies and private consulting companies involved in preparing EVTEAs is sometimes inaccurate. Even in cases where a consulting company may prepare an EVTEA in complete good faith, some of the official information they base their EVTEA findings on may be judged as inaccurate and when reviewed by the TCU, and these inaccuracies may jeopardize the infrastructure project altogether (GONÇALVES et al., 2017).

Due to institutional time constraints, the TCU's technical analysts have a short amount of time to review EVTEA studies (formerly only 30 days but recently extended to 75 days) (NÓBREGA et al., 2016; TCU, 2018). In this context, the common lapse of adequate due diligence on the part of DNIT and their contracted consulting firms when drafting EVTEAs for highways and railroads is often not completely caught by the TCU's technical analysts (NÓBREGA et al., 2016).

In the event that unresolved issues sneak their way through the TCU's feasibility review stage, the projects that were given inadequate proposal design prior to concessionary auctions may create significant regulatory risk for the concessionary auction winner once they begin the EIA process (ARMIJO; RHODES, 2017). This is because the due diligence responsibility for resolving environmental and social impacts is passed onto the concession winner once a project arrives at the EIA and Preliminary Licensing (PL) stage. In many of such cases, the concession winner is commonly ill equipped to deal with the unresolved environmental and social impact issues and significant delays with IBAMA are caused due to a lack of adequate prior scoping (BORIONI; GALLARDO; SÁNCHEZ, 2017). As a result of leaving a significant amount of the environmental and social impacts to be resolved at this final stage, which also lies at the final stages of Brazil's governance structure, it is no surprise that the literature also overwhelmingly indicates that the environmental licensing process in Brazil has significant problems (BORIONI; GALLARDO; SÁNCHEZ, 2017; DUARTE; DIBO; SÁNCHEZ, 2017; FONSECA; SÁNCHEZ; RIBEIRO, 2017; HANNA et al., 2014; HOCHSTETLER, 2017; RITTER et al., 2017) and specifically at the PL stage when the infrastructure project's final location and design are analyzed (LIMA; MAGRINI, 2010).

These three stages, the PPP stage (when SEA is implemented), the EVTEA stage and the EIA/LP stage, mark the specific systemic breakdown points where socioenvironmental rights and protections covered by the constitution, secondary laws, and international conventions are infringed upon or ignored. Although we cannot determine intent nor whether on purpose or not, we can highlight that improved socioenvironmental considerations, protections and safeguards must be implemented at these stages. Large infrastructure projects in general, but transportation infrastructure in specific, when not planned correctly lead to significant environmental and social impacts.

In this context, we highlight three relevant ministries and internal public policymaking processes that contextualized the interchanges, or lack thereof, between MTPA/MoI, MMA, and Brazil's Ministry of Foreign Affairs (henceforth MRE, for *Ministério de Relações Exteriores*). MTPA/MoI, and its sub-agency DNIT are charged with implementing transportation policy and supposed to consider environmental and social considerations during transportation planning and implementation. MMA is charged with implementing environmental policy relevant to climate change, deforestation and LULC change, and biodiversity conservation, which are commonly negatively impacted by Brazil's large transportation infrastructure projects. MRE is charged with negotiating international agreements on behalf of the Brazilian government that cover the same environmental and human rights issues that commonly come into conflict with transportation infrastructure projects at the implementation stage.

Moreover, the three aforementioned systemic breakdown points, the PPP stage (when SEA is implemented), the EVTEA stage and the EIA/LP stage, occur concurrently at four public policymaking stages within each of the highlighted ministry's policy arenas: the policy formulation, adoption, implementation, and evaluation stages. We postulate that, aside from all other overarching factors already discussed, siloed public policymaking leads to low horizontal cross-ministerial communication and with this structural issue at play significant problems and policy contradictions are bound to occur.

2.7 – Brazil's Conflicting Legal Basis: Governance Outcomes Start at the Beginning

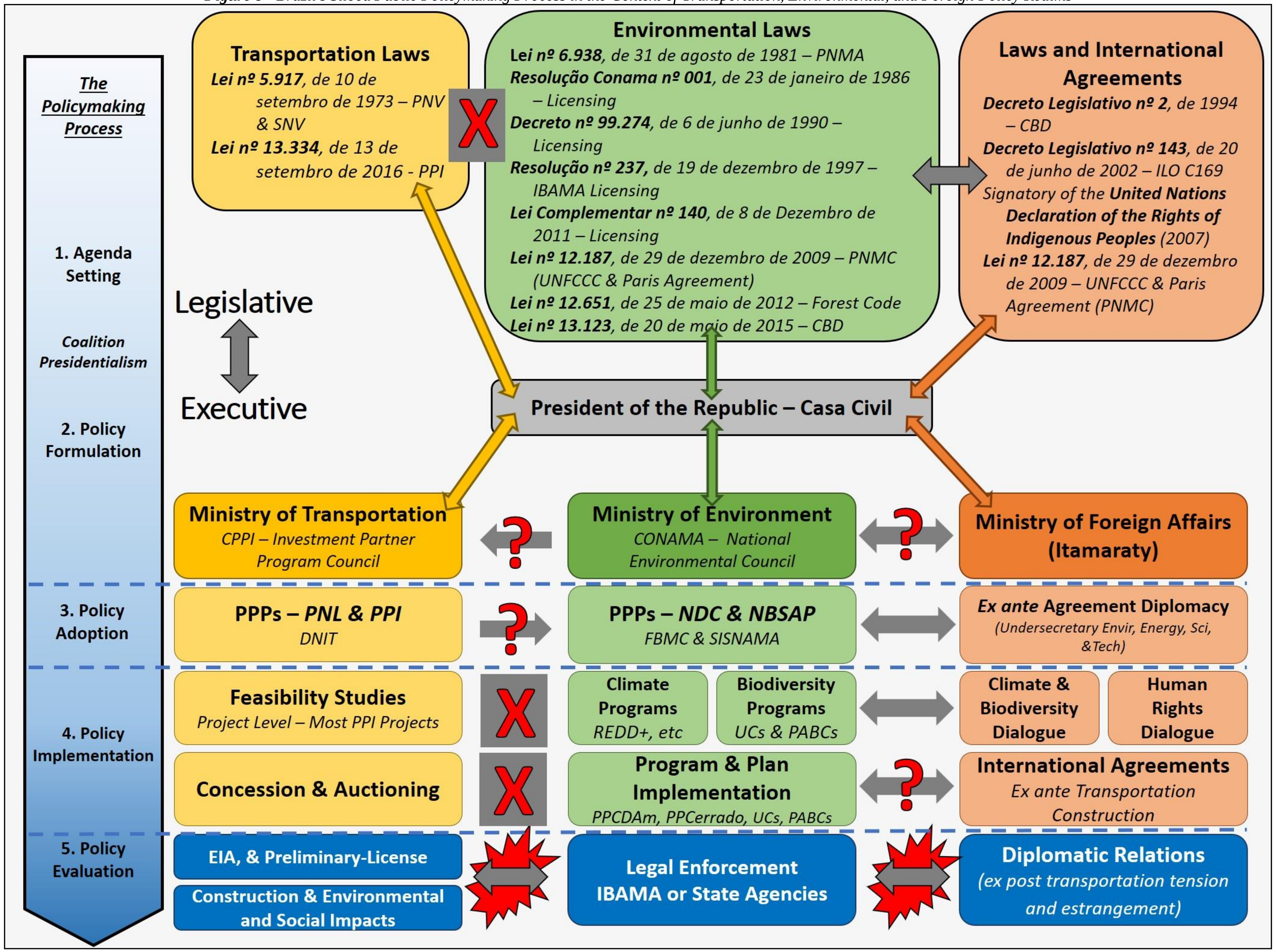
Public policymaking occurs within an already existing legal structure. Policymaking can result in new laws; however, it usually has to work within the confines of existing laws or have new secondary laws drafted to support established goals. The legal framework for the policy areas of each of the three mentioned ministries shows conflict. The environmental laws and regulations that form the legal mandates for MMA are complementary to the international environmental and human rights agreements negotiated by MRE. However, these laws and international agreements directly conflict with the goals, design and articulation of the two main laws that form the foundation for Brazil's current transportation policies. Firstly, the law that principally guides the design and interregional connections of Brazil's federal highway and railroad systems, Federal Law n. 5.917, of September 10, 1973 was established before any of Brazil's significant environmental protection, environmental licensing or current international environmental and human rights agreements came into effect (BRAZIL, 1973). This means that no changes have been made to Brazil's guiding blueprint for terrestrial transportation infrastructure even in the light of significant advances in environmental and human rights protections. Secondly, some of these same plans are now being called into implementation by Federal Law n. 13.334 of September 13, 2016 which established the PPI infrastructure program (BRAZIL, 2016a). Moreover, this law stipulates that PPI's Executive Council has the power to mandate deadlines for IBAMA, FUNAI and any other relevant agencies involved in the EIA/LP stages and demand licensing approval regardless of impacts or complexity of the EIA (FEARNSIDE, 2018).

2.8 – Governance Analysis Synthesis

The diagramed synthesis of our analysis is outlined by Figures 8, 9, 10 and 11. **Figure 8** outlines the three legal areas and the current laws on the books that are the foundation for policy making in each of the aforementioned ministry's general public policymaking arenas. Then the public policy stages are matched to institutional policy workflows at each of the three ministries. Finally, the siloed manner of implementing policy in each of the three ministries creates difficulty when an infrastructure project undergoes an EIA and is reviewed at the LP stage. **Figure 9** complements Figure 8 by indicating where the systemic breakpoints of socioenvironmental impacts are located in relation to the policymaking stages and ministerial workflows. Finally, **Figure 10** presents our understood Political and Public Policymaking Systems model in the context of Brazil and infrastructure development and **Figure 11** presents a modified and more realistic version of Brazil's governance structure in the context of infrastructure and socioenvironmental issues as opposed to the generic ideal structure proposed in **Figure 7**.

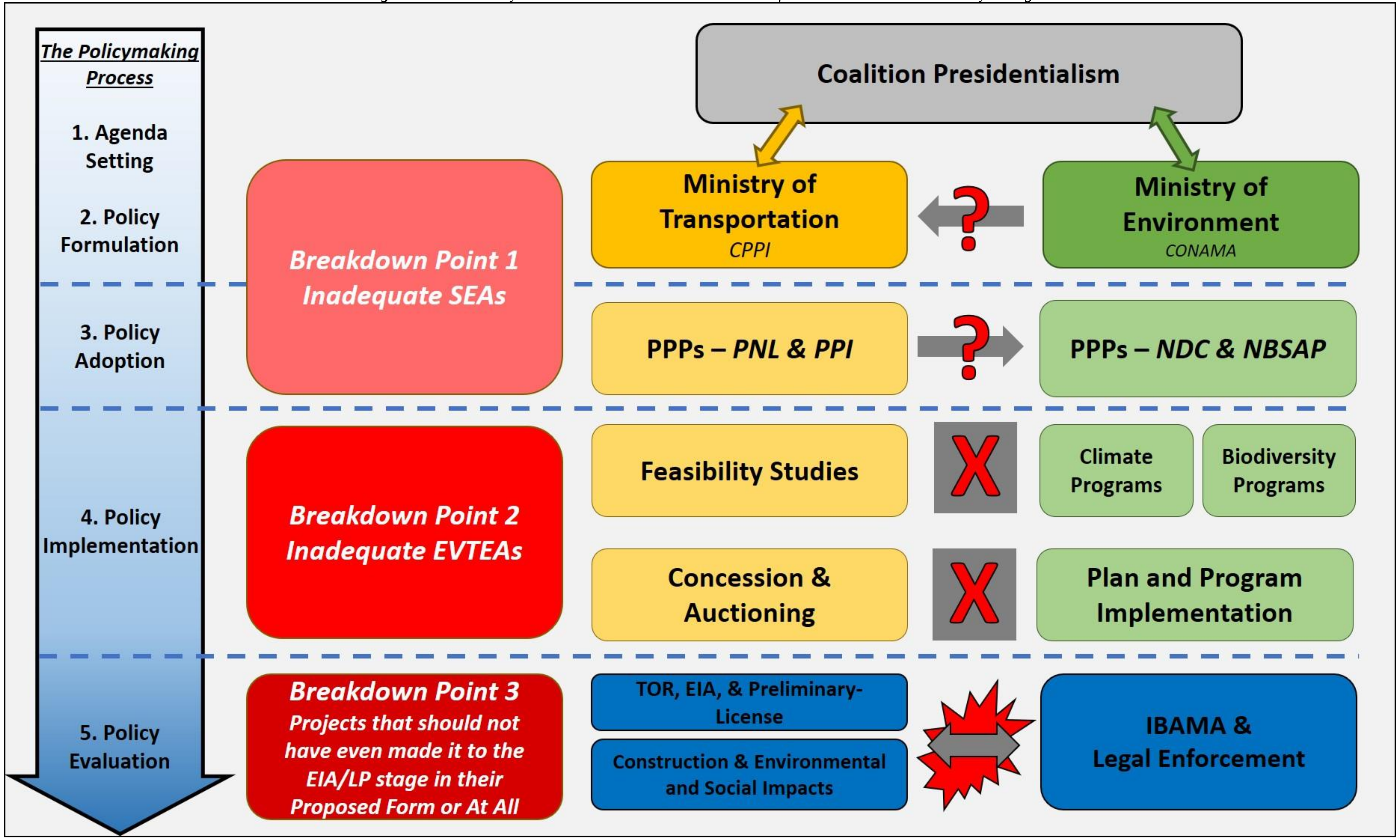
In synthesis, these diagrams show that the EIA/LP process is set up for significant problems from the very beginning of infrastructure planning. The combination of conflicting laws, pork barrel politics, systemic breakdown points, siloed policymaking, potential corruption, and the overall governance structure has ensured that a system of conflict has persisted. On the one hand the EIA/LP process has repeatedly come under scrutiny by environmental advocates and most environmental scientists who believe that there are many problems with the effectiveness of the Brazilian EIA process (DUARTE; DIBO; SÁNCHEZ, 2017). On the other hand, politicians and business groups believe the environmental licensing process is a significant and unjust burden and needs to be reformed and streamlined (FONSECA; SÁNCHEZ; RIBEIRO, 2017). The angst felt by both sides is due to the fact that problematic environmental and social issues commonly emerge that could have been avoided earlier (BAKER et al., 2013), which in turn leads to a challenging scoping process and thus significantly complicating and delaying the completion of the EIA. Furthermore, this causes the publication of the project specific Environmental Impact Statement (henceforth RIMA, for *Relatório de Impacto ao Meio Ambiente*) to be delayed thus delaying the issuance of the LP. As a result, there are significant delays in the infrastructure project's development (BORIONI; GALLARDO; SÁNCHEZ, 2017).

Figure 8 *- Brazil's Siloed Public Policymaking Process in the Context of Transportation, Environmental, and Foreign Policy Realms*



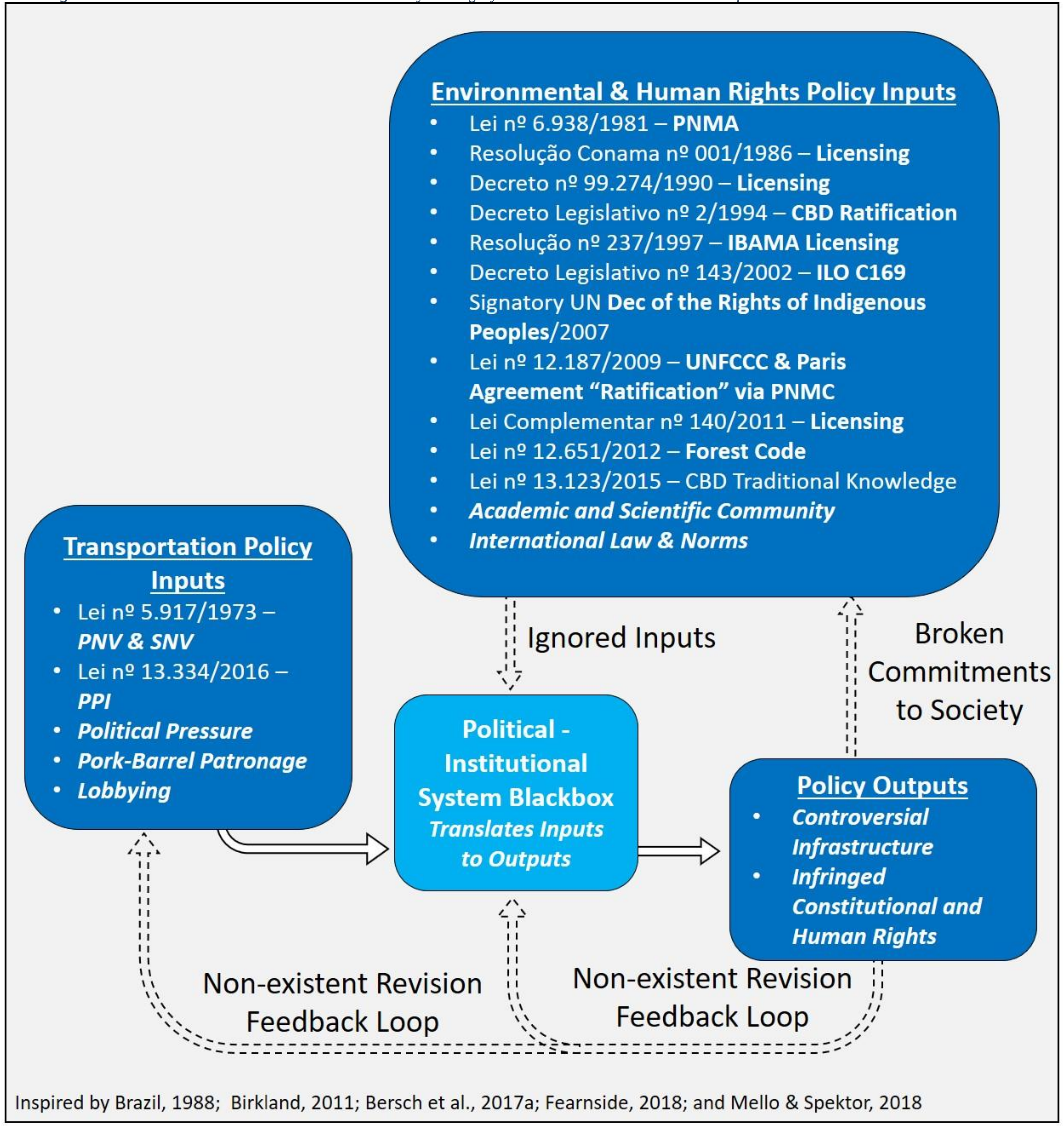
This graphic represents three executive ministries that guide the public policy processes connected to transportation development and socioenvironmental issues. Moreover, the policies being formed, adopted, implemented and 'evaluated' by these agencies occurs with a conflicting legal foundation. Brazil's principal transportation law, Federal Law n. 5.917/1973 guides the Federal Highways and Railroads that are to be eventually built throughout the country. These proposed routes were designed before almost any of Brazil's significant environmental and social laws and international treaties became official. Furthermore, a recent transportation law, Federal Law n. 13.334/2016 includes a specific clause which can compromise the integrity of the environmental licensing process and thus the legal protection of Brazil's socioenvironmental laws and ratified treaties. Unfortunately, due to a siloed policy making process, these contradictions appear at the environmental impact assessment and preliminary licensing stages when the concessionary rights to an ill-planned infrastructure project has already been auctioned off to a developer. **Bi-directional arrows** indicate areas where horizontal compatibility or communication may exist between federal law categories or between ministries at the same policymaking stage. **Unidirectional arrows with question marks** indicate that there is stipulated one-way communication between ministries at the same policymaking stage; however, the effectiveness of communication or if communication actually even happens are highly questionable. **Boxes with a red X** indicate areas where horizontal compatibility of communication have no believable evidence of existing between federal law categories laws or between ministries at the same policymaking stage. Finally, **bi-directional arrows with a red explosion** at the bottom of the graphic, indicate the culmination of inadequate cross-ministerial policy integration and inadequate consideration of socioenvironmental impacts in the planning of transportation infrastructure that commonly result in a contentious and drawn out EIA/LP process.

Figure 9 *- The Three Systemic Breakdown Points in the Context of Siloed Ministerial Public Policymaking*



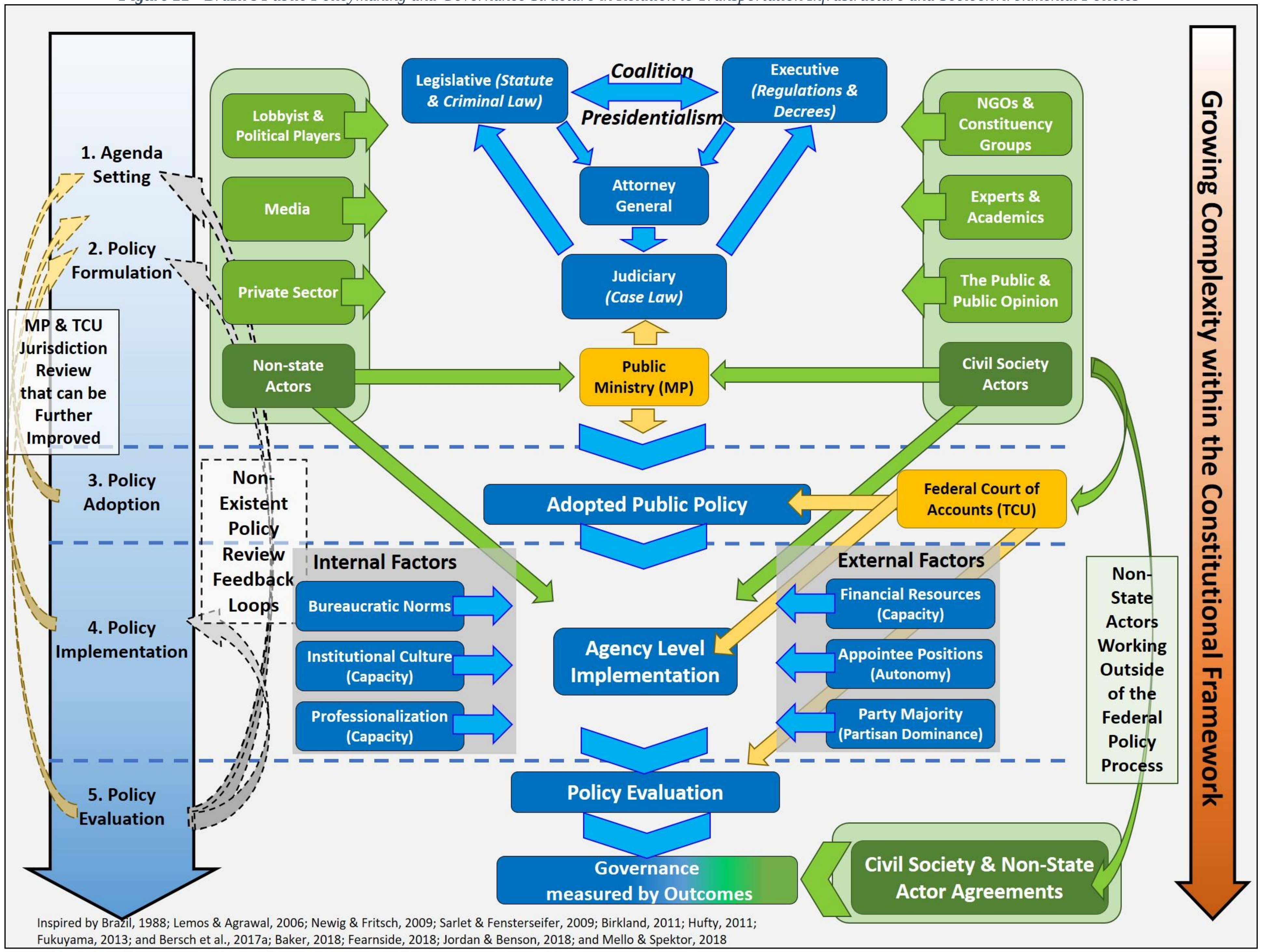
This graphic locates the three identified systemic breakpoints where socioenvironmental considerations occur in the context of the relevant ministerial public policymaking process.

Figure 10 *- The Brazilian Political and Public Policymaking Systems Model Related to the Transportation and Socioenvironmental Arenas*



This graphic can be compared to Figure 3 as being the actual Political and Public Policymaking systems model for transportation infrastructure and socioenvironmental issues in Brazil. In using a systems thinking approach, it becomes clear that system socioenvironmental inputs and revision feedback loops are blocked or non-existent.

Figure 11 *- Brazil's Public Policymaking and Governance Structure in Relation to Transportation Infrastructure and Socioenvironmental Policies*



This graphic differs slightly from Figure 7, in that it represents Brazil's public policymaking and governance structure in relation to large transportation infrastructure and socioeconomic policies and issues. Two subtle yet impacting differences are found on the left-hand side of the graphic. These include the **'weaker' yellow feedback loops** representing the MP and TCU's influence on policy and the **missing blue policy revision feedback loops** that the executive and legislative branch should undertake but appear not to. The yellow feedback loops in this image are "weaker" compared to Figure 7 due to a couple of factors. The MP, which is a very effective and high capacity institution (MUELLER, 2010), imposes a significant power in ensuring that environmental rights are protected. However, the judiciary system has to process a staggering number of caseloads and is notoriously slow (MCALLISTER, 2005; ZIMMERMANN, 2008). Additionally, judges do not always have the environmental scientific knowledge or expertise needed to understand complex environmental issues (SARLET; FENSTERSEIFER, 2009). Therefore, while the MP may not necessarily suffer from any weaknesses, the organization may benefit from additional outside help to make their cases more finetuned to be even more effective in the judicial process. For the TCU, due to previously mentioned analysis time constraints, having not incorporated existing environmental economic valuation methods into its analysis, and for past TCU suggestions to the executive branch to implement SEA, which evidence has indicated was not implemented efficiently, we believe that these feedback loops can be strengthened beyond their current state. The missing policy feedback loops represent the reality that infrastructure policy is still based on law that was drafted before any of Brazil's major environmental laws were passed and still has not been reformed to reflect current environmental policy objectives. Moreover, the reality on the ground indicates that environmental and social concerns are still ignored and thus no effective revision to reincorporate environmental and social impacts in the transportation policy process has appeared to have occurred. The result of 'weak' or missing feedback loops is indicated by the governance block which has a color gradient change from a low amount of green to a majority amount of blue. The green represents the fact that there have been successful non-state actor governance outcomes in recent years in Brazil, the SoyM being an example. However, state dominated outcomes, which overwhelmingly favor large transportation infrastructure projects with high environmental and social impacts, are still dominate.

2.9 – Proposed Call to Action to Counteract Socioenvironmental Governance Breakdowns

Using the graphical representations to highlight where the weak points for environmental and social considerations occur along Brazil policymaking process for transportation infrastructure and due to the current institutional capacity that fails to bring about change, an innovative approach is needed to fill these gaps in the decision making process (NÓBREGA et al., 2016). With scrutiny surrounding the EIA/LP processes in Brazil, we believe that neither drastic reform nor drastic additional rigor would be necessary if infrastructure was planned correctly in the first place. EIAs and the LP stage should always be rigorous; however, infrastructure that arrives at that point should also have already been properly vetted for socioenvironmental impacts twice before. We believe that spatially based models, focusing on context relevant environmental and social information, and incorporating a strong legal basis can serve as powerful reinforcements in the policy making process to help ensure that the good of the public prevails and well-planned infrastructure is proposed. Moreover, these spatial models should be designed to ensure that 'outside' or political forces with corrupt motives have a difficult time infiltrating the decision-making processes. This includes spatial models that incorporate spatial data on Brazil's pertinent environmental policy relevant to conserving biodiversity and stopping deforestation.

These models should put Brazil's indigenous, tribal and traditional peoples on the map, so that they cannot be ignored or forgotten during the infrastructure planning process. As established by international law with Brazil's ratification of the ILO C169, before any law or development plan that directly impacts an indigenous or tribal community can be considered, the relevant indigenous and tribal communities must receive Free, Prior and Informed consultation (FPICon) as clearly stated in the convention's text. Moreover, starting at the planning stages these peoples have the right to directly participate in the planning process. As Brazil is a signatory to the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP), Brazil committed itself to giving tribal and indigenous people FPIC, which means the communities under consideration should have the right to say 'no' and have their decision be respected by authorities.

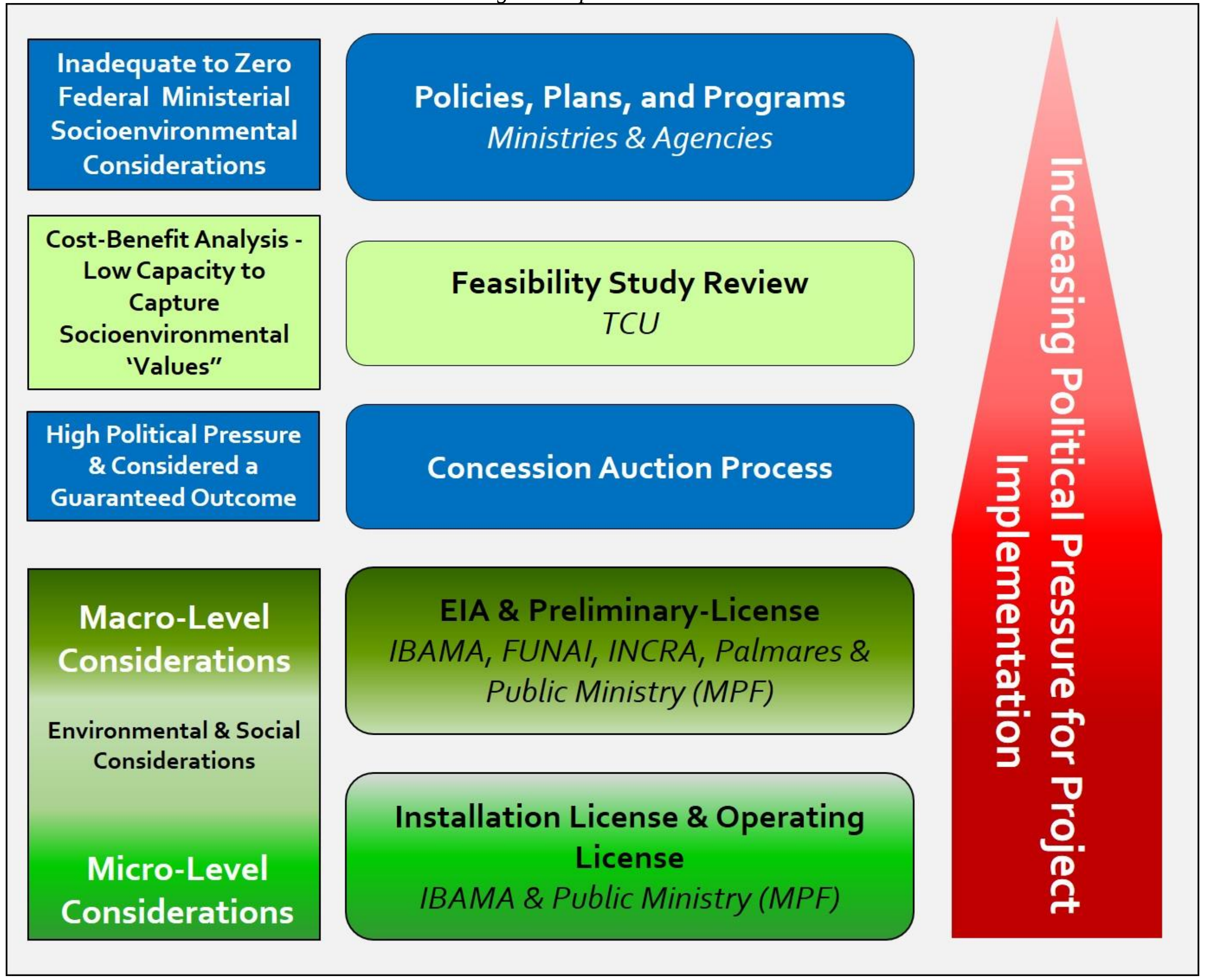
The TCU as an independent institution has the mandate to ensure that Brazil's national patrimony and its natural capital are used in a legal, legitimate, and economically efficient manner. The separate but related fields of environmental and ecological economics have been developing methodologies to assign environmental assets with a market value. However, such undertakings are no trivial tasks. Due to the time and investment needed to calculate the market value estimates of natural capital, the majority of the financial loss that results from infrastructure impacts is not usually accounted for in TCU analyses.

We believe that spatially explicit models can resolve these issues. Moreover, we believe that spatially explicit models addressing these issues should be made available to all actors involved in Brazil's environmental governance process. Federal ministries and agencies could incorporate these models into their planning processes, the TCU could incorporate them into their analysis and external control processes, civil society actors and citizens could use these models to keep track of plans that could affect them and their neighbors. Additionally, the MP could use these models to aid in their legal cases when government actors have blatantly ignored and infringed upon the fundamental rights to an ecologically balanced environment and cultural diversity. Moreover, we would encourage private sector actors to incorporate such models into their planning so that they can gauge the true regulatory risks of doing business in Brazil and thus pressure government actors to plan better infrastructure proposals for better economic outcomes.

The final two figures demonstrate the system that we are working against and the system we hope to help achieve. **Figure 12** shows the current reality that socioenvironmental considerations are left for the last possible phases of the planning and implementation process, often when there is significant political pressure for the project to proceed and it is often too late to make significant and low impact improvements to the project. **Figure 13** shows the systemic structure that we hope to achieve. By using spatially explicit models that are available for all stakeholders to use and with a strong legal basis we hope that political pressure can be stifled at the beginning stages so that the best possible outcomes and lowest possible impacts can be achieved for the public at large while also protecting the most vulnerable. Moreover, we hope that the incorporation of this information can, at the initial planning stages, prevent infrastructure projects that should not be built from even being considered.

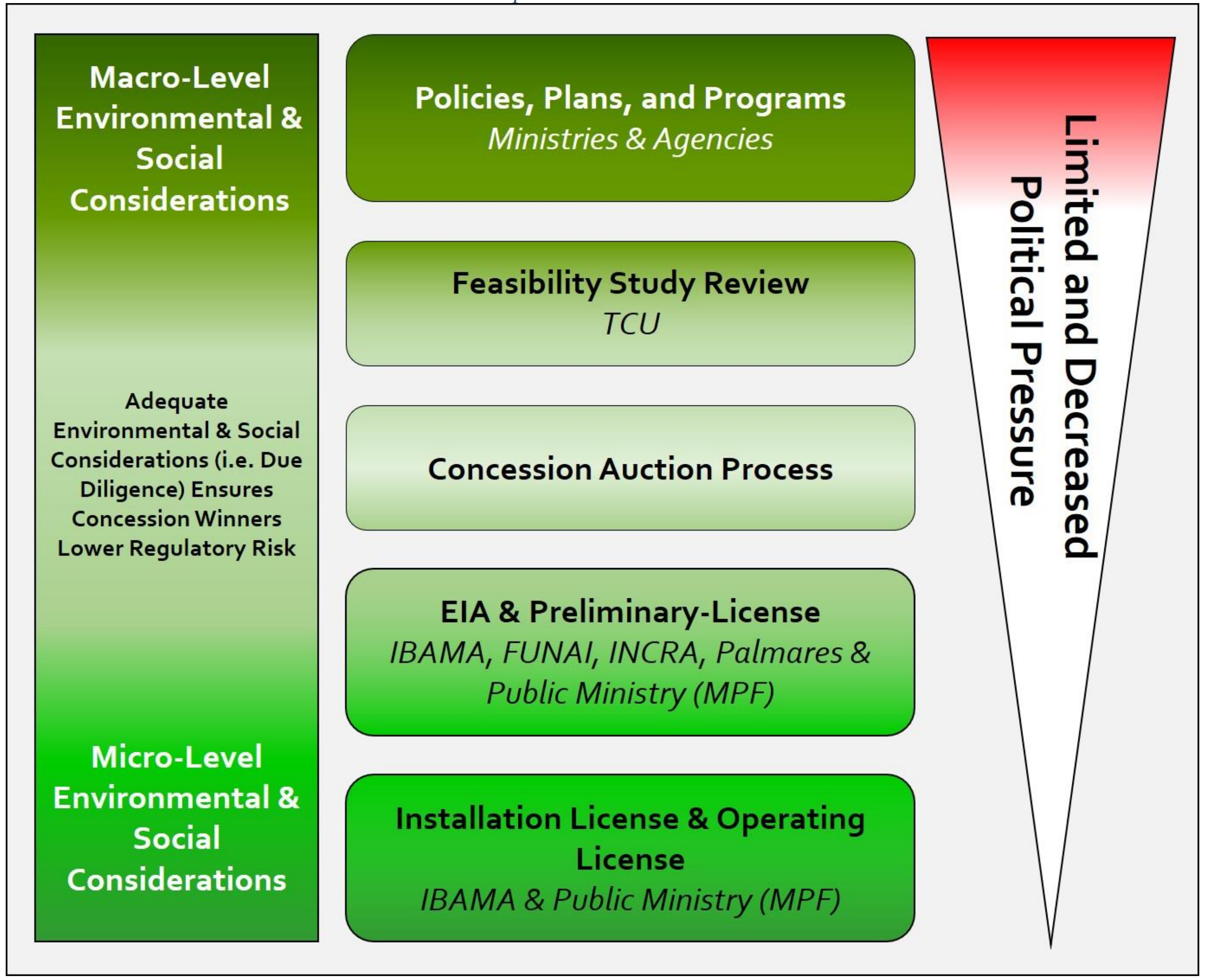
Finally, Brazil's scientific and academic community will play an important role in ensuring that the ideal process in **Figure 13**, actually comes to fruition. By understanding where and how scientific research has potential entry points into and could be used within Brazil's policy and governance structures, Brazilian scientists will be better equipped to engage and support key state institutional actors, such as the MP and TCU among others, to assure that science actually impacts and guides the direction of policymaking in Brazil. Publishing articles in peer-reviewed publications is only the beginning, Brazilian scientists also need to make sure that their research makes its way to the general public in an easily understandable, digestible and effective format (ESCOBAR, 2018) and into the hands of institutional actors that can implement it (AZEVEDO-SANTOS et al., 2017). Afterall, as scientists and as citizens, it is our constitutional mandate to help safeguard an ecologically balanced environment for present and future generations.

Figure 12 *- Brazil's Current Reality of Where Socioenvironmental Considerations Are Considered along the Infrastructure Planning and Implementation Process*



As a transportation infrastructure project advances through the planning stages, by the time it reaches the EIA/LP process there is usually significant political pressure pushing for the project's construction. Moreover, if a concessionary company is involved, there are usually millions to billions of Reais (BRL) that have been paid to the government. However, the EIA/LP stage – which is intended for Micro-Level environmental impacts – usually serves as the first time when Macro-Level issues are seriously analyzed. For Micro-Level, we give the example of studying and determining which type of crossing structure or design would allow for amphibians to cross to the other side of a proposed highway in relative safety so that the highway's genetic barrier effect is mitigated. For Macro-Level, in the context of the PPI program goals of encouraging investment bidding so that the government can sell concessions at the highest amount possible, we give the example of whether MTPA/MoI actors think that prosing a highway through an indigenous territory and not giving the indigenous population FPIC, while knowing that the MP may very well be engaged by popular action and issue a legal injunction on the issuance of an LP until proper FPICon and anthropological assessment is conducted, actually sounds like an attractive FDI opportunity for potential foreign bidders.

Figure 13 *- Ideal Reality of Where Socioenvironmental Considerations Are Considered along the Infrastructure Planning and Implementation Process*



In the ideal process where socioenvironmental impacts are appropriately considered at the correct stage of the transportation policy process, Macro-Level socioenvironmental impacts are effectively considered at the very beginning. For example, FPIC is appropriately conduction by contacting and coordinating with local indigenous and tribal communities to see if they would like the proposed infrastructure project to be carried out in their territory or in the region around their territory. Moreover, to determine if their development goals could benefit from the infrastructure project or not. In the event that the local indigenous population does not want the development project to occur on or near their territory, an alternative is planned and verified to not likely impact the indigenous population in any significant way before sending the project's EVTEA to the TCU for review. For Micro-Level considerations, once the project is sold in the concession auction, the concession winner and licensing agency IBAMA are able to have a productive scoping process and determine that the vast majority of the mitigation procedures are simple engineering and design changes that have been scientifically studied by ecologist and biologist.

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Section 3: Chapter 2 – Model 1

Brazil's Roadless and Railroad-Less Areas – Identifying Brazil's Conservation Opportunities and Environmental Threats

Abstract: Brazil's transportation infrastructure is significantly underdeveloped for the size of the country's economy and arguably needs significant upgrades. The Brazilian government has also long claimed that that the country's transportation network does not adequately cover the national territory and should be further expanded into remote areas. As such, new and expanded roads and railroads are being planned and constructed as a means of improving the country's economy. However, federal policy related to transportation infrastructure often disregards conservation planning and practices as well as official environmental policy and internationally committed goals. Moreover, there is a growing scientific awareness that developing terrestrial transportation infrastructure in previously low or unsettled areas often catalyze increased native vegetation clearing and encourages new human settlement and expansion of existing settled areas, among other land use changes, which all result in ecosystem degradation. This study presents an investigation that resulted in a comprehensive spatial model developed to identify where Brazil's federal terrestrial transportation infrastructure plans conflict with the country's environmental policy, international environmental agreements, and scientific consensus. The model comprises: (i) official spatial data for Brazil's federal highway and railroad systems, (ii) identified Important Environmental Areas (IEAs) which include Roadless and Railroad-less (RLRL) areas, various Legally Protected Areas (LPAs), areas that are awaiting land tenure regularization, and the Brazilian Ministry of Environment's unprotected Priority Areas for Biodiversity Conservation (PABCs); (iii) native vegetation cover; and (iv) set quantitative goals for the Convention on Biological Diversity (CBD) and the Paris Agreement. RLRL areas were computed at distances of 1 and 5 kilometers away from all known existing roads and railroads and account for approximately 71.3% and 39.1% of Brazil's continental territory respectively. At the national level 25.5% of unprotected PABCs overlap with 1km RLRLs, accounting to 18.2% of Brazil's continental territory. Nationally, 19.3% of unprotected PABCs overlap with 5km RLRLs, accounting to 7.5% of Brazil's continental territory. When considering direct impacts of official terrestrial infrastructure plans mandated by federal law, 70.4% of planned unbuilt highways and 56.6% of planned unbuilt railroads in the federal network would impact IEAs. Finally, we analyzed Brazil's progress towards meeting its major international environmental commitments and highlight conservation opportunities. In regard to the CBD, five out of the country's six biomes are far from reaching Aichi Target 11 by 2020. We highlight opportunities that could be used to achieve Aichi Target 11 In regard to the Paris Agreement using unprotected and unvegetated PABCs as starting point, Brazil has ample land identified that could be reforested to meet its 12 million hectares of reforestation commitment.

3.1 – Introduction

The existing natural capital found within the tropics commonly constitutes a greater share of tropical countries' wealth compared to their man-made capital (COMBES et al., 2018). Ecosystems in tropical countries, especially but not limited to forests, hold a large portion of the world's biomass retained carbon stock (BACCINI et al., 2017), play a vital role in providing climate regulation and other ecosystem services (ELLISON et al., 2017), and are highly biodiverse (BRADSHAW; SODHI; BROOK, 2009; OVERBECK et al., 2015). In much of the developing world, macroeconomies are often dependent on natural resource extraction, agriculture, or both (BARBIER, 2004), the second itself being dependent on ecosystem services provided by tropical ecosystems. Moreover, the majority of tropical countries are in the process of development (BRADSHAW; SODHI; BROOK, 2009; SACHS, 2001) and expansion of transportation networks and infrastructure are commonly key parts of their economic development plans (LAURANCE, 2018; LAURANCE et al., 2015). Transportation connectivity and infrastructure are key components for making factors of production more effective (RIETVELD; BRUINSMA, 2007). For undercapitalized middle-income countries, improving and expanding the transportation network has been shown to encourage stable long-term economic growth and provide high returns on investment (CANNING; FAY, 1993).

However, increasing rates of tropical deforestation and land-use land-cover (LULC) change and increased transportation development plans in the tropics are of grave concern (ASCENSÃO et al., 2018) as they are jeopardizing the provisioning, regulating and supporting ecosystem services that maintain global climatic, ecological, and economic stability (LAURANCE, 2018). As reported by the literature, tropical deforestation and LULC change predominantly occur in areas that are accessible via the transportation network, especially roads (ALAMGIR et al., 2017; LAURANCE; BALMFORD, 2013; LAURANCE, 2015; LAURANCE et al., 2014).

The preservation of road-free areas is important for conservation as these areas significantly contribute to the preservation of biodiversity and ecosystem services (SELVA et al., 2015). Globally, roads are substantial determinants of humanity's ecological footprint (LAURANCE, 2015). They disrupt ecosystems, change natural drainage and sediment transportation, and reduce population persistence for various species due to decreased habitat quality, cause barrier effects and direct wildlife mortality (POCEWICZ; GARCIA, 2016; VAN DER REE; SMITH; GRILO, 2015). The most environmentally damaging roads are those that penetrate previously roadless and intact ecosystems (LAURANCE, 2015). Roads and paved highways open access to forested and other untouched regions making them vulnerable to exploitation by hunters, miners and colonists, which in countries with weak enforcement capabilities could be a recipe for ecological disaster (LAURANCE, 2015). Roads providing access to remote areas promote "contagious development" leading to more roads and more LULC change (FEARNSIDE, 1987; IBISCH et al., 2016; LAURANCE et al., 2002; SELVA et al., 2015). From the ecological standpoint, the best way to avoid significant environmental impacts from roads is to prevent the first cut altogether (LAURANCE, 2015, 2018).

Railroads, in theory, may be less ecologically impacting than roads given that their impact can be partially controlled by strategically locating stopping points (LAURANCE; BALMFORD, 2013; LAURANCE; GOOSEM; LAURANCE, 2009). However, this does not mean that railroads are impact free (DORSEY; OLSSON; REW, 2015; KARLSON et al., 2016; POPP; BOYLE, 2017). The location of railroads can determine the spatial extent and reach of deforestation forces. For example, railroads have contributed to Amazonian deforestation in the past and have provided deforesting colonists with migratory access to forested areas (FEARNSIDE, 2008; PRATES; BACHA, 2011). Moreover, it is important to highlight that before the advent and mass use of automobiles, railroads were probably the leading cause of worldwide LULC change that was facilitated by man-made structures (HEILIG, 1994). Railroads also directly impact wildlife, provide access corridors for invasive species, and cause habitat fragmentation. Thus, future plans for railroads in Brazil and around the tropical world should be approached with extreme caution. Railroads do not automatically cause lower ecological impacts; similar to roads, railroads' ecological impacts are only reduced with appropriate planning and effective environmental law enforcement that adequately counter acts environmentally damaging economic forces and regulates mitigation strategies to protect biodiversity impacts.

Rivers are an efficient means of transportation and provide a cost-efficient alternative to terrestrial transportation for shipping large quantities of products over long distances. Moreover, 40% of the Brazilian Amazon is closer to a navigable river than it is to a road (BARBER et al., 2014). Rivers have been shown to influence the deforestation that occurs in the Amazon's protected areas, for example illegal logging and using rivers to float timber, more so than the influence of roads. However, the mitigating effect of a protected area's status and the influence of navigable rivers on overall Brazilian Amazon wide deforestation levels has been statistically shown to be significantly lower than terrestrial transportation infrastructure such as roads (BARBER et al., 2014).

Developing countries' exports are, in large part, natural resources and primary agricultural products commonly sold to more developed countries (BARBIER, 2012; SMITH et al., 2010). Furthermore, developing countries are concurrently experiencing growing domestic demand for agricultural land expansion in order to keep up with population growth and ever more meat-intensive diets (SMITH et al., 2010). Therefore, developing countries' remaining ecosystems, especially in the tropics, are facing growing pressures from both the domestic and international economic and cultural fronts. In this context, tropical countries in the pursuit of development are commonly faced with similar economic development and socio-cultural welfare 'dilemmas' due to: (i) increased market demands, (ii) perceived and misguiding short-term development benefits, and (iii) ignored or misunderstood long-term environmental impacts (BARBIER, 2012).

The principal economic development 'dilemma' is whether: (i) to expand economic activities into remote areas as a means of achieving growth (in the short-term) in the natural resource, agricultural and extractive dependent economic sectors that national economies often revolve around (while likely damaging long-term economic and environmental stability); or, (ii) to forego 'immediate' economic growth by not expanding production in these sectors (i.e. avoiding short-term economic growth) while also having difficulty over the long run to develop alternative, globally competitive, and sustainable economic activities (which if successful in achieving would bring economic and possibly environment stability for that country) (BARBIER, 2012). A principal socio-cultural welfare 'dilemma' is whether: (i) to support or allow for agricultural expansion and production increases to meet the domestic market demands for an intensifying animal protein-based diet; or, (ii) to restrict dietary choices and incentivize lower consumption of animal based-protein to reduce pressure for expanding agricultural areas. For these two 'dilemmas' and other environmentally relevant decisions, the ecologically sustainable options are rarely, if ever, taken (BAGER; BORGHI; SECCO, 2015).

Unfortunately, at the global scale and in an ever-increasing globalized world, natural resource abundant economies have overwhelmingly lower growth rates than resource scarce countries (BARBIER, 2012). This is likely because resource abundant developing countries commonly suffer from boom-and-bust commodity price cycles and government institutions that promote procyclical rather than countercyclical government spending. This combines to hamper the sustained growth of more labor-intensive manufacturing and technological sectors which have less volatile price fluctuations (FRANKEL, 2010). Moreover, when booms occur, resource rents are not commonly and efficiently re-invested into other productive sectors of the economy (BARBIER, 2012). Thus, when the commodity busts occur, governments often are forced to cut spending through austerity measures due to reduced tax revenue and an acquired deficit from procyclical spending during the boom (FRANKEL, 2010). In general, tropical countries that choose agricultural land expansion to achieve growth are actually more likely to have lower per capita GDP over the long run because of these boom-and-bust cycles (BARBIER, 2012). This reality runs contrary to the current political rhetoric advocating for expanding agricultural production and natural resource extraction in Brazil.

The above-mentioned natural resource and agricultural economic growth schemes are commonly facilitated by transportation infrastructure projects that increase access to remote areas (LAURANCE, 2015). Paradoxically, the transportation infrastructure component of economic development policies – to facilitate growth (BAGER; BORGHI; SECCO, 2015) – are increasingly pushing ecosystem stability towards tipping points through incentivized deforestation and LULC change that will likely further negate economic growth and stability in the long run (LAWRENCE; VANDECAR, 2015; STEFFEN et al., 2018). In other words, the current approach to transportation development in tropical countries is unsustainable. However, if planned carefully and in the right areas roads and transportation infrastructure projects can have lower environmental impacts and positive economic and social results (LAURANCE; BALMFORD, 2013; LAURANCE; ARREA, 2017), especially if they are designed to benefit multiple sectors of the economy such as labor intensive manufacturing and technology; unfortunately, the current push for development is commonly generating more bad roads rather than good roads (LAURANCE, 2015).

Brazil is currently confronting this development trade off and stands at a historical crossroads. Firstly, it is the world’s largest tropical country in terms of territorial landmass and home to megadiverse ecosystems making it the world’s most biodiverse country in terms of terrestrial biota (BRANDON et al., 2005; STRASSBURG et al., 2014). The Amazon is the largest remaining area of tropical rainforest in the world (FOLEY et al., 2007), the largest known carbon sink in the world (NOGUEIRA et al., 2015; STRASSBURG et al., 2014), and a significant source of local, regional and international ecosystem services (AHMED; EWERS, 2012; BÖRNER; MENDOZA; VOSTI, 2007; DAVIDSON et al., 2012; FEARNSIDE, 2004; HARGRAVE; KIS-KATOS, 2013; MANN et al., 2012; STRAND et al., 2018). Another Brazilian biome, the Cerrado, a biodiversity hotspot (MYERS et al., 2002), is likely the most threatened tropical savanna in the world (COE et al., 2017; SANO et al., 2019) as almost half of its natural vegetation landcover has already been converted to pasture and croplands (NOOJIPADY et al., 2017).

Brazil is the world’s 8^{th} largest economy by nominal GDP (THE WORLD BANK, 2018) and in the past three decades it has emerged as one of the world’s foremost agricultural exporters for items such as soy, corn, sugar cane products, and meat (AN; OUYANG, 2016; GUIDOTTI et al., 2015; MARTINELLI et al., 2010; MEADE et al., 2016; MUELLER; MUELLER, 2016); and has established export-oriented industries for mineral commodities (SONTER et al., 2017) and petroleum (DÖRING; SANTOS; POCHER, 2017). In 2010 over half of Brazil's exports were primary products (mineral and non-mineral) and natural resource-based manufactures (SANTOS-PAULINO, 2010) and this trend has continued up to today (CENTER FOR INTERNATIONAL DEVELOPMENT AT HARVARD UNIVERSITY, 2018). Moreover, inadequate transportation infrastructure is currently cited as the principal barrier that Brazil needs to overcome to achieve future economic growth in its export commodities industries (ARMIJO; RHODES, 2017, p. 232; GONÇALVES et al., 2017, p. 23). Brazil's current freight transportation network is disproportionately highway centric rather than appropriately multimodal (PEREIRA; LESSA, 2011) and in general is insufficient (BURRIER, 2018).

Although an improved transportation system is needed for Brazil's development, where transportation infrastructure is developed matters for the environmental impacts it will cause or facilitate (PFAFF et al., 2018). Brazil's current transportation network, and LULC change it commonly facilitates, is a source of several negative impacts on Brazil's terrestrial and aquatic ecosystems (PINTO, 2019; POCEWICZ; GARCIA, 2016) by triggering biodiversity loss and other cascading effects that compromise ecosystem function (TUCKER LIMA et al., 2016). Furthermore, agriculture is the single largest driver of deforestation and LULC change nationwide in Brazil (OVERBECK et al., 2015), and the economic viability of agriculture is heavily determined by access to transportation. In the case of the Amazon, both paved and unpaved roads are highly connected to deforestation (KIRBY et al., 2006) and 95% of Brazilian Amazonian deforestation occurs within 5.5 kilometers (km) of a road, but impacts may extend as far as 50 km from a road (BARBER et al., 2014; LAURANCE, 2015).

Brazil has made many international environmental and conservation commitments through being a signatory to international agreements, such as the Convention on Biological Diversity (CBD), the United Nations Framework Convention on Climate Change (UNFCCC) and the 2015 Paris Agreement (JÓNSSON, 2016). Brazil ratified and promulgated its legally-binding commitment (UN, 1992) to the CDB by Legislative Decree n. 2 of 1994 and Presidential Decree n. 2.519 of March 16, 1998 (BRAZIL, 1994, 1998) and has committed itself to fulfilling the Aichi Biodiversity Targets (henceforth Aichi targets) (CBD, 2010) by the end of 2020 through developing and implementing a national action plan (CONABIO, 2013) which is highlighted in Brazil's third version of its National Biodiversity Strategy and Action Plan (NBSAP). The NBSAP is stipulated by article 6 of the CBD (UN, 1992) of which Brazil's most up-to-date version of the NBSAP was submitted to the CBD in 2017 (MMA, 2017).

Most notable of Brazil's targets outlined in the NBSAP is target 11, reflecting Aichi target 11, through which Brazil aims to ensure that at least 30% of the Amazon and 17% of each of Brazil's five other biomes are legally protected by conservation measures and areas (MMA, 2017). Furthermore, NBSAP target 15, reflecting Aichi target 15, outlines Brazil's goal for restoring 15% of degraded ecosystems, beginning with the most degraded (MMA, 2017). National target 15 also highlights that degraded ecosystem restoration is a necessary process for enhancing ecosystem resilience and acknowledges biodiversity's contribution to maintaining carbon stocks (MMA, 2017). Finally, NBSAP target 17, reflecting Aichi target 17, stipulates that the national biodiversity strategy, guided by the NBSAP, was to be implemented by 2014, as a policy instrument for achieving Brazil's committed goals. It is important to highlight that federal institutions partnering with Brazil's Ministry of the Environment (henceforth MMA, for *Ministério do Meio Ambiente*) to implement the country's NBSAP targets do not include the Ministry of Transportation, Ports and Aviation (MTPA) (MMA, 2017), which recently became the Ministry of Infrastructure (MoI) (BRAZIL, 2019).

Given the scientific evidence in the literature of the role that transportation infrastructure plays in negatively impacting biodiversity and its role in facilitating deforestation and LULC change, the exclusion of MTPA/MoI[1] appears to be a disregard for the spirit of the CBD, Aichi targets, and Brazil's commitment to them. Both the original convention text (UN, 1992) and the text of the CBD's Strategic Plan for Biodiversity 2011-2020 and the Aichi targets (CBD, 2010) clearly state the importance of effective integration of relevant policies, plans and programs (PPPs[2]) and government sectors for the implementation of national biodiversity plans (CBD, 2010; CONABIO, 2013; UN, 1992).

In relation to the UNFCCC and Paris Agreement, which are ratified and promulgated into Brazilian law by Federal Law n. 12.187, of December 29, 2009 and Presidential Decree n. 9.073, of June 5, 2017 (BRAZIL, 2009, 2017a), Brazil presented ambitious goals in its Nationally Determined Contribution (NDC) for the Paris Agreement (BRAZIL, 2015a; DE OLIVEIRA SILVA et al., 2018; STRASSBURG et al., 2017). The cornerstone of the country's committed emissions reductions is based on a Low Carbon Agriculture Plan (Plano ABC, for *Plano de Agricultura de Baixa Emissão de Carbono*) (MAPA, 2012) which allows for continued agricultural growth through intensification practices, technological development, and restoration of degraded pastures for re-use (BRAZIL, 2015a; DE OLIVEIRA SILVA et al., 2018; ROCHEDO et al., 2018). However, significant components of the NDC also include the intended reduction of deforestation rates in the Amazon to 0% by 2030 in combination with reforestation of 12 million hectares of forest throughout Brazil for multiple sustainable uses (BRAZIL, 2015a).

[1] Throughout the text MTPA and MoI will be referenced, at times separately. However, they should be synonymously interpreted as being the same federal ministry. Due to the ministerial restructuring and renaming occurring in the Bolsonaro administration, Brazil's federal laws are still being changed to account for the change in names of the executive ministries. Therefore, most current transportation laws and PPPs still reference MTPA, but are now allocated to MoI as MTPA's successor ministry.

[2] Policies, Plans, and Programs (PPPs) is a term used to highlight the strategic decision-making levels which occur prior to or above a project specific level (FISCHER, 2002). The definition of the three terms can vary depending on the country or organization in question; however, generic definitions are almost always applicable. Policies include the inspiration and guidance for action. Plans are a set of coordinated and timed objectives for implementing the policy. Programs are a group of projects in a particular area (ANNANDALE et al., 2001, p. 412).

In terms of environmental protection laws and historical environmental governance in Brazil, a stark dichotomy between *de jure* standards and *de facto* realities must be understood and resolved. On one hand, Brazil has a comprehensive and modern set of environmental protection and licensing laws in place (DE OLIVEIRA; ANDREOLI; DA MATA CAVALCANTE, 2019), which is an important step for any country to achieve on its path towards sustainable development. On the other hand, upholding and enforcing environmental laws, resolving conflicting laws, fighting corruption during the environmental licensing process, and in general the federal government's capacity to plan in accordance to and political willingness to respect federal environmental legal frameworks has yet to become a mainstay at the federal ministerial level (AZEVEDO-SANTOS et al., 2017; DE OLIVEIRA; ANDREOLI; DA MATA CAVALCANTE, 2019).

Although Brazil did have a momentary improvement in environmental governance outcomes in the late 2000s and early 2010s (NEPSTAD et al., 2014), a reversal has occurred and if poor environmental governance continues or even worsens in the near future then achieving the NBSAP or the NDC goals is unlikely (FREITAS et al., 2018; ROCHEDO et al., 2018). Furthermore, recent political developments with the election of President Bolsonaro and his proposed federal policy changes and proposed infrastructure projects threaten to undermine Brazil's capacity to achieve its commitments in preserving biodiversity, enlarging protected areas, and reducing net greenhouse gas (GHG) emissions by stopping deforestation and achieving reforestation (BRAZIL'S SUSTAINABILITY NEEDS SOCIAL SCIENCES, 2018; MONTEIRO; BORGES, 2019; TOLLEFSON, 2018). Moreover, the final release and implementation of Brazil's Rural Environmental Registry (henceforth CAR, for *Cadastro Ambiental Rural*), a key tool for implementing many official environmental policy goals, has had its property registration and georeferenced spatial data submission deadline date delayed and rescheduled for the end of 2019 (BRAZIL, 2018), three years past its initially proposed submission deadline (JUNG et al., 2017). CAR is one of the tools identified by the NBSAP to be used for assessing and achieving progress towards conservation targets (MMA, 2017) as it is intended to be used to enforce native vegetation quotas in the form of Legal Reserves (henceforth RLs, for *Reservas Legais*) and Areas of Permanent Protection (henceforth APPs, for *Áreas de Proteção Permanente*) as stipulated by Brazil's Forest Code (FC) outlined by Federal Law n. 12.651 of May 25, 2012 (BRAZIL, 2012). Moreover, CAR was originally expected to have high impact in helping to stop deforestation and LULC change; however, recent analysis indicates that spatial registration in the database has not significantly dissuaded deforestation on private properties (AZEVEDO et al., 2017).

What-is-more, and unfortunate, evidence suggests that policymakers behind Brazil's federal transportation PPPs usually do not take the country's comprehensive environmental and conservation goals into consideration during federal level infrastructure planning stages (MALVESTIO; FISCHER; MONTAÑO, 2018) and in the instances when environmental and conservation issues are considered they are usually given lower priority than economic and regional connectivity concerns (MALVESTIO; FISCHER; MONTAÑO, 2018; RABELLO QUADROS; NASSI, 2015; ZIONI; FREITAS, 2015). This echoes a similar reality across much of Brazil's federal and state bureaucracies as key environmental considerations are often left out of the planning process for energy, regional development, and federal level tourism development endeavors (DO NASCIMENTO NADRUZ et al., 2018; SÁNCHEZ, 2017).

Even within MMA's policymaking structures, evidence suggests a history of a lower than desired level of integration between climate change and biodiversity policies (DONADELLI, 2017). However, it is important to note evidence that professional bureaucrats within MMA have kept institutional momentum focused on environmental issues in times of political pressure, taking for example policy proposals for the Green Grants Program (Bolsa Verde) during the Rousseff administration (ABERS, 2019).

This cultural reality in some of Brazil's bureaucratic institutions, especially infrastructure related institutions, has occurred in combination with the fact that Brazil's federal transportation policy has traditionally focused on building an extensive highway network as the primary means of stimulating economic development and facilitating intra-regional connection since the 1950s (PEREIRA; LESSA, 2011). Finally, the guiding principles and design for system expansion and organization are still based on the past National Transportation Plan (henceforth PNV, for *Plano Nacional de Viação*) and the National Transportation System (henceforth SNV, for *Sistema Nacional de Viação*) which is still to this day stipulated and guided by Federal Law n. 5.917 of September 10, 1973 (BRAZIL, 1973), as outlined in Federal Laws n.11.772 of September 17, 2008 and n. 12.379 of January 6, 2011 (BRAZIL, 2008, 2011). It is important to highlight that current official design of the PNV entered into legal standing before the majority of Brazil's current environmental laws, licensing procedures, and PPPs were formulated.

3.2 - Objectives

Given the multiple policy and development areas connected and holistically analyzed by our research, this paper aims to inform national policy makers, as well as academic researchers and professionals in the private and NGO sectors, involved in transportation planning and infrastructure development, agricultural planning, diplomatic relations, as well as environmental conservation and climate change mitigation by:

(1) identifying where Brazil's Roadless and Railroad-less (RLRL) areas are and the status of their legal protection, biodiversity conservation priority, and land-use and vegetation characteristics;

(2) connecting the aforementioned environmental variables to Brazil's international commitment and stated quantitative goals to the Convention on Biological Diversity (CBD) and the United Nations Framework Convention on Climate Change (UNFCCC) and Brazil's submitted Nationally Determined Contribution (NDC) for the Paris Agreement; and

(3) by identifying existing and planned federal transportation infrastructure that currently impact, or if built would impact, identified Important Environmental Areas (IEAs[3]) relevant to federal environmental and land tenure PPPs as well as planned infrastructure that threatens intact ecosystems in existing RLRL areas. Our framework and methodology is inspired by Ibisch et al.'s (IBISCH et al., 2016) work on mapping global roadless areas.

3.3 – Data and Modeling Methods

Our study area includes the total territorial continental extent of Brazil and excludes maritime territory and outer lying islands in the Atlantic Ocean. Furthermore, Brazil encompasses 6 classified terrestrial biomes which include: the Atlantic Forest, Amazon, Caatinga, Cerrado, Pampas, and Pantanal (**Figure 14**). Although 5 out of 6 of Brazil's biomes also extend into neighboring countries; our analysis only focuses on the Brazilian portions of these biomes. To identify the divisions of these biomes in our modeling and analysis we used the biome limits developed by Project Mapbiomas (ROSA; PROJECT MAPBIOMAS, 2016) due to inconsistencies in the Brazilian Institute of Geography and Statistics' (henceforth IBGE, for *Instituto Brasileiro de Geografia e Estatística*) territorial coverage from its 1:250,000 scaled Continuous Cartographic Database of Brazil (henceforth BC250, for *Base Cartográfica Contínua do Brasil*) (IBGE, 2017) (**Sup. Mat. Ch. 2, Sec. 1 & Fig. S1**).

Figure 14 *- General Study Area (Continental Brazil and Terrestrial Biomes)*

[3] Important Environmental Areas (IEAs) consist of several environmental variables used in this study and are highlighted in Section 2. However, as a precursor, in the context of this study IEAs are: RLRL areas, Conservation Units, Indigenous Territories, Quilombo Community Territories and Priority Areas for Biodiversity Conservation.

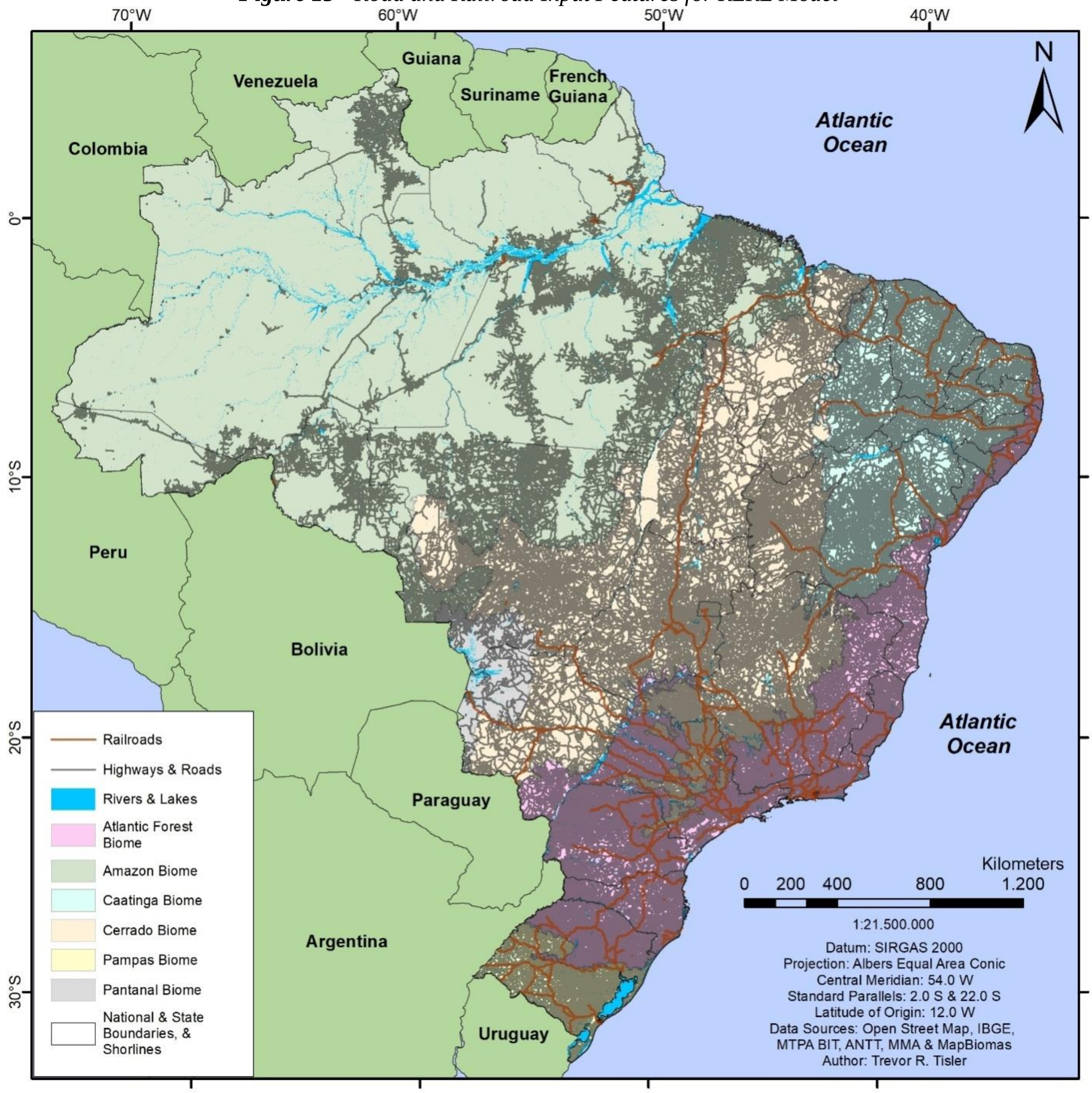
To model Brazil's RLRL areas, we included two data sources for existing roads in our spatial database: (i) national road data from IBGE's BC250 (IBGE, 2017) and (ii) Open Street Map (OSM) data for Brazil provided by GEOFABRIK (2018) (**Figure 15**). We chose to include IBGE's BC250 road data so that all officially documented roads (documented by the federal government) were captured by our model (IBGE, 2017). OSM is a crowdsourced geospatial database and was used by Ibisch et al. (2016) in their global roadless area model. However, the accuracy and completeness of OSM data has been documented to vary among different regions in Brazil (CAMBOIM; BRAVO; SLUTER, 2015). Although OSM appears to have larger geographic coverage than IBGE's 2017 BC250 national road data, it is possible that some officially documented roads from IBGE could have been left out of the model if we solely depended on OSM. Thus, both data sources were included to err on the side of caution.

As for the railroads included in our spatial database, four data sources for existing railroads were used: (i) OSM's railroad data, (ii) MTPA's Transportation Information Database (henceforth BIT, for *Banco de Informações de Transportes*) (MTPA, 2018c), (iii) the National Agency for Terrestrial Transport's (henceforth ANTT, for *Agência Nacional de Transportes Terrestres*) Georeferenced Federal Railroad Network (*Malha Ferroviária Federal Georreferenciada*) (ANTT, 2016), and (iv) IBGE's 2017 BC250 (IBGE, 2017) (**Figure 15**). These different sources were used to capture all railroads which could fall under the jurisdiction of federal, state or municipal governments.

The aforementioned spatial data was used to model Brazil's RLRL areas at 1 km and 5 km in distance from any of documented road or railroad feature by using a Euclidean Distance function. We determined that the 1km and 5km distances highlighted for road impacts in the literature (BARBER et al., 2014; IBISCH et al., 2016) would be appropriate to apply to railroads for the time being due to the general lack of railroad specific impact quantifications in the literature. Even so, we encourage the scientific community to investigate the impacts of railroads further.

Although, past studies have indicated that navigable rivers do have some degree of influence on deforestation patterns specifically in the Brazilian Amazon (BARBER et al., 2014), their direct contribution to overall deforestation is much lower than terrestrial transportation infrastructure. Secondly, given that this study uses Ibisch et al. (2016) as the methodloglical starting point for constructing the model, which was applied to all of Brazil's terrestrial biomes, their analysis covering the all of the world's terrestrial biome also did not include rivers. For these two reasons, as well as the fact that rivers are natural features that, for all intents and purposes are mostly outside of the control of human influence for choosing their location, except for instances of costly and large scale engineering and damning projects, we decided not to include rivers in the scope of modeling RLRL areas. However, we still do caution that proposed large scale development projects to increase transportation access or capacity on rivers very likely could cause significant changes on land use and land cover in any biome.

Figure 15 *- Road and Railroad Input Features for RLRL Model*



Using basic geoprocessing operations (**Sup. Mat. Ch. 2, Sec. 3 & Tab. S7**) and the ArcMAP 10.4.1 software interface (ESRI, 2016) all road and railroad data was preprocessed and projected to IBGE's standard Albers Conic Equal Area projection (IBGE, 2015) (**Sup. Mat. Ch. 2, Sec. 4 & Fig. S2**). Once all input data was organized and ready for modeling, we then calculated the Euclidean distances from all of the identified road or railroad features at a spatial resolution of 250 by 250 meters for all of our study area (**Sup. Mat. Ch. 2, Sec. 5 & Fig. S3**). Spatial information from the resulting raster layer was converted to vector shapefiles for 1km and 5km RLRL areas, and thus we were able to calculate the territorial coverage and other statistics outlined in the results section.

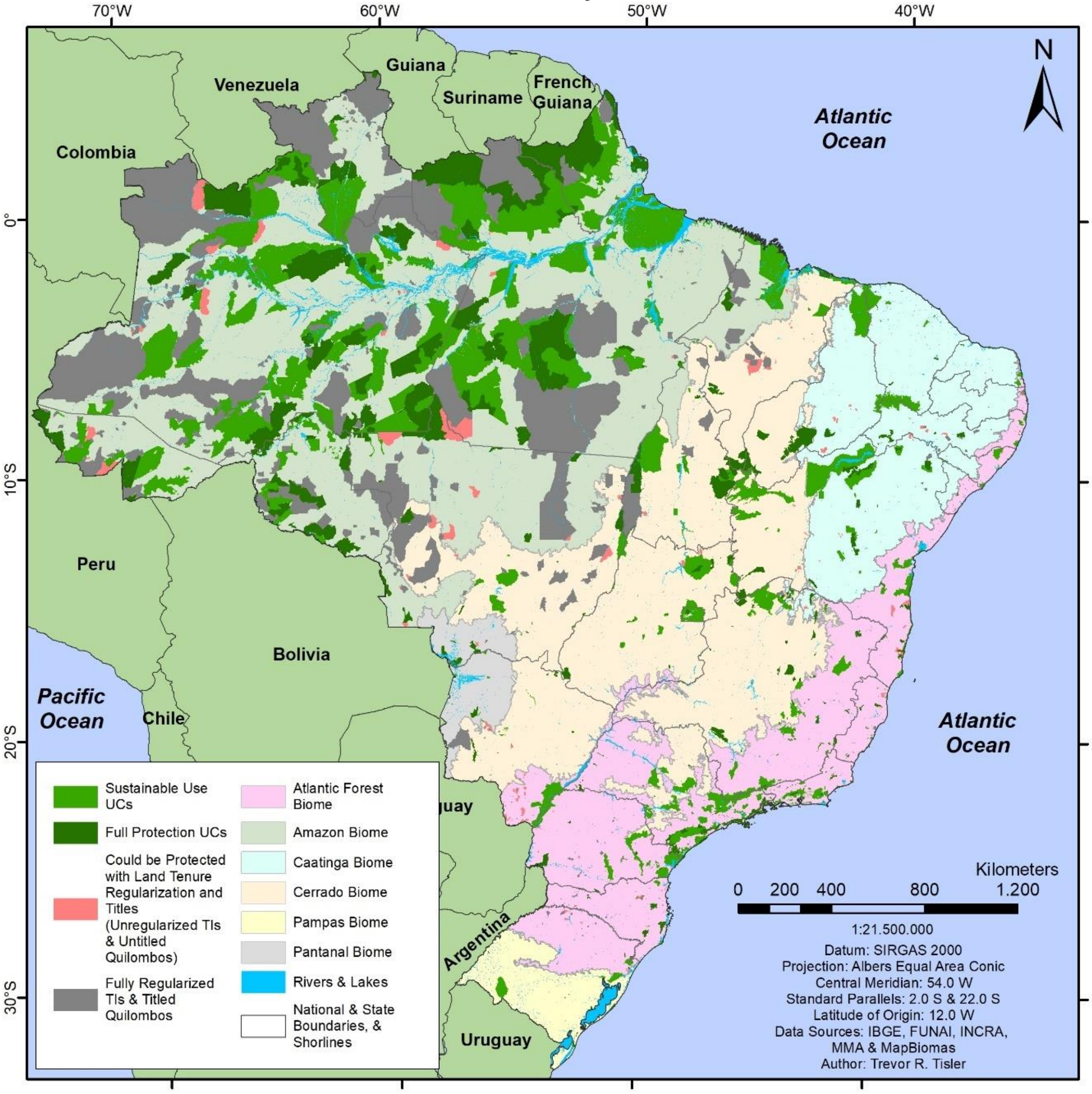
Brazil shares an extensive land border with 10 neighboring countries that totals 16,145 km and has a significant coastline of 7,491 km (CIA, 2018). Given that Brazil only has sovereign control over its territory and does not control if roads or railroads are constructed on the other side of its borders, our measurement and identification of the RLRL areas stops at Brazil's borders and coastline. It is likely that many of Brazil's RLRL areas do continue to extend into neighboring countries; however, their identification was not included in the scope of this study.

In addition to identifying Brazil's RLRL areas, it was important to consider spatial components of Brazil's principal environmental and biodiversity conservation policies and legal framework, as well as its transportation development policies to determine opportunities and conflicts between these two policy arenas. In this sense, Brazil's primarily tool for enacting its biodiversity and conservation policies is through the designation of Protected Areas, termed Conservation Units (henceforth UCs, for *Unidades de Conservação*) (PFAFF et al., 2015; TESFAW et al., 2018). Brazilian UCs have two principal categories: a) Full Protection (henceforth PIs, for *Proteção Integral*) which correspond to International Union for Conservation of Nature (IUCN) protected area categories I, II and III; and b) Sustainable Use (henceforth US, for *Uso Sustentável*) which correspond to IUCN protected area categories IV, V, and VI (KERE et al., 2017; PFAFF et al., 2015). Furthermore, these two types of UCs can be instated by federal, state or municipal governments in Brazil as outlined in Federal Law n. 9.985 of July 18, 2000 (BRAZIL, 2000). To identify synergies between UCs and RLRL areas we used official spatial data from MMA's National Registry of Conservation Units (henceforth CNUC, for *Cadastro Nacional de Unidades de Conservação*) which is the principal database for spatial data for UCs administered at all three levels of government in Brazil (MMA, 2018c) (**Figure 16**).

Indigenous Territories (henceforth TIs, for *Terras Indígenas*) in Brazil also play an important role in conserving native vegetation cover and biodiversity, especially in areas with high deforestation pressure (CARRANZA et al., 2014; HARGRAVE; KIS-KATOS, 2013; KERE et al., 2017; NOGUEIRA et al., 2017; NOLTE et al., 2013; SOARES-FILHO et al., 2010). Furthermore, Amazonian TIs are the guardians of extensive above-ground carbon reserves that if lost could destabilize global climate patterns (WALKER et al., 2014). Additionally, Brazil's Maroon[4] Community Territories (henceforth Quilombos) have been shown to contribute to native vegetation protection (NOGUEIRA et al., 2018, 2017) and in general have low deforestation rates (TRITSCH; LE TOURNEAU, 2016). Given the contributions of TIs and Quilombos to biodiversity conservation both were included in our study (**Figure 16**).

[4] Quilombos refer to the geographic territory of Brazil's Afro-descendent Maroon communities (descendants of escaped slaves, known as Quilombolas) (HANNA et al., 2014, p. 59).

Figure 16 - Legally Protected Areas: UCs, Regularized TIs & Titled Quilombos. Additionally, Unregularized TIs & Untitled Quilombos



TIs and Quilombos are governed by different legislation from UCs and therefore should be considered as different types of legally protected areas (LPAs) from UCs (CARRANZA et al., 2014). However, in the case of the Legal Amazon[5], there is an important caveat which highlights the current complexity and often contradictory nature of Brazil's environmental legal protections (DRUMMOND; BARROS-PLATIAU, 2006), economic development priorities (MYSZCZUK; SOUZA, 2016), land tenure status (FAO; SEAD, 2017; PAULINO, 2014) and international commitments (JÓNSSON, 2016). Brazil's 2012 Forest Code (FC), Federal Law n. 12.651 of May 25, 2012 Art. 12 §4 and §5 indicate if

[5] Brazil's Legal Amazon, defined by Federal Law n. 5.173 of October 27, 1966 (BRAZIL, 1966, Art. 2), is a socio-economic area that determines the geographic applicability of all laws related to vegetation protection, development, public policy, social issues, and much more, in the Amazon. Brazil's Legal Amazon includes all of the Brazilian Amazon Biome in addition to parts of the Pantanal and Cerrado Biomes.

50% or more of a municipality's territory or if 65% or more of a state's territory in the Legal Amazon is covered by publicly owned UCs and homologated TIs[6] – which are not necessarily fully Regularized TIs, thus still having an unsecure land rights status (**Sup. Mat. Ch. 2, Sec. 6**) – then the FC's legal requirement that 80% of private properties be set aside as Legal Reserves (henceforth RL, for *Reserva Legal*) in combination with the area of defined Permanently Protected Areas (henceforth APP, for *Área de Preservação Permanente*), can be reduced to 50% if approved by the state's governing Environmental Council (*Conselho Estadual de Meio Ambiente*) (BRAZIL, 2012, Art 12. § 4 & 5).

Aside from this legal loophole in the Legal Amazon, for all intents and purposes, both TIs and Quilombos should still be considered as valuable conservation tools. Official spatial data for TIs comes from Brazil's National Foundation for Indigenous Peoples (henceforth FUNAI, for *Fundação Nacional do Índio*) (FUNAI, 2018b). Official spatial data for Quilombos comes from Brazil's National Institute for Colonization and Agrarian Reform (henceforth INCRA, for *Instituto Nacional de Colonização e Reforma Agrária*) (INCRA, 2018).

It is important to note that the process for legally recognizing TIs and Quilombos and their land rights in Brazil is a multistep, complex and bureaucratic process (BRAZIL, 1996, 2003; COSTA, 2016; COSTA; CHIAVARI; LEME LOPES, 2017; FUNAI, 2018a; INCRA, 2009a, 2009b). Even after the territorial limits of a TI or Quilombo are identified, the community faces many additional legal steps (COSTA; CHIAVARI; LEME LOPES, 2017) before obtaining land rights to that territory and the important legal and constitutional protections that come with secured land rights (BENYISHAY et al., 2017) (**Sup. Mat. Ch. 2, Sec. 6**). Therefore, based on this important legal difference in land rights status, the identified TIs and Quilombos were split between two categories, (i) those that enjoy full legal and constitutional rights through regularization and land titles and, (ii) those that still do not enjoy full legal and constitutional rights as they have not completed the administrative process of land regularization and do not hold land titles. This distinction was made in the data to identify legally sound conservation opportunities that would result in biodiversity conservation and that would be legally guaranteed to continue in the future if the land rights of these territories were to be completely formalized (BENYISHAY et al., 2017) (**Figure 16**). Furthermore, the Brazilian Forum on Climate Change (henceforth FBMC, for *Fórum Brasileiro de Mudança do Clima*), which is sanctioned by Presidential Decree n. 9.082 of June 26, 2017 (BRAZIL, 2017b) to guide proposals for how Brazil could achieve the successful implementation of its NDC for the Paris Agreement, published their initial proposal action plan in which the FBMC highlighted that there are many proposed UCs and unregularized TIs waiting for the stroke of a pen to be formally created and regularized. Moreover, Brazil's NDC states the important role of TIs, both regularized and unregularized with delimited boundaries, for sustainable

[6] Homologated TIs are one step before the status of regularization (FUNAI, 2018a). Although Homologated indicates that a Presidential Decree has been issued instating the Federal Government's acknowledgement of an Indigenous people's rights to a defined territory, this status does not guarantee that the Indigenous tribe holds the deed to the land (**Sup. Mat. Sec. 6**).

forest management (BRAZIL, 2015a, p. 2). If these proposed UCs and unregularized TIs were to be formally created and regularized then Brazil would advance towards meeting its international commitments in its NDC in a relatively easy and inexpensive manner (FBMC, 2017, p. 11). Finally, it is important to note that FUNAI's data included additional areas of potential indigenous territories; however, the area of these territories and defined borders are not identified in the data set and therefore they were not included in our analysis. Thus, there are likely even more conservation opportunities and conflicts with transportation policy that could result from the demarcation and regularization of these specific TIs. To conclude, all UCs and all regularized TIs and titled Quilombos were classified as legally protected areas (LPAs[7]) in our analysis and were given the same importance.

In addition to UCs in the CNUC database, MMA has identified Priority Areas for Biodiversity Conservation (PABCs) in all of Brazil's six biomes, and as outlined in MMA Ministerial Order (*Portaria*) n. 463, of December 18, 2018, PABCs have the explicit purpose of informing and guiding environmental PPPs related to: (i) in situ biodiversity conservation, (ii) sustainable use of biodiversity components, (iii) sharing of benefits arising from access to genetic resources and associated traditional knowledge, (iv) research and inventories on biodiversity, (v) recovery of degraded areas and overexploited or threatened species, and (vi) economic valuation of biodiversity (MMA, 2018a, Art. 1 Sec. I to VI). These areas have been identified and updated in a second revision which was finished and released to the public in December 2018 (MMA, 2018b). The spatial distribution of PABCs can be divided between two main categories of importance for this study: (i) parts of PABCs that are already protected by UCs, regularized TIs or titled Quilombos, and (ii) parts of PABCs that are not protected by any of the aforementioned legally protected areas (**Figure 17**). Therefore, for this study only the areas of PABCs that are not already protected by legally protected areas were included in our analysis. This was done to identify the locations where unprotected RLRL areas also coincide with unprotected PABCs. These identified overlaps thus could be additional conservation and biodiversity protection opportunities for Brazil whether in the form of newly created UCs, regularized TIs or titled Quilombos. Furthermore, PABCs identified in relation to one biome sometimes overlap with PABCs in relation to other biomes along the ecotone regions in Brazil. Therefore, we corrected area measurements and spatial data structures to prevent double counting of these instances. We used official spatial data for PABCs from MMA (MMA, 2018b).

We also evaluated the natural vegetation[8] land cover status in our generated RLRL areas, MMA's PABCs, and the overlapping areas of these two features, by using land-use classification data

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[7] The term legally protected areas (LPAs) is used throughout this chapter to refer specifically to (i) established Conservation Units (UCs), (ii) Regularized Indigenous Territories (TIs), and (iii) Titled Quilombolos.

[8] The terms natural vegetation and native vegetation are used throughout the text. The term natural vegetation is used because the landcover data category provided by Project MapBiomas is titled "natural vegetation". Natural vegetation excludes other non-vegetation natural features such as: rivers, lakes, naturally barren land, rock or salt flat features. As the data is remotely sensed, it does not exclude the possibility that non-native vegetation is co-classified in the natural vegetation category. Native vegetation is used in Brazil's environmental laws (*vegetação*

from the 3rd version of Project MapBiomas (2018), using classified year 2017, which was released in October 2018. This was done to further identify RLRL areas and PABCs with ecological assets that could benefit from conservation action. Project MapBiomas data comes in raster format at a spatial resolution of 30 by 30 meters. Due to computational processing constraints we converted land cover classifications falling into the natural vegetation category to 250 by 250-meter resolution and then transformed the data into vector format (**Figure 18**)

To gauge how Brazil's transportation policies impact environmental policies and conservation opportunities as well as how transportation policies could potentially impact Brazil's targets for the CBD and Paris Agreement, we evaluated the existing and potential impacts of Brazil's SNV on the following IEAs: (i) Legally Protected Areas (LPAs), which included UCs, regularized TIs, and titled Quilombos; (ii) areas that could be protected with land regularization (unregularized TIs and untitled Quilombos); (iii) MMA's Unprotected PABCs; and (iv) as an additional step for all planned highways and railroads, potential impacts to Brazil's 1km and 5km RLRL areas.

Brazil's SNV consists of highways, railroads, navigable waterways, and infrastructure related to air transportation (BRAZIL, 2011) and its overall terrestrial geographic design and reach dates from Federal Law n. 5.917 of September 10, 1973 (BRAZIL, 1973). Our analysis focuses on the two main terrestrial components of the SNV, the federal highway subsystem and the federal railroad subsystem.

For our specific federal transportation network impact analysis, we used official government data from the National Department of Transportation Infrastructure (henceforth DNIT, for *Departamento Nacional de Infraestrutura de Transportes*) for Brazil's federal highway subsystem (DNIT, 2018). From this data we classified Brazil's federal highways into four categories: 4-Lane Paved Highways, 2-Land Paved Highways, Dirt Highways (essentially gravel or dirt roads), and Planned Highways (currently do not exist but are legally called to be constructed) (**Sup. Mat. Ch. 2, Sec. 7.1 – 7.2**). It is important to note that parts of polemic highways such as the BR-319 (Porto Velho – Manaus) and the BR-163 (northern stretches from the Amazon River to the Border with Suriname) are presented in the DNIT database as being 'built' (as well as on Google Earth and Google Maps), even though they have never been built or have been completely abandoned and are now severely degraded and 'out of commission'.

To investigate transportation policy in relation to federal railroads, we included data from MTPA's BIT which specifically represents the federal railway subsystem (MTPA, 2018c) and does not include railroads that are controlled by state or municipal levels. From this data we classified Brazil's federal railroads into 2 categories: Existing Railroads (in operation, built but deactivated, built but operation status unknown, or in the process of construction), and Planned Railroads (planned or under study) (**Sup. Mat. Ch. 2, Sec. 7.3**)

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nativa) and thus referenced as so. However, in this text natural and native vegetation should be interpreted synonymously.

Figure 17 *- MMA's Second Revision of Priority Areas for Biodiversity Conservation (PABCs)*

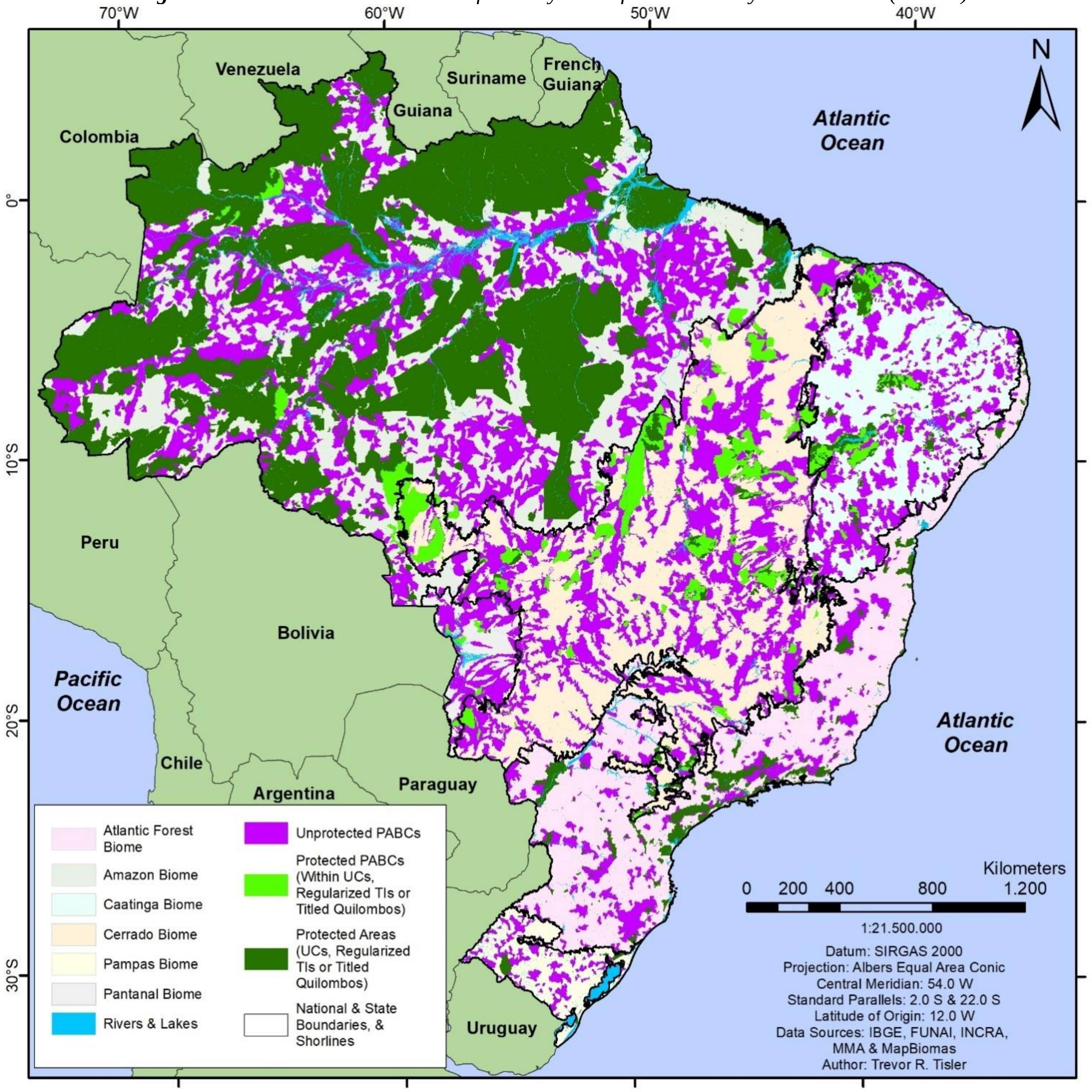
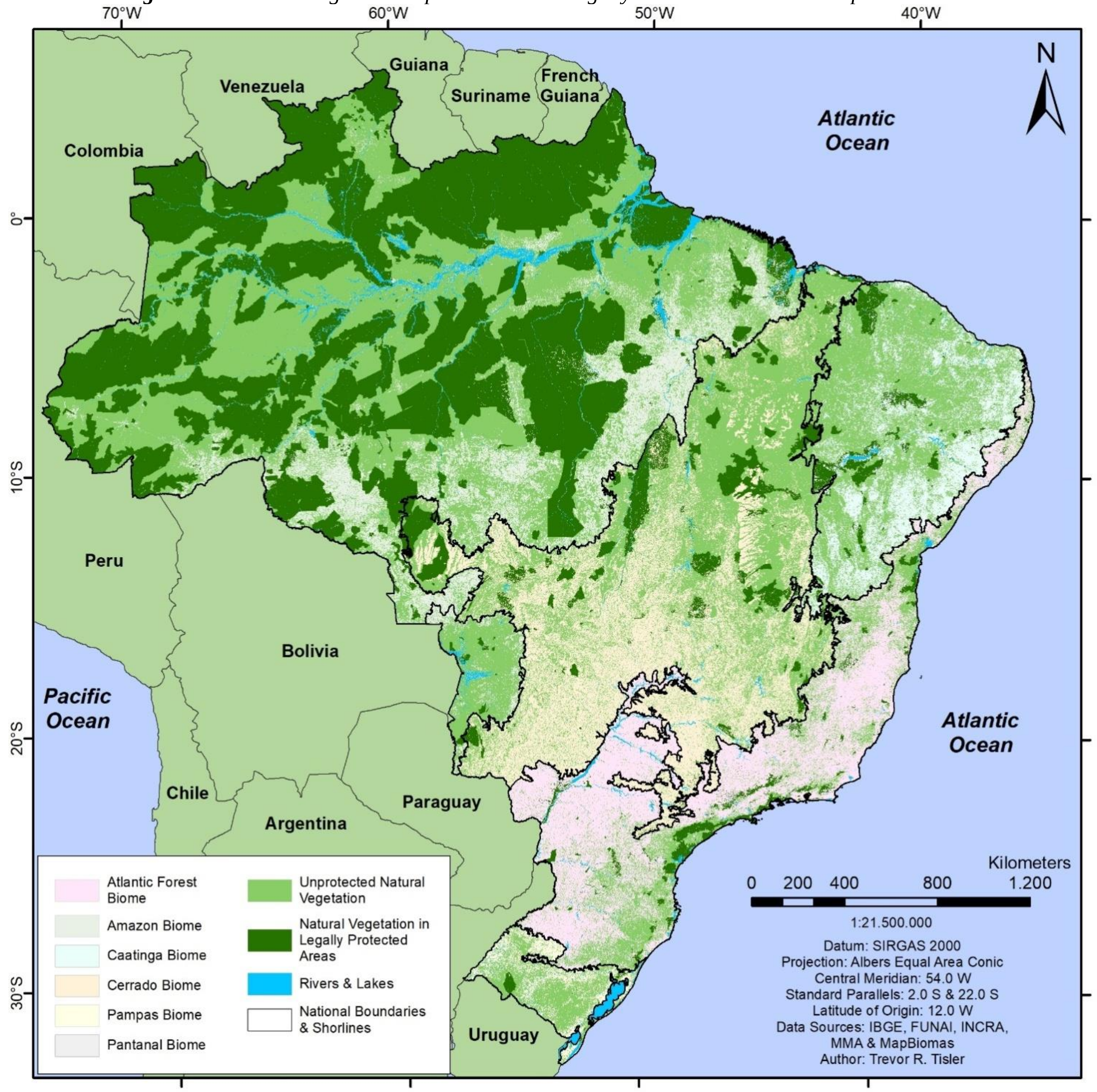


Figure 18 *- Natural Vegetation Input Variable in Legally Protected Areas and Unprotected Areas*



3.4 – RLRL Results

We found that 71.33% of Brazil's territory (including most major continental water bodies but excluding Lagoa dos Patos and Lagoa de Mirim) is more than 1km away from any documented road or railroad feature and that 39.14% of the country's territory falls within the 5km RLRL areas (5km or more away from any documented road or railroad feature). However, it is important to note that per biome results vary significantly. For example, the Amazon's 1km and 5km RLRL areas account for 43.89% and 33.83% of Brazil's national extent, respectively, whereas the Pampas' 1km and 5km RLRL areas only account for 0.87% and 0.02% of the country, respectively (**Figures 19** to **22**).

In relation to our defined study area for Brazil's territorial continental extent, 1km RLRLs and 5km RLRLs that fall in LPAs account for 28.20% and 24.12% of the country's continental territory, respectively (**Table 1**). It is important to note that these averages do not represent an even spread across Brazil's six biomes. In fact, the Amazon's protected 1km and 5km RLRLs account for 24.79% and 22.82% of Brazil's national territory, whereas the combined total area of the protected 1km and 5km RLRLs in Brazil's five other biomes accounts to just 3.41% and 1.30% of Brazil's national territory, respectively. Moreover, Brazil's unprotected 1km and 5km RLRL areas account for 44.34% and 16.04% of the country's continental territory respectively (**Table 2**). However, the Amazon's unprotected 1km and 5km RLRLs account for 20.01% and 11.85% of Brazil's national territory, whereas the combined total area of the unprotected 1km and 5km RLRLs in Brazil's five other biomes accounts to 24.25% and 4.11% of Brazil's national territory, respectively. The aforementioned RLRL estimates also include, in addition to natural vegetation, water bodies, non-vegetated natural areas, and areas of anthropogenic land use. The percentage of RLRL areas that are 10 hectares or above account for 99.9% of the total 1km RLRL areas and 99.9% of the total 5km RLRL areas nationwide.

Table 1 *- Breakdown of Protected 1km and 5km RLRL Areas to Biome and National Territorial Extent*

Biomes	Biome Area (ha)	Protected 1km RLRLs Total Area (ha)	% Protected 1km RLRL Areas to Total Biome Area	Protected 5km RLRLs Total Area (ha)	% Protected 5km RLRL Areas to Total Biome Area
Atlantic Forest	*110,674,019*	*5,357,317*	*4.84%*	*767,960*	*0.69%*
Amazon	*421,564,800*	*210,808,777*	*50.01%*	*194,071,950*	*46.04%*
Caatinga	*83,600,127*	*5,049,726*	*6.04%*	*1,310,859*	*1.57%*
Cerrado	*202,963,869*	*17,725,103*	*8.73%*	*8,567,362*	*4.22%*
Pampas	*16,456,620*	*301,977*	*1.83%*	*17,728*	*0.11%*
Pantanal	*15,014,413*	*567,588*	*3.78%*	*407,000*	*2.71%*
National Total	**850,273,851**	**239,810,490**	**28.20%**	**205,142,862.56**	**24.12%**

Table 2 *- Breakdown of Unprotected 1km and 5km RLRL Areas to Biome and National Territorial Extent*

Biomes	Biome Area (ha)	Unprotected 1km RLRLs Total Area (ha)	% Unprotected 1km RLRL Areas to Total Biome Area	Unprotected 5km RLRLs Total Area (ha)	% Unprotected 5km RLRL Areas to Total Biome Area
Atlantic Forest	*110,674,019*	*36,514,157*	*32.99%*	*1,959,167*	*1.77%*
Amazon	*421,564,800*	*170,115,714*	*40.35%*	*100,759,767*	*23.90%*
Caatinga	*83,600,127*	*39,566,301*	*47.33%*	*3,752,437*	*4.49%*
Cerrado	*202,963,869*	*111,397,263*	*54.89%*	*23,129,000*	*11.40%*
Pampas	*16,456,620*	*7,064,909*	*42.93%*	*193,574*	*1.18%*
Pantanal	*15,014,413*	*11,609,776*	*77.32%*	*5,883,255*	*39.18%*
National Total	**850,273,852**	**376,268,124**	**44.25%**	**135,677,203**	**15.96%**

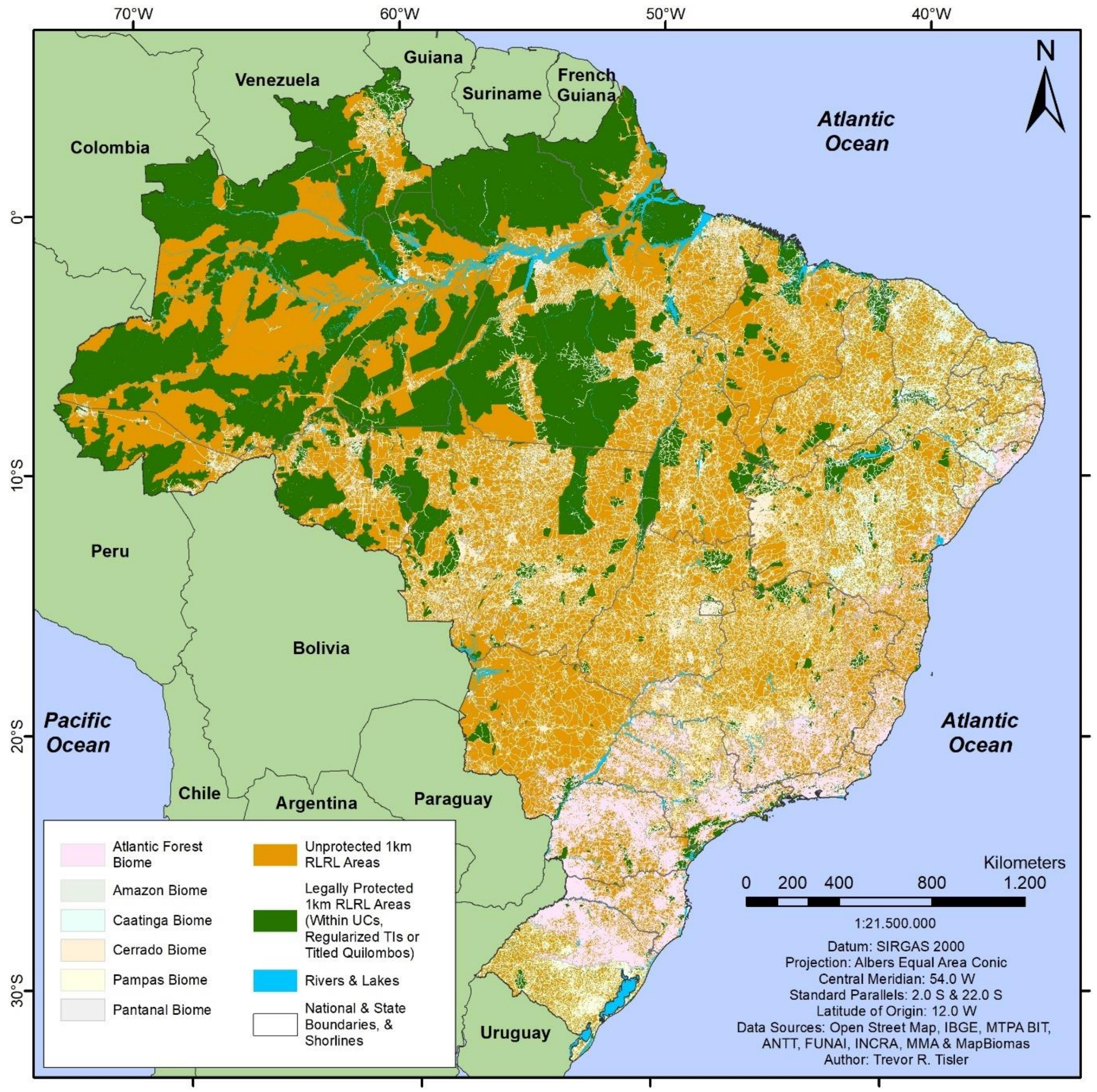


Figure 19 *- Brazil's 1km RLRL Areas*

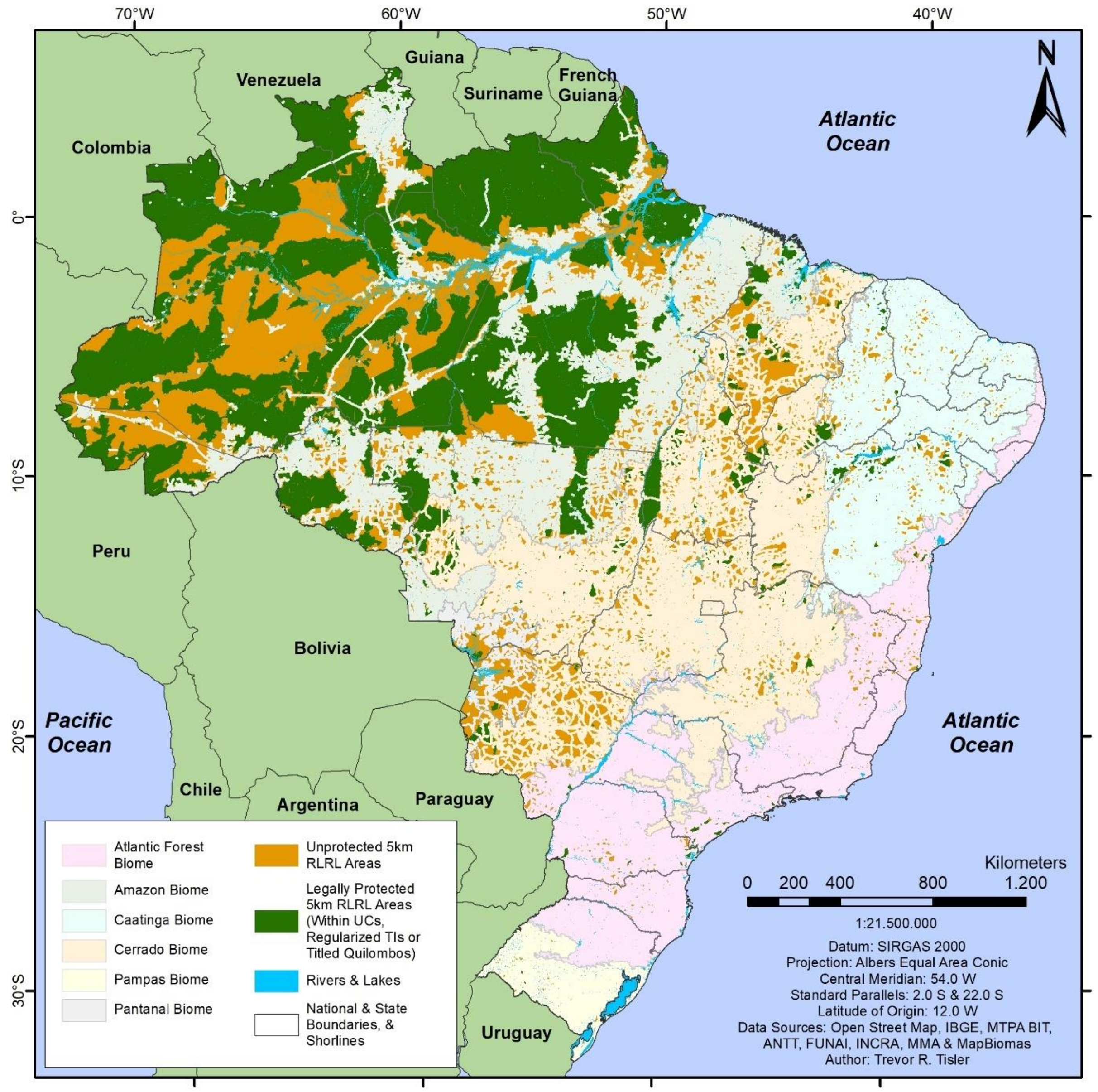


Figure 21 *- Brazil's 5km RLRL Areas*

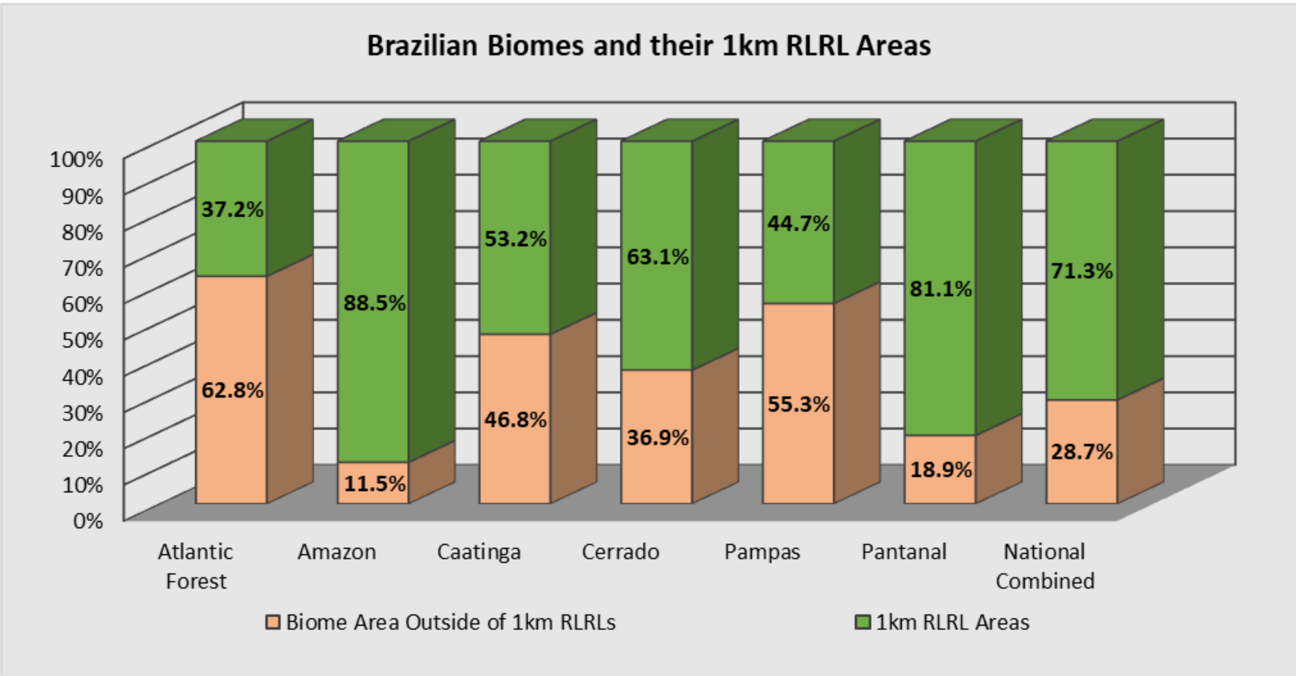


Figure 20 *- Brazilian Biomes and their 1km RLRL Areas*

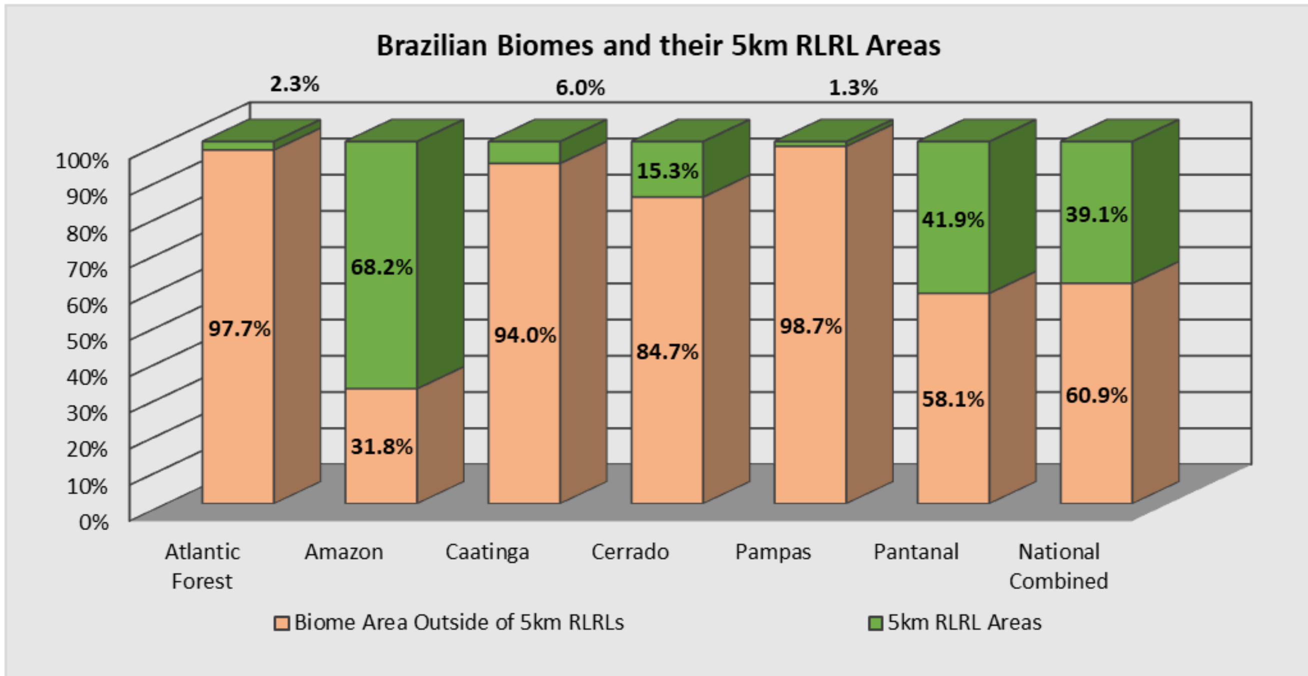


Figure 22 *- Brazilian Biomes and their 5km RLRL Areas*

Our findings show that 81.66% of Brazil's natural vegetation formations are 1km away or more from any road or railroad feature and 52.90 % of the country's natural vegetation formations are 5km away or more from any road or railroad feature (**Figures 23** and **24**, and **Table 3**). When comparing the biome level estimates a range of statuses can be seen (**Tables 3**, **4**, and **5**). For the Amazon, the vast majority of its remaining natural vegetation is found in both 1km and 5km RLRLs and a majority is protected. However, the Atlantic Forest and the Pampas are the only two biomes with less than 50% of their remaining natural vegetation in 1km RLRL areas and both have a critically low amount of remaining natural vegetation in 5km RLRLs. The per biome visual breakdown and protection status of 1km and 5km RLRL natural vegetation features can be seen in the supplemental material (**Sup. Mat. Ch. 2, Sec. 9**).

Table 3 *- Breakdown of Natural Vegetation 1km and 5km RLRLs in Relation to Overall Biome Natural Vegetation*

Biomes	Biome's Total Natural Vegetation (ha)	Natural Vegetation in 1km RLRLs (ha)	% 1km RLRL Vegetation to Total Biome Vegetation	Natural Vegetation in 5km RLRLs (ha)	% 5km RLRL Vegetation to Total Biome Vegetation
Atlantic Forest	*33,346,681*	*14,795,435*	*44.37%*	*1,131,115*	*3.39 %*
Amazon	*361,490,404*	*335,046,707*	*92.68%*	*273,948,824*	*75.78%*
Caatinga	*51,587,999*	*30,722,119*	*59.55%*	*3,743,133*	*7.26%*
Cerrado	*111,398,185*	*78,257,984*	*70.25%*	*22,217,760*	*19.94%*
Pampas	*9,436,342*	*4,170,790*	*44.20%*	*104,647*	*1.11%*
Pantanal	*11,931,494*	*10,016,743*	*83.95%*	*5,300,196*	*44.42%*
National Total	**579,191,108**	**473,009,782**	**81.66%**	**306,445,678**	**52.90 %**

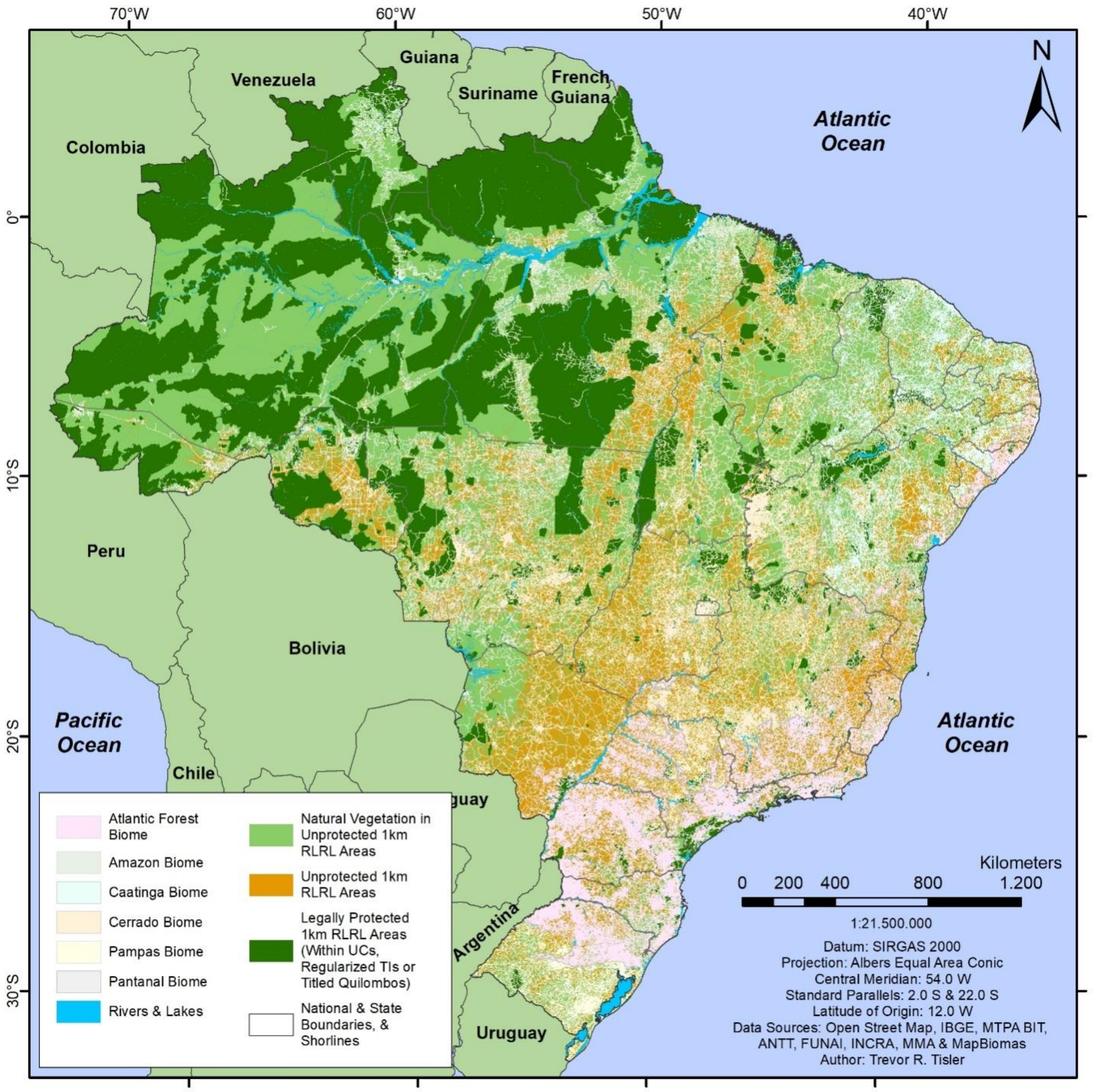


Figure 23 *- Brazil's 1km RLRLs with Natural Vegetation Formations*

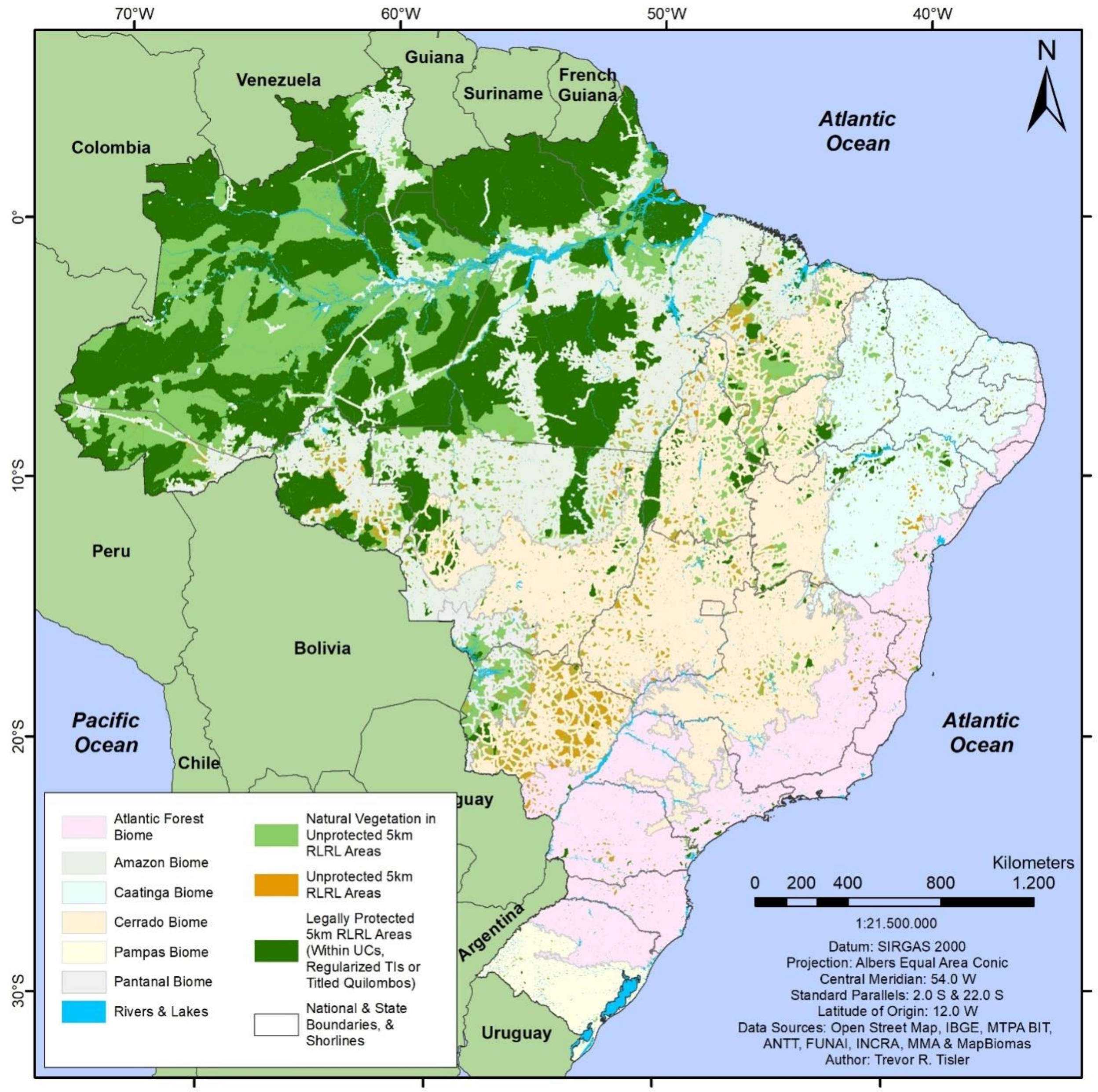


Figure 24 *- Brazil's 5km RLRLs with Natural Vegetation Formations*

Biomes	Biome's Total 1km RLRL Natural Vegetation (ha)	Protected Natural Vegetation in 1km RLRLs (ha)	% Protected Natural Vegetation in 1km RLRLs	Biome's Total 5km RLRL Natural Vegetation (ha)	Protected Natural Vegetation in 5km RLRLs (ha)	% Protected Natural Vegetation in 5km RLRLs
Atlantic Forest	*14,795,435*	*3,935,209*	*26.06%*	*1,131,115*	*523,271*	*46.26%*
Amazon	*335,046,707*	*206,851,672*	*61.74%*	*273,948,824*	*184,216,496*	*67.24%*
Caatinga	*30,722,119*	*4,077,658*	*13.27%*	*3,743,133*	*990,147*	*26.45%*
Cerrado	*78,257,984*	*16,037,099*	*20.49%*	*22,217,760*	*7,591,427*	*34.17%*
Pampas	*4,170,790*	*254,381*	*6.10%*	*104,647*	*14,049*	*13.43%*
Pantanal	*10,016,743*	*481,561*	*4.81%*	*5,300,196*	*333,870*	*6.30%*
National Total	**473,009,781**	**231,637,584**	**48.97%**	**306,445,678**	**193,669,262**	**63.19%**

Table 4 *- Protected Natural Vegetation in 1km and 5km RLRL Areas*

Biomes	Biome's Total 1km RLRL Natural Vegetation (ha)	Unprotected Natural Vegetation in 1km RLRLs (ha)	% Unprotected Natural Vegetation in 1km RLRLs	Biome's Total 5km RLRL Natural Vegetation (ha)	Unprotected Natural Vegetation in 5km RLRLs (ha)	% Unprotected Natural Vegetation in 5km RLRLs
Atlantic Forest	*14,795,435*	*11,446,821*	*77.37%*	*1,131,115*	*607,844*	*53.74%*
Amazon	*335,046,707*	*135,756,513*	*40.52%*	*273,948,824*	*89,732,327*	*32.76%*
Caatinga	*30,722,119*	*26,750,330*	*87.07%*	*3,743,133*	*2,752,986*	*73.55%*
Cerrado	*78,257,984*	*63,207,150*	*80.77%*	*22,217,760*	*14,626,333*	*65.83%*
Pampas	*4,170,790*	*3,920,636*	*94.00%*	*104,647*	*90,598*	*86.57%*
Pantanal	*10,016,743*	*9,535,199*	*95.19%*	*5,300,196*	*4,966,325*	*93.70%*
National Total	**473,009,781**	**250,616,653**	**52.98%**	**306,445,678**	**112,776,415**	**36.80%**

Table 5 *- Unprotected Natural Vegetation in 1km and 5km RLRL Areas*

To highlight overlaps and synergies among PABCs and RLRL areas for the purpose of conservation opportunities, we identified and focused on unprotected PABCs, that is, PABCs that are not already protected by LPAs. Nationwide, unprotected PABCs total 214,698,818 ha, which amounts to 25.22% of Brazil's national territory as defined by our study area. The natural vegetation in unprotected PABCs totals 143,500,603 ha and amounts to 24.77% of all nationwide natural vegetation (**Table 6** and **Figure 25**)

Table 6 *- Comparisons between Biome Area, Unprotected PABC Area, Biome Natural Vegetation Area, and Natural Vegetation Area in Unprotected PABCs*

Biomes	Biome Area (ha)	Unprotected PABCs (ha)	% Unprotected PABCs to Biome Areas	Biome's Total Natural Vegetation (ha)	Biome's Total Unprotected PABC Natural Vegetation (ha)	% Unprotected PABC Vegetation to Total Biome Vegetation
Atlantic Forest	*110,674,019*	*15,950,648*	*14.41%*	*33,346,681*	*5,658,587*	*16.97%*
Amazon	*421,564,800*	*98,323,376*	*23.32%*	*361,490,404*	*74,421,558*	*20.59%*
Caatinga	*83,600,127*	*26,062,361*	*31.18%*	*51,587,999*	*16,678,922*	*32.33%*
Cerrado	*202,963,869*	*63,651,125*	*31.36%*	*111,398,185*	*38,389,253*	*34.46%*
Pampas	*16,456,620*	*3,654,337*	*22.21%*	*9,436,342*	*2,583,271*	*27.38%*
Pantanal	*15,014,413*	*7,056,327*	*47.00%*	*11,931,494*	*5,769,010*	*48.35%*
National Total (with Amazon)	**850,273,851**	**214,698,175**	**25.25%**	**579,191,107**	**143,500,603**	**24.77%**
National Total (without Amazon)	**428,709,051**	**116,374,799**	**27.14%**	**217,700,703**	**69,079,044**	**31.73%**

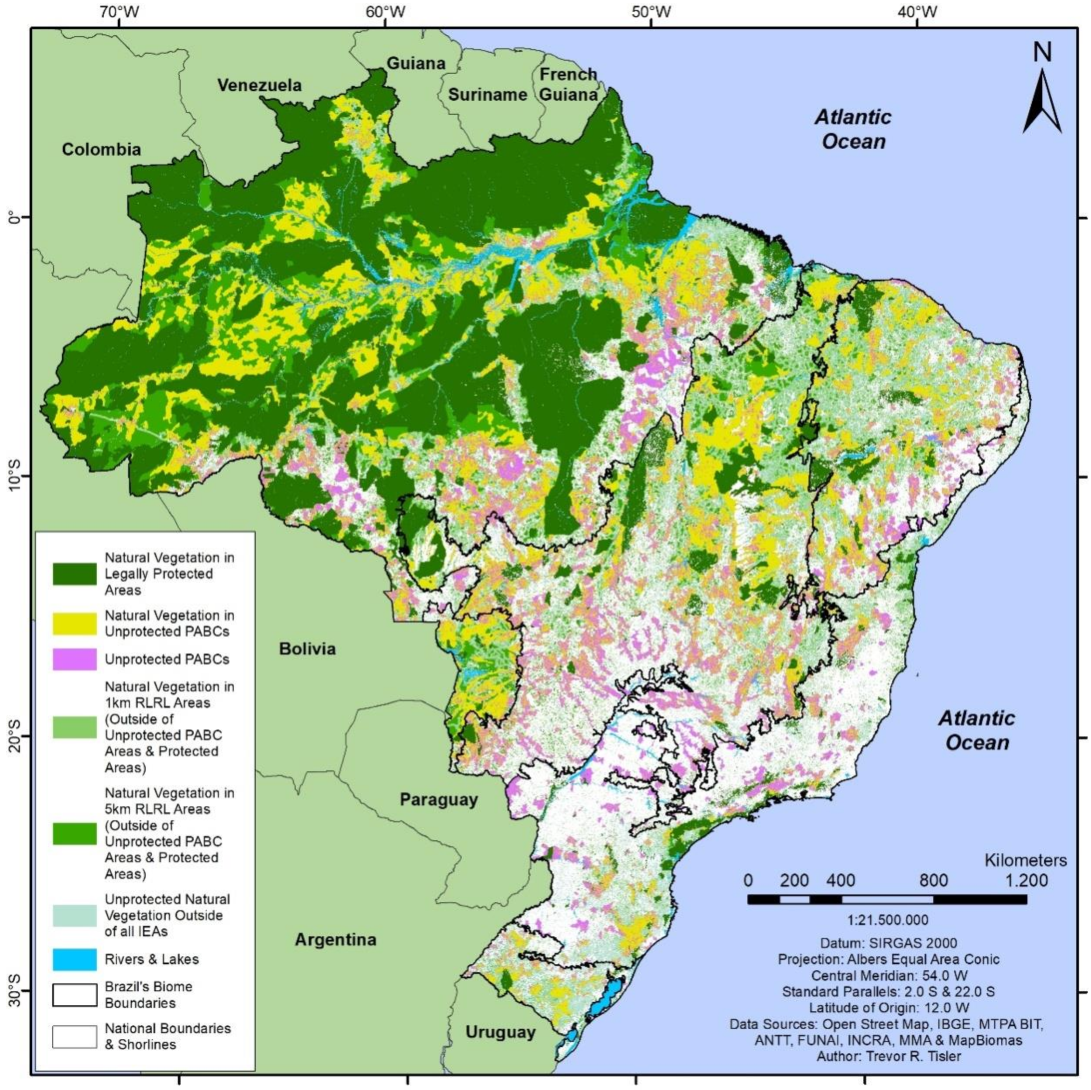
In relation to unprotected PABCs and 1km RLRL areas, we found that 68.68% of unprotected PABCs (147,455,148 ha) coincide with 1km RLRL areas at the national level (**Figure 26** and **Table 7**). When considering the relationships involving the remaining natural vegetation located in overlapping unprotected PABCs and 1km RLRL areas (109,377,338 ha), we found the following relationships **(Figure 28** and **Table 9**, columns marked **A**, **B**, and **C**):

A. the natural vegetation specifically in overlapping unprotected PABCs and 1km RLRL areas equates to 12.86% of national territory; however, this varies considerably per biome level area (**Table 9**, columns marked **A**);

B. 18.88% of all remaining nationwide natural vegetation is found in overlapping unprotected PABCs and 1km RLRL areas; however, this varies considerably per each biome (**Table 9**, columns marked **B**);

C. 43.64% of the remaining natural vegetation only in **unprotected** 1km RLRL areas is both in an overlapping unprotected PABC and 1km RLRL area; however, this varies considerably per biome level (**Table 9**, columns marked **C**).

***Figure 25** - Natural Vegetation in Unprotected PABC Areas, 1km RLRL Areas, Protected Areas, and Outside of All IEAs*



In relation to unprotected PABCs and 5km RLRL areas, we found that 28.66% of unprotected PABCs (61,528,855 ha) coincide with 5km RLRL areas at the national level (**Figure 27** and **Table 8**). When considering the relationships involving the remaining natural vegetation located in overlapping unprotected PABCs and 5km RLRL areas (53,067,802 ha), we found the following relationships (**Figure 29** and **Table 10**, columns marked **D**, **E**, and **F**):

D. the natural vegetation specifically in overlapping unprotected PABCs and 5km RLRL areas equates to 6.24% of national territory; however, this varies considerably per biome level area (**Table 10**, columns marked **D**);

E. 9.16% of all remaining nationwide natural vegetation (579,191,107 ha) is found in overlapping unprotected PABCs and 5km RLRL areas; however, this varies considerably per each biome's remaining natural vegetation levels (**Table 10**, columns marked **E**);

F. 47.06% of remaining natural vegetation only in **unprotected** 5km RLRL areas is both in an overlapping unprotected PABC and 5km RLRL area; however, this varies considerably per biome level (**Table 10**, columns marked **F**).

Figure 26 *- Unprotected PABCs in Relation to 1km RLRLs*

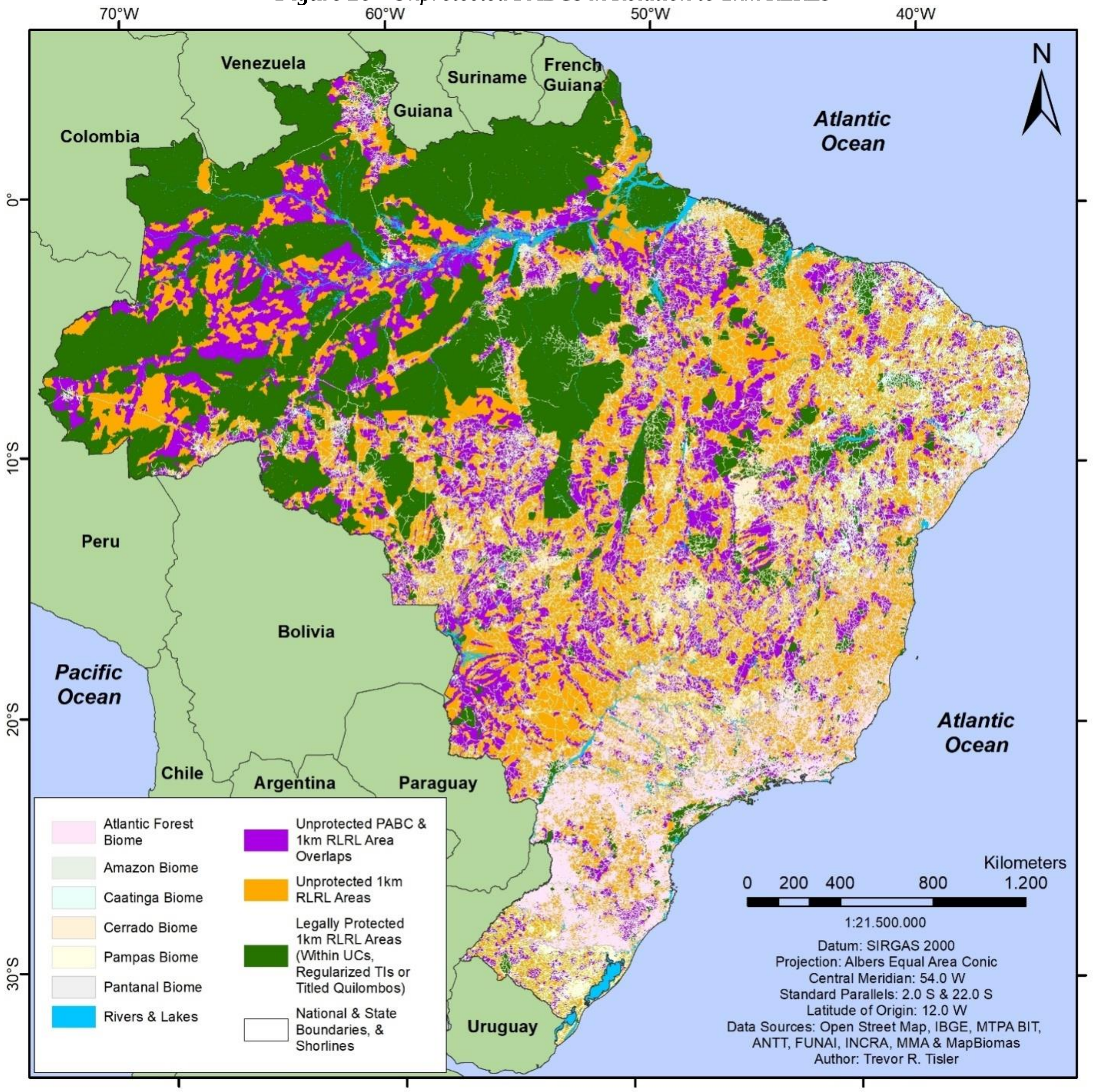


Figure 27 *- Unprotected PABCs in Relation to 5km RLRLs*

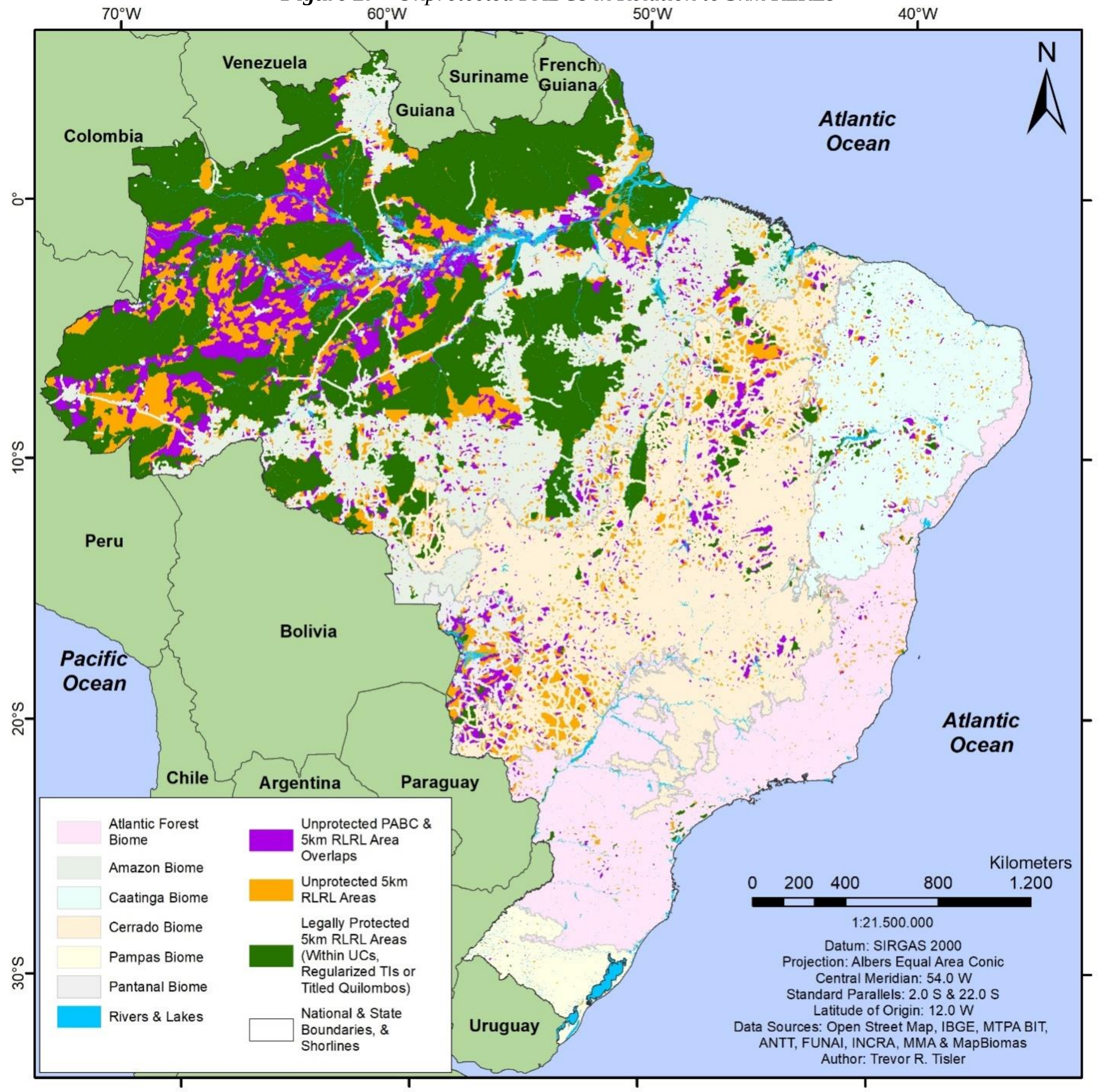


Table 7 *- Unprotected PABCs, 1km RLRLs and Overlaps in Relation to Biome Area*

Biomes	Biome Area (ha)	Unprotected PABCs (ha)	% Unprotected PABCs to Biome Areas	Unprotected PABCs & 1km RLRL Area Overlaps (ha)	% Unprotected PABCs 1km RLRL Overlap to Biome Area
Atlantic Forest	*110,674,019*	*15,950,648*	*14.41%*	*6,442,431*	*5.82%*
Amazon	*421,564,800*	*98,323,376*	*23.32%*	*78,721,417*	*18.67%*
Caatinga	*83,600,127*	*26,062,361*	*31.18%*	*13,702,354*	*16.39%*
Cerrado	*202,963,869*	*63,651,125*	*31.36%*	*41,163,063*	*20.28%*
Pampas	*16,456,620*	*3,654,337*	*22.21%*	*1,715,873*	*10.43%*
Pantanal	*15,014,413*	*7,056,327*	*47.00%*	*5,709,883*	*38.03%*
National Total (with Amazon)	**850,273,851**	**214,698,175**	**25.25%**	**147,455,024**	**17.34%**
National Total (without Amazon)	**428,709,051**	**116,374,799**	**27.14%**	**68,733,606**	**16.03%**

Table 8 *- Unprotected PABCs, 5km RLRLs and Overlaps in Relation to Biome Area*

Biomes	Biome Area (ha)	Unprotected PABCs (ha)	% Unprotected PABCs to Biome Areas	Unprotected PABCs & 5km RLRL Overlap (ha)	% Unprotected PABCs 5km RLRL Overlap to Biome Area
Atlantic Forest	*110,674,019*	*15,950,648*	*14.41%*	*432,767*	*0.39%*
Amazon	*421,564,800*	*98,323,376*	*23.32%*	*47,501,326*	*11.27%*
Caatinga	*83,600,127*	*26,062,361*	*31.18%*	*1,451,545*	*1.74%*
Cerrado	*202,963,869*	*63,651,125*	*31.36%*	*9,327,073*	*4.60%*
Pampas	*16,456,620*	*3,654,337*	*22.21%*	*37,965*	*0.23%*
Pantanal	*15,014,413*	*7,056,327*	*47.00%*	*2,778,177*	*18.50%*
National Total (with Amazon)	**850,273,851**	**214,698,175**	**25.25%**	**61,528,854**	**7.24%**
National Total (without Amazon)	**428,709,051**	**116,374,799**	**27.14%**	**14,027,528**	**3.27%**

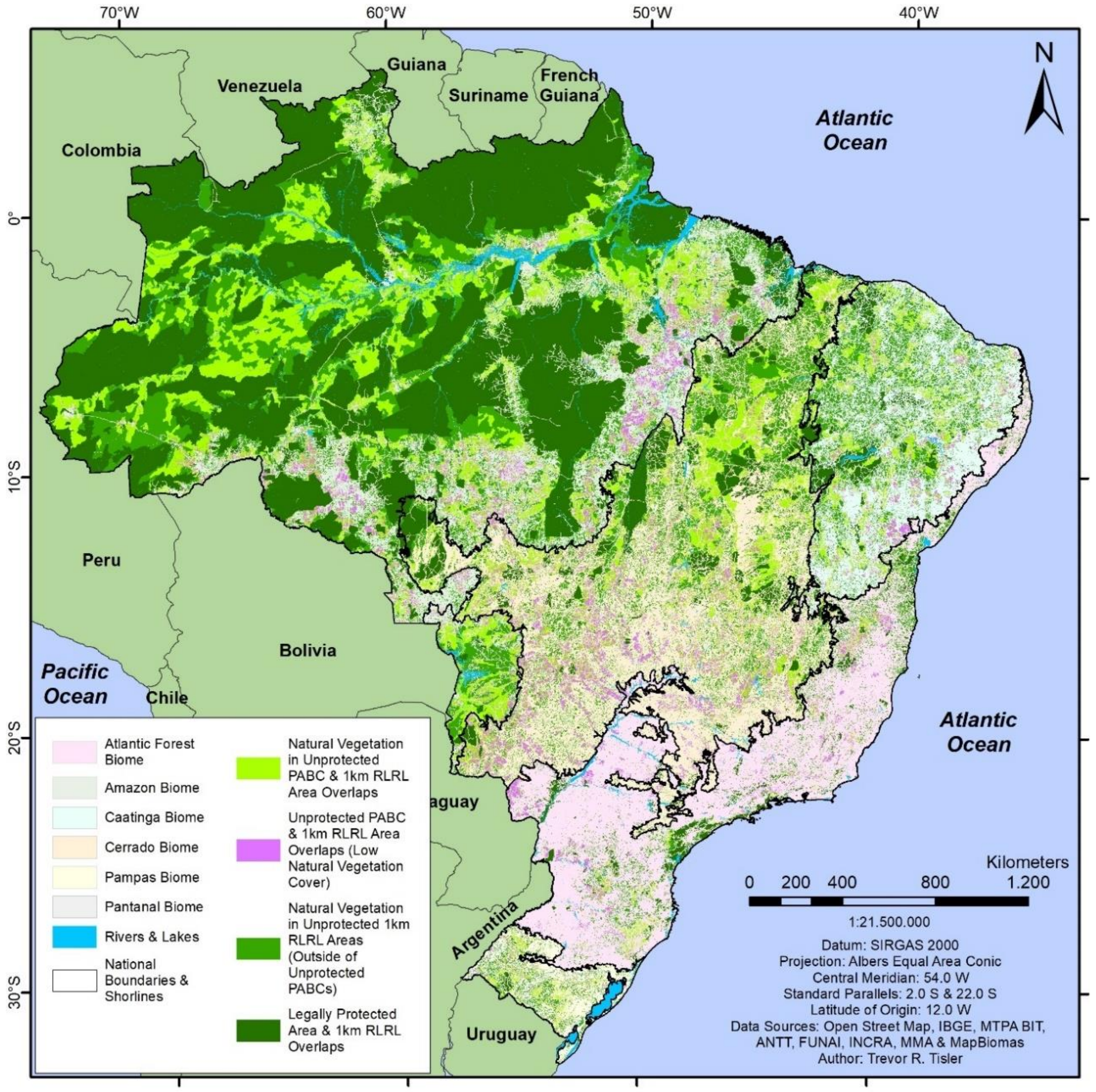


Figure 28 *- Natural Vegetation in Relation to: Biome Area, Unprotected PABCs and 1km RLRL Overlaps*

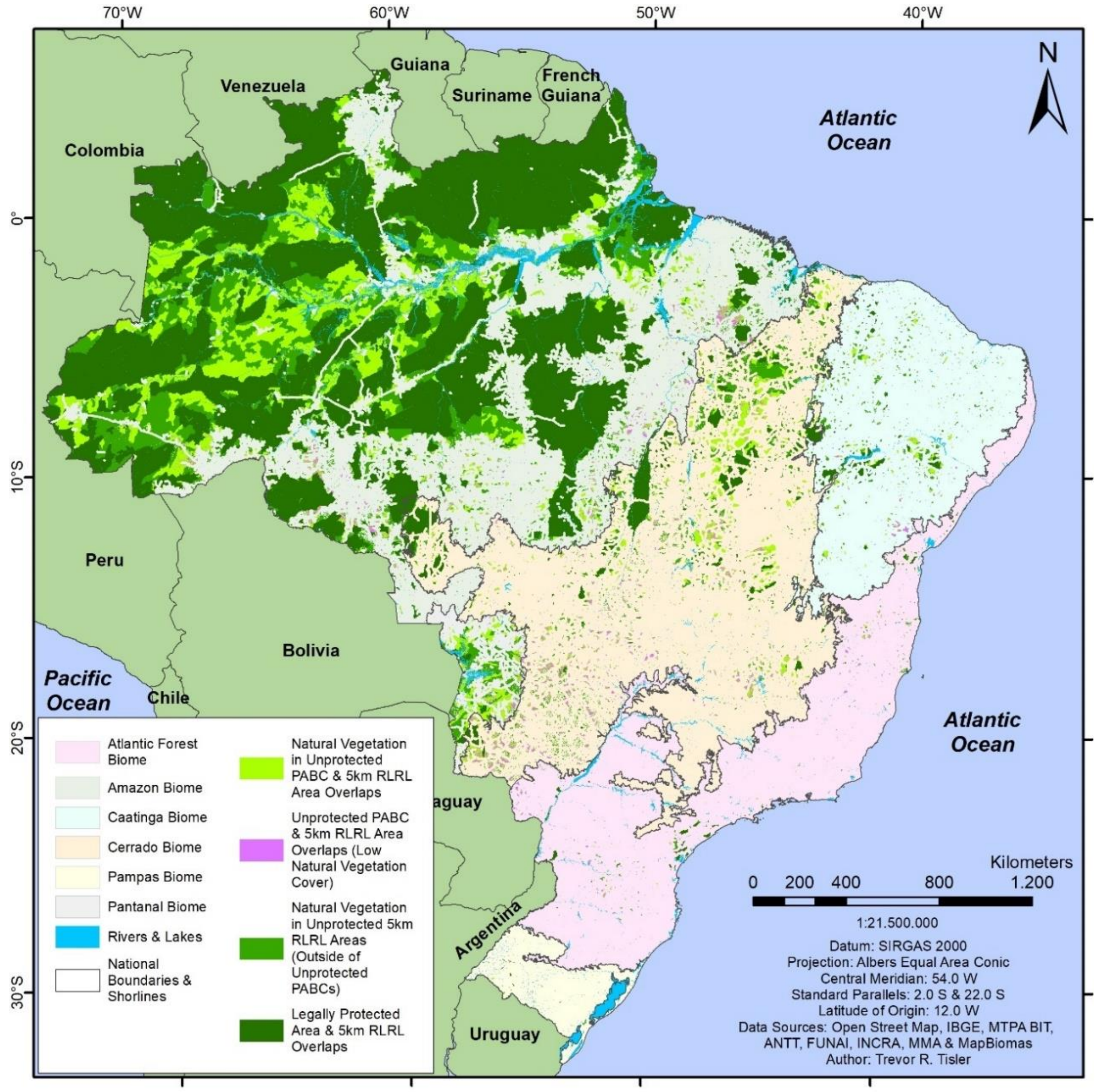


Figure 29 *- Natural Vegetation in Relation to: Biome Area, Unprotected PABCs and 5km RLRL Overlaps*

Biomes	Numerator	A *Denominator*	A *Result*	B *Denominator*	B *Result*	C *Denominator*	C *Result*
	Natural Vegetation in Unprotected PABCs & 1km RLRL Area Overlaps (ha)	Biome Area (ha)	% Natural Vegetation in Unprotected PABC & 1km RLRL Overlaps to Total Biome Area	Biome's Total Natural Vegetation (ha)	% Natural Vegetation in Unprotected PABC & 1km RLRL Overlaps to Biome Total Natural Vegetation	Unprotected Natural Vegetation in 1km RLRLs (ha)	% 1km RLRL Natural Vegetation that is both Unprotected and in a PABC
Atlantic Forest	*2,608,541*	*110,674,019*	*2.36%*	*33,346,681*	*7.82%*	*11,446,821*	*22.79%*
Amazon	*64,123,440*	*421,564,800*	*15.21%*	*361,490,404*	*17.74%*	*135,756,513*	*47.23%*
Caatinga	*9,801,276*	*83,600,127*	*11.72%*	*51,587,999*	*19.00%*	*26,750,330*	*36.64%*
Cerrado	*26,824,350*	*202,963,869*	*13.22%*	*111,398,185*	*24.08%*	*63,207,150*	*42.44%*
Pampas	*1,204,952*	*16,456,620*	*7.32%*	*9,436,342*	*12.77%*	*3,920,636*	*30.73%*
Pantanal	*4,814,776*	*15,014,413*	*32.07%*	*11,931,494*	*40.35%*	*9,535,199*	*50.49%*
National Total	**109,377,338**	**850,273,851**	**12.86%**	**579,191,107**	**18.88%**	**250,616,653**	**43.64%**

Table 1 *- Natural Vegetation, Unprotected PABC and 1km RLRL Overlaps in Relation to Total Biome Area and Total Biome Remaining Natural Vegetation*

Biomes	Numerator	D *Denominator*	D *Result*	E *Denominator*	E *Result*	F *Denominator*	F *Result*
	Natural Vegetation in Unprotected PABCs & 5km RLRL Area Overlaps (ha)	Biome Area (ha)	% Natural Vegetation in Unprotected PABC & 5km RLRL Overlaps to Total Biome Area	Biome's Total Natural Vegetation (ha)	% Natural Vegetation in Unprotected PABC & 5km RLRL Overlaps to Biome Total Natural Vegetation	Unprotected Natural Vegetation in 5km RLRLs (ha)	% 5km RLRL Natural Vegetation that is both Unprotected and in a PABC
Atlantic Forest	*157,672*	*110,674,019*	*0.14%*	*33,346,681*	*0.47%*	*607,844*	*25.94%*
Amazon	*42,586,672*	*421,564,800*	*10.10%*	*361,490,404*	*11.78%*	*89,732,327*	*47.46%*
Caatinga	*1,125,100*	*83,600,127*	*1.35%*	*51,587,999*	*2.18%*	*2,752,986*	*40.87%*
Cerrado	*6,765,876*	*202,963,869*	*3.33%*	*111,398,185*	*6.07%*	*14,626,333*	*46.26%*
Pampas	*24,122*	*16,456,620*	*0.15%*	*9,436,342*	*0.26%*	*90,598*	*26.63%*
Pantanal	*2,408,358*	*15,014,413*	*16.04%*	*11,931,494*	*20.18%*	*4,966,325*	*48.49%*
National Total	**53,067,802**	**850,273,851**	**6.24%**	**579,191,107**	**9.16%**	**112,776,415**	**47.06%**

Table 2 *- Natural Vegetation, Unprotected PABC and 5km RLRL Overlaps in Relation to Total Biome Area and Total Biome Remaining Natural Vegetation*

In relation to Brazil's commitments to the CBD, **Tables 11** and **12** show that increased levels of protection are drastically needed for five of Brazil's biomes. When considering both: (i) general biome area, and (ii) remaining natural vegetation in these five biomes; Brazil has much progress to make towards its NBSAP and Aichi targets 11 and 15 by year's end of 2020. Therefore, the breakdown of the potential conservation synergies related to unprotected PABCs, RLRLs and native vegetation per biome in **Tables 9** and **10** could serve as opportunities to decrease the conservation deficits below.

Biomes	Biome Area (ha)	Biome's Total Protected Area (ha)	% Protected Areas to Biome Total Area	Surplus or Deficit for Brazil's NBSAP Target 11 and for CDB Aichi Target 11 (30% Protected for Amazon, 17% for all other Biomes)
Atlantic Forest	*110,674,019*	*10,925,197*	*9.87%*	***Deficit*** *(7.13%)*
Amazon	*421,564,800*	*216,222,219*	*51.29%*	*Surplus* *21.29%*
Caatinga	*83,600,127*	*7,532,207*	*9.01%*	***Deficit*** *(7.99%)*
Cerrado	*202,963,869*	*23,826,699*	*11.74%*	***Deficit*** *(5.26%)*
Pampas	*16,456,620*	*558,005*	*3.39%*	***Deficit*** *(13.61%)*
Pantanal	*15,014,413*	*639,441*	*4.26%*	***Deficit*** *(12.74%)*
National Total	**850,273,851**	**259,703,771**	**30.54%**	Surplus **(13.54%)**
National Total (without the Amazon)	**428,709,051**	**43,481,552**	**10.14%**	**Deficit (6.86%)**

Table 11 *- Biome Protected Area Status Compared to Brazil's NBSAP Target 11 and Aichi Target 11*

Biomes	Biome Area (ha)	Biome's Total Protected Natural Vegetation Area (ha)	% Protected Natural Vegetation Area to Biome Total Area	Surplus or Deficit for Brazil's NBSAP Target 11 and CDB Aichi Target 11 (30% Protected for Amazon, 17% for all other Biomes)
Atlantic Forest	*110,674,019*	*5,807,705*	*5.25%*	***Deficit*** *(11.75%)*
Amazon	*421,564,800*	*203,821,732*	*48.35%*	*Surplus* *18.35%*
Caatinga	*83,600,127*	*5,793,571*	*6.93%*	***Deficit*** *(10.07%)*
Cerrado	*202,963,869*	*19,003,905*	*9.36%*	***Deficit*** *(7.64%)*
Pampas	*16,456,620*	*440,800*	*2.68%*	***Deficit*** *(14.32%)*
Pantanal	*15,014,413*	*548,366*	*3.65%*	***Deficit*** *(13.35%)*
National Total	**850,273,851**	**235,416,082**	**27.69%**	Surplus **(10.69%)**
National Total (without the Amazon)	**428,709,051**	**31,594,349**	**7.37%**	**Deficit (9.63%)**

Table 12 *- Biome Protected Area Natural Vegetation Status Compared to Brazil's NBSAP Target 11 and Aichi Target 11*

Brazil's SNV highways account to 110,876.73 km of constructed highways and 17,434.68 km of planned highways (DNIT, 2018). Brazil's SNV railroads account to 37,302.60 km of constructed railroads and 19,237.63 km of planned railroads (MTPA, 2018c). At the national level, 32.69% of Brazil's built SNV highway system extension and 27.51% of the built SNV railroad system impacts at least one of three possible IEAs: (i) LPAs (UCs, regularized TIs, or titled Quilombos), (ii) areas that could be legally protected with land regularization (unregularized TIs or untitled Quilombos), or (iii) unprotected PABCs (**Tables 13** and **14**).

When considering potential impacts of planned components of the SNV, 70.39% of planned SNV highways and 56.59% of planned SNV railroads would impact at least one of five possible IEAs: (i) LPAs, (ii) areas that could be legally protected with land regularization, (iii) unprotected PABCs, (iv) 1km RLRL areas, or (v) 5km RLRL areas (**Table 15**).

For roads, when broken down per IEA category: 6.79% of the built SNV highway km impacts LPAs, 0.16% impacts areas that could be protected with land regularization, and 25.74% impacts unprotected PABCs (**Figure 30** and **Tables 16**, **17** and **18**). As for planned highways in the SNV system, 33.26% of the planned SNV highway network would impact LPAs if built, 0.80% would impact areas that could be protected with land regularization if built, and 24.78% would impact unprotected PABCs if built (**Figure 30** and **Tables 16**, **17** and **18**). Furthermore, 56.90% of the planned SNV highway network extension would impact 1km RLRLs and 34.14% would impact 5km RLRLs if built (**Table 15**).

For railroads, when broken down per IEA category: 4.69% of built SNV railroad km impacts LPAs, 0.20% impacts areas that could be protected with land regularization, and 22.62% impacts unprotected PABCs (**Figure 31** and **Tables 19**, **20**, and **21**). As for planned railroads in the SNV system, 8.71% of the planned SNV railroad kilometrage would impact LPAs if built, 0.33% would impact areas that could be protected with land regularization if built, and 34.62% would impact unprotected PABCs if built (**Figure 31** and **Tables 19**, **20**, and **21**). Furthermore, 37.98% of the planned SNV railroad network kilometrage would impact 1km RLRLs and 7.67% would impact 5km RLRLs if built (**Table 15**).

Built SNV Highway System Impacts on all Three Possible IEAs				
Highway Categories	***4-Lane Highways***	***2-Lane Highways***	***Dirt Highways***	***Built System***
Total Built Kilometrage (km)	*12,187.62*	*85,672.76*	*13,016.36*	*110,876.73*
Total Built Highway Impacts on all Three Possible IEAs (km) *(No Double Counting among the Three Possible IEAs)*	*3,481.15*	*26,663.96*	*6,103.09*	*36,248.21*
Percent of Built Kilometrage Impacting IEAs to Total Built SNV Highways	**28.56%**	**31.12%**	**46.89%**	**32.69%**

Table 13 *- Built SNV Highway System Impacts on IEAs*

Built SNV Railroad System Impacts on all Three Possible IEAs	
Railroad Categories	***Built Railroads***
Total Built Kilometrage (km)	*37,302.60*
Total Built Railroad Impacts on all Three Possible IEAs (km) *(No Double Counting among the Three Possible IEAs)*	*10,262.73*
Percent of Built Kilometrage Impacting IEAs to Total Built SNV Highways	**27.51%**

Table 14 *- Built SNV Railroad System Impacts on IEAs*

Planned SNV Highway & Railroad Impacts on all Five Possible IEAs				
Planned Infrastructure	***Planned Highways (km)***	***Percent Planned Highways***	***Planned Railroads (km)***	***Percent Planned Railroads***
Total Planned Kilometrage	*17,434.68*	---	*19,237.63*	---
Legally Protected Area Impacts	*5,799.41*	**33.26%**	*1,675.97*	**8.71%**
Could be Protected Area Impacts	*139.81*	**0.80%**	*62.48*	**0.33%**
Unprotected PABCs Impacts	*4,320.03*	**24.78%**	*4,984.59*	**25.91%**
1km RLRL Area Impacts Kilometrage	*9,920.47*	**56.90%**	*7,306.62*	**37.98%**
5km RLRL Area Impacts Kilometrage	*5,952.82*	**34.14%**	*1,475.41*	**7.67%**
Built Kilometrage Impacting IEAs *(No Double Counting among the Five Possible IEAs)*	*12,271.74*	**70.39%**	*10,886.94*	**56.59%**

Table 15 *- Planned SNV Highway & Railroad Impacts on RLRL Areas*

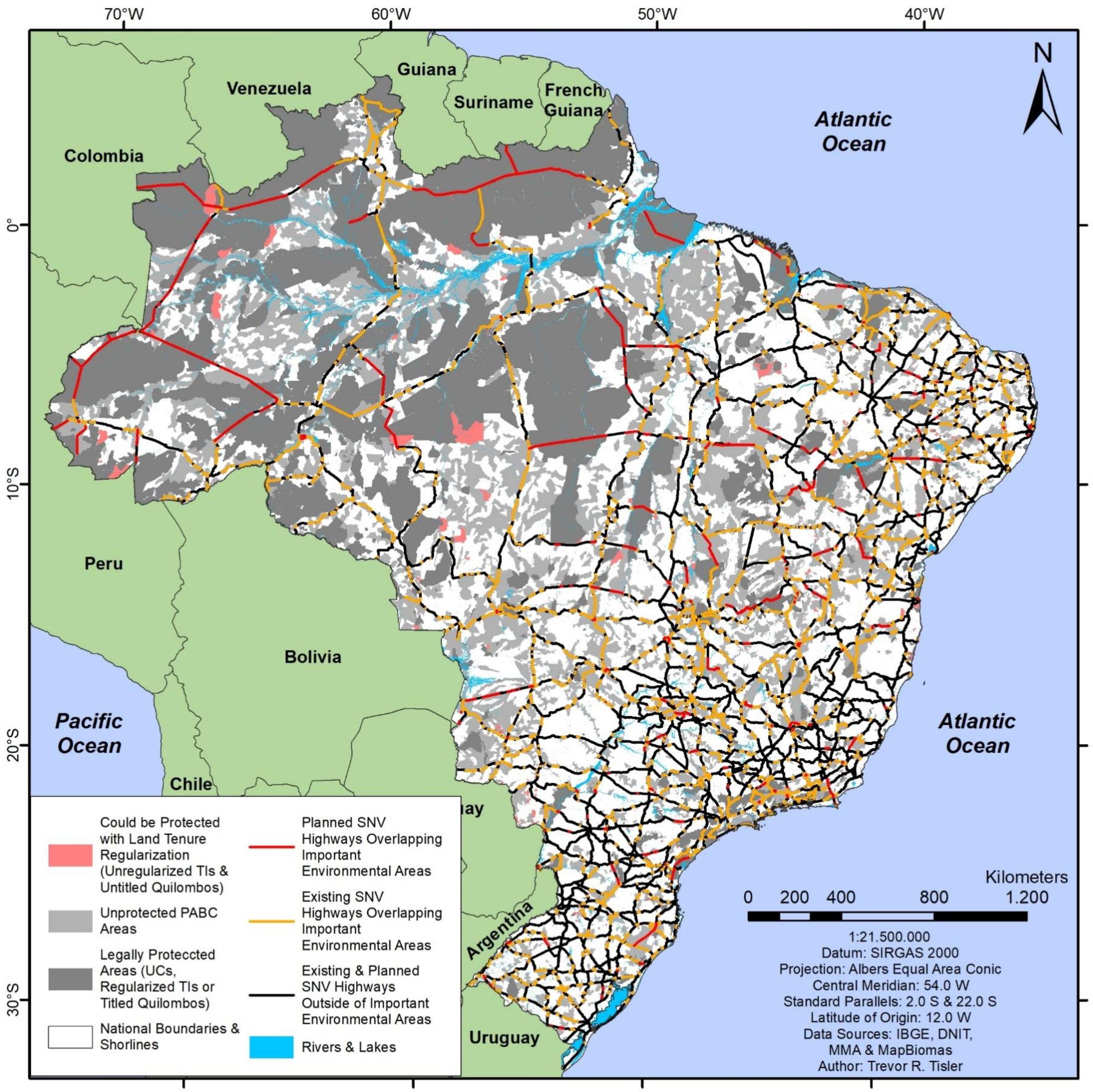


***Figure 30** - Brazil's SNV Highway Impacts on Important Environmental Areas*

SNV Highway System Impacts on Legally Protected Areas						
Highway Categories	*4-Lane Highways*	*2-Lane Highways*	*Dirt Highways*	*Planned Highways*	*Constructed System*	*Total Legal SNV System*
Total Kilometrage (km)	*12,187.62*	*85,672.76*	*13,016.36*	*17,434.68*	*110,876.73*	*128,311.42*
Legally Protected Area Impacts (km)	*1,240.18*	*4,075.07*	*2,213.49*	*5,799.41*	*7,528.75*	*13,328.16*
Percent of Kilometrage Impacting Legally Protected Areas (km)	**10.18%**	**4.76%**	**17.01%**	**33.26%**	**6.79%**	**10.39%**

***Table 16** - SNV Highway System Impacts on Protected Areas*

SNV Highway System Impacts on Areas that Could Be Protected with Land Regularization						
Highway Categories	*4-Lane Highways*	*2-Lane Highways*	*Dirt Highways*	*Planned Highways*	*Constructed System*	*Total Legal SNV System*
Total Kilometrage (km)	*12,187.62*	*85,672.76*	*13,016.36*	*17,434.68*	*110,876.73*	*128,311.42*
Could be Protected Area Impacts (km)	*16.78*	*103.54*	*56.76*	*139.81*	*177.08*	*316.89*
Percent of Kilometrage Impacting Could be Protected Areas (km)	**0.14%**	**0.12%**	**0.44%**	**0.80%**	**0.16%**	**0.25%**

***Table 17** - SNV Highway System Impacts on Areas that Could Be Protected with Land Regularization*

SNV Highway System Impacts on Unprotected PABCs						
Highway Categories	*4-Lane Highways*	*2-Lane Highways*	*Dirt Highways*	*Planned Highways*	*Constructed System*	*Total Legal SNV System*
Total Kilometrage (km)	*12,187.62*	*85,672.76*	*13,016.36*	*17,434.68*	*110,876.73*	*128,311.42*
Unprotected PABC Impacts (km)	*2,224.20*	*22,485.35*	*3,832.83*	*4,320.03*	*28,542.37*	*32,862.40*
Percent of Kilometrage Impacting Unprotected PABCs	**18.25%**	**26.25%**	**29.45%**	**24.78%**	**25.74%**	**25.61%**

***Table 18** - SNV Highway System Impacts on Unprotected PABCs*

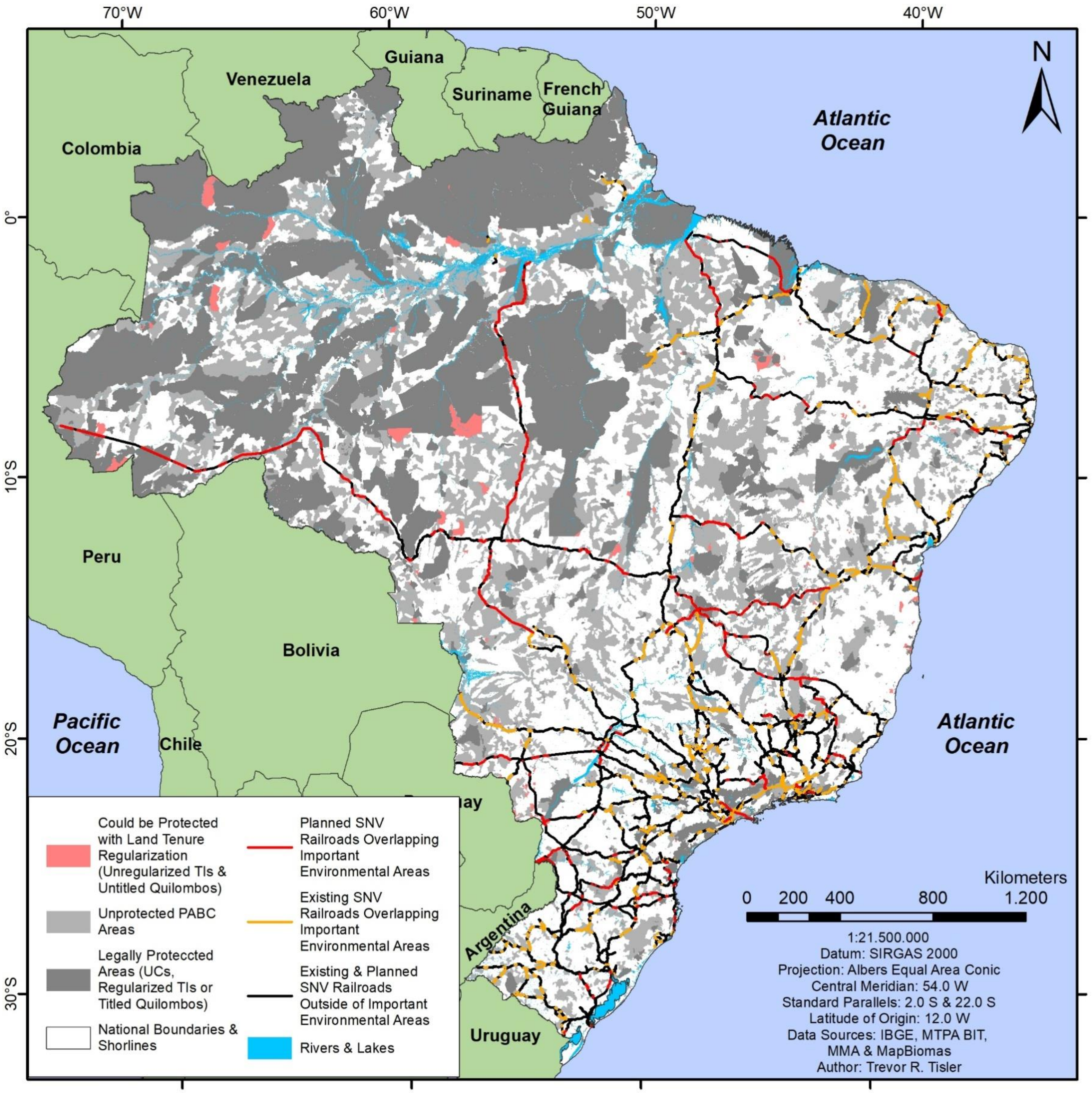


Figure 31 *- Brazil's SNV Railroad Impacts on Important Environmental Areas*

SNV Railroad System Impacts on Legally Protected Areas		
Railroad Categories	***Existing***	***Planned***
Total Kilometrage (km)	*37,302.60*	*19,237.63*
Legally Protected Area Impacts (km)	*1,749.26*	*1,675.97*
Percent of Kilometrage Impacting Legally Protected Areas	**4.69%**	**8.71%**

Table 19 *- SNV Railroad System Impacts on Protected Areas*

SNV Railroad System Impacts Areas that Could be Protected with Land Regularization		
Railroad Categories	***Existing***	***Planned***
Total Kilometrage (km)	*37,302.60*	*19,237.63*
Could be Protected Area Impacts (km)	*75.24*	*62.48*
Percent of Kilometrage Impacting Could be Protected Areas	**0.202%**	**0.325%**

Table 20 *- SNV Railroad System Impacts Areas that Could be Protected with Land Regularization*

SNV Railroad System Impacts on Unprotected PABCs		
Railroad Categories	***Existing***	***Planned***
Total Kilometrage (km)	*37,302.60*	*19,237.63*
Unprotected PABC Impacts (km)	*8,438.23*	*4,984.60*
Percent of Kilometrage Impacting Unprotected PABCs	**22.62%**	**25.91%**

Table 21 *- SNV Railroad System Impacts on Unprotected PABCs*

Although Brazil has had advanced environmental licensing laws in place since 1981, as of November 2018, 43.83% of Brazil's built SNV highway extension (48,604.91 km) is still in operation without any environmental licensing (DNIT, 2016) and 13.70% of Brazil's built SNV highway extension (15,189.14 km) is both unlicensed and crossing IEAs (**Figure 32** and **Table 22**). A Breakdown per IEA category is presented in **Tables 23**, **24** and **25**.

PROFAS Highways Compared to Constructed SNV Highways				
Highway Categories	*4-Lane Highways*	*2-Lane Highways*	*Dirt Highways*	*Constructed System*
Total SNV System Kilometrage (km)	*12,187.62*	*85,672.76*	*13,016.36*	*110,876.73*
Total PROFAS Kilometrage (km) (Without Licensing)	*2,931.30*	*45,480.51*	*139.15*	*48,550.96*
Percent PROFAS Highway Kilometrage to Total SNV System Kilometrage	**24.05%**	**53.09%**	**1.07%**	**43.79%**
PROFAS Impacts on all Three Possible IEAs (km) *(No Double Counting among the Three Possible IEAs)*	*671.37*	*14,459.73*	*58.04*	*15,189.14*
Total PROFAS IEA Impacts to Total PROFAS Highways km	**22.90%**	**31.79%**	**41.71%**	**31.25%**
Total PROFAS IEA Impacts to Total Built SNV Highways km	**5.51%**	**16.88%**	**0.45%**	**13.70%**

Table 22 *- Brazil's PROFAS Highways Compared to Constructed SNV Highways and Total IEA Impacts*

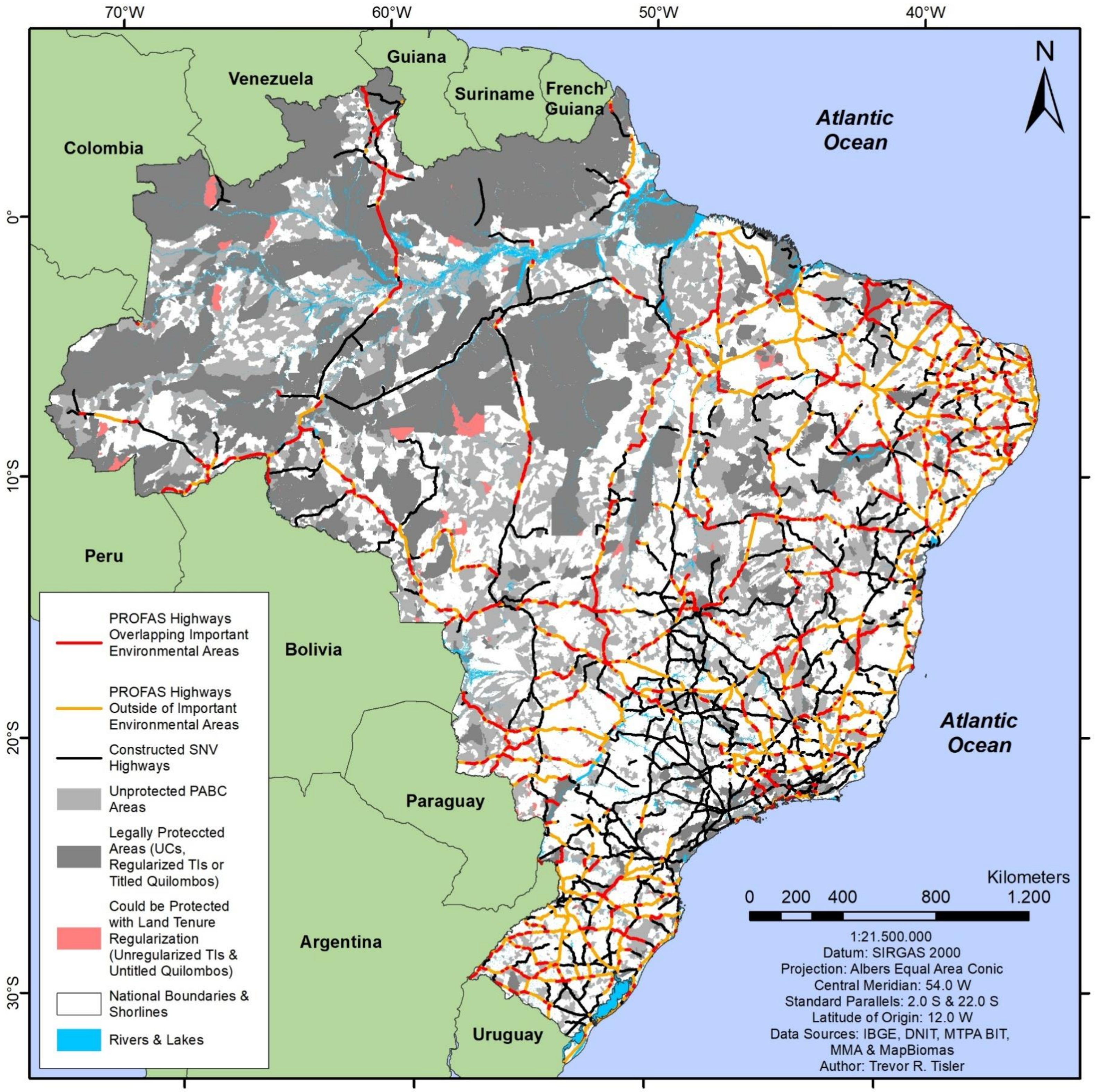


Figure 32 - Brazil's PROFAS Highways, their impacts on IEAs, and their Relation to Constructed SNV Highways

PROFAS Highway Impacts on Legally Protected Areas Compared to Constructed SNV Highways				
Highway Categories	***4-Lane Highways***	***2-Lane Highways***	***Dirt Highways***	***Constructed System***
Total SNV System Kilometrage (km)	*12,187.62*	*85,672.76*	*13,016.36*	*110,876.73*
PROFAS Highways Impacting Legally Protected Areas (km)	*162.92*	*1,813.75*	*30.54*	*2,007.21*
Percent PROFAS Highways Impacting PAs to Total SNV System	**1.34%**	**2.12%**	**0.23%**	**1.81%**

Table 23 - PROFAS Highway Impacts on Protected Areas (PAs) Compared to Constructed SNV Highways

PROFAS Highway Impacts on Could be Protected Areas Compared to Constructed SNV Highways				
Highway Categories	***4-Lane Highways***	***2-Lane Highways***	***Dirt Highways***	***Constructed System***
Total SNV System Kilometrage (km)	*12,187.62*	*85,672.76*	*13,016.36*	*110,876.73*
PROFAS Highways Impacting Could be Protected Areas (km)	*9.70*	*51.22*	*0.00*	*60.92*
Percent PROFAS Highways Impacting Could be Protected Areas to Total SNV System	**0.08%**	**0.06%**	**0.00%**	**0.05%**

Table 24 - PROFAS Highway Impacts on Could be Protected Areas Compared to Constructed SNV Highways

PROFAS Highway Impacts on Unprotected PABCs Compared to Constructed SNV Highways				
Highway Categories	***4-Lane Highways***	***2-Lane Highways***	***Dirt Highways***	***Constructed System***
Total SNV System Kilometrage (km)	*12,187.62*	*85,672.76*	*13,016.36*	*110,876.73*
PROFAS Highways Impacting Unprotected PABCs (km)	*498.75*	*12,594.76*	*27.50*	*13,121.01*
Percent PROFAS Highways Impacting Unprotected PABCs to Total SNV System	**4.09%**	**14.70%**	**0.21%**	**11.83%**

Table 25 - PROFAS Highway Impacts on Unprotected PABCs Compared to Constructed SNV Highways

3.5 - Discussion

All of Brazil's six terrestrial biomes still hold large extensions of unprotected 1km RLRL areas with remaining natural vegetation (**Table 5**). Furthermore, additional overlaps exist between the vegetated portions of unprotected 1km RLRL areas and MMA's PABCs (**Tables 9** and **10**). These spatially identified areas could serve as valuable starting points for identifying and enacting conservation opportunities (**Figures 28** and **29**) given the ecological importance of these areas remaining roadless and railroad-less and that Brazil appears to be falling short of its CBD commitments.

When considering 5km RLRL areas in Brazil's six terrestrial biomes, two distinct trends emerge. The first trend highlights urgent conservation priorities that should be acted on soon in four of Brazil's biomes: the Atlantic Forest, Caatinga, Cerrado and Pampas. These biomes have low amounts of remaining 5km RLRL areas when compared to their total biome extent (**Table 2** and **Sup. Mat. Ch. 2, Sec. 9**). Furthermore, the vast majority of the remaining natural vegetation found in these few 5km RLRL areas is unprotected (**Table 5**). Moreover, a sizable amount of that unprotected natural vegetation in 5km RLRL areas (between 25 to 46% depending on the biome) is located in an unprotected PABC (**Table 10**). Conservation of these areas should be done either through the creation or enlargement of UCs or by granting land rights to any coincident unregularized TIs or untitled Quilombos.

The second trend includes the Amazon and Pantanal which still have extensive remaining 5km RLRL areas (**Figures 21** and **24**; and **Sup. Mat. Ch. 2, Sec. 9**). Moreover, the unprotected portions of these 5km RLRL areas account to 23.90% and 39.18% of each biome's total area respectively (**Table 2**). Concurrently, the unprotected portion of these biomes' 5km RLRLs areas hold significantly large amounts of unprotected vegetation (**Table 5**), of which 47.46% (Amazon) and 48.49% (Pantanal) falls within PABCs (**Table 10**). These identified areas represent ample conservation opportunities for the creation of UCs or through land regularization if they coincide with Unregularized TIs or Untitled Quilombos.

In regard to Brazil's built portions of the SNV, both for highways and railroads, our results show that almost one third of the overall built system crosses and impacts IEAs, which includes LPAs, areas that could be protected with regularization, and unprotected PABCs. Furthermore, if all planned SNV highways and railroads are built, they will overwhelmingly impact IEAs. The current reality lies in the fact that the guiding blueprints of Brazil's SNV were designed and entered into law in 1973, an era before the vast majority of Brazil's environmental licensing framework, legal protection, conservation and scientific movement, or widespread acknowledgement of climate change were established, enacted, organized and understood.

What-is-more, 38 years after the watershed moment when Federal Law n. 6.938 of August 31, 1981 enacted the National Environment Policy (henceforth PNMA, for *Política Nacional do Meio Ambiente*) and established environmental licensing procedures in Brazil (BRAZIL, 1981), 43.83% of Brazil's built SNV highway extension (48,604.91 km) is still in operation without any environmental licensing and 13.70% of Brazil's built SNV highway extension (15,189.13 km) is both unlicensed and crosses IEAs (DNIT, 2016) (**Figure 32** and **Tables 22**, **23**, **24**, and **25**). In 2015, Presidential Decree n. 8.437 of April 22, 2015 was issued and requires that existing SNV highways constructed before the 1981 enactment of the PNMA undergo environmental regularization to bring them up to current mitigation standards in order for them to obtain an operating license (BRAZIL, 2015b). Although this is being undertaken by DNIT and Brazil's environmental licensing agency, the Brazilian Institute of the Environment and Renewable Natural Resources (henceforth IBAMA, for *Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais*) through the Environmentally Sustainable Federal Highways Program (henceforth PROFAS, for *Programa de Rodovias Federais Ambientalmente Sustentáveis*) (DNIT; IBAMA, 2012), significant progress has yet to be made. Of the 51,074 km of highways originally identified by DNIT to undergo environmental regularization and to obtain operational licensing by IBAMA (DNIT, 2016), our identification of 48,550.96 km of remaining unlicensed PROFAS highways (**Table 22**) indicates that only 2,469.09 km of highways have been regularized and obtained operating licenses since being legally required to do so. Finally, many planned SNV highways are designated to be connected to many still unlicensed PROFAS' highways.

In the 31 years since Brazil's 1988 Federal Constitution enshrined an ecologically balanced environment as a democratic right for current and future generations (BRAZIL, 1988, Art. 225), significant scientific research has amassed and documented the connection between transportation infrastructure, deforestation, LULC change, and negative biodiversity impacts. Yet, the 1973 SNV network plans continue to form the foundation for many contemporary transportation PPPs. These include PPPs dating from both the Lula da Silva and Rousseff presidential administrations such as the National Plan for Logistics and Transport (henceforth PNLT, for *Plano Nacional de Logistica e Transporte*s) and many transportation projects involved in the Growth Acceleration Program (henceforth PAC, for *Programa de Aceleração de Cresimento*) (PEREIRA; LESSA, 2011; VERDUM, 2012), as well as the current transportation PPPs still on the books from the Temer and Bolsonaro presidential administrations such as the Investment Partner Program (henceforth PPI, for *Programa de Parcerias de Investimentos*), the National Transportation Policy (henceforth PNT, for *Política Nacional de Transportes*), and the National Logistics Plan (henceforth PNL, for *Plano Nacional de Logística*) (EPL, 2018; MTPA, 2018a; PAULA, 2018; PPI, 2018). These current PPPs incorporate planned SNV highways and railroads that would impact IEAs as indicated by our results; and moreover, the PNL calls for them to be built by 2025 (EPL, 2018). In particular, the PNL infrastructure projects are still part of the larger master SNV plans which are also still intended to be built and integrated into the national network beyond 2025.

The existing literature indicates that in Brazil environmental and social consideration are frequently, if not almost always, inadequately considered or not considered at all during the initial stages of the transportation PPP forming process (DO NASCIMENTO NADRUZ et al., 2018; MALVESTIO; FISCHER; MONTAÑO, 2018; SÁNCHEZ, 2017). This reality includes the aforementioned transportation PPPs (MALVESTIO; FISCHER; MONTAÑO, 2018) but also extends to many other federal infrastructure PPPs such as energy, large industry and agriculture (DO NASCIMENTO NADRUZ et al., 2018; SÁNCHEZ, 2017). Unfortunately, this negligence has even commonly occurred in cases where Strategic Environmental Assessment (SEA) was implemented (DO NASCIMENTO NADRUZ et al., 2018; MALVESTIO; FISCHER; MONTAÑO, 2018; SÁNCHEZ, 2017; ZIONI; FREITAS, 2015), which is the policy level mechanism specifically designed and intended to incorporate environmental and social issues into PPPs to avoid possible negative impacts (FISCHER, 2002).

Multilateral funding agencies, development banks, and even multinational corporations worried about capital and regulatory risk[9] as well as corporate social responsibility[10] are increasingly implementing safeguard policies, which call for the use of SEA or other forms of environmental and social impact assessments to be conducted before lending to borrowing countries for infrastructure and development projects (DE OLIVEIRA; MONTAÑO; DE SOUZA, 2013; DENDENA; CORSI, 2015; SILVA et al., 2014). However, the current reality of SEA in Brazil is of significant concern as the mentioned types of organizations may be partaking in the federal government's PPI initiative, and as the future financial backers of PNL and SNV infrastructure, they may be misled into investing in infrastructure projects that may not have actually been planned to the standards of their safeguard policies. Thus, the situation in Brazil could possibly jeopardize confidence that lending agencies, development banks, and multinational corporations have in Brazil's institutions if unexpected environmental and social impacts come to light in large numbers when they should have been addressed beforehand in the PPP process. Given that our results show that the SNV has significant impacts on IEAs, both existing and planned components, it might be prudent to take the SNV and PNL back to the drawing board and rethink some of the infrastructure that is part of the PPI.

With respect to the two international commitments highlighted in the scope of this study, the CBD and the Paris Agreement, our results indicate that Brazil has pressing conservation opportunities to act on before further LULC change occurs. Furthermore, if Brazil were to act on the highlighted conservation opportunities shown by our results, the country would be mutually and synergistically working towards achieving its commitments and targets for both the CBD and Paris Agreement, effectively "preserving two birds with one act". Brazil has legally committed itself to meet its land use relevant biodiversity conservation targets for the CDB by the end of 2020 (MMA, 2017), although this appears unlikely. Moreover, Brazil is to begin working towards its NDC commitments by 2020, which

[9] Capital Risk is the potential risk or loss of an investment, for example when a company invests in a project and there are unexpected problems there is a risk that the capital investment will not bring expected revenue as a result. Regulatory Risk is the risk of having the 'license' or 'permission' to partake in or operate business activities withdrawn by a regulator, or having conditions applied (retrospectively or prospectively) that negatively impact the economic returns of a business enterprise (INVESTOPEDIA, 2018a, 2018b).

[10] Corporate Social Responsibility (CSR) is a self-regulating business model that aids a company maintain accountability, to itself, to stakeholders and investors, the public and civil society organizations, and even the government. This approach allows a company to be conscious of all the ways that its operations impact the economy, society and the environment (INVESTOPEDIA, 2019).

is when Paris Agreement signatories committed to start implementing their NDCs and is also the deadline for signatories to make any updates to their 2030 commitments (BRAZIL, 2015a; UNFCCC, 2015). With the identification of the natural vegetation status of Brazil's PABCs at a biome level, our results identify not only current conservation opportunities, but also potential areas for reforestation or natural vegetation restoration (**Tables 6**, **7**, **8**, **9**, and **10**) that could serve as opportunities for the reforestation of 12 million hectares of forests as Brazil committed to doing in its NDC (BRAZIL, 2015a). However, if reforestation is intended for sustainable use then the implantation of sustainable use forests in PABCs should depend on location and context-specific biodiversity sensitivities or local land tenure situations.

However, to meet these targets, policymakers and federal bureaucrats need to actually integrate the stated goals from these international commitments into the policy formulation and decision-making processes. This needs to be done at all relevant federal ministries involved in land-use and regional planning. This is especially important for, and may be a significant challenge for, the newly created MoI (previously MTPA) which has had some of its PPP implementation responsibilities, such as SNV highway and railroad construction and upgrading devolved to state transportation agencies by the Bolsonaro administration (BRAZIL, 2019, Art. 35, Parágrafo único, VII). This means that Brazil's 27 state and federal district level transportation agencies now will have a *de facto* responsibility for upholding certain aspects of Brazil's international environmental commitments.

In the context of the Amazon, Brazil has publicly promised to strengthen policies and actions to bring net illegal deforestation rates to zero by 2030 in its NDC (BRAZIL, 2015a); yet, deforestation rates have risen in the past years (ROCHEDO et al., 2018). In relation to the CBD, the Amazon is the only biome that appears to already meet NBSAP conservation commitments as the biome already has an overall protected area exceeding the NBSAP's 30% promised protected area target (MMA, 2017); we estimate that 51.29% of the Brazilian Amazon's total area is currently legally protected by UCs, regularized TIs and titled Quilombos. However, it is important to highlight the national and global significance of the Amazon (SANTIAGO; CAVIGLIA-HARRIS; PEREIRA DE REZENDE, 2018; STEFFEN et al., 2018) and that the future protection of the remaining Amazon outside of LPAs, primarily on private properties, relies on the successful implementation and enforcement of CAR. Aside from the repeated delays of CAR's rollout (BRAZIL, 2018; JUNG et al., 2017) the 95% of all rural properties that have occurred so far does not appear to have had significant impact in dissuading land owners from stopping illegal deforestation (AZEVEDO et al., 2017; SOARES-FILHO; RAJÃO, 2018). Furthermore, with the consideration of planned infrastructure in the Amazon and its clear connection to deforestation, it is crucial to protect RLRL areas to avoid the negative effects of transportation systems on these ecosystems (SELVA et al., 2015).

One more point relating to the Amazon is Article 12 §4 and §5 of the 2012 FC (BRAZIL, 2012, Art 12. § 4 & 5) which could allow for a reduction of combined RL and APP native vegetation quotas from a total 80% to 50% at the municipal or state level in the Legal Amazon, if 50% or more of a municipality and 65% or more of a state's territory is conserved by UCs and/or homologated TIs. Although this reduction would still require approval from the Governing Environmental Council in any of the 9 states in Brazil's Legal Amazon arriving at these levels of conserved land, if the political pressure on a state's Governing Environmental Council is sufficient then significant forest reserves could be legally opened up for deforested in a worst-case scenario (FREITAS et al., 2018). Freitas et al. (2018) spatially modeled the possibility of this occurring in Amapá, Amazonas and Roriama, states that are close to or at 65% conservation coverage, and their results indicate that in the worst case scenario of all three of these states having their RL and APP combined quotas reduced statewide, a combined total of 15 million hectares (Mha) of preserved forest and significant sections of MMA's PABCs would be put at deforestation risk. Moreover, Amapá already qualifies for the RL quota reduction, as 70% of the state's territory is already protected by UCs and TIs (FREITAS et al., 2018).

Brazil's five other biomes do not appear to be in line to achieve NBSAP and Aichi targets 11 and 15 by the end of 2020. Firstly, of the possible tools outlined to achieve biodiversity conservation, Brazil's NBSAP outlines the importance of using the FC's RLs and APPs to help achieve conservation targets (MMA, 2017). As already stated, these 'tools' are contingent on a completed and enforceable CAR. Aside from the uncertainty that CAR will be ready as an enforcement tool by 2020, one must understand the legal stipulations of applying RLs and APPs in the context of each biome and in relation to the intentions of the Aichi targets. For example, Vieira et al. (2018) have modeled that the enforcement of the 2012 FC's RL and APP requirements in the Cerrado would legally allow for 40% of the remaining native vegetation to be deforested. This would result in a net biodiversity loss due to likely induced flora and fauna extinctions, which beyond the Cerrado already being a biodiversity hotspot (MYERS et al., 2002), would also be detrimental to regional water supply and increase Brazil's GHG emissions (VIEIRA et al., 2018).

Non-Forest Ecosystems (NFEs) were protected for the first time by their addition to the 2012 FC, as NFEs were completely unprotected by the previous FCs. Moreover, these areas have already suffered severe vegetation losses in a magnitude similar to the deforestation of the Amazon forest (OVERBECK et al., 2015). However, Brazil's NFEs have comparatively very little conservation protection in the form of LPAs (whether UCs, regularized TIs and titled Quilombos) compared to Brazil's forested ecosystems (OVERBECK et al., 2015). Therefore, unless UCs, TIs and Quilombos are established, regularized or titled and cover significant areas of Brazil's NFEs by the end of 2020, the protection of biodiverse NFEs for NBSAP and Aichi targets 11 and 15 in biomes such as the Caatinga, Cerrado, and the Pampas will be dependent on: (i) the successful rollout of CAR, then (ii) the effective enforcement of RL and APP vegetation quotas in those biomes, and (iii) hopefully that RL and APP quotas will require native vegetation restoration rather than allow for additional LULC change. Moreover, if UCs, TIs or Quilombos are not officialized in the areas of NFEs that were highlighted as conservation priorities by MMA's PABCs by the end of 2020, then biodiversity conservation in those areas will depend on whether the RL and APP quotas and their spatial organizations are large enough and adequately connected to prevent species extinctions.

3.6 – Conclusion

The presented realities and impacts became visible by applying the roadless areas approach of Ibisch et al. (2016) into a macro national level analysis that also included relevant spatial components related to Brazil's federal transportation and environmental policy, both domestic and international. Although local participation and local environmental impacts are always of utmost importance for consideration in transportation planning, a holistic analysis of conflicts between transportation and environmental conflicts is also important in order to understand systemic contradictions at the regional and national levels. If systemic contradictions are identified and mediated early, then long-run policy success in both transportation and environmental policy realms would likely be achieved.

Thus, we believe that transportation PPPs should only propose new or improved infrastructure projects that: (i) are planned to go around and avoid IEAs; (ii) are designed to only directly connect underperforming settled areas without significant natural capital assets nor identified PABCs to other already settled areas; and (iii) are focused on improving the freight capacity of already existing transportation infrastructure in consolidated and not environmentally sensitive areas. If this is done, then significant environmental degradation and deforestation will likely be avoided while at the same time improving the country's total agricultural output.

Our results provide opportunities for Brazil's policymakers to act on now so that the country can uphold its publicly made environmental and biodiversity conservation targets and commitments to the CBD and Paris Agreement. Furthermore, we have provided results that could be used to analyze transportation PPPs to aid in reformulating policy design to lead Brazil towards a more prosperous and sustainable future. With smart transportation and infrastructure planning, environmental and transportation PPPs can work together synergistically to help Brazil achieve its environmental and biodiversity conservation targets as well as meet its future agricultural production demands and benefit other sectors of the economy at least for the foreseeable future.

The preservation of RLRL areas with natural vegetation cover should be an important consideration for future transportation infrastructure planning as the functionality and scale of the services that their corresponding ecosystems provide to local, regional and global scales is substantial (FREUDENBERGER et al., 2012). Furthermore, by integrating RLRL areas with spatial information on unprotected PABCs and their natural vegetation cover status – key components of MMA's environmental and biodiversity conservation PPPs – we highlighted important areas that should be kept free from future development and that if legally protected will aid Brazil in its efforts to reach its NBSAP and NDC goals for the CBD and Paris Agreement.

If the highlighted conservation opportunities were combined with protected area expansion and land regularization for TIs and titling for Quilombos, as well as if the highlighted synergies were used to revise and rethink conflicting transportation plans, Brazil would show the international community that it truly backs its self-stated and self-proposed commitments to the CBD and the Paris Agreement. At the same time, Brazil will likely also be able to uphold its mandated social protections for indigenous and traditional communities as required by Brazil's 1988 Federal Constitution (BRAZIL, 1988, Ch. 3, Sec. 2, Arts. 215 & 216; and, Act of Transitional Constitutional Provisions, Arts. 67 & 68) and promised by Brazil to the international community in being a signatory to the International Labour Organization Convention 169 (ILO C169) (BRAZIL, 2002, 2004; ILO, 1989) and being a signatory to the 2007 United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) (HANNA, 2016; HANNA et al., 2014; UN, 2007). Only hard outcomes and tangible progress will actually give Brazil's environmental promises any weight.

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Section 4: Chapter 3 – Model 2

The Brazilian Amazon's Social Cost of Carbon

Abstract: Brazil is an incredibly biodiverse country and home to the largest remaining extent of tropical forests, the Amazon. The Amazon holds a significant role in delivering a diversified set of ecosystem services (regulating, provisioning, supporting, and cultural) which provide stability to Brazil's economy, public health, and overall security. However, in the past decades Brazil's economic growth has become ever more reliant on commodity-oriented exports which play a significant role in influencing the geographic location of infrastructure construction. Aside from Hydroelectric dams, transportation infrastructure and the economic activities that are dependent on it, are highly correlated to deforestation in the Brazilian Amazon. The academic area of economics has increasingly acknowledged that market failures occur in relation to the environment and that current mainstream market practices do not capture the value of the ecosystem services provided by the Amazon. Ecological and economic research has tried to improve upon methodologies to estimate the market values of ecosystem services to quantify market failures. However, to date, the majority of these approaches, especially in the case of the Amazon, have often overlooked key aspects such as spatially explicit heterogeneity of ecosystem variables and the likely existence of ecosystem tipping points. Here, in an effort to incorporate these important considerations, we used spatially explicit data to identify the distribution of the Brazilian Amazon's remaining Carbon Dioxide equivalent stock in combination with a novel approach for incorporating carbon loss estimates if an ecosystem tipping-point were to occur. With these variables at hand we were able to calculate the Social Cost of the Brazilian Amazon's Carbon by incorporating modeled Social Cost of Carbon (SCC) value estimates from the literature. From this we were able to calculate an estimated range of the market value impact that losing the Brazilian Amazon's carbon to a tipping-point could cause for future generations. For Brazil's economy, if the Amazon were to undergo a tipping point induced massive forest dieback, a total impact range of between \$4.6 to \$9.9 trillion (*USD 2017*) of carbon sequestration services could be lost. For the global economy, if the Amazon were to undergo tipping point induced massive forest dieback, a total impact range of between \$6.1 to \$243.1 trillion (*USD 2017*) of carbon sequestration services could be lost.

4.1 – Introduction: Brazil's Policy Conflicts with the Amazon

Deforestation in the Brazilian Amazon, in a general economic sense, is a societal tradeoff. Alternative anthropogenic land-uses provide 'benefits' to society at large scales in the form of food, access to water, and access other natural resources (DEFRIES; FOLEY; ASNER, 2004); whereas, areas with significant native vegetation are not locally 'perceived' to offer the same benefits. Commonly, clearing forest in the Amazon is a local practice that aids private actors in claiming ownership over the public good that is the Amazon forest. Indeed, economic expansion into natural areas does provide jobs and income (FOLEY et al., 2007) which are recognized by market metrics and are often politically beneficial for politicians. However, not being perceived does not mean non-existing nor does it mean that negative impacts do not exist.

Economic and transportation policies commonly counteract and clash with Brazil's environmental policies and international environmental commitments (BRAGAGNOLO et al., 2017; HOCHSTETLER, 2017; JÓNSSON, 2016; MALVESTIO; FISCHER; MONTAÑO, 2018; RABELLO QUADROS; NASSI, 2015; ZIONI; FREITAS, 2015), and this is likely due to Brazil's growing economic dependence on resource commodity exports and its suboptimal transportation infrastructure. Counter intuitively, continued agricultural expansion and transportation infrastructure construction commonly degrades and puts at risk the very ecosystem services (ES) that have helped to make Brazil an agricultural powerhouse (FOLEY et al., 2005; OLIVEIRA et al., 2013; STRAND et al., 2018). In developing countries natural capital commonly constitutes a greater share of a country's wealth than man-made capital (COMBES et al., 2018). This is likely true for Brazil as its natural capital is substantial (BRANDON et al., 2005). However, the failure to acknowledge this is a result of a significant market failure (NOBRE et al., 2016), as well as a situation of disorganization and lack of political will in Brazil's federal public policy and governance structures. Policy makers and private enterprise, in Brazil and around the world, often fail to understand the economic contributions and value that ecosystems provide to the market (COSTANZA et al., 1997).

Brazil's deforestation tradeoff results from the wild west reality of illegal land-grabs and the underestimated or ignored consequences that deforestation has on the local and regional watersheds, the global atmosphere, human health, and biodiversity (NOBRE et al., 2016); which all will likely cause future negative implications on economic stability (LAWRENCE; VANDECAR, 2015) and could play a role as a potential catalyst for political instability (NORDÅS; GLEDITSCH, 2015). Commonly, the decision for the colonizer to clear, degrade or modify native vegetation cover results from the assumption that the intended economic results of the new anthropogenic activity, which includes potentially securing land rights, outweigh the unintended impacts on ecosystem services (DEFRIES; FOLEY; ASNER, 2004).

However, as the Earth System enters the Anthropocene, as greenhouse gas (GHG) emissions continue to increase average global temperatures above pre-industrial levels, and as human economic activities continue to degrade ecosystems and jeopardize their resiliency, it is becoming more likely that anthropogenic impacts on the environment will push the earth's regulating components past a threshold of no return (STEFFEN et al., 2018). This would likely cause cascading and reinforcing positive feedback cycles leading to the degradation of the Earth System's regulating components and lead the planet to a "hothouse" future that has not been witnessed in hundreds of millions of years (STEFFEN et al., 2018).

The Amazon is one of the Earth System's key regulating components and the deforestation tradeoff does not acknowledge the vital life-support role that it plays for the Earth System. Forest clearing releases stored aboveground and belowground carbon into the atmosphere (BACCINI et al., 2012). Furthermore, the deforestation tradeoff does not acknowledge that with each cut or burned hectare the Amazon's resilience to future climate change is evermore degraded (HOEGH-GULDBERG et al., 2018). In order to face future climate pressures, the Amazon and many other ecosystems are in need of increased stewardship rather than continued squandering.

Deforestation in the Amazon is spatially connected to the transportation network, especially roads, as the literature indicates that the majority of deforestation and forest degradation (95%) in the Brazilian Amazon occurs within 5.5 km from roads and 1km from navigable rivers (ALAMGIR et al., 2017; BARBER et al., 2014; LAURANCE, 2015). Unfortunately, Brazil's federal policy apparatus has difficulty in reconciling the country's infrastructure development plans with its environmental policy, resulting in continued deforestation. The literature indicates a severe lack of environmental and social impact considerations at the federal ministerial level for infrastructure planning (MALVESTIO; FISCHER; MONTAÑO, 2018; RABELLO QUADROS; NASSI, 2015; ZIONI; FREITAS, 2015) which likely occurs because legal and policy mechanisms are deficient in enforcing their consideration (MALVESTIO; FISCHER; MONTAÑO, 2018).

Before 2014, deforestation was Brazil's largest contributor to its total GHG emissions (DE OLIVEIRA SILVA et al., 2018; FREITAS et al., 2018; NOOJIPADY et al., 2017; ROCHEDO et al., 2018; ZARIN et al., 2016) and while deforestation has decreased significantly in the past decade, recent upticks in deforestation rates (ROCHEDO et al., 2018) as well as recent policy and infrastructure proposals (MONTEIRO; BORGES, 2019) raise alarm for a potential return to high deforestation rates and resulting CO_2 emissions.

One of the reasons that can explain the market failure, the ignoring the value the Amazon as a whole, is that the benefits that the Amazon provides to society – the regulating, provisioning, supporting and cultural ecosystem services – such as carbon sequestration, evapotranspiration and rain provision, hydrological regulation, biodiversity, benefitting both the local and global communities – are pure public goods (FRANKLIN; PINDYCK, 2018; MANN et al., 2012). Nobre et al. (2016) assert that tropical deforestation in the Amazon is probably the greatest market failure and Hope and Castilla-Rubio (2008) estimated that if 2010 GHG emission levels from global tropical deforestation and forest degradation were reduced by 50% the world would receive a total estimated net benefit of $3.7 trillion (*USD 2010*).

Traditional market activities and Brazil's government promoted development schemes in the Amazon have been geared toward cattle ranching, soy farming, timber extraction, and hydropower generation; thus, leading to significant negative externalities (NOBRE et al., 2016). National development programs need to be reconciled with scientific evidence in order to reshape economic development and how we calculate economic benefits of our remaining tropical ecosystems such as the Amazon.

4.2 – Tipping Point

Ecosystem responses to anthropogenic pressures are usually non-linear and likely have a system tipping point. Once a tipping point is reached an ecosystem is committed substantial changes, which once they occur, the system can no longer be restored to its original state (DEFRIES; FOLEY; ASNER, 2004; PLATTNER, 2009). Moreover, in the face of climate change due to global warming, ecosystems may become committed to future tipping-points before any current changes become observable (JONES et al., 2009). It is important to begin acknowledging that ecosystems are complex when accounting for their current and future contributions to society and economies. This is particularly important when tipping points have been foreseen, as is the case for the Amazon (LOVEJOY; NOBRE, 2018; NOBRE et al., 2016). Tipping points can be associated to changes where a small perturbation triggers a large response. They produce abrupt and sometimes irreversible change and thus pose considerable challenges to the occupants and managers of those environmental systems (LENTON, 2013).

The risks that deforestation poses are too great to continue ignoring. In terms of an estimated tipping-point scenario, a level of 40% deforestation of the total Brazilian Amazon has been projected to likely induce massive forest dieback for much of the Amazon basin which would result in significant levels of additional GHG emissions (NOBRE; BORMA, 2009). A massive forest dieback in the Amazon would represent a global cataclysmic loss (NOBRE et al., 2016; STEFFEN et al., 2018). Furthermore, Lovejoy and Nobre (2018) emphasize that a partial tipping point at 20% to 25% of deforestation of the total original extent of the Brazilian Amazon, likely to be reached in the southern and eastern portions of the Brazilian Amazon, could lead to a partial system flip. This would also likely occur in the southern, eastern and central portions of the Brazilian Amazon where the forests would transition to savanna vegetation. Moreover, once started, this system change would remain irreversible for hundreds if not thousands of years.

4.3 – Services and Economic Ramifications at Risk

Simply put, the Amazon and the services it provides are incredibly important. Specifically, the Amazon is very important for the hydrological cycle at national, continental, and even global scales. Using a projected estimate of 40% Amazon deforestation by 2050, models show that, within the Amazon biome, a 12% reduction in wet-season precipitation and a 21% reduction in dry-season precipitation would occur (SPRACKLEN; ARNOLD; TAYLOR, 2012). To the south outside of the Amazon, models indicate that the Rio de la Plata basin of Argentina would experience a 4% decrease in annual precipitation at 40% deforestation levels (SPRACKLEN; ARNOLD; TAYLOR, 2012). Although impact estimates vary, it is certain that the Amazon plays an important role in South America's tropical and sub-tropical rainy season as well as its dry seasons (ARRAUT et al., 2012; LOVEJOY; NOBRE, 2018). Studies indicate that pasture productivity could decline by 28 to 33%, soy yields could drop by as much as 25% overall and in some of Brazil's soy producing regions this could be as high as a 60% decline (LAWRENCE; VANDECAR, 2015). If Brazil's future includes continued deforestation and LULC change, then regional grain production, such as soy, and livestock yields will likely decrease due to declining precipitation and changing climate factors. Moreover, even if technological development does result in any net output gains, they will likely be marginal when combined with negative environmental impacts, which is a no-win situation for everyone (MAY; SOARES-FILHO; STRAND, 2013; OLIVEIRA et al., 2013).

The regulation of water flow provided by Amazonian forests has significant local and regional impacts. This ranges from facilitating transportation along the Amazon's river networks to helping to maintain reservoir water levels for hydroelectric plants (SUMILA et al., 2017), ground water recharge, and rain resulting from evapotranspiration, among other impacts (FOLEY et al., 2007; STICKLER et al., 2013). For example, continued deforestation will likely impact evapotranspiration fed rain and reduce water discharge rates in the Xingu river basin (SUMILA et al., 2017) likely causing a shortage of water during dry season at the Belo Monte hydropower complex and potentially up to a 25% flow reduction in the Amazon river basin overall (HOEGH-GULDBERG et al., 2018, p. 202). This would likely lead to energy shortages in Brazil's national grid system (STICKLER et al., 2013; SUMILA et al., 2017).

Deforestation of the Brazilian Amazon likely has negative impacts that are far reaching (ROCKSTRÖM et al., 2009). It could affect atmospheric circulation and air moisture movement along the world's northern and southern Hadley cells, which would likely cause larger scale climatic impacts in distant regions away from the Amazon (LAWRENCE; VANDECAR, 2015). Such distant impacts could also drastically change the functioning of ecosystems and thus provisioning of ecosystem services in those locations. This could cause significant impacts to the global economy and global agricultural system in addition to freshwater supply systems (FOLEY et al., 2007).

In terms of vector-born illnesses, evidence suggests that the most prone vectors of tropical diseases, such as various mosquito species, can survive better in deforested landscapes than in forested landscapes (FOLEY et al., 2007). Chaves et al. (2018) found strong correlation between deforested landscapes of 5km^2 in area or less and increased cases of malaria infection during dry season in the Brazilian Amazon. This underscores that small forest patches intermixed with human settlements are strongly correlated with malaria infections and public health costs. This is significant given that 99% of Brazil's 3.8 million reported malaria cases in the past decade have occurred in the Amazon (SANTOS; ALMEIDA, 2018). Areas close to forest fringes that concurrently suffer from changing climate appear to experience shifts in their ecological balances which may have an effect on the transmission dynamics of parasites and may also allow for spillover infections in neighboring areas (SANTOS; ALMEIDA, 2018).

If the Brazilian Amazon crosses a systemwide tipping point, even if considerable technological advances in the agricultural sector are achieved, regional and even national agricultural output will likely not see any significant production output increases due to precipitation decreases (LAWRENCE; VANDECAR, 2015). Moreover, this scenario could very well result in net production decreases. It is important to consider that an ecosystem tipping point would also occur in the context of global climate change, which when both are synergistically combined, could very well override any technological advancement and result in the significant loss of ecosystem services (**Figure 33**). It is important to remember that global crop demand is expected to increase over the course of the century (RAY et al., 2013; TILMAN et al., 2011), and that Brazil, already being a major agricultural exporter, will likely continue to play a principal role in exporting agricultural products. Given the grim outlook of business as usual practices, Brazil should instead advance a net-zero agricultural land expansion plan that couples research on environmentally friendly low-impact technological advances intended for already existing agricultural land and additionally improved logistics and storage infrastructure capacity in already established agricultural areas (FOLEY et al., 2011). Moreover, this agricultural approach should coincide with strengthened conservation activities and native vegetation regeneration. In turn, by ensuring the ecosystem resilience of the Brazilian Amazon in the face of global climate change, such a development approach would also likely be ensuring the resilience of many portions of Brazil's society and economy, including its agricultural sector, in the face of global climate change (**Figure 34**).

However, improving Brazil's future agricultural production in a sustainable way will not be easy and will require a multi-pronged approach (GARNETT et al., 2013). Given the complexity of maintaining economic stability, meeting future food demands, and conserving and even enhancing biodiversity, achieving a net-zero deforestation future while increasing agricultural output in an environmentally friendly manner is no trivial task. Although there is controversy and debate in the academic community between land-sharing and land-sparing conservation practices (FISCHER et al., 2014), land-sparing practices have been demonstrated to allow for higher levels of maintained biodiversity in the spared natural habitats (PHALAN et al., 2011). However, for land-sparing to achieve maximum biodiversity conservation, high quality and biologically diverse habitates must actually be spared (BALMFORD et al., 2019). One the other hand, land-sharing agricultural practices arguably have lower direct impacts on local biodiveristy than intensive industrial farming. A sustainable future likely depends on finding the appropriate mix of land-sparing high-quality natural habitats and land-sharing in agriculturally suitable areas that are consequentially of lower natural habitat quality and that does not push ecosystems past tipping point boundaries. Finally, agriculture in these land-sharing areas should be combined with environmentally friendly technological advances that improve yields in a low impact manner (TILMAN et al., 2011). Again, this will not be an easy task.

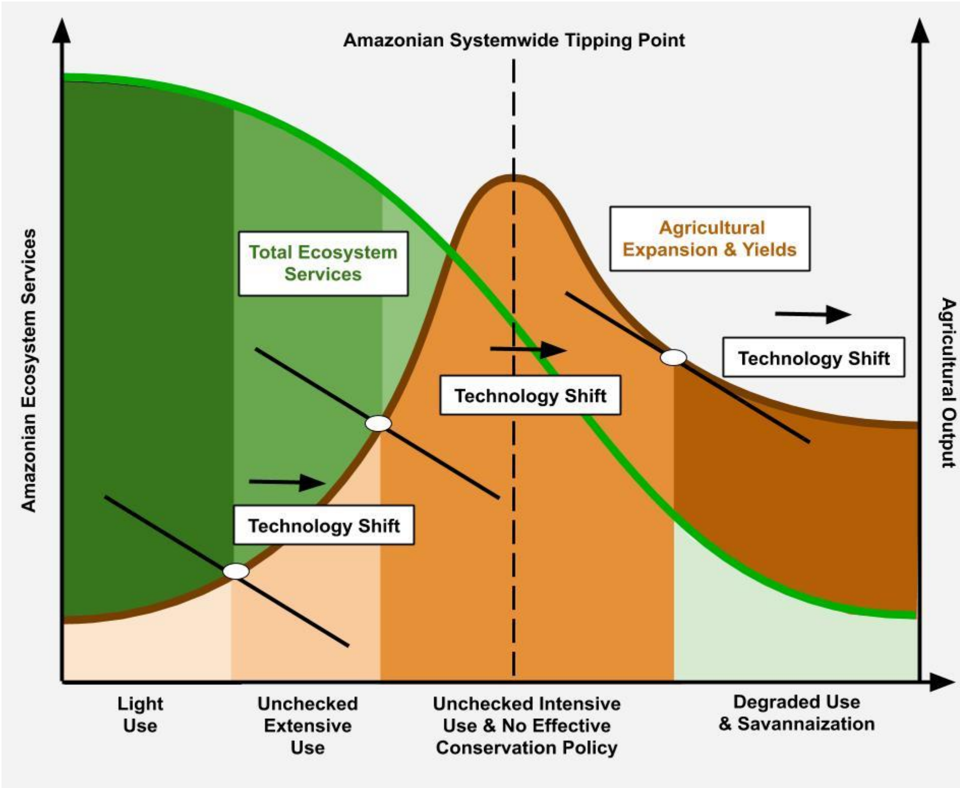

Figure 33 *- Unsustainable Increases (not acknowledging a tipping point) in Amazonian Forest-Farmland Conversion and Agricultural Output Coupled with Technological Development.*
Adapted from Braat and de Groot (2012) and Franklin and Pindyck (2018) with inspiration from Clark (1973) and Farmer and Randall (1998).

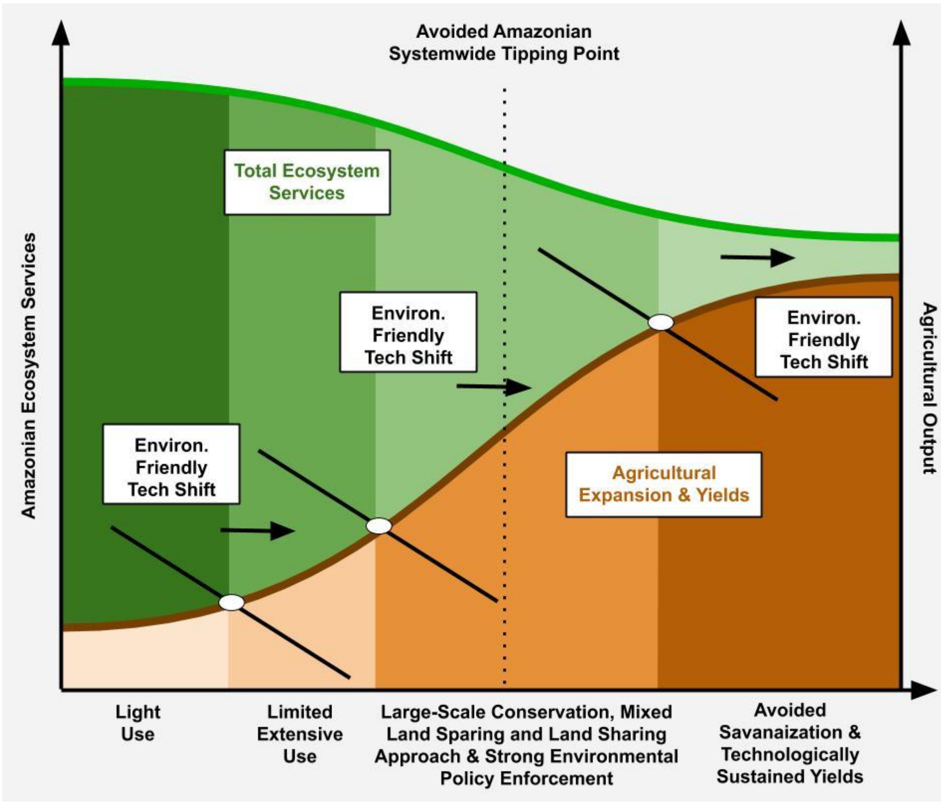

Figure 34 *- Sustainable Increases (acknowledging a tipping point) in Amazonian Forest-Farmland Conversion and Agricultural Output Coupled with Technological Development.*
Adapted from Braat and de Groot (2012) and Franklin and Pindyck (2018) with inspiration from Clark (1973) and Farmer and Randall (1998).

4.4 – Valuing Ecosystem Services

Valuing nature in the economic sense is not an easy task (STRAND et al., 2018), yet nature is of significant value to humans. We depend on its ecosystem services for our survival, but unfortunately human society has historically failed to understand the importance of ecosystem services until they are lost (DAILY et al., 2000; DAILY, 1997). One approach has been to assign economic value to ecosystems and their services. This is a controversial approach as it has caused criticism from some sides of the academic debate arguing that the intrinsic value of nature should not be represented in monetary form and that the ecosystem services approach is a neo-liberalization of nature (BARNAUD; ANTONA, 2014; KULL; ARNAULD DE SARTRE; CASTRO-LARRAÑAGA, 2015); however, as stated by Costanza et al. (2017), "There is not one right way to assess and value of ecosystem services. There is however a wrong way, that is, not to do it at all."

Moreover, valuing ecosystem services in monetary terms does not mean that they should be, nor could they be, privatized and sold on the open market, this is because they are in large part public goods (DE GROOT et al., 2012, p. 57). Rather, estimating the monetary value of ecosystem services should serve as a tool for stimulating the thoughtful consideration of environmental and social tradeoffs during the policymaking process, a process in which they are often ignored, commonly under considered, and in general not analyzed on a level playing field with other perceived economic benefits (BOEREMA et al., 2016, p. 8; DE GROOT et al., 2012, p. 57). The world's economies depend on the many services provided by the earth's ecosystems and a significant loss in these services would greatly impact many economies, maybe even bringing the global economy to a halt (COSTANZA et al., 1997). Therefore, by being forced to respond to ecosystem service value assessments policymakers may internalize ecosystem services' economic importance in the decision-making process (DE GROOT et al., 2012, p. 57).

In the past two decades there has been an increase in initiatives to streamline the application of ecosystem services knowledge through projects such as The Economics of Ecosystems & Biodiversity (TEEB) (SUKHDEV et al., 2010) and the Millennium Ecosystem Assessment (MA) framework and through contributions of scientists and economists to the academic field of ecological economics (BRAAT; DE GROOT, 2012; COSTANZA et al., 2017; PANDEYA et al., 2016). Furthermore, dynamic and spatially explicit modeling has become increasingly used as a tool to understand ecosystem services (COSTANZA et al., 2017).

However, efforts to incorporate the multidisciplinary concepts, approaches, and knowledge about the environment's relationships with society and the economy must be expanded further so that scientists and economists can estimate ecosystem service values in a more accurate and reliable manner (PANDEYA et al., 2016). Particularities between the four main classes of ecosystem services – provisioning, regulating, supporting, and cultural –, their direct or indirect use characteristics, as well as their spatially explicit relationships and differences with their pertaining ecosystems, to society, and over time are of utmost importance to understand when mapping and interpreting economic value estimates (CARRASCO et al., 2014; SCHMIDT; MANCEUR; SEPPELT, 2016). Incorporating spatially explicit estimates for ecosystem service values is important (CARRASCO et al., 2014). Generalizing and applying average values across an ecosystem dilutes spatially determined importance of many ecosystem services (SCHMIDT; MANCEUR; SEPPELT, 2016). However, given the different classes of ecosystem services policy makers must understand what is and what is not being captured by the map in front of them when interpreting ecosystem service value estimates in spatially explicit form (TEOH et al., 2019).

For example, policy makers dealing with biodiversity conservation planning should understand what values are relevant for them to consider. Using only provisioning and cultural ecosystem services in a spatially explicit form, such as estimated extractivism and ecotourism land rent values, would be an inappropriate use of ecosystem service values to guide biodiversity conservation planning. This misuse could lead to significant errors and egregiously poor choices that could negatively impact biodiversity conservation (CARRASCO et al., 2014). Carrasco et al. (2014) and Teoh et al. (2019) concluded that the dependence of many provisioning and cultural ecosystem service values are highly dependent on market and transportation network accessibility. Thus, anthropogenic factors rather than biotic factors such as species richness of flora and fauna are predominantly the main determinants of these classes of ecosystem service values (TEOH et al., 2019). Thus, it would therefore be inappropriate to use these values in a biodiversity conservation planning context for example.

4.5 – How to Represent Market Values of Brazil's Amazon Rainforest

Recently for the Amazon, studies have begun incorporating spatially explicit modeling techniques to estimate the forest land rents of various provisioning ecosystem services and values of some regulating ecosystem services. At Brazil's national level, there has been a proliferation of discussion on Payments for Ecosystem Services (PES), as well as some mechanisms being established at varying geographic and ecosystem scales (BALVANERA et al., 2012) and an increasing legal incorporation of the ecosystem services concept at state and federal legislative assemblies as well as in judicial decisions (ALTMANN; SILVA STANTON, 2018). However, in conducting a literature review in the Scopus database for ecosystem service valuation estimates and analyzing the TEEB database for non-transfer benefit derived ecosystem service value estimates for the Brazilian Amazon, the former only resulted in 15 articles and the later 2 articles (**Sup. Mat. Ch. 3. Sec. 6)**. At the national scale, a Scopus literature review pulled 53 articles the TEEB database included only 4 articles. This leads to the question: are the derived payment values of Brazil's proposed and existing PES programs[1] as well as

[1] The only government level administered PES programs that the authors could find in Brazil include the Bolsa Verde program administered by MMA and the Bolsa Floresta program administered by the State of Amazonas. Bolsa Verde only being applicable to families in situations of extreme poverty and already being beneficiaries of the Bolsa Família program as well as being located in sustainable use Protected Areas/Conservation Unites, Rural Agrarian Reform Settlements, or being part of a defined indigenous, quilombola, or one of the legally recognized

the country's increasing legal 'jurisprudence' capturing the true value or even a close approximate value of the ecosystem services they are applied to? In the case of the Amazon there are relatively few ecosystem service value estimates in relation to the Amazon's extreme global importance, whether for future climate stability, biodiversity conservation, or indigenous and traditional livelihoods. Therefore, the Amazon serves as an example and opportunity of where academic research should concentrate on improving spatially explicit approaches to ecosystem services valuation.

For the Brazilian Amazon, examples of spatially explicit estimates of provisioning ecosystem services include estimates of possible resource rent values from extractivism for açaí berries by Lopes et al. (2019); rubber tapping and Brazil nuts by Carvalho Ribeiro et al. (2018), Soares-Filho et al. (2017), and Strand et al. (2018); and low-impact timber harvesting by Strand et al. (2018). Furthermore, Strand et al. (2018) and Soares-Filho et al. (2017) have modeled spatially explicit current value estimates for climate regulating ecosystem services in the Amazon and the impacts that deforestation would cause to regional soy production, livestock farming, and hydro-energy production. These are significant advances that are moving valuation of the Amazon's ecosystem services in the right direction. Moreover, in the pursuit of a sustainable development paradigm for the inhabitants of the Amazon, finding a way to incorporate the various Non-Timber Forest Products (NTFPs) into the development paradigm to ensure biodiversity conservation and maintenance of indigenous and traditional livelihoods is needed (SOARES-FILHO et al., 2017). However, we believe that in order for these NTFPs to be effective in offering an alternative to deforestation causing economic activities at a large scale, tailored infrastructure for the unique needs of NTFP activities as well as establishing robust sustainable value chains in the region are still needed so that value-added and more labor-intensive final products can be produced locally and employ more individuals in a sustainable manner.

However, one must be careful in how ecosystem service values, for the Amazon and other ecosystems worldwide, are represented. Many ecosystems have tipping points and once a threshold is crossed, ecosystems react and change in a non-linear fashion until they reach a new system equilibrium (HUGHES et al., 2013; PLUMMER; ARMITAGE, 2007). A major misuse of current ecosystem value estimates for the Amazon involves how they are represented as marginal values without considering the economic consequences of a tipping point (FRANKLIN JR.; PINDYCK, 2017; FRANKLIN; PINDYCK, 2018). If the Amazon's tipping-point is passed, then all remaining standing forest values and the value of their ecosystem services will be reduced drastically and in a non-linear fashion as the forest transitions to a savanna state. Therefore, the face value of estimated ecosystem services in the Amazon must be understood in the context of their relationship to a biome tipping point. This is

traditional communities (PCTs). Bolsa Verde paid R$300 once every three months (R$100 per month) and was not linked to a specific size of native vegetation cover, but required the continued presence of native vegetation cover, checked by satellite monitoring, as a mandatory condition to continue receiving payments (BRAZIL, 2011; MMA, 2017). Bolsa Floresta, being administered by the State of Amazonas, is funded in part by the Amazon Fund and pays families R$50 per month for committing to zero deforestation on the land they occupy (KIM-BAKKEGAARD; BREDAHL; WUNDER, 2017).

necessary in order to reshape perceptions of which land-use activities really provide the most beneficial tradeoffs to society.

A final point that must be addressed is consolidating and agreeing on the monetary value unit that scientists and economists use to represent the value of the ecosystem services in the Amazon and generally throughout Brazil. The economic realities of many countries that are home to a significant portion of the world's tropical ecosystem services are also some of the world's most unstable economies (SIRIMANEETHAM; TEMPLE, 2009). Even in the case of Brazil, which is relatively more stable than the majority of other tropical economies, nominal exchange rate and inflation fluctuations have gone up and down for the Brazilian Real (BRL) in the past twenty years (RICHARDS; ARIMA, 2018). If ecosystem services are assigned a value in the International Dollar (I$) but using the nominal exchange rate, these fluctuations could cause significant undervaluation of ecosystem service values between years. We argue that either automatically valuing ES values in I$ or using the real exchange rate (using Purchasing Power Parity) to convert values in the Real (BRL) to the I$ is currently the most appropriate way to represent ES values. For example, if the forthcoming results of this study were calculated using both the 2012 and then the 2014 nominal exchange rates between the BRL and I$, the overall value of the Amazon's ESs would have lost almost half of its value between 2012 and 2014.

4.6 – Calculating the Amazon's Value

It has been argued that although considerable efforts have been made for valuing the Amazon's forest, its undervaluation (a common reality for other tropical forests) has discriminated against their sustainable management. While some argue that putting a price is conceptually worthless, others point to methodological issues. Despite acknowledging the controversies surrounding assigning monetary values to nature, we aim at estimating the Amazon's value in the context of approaching a tipping-point and the economic damages that would likely cause. The following sections set the scene for this valuation exercise.

4.6.1 – Economic Foundations

Franklin and Pindyck (2018) have proposed a method for calculating the Average Incremental Social Cost of Deforestation (AISCD) caused by the deforestation of an average hectare of forest. Their proposed equation for the AISCD incorporates a committed ecosystem tipping point in the Amazon and transition to a savanna-like state. Specifically, the incorporation of the tipping point into value estimates is important. Once the Amazon reaches the threshold of a committed tipping point, the loss of forest beyond the tipping point is guaranteed at significant levels. Therefore, Franklin and Pindyck (2018) proposed incorporating the value of post tipping point forest into the value of the pre-tipping point forest.

Franklin and Pindyck (2018) used the Total Economic Value (TEV)[2] approach to estimate a per hectare social cost of deforestation by using value estimates from some of the key, but mostly outdated, economic valuations available in the literature for the Amazon's ecosystem services. Moreover, these values were applied as blanket averages to an estimated 372 million hectares (Mha) of Brazilian Amazon forest to arrive at their final value estimates. Their estimates thus do not consider the spatially explicit forest variation inherent across a biome like the Amazon, nor do they likely capture recent forest loss. While we praise Franklin and Pindyck (2018) for their economic foundation, we encourage the economic and scientific community to continue to build upon it and improve it. For this study however, we decided to incorporate Franklin and Pindyck's (2018) approach while also focusing only on one key value estimate, the Social Cost of Carbon (SCC).

We combined Franklin and Pindyck's calculation approach with SCC value estimates available in the literature. Most SCC value estimates are results of Integrated Assessment Models (IAMs)[3]. Among these estimates are the SCC values calculated by Nobel Prize winning economist William Nordhaus and his Dynamic Integrated Climate-Economy Model (DICE-2016R) Integrated Assessment Model (IAM) (KUNGL VETENSKAPS AKADEMIEN, 2018; NORDHAUS, 2017). As GHG emissions are one of the principal environmental impacts resulting from tropical deforestation, we believe that calculating the SCC of GHG emissions resulting from continued deforestation and a potential biome-wide tipping point, and doing so in a spatially explicit format, would be a novel contribution to the ES valuation and estimates literature for the Amazon forest. This study aims to bridge the gap between the world of environmental economics and the world of environmental sciences, ecological economics, and spatially explicit modeling. To do this we must outline the needed variables to complete the task at hand. We will only focus on the biogeographical biome of Brazilian Amazon for the scope of this study.

4.6.2 – The Social Cost of Carbon

The Social Cost of Carbon (SCC) is a marginal cost estimate which represents the net economic cost of climate change (i.e. economic damage) that is caused by the emission of an additional tonne of Carbon Dioxide (CO_2) in a given year (RICKE et al., 2018) and is represented in US dollars for that year (NATIONAL ACADEMIES OF SCIENCES, 2016). Nordhaus (2017, p. 1518) adds that the SCC is the

[2] Total Economic Value (TEV) = Direct use value + Indirect use value + Option value + Existence value

[3] IAMs have been used, to compute the social cost of carbon (SCC), defined as the incremental damage caused by one more ton of carbon emissions. IAMs include the economic and natural processes that produce GHG emissions. GHG emissions projections are used to drive a representation of the global carbon cycle and the chemical composition of the atmosphere and then their influence on climate and sea level. IAMs then project how those changes impact natural systems on earth. Some IAMs represent the whole earth system with a small number of equations, while others include many complex equations drawn from physics, chemistry, biology, and economics. IAMs range from providing an aggregated representation of climate change mitigation costs and impacts by sector and region into a single economic metric, or to providing projections of climate change impacts at detailed regional and sectoral levels (using economic valuation and projections of physical impacts such as reductions in crop growth, land inundated by sea level rise, and additional deaths from heat stress) (WEYANT, 2017).

"change in the discounted value of economic welfare from an additional unit of CO_2-equivalent emissions." The SCC can also be thought of as the economic benefit of reducing CO_2 emissions per tonne in an identified year. However, the SCC is not without controversy, as key inputs into IAMs used to calculate SCC estimates are based on assumptions and uncertainties about global and regional development pathways, involve ethical disputes about appropriate intergenerational discount rates, and have general uncertainty about chosen damage functions for estimating how and to what level climate change will negatively impact economies worldwide a hundred years from now (PEZZEY, 2019; PINDYCK, 2017).

While the IAMs for calculating SCC may not be perfect, we again argue that for the scope of this study there may not yet be scientific and economic consensus on how to value CO_2 emissions in the face of climate change, but there is a wrong way, and that is to not do it at all. However, in order to accommodate the vast range of value estimates that have been calculated for the SCC, we will present calculations based on values resulting from the most used, most comprehensive SCC-IAMs, and recent advances in the current literature (**Table 26**).

Source	**SCC Calculation Metrics**	**SCC per tonne of CO_2 Equivalent in 2017 USD**
Worldwide Total Net Economic Impact of emissions per each tonne of CO_2 in 2017		
Nordhaus (2017)	**Global net total** 4% Fixed Discount Rate	$37.93
Stern (2006)	**Global net total** 2.5% Fixed Discount Rate	$151.75
Stern (2006)	**Global net total** 5% Fixed Discount Rate	$24.41
Ricke et al. (2018)	**Global net total** 3% Fixed Discount Rate	$406.00
Ricke et al. (2018)	**Global net total – High Bound Estimates** 3% Fixed Discount Rate	$657.00
Ricke et al. (2018)	**Global net total – Low Bound Estimates** 3% Fixed Discount Rate	$31.00
Latin America/Brazilian Total Net Economic Impact of emissions per each tonne of CO_2 in 2017		
Nordhaus (2017)	**Latin America net total** 4% Fixed Discount Rate	$2.27
Ricke et al. (2018)	**Brazilian Country Level net total** 3% Fixed Discount Rate	$22.60
Ricke et al. (2018)	**Brazilian Country Level net total – High Bound Estimates** 3% Fixed Discount Rate	$26.80
Ricke et al. (2018)	**Brazilian Country Level net total – Low Bound Estimates** 3% Fixed Discount Rate	$18.50

Table 26 *- Key and recent SCC calculations in the literature.*

*Ricke et al. (2018) was included as it is the first SCC-IAM to estimate CO_2 emission impacts on country level economies.

4.6.3 – Proposed Calculation Components and Equation

The proposed equation for calculating the SCC for the Brazilian Amazon must incorporate the following elements:

1) The original extent of the Brazilian Amazon and remaining current primary forest extent[4] (FRANKLIN; PINDYCK, 2018);
2) The remaining extent between remaining primary forest until an estimated tipping-point threshold is reached (FRANKLIN; PINDYCK, 2018);
3) A spatially explicit map which identifies the location of forest that could be deforested before reaching a tipping point as well as the location of forest that would go through a vegetation transition after a tipping point is reached;
4) The carbon stock of the remaining primary forest, including aboveground, belowground (roots), and soil organic carbon content in spatially explicit form;
5) An estimation of net carbon loss (the net loss of carbon in above ground, below ground, and organic soil content) that would result from an ecosystem tipping point such as a transition to savanna; and
6) Estimated SCC values modeled from IAMs and converted to USD of the same year as the input spatial data of forest cover.

To accomplish this, we propose the following approach. First, in using spatially explicit raster data with a spatial resolution of 1ha by 1ha, we start by letting $\mathbf{F_{Original}}$ represent the original extent of the Brazilian Amazon Forest (see **Tables 27** and **28**), namely:

$$F_{Original} = 398{,}096{,}167\ ha \qquad (eq.\ 1)$$

We consider a tipping point scenario $\mathbf{TP}$ caused by deforesting an extent (in hectares) of primary forest corresponding to a defined percentage $\mathbf{X\%}$ of the original forest $\mathbf{F_{Original}}$:

$$TP = X\%\ of\ F_{Original} \qquad (eq.\ 2)$$

We want to estimate the extent $\mathbf{F_{PreTip}}$ of current primary forest that can be deforested before reaching the committed tipping point threshold $\mathbf{TP}$. By letting $\mathbf{F_{Current}}$ be the extent of 'currently' (as of 2017 spatial data) remaining primary forest in the Amazon, we have that:

[4] We only used identified 'primary' or 'likely old growth forest' due to uncertainties in the accuracy of identified secondary forest as highlighted in **footnote 7**.

$$F_{PreTip} = [\ TP - F_{Current} \times \text{-}1 \mid F_{Current} > F_{Original} - TP\ ] \qquad (eq.\ 3)$$[5]

But more than finding simply the area $\mathbf{F_{PreTip}}$, we want to find the corresponding map showing exactly what parts of the current Amazon will most likely be deforested before reaching this tipping point. Since deforestation happens mostly around transportation infrastructure, especially roads (BARBER et al., 2014), our model estimates the actual map of primary forest corresponding to $\mathbf{F_{PreTip}}$ as forest standing in an area of fixed width $\mathbf{w}$ around every existing road and railroad in the Brazilian Amazon. To find the $\mathbf{w}$ value of all $\mathbf{F_{Current}}$ (in order to identify $\mathbf{F_{PreTip}}$ and $\mathbf{F_{PostTip}}$) we generate a Distance Map $\mathbf{D_{(p)}}$, whose values $\mathbf{p_{(x,\ y)}}$ represent each $\mathbf{F_{Current\ \mathit{i}}}$ pixel, by calculating the shortest Euclidean distance ***min d(p, q)*** of $\mathbf{p_{(x,\ y)}}$ to the nearest road or railroad **NRR** at location $\mathbf{q_{(x,\ y)}}$.

$$d(p,q) = \sqrt{(p_x - q_x)^2 + \left(p_y - q_y\right)^2} \qquad (eq.\ 4A)$$

$$F_{Current\ i}\ W\ value = D(p) = min\{d(p,q) \mid q\ \in\ NRR\} \qquad (eq.\ 4B)$$

We then set $\mathbf{w}$ to be the width that satisfies the property that the summed area of remaining current forest $\mathbf{F_{current}}$ at distance at most $\mathbf{w}$ from the nearest road or railroad equals the amount of forest in $\mathbf{F_{PreTip}}$ for scenario **TP**. In the process, we determine a map with the spatially explicit locations (i.e., set of pixels with a resolution of 1ha x 1ha) of the current primary forest $\mathbf{F_{PreTip\ \mathit{i}\ (x,\ y)}}$ most likely to be deforested before reaching a tipping point. This also determines a map with the spatially explicit locations (i.e., set of pixels with a resolution of 1ha x 1ha) of post-tipping point forest $\mathbf{F_{PostTip\ \mathit{i}\ (x,\ y)}}$ that will remain right after the tipping point is reached but soon likely undergo massive forest dieback or savannization.

To begin estimating the monetary value of the forest, we must select a modeled Social Cost of Carbon[6] **$SCC** from the literature and incorporate spatially explicit data showing estimated tonnes of $\mathbf{CO_2}$ **equivalent** of spatially explicit carbon stock for each hectare of $\mathbf{F_{Current}}$. With these in hand, we then can calculate the Estimated Cost **EC** of all post-tipping point primary forest $\mathbf{F_{PostTip}}$:

$$EC\ of\ F_{PostTip} = \sum_{i=1}^{n}\left(\frac{\$SCC}{TonneCO_2equivalent} \times \frac{TonneCO_2equivalent}{F_{PostTip\ i\ (x,y)}}\right) \qquad (eq.\ 5)$$

[5] This equation can be understood as stating the following: the remaining pre-tipping point forest $\mathbf{F_{PreTip}}$ is the result of subtracting the number of hectares representing the total current standing forest $\mathbf{F_{current}}$ from the number of hectares representing the tipping point 'cushion' **TP**.
[6] Social Cost of Carbon (SCC) are estimates of incremental damage caused by one more ton of carbon emissions resulting from Integrated Assessment Models (IAMs) (WEYANT, 2017).

If a tipping point is reached, the remaining post-tipping point primary forest $\mathbf{F_{PostTip}}$ would likely undergo a savannization process; and moreover, it would not be immediately deforested for land conversion. Therefore, a majority of the resulting carbon stock loss in $\mathbf{F_{PostTip}}$ would result from forest dieback and savannization or vegetation transition. In this context, the pre-tipping point primary forest $\mathbf{F_{PreTip}}$ would have already been completely deforested, and thus a significant majority of its above and belowground carbon stock would have already been lost. However, the $\mathbf{F_{PostTip}}$ that undergoes a forest dieback and savannization process would lose its carbon stock at a different level than deforested areas. So, when considering the potential Post Tipping-Point Carbon Loss for $\mathbf{F_{PostTip}}$:

1) If the Tipping Point triggers a forest dieback and vegetation transition to a dense Savanna Forest, say at most 60% of carbon would remain, so the EC in the savannah scenario would be 40% of its total EC:

$$EC(Savana) = 40\% \times \sum_{i=1}^{n} \left(\frac{\$SCC}{TonneCO_2 equivalent} \times \frac{TonneCO_2 equivalent}{F_{PostTip\ i\ (x,y)}} \right) \qquad (eq.\ 6A)$$

2) If the Tipping Point triggers a more severe forest dieback and transition to a desert like state, say potentially only 25% of carbon would remain, so the EC in the desertification scenario would be 75% of its total EC:

$$EC(Desert) = 75\% \times \sum_{i=1}^{n} \left(\frac{\$SCC}{TonneCO_2 equivalent} \times \frac{TonneCO_2 equivalent}{F_{PostTip\ i\ (x,y)}} \right) \qquad (eq.\ 6B)$$

Under a determined post-tipping point scenario (savannization or desertification) we assume that the resulting $\mathbf{EC_{Final}}$ value is then going to be evenly split among all the $\mathbf{F_{PreTip}}$ pixels, which equates to an additional cost per pixel **ACPP**:

$$ACPP = \frac{EC_{Final}}{Number\ of\ F_{PreTip}\ pixels} \qquad (eq.\ 7)$$

For any currently standing spatially identified $\mathbf{F_{PreTip\ \mathit{i}\ (x,y)}}$, its standing unique Cost Per Pixel **CPP** must be calculated in a similar fashion, but on an individual basis, to the **EC of** $\mathbf{F_{PreTip}}$:

$$CPP\ of F_{PreTip\ i\ (x,y)} = \left(\frac{\$SCC}{TonneCO_2 equivalent} \times \frac{TonneCO_2 equivalent}{F_{PreTip\ i\ (x,y)}} \right) \qquad (eq.\ 8)$$

When considering that any currently standing pre-tipping point forest $\mathbf{F_{PreTip\ \mathit{i}\ (x,y)}}$ has its own carbon stock value and holds a portion of the representative carbon stock value **ACPP** that would be lost from post-tipping point forest $\mathbf{F_{PostTip}}$ in the event of crossing a tipping point, the final New Updated Cost Per Pixel **NUCPP** for each of the $\mathbf{F_{PreTip\ \mathit{i}\ (x,y)}}$ is calculated as follows:

$$NUCPP\ of F_{PreTip\ i\ (x,y)} = CPP\ of F_{PreTip\ i\ (x,y)} + ACPP \qquad (eq.\ 9)$$

Once all of the nine previous calculations are made on the spatially explicit data set, a final Social Cost of Carbon estimate for the Brazilian Amazon can be calculated:

$$SCC\ Value\ Estimate\ of\ the\ Brazilian\ Amazon = \sum_{i=1}^{n} NUCPP\ of\ F_{PreTip\ i} \qquad (eq.\ 10)$$

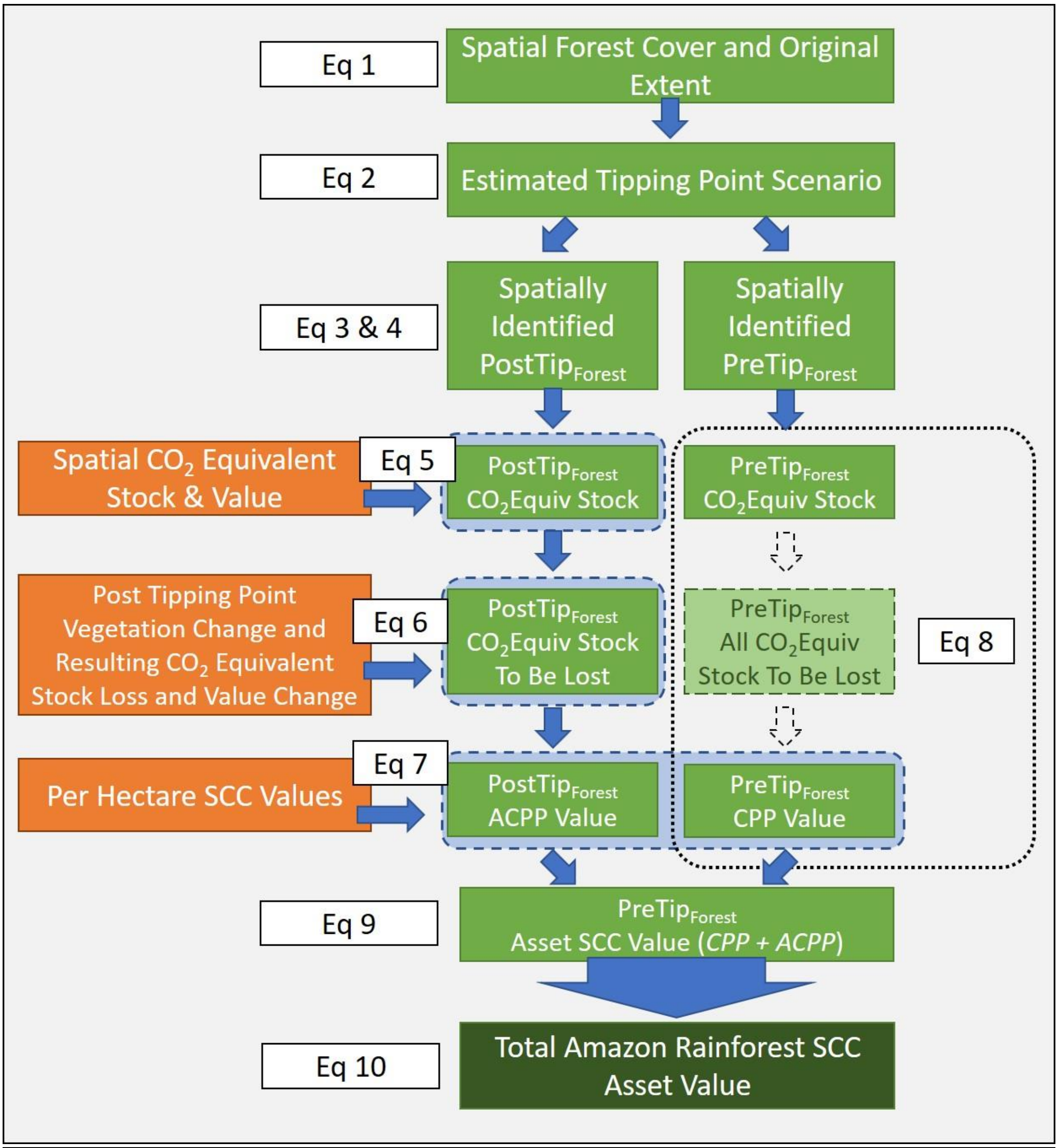

Figure 35 *– Graphical Flowchart of Equation Components for Calculating the SCC of the Brazilian Amazon*

4.6.3.1 – Original Extent of the Amazon Forest

An important factor for the economic calculations is knowing how close the Amazon is to the estimated tipping point $\mathbf{TP}$. However, to do this it is necessary to know how much original forest cover $\mathbf{F_{Original}}$ there was and then identify how much of the original forest cover has been deforested. The literature presents many different estimates for the original extent of the Brazilian and continental Amazon forests (MALHI et al., 2008; MARGULIS, 2004; PACHECO, 2002; SOARES-FILHO et al., 2006). For example, estimates in the literate for the original extent of the Brazilian Amazon range between 356 million to 419 million hectares (Mha) (MALHI et al., 2008; MARGULIS, 2003; PACHECO, 2002), a difference of 63 Mha. Therefore, given the discrepancies we determined that it was important to try to identify and estimate all areas that have been deforested in the Amazon from available and reliable spatial data. To accomplish this we used a combination of land-cover data, forest vegetation categorization data, and historical deforestation data from (i) Project MapBiomas (2018), (ii) the Amazonian Network of Georeferenced Socio-Environmental Information – *RAISG* (2015), (iii) Project PRODES from the National Institute for Space Research – *INPE* (2018), and (iv) the Natural Resource Mapping of Brazil from the Brazilian Institute of Geography and Statistics – *IBGE* (2018). Using these data sources, we arrived at two estimates for deforestation in the Brazilian Amazon based on the differences in the temporal resolution of the aforementioned data sources. The first estimate, which is a result of combining spatially mosaicking of all of the data sources, resulted in an estimate of original extent of the Brazilian Amazon being 398,096,167 ha, and of that, 88,517,951 ha (22.24%) having been deforested (**Table 27**). This estimate takes account of areas in the Brazilian Amazon that IBGE (2018) indicated to be originally forested, but due to being deforested before comprehensive satellite remote sensing monitoring began, the areas cannot be confirmed with past satellite imagery.

We used this first estimate in our equations. A second estimate was calculated using spatial data from RAISG dating to 1970, Project MapBiomas dating to 1985, and INPE dating to 1988, but excluding IBGE data. This second estimate puts the Brazilian Amazon as being 389,997,930 ha, as of 1970, and since then losing 78,352,727 ha (20.09%) to deforestation. However, we chose not to use this second estimate in our calculations. For more details on the data sources and cartographic operations to arrive at these estimates see (**Sup. Mat. Ch. 3. Sec. 4**). The spatial results of identified likely old growth or ‘primary’ forest, historically deforested areas, and potentially regenerating secondary growth forest are presented in **Figures 35** to **37**.

Identified Brazilian Amazon Forest Cover	HA	Percent to Identified Original Forest Cover
Potential Original Forested Areas of the Brazilian Amazon	398,096,167	100%
Identified Deforested Areas	88,517,951	22.24%
Remaining Legally Defined Forests (Likely Old Growth and Primary)	309,578,216	77.76%
Secondary Regrowth Forests[7]	~ 31,824,677	~7.99%

Table 27 *- Brazilian Amazon Forest Inventory – (Based on spatial data with a 100 by 100-meter resolution)*
Data Sources: (IBGE, 2018; INPE, 2018; PROJECT MAPBIOMAS, 2018; RAISG, 2015).

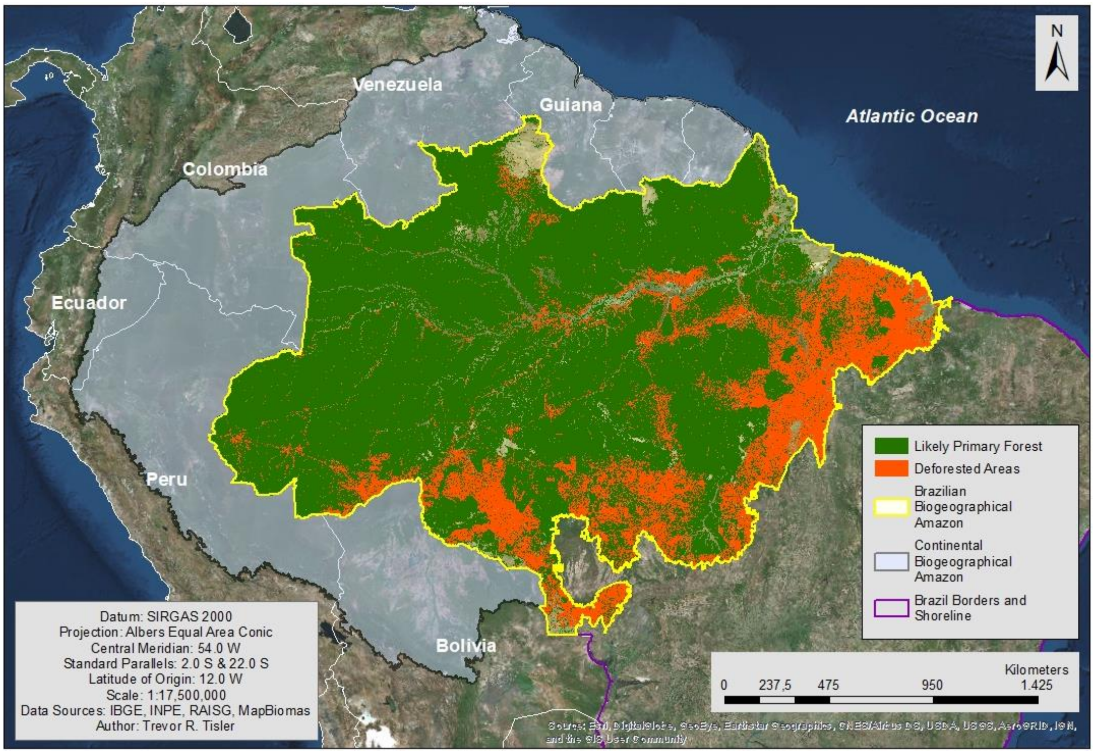

Figure 36 *– Identified Historically Deforested Areas and Likely Primary Forests in Brazil's Biogeographical Amazon Biome*

[7] We believe that this amount of secondary regrowth forest is an over estimation and is likely lower than 7.99% of original forest cover. Identified secondary forests are areas that PRODES and RAISG identified as historically suffering from deforested but that Project MapBiomas classified as forest in 2017. After visual examination of areas that were identified as secondary forests, we believe that a portion of agricultural or pasture areas were classified as forested areas by Project MapBiomas.

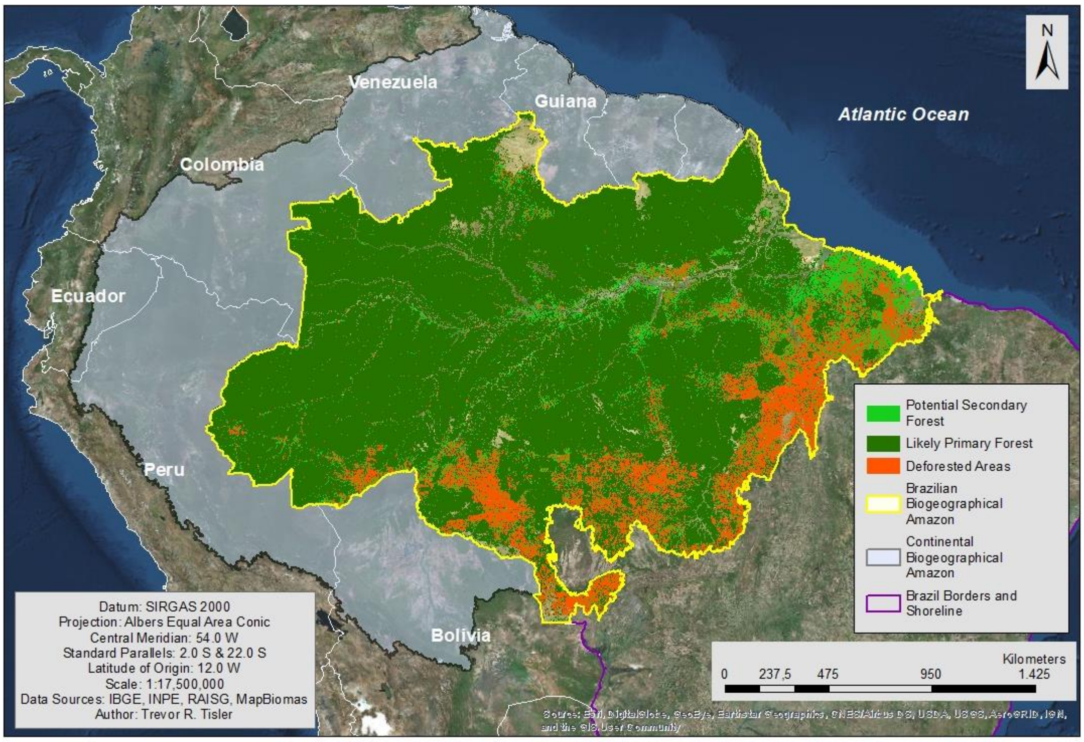

Figure 37 *- Potential Secondary Growth Forests, Identified Historically Deforested Areas and Likely Primary Forests in Brazil's Biogeographical Amazon Biome*

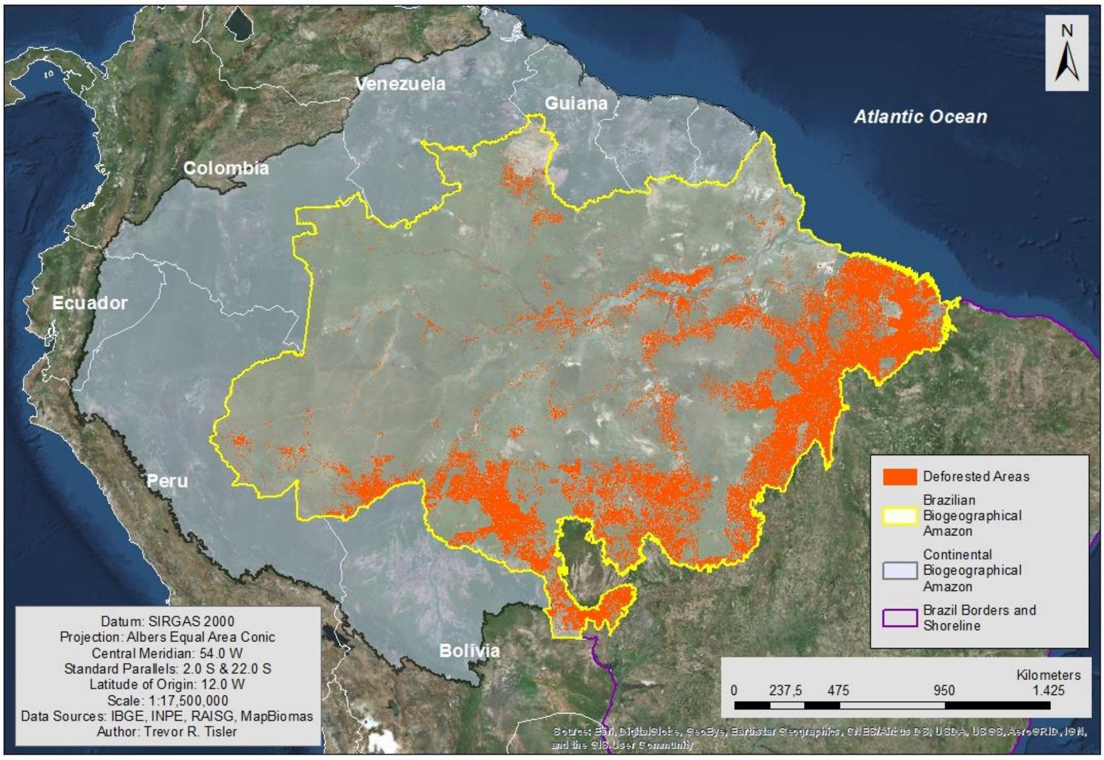

Figure 38 *- Identified Areas were Primary Forests have been Historically Deforested in Brazil's Biogeographical Amazon Biome*

4.6.3.2 – Tipping Point Scenarios of the Brazilian Amazon Forest

Additionally, given the spatially explicit nature of our model, we needed a spatially explicit way to identify which forests are likely to be post-tipping point primary forests $\mathbf{F_{PostTip}}$ and which remaining primary forests are likely to be the biome's pre-tipping point primary forests $\mathbf{F_{PreTip}}$. For this calculation we made two considerations in spatially identifying tipping point limits: a low bound $\mathbf{TP_{LowBound}}$ and high bound $\mathbf{TP_{HighBound}}$ estimate for a tipping point that takes into consideration the spatial locations of the remaining primary forests, so:

$$\mathbf{TP_{LowBound} = 30\%} \text{ deforestation of } \mathbf{F_{Original}}$$

$$\mathbf{TP_{HighBound} = 40\%} \text{ deforestation of } \mathbf{F_{Original}}$$

Given that deforestation in the Amazon is spatially related to the transportation network, especially roads (ALAMGIR et al., 2017; BARBER et al., 2014; LAURANCE, 2015) we incorporated modeled roadless and railroad-less (RLRL) areas of the Amazon to identify which forests are likely more vulnerable to deforestation in the near future. The RLRL areas were modeled using Euclidean distances calculated from every road and railroad in the Brazilian Amazon served as the width mechanism $\mathbf{w}$ for spatially identifying the $\mathbf{F_{PreTip}}$ primary forest. When $\mathbf{w}$ was set to 2.5km it satisfied the property that the amount of remaining current primary forest $\mathbf{F_{Current}}$ from the nearest road or railroad ≈ the amount of forest in $\mathbf{F_{PreTip} = TP_{LowBound} - F_{Current} \times -1}$ (**Equation 3** and **Table 28**). When $\mathbf{w}$ was set to 8km it satisfied the property that the amount of remaining current primary forest from any road or railroad ≈ (approximately equals) the amount of forest in $\mathbf{F_{Pre\text{-}Tip} = TP_{HighBound} - F_{current} \times -1}$ (**Equation 3** and **Table 28**).

Forests inside and outside of RLRL Areas	HA	% of Original Forest Extent
Estimated **Original Forested Areas** of the Brazilian Amazon	398,096,167	100%
Low bound tipping point scenario ~30% Original Deforestation		
Pre-tipping Point Forests Likely Remaining Original Forest Outside 2.5km RLRL Areas	32,278,026	8.11%
Post-tipping Point Forests Likely Remaining Original Forest Inside 2.5km RLRLs	277,300,190	69.66%
High bound tipping point scenario ~40% Original Deforestation		
Pre-tipping Point Forests Likely Remaining Original Forest Outside 8km RLRL Areas	72,091,754	18.11%
Post-tipping Point Forests Likely Remaining Original Forest Inside 8km RLRLs	237,486,462	59.66%

Table 28 *- Identified Pre-Tipping Point and Post Tipping Point Forests (Low and High Bound) from using 2.5km RLRL and 8km RLRL Areas.*

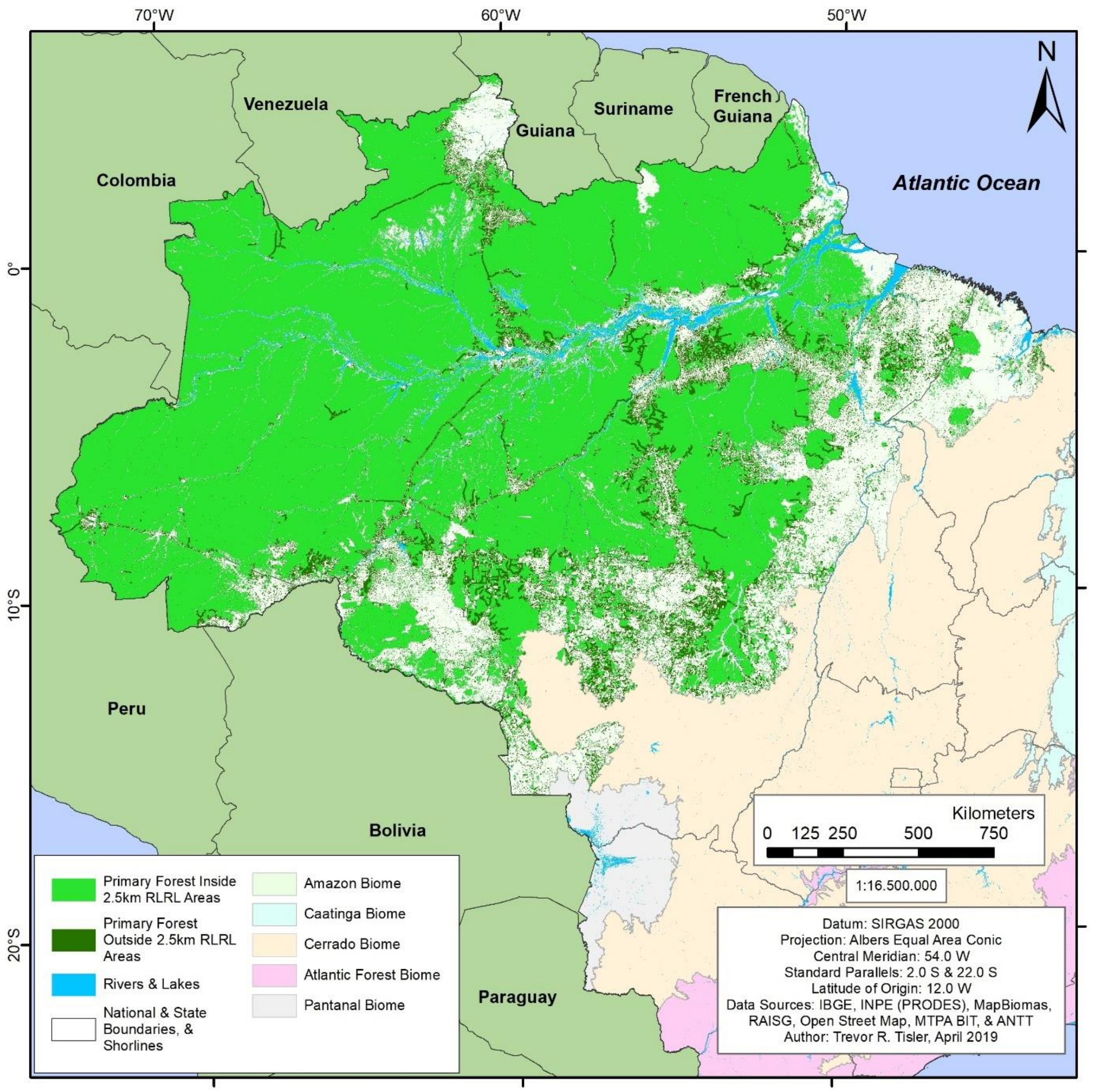

Figure 39 *- Remaining Likely Primary Amazon Forests within and Outside of 2.5km RLRL Areas*

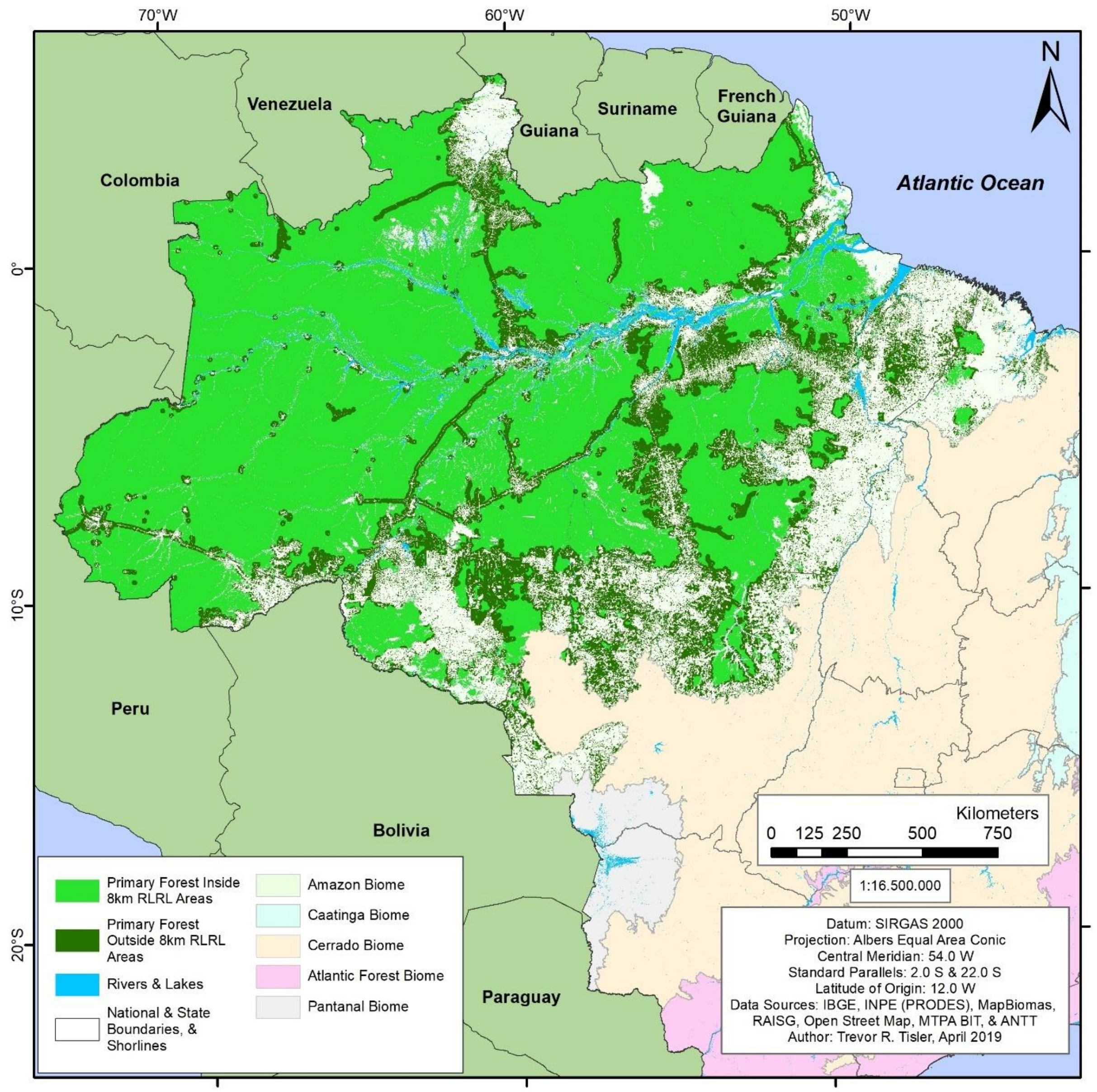

Figure 40 *- Remaining Likely Primary Amazon Forests within and Outside of 8km RLRL Areas*

4.6.3.3 – Calculating the Carbon Stock of the Brazilian Amazon Forest

Once the tipping point forest boundaries were determined the next task was to determine the spatially explicit carbon stock of the Brazilian Amazon's primary forests, which included the incorporation of three carbon data sources (**Table 29** and **Figure 40**). The measurement unit of these data sources were transformed to tonnes of carbon (C) per hectare and then transformed to tonnes of CO_2-equivalent per hectare by atomic weight conversion factor 3.667 as used by the IPCC (IPCC, 2013, p. 12)

It is important to note that recent models indicate that the Amazon basin has significant peat reserves (GUMBRICHT et al., 2017). Moreover, peat is located in areas that are normally water-logged year-round. If water levels and precipitation change in the event of climate change or a savannization of the Amazon, it is probable that significant amounts of peat will dry and oxidize or catch fire in the event of increased forest fires in the Amazon (WANG et al., 2018). In the event of these two possibilities the amount of CO_2 emissions that would occur in the event of our post-tipping point scenarios would likely be even substantially higher. However, at this moment spatial and modeling data are not available to determine how much more CO_2 emissions would occur due to peat oxidation and fires.

Amazon Forest Carbon Stock Data		
Atomic Weight Conversion Factor (tonnes of Carbon to tonnes of CO_2) as used by IPCC		
Variable	**Details**	**Source**
Biomass Carbon to CO_2 conversion Factor	IPCC assigned constant value of 3.667 for conversion of GigaTonnes of C to GigaTonnes of CO_2 **1 GtC = 3.667 GtCO2**	(IPCC, 2013, p. 12)
Carbon Stock Variables		
Variable	**Details**	**Source**
Above Ground Carbon Estimates	Raster Layer Showing Above Ground Carbon Estimates in Tonnes per Hectare	(WHRC, 2012) & (BACCINI et al., 2012)
Below Ground Biomass (Roots)	IPCC assigned constant value of 0.37 for below ground biomass multiplied by above ground biomass. Results in Tonnes per Hectare	(IPCC, 2006)
Soil Organic Carbon	Raster Layers from EMBRAPA with modeled 0 to 30 cm below ground Organic Soil Carbon Content in Tonnes per Hectare	(VASQUES et al., 2017)

Table 29 *- Spatially Explicit Carbon Data Used in SCC of the Brazilian Amazon Model*

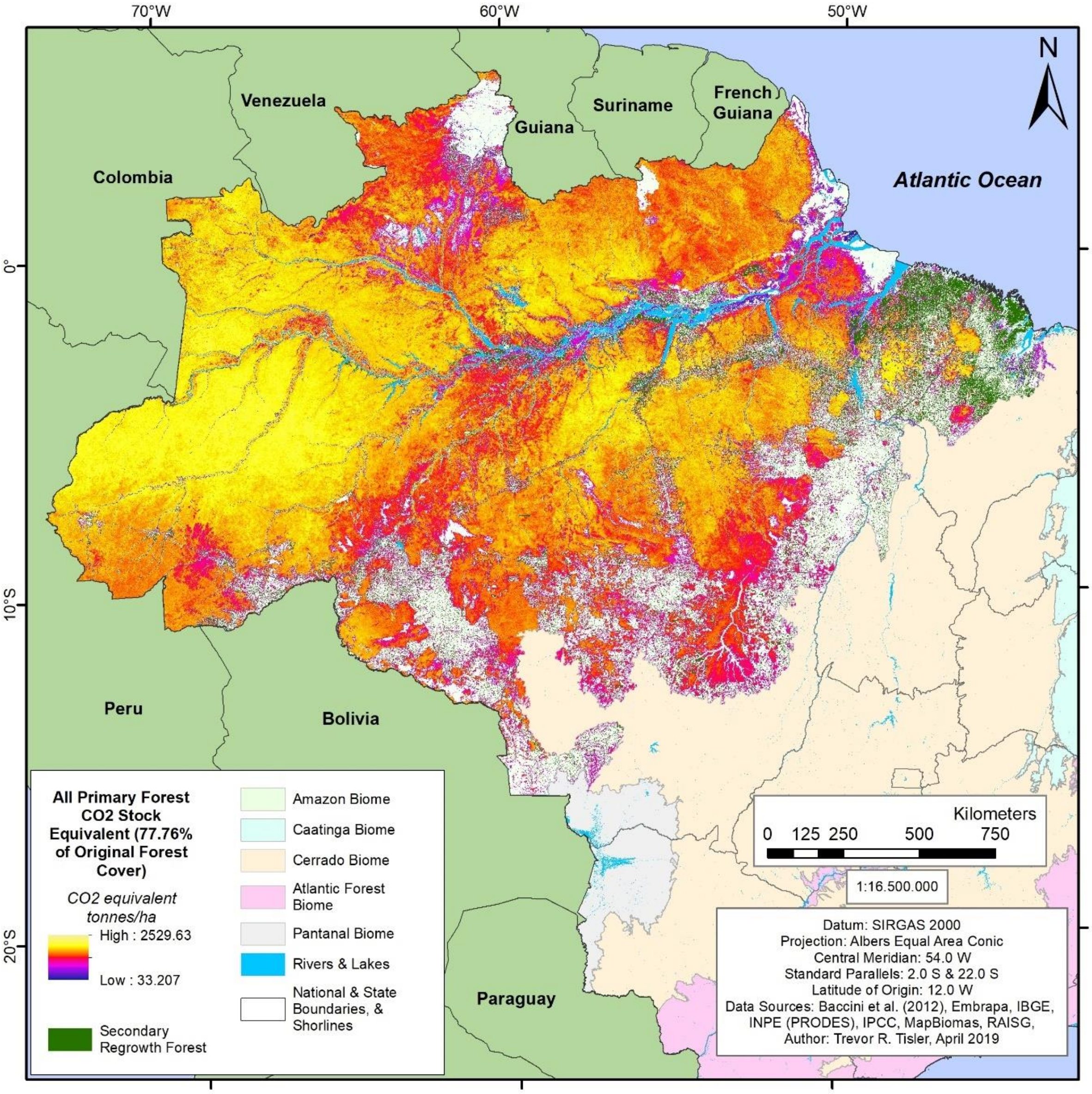

Figure 41 - *The Total Identified CO_2 Equivalent Stock of Brazilian Amazon's Remaining Primary Forest = 479,770,002,852 tonnes* (BACCINI et al., 2012; IPCC, 2006; VASQUES et al., 2017)

Then using the spatially identified tipping-point scenarios, we were able to calculate the CO_2 equivalent totals for both the **$TP_{LowBound}$** and high bound **$TP_{HighBound}$** tipping-point scenarios. The amounts are listed in **Table 30** and the **$TP_{LowBound}$** spatial distribution is presented in **Figures 41** and **42** for post-tipping point CO_2 equivalent stock totals and pre-tipping point CO_2 equivalent stock totals respectively. The **$TP_{HighBound}$** spatial distribution is presented in **Figures 43** and **44** for post-tipping point CO_2 equivalent stock totals and pre-tipping point CO_2 equivalent stock totals respectively.

Calculated Total CO_2 Equivalent Stock in Remaining Old growth/Primary Forest		
Old Growth/Primary Forests Inside and Outside of RLRL Areas	**Tonnes of CO_2 Equivalent**	**% of Total CO_2 Equivalent Stock**
Estimated Total **Remaining Old growth / Primary Forest**	479,770,002,852	100%
Low bound committed tipping point scenario ~30% Original Deforestation		
Pre-tipping Point Primary Forests Likely Remaining Original Forest Outside 2.5km RLRL Areas	40,656,204,795	8.47%
Post-tipping Point Primary Forests Likely Remaining Original Forest Inside 2.5km RLRLs	439,078,503,227	91.52%
High bound committed tipping point scenario ~40% Original Deforestation		
Pre-tipping Point Primary Forests Likely Remaining Original Forest Outside 8km RLRL Areas	96,457,843,565	20.11%
Post-tipping Point Primary Forests Likely Remaining Original Forest Inside 8km RLRLs	383,276,337,379	79.89%

Table 30 *– Total CO_2 Equivalent Stock for Committed Tipping-Point Scenarios*

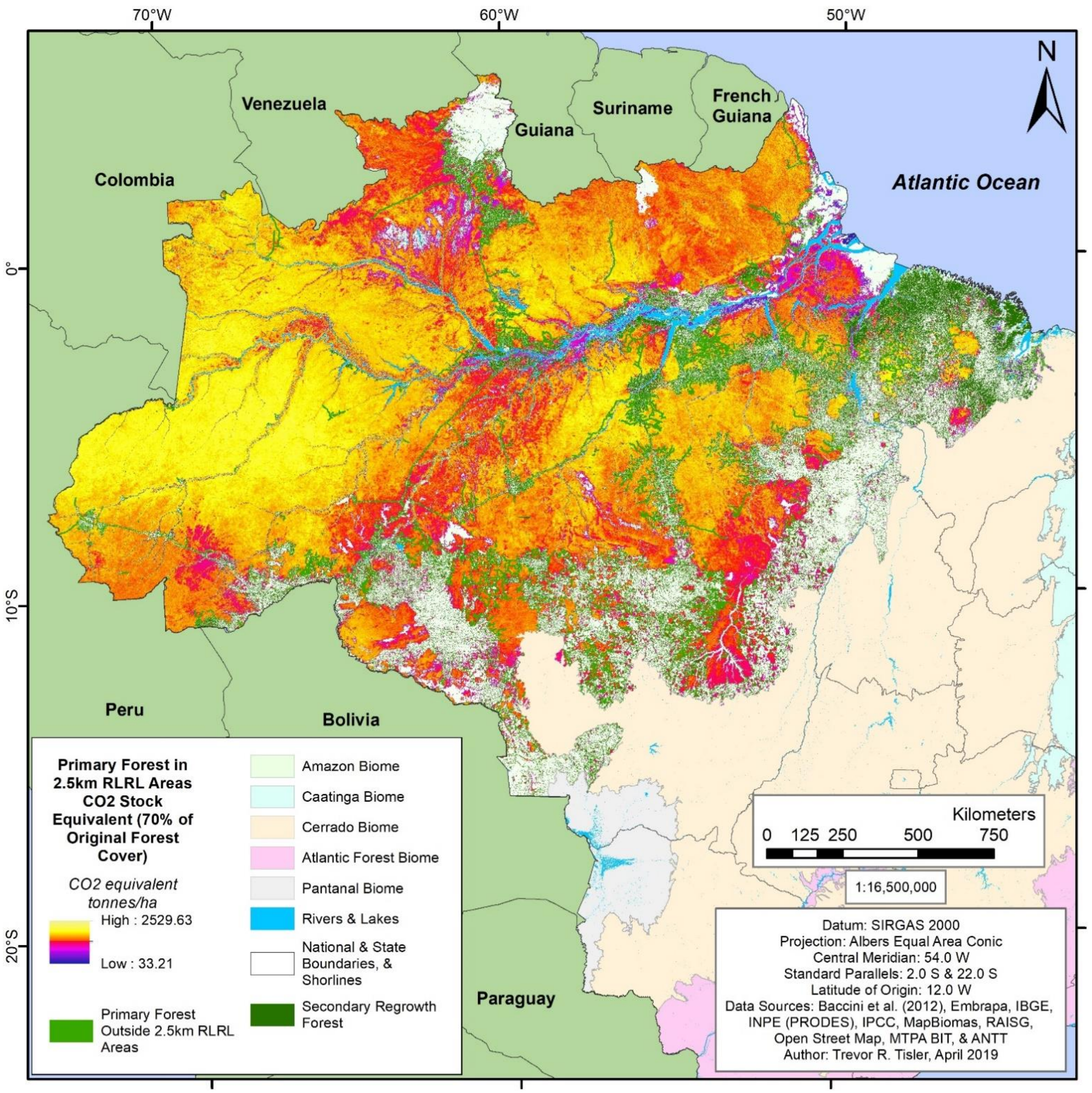

Figure 42 *- Low Bound Committed Tipping Point Scenario (30% Deforestation) Post Tipping Point Forest (inside 2.5km RLRLs)* CO_2 *Equivalent Stock = 439,078,503,227 tonnes*

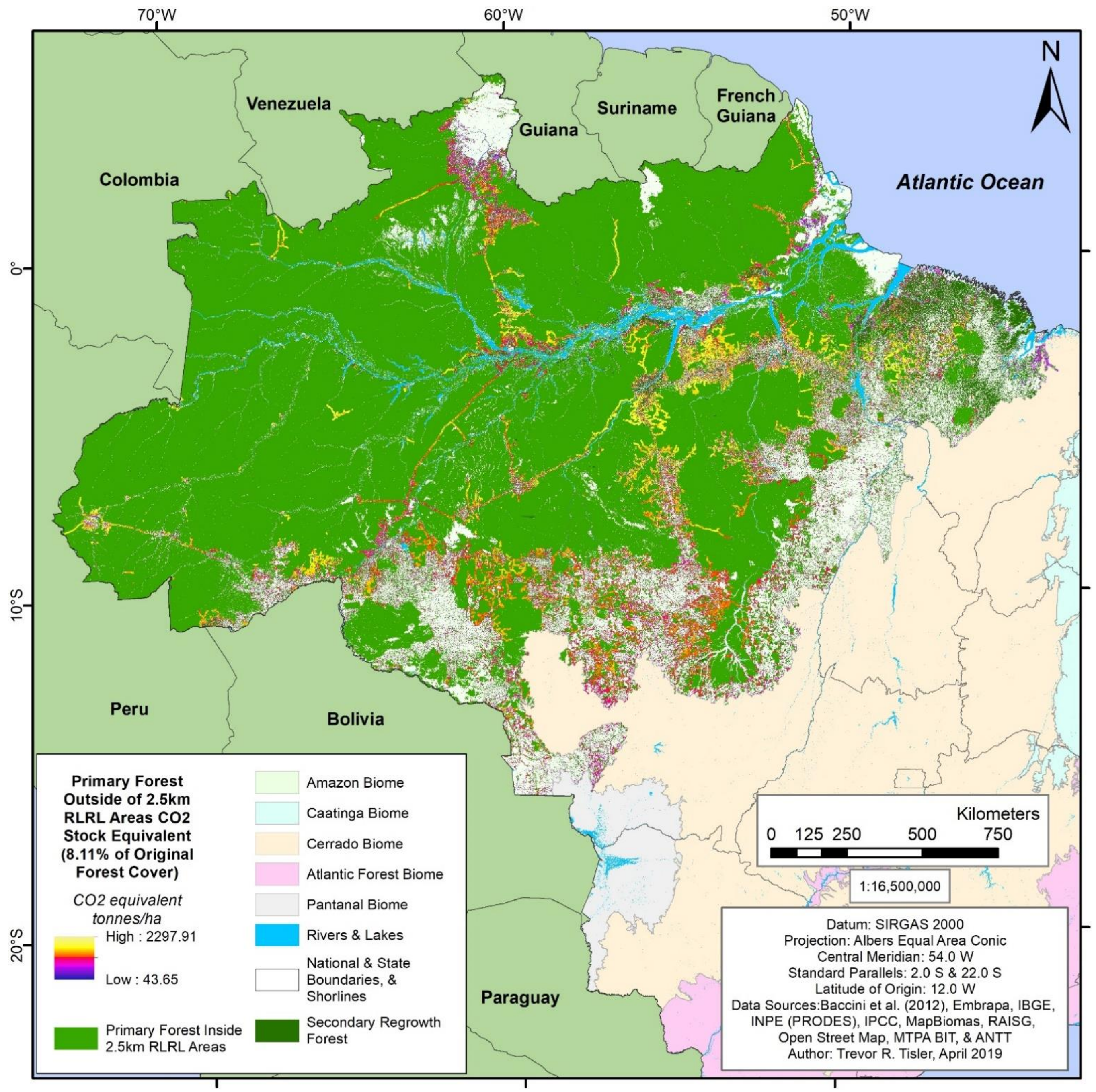

Figure 43 *- Low Bound Committed Tipping-Point Scenario (30% Deforestation) Pre-Tipping Point Forest (outside of 2.5km RLRLs)* CO_2 *Equivalent Stock = 40,656,204,795 tonnes*

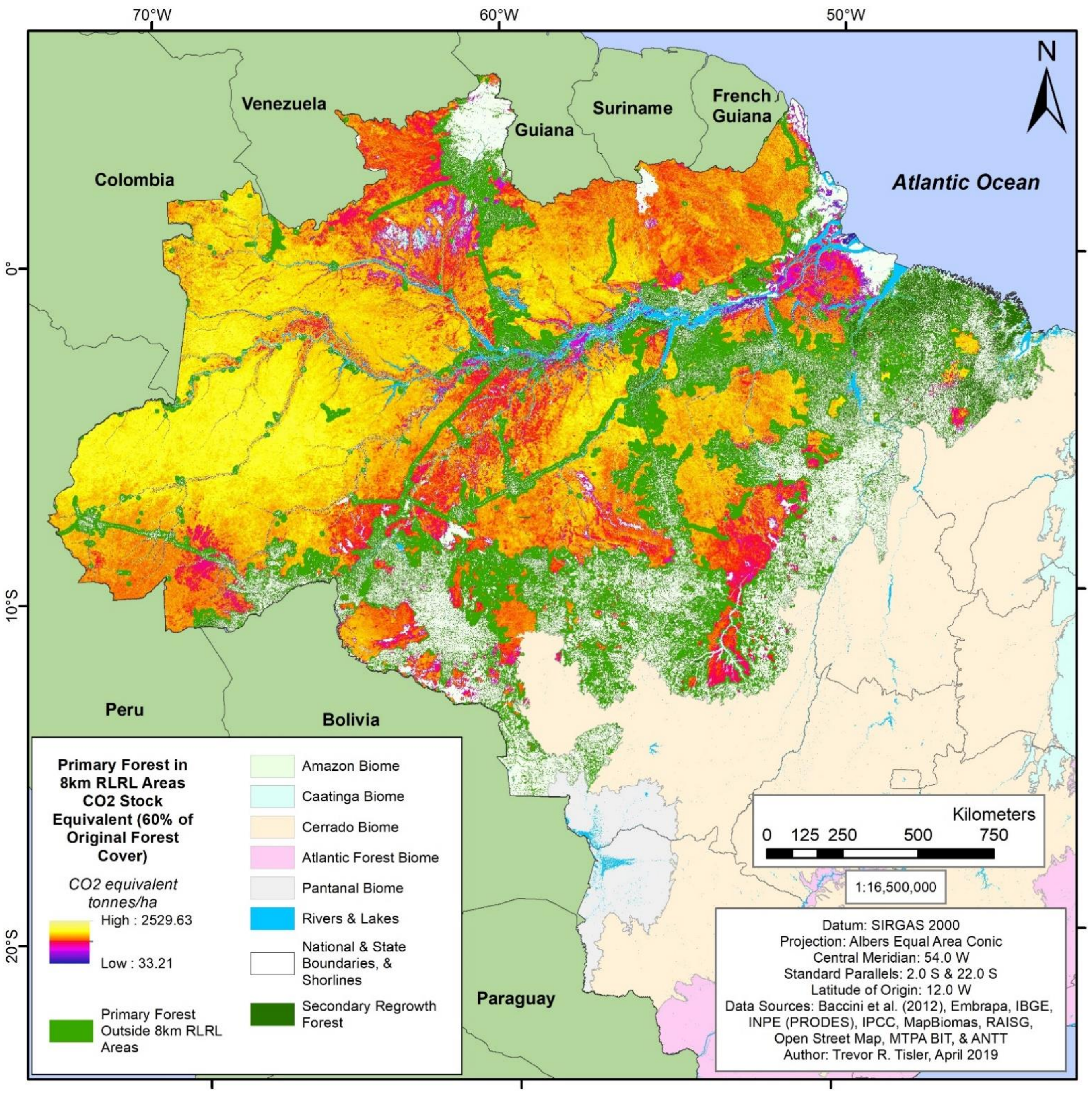

Figure 44 - *High Bound Committed Tipping-Point Scenario (40% Deforestation) Post Tipping Point Forest (inside 8km RLRLs)* CO_2 *Equivalent Stock = 383,276,337,379 tonnes*

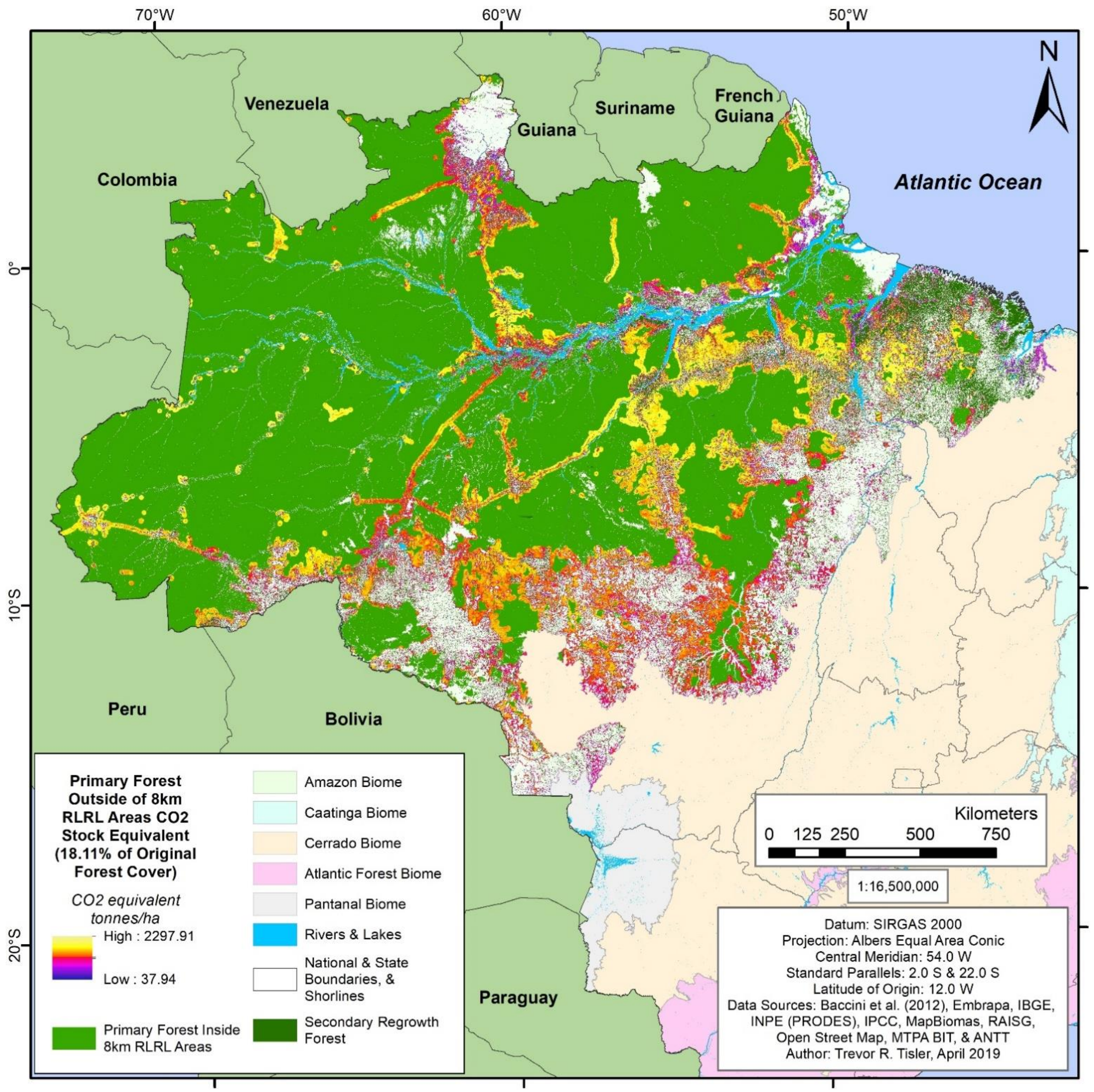

Figure 45 - *High Bound Committed Tipping-Point Scenario (40% Deforestation) Pre-Tipping Point Forest (outside 8km RLRLs)* CO_2 *Equivalent Stock = 96,457,843,565 tonnes*

4.6.3.4 – Post-Tipping Point Carbon Loss

The next step includes using the most uncertain variable involved in the equation. The majority of the literature indicates that if deforestation continues unchecked, it is possible that the Amazon will reach a tipping-point and thus will likely undergo a process of savannization or massive forest dieback. However, we were unable to identify any concrete estimates in the literature that indicate how much lower carbon stock a savannaized Amazon would have in comparison to current forest carbon densities. Therefore, we decided to create high-bound and low-bound carbon density change scenarios. We recognize that there is no evidence in the literature to back these assumptions; however, we feel that for the purpose of demonstration they will suffice.

For the low-bound committed tipping point scenario we estimated that the $\mathbf{F_{PostTip}}$ Amazon will be committed to lose only 40% of its combined CO_2 equivalent carbon stock (aboveground, belowground, and soil organic carbon material) on a per hectare basis in the event of a less severe savannization transition. For the high-bound committed tipping point scenario we estimated that the $\mathbf{F_{PostTip}}$ Amazon will be committed to lose 75% of its combined CO_2 equivalent carbon stock (aboveground, belowground, and soil organic carbon material) on a per hectare basis in the event of a severe massive-forest dieback and desertification. Moreover, it is important to highlight that $\mathbf{F_{PreTip}}$ forest would be deforested before the tipping point is triggered, hence the carbon loss for these areas would be much more severe (closer to 100% of carbon loss) than the $\mathbf{F_{PostTip}}$ forest undergoing vegetation change. Totals are given in **Table 31**.

Calculated CO_2 Equivalent of Loss in Committed Tipping Point Scenarios				
Old Growth/Primary Forests Inside and Outside of RLRL Areas	**Tonnes of CO_2 Equivalent**	**% of Total Carbon Stock**	**Tonnes of CO_2 Equivalent After 40% ΔCO_2 Forest to Savanna Change**	**Tonnes of CO_2 Equivalent After 75% ΔCO_2 Forest to Desert Change**
Estimated Total Remaining Primary Forest	479,770,002,852	100%	287,862,001,711	119,942,500,713
Low bound committed tipping point scenario ~30% Original Deforestation				
Pre-tipping Point Primary Forests (Outside 2.5km RLRL Areas)	40,656,204,795	8.47%	---	---
Post-tipping Point Primary Forests (Inside 2.5km RLRL Areas)	439,078,503,227	91.52%	263,447,101,936	109,769,625,806
High bound committed tipping point scenario ~40% Original Deforestation				
Pre-tipping Point Primary Forests (Outside 8km RLRL Areas)	96,457,843,565	20.11%	---	---
Post-tipping Point Primary Forests (Inside 8km RLRL Areas)	383,276,337,379	79.89%	229,965,802,427	95,819,084,344

***Table 31** – CO_2 equivalent stock for Low Bound and High Bound Committed Tipping-Point Scenarios with Savannization and Desertification Carbon Density Change*

4.6.3.5 – Calculating the SCC of the Brazilian Amazon

We are now able to calculate the SCC value scenarios for the Brazilian Amazon. Given that there are many SCC value estimates, in combination with our stipulated low bound and high bound tipping point scenarios, there many possible SCC estimates that can be calculated. Therefore, we have selected the lowest possible and the highest possible SCC scenarios. This means matching the lowest SCC value estimate with the higher bound tipping point (40% deforestation) and the lowest carbon loss at only 40% in the savannization scenario. The highest possible SCC scenario includes the highest SCC value estimate with the lower bound tipping point (30% deforestation) and the highest carbon loss at 75% in the desertification scenario. With this selection of variables, we are calculating the lowest possible and highest possible values to create a minimum-maximum range for the Brazilian Amazon's SCC value. The variables needed to calculate these minimum and maximum values for both the global impact SCC values and Brazil's country specific impact SCC values are listed in **Tables 32** and **33**. Moreover, **Tables 34** and **35** list the monetary values that result from these lowest of the low and highest of the high scenarios and **Figures 45** to **48** show the Global and Brazil specific spatially explicit application of these results.

Global SCC Value Estimates for the loss of the Amazon		
Variables to Consider	**Lowest Brazilian Amazon Global Impact SCC Scenario**	**Highest Brazilian Amazon Global Impact SCC Scenario**
Global SCC Value	Stern Review (5% Fixed Discount Rate) $24.41 per tonne of CO_2	Ricke et al., 2018 (3% Fixed Discount Rate) $657.00 per tonne of CO_2
Tipping Point	40% Deforestation Tipping Point Scenario	30% Deforestation Tipping Point Scenario
$F_{PostTip}$ Carbon Loss	40% Carbon Loss (Carbon Loss)	75% Carbon Loss (Desertification)

Table 32 *– Variables Needed to Calculate the Global SCC Low and High Impact Values for the Loss of the Brazilian Amazon*

Brazil's Country Specific SCC Value Estimates for the loss of the Amazon		
Variables to Consider	**Lowest Brazilian Amazon Brazil Specific Impact SCC Scenario**	**Highest Brazilian Amazon Brazil Specific Impact SCC Scenario**
Brazil Specific SCC Value	Ricke et al., 2018 (3% Fixed Discount Rate) $18.50 per tonne of CO_2	Ricke et al., 2018 (3% Fixed Discount Rate) $26.80 per tonne of CO_2
Tipping Point	40% Deforestation Tipping Point Scenario	30% Deforestation Tipping Point Scenario
$F_{PostTip}$ Carbon Loss	40% Carbon Loss (Carbon Loss)	75% Carbon Loss (Desertification)

Table 33 *– Variables Needed to Calculate the Brazil Specific SCC Low and High SCC Values for the Loss of the Brazilian Amazon*

Global Level SCC Impact Low-High Range Scenarios		
Low Bound Estimates		
Total Low Bound Global Value of the Brazilian Amazon Stern Review Global SCC (5% Fixed Discount Rate)	**$**	**6,096,846,119,598.74**
60% Remaining Carbon (Post Tipping-Point Forest $\mathbf{F_{PostTip}}$)	$	3,742,310,158,168.74
Pre-Tipping Point Forest $\mathbf{F_{PreTip}}$ Total Carbon Loss (due to Complete deforestation and eventual degraded soils)	$	2,354,535,961,430.00
Price to be added to each Pre-Tipping Point Hectare of Forest **ACPP**	$	51,910.38
High Bound Estimates		
Total High Bound Global Value of the Brazilian Amazon Ricke et al. High Bound Global SCC (3% Fixed Discount Rate)	**$**	**243,067,059,015,792.00**
25% Remaining Carbon (Post Tipping-Point Forest $\mathbf{F_{PostTip}}$)	$	216,355,932,465,133.00
Pre-Tipping Point Forest $\mathbf{F_{PreTip}}$ Total Carbon Loss (due to Complete deforestation and eventual degraded soils)	$	26,711,126,550,659.10
Price to be added to each Pre-Tipping Point Hectare of Forest **ACPP**	$	6,702,886.12

***Table 34** – The Global Level Impact Value Range of the Brazilian Amazon's SCC in the event of a Tipping Point*

Brazil Specific Level SCC Impact Low-High Range Scenarios		
Low Bound Estimates		
Total Low Bound Brazil Specific Value of the Brazilian Amazon Ricke et al. Brazil's Low Bound SCC (3% Fixed Discount Rate)	**$**	**4,620,715,002,563.57**
60% Remaining Carbon (Post Tipping-Point Forest $\mathbf{F_{PostTip}}$)	$	2,836,244,896,604.74
Pre-Tipping Point Forest $\mathbf{F_{PreTip}}$ Total Carbon Loss (due to Complete deforestation and eventual degraded soils)	$	1,784,470,105,958.83
Price to be added to each Pre-Tipping Point Hectare of Forest **ACPP**	$	39,342.15
High Bound Estimates		
Total High Bound Brazil Specific Value of the Brazilian Amazon Ricke et al. Brazil's SCC (3% Fixed Discount Rate)	**$**	**9,915,064,203,383.90**
25% Remaining Carbon (Post Tipping-Point Forest $\mathbf{F_{PostTip}}$)	$	8,825,477,914,863.87
Pre-Tipping Point Forest $\mathbf{F_{PreTip}}$ Total Carbon Loss (due to Complete deforestation and eventual degraded soils)	$	1,089,586,288,520.04
Price to be added to each Pre-Tipping Point Hectare of Forest **ACPP**	$	273,420.62

***Table 35** – Brazil's Country Specific Level Impact Value Range of the Brazilian Amazon's SCC in the event of a Tipping Point*

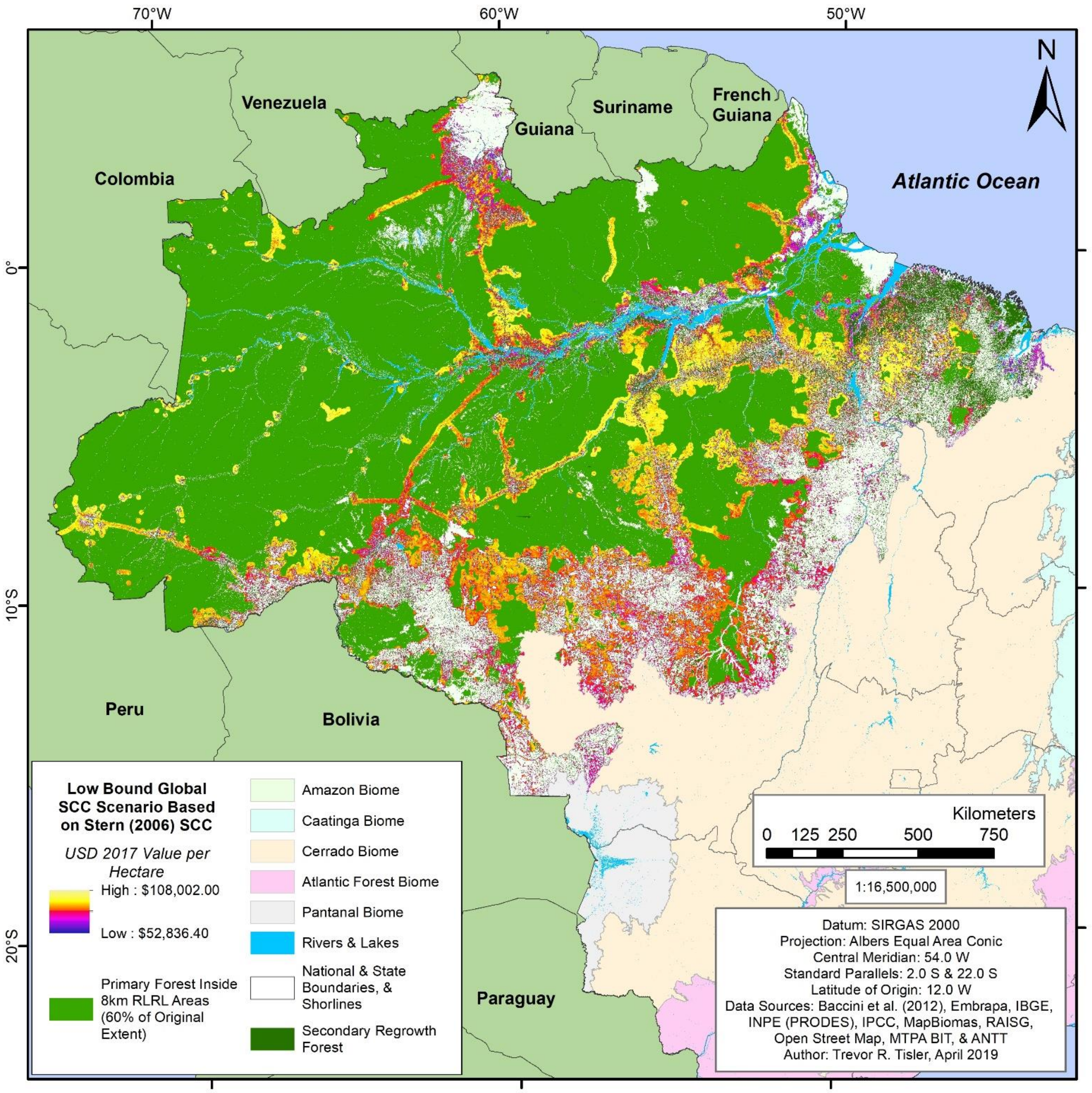

***Figure 46** – Low Bound Global SCC Scenario Based on Stern Review (2006) SCC*

The identified Pre-Tipping Point Forest account to an approximate value of $ 6.1 trillion USD 2017

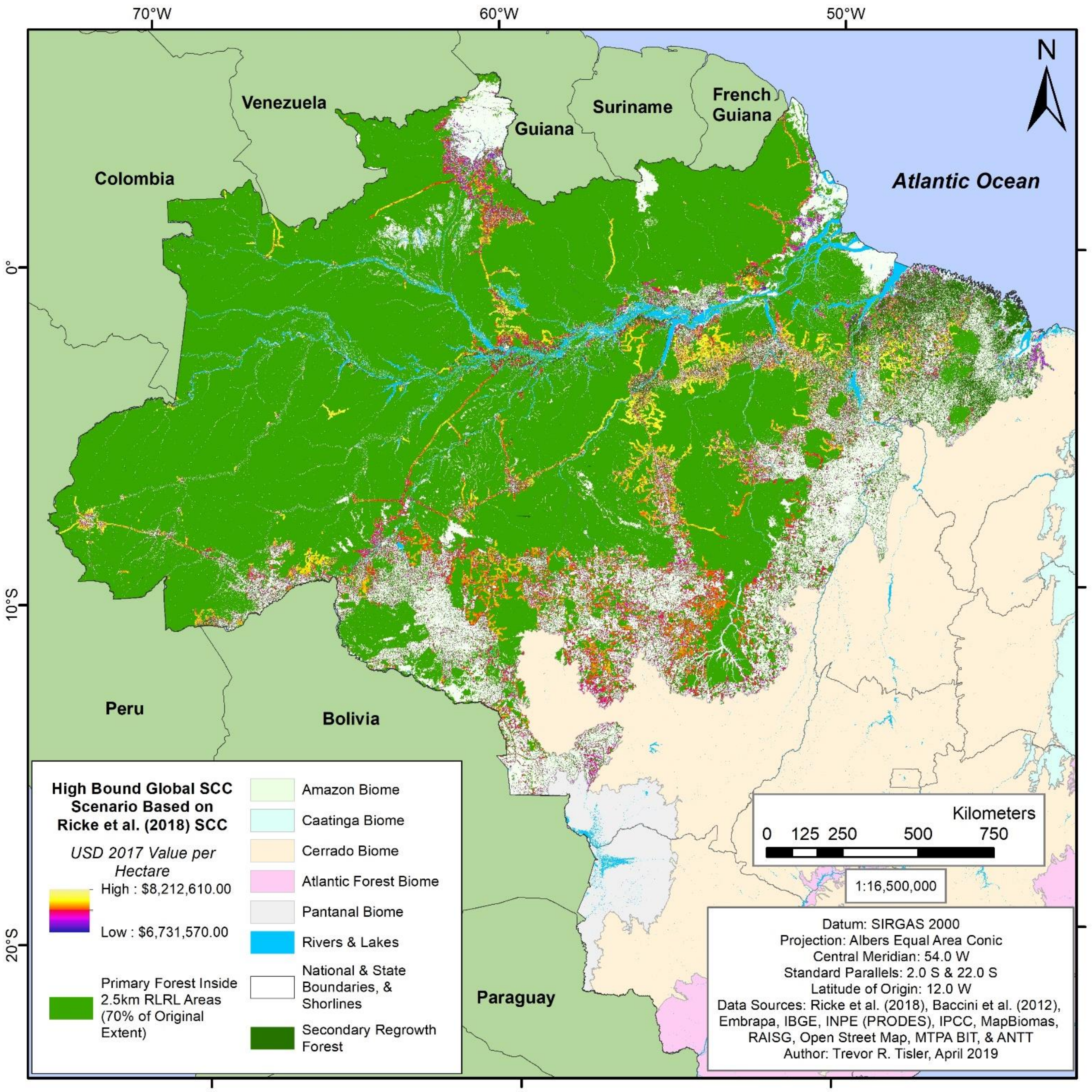

***Figure 47** – High Bound Global SCC Scenario Based on Ricke et al. (2018) SCC*

The identified Pre-Tipping Point Forest account to an approximate value of $ 243.1 trillion USD 2017

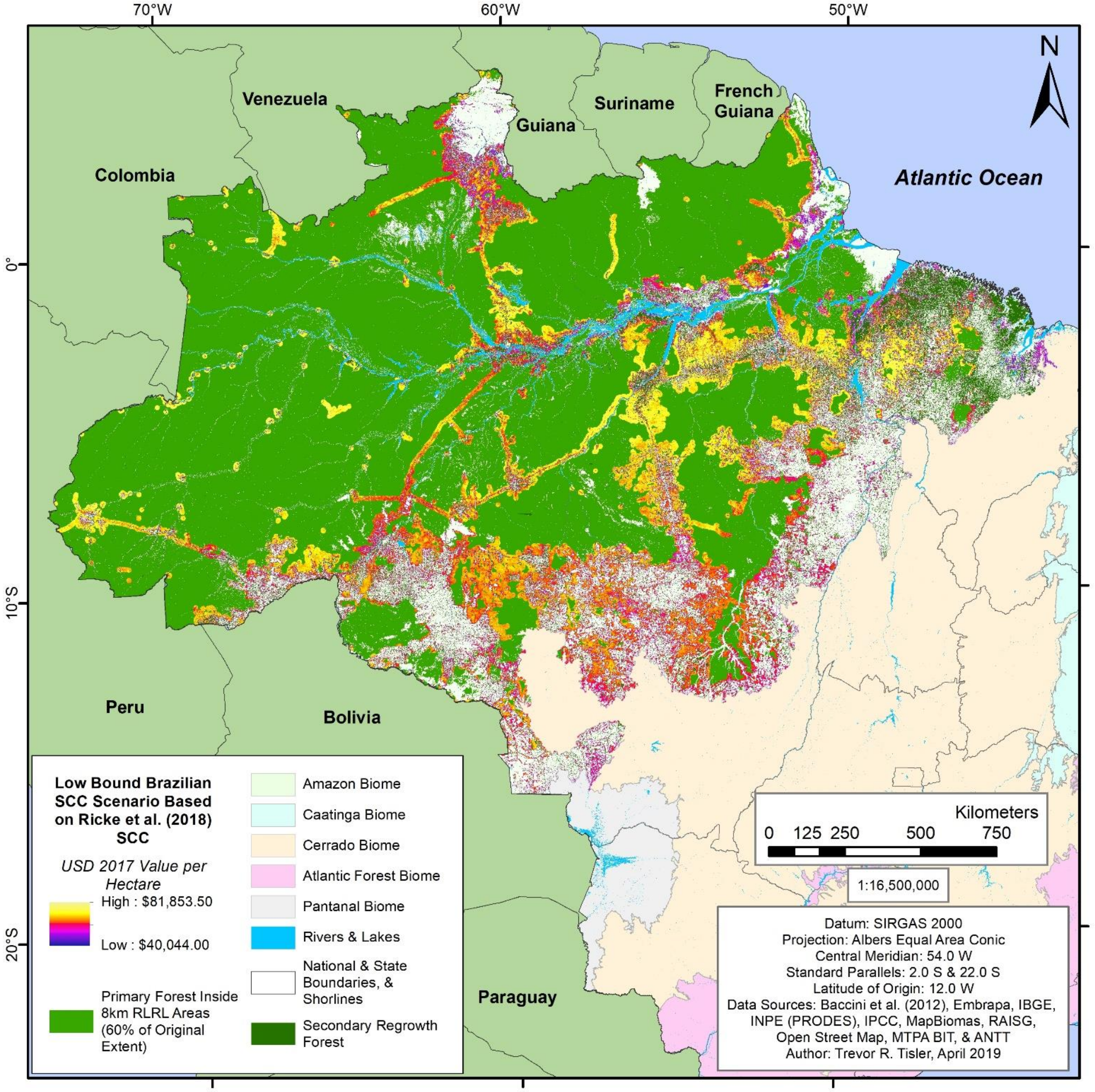

***Figure 48** – Low Bound Brazil Specific SCC Scenario Based on Ricke et al (2018) SCC*

The identified Pre-Tipping Point Forest account to an approximate value of $ 4.6 trillion USD 2017

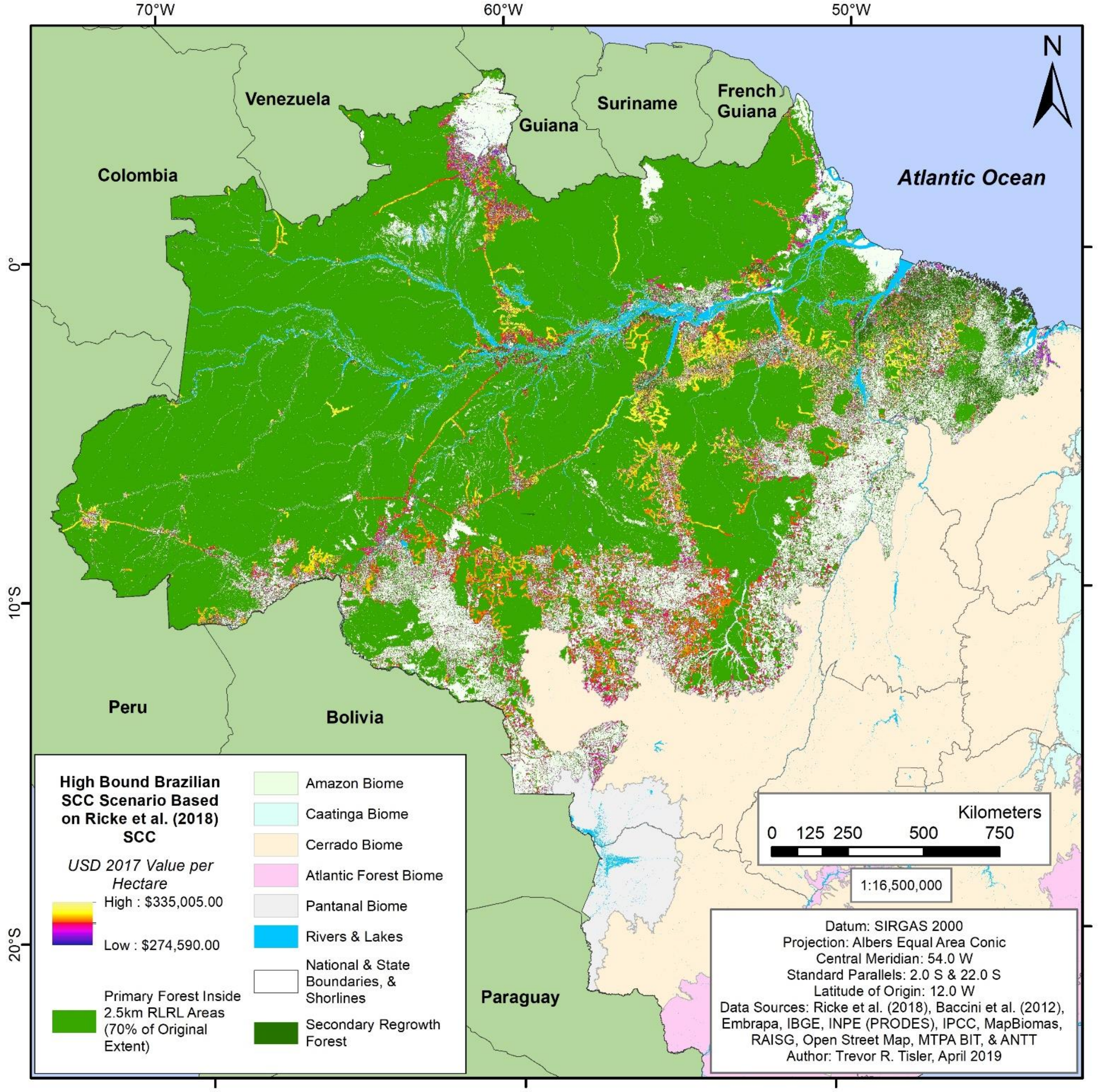

***Figure 49** – High Bound Brazil Specific SCC Scenario Based on Ricke et al (2018) SCC*

The identified Pre-Tipping Point Forest account to an approximate value of $ 9.9 trillion USD 2017

4.7 – Discussion

Our estimates show that in terms of global impact, the loss of the Brazilian Amazon to a tipping point results in a SCC impact value ranging between $6.1 to $243.1 trillion (*USD 2017*). In the global impact low bound estimate, each hectare of remaining primary forest has a SCC impact value ranging between $52,000 to $108,000 (*USD 2017*). In the global impact high bound estimate, each hectare of remaining primary forest has a SCC impact value ranging between $6.7 to $8.2 million (*USD 2017*). In terms of impact specifically to Brazil and its economy, as calculated by Ricke et al. (2018), the loss of the Amazon could result in a SCC impact value ranging between $4.6 to $9.9 trillion (*USD 2017*). In the Brazil country specific impact low bound estimate, each hectare of remaining primary forest has a SCC impact value ranging between approximately $40,000 to $82,000 (*USD 2017*). In the Brazil country specific impact high bound estimate, each hectare of remaining primary forest has a SCC impact value ranging between $274,000 to $335,000 (*USD 2017*).

We believe that our value estimates demonstrate that the Amazon is worth saving given the sheer value of one service, carbon sequestration, that the Amazon provides to both Brazil and the world. Scientists have regularly stated the importance of the Brazilian Amazon and we believe that our findings further back the overwhelming stance of the scientific community. We believe that these value estimates and spatially explicit data could and should be incorporated at the policymaking stage at federal ministries as well as at financial review and external control stages undertaken by Brazil's Federal Court of Accounts (TCU) in cost-benefit analysis calculations done for policy and infrastructure programs in the Brazilian Amazon.

Furthermore, Brazil promised to reduce its deforestation rates to net zero, reforest 12 million hectares of land and reduce its overall GHG emissions through low carbon agricultural practices and development as part of its NDC for the Paris Agreement (BRAZIL, 2015). However, since 2015 very few tangible advances have been made in Brazil which demonstrate that the country is seriously working on achieving these goals, and furthermore, federal policy and law enforcement repeatedly continues to ignore or remain incapable of upholding the tenants of the country's environmental and biological conservation laws and the international agreements that Brazil signed on to (JÓNSSON, 2016; MALVESTIO; FISCHER; MONTAÑO, 2018; RABELLO QUADROS; NASSI, 2015; ZIONI; FREITAS, 2015). Given the growing adoption of the ecosystem services concept and approach in federal and state legal frameworks in Brazil (ALTMANN; SILVA STANTON, 2018), we believe that our value estimate approach for the Amazon, and future research on the Amazon and Brazil's other biomes could be integrated into the legal framework to ensuring that 'closer to accurate' values are part of the decision process and any Payments of Ecosystem Services programs.

We would like to highlight that we were only able to capture a fraction of the value of ecosystem services that the Amazon provides to Brazil and the world. Given the surprisingly low amount of ecosystem service value estimates for the Amazon that we could find in the literature in comparison to the biome's global importance, we implore the scientific and economic communities to conduct further research with care, intensity and urgency in order to calculate and document ecosystem service value estimates for all four ecosystem service categories (regulating, provisioning, supporting, and cultural) whether direct use or indirect use. There are surely variables that are not being captured whether for the ecosystem services or for the sustainable resource extraction potential that the Amazon offers.

4.8 - Conclusion

There is significant cause for alarm with the openly stated plans aimed to decrease environmental protection of the Brazilian Amazon and open it up to additional soy and cattle ranching development by Brazil's current president (TOLLEFSON, 2018) as well as with the recently announced federal ministerial plans to construct new highways and hydroelectric power plants in many forested and legally protected areas of the Brazilian Amazon (MONTEIRO; BORGES, 2019). However, it is also important to highlight that, historically and at the current moment, Brazil's export potential relies primarily on its commodities, of which agriculture plays a significant role (MEADE et al., 2016; MUELLER; MUELLER, 2016). However, a balance must be found, as Brazil cannot significantly deforest the Amazon and still expect the same prosperous agricultural sector in the future (LAWRENCE; VANDECAR, 2015).

Our calculations show that if a committed tipping point were reached and a savannization or massive forest dieback process were to happen, the significant impact on the Amazon's carbon sequestration services could lead to a negative impact on Brazil and the global community that accounts to a significant portion or more than annual global GDP. In 2017 for example, total global GDP amounted to $80.6 trillion (THE WORLD BANK, 2018), our low bound global impact estimate accounts to 7.5% of 2017 global GDP; whereas our high bound global impact estimate, which is derived from more recent economic modeling, amounts to three times 2017 global GDP. Moreover, it is important to highlight that our estimates do not account for many more of the ecosystem services provided by the Brazilian Amazon. Although these calculations will likely fall on deaf ears in Brazil given that the federal financial and development sectors already favor expanding commodity oriented sectors (EATON, 2018), other actors in Brazil and the international community should be significantly alarmed at what is at stake and be prepared to use these values to negotiate and pressure president Bolsonaro's administration to reverse its unwise stance on deforestation.

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Section 5: Final Considerations

The three principal chapters of this thesis brought to light concepts that appear to only be lightly covered in the literature, especially in the context of Brazil. The public policymaking and governance analysis aimed to incorporate a systems thinking approach to identify why poor socioenvironmental governance still continues in the context of large transportation infrastructure projects in Brazil. This is in spite of repeated controversy and consternation from all sides of actors involved, yet the *status quo* has not changed. Moreover, through the implemented governance analytical framework (GAF), a systemic synthesis incorporating actors, processes, breakpoints, laws and norms was contextualized and presented in detail. Although the policymaking process and governance structures are becoming ever more dynamic, multi-leveled, and influenced by growing numbers of non-state actors, the role of the State remains an important and key force in determining overall governance outcomes. By identifying possible entry points and key institutional actors in Brazil's transportation and socioenvironmental public policymaking process and governance structure, a call for action was issued to Brazil's scientific and academic community to take heed of this information and orient their research to ensure that science informs and builds the foundation of future public policies.

By modeling Brazil's roadless and railroad-less (RLRL) areas, the second chapter was able to put the environmental impacts of contradictory policymaking into context. The existing transportation infrastructure and future expansions of Brazil's federal transportation system will impact many areas relevant to Brazil's biodiversity conservation and environmental protection policies and programs. Moreover, in the context of Brazil's international agreements, significant progress in environmental policy implementation must be made in the coming years if Brazil is to actually uphold its biodiversity conservation and deforestation reduction commitments. However, these challenges must be overcome in the very same policy system which has allowed significant portions of Brazil's federal highway system to operate without any form of environmental licensing to this day. In this context, the future looks bleak as significant cross-ministerial policy integration and reorientation would have to occur for set environmental policy goals to even have a chance of being accomplished.

By identifying the Brazilian Amazon's remaining forest extent and incorporating innovative advances in environmental economics in the third chapter of this thesis, advances in estimated market valuation for the Brazilian Amazon's carbon sequestration and climate change mitigation services were made by using the Social Cost of Carbon (SCC). The resulting market value estimates, which fall in the trillions of dollars, indicate that the continued deforestation of the Amazon not only has significant environmental impacts but also large economic impacts that the market does not capture. In the context of emerging proposals and programs to implement Payments for Ecosystem Services (PESs) in Brazil, it is imperative that value estimates with a strong economic backing are central components of the PES policymaking process. Moreover, these values or this approach could potentially be incorporated by the Federal Court of Accounts (TCU), which is looking to incorporate environmental monetization methodologies into its calculations, to perform more comprehensive cost-benefit analyses during its external control of policy and infrastructure plans that are proposed for development in the Amazon.

It is desirable that the developed public policy and governance synthesis, alongside with the RLRL model and SCC model for the Brazilian Amazon be reviewed by the scientific and academic community, be improved upon, and be communicated to the public and relevant actors involved in governance. This is critical, not only for the research of this thesis but also for so much of the academic research that is undertaken in Brazil. As a scientific and academic community, we can ensure that Brazil's socioenvironmental constitutional rights and policies do not continue to fall through the cracks or be ignored.

Section 6 - Annex

Section 6.1 - Supplemental Material for Chapter 2

Supplemental Material for: Brazil's Roadless and Railroad-Less *Areas – Identifying Brazil's Conservation Opportunities and Environmental Threats*

Supplemental Material Section Outline

Supplemental Figures

Supplemental Tables

Section 1 – Spatial Data for Identifying Study Area and Examining Official Data Issues

***Figure S 1** - Highlighted Area Coverage Differences between IBGE's BC250 National Territorial Coverage and Rosa and MapBiomas' (2016) Adaptation of Brazil's Terrestrial Biome Coverage*

Unfortunately, the Brazilian Institute of Geography and Statistics' (IBGE) official spatial data identifying Brazil's terrestrial biomes (scaled 1:5,000,000) and IBGE's official data for identifying Brazil's territorial extent in the 2017 1:250,000 scaled Continuous Cartographic Database of Brazil (Base Cartográfica Continua do Brasil - BC250) are not available in the same scale and as a result vary significantly in their territorial coverage (IBGE, 2006, 2017). Therefore, the area measurements for our study area are defined by an adaptation of IBGE's spatial biome data that was developed by Project Mapbiomas (ROSA; PROJECT MAPBIOMAS, 2016) which provides a lower amount of spatial area coverage inconsistencies to IBGE's 2017 BC250 national territorial data as opposed to IBGE's own official biome spatial data (IBGE, 2017). Therefore, the defined study area when considering identified terrestrial biomes covers 850,273,851 hectares (ha), even though the national area coverage of IBGE's 2017 BC250 national territorial extent spatial data equals to 851,419,849 ha when protected using IBGE's official projection (see Sup Mat. Sec. 2) (IBGE, 2017).

According to IBGE (2015), "The total value of the Brazilian surface was kept at 8,515,767.049 km^2 (851,576,704.90 ha), as published in the Brazilian Official Gazette of no. 118 of June 22, 2016, according to Resolution no. 02, of June 21, 2016." However, using data from IBGE's 2017 BC250, and having to correct for errors in the shapefile geometry and using IBGE's official projection (see Sup Mat. Sec. 2) we calculated Brazil's national territory at 8,514,198.492 km^2 (851,419,849.20 ha). A difference of 1,568.557 km^2 (156,855.70 ha). However, it is important to note that 77% of this appears to be Lagoa dos Patos and Lagoa Mirim in Rio Grande do Sul and 23 % appears to be land along Brazil's shoreline and with small costal islands not captured by the differences in scale and discrepancies along Brazil's international borders.

Data Name	Source	Scale	Area in HA	Difference to IBGE's Official National Territory Spatial Data
Lim_Unidade_Federacao (Official Shapefile for State and National Borders)	(IBGE, 2017)	1:250,000	851,419,849.20	-
Mapa de Biomas do Brasil (Official Shapefile for Brazil's Terrestrial Biomes)	(IBGE, 2006)	1:5,000,000	848,737,340.23	2,682,508.97 (HA) 26,825.09 (km^2)
Mapa de Limite dos Biomas 1:1.000.000 (MapBiomas Adaptation of Brazil's Terrestrial Biomes based on Official IBGE Data)	(ROSA; PROJECT MAPBIOMAS, 2016)	1:1,000,000	850,273,851.85	1,145,997.35 (HA) 11,459.97 (km^2)

Table S 1 *- Breakdown of Discrepancies in IBGE's Official Territorial Data, Biome Data, and MapBiomas Adaptations of IBGE's Biome Delineations*

Section 2 – RLRL Input Data and Modeling

To model our RLRL areas, we specifically used both IBGE's spatial road network data from the BC250 and Open Street Map (OSM) to ensure that all know roads (officially documented or crowdsource identified) were included in our model. Furthermore, OSM data includes identified pathways, such as bridleways, hiking footways, etc. that are not automobile dominated roads. However, as included by Ibisch et al. (2016), we decided to include all of these types of 'roads' in our model database as all road categories have impacts (IBISCH et al., 2016), whether large or small as they could possibly be used by all-terrain vehicles (ATVs) which could potentially impact surrounding flora and fauna as well as be used for colonization and human settlement, which in extreme cases could be facilitated by traveling by foot. Further information on OSM's road categories is listed in **Table S 2**.

Data from the Global Roads Open Access Data Set (gROADS) (CIESIN; ITOS, 2013) was considered for incorporation in our model as it has been used in past roadless area studies (IBISCH et al., 2016; LAURANCE et al., 2014); however, after visual examination with Google Earth Pro imagery (GOOGLE, 2018) the quality of gROADS data for Brazil was determined to be questionable and thus not included. We believe that gROADS data should now be reviewed on a per country basis for positional and coverage accuracy given the discrepancies between it and both official government and crowdsourced spatial data for Brazil.

Open Street Map Road Variables Included in Input Data	
Automobile Dominated	a. Motorway & Motorway link b. Trunk & Trunk link c. Primary & Primary link d. Secondary & Secondary link e. Tertiary & Tertiary link f. Unclassified g. Residential h. Service
Not Automobile Dominated	a. Living Street b. Pedestrian c. Track
Paths Category	a. Footway b. Bridleway c. Steps d. Path
Others	a. Cycleway b. Busway

Table S 2 - *Open Street Map Roadway Categories Included in the RLRL Modeling* (OPENSTREETMAP WIKI, 2019)

Data Category: Study Area				
Spatial Data	**Source**	**Temporal Resolution / Representation Date**	**Scale**	**Format and other Information**
Territorial Extent of Brazil *(Used for initial Country wide modeling)*	(IBGE, 2017)	2017	1:250,000	Vector Shapefile
Biomes of Brazil *(MapBiomas improved adaptation of IBGE's official Biome Boundaries)*	(ROSA; PROJECT MAPBIOMAS, 2016)	2016	1:1,000,000	Vector Shapefile

Table S 3 *- Model and Analysis Spatial Data: Study Area*

Data Category: Roadless and Railroad-less (RLRL) Areas				
Spatial Data	**Source**	**Temporal Resolution / Representation Date**	**Scale**	**Format and other Information**
Open Street Map - Roads *(Brazil's Road Data)*	(GEOFABRIK; OPENSTREETMAP, 2018)	May 2018	Unknown *Suspected to be equivalent to or Larger Scale than 1:250,000*	Vector Shapefile
Base Cartográfica Continua do Brasil – BC250 *(National Road Data)*	(IBGE, 2017)	2017	1:250,000	Vector Shapefile
Open Street Map - Railroads *(Brazil's Railroad Data)*	(GEOFABRIK; OPENSTREETMAP, 2018)	May 2018	Unknown *Suspected to be equivalent to or Larger Scale than 1:250,000*	Vector Shapefile
Railroads in the Transportation Information Database *(Ferrovias do Banco de Informações de Transporte – BIT)*	(MTPA, 2018)	2018	Unknown *Suspected 1:5,300,000*	Vector Shapefile
Georeferenced Federal Railroad Network *(Malha Ferroviária Federal Georreferenciada)*	(ANTT, 2016)	2017	Unknown	Vector Shapefile
Base Cartográfica Continua do Brasil – BC250	(IBGE, 2017)	2017	1:250,000	Vector Shapefile

(National Railroad Data)				

Table S 4 *- Model and Analysis Spatial Data: Roadless and Railroad-less Areas*

Data Category: Environmental Variables				
Spatial Data	**Source**	**Temporal Resolution / Representation Date**	**Scale**	**Format and other Information**
Conservation Units – Federal, State and Municipal *(Unidades de Conservação da Cadastro Nacional de Unidades de Conservação)*	(MMA, 2018b)	2018	Varies between 1:5.000 to 1:100.000	Vector Shapefile
Indigenous Territories *(Terras Indigenas)*	(FUNAI, 2018)	2018	Unknown *(Suspected 1:250,000)*	Vector Shapefile
Quilombos *(Maroon Community Lands)*	(INCRA, 2018)	2018	Unknown *(Suspected 1:250,000)*	Vector Shapefile
Priority Areas for Biodiversity Conservation *(Áreas Prioritárias para Conservação da Biodiversidade)*	(MMA, 2018a)	2018	Unknown *(Suspected 1:250,000)*	Vector Shapefile
Natural Vegetation Formations *(Classified Landsat imagery from Project MapBiomes)*	(PROJECT MAPBIOMAS, 2018)	2017	30 by 30 meter resolution upscaled to 250 by 250 meter resolution	Raster upscaled and then transformed to Vector Data with polygon border simplification.

Table S 5 *- Model and Analysis Spatial Data: Environmental Variables*

Data Category: Federal Level National Transportation System (SNV)				
Spatial Data	**Source**	**Temporal Resolution / Representation Date**	**Scale**	**Format and other Information**
Highways part of the SNV *(Rodovias no SNV)*	(DNIT, 2018)	November 26, 2018	Unknown	Vector Shapefile
Railroads part of the SNV *(Ferrovias no SNV do Banco de Informações de Transporte – BIT)*	(MTPA, 2018)	October 2, 2018	Unknown *Suspected 1:5,300,000*	Vector Shapefile
PROFAS Highways part of the SNV *(PROFAS Rodovias no SNV)*	(DNIT, 2016, 2018)	PROFAS Highways List (Unknown)	Unknown	Spreadsheet joined to Vector Shapfile

Table S 6 *- Model and Analysis Spatial Data: Federal National Transportation System (SNV)*

Section 3 – Basic Geoprocessing Operations Used to Preprocess and Model Results in our Study

Geoprocessing Tools	Description
Clip	To cut the various geographic input data according to the established study area and feature of interest.
Erase	To erase away various unneeded geographic information and leaving desired geographic input data available for use.
Intersect	To identify and result in desired combinations of overlapping geographic input variables.
Union	To create a geographic union of overlapping features and so that they maintain all attribute data.
Merge	To combine multiple geographic input variables into the same file.
Calculate Geometry	To calculate the area or distance of geographic variables of interest for the study.
Euclidean Distance	To generate a raster file showing the continuous distance of areas away from identified Road and Railroad features.
Conversion Tools	To convert raster data to vector data and vice-versa.

***Table S 7 -** Basic Geoprocessing Operations for the RLRL Modeling and Analysis*

The above table describes basic geoprocessing operations to perform the basic data manipulation and analysis required to calculate the results present throughout this study. These cartographic operations were undertaken using the ArcMAP 10.4.1 software interface (ESRI, 2016). However, these same operations could easily be undertaken using other GIS software, especially opensource software such as Quantum GIS (QGIS). However, in the instance of using opensource software the names of the tools to conduct these operations may be different.

Section 4 – IBGE's Official Projection

Figure S 2 *- IBGE Projection Configurations on Study Area*

IBGE's Albers Equal Area Conic Projection

Projection: Albers
False_Easting: 5000000,0
False_Northing: 10000000,0
Central_Meridian: -54,0
Standard_Parallel_1: -2,0
Standard_Parallel_2: -22,0
Latitude_Of_Origin: -12,0

Linear Unit: Meter (1,0)
Geographic Coordinate System: GCS_SIRGAS_2000
Angular Unit: Degree (0,0174532925199433)
Prime Meridian: Greenwich (0,0)
Datum: D_SIRGAS_2000

Spheroid: GRS_1980
Semimajor Axis: 6378137,0
Semiminor Axis: 6356752,314140356
Inverse Flattening: 298,257222101

Section 5 – Modeled Euclidean Distances from All Road and Railroad inputs

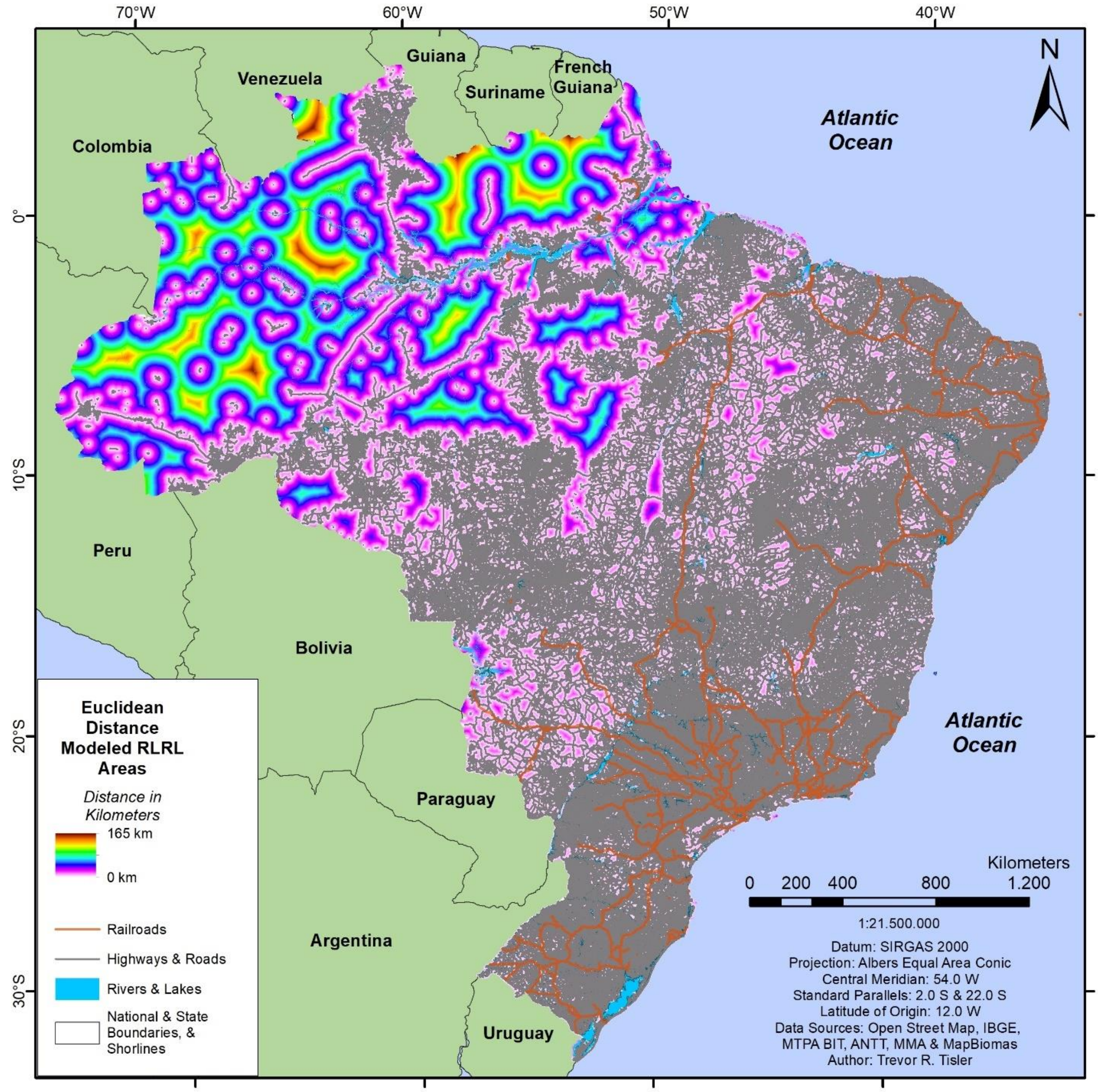

Figure S 3 - *Modeled Euclidean Distances from All Road and Railroad Input Data*

Section 6 – Legal Considerations of TI and Quilombo Bureaucratic and Constitutional Recognition

Com descrição clara na Constituição Federal Brasileira de 1988[1], povos indígenas (231 e 232, ADCT art.67) e afro-brasileiros (215,216, ADCT 68) como grupos participantes do processo civilizatório nacional é importante destacar a burocracia que envolve o processo de reconhecimento legal de TIs e Quilombos no Brasil. Com procedimentos administrativos e órgãos estatais distintos, cabe a Fundação Nacional do Índio (FUNAI), desde 1967 (Lei nº 5.371) coordenar e executar a política indigenista baseando-se na Convenção 169 da OIT sobre Povos Indígenas e Tribais, integralmente promulgada através do Decreto nº 5.051/2004, e no Estatuto do Índio (Lei 6.001/73). Referente a demarcação das terras, os índios terão a posse, que possui natureza originária e coletiva sendo a propriedade da União (Estado Brasileiro). O processo de demarcação é guiado pelo Decreto nº 1775/96. Atribui-se a Fundação Cultural Palmares (Quilombos), conforme § 4º do art. 3º do Decreto nº 4.887/2003[2] a competência pela emissão de certidão às comunidades quilombolas e sua inscrição em cadastro geral. A documentação exigida pode ser encontrada na Portaria FCP nº 98, de 26 de novembro de 2007[3].

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[1] http://www.planalto.gov.br/ccivil_03/Constituicao/ConstituicaoCompilado.htm
[2] http://www.planalto.gov.br/ccivil_03/decreto/2003/d4887.htm
[3] http://www.palmares.gov.br/wp-content/uploads/2010/11/legis21.pdf

Section 7 – Brazil's National Transport System (SNV)

Section 7.1 – DNIT's SNV Highway Data

Highway Classification	Abbreviation in Spatial Data	Brief Notes	DNIT Definition	Assigned Category in Study
Planejada (Planned)	PLA	Planned – Not Constructed	"Rodovia que consta de um planejamento e cuja construção se acha em perspectiva. Rodovias fisicamente inexistentes, mas para as quais são previstos pontos de passagem que estabelecem uma diretriz destinada a atender uma demanda potencial de tráfego. Estes pontos de passagem não são obrigatórios até que a realização de estudos e/ou projetos estabeleçam o traçado definitivo da rodovia."	Planned
Leito Natural (Dirt Road)	LEN	Dirt Road – does not meet engineering, grading and curve geometry requirements	"Rodovia construída em primeira abertura, em terreno natural, sem atendimento às normas, podendo eventualmente receber revestimento primário. Rodovias que não atendem às normas rodoviárias de projeto geométrico, não se enquadrando, portanto em nenhuma das classes de rodovias estabelecidas pelo DNIT. Sua superfície de rolamento se apresenta no próprio terreno natural."	Dirt Road
Em Obras de Implantação (In construction phase to become a gravel road)	EOI	Planned or Existing Dirt Highways being constructed with Gravel finishing and meeting engineering, grading and curve geometry requirements.	"Assim devem ser considerados os trechos de rodovia planejada ou em leito natural em que se estejam executando serviços de Implantação, o trecho será designado como em obras de Implantação."	Dirt Road
Implantada (Gravel Road)	IMP	Engineered dirt or gravel roads that have subgrade material and meet grading and curve geometry requirements.	"Rodovias construídas de acordo com as normas rodoviárias de projeto geométrico e que se enquadram em determinada classe estabelecida pelo DNIT. Apresentam superfície de rolamento sem pavimentação. Estas rodovias normalmente apresentam sua superfície em revestimento primário e permitem tráfego o ano todo."	Dirt Road
Em Obras de Pavimentação (In construction phase to become a paved road)	EOP	An already existing gravel road that is in the process of being paved	"Assim devem ser considerados os trechos de rodovia implantada em que se estejam executando serviços de Pavimentação, o trecho será designado como em obras de Pavimentação."	2 – Lane Paved Road

Pavimentada (Paved Road – usually 2 lanes)	PAV	Paved 2 Lane Road	"Rodovia com revestimento superior. Rodovias implantadas que apresentam sua superfície com pavimento asfáltico, de concreto cimento ou de alvenaria poliédrica."	2 – Lane Highway
Em Obras de Duplicação (In the process of being converted into a 4-lane separated highway)	EOD	Under construction to become a 4 Lane separated with a median highway	"Assim devem ser considerados os trechos de rodovia pavimentada em que se estejam executando serviços de Duplicação, o trecho será designado como em obras de Duplicação."	4 – Lane Highway
Duplicada (4 – Lane Highway with Central Median)	DUP	Large Highways with 4 or more lanes with both directions divided by a central median	"Rodovias Duplicadas são aquelas formadas por duas pistas com duas ou mais faixas para cada sentido, separadas por canteiro central, por separador rígido ou ainda com traçados separados muitas vezes contornando obstáculos."	4 – Lane Highway

Table S 8 *- DNIT Highway Classification Found in the Current SNV System - Study Category Assignments* (DNIT, 2007, pp. 3–4)

<u>Section 7.2 – Explanation of how SNV data from DNIT was organized</u>

Highways in the SNV can be categorized as being under federal control or being under state or municipal control. Even though the SNV is the Federal Highway System, many of the highways in the SNV coincide with state highways and even in a few instances municipal controlled roadways. Therefore, when organizing the data for our analysis, first highways that were under federal control versus state or municipal control were separated, and then categorized into our 4 study categories separately (4-Lane, 2-Lane, Dirt, and Planned Highways). This was done because of DNIT (DNIT, 2018) spatial data's attribute category organization. For example, a highway that is under state control and its current physical form is a 4-Lane highway will be indicated in some attribute fields, whereas in the attribute fields related to federal categories it would likely still be categorized as a planned highway.

It is important to note that we believe the data contains some miss-classifications as we discovered that some of the highway features in the Amazon biome are not accurate. The largest suspected miss-classification involves a 182 kilometer stretch of the BR-210 in northwestern Pará (ending at the border with Roraima) that is classified as "existing gravel highway – Implantada – IMP" (DNIT, 2007, 2018). However, after visual examination with Google Earth Pro imagery (GOOGLE, 2018), Sentinal-2 imagery, and Landsat Imagery, and further comparison with IBGE and Open Street Map's road spatial data, we believe that this stretch of highway does not exist. Additionally, there is a stretch of the BR-163 (approximately 150 kilometers) in northwestern Pará that is classified as an "existing gravel highway – Implantada – IMP" (DNIT, 2007, 2018) which we believe is actually classified as an abandoned, half-finished, inaccessible dirt road in its current form. The "Implantada – IMP" designation means that the highway meets engineering, grading, and curve geometry standards. This second likely miss-classification is of concern as Brazil's federal government recently announced intentions to construct this stretch of highway and extend it to Brazil's border with Suriname (MONTEIRO; BORGES, 2019).

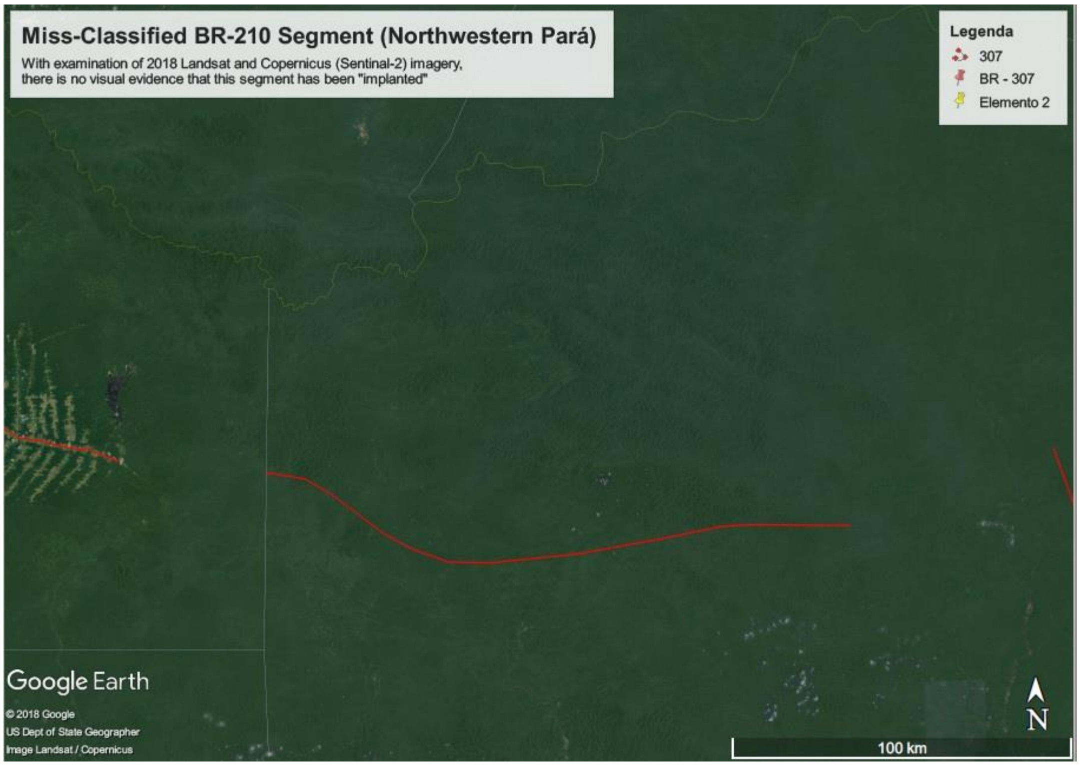

Figure S 4 - *Miss-Classified Portion of BR-210 on Pará-Roriama Border*

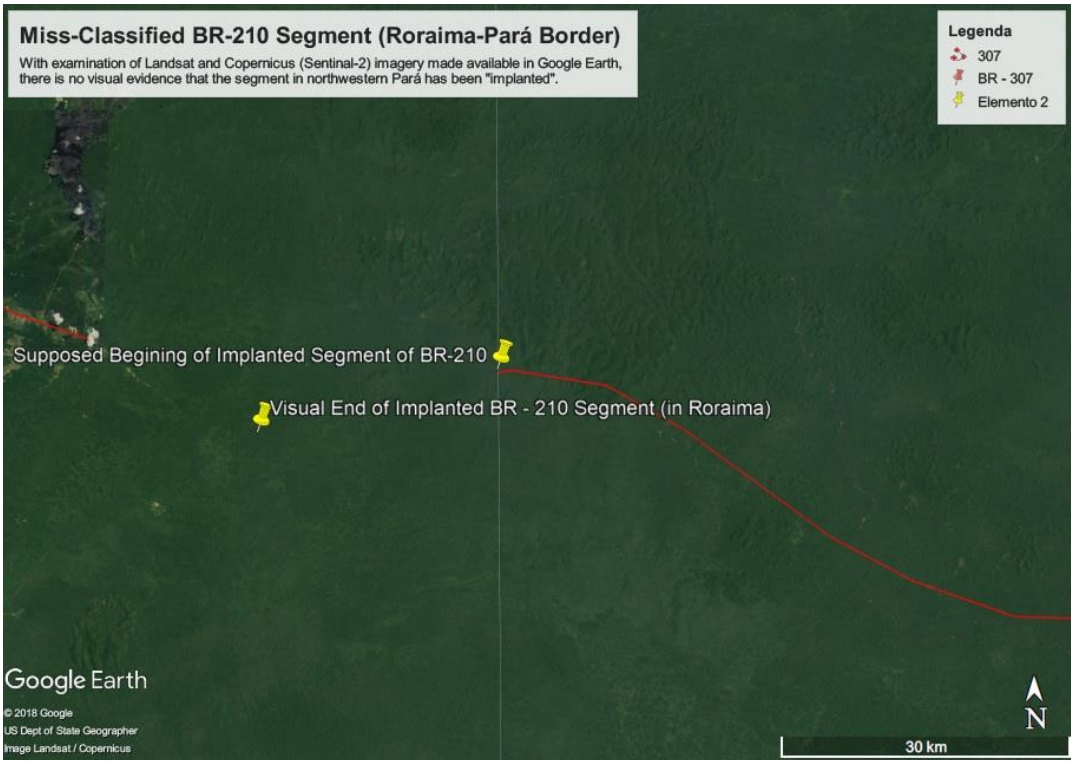

Figure S 5 - Miss-Classified Portion of BR-210 on Pará-Roriama Border (2)

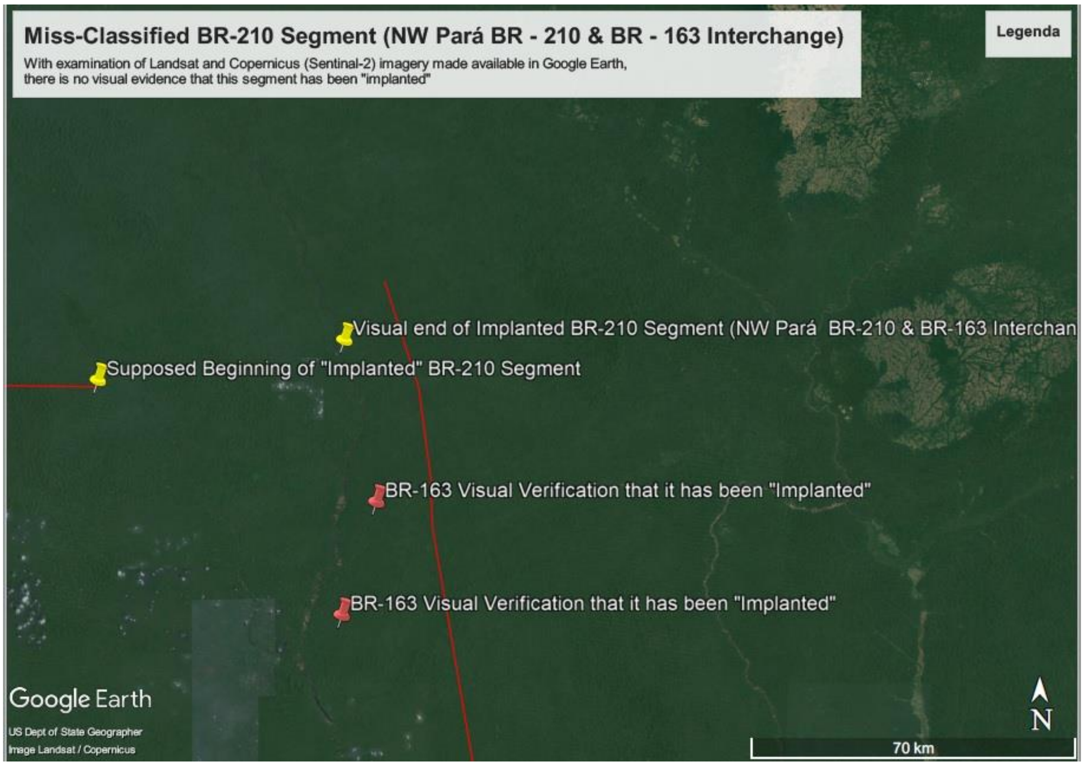

Figure S 6 - Miss-Classified Portion of BR-210 in Northwestern Pará

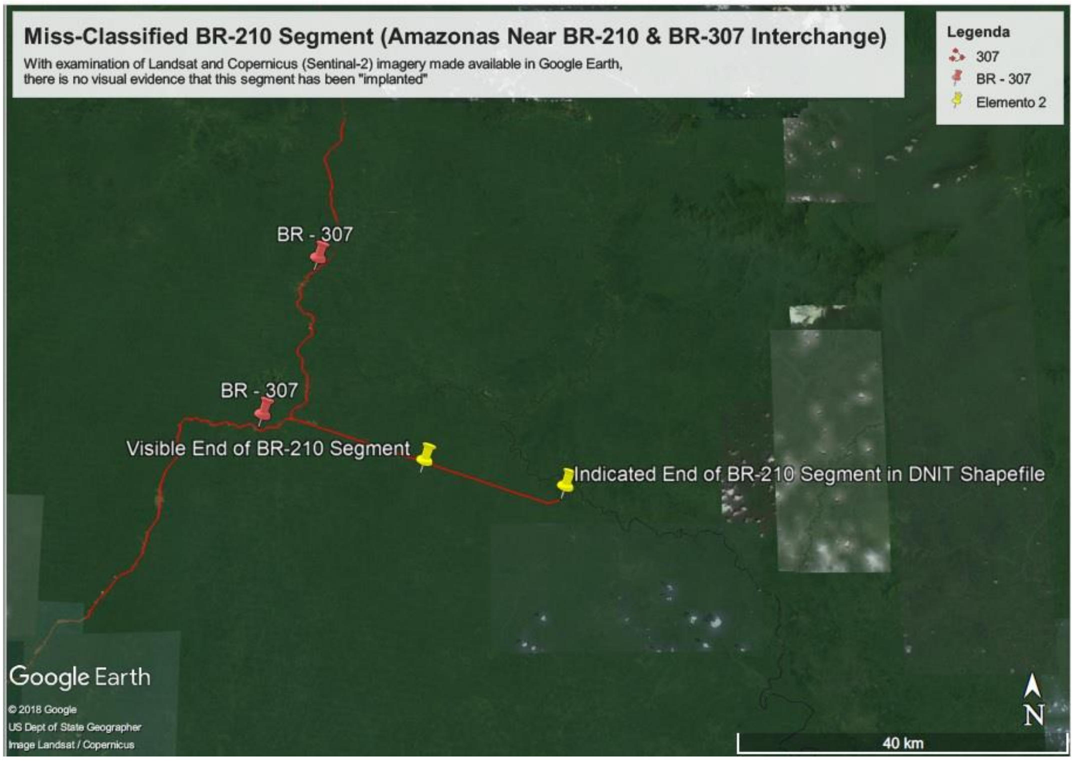

Figure S 7 - Miss-Classified Portion of BR-210 in Northwestern Amazonas

<u>Section 7.3 – Information about Categories for Brazil's SNV Railroads</u>

To investigate transportation policy in relation to federal railroads, we included data from MTPA's BIT representing the Federal Railway Subsystem (Subsistema Ferroviário Federal). Data for federal railroads was downloaded in October of 2018 (MTPA, 2018). From this data we classified Brazil's Federal Railroads into 2 categories: Existing Railroads (in operation, built but deactivated, built but operation status unknown, and in the process of construction), and Planned (planned and understudy). Both the highway and railroad subsystems are currently defined and called to be constructed by Federal Law 12,379 of January 6, 2011 (BRAZIL, 2011).

<u>Section 8 – Relevant Aichi Biodiversity Targets and Brazil's National Biodiversity Strategy Action Plan Targets</u>

<u>National Target Highlights from Brazil's NBSAP Submitted to the CBD</u>
(MMA, 2017)

<u>National Target 11</u>: By 2020, at least 30% of the Amazon, 17% of each of the other terrestrial biomes, and 10% of the marine and coastal areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through protected areas foreseen under the SNUC Law and other categories of officially protected areas such as Permanent Protection Areas, legal reserves, and indigenous lands with native vegetation, ensuring and respecting the demarcation, regularization, and effective and equitable management, so as to ensure ecological interconnection, integration and representation in broader landscapes and seascapes.

<u>National Target 14</u>: By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, traditional peoples and communities, indigenous peoples and local communities, and the poor and vulnerable.

<u>National Target 15</u>: By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced through conservation and restoration actions, including restoration of at least 15% of degraded ecosystems, prioritizing the most degraded biomes, hydrographic regions and ecoregions, thereby contributing to climate change mitigation and adaptation and to combatting desertification.

<u>National Target 17</u>: By 2014, the national biodiversity strategy is updated and adopted as policy instrument, with effective, participatory and updated action plans, which foresee periodic monitoring and evaluation.

<u>National Target 18</u>: By 2020, the traditional knowledge, innovations and practices of indigenous peoples, family rural producers and traditional communities relevant for the conservation and sustainable use of biodiversity, and their customary use of biological resources, are respected, in accordance with their uses, customs and traditions, national legislation and relevant international commitments, and fully integrated and reflected in the implementation of the CBD, with the full and effective participation of indigenous peoples, family rural producers and traditional communities, at all relevant levels.

Section 9 – Per Biome Maps of RLRL Areas

Section 9.1 – Atlantic Forest Biome's RLRL Areas

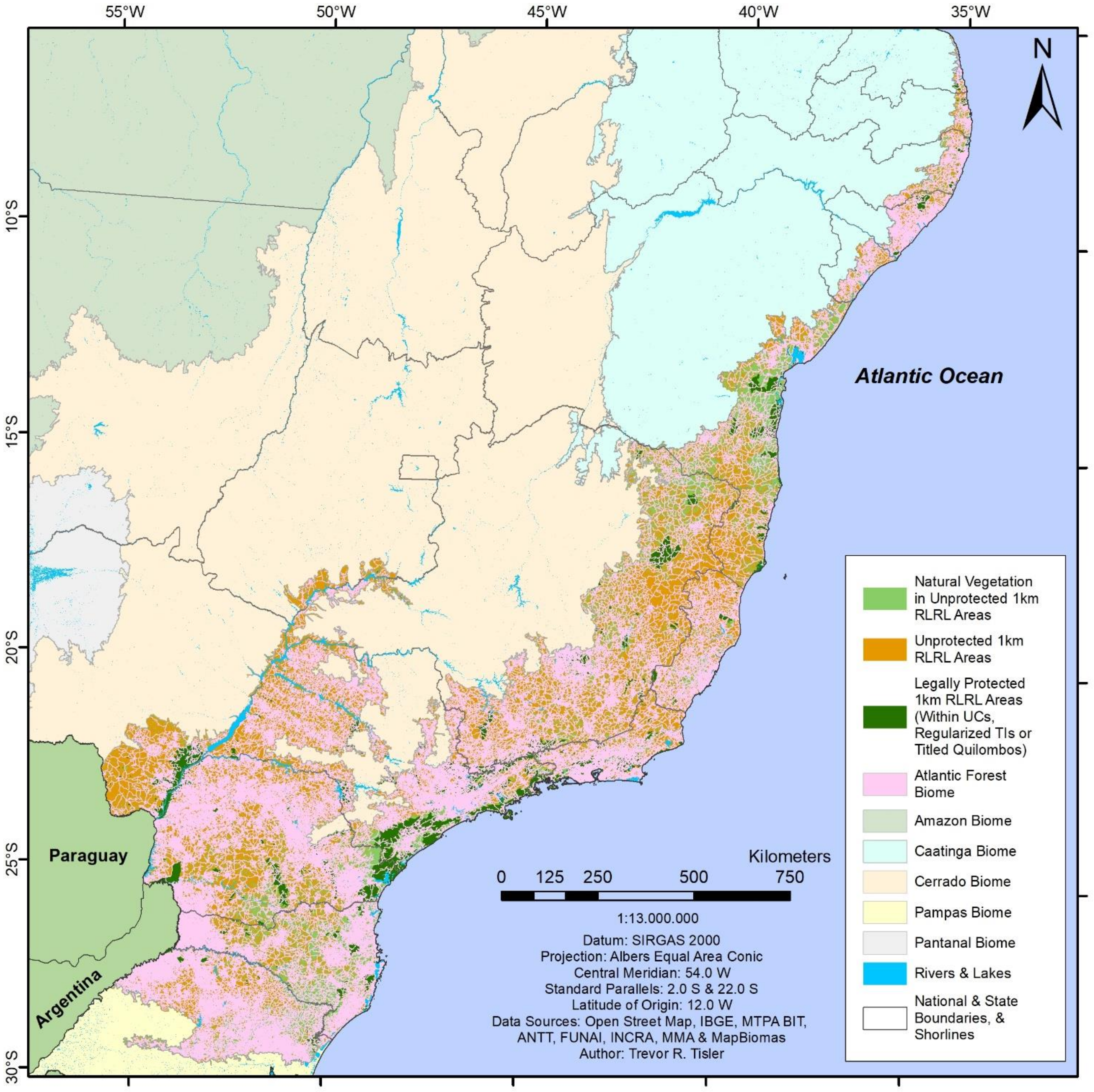

Figure S 8 - Atlantic Forest Biome's 1km RLRL Areas and Vegetation Coverage

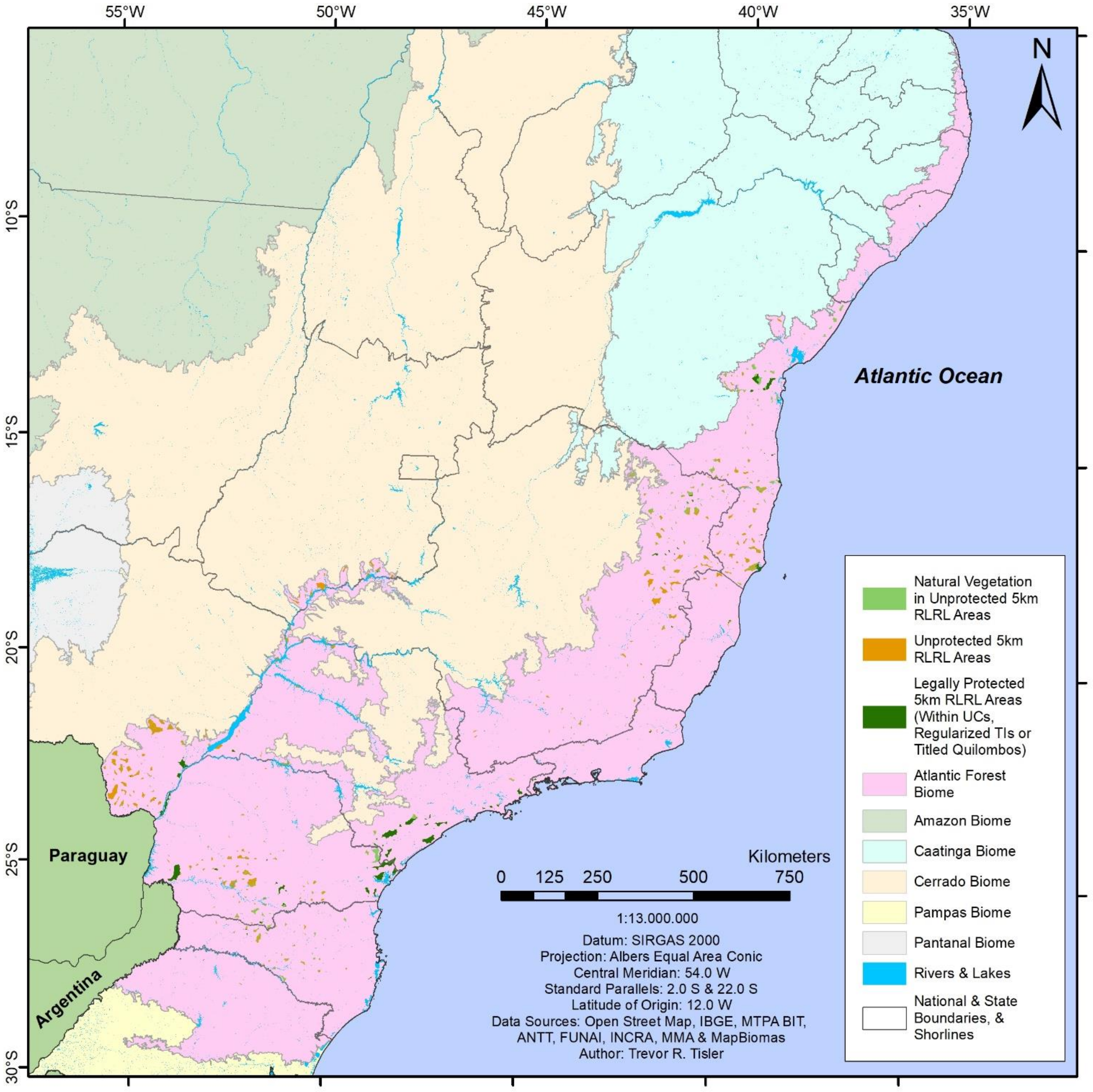

Figure S 9 - Atlantic Forest Biome's 5km RLRL Areas and Vegetation Coverage

Section 9.2 – Amazon Biome's RLRL Areas

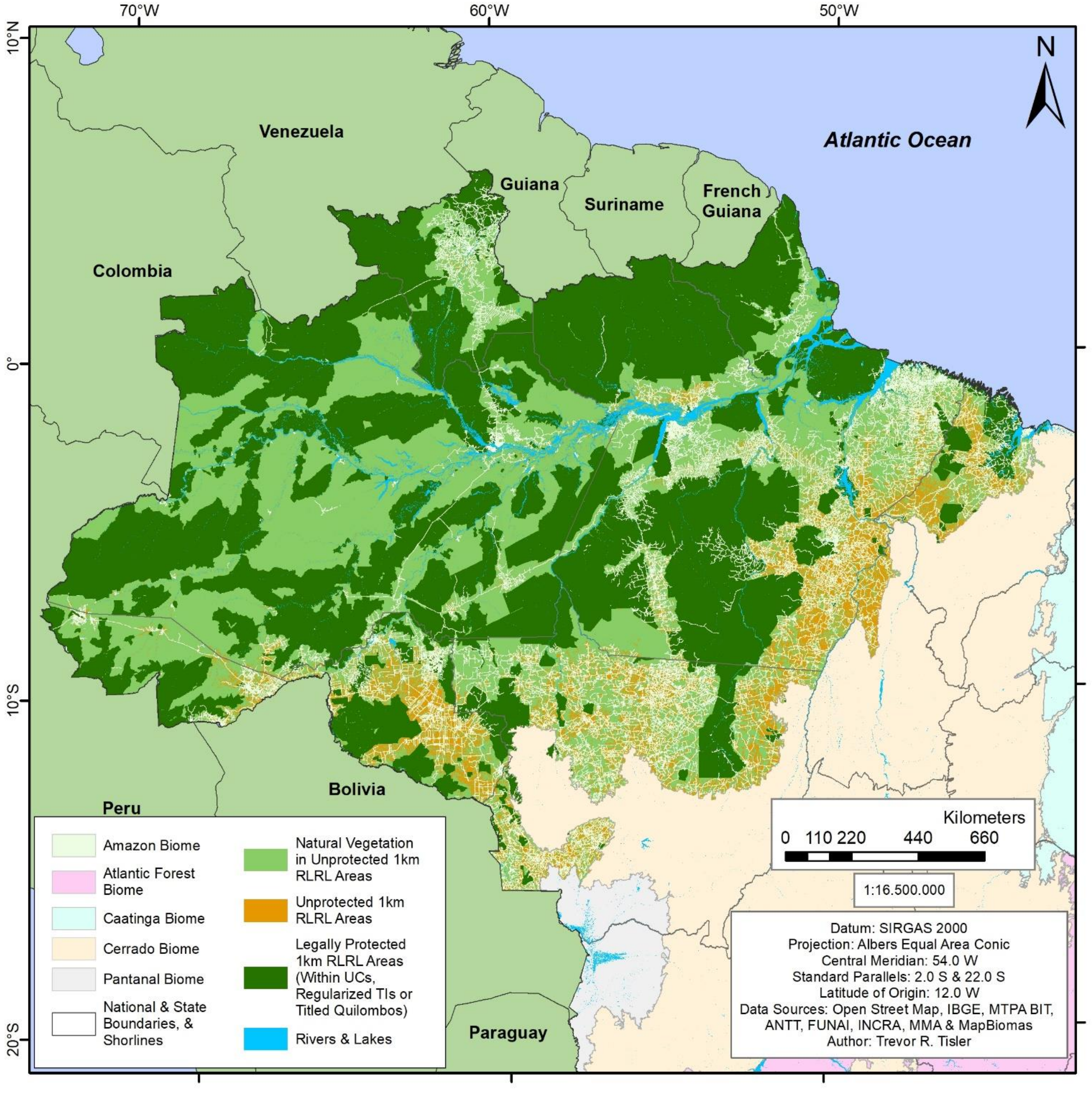

Figure S 10 - Amazon Biome's 1km RLRL Areas and Vegetation Coverage

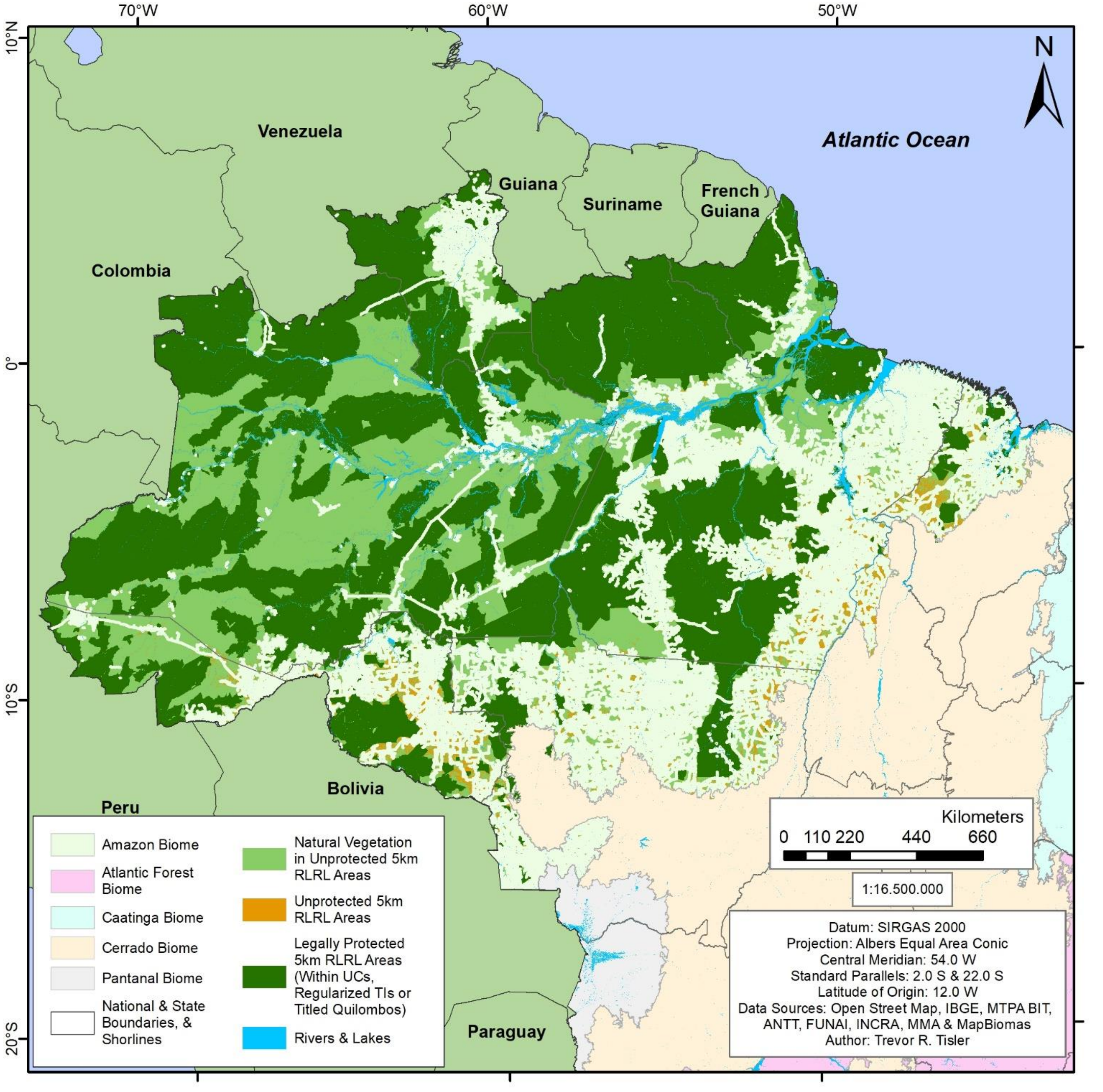

Figure S 11 - Amazon Biome's 5km RLRL Areas and Vegetation Coverage

Section 9.3 – Caatinga Biome's RLRL Areas

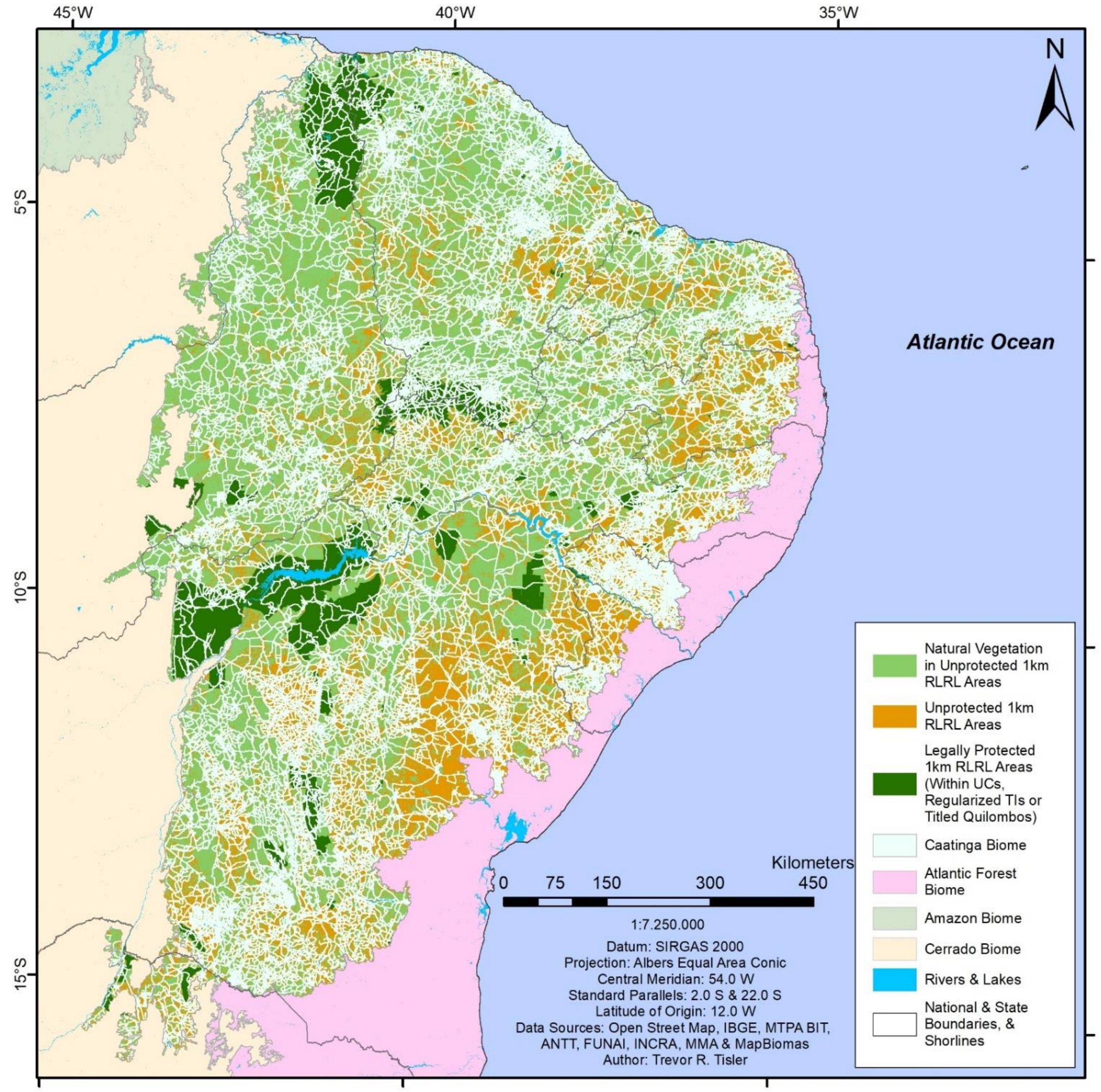

Figure S 12 - Caatinga Biome's 1km RLRL Areas and Vegetation Coverage

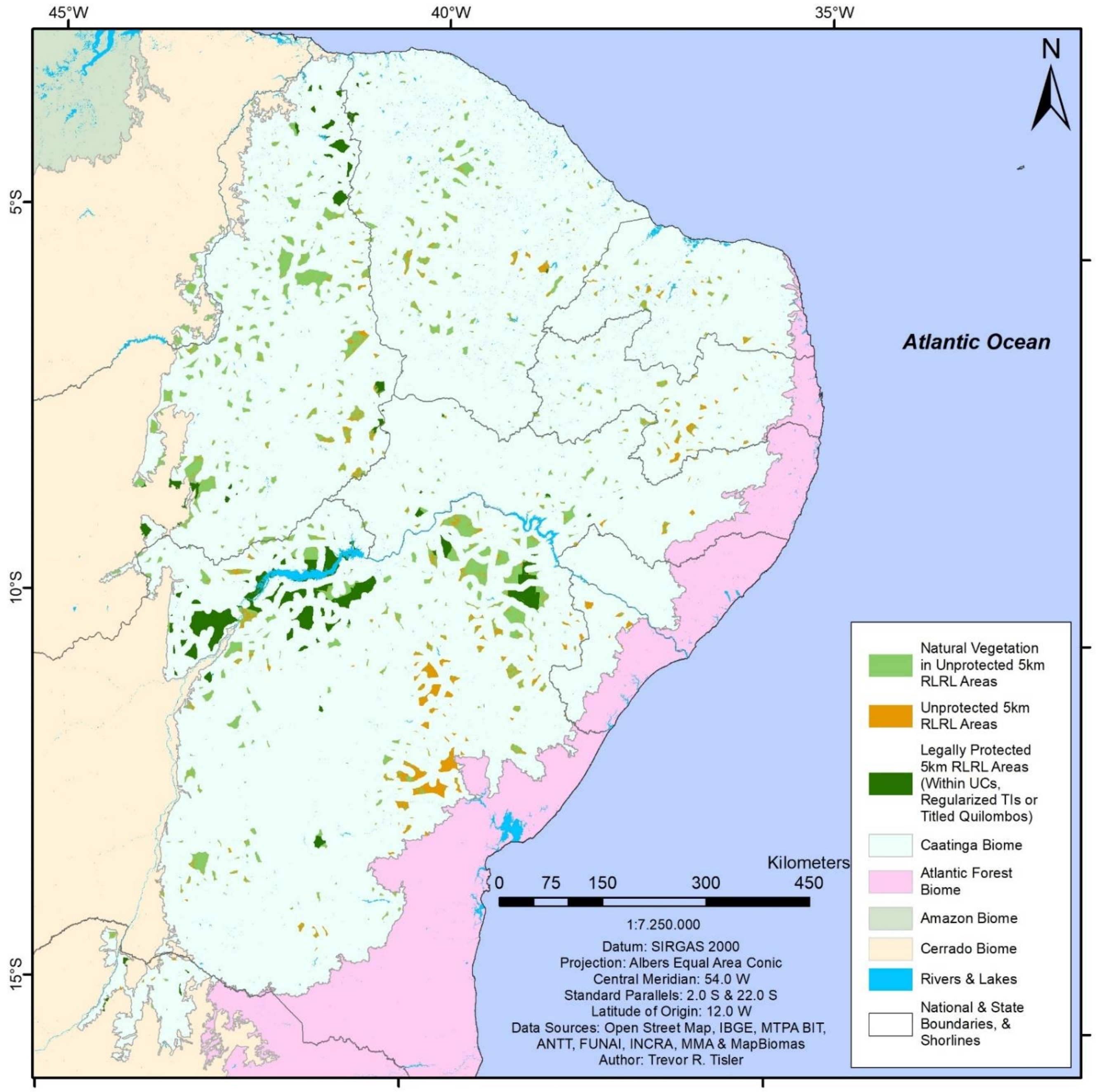

Figure S 13 - Caatinga Biome's 5km RLRL Areas and Vegetation Coverage

Section 9.4 – Cerrado Biome's RLRL Areas

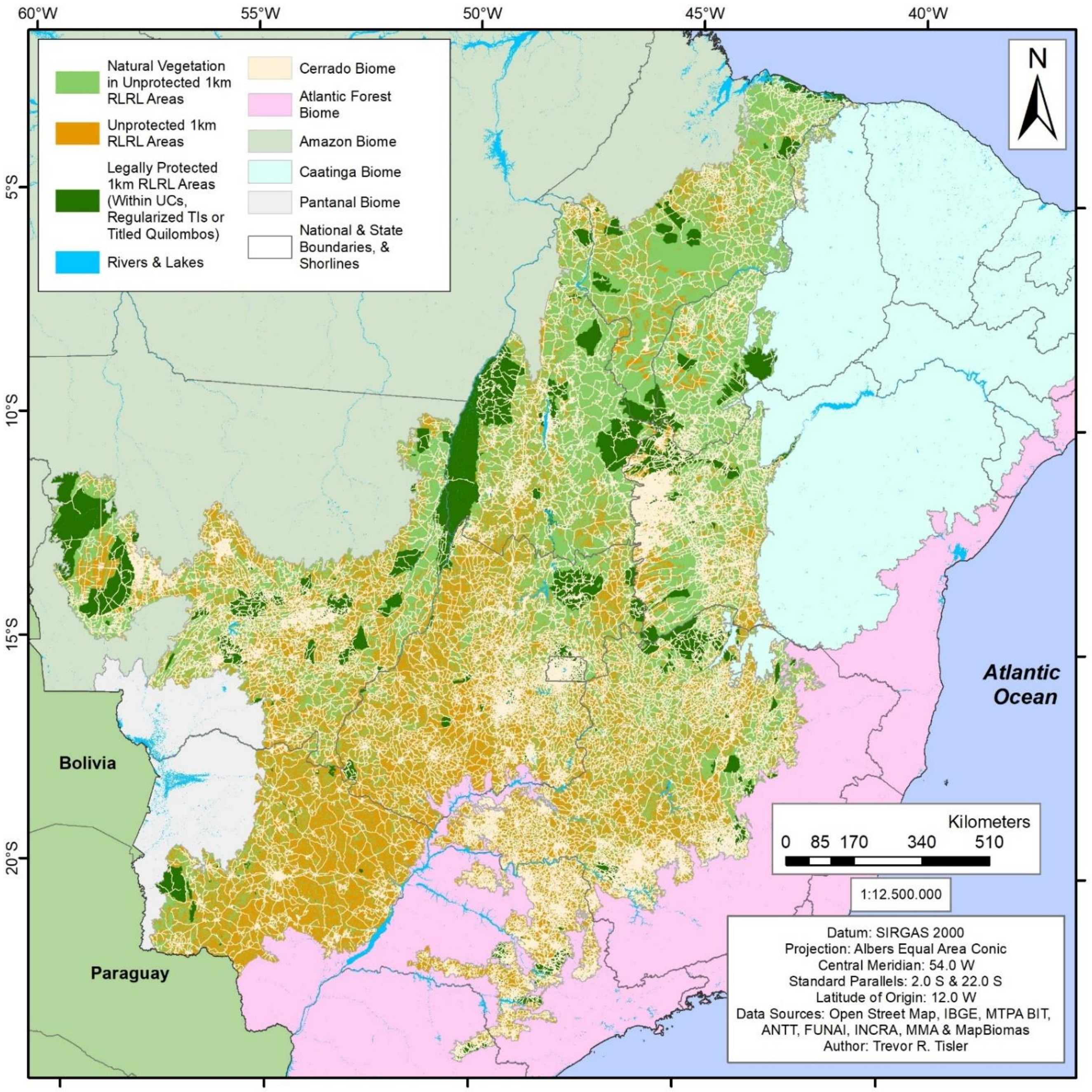

Figure S 14 - Cerrado Biome's 1km RLRL Areas and Vegetation Coverage

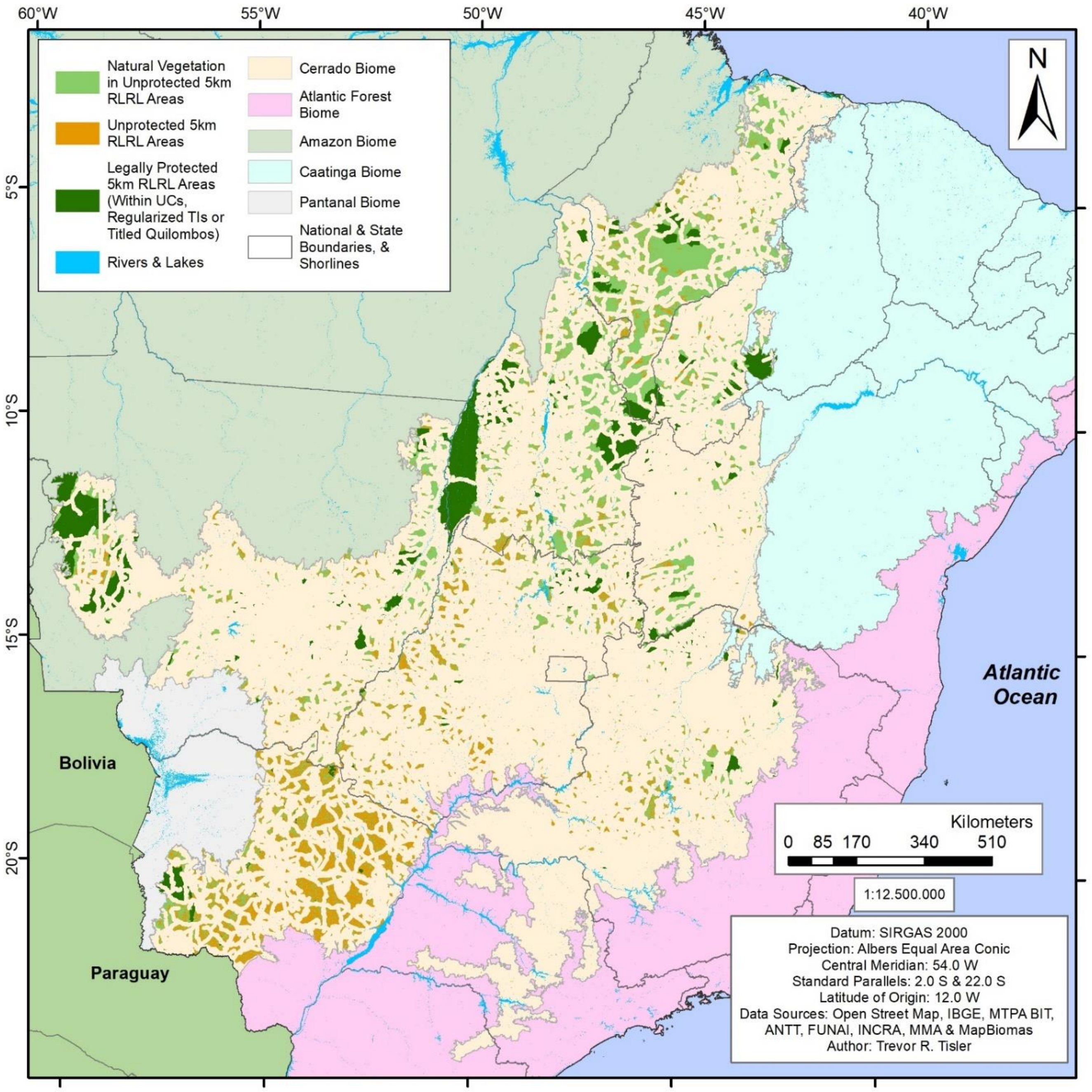

Figure S 15 - Cerrado Biome's 5km RLRL Areas and Vegetation Coverage

Section 9.5 – The Pampas Biome's RLRL Areas

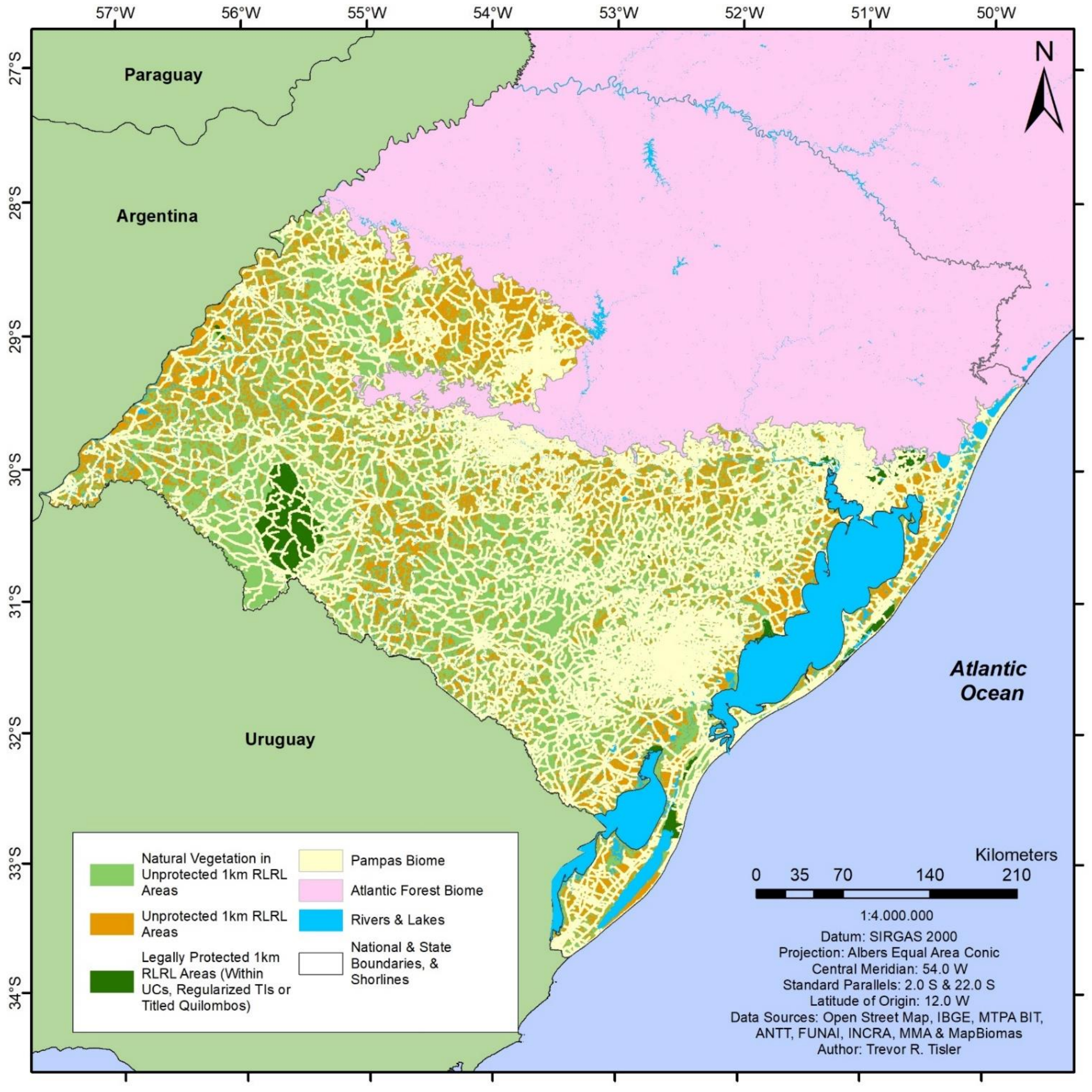

Figure S 16 - The Pampas Biome's 1km RLRL Areas and Vegetation Coverage

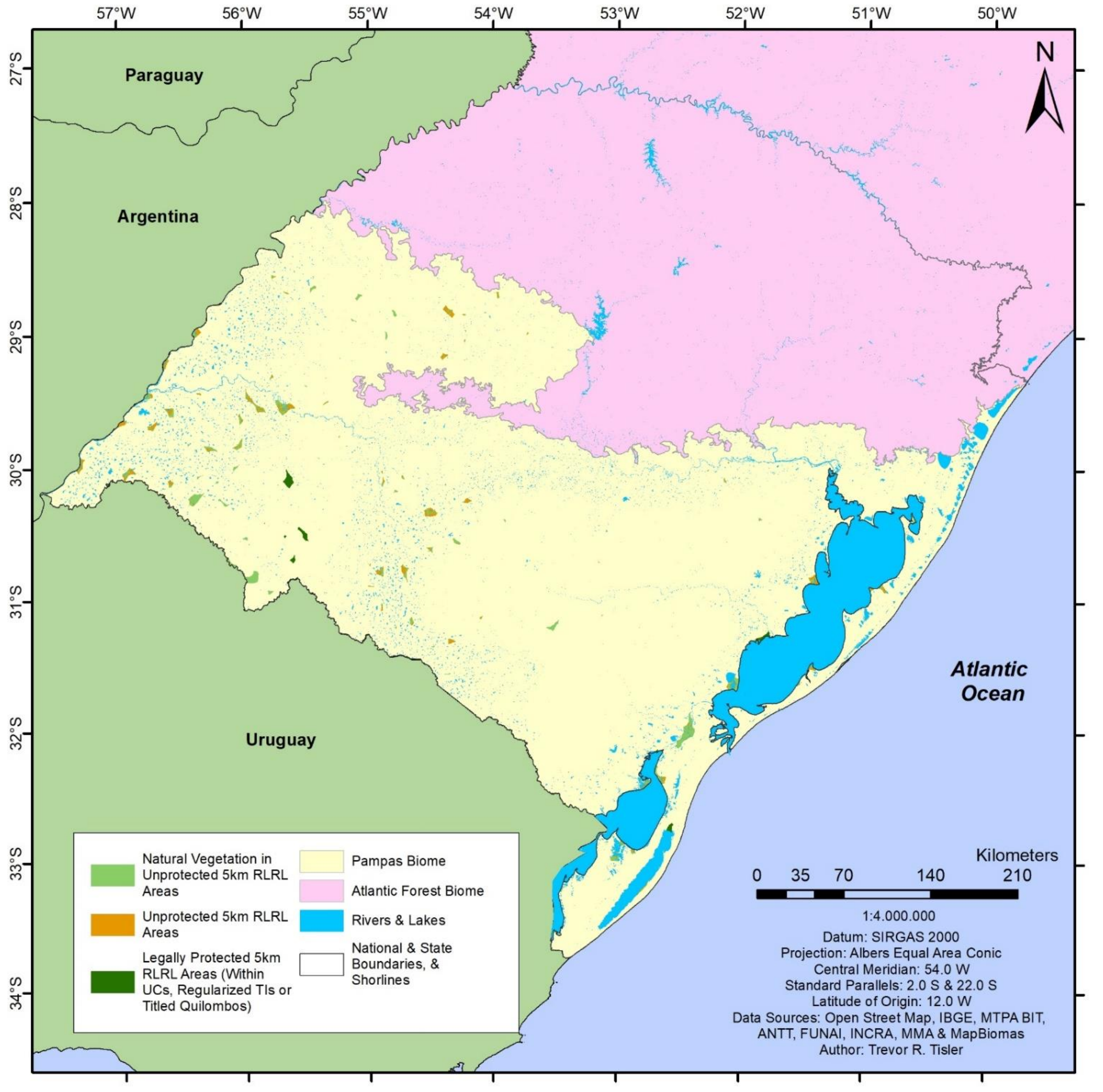

Figure S 17 - The Pampas Biome's 5km RLRL Areas and Vegetation Coverage

Section 9.6 – Pantanal Biome's RLRL Areas

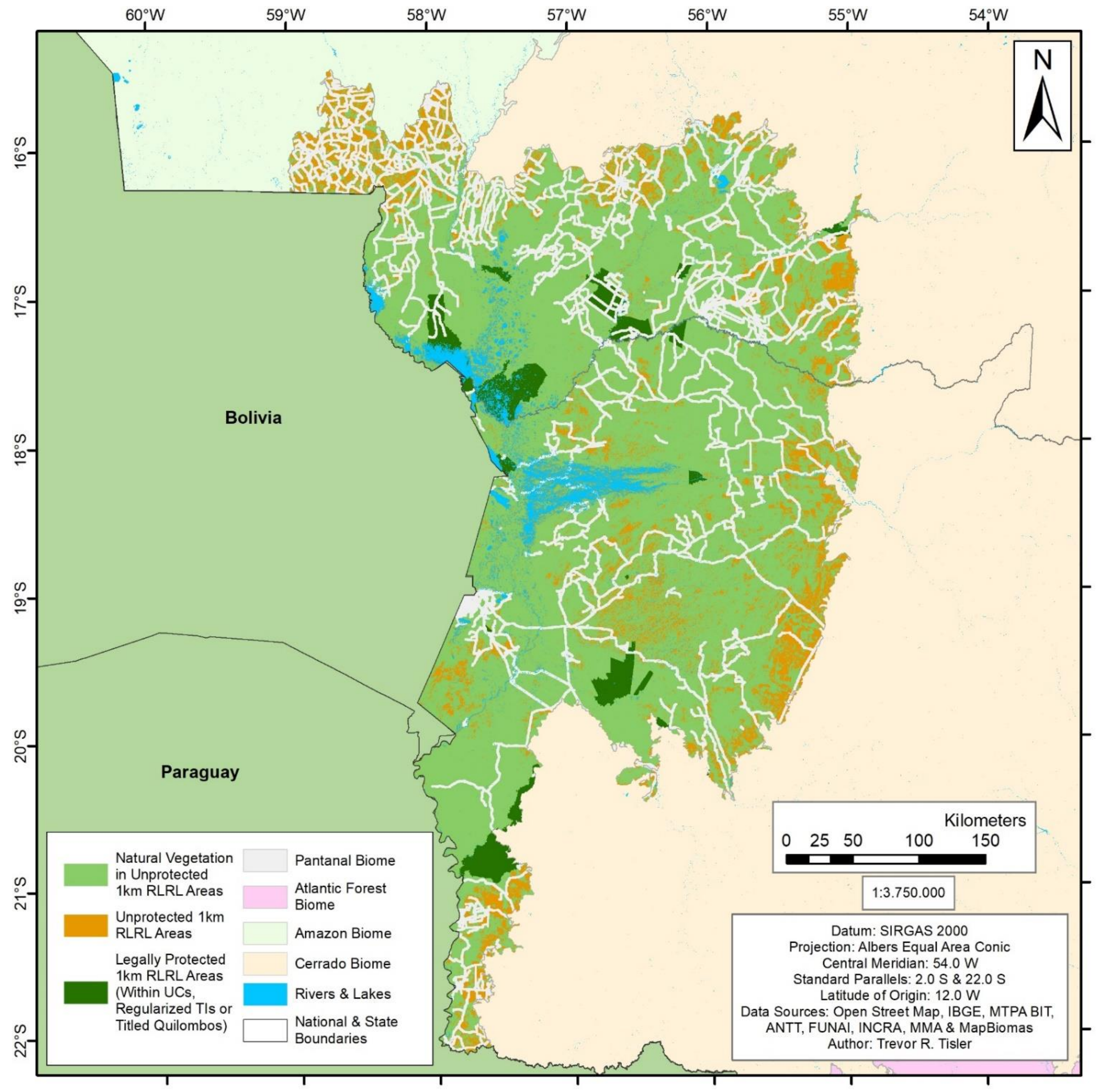

Figure S 18 - Pantanal Biome's 1km RLRL Areas and Vegetation Coverage

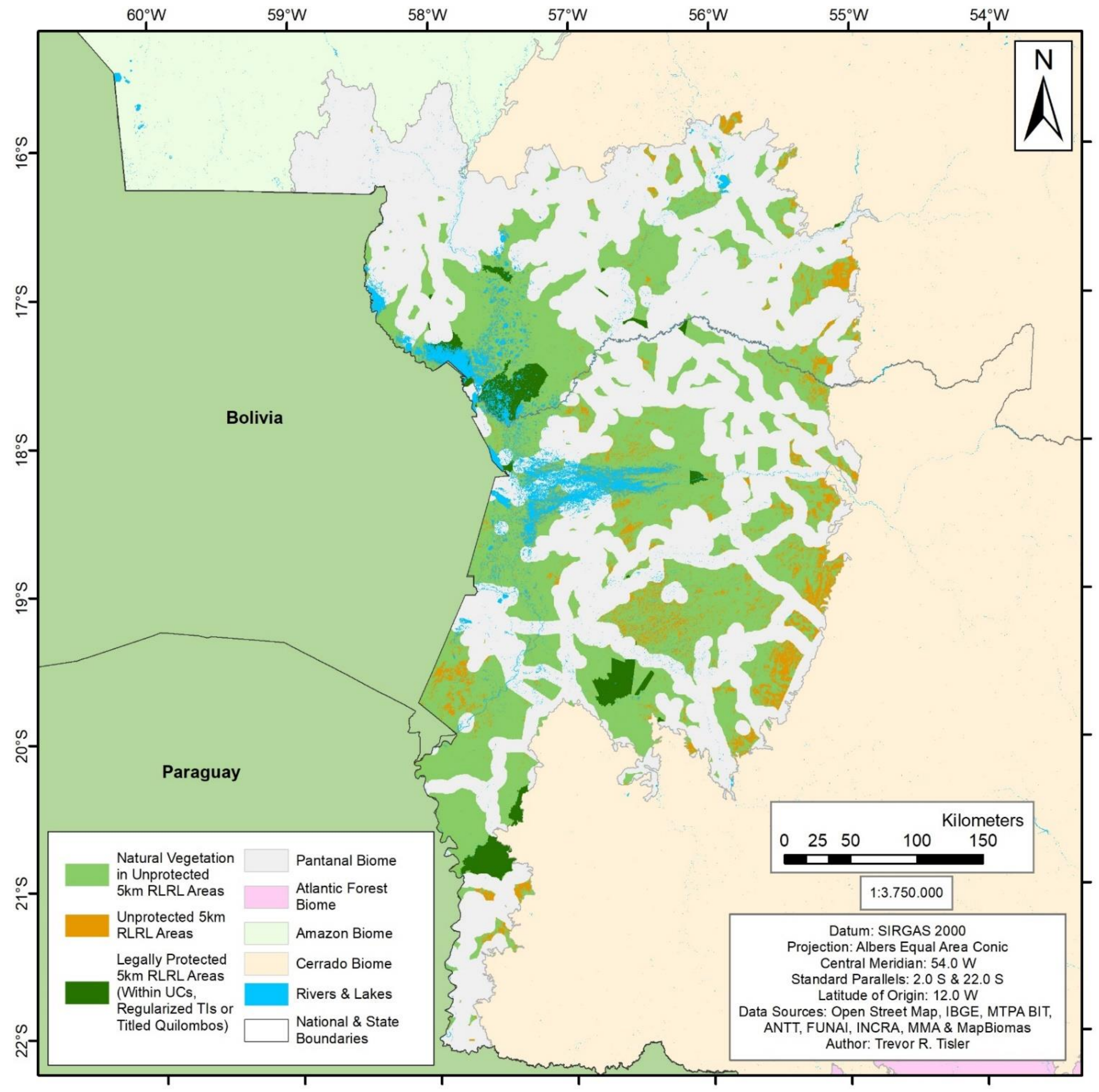

Figure S 19 - Pantanal Biome's 5km RLRL Areas and Vegetation Coverage

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Annex – Section 6.2 - Supplemental Material for Chapter 3

Supplemental Material for: The Brazilian Amazon's Social Cost of Carbon

Section 1 – Spatial Data for Creating the Brazilian Amazon SCC CO_2 equivalent stock

Main ES Value	Input Variable Types for Final Individual ES Value Map	Notes	Bibliographic Source
Social Cost of Carbon	Economic Value Estimate ton of CO_2	Calculated Value Estimate from Source Authors	(NORDHAUS, 2017; RICKE et al., 2018; STERN, 2006)
	Biomass Carbon to CO_2 conversion Factor	IPCC assigned constant value of 3.667 for conversion of GigaTonnes of C to GigaTonnes of CO_2 **1 GtC = 3.667 GtCO2**	(IPCC, 2013, p. 12)
	Above Ground Carbon Estimates	Raster Layer from Authors showing Above Ground Carbon Estimates of Tons per Hectare **MegaGrams per Hectare – (Mg/Ha) = 1 Mg = 1 Tonne**	(WHRC, 2012) & (BACCINI et al., 2012)
	Below Ground Biomass	IPCC assigned constant value of 0.37 for below ground biomass of above ground biomass **1 MG = 1 Tonne**	(IPCC, 2006)
	Soil Organic Carbon	Raster Layers from EMBRAPA from 0 to 30 cm below ground **Tonnes/Ha = MG/HA**	(VASQUES et al., 2017)
	2017 Forested Areas	Raster Layer Values for Identified Forest Formations	(VASQUES et al., 2017)

<u>Section 2 – Sources for SCC Estimates, based on Economic IAMs</u>

Source	Value Metrics	USD 2017 Value of SCC of CO_2 Equivalent based on Inflation Correction and Estimate's Defined Discount Rate
Worldwide Total Net Economic Impact of emissions per each tonne of CO_2 in 2017		
Nordhaus (2017) - ***Revisiting the social cost of carbon*** (Global total)	4% Discount Rate, originally estimated in 2010 USD (12.4% inflation rate between 2010 and 2017)	$ 37.93
Stern (2006) - ***The Economics of Climate Change: The Stern Review*** (Global Total)	2.5% Fixed Discount Rate	$ 151.75
Stern (2006) - ***The Economics of Climate Change: The Stern Review*** (Global Total)	5.0% Fixed Discount Rate	$ 24.41
Ricke et al. (2018) - ***Country-level social cost of carbon*** (Average Global Total – 3% Fixed Discount Rate)	SSP2/RCP60 Scenario - 3% Fixed Discount Rate, originally estimated in 2010 USD (12.4% inflation rate between 2010 and 2017)	$ 406.00
Ricke et al. (2018) - ***Country-level social cost of carbon*** (High Bound Global SCC - 3% Fixed Discount Rate)	SSP2/RCP60 Scenario - 3% Fixed Discount Rate, originally estimated in 2010 USD (12.4% inflation rate between 2010 and 2017)	$ 657.00
Ricke et al. (2018) - ***Country-level social cost of carbon*** (Low Bound Global SCC - 3% Fixed Discount Rate)	SSP2/RCP60 Scenario - 3% Fixed Discount Rate, originally estimated in 2010 USD (12.4% inflation rate between 2010 and 2017)	$ 31.00
Latin America/Brazilian Total Net Economic Impact of emissions per each tonne of CO_2 in 2017		
Nordhaus (2017) - ***Revisiting the social cost of carbon*** (Latin America)	4% Discount Rate, originally estimated in 2010 USD (12.4% inflation rate between 2010 and 2017)	$ 2.27
Ricke et al. (2018) - ***Country-level social cost of carbon*** (Average Brazilian Total – 3% Fixed Discount Rate)	Brazilian only SCC estimate with SSP2/RCP60 Scenario - 3% Fixed Discount Rate, originally estimated in 2010 USD (12.4% inflation rate between 2010 and 2017)	$ 22.60
Ricke et al. (2018) - ***Country-level social cost of carbon*** (High Bound Brazilian SCC - 3% Fixed Discount Rate)	Brazilian only SCC estimate with SSP2/RCP60 Scenario - 3% Fixed Discount Rate, originally estimated in 2010 USD (12.4% inflation rate between 2010 and 2017)	$ 26.80
Ricke et al. (2018) - ***Country-level social cost of carbon*** (Low Bound Brazilian SCC - 3% Fixed Discount Rate)	Brazilian only SCC estimate with SSP2/RCP60 Scenario - 3% Fixed Discount Rate, originally estimated in 2010 USD (12.4% inflation rate between 2010 and 2017)	$ 18.50

* All original 2010 SCC estimates had their added interest accumulation added for the time between 2010 and 2017. Then 2010 USD value estimates for 2017 were converted into 2017 USD. Nordhaus (2017) had already converted Stern (2006) value estimates to 2010 USD values. These value estimates were converted using an inflation rate adjustment of 12.4% between 2010 and 2017.

Section 3 – Differentiating between the different "Amazons" that environmental economist have miss understood

Figure 1A: Brazil's Biogeographical Amazon Biome and South America's Continental Biogeographical Amazon Biome

Figure 1B: Brazil's Biogeographical Amazon Biome compared to: Brazil's Legal Amazon, the Amazon River's Catchment Basin and South America's Continental Biogeographical Amazon Biome

Section 4 – Flow chart for Calculating Original Extent of Brazilian Amazon

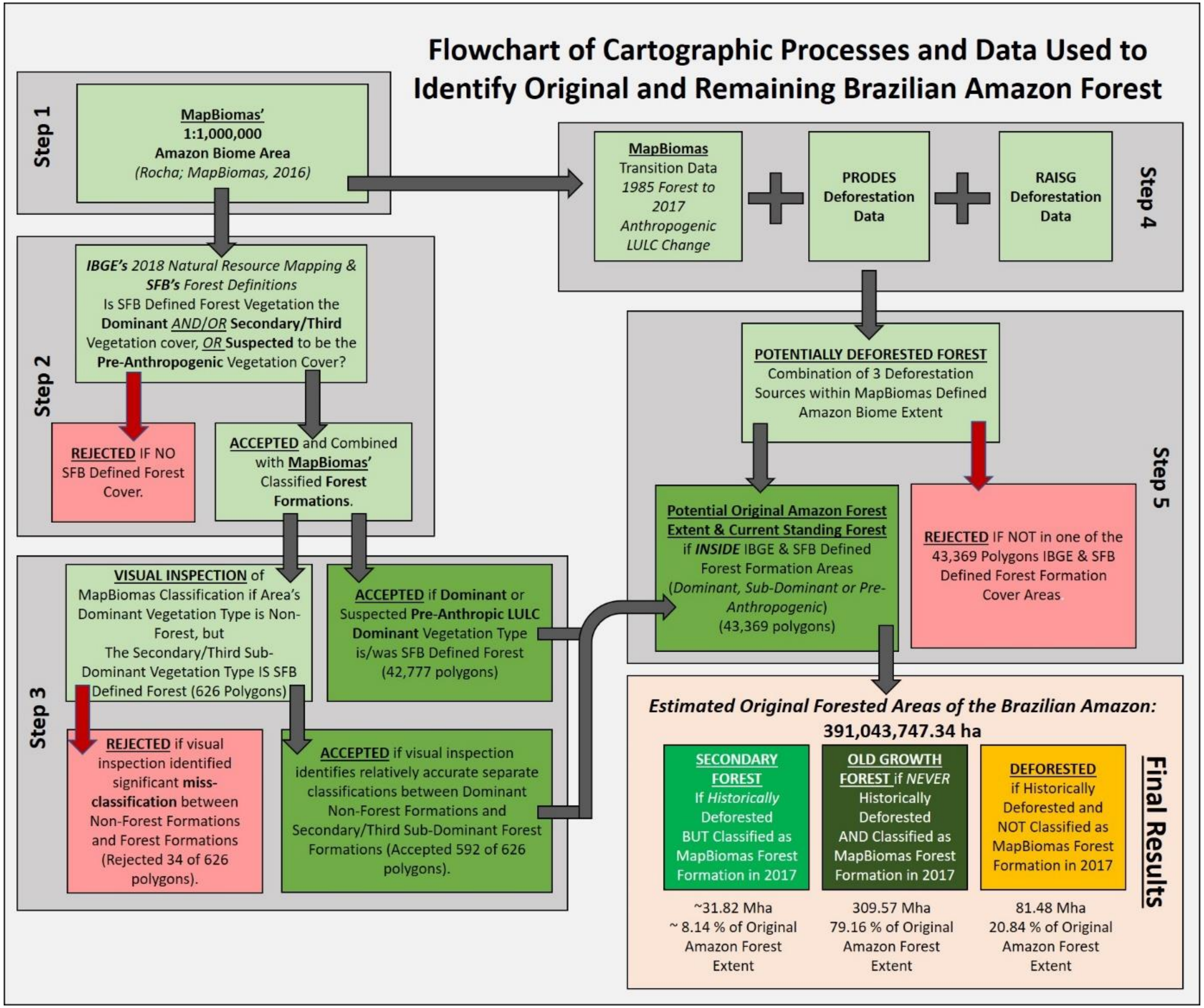

Figure 2 – Primary Forest Identification Flow Chart – Data Sources: (IBGE, 2018; INPE, 2018; PROJECT MAPBIOMAS, 2018; RAISG, 2015). Based on spatial data with a 100 by 100-meter resolution

Section 5 – Iterations to Find the W value of Euclidean Distance from all Roads and Railroads

Forest Layers	Area in ha (based on 100-meter resolution raster)	Pecentage of Original Extent	Total Tonnes of Carbon	Total CO2 Equivalent (tonnes of CO_2 Equivalent (Conversion Factor 1 tonne Carbon = 3.667 tonnes CO_2) (Source: IPCC, 2013)
Original 'Legal' Forest Extent	398,096,167.39	100.00%	--	--
Estimated All Remaining Forests (Primary and Secondary*)	341,402,893.00	85.76%	138,889,260,037.72	509,306,916,558.31
All "Legal" Secondary Forests	31,824,677.00	7.99%	8,054,789,666.19	29,536,913,705.93
All 'Legal' Primary Forests	309,578,216.00	77.76%	130,834,470,371.53	479,770,002,852.39
Primary Forests in 1km RLRLs	297,324,685.00	74.69%	126,757,459,066.01	464,819,602,395.07
Primary Forests in 2km RLRLs	283,422,107.00	71.19%	121,938,294,059.63	447,147,724,316.67
Primary Forests in 2.5km RLRLs	277,300,190.00	69.66%	119,737,797,443.98	439,078,503,227.06
Primary Forests in 3km RLRLs	272,303,189.00	68.40%	117,910,819,910.16	432,378,976,610.54
Primary Forests in 4km RLRLs	263,004,610.00	66.07%	114,442,276,185.11	419,659,826,770.80
Primary Forests in 4.5km RLRLs	259,041,171.00	65.07%	112,927,433,864.50	414,104,899,981.14
Primary Forests in 5km RLRLs	255,339,173.00	64.14%	111,518,538,955.84	408,938,482,351.05
Primary Forests in 6km RLRLs	248,830,238.00	62.51%	108,996,966,510.91	399,691,876,195.52
Primary Forests in 7km RLRLs	242,871,159.00	61.01%	106,657,807,860.86	391,114,181,425.76
Primary Forests in 8km RLRLs	237,486,462.00	59.66%	104,520,408,338.97	383,276,337,379.02
Primary Forests in 9km RLRLs	232,624,401.00	58.43%	102,569,542,079.13	376,122,510,804.18
Primary Forests in 10km RLRLs	227,929,763.00	57.25%	100,658,940,052.34	369,116,333,171.93
Primary Forests in 11km RLRLs	223,483,762.00	56.14%	98,844,455,876.03	362,462,619,697.40
Primary Forests in 12km RLRLs	219,292,853.00	55.09%	97,124,324,259.73	356,154,897,060.42

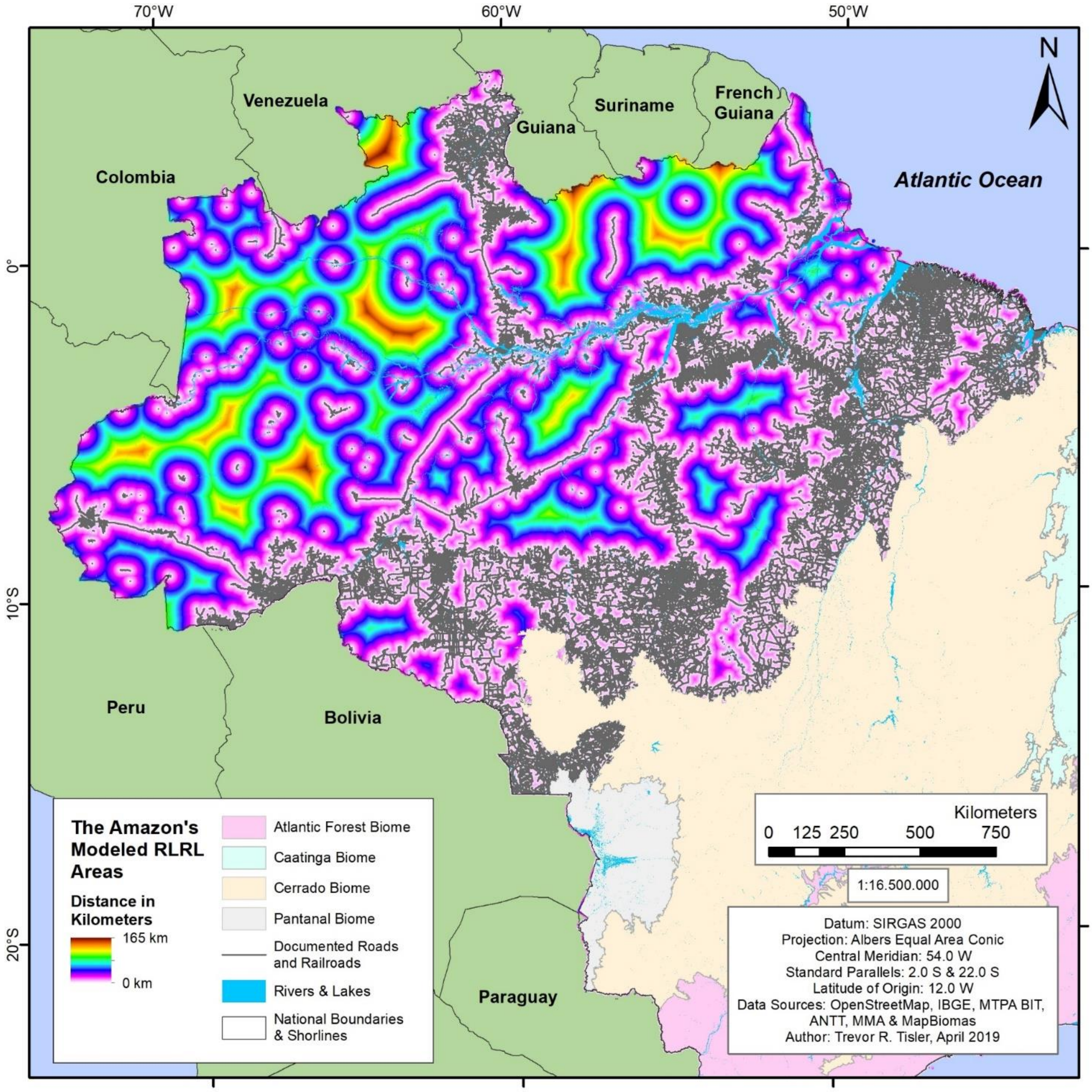

Figure 3 - Euclidean Distance Raster to aid in Calculating **W** in SCC Equation

Section 6 – Brazilian Amazon Specific Non-Transfer Benefit Derived Ecosystem Service Valuation Estimates Literature Review

Section 6.1 – Scopus database for non-transfer benefit derived ecosystem service valuation estimates for the Brazilian Amazon

Number	Authors	Title	Year	Source title	Volume	Issue	DOI
1	Strand J., Soares-Filho B., Costa M.H., Oliveira U., Ribeiro S.C., Pires G.F., Oliveira A., Rajão R., May P., van der Hoff R., Siikamäki J., da Motta R.S., Toman M.	Spatially explicit valuation of the Brazilian Amazon Forest's Ecosystem Services	2018	Nature Sustainability	1	11	10.1038/s41893-018-0175-0
2	Le Clec'h S., Sloan S., Gond V., Cornu G., Decaens T., Dufour S., Grimaldi M., Oszwald J.	Mapping ecosystem services at the regional scale: the validity of an upscaling approach	2018	International Journal of Geographical Information Science	32	8	10.1080/13658816.2018.1445256
3	Carvalho Ribeiro S.M., Soares Filho B., Leles Costa W., Bachi L., Ribeiro de Oliveira A., Bilotta P., Saadi A., Lopes E., O'Riordan T., Lôbo Pennacchio H., Queiroz L., Hecht S., Rajão R., Oliveira U., Cioce Sampaio C.	Can multifunctional livelihoods including recreational ecosystem services (RES) and non timber forest products (NTFP) maintain biodiverse forests in the Brazilian Amazon?	2018	Ecosystem Services	31		10.1016/j.ecoser.2018.03.016
4	Le Clec'h S., Jégou N., Decaens T., Dufour S., Grimaldi M., Oszwald J.	From Field Data to Ecosystem Services Maps: Using Regressions for the Case of Deforested Areas Within the Amazon	2018	Ecosystems	21	2	10.1007/s10021-017-0145-9
5	Schwartz G., Pereira P.C.G., Siviero M.A., Pereira J.F., Ruschel A.R., Yared J.A.G.	Enrichment planting in logging gaps with Schizolobium parahyba var. amazonicum (Huber ex	2017	Forest Ecology and Management	390		10.1016/j.foreco.2017.01.031

		Ducke) Barneby: A financially profitable alternative for degraded tropical forests in the Amazon					
6	Krause T., Ness B.	Energizing agroforestry: Ilex guayusa as an additional commodity to diversify amazonian agroforestry systems	2017	International Journal of Biodiversity Science, Ecosystem Services and Management	13	1	10.1080/21513732.2017.1303646
7	Dias T.C.A.C., Cunha A.C., Silva J.M.C.	Return on investment of the ecological infrastructure in a new forest frontier in Brazilian Amazonia	2016	Biological Conservation	194		10.1016/j.biocon.2015.12.016
8	Tremblay S., Lucotte M., Revéret J.-P., Davidson R., Mertens F., Passos C.J.S., Romaña C.A.	Agroforestry systems as a profitable alternative to slash and burn practices in small-scale agriculture of the Brazilian Amazon	2015	Agroforestry Systems	89	2	10.1007/s10457-014-9753-y
9	Schwartzman S., Boas A.V., Ono K.Y., Fonseca M.G., Doblas J., Zimmerman B., Junqueira P., Jerozolimski A., Salazar M., Junqueira R.P., Torres M.	The natural and social history of the indigenous lands and protected areas corridor of the Xingu River basin	2013	Philosophical Transactions of the Royal Society B: Biological Sciences	368	1619	10.1098/rstb.2012.0164
10	Stickler C.M., Nepstad D.C., Azevedo A.A., McGrath D.G.	Defending public interests in private lands: Compliance, costs and potential environmental consequences	2013	Philosophical Transactions of the Royal Society B: Biological Sciences	368	1619	10.1098/rstb.2012.0160

		of the Brazilian Forest Code in Mato Grosso					
11	Ahmed S.E., Ewers R.M.	Spatial pattern of standing timber value across the Brazilian Amazon	2012	PLoS ONE	7	5	10.1371/journal.pone.0036099
12	Mann M.L., Kaufmann R.K., Bauer D.M., Gopal S., Baldwin J.G., Del Carmen Vera-Diaz M.	Ecosystem Service Value and Agricultural Conversion in the Amazon: Implications for Policy Intervention	2012	Environmental and Resource Economics	53	2	10.1007/s10640-012-9562-6
13	Klemick H.	Shifting cultivation, forest fallow, and externalities in ecosystem services: Evidence from the Eastern Amazon	2011	Journal of Environmental Economics and Management	61	1	10.1016/j.jeem.2010.07.003
14	Stickler C.M., Nepstad D.C., Coe M.T., McGrath D.G., Rodrigues H.O., Walker W.S., Soares-Filho B.S., Davidson E.A.	The potential ecological costs and cobenefits of REDD: A critical review and case study from the Amazon region	2009	Global Change Biology	15	12	10.1111/j.1365-2486.2009.02109.x
15	Costanza R., Voinov A.	Modeling ecological and economic systems with STELLA: Part III	2001	Ecological Modelling	143	2-Jan	10.1016/S0304-3800(01)00358-1

Section 6.2 – TEEB database for non-transfer benefit derived ecosystem service valuation estimates for the Brazilian Amazon

Authors	Year Of Publication	Title	Full reference
Godoy, R., R. Lubowski, and A. Markandya	1993	A method for the economic valuation of non-timber tropical forest products. Economic Botany 47(3): 220-233.	Godoy, R., R. Lubowski, and A. Markandya (1993) A method for the economic valuation of non-timber tropical forest products. Economic Botany 47(3): 220-233.
Rausser, G.C. and A.A. Small	2000	Valuing research leads: bioprospecting and the conservation of genetic resources. UC Berkeley: Berkeley Program in Law and Economics. Journal of Political Economy 108(1): 173-206.	Rausser, G.C. and A.A. Small (2000) Valuing research leads: bioprospecting and the conservation of genetic resources. UC Berkeley: Berkeley Program in Law and Economics. Journal of Political Economy 108(1): 173-206.

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STERN, N. The Economics of Climate Change: The Stern Review. London, England, United Kingdom: Her Majesty's Treasury of the UK Government, 2006. Accessible at: <https://webarchive.nationalarchives.gov.uk/20100407172811/http://www.hm-treasury.gov.uk/stern_review_report.htm>.

VASQUES, Gustavo M. et al. **Soil Organic Carbon Stock at 0-30 cm Map for Brazil**. Rio de Janeiro, RJ, Brazil: Embrapa Solos, 2017. Accessible at: <http://geoinfo.cnps.embrapa.br/documents/1060/metadata_read>. Accessed on: 15 may. 2018.

WHRC. **Pantropical National Level Carbon Stock Dataset**. Falmouth, MA, USA: Woods Hole Research Center, 2012. Accessible at: <http://whrc.org/publications-data/datasets/pantropical-national-level-carbon-stock/>. Accessed on: 10 may. 2018.

Annex: Section 6.3 - Supplemental Material Unfinished Chapter – Model 3

Putting Traditional Livelihoods in Brazil on the Map: Legal and Data (Un)certainties

Abstract: Traditional livelihoods play important roles in managing a variety of land biomes; however, no attempt has been made to comprehensively map their diversity, particularly in bioculturally diverse countries like Brazil. Reconciling differences between scale, extent and grain remains a challenge to mapping and incorporating the interwoven occupancy patterns of diverse livelihoods into land governance frameworks; yet is paramount for sustainable development. To address this challenge, a traditional livelihood diversity index was created for Brazil using publicly available geospatial data. Two confidence levels emerged among identified occupancy patterns: higher confidence for indigenous (covering 2 million km^2) and agrarian reform settlement (435 thousand km^2) communities; and lower confidence for maroon (2.7 million km^2) other traditional (in 1633 counties at 5.8 million km^2) communities, and small-scale family farmers (nationwide). We highlight legal and data uncertainties and explore possible ways forward so that progress can be made in mapping livelihood diversity with improved accuracy.

6.3.1 – INTRODUCTION

Livelihoods are shaped by the capabilities, assets (*stores, resources, claims and access*) and activities used as the means to achieve basic human needs as well as physical and social well-being (CHAMBERS, 1986; CHAMBERS; CONWAY, 1991). As defined by Ellis (2000, p. 10), “A livelihood comprises the assets (natural, physical, human, financial, and social capital), the activities, and the access to these (mediated by institutions and social relations) that together determine the living gained by the individual or household”. A livelihood is deemed to be a sustainable livelihood when it can cope with and recover from stresses and shocks, i.e. resilience, while at the same time maintain or enhance its current and future capabilities and assets without undermining the its current or future natural resource base (CHAMBERS; CONWAY, 1991; DFID, 1999; FAO, 2018). In turn, such a sustainable livelihood will also provide sustainable livelihood opportunities for the next generation and contribute net benefits to other livelihoods at the local and global levels in the short and long term (CHAMBERS; CONWAY, 1991, p. 6). A key component of sustainable livelihoods are their ability to increase their resilience after being affected by external factors and thus reduce their vulnerability (SCOONES, 1998). A livelihood’s environmental sustainability concerns its external impact on other livelihoods and a livelihood’s social sustainability concerns its internal capacity to withstand outside pressures (CHAMBERS; CONWAY, 1991, p. 9).

A diversity of sustainable livelihoods, comprising both a high number of actors (*i.e. actor richness*) and the diversity of their skills that characterize their management capabilities (*i.e. actors’ functional diversity*), is of paramount importance for sustainably managing diverse ecosystems such as: mountains (GRÊT-REGAMEY; HUBER; HUBER, 2019), tropical forests (EDWARDS et al., 2014; SASAKI et al., 2016) savannas (FERRAZ-DE-OLIVEIRA; AZEDA; PINTO-CORREIA, 2016), marine protected areas (BAN; FRID, 2018; CHRISTIE et al., 2017) among others. As different actors have different perceptions of and access to ecosystem services (ES), their diversity (*actor richness* and *actors’* *functional diversity*) might directly or indirectly be associated to a range of natural resource management strategies that comprise actors' different types of livelihoods (DÍAZ et al., 2011; JASPARS, 2006).

Livelihoods, ecosystems, resources and governance systems are all parts of larger scale and complex socio-ecological systems (SESs). Although, these sub-elements may appear separable, they still interact to produce outcomes at the SES level which can feed back into the SES and affect its elements as well as feed back into other SESs (OSTROM, 2009). Resilience is also important at the SES scale. SES resilience can be defined as "[…] the capacity of a socio-ecological system to absorb disturbance and reorganize while undergoing change, so as to still retain essentially the same function, structure, identity and feedbacks" (PRADO; SEIXAS; BERKES, 2015, p. 30). As livelihoods are subcomponents of SESs, and sustainable livelihoods are key to sustainably managing diverse ecosystems and their resources, the incorporation of sustainable livelihoods and understanding of their diversity into governance structures is of paramount important for maintaining highly resilient SESs.

To understand the notions of *livelihood diversity* and the *diversity of livelihoods*, through the lens of the sustainable livelihoods thinking approach (CHAMBERS, 1986) coupled with biodiversity, human and landscape ecological sciences, we associate the concepts of *actor richness* to the concepts of *species richness* and *cultural richness* and we associate *actors' functional diversity* to the concepts of *species functional diversity*, *Traditional Ecological Knowledge (TEK)* and *livelihood diversification*. As livelihood activities are usually carried out repeatedly using a diverse set of skills and practices, we define *Sustainable Livelihood Diversity* as a diverse portfolio of activities involving the securing of water, food, fodder, medicine, shelter, clothing, and the capacity to acquire these necessities, either by working individually or as a group, by using resources, both human and material, for meeting the requirements of the self and his/her household or community and to achieve or maintain well-being on a sustainable basis and with dignity (ELLIS, 1999, 2000; INTERNATIONAL RECOVERY PLATFORM, 2010; JASPARS, 2006; SOAS UNIVERSITY OF LONDON, 2019). By *sustainable* we mean: the use of components, including biological diversity, in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations (ELLIS, 2000; INTERNATIONAL RECOVERY PLATFORM, 2010; SOAS UNIVERSITY OF LONDON, 2019).

In thinking about the *diversity of livelihoods* within an SES or at the ecosystem level, we relate it to *livelihood diversity* within a set *livelihood landscape*, but with an added layer which also relates to the *cultural diversity* and *ethnic diversity* within the livelihood landscape. Traditional communities are commonly associated with traditional livelihoods and in turn, traditional livelihoods are highly correlated to sustainable livelihoods. Traditional communities and associated traditional livelihoods are characterized by the relationships between living beings (including humans) and with their environment that have been ingrained into a set of practices, knowledge and beliefs, i.e. Traditional Ecological Knowledge (TEK), that continuously evolves by adaptive processes and is handed down through generations by cultural transmission (ALTIERI, 1994; DÍAZ et al., 2015; HUNTINGTON, 2000;

TROSPER, 2002). Moreover, many traditional communities hold a strong relationship with the land failing within the purview of their TEK, otherwise known as a 'place attachment'. This resulting 'territoriality' can be considered similar to the concept of defining a traditional community's homeland (HANNA et al., 2014; LITTLE, 2004). Therefore, understanding traditional communities also involves understanding that their cultural reproduction and livelihood diversity is commonly dependent on the occupation, management and continued relationship with their 'territory' (HANNA et al., 2014). As such, TEK often ensures that a traditional community's territory continues to sustainably meet the natural resource needs of present and future generations, thus fulfilling the environmental sustainability prerequisite of sustainable livelihoods as outlined by Chambers and Conway (1991, p. 9). However, in the face of global climate change, many traditional communities and TEK systems may be tested by future climatic changes to their ecosystems (HENRIKSEN, 2007).

6.3.2 – SUSTAINABLE AND TRADITIONAL LIVELIHOODS IN BRAZIL

Traditional livelihoods and a very rich body of TEK are inevitably linked to indigenous lands. Indigenous lands appear to have the appropriate scale (grain and extent) for supporting the implementation of several global conservation and climate agreements (GARNETT et al., 2018). Indigenous lands occupy over a quarter of the world's land surface, intersecting about 40% of all terrestrial protected areas and ecologically intact landscapes (for example, boreal and tropical primary forests, savannas and marshes) (GARNETT et al., 2018). The spatial occupancy pattern of indigenous lands seems to contrast with other types of finer grained traditional livelihood occupancy modes. It is well known that the pattern detected in any land mosaic is a function of scale, and that in turn, the concept of spatial scale encompasses both extent and grain. Extent refers to the area included within the study landscape boundary. Grain, on the other hand, is the size of the individual landscape units. Traditional livelihoods occur across vast areas of the planet, comprising different geographical grain(s) and extent(s). On the contrary to the spatial grain and extent of most indigenous lands, which were recently mapped at the global scale (GARNETT et al., 2018), the grain, extent, and the spatial scale of other traditional livelihoods' occupancy patterns such as: small-scale family farming is believed to be "too fine", raising enormous issues not only for mapping but also for planning and governing across different governance levels (from the pixel level to the national scale).

In Brazil the diversity of traditional livelihoods, beyond the rich legacy of indigenous lands, include but are not limited to maroon communities (termed *quilombolas*) and other culturally diverse traditional 'tribal' people and communities (HANNA et al., 2014), and often are associated with small-scale farming (which also include small scale livestock rearing, fishing, hunting), the gathering of timber and non-timber forest products (NTFP), making of handicrafts and food items, small scale mining, among other livelihood occupations. Although there is an enormous gap in knowledge concerning the status and trends of the sustainable use of wild species by traditional livelihoods (IPBES, 2018) as well as the sustainability of small scale faming and husbandry; still, traditional livelihood activities both within and outside of indigenous lands are often associated with higher levels of biological diversity and lower ecological footprints than 'industrialized human cultures'(PRETTY et al., 2009, p. 103). Moreover, their land management practices have been acknowledged as Bioculturally diverse (LOH; HARMON, 2005) and are connected to Sociobiodiversity territories (MMA, 2009) or biocultural landscapes.

Despite a widespread agreement on the important role of traditional livelihoods in land management and multiscale governance, so far, to our knowledge no attempt has been made to assess in a spatially explicit manner a diversity of livelihoods especially in a bioculturally diverse country such as Brazil. We aim to go beyond the state of art by contributing, estimating, and mapping the grain(s) and extent(s) of a set of five predefined types of traditional livelihoods present in Brazil, as defined in **Box 1** and with further detailed in **SM1**. In order to address the scale issues involved in mapping livelihoods with very different grain(s) and extent(s) we used a multi-scale framework from 250 m^2 pixels to the municipal (county) scale, which spans across the continental territorial extent of Brazil.

Identified Traditional Livelihoods in Brazil	
Livelihood Category	**Principal Legal Basis on Brazil's Legal Code**
Indigenous Livelihoods	1) Federal Constitution Arts. 231 & 232, and Supplemental Article 67; 2) Federal Law 6.001 of 1973 – The Statute of the Indian; 3) Promulgated Ratification of ILO Convention n. 169 on Indigenous and Tribal Peoples;
Maroon Communities (Known as Quilombolas in Brazil)	1) Federal Constitution Arts. 215 & 216, and Supplemental Article 68; 2) Promulgated Ratification of ILO Convention n. 169 on Indigenous and Tribal Peoples; 3) Presidential Decree 8.750 of 2016 – Instituting the National Council of Traditional Peoples and Communities;
'Other' Traditional Peoples and Communities – a set of 27 culturally differentiated peoples in Brazil	1) Promulgated Ratification of ILO Convention n. 169 on Indigenous and Tribal Peoples; 2) Presidential Decree 6.040 of 2007 – Instituted the Nacional Policy for the Sustainable Development of Traditional Peoples and Communities; 3) Presidential Decree 8.750 of 2016 – Instituting the National Council of Traditional Peoples and Communities;
Family Farming	1) Federal Law 11.326 of 2006 – Establishing the Guidelines and Fundamental Concepts for the Formation of a National Policy on Family Agriculture and Rural Family Farms;
Agrarian Reform Rural Settlements	1) Federal Constitution Arts. 184 & 191; 2) Federal Law 8.629 of 1993 – Regulations for the Implementations of the Constitutional Requisites for Agrarian Reform.

Box 1 – *Identified Traditional Livelihoods in Brazil*

6.3.2.1 – INDIGENOUS LIVELIHOODS

We use the legal definition of indigenous people and tribes based on Brazil's 1988 Federal Constitution (FC88), federal law and ratification and promulgation of an international convention:

1) The FC88 recognizes indigenous peoples in articles 215, 231 and 232 (BRAZIL, 1988 Arts. 215, 231 & 232). Article 215 awards indigenous people and groups cultural protection (along with mainstream, quilombola, and other groups participating in the national civiliatory process). Article 231 calls for the recognition and protection of indigenous peoples' unique societal organization, customs, language, traditions and beliefs and their rights to the lands that they have traditionally occupied. Their lands are inalienable, indispensable and indefeasible. Article 232 grants indigenous peoples the rights to petition the justice system and call upon the Public Ministry (MP) to provide counsel.
2) Federal Law 6.001/1973 (BRAZIL, 1973), known as 'The Indian Statute' defines indigenous peoples as: "[..] all individuals of pre-Columbian origin and descent who identify and are identified as belonging to an ethnic group whose cultural characteristics distinguish it from other groups in the society (Author Translation)."
3) Brazil's ratification and promulgation of the International Labour Organization's (ILO) Convention 169 (BRAZIL, 2002, 2004; ILO, 1989) grants indigenous peoples the rights to self-declaration and defining power of their indigenous identity, a right of self-determination for their path of development, as well as the rights to free informed prior consultation for any law, policy or activity that could directly affect an indigenous community.

6.3.2.2 – MAROON COMMUNITIES (QUILOMBOLAS)

We use the legal definition of maroon communities (quilombolas) based the FC88 and Federal law:

1) Presidential Decree 4.887/2003 (BRAZIL, 2003 Art. 2) defines quilombolas as, "the ethnic-racial groups, in accordance with self-declaration and with their own historical trajectory, holding a specific territorial relationship, with a presumption of black ancestry related to the resistance to historical oppression suffered (i.e. from slavery). For the purposes of this decree, the characterization of remnants of quilombos communities will be attested by means of self-definition by the community itself" (Author Translation).
2) The FC88 recognizes quilombolas in two specific sections, firstly and indirectly in articles 215 and 216, and then secondly in supplemental article 68 (BRAZIL, 1988 Arts. 215 & 216, Sup Art. 68):
    a. Articles 215 and 216 call on the State to protect afro-brazilian culture and moreover identifies these groups (as well as all cultural manifestations of Brazil's society) as national patrimony which includes their expression; way of life; artistic,

technological and scientific creation; artifacts and places of cultural production and historical significance.

b. Supplemental Article 68 calls for all remaining quilombola communities that are still occupying their traditional lands shall have their land tenure definitively established on those lands and for the State to issue those communities land titles.

6.3.2.3 – 'OTHER' TRADITIONAL PEOPLES AND COMMUNITIES

Other Traditional Peoples and Communities (PCTs) are arguably legally granted constitutional rights by FC88 in article 215 by the separation of 'other' groups participating in the national civilization process aside from indigenous and quilombola communities (BRAZIL, 1988 Art. 215). Moreover, two distinct federal laws help to define the attributes and identifiable cultures that are attributed to Brazil's other PCTs:

1) Presidential Decree 6.040/2007 (BRAZIL, 2007), which institutes the National Policy for the Sustainable Development of Traditional Peoples and Communities states that: "…[they] shall be understood as: "culturally differentiated and recognized groups that have their own forms of social organization that occupy and use their territories and natural resources as a condition for their cultural, social, religious, ancestral and economic reproduction, using knowledge, innovations and practices generated and transmitted by tradition (Author Translation)." Additionally, this decree defines their Traditional Territories as "the spaces necessary for the cultural, social and economic reproduction of traditional peoples and communities, whether they are used permanently or temporarily, and with the observation and respect to the indigenous and quilombola peoples, as provided by article 231 of the Brazilian Federal Constitution and the 68 of the Transitional Constitutional Provisions Act and other regulations" (Author Translation).
2) Presidential Decree 8.750/2016 (BRAZIL, 2016), which created the National Council of Traditional Peoples and Communities specifically names 26 distinct groups eligible for representation on the council (in addition to indigenous and quilombola peoples, as well as youth and adolescents representing PCTs as a whole) which include: povos e comunidades de terreiro/povos e comunidades de matriz africana; povos ciganos; pescadores artesanais; extrativistas; extrativistas costeiros e marinhos; caiçaras; faxinalenses; benzedeiros; ilhéus; raizeiros; geraizeiros; caatingueiros; vazanteiros; veredeiros; apanhadores de flores sempre vivas; pantaneiros; morroquianos; povo pomerano; catadores de mangaba; quebradeiras de coco babaçu; retireiros do Araguaia; comunidades de fundos e fechos de pasto; ribeirinhos; cipozeiros; andirobeiros; and caboclos.
    a. To aid in understanding the diversity of these identified PCTs, here are some further definitions of a selected few of these PCTs: Extractivists are here defined as people living in forest areas that gather raw materials or other products from the forest like wild vegetables, fruits, herbal medicines, honey, rattan and other non-timber forest

products (NTFP). These forest products are both for local consumption and for sale in the market. Communities living near the sea, Caiçaras in southeast Brazil (HANAZAKI et al., 2013) or the Ribeirinhos in the Brazilian Amazon along inland water bodies like rivers, ponds, and lakes depend on fishing as a significant traditional occupation (SCHOR; AZENHA; BARTOLI, 2018).

3) The FC88 in article 215 outlines four segments of society that are guaranteed constitutional protection of their cultural expression, this includes mainstream society, indigenous cultures, Afro-Brazilian cultures (which would encompass quilombola communities), and 'other groups' (BRAZIL, 1988 Art. 215). Although there is no established jurisprudence that we could find, it would appear that the 26 identified PCTs could be included as these 'other groups' and thus be granted constitutional cultural protections.

6.3.2.4 – SMALL SCALE FAMILY FARMING

Small-scale agriculture and agro husbandry are activities linked to several traditional livelihoods and to family farming. Agriculture is practiced both for subsistence and also for trading in local markets. Small scale farming systems often include a diversity of products based on crop rotation cultivation and agro-forestry practices. This system depends on the cultivation of a different types of crops on the same plot, in recognition that different crops extract and replenish different nutrients from and to the soil. Crop rotation is increasingly done for vegetables and other crops like corn, legumes, root vegetables are also grown in home gardens or vegetable fields and terraces. In Brazil small scale farmers are responsible for the production of 80% of beans consumed internally, and as of 2006 family farms produced approximately 70% of total domestic food consumption. Moreover, family farms are estimated to consist or 84% of all farm holdings and 74% of the country's agricultural labor; however, family farms only represent 24.3% of the country's total agricultural area (GRAEUB et al., 2016). Small-scale farmers also are well known for raising domesticated animals or livestock including cattle, horses, pigs, goats, chickens, ducks, among others. This is usually done to provide a source of protein in the diet and to augment crop production for the needs of the household. Livestock are also raised to provide the needed animals in the performance of traditional rituals and as a source of cash for emergency needs.

In Brazil, family farming is legally defined and protected, and we use these legal definitions as the basis for our understanding of family farming:

1) Federal Law 11.326/2006 (BRAZIL, 2006) and Presidential Decree 9.064/2017 (BRAZIL, 2017), which established and altered the guidelines and fundamental concepts for the Formation of a National Policy on Family Agriculture and Rural Family Farms, defines family farms based on the following characteristics:
    a. The family does not hold, in any way, an area greater than four (4) fiscal modules[1];

[1] Módulo Fiscal (*fiscal module*), refers to a unit of area measurement used in Brazil for agricultural purposes. The unit of area is represented in hectares and is fixed per county but variable between counties. The defined hectares

b. The activities undertaken in the rural establishment that generate income are undertaken by at least half of the legally eligible family members on the farms labor force (in respect to child employment protection);
c. Requires that half of the family combined income must come from activities undertaken or resulting from the family farm;
d. and, the farm must be under the management of the family.

2) Moreover, Federal Law 11.326/2006 (BRAZIL, 2006) further highlights that the following livelihood groups and occupations are granted the protections outline by this law:
    a. Silviculturists, who meet the labor and income requirements, and cultivate native or exotic forests and promote the sustainable management of those environments;
    b. Aquaculturists, who meet all the requirements land, labor and income requirements, and utilize water reservoirs with a total surface area of up to 2ha (two hectares) or occupying up to 500m³ (500 cubic meters) of water, when the operation takes place in network of tanks;
    c. Extractivists, who meet the labor and income requirements, and exercise this activity in the rural environment, but excluding garimpeiros[2] and faiscadores[3];
    d. Fishermen, who meet the labor and income requirements, and only carry out artisan fishing activities;
    e. Indigenous peoples, who meet the labor and income requirements;
    f. Members of rural quilombos and other PCTs who meet the labor and income requirements.

6.3.2.5 – AGRARIAN REFORM SETTLEMENTS

Agrarian Reform Settlements (as part of the National *Agrarian Reform Program*), called *assentamentos* in Portuguese, are defined by the foundations set by Federal Law 8.629/1993 (BRAZIL, 1993). Agrarian Reform Settlements are agricultural communities, constituting of individual and independent land holdings, that were organized and instate by Brazil's Federal Agency for Agrarian Reform (INCRA, Portuguese for *Insituto Nacional de Colonização e Reforma Agraria*). Individual land holdings in an organized community are devolved to families, wishing to conduct rural and agricultural livelihood activities, deemed to have no economic resources or capacity that would allow them to acquire a rural property by another manner. The amount of land allocated in an agrarian reform settlement is determined by the geography and the productive capacity of the land to support a calculated number of settlement families. However, it is important to note that the metrics used to determine the

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per modulo fiscal is based on the tenants of what is considered to be the minimum area necessary for a farm to be economically viable based on the predominant types of economic agricultural activities taking place in a specific county (EMBRAPA, 2018).

[2] Garimpeiros are small scale artesian miners.

[3] Faiscadores are people who undertake mineral panning extractive activities in lakes, rivers and streams.

economic viability and support capacity for family farming activities in agrarian reform settlements have be scrutinized as not being sufficient for settlers to benefit from the appropriate economies of scale that would make their agricultural ventures economically, socially, and environmentally sustainable (SCHNEIDER; PERES, 2015). As such, we considered any rural agrarian reform settlement in INCRA's database, whether being organized by INCRA, or organized by another entity but recognized by INCRA, as our definition of an agrarian reform settlement.

6.3.3 – CAN THESE TRADITIONAL LIVELIHOODS BE MAPPED? THE LEGAL AND DATA (UN)CERTAINTIES

Aside from being a mega biodiverse country (BRANDON et al., 2005), Brazil is also home to significant biocultural diversity (LOH; HARMON, 2005) and socio-biodiversity (MMA, 2009). Over 240 native languages are spoken across Brazil, and the country includes over 224 ethnic groups (HANNA, 2016; HANNA et al., 2014). However, the documentation of this diversity leads often leads to uncertainties. For example, the last demographic census in Brazil reports 896,000 indigenous people, while 572,000 (63.8%) lived in rural areas, and 517,000 (57.5%) resided on officially recognized indigenous lands (IBGE, 2011). However, only just six years earlier, approximately 450,000 indigenous peoples were registered with FUNAI (FUNAI, 2004). For quilombola communities we could find that there are over 4,500 families documented (MMA, 2009). As for Brazil's other traditional communities and livelihoods, we could not find any data sources that we believed captured population statistics with an appropriate level of confidence.

Brazil's 1988 Federal Constitution (FC88) grants mainstream society, indigenous peoples, quilombola communities, and "other" societal groups participating in the national civiliatory process constitutional cultural protections. While indigenous peoples (Articles 215, 231, 232 & Sup Art. 67) and quilombola communities (Articles 215, 216 & Sup Art. 68) are directly mentioned and thus blatantly hold juridical guarantees specifically outlined by the FC 1988, Brazil's 'other' societal are not directly mentioned or defined by the FC88. However, as already mentioned, given that federal law has already defined 26 PCTs as distinct cultures within Brazil, it would be arguable that these 26 PCTs are 'other' groups participating in the national civilatory process and thus are constitutionally protected (BRAZIL, 1988 Art. 215, 2007, 2016).

For indigenous peoples, the legal framework allows for a process of a self-declaration and formal acknowledgement by the community. In Brazil, administrative interaction between indigenous communities and the State is performed by the National Foundation for Indigenous People (FUNAI, Portuguese for *Fundação Nacional do Indio)*. For quilombola communities, which also are awarded the right to self-declaration, administrative interaction between the quilombola communities and the State is performed by the Palmares Cultural Foundation. While Brazil's 'other' traditional communities (PCTs, Portuguese for *Povos e Comunidades Tradicionais*) do have some federal legislation that outlines who they are, which may be constitutionally backed. The 26 different traditional communities (aside from indigenous peoples, quilombola communities, and PCT youth) are members of the National Council of Traditional Peoples and Communities (Conselho Nacional de Povos e Comunidades Tradicionais), which to our knowledge is the only federal institution that oversees any administrative process or communication between these groups and the State. Moreover, it is possible that additional traditional communities are not included on the National Council of PCTs and possibly should be.

Brazil is recognized for its 'superior' legal framework for its protections of indigenous, quilombola and other traditional communities compared to many other countries in Latin America (ORTIGA, 2004; STOCKS, 2005). However, despite having a robust legal framework, many of Brazil's traditional communities still suffer as victims of violence, threats, intimidation and land grabs from gold miners, ranchers, guerilla and paramilitary groups, police, oil companies, loggers and other groups who circumvent the legal framework to claim the land and resources that are occupied by traditional communities. While *de jure* standards may set the regional bar, *de facto* realities on the ground show an example of failed law enforcement, denied constitutional protections, and the reality of the country's unstable rule of law. In addition to these legal 'uncertainties' there are issues involving data uncertainties. Although there are many different datasets from governmental and nongovernmental institutions, data irregularities and contradictions both amongst government institutions and between government institutions and nongovernmental institutions create a state of uncertainty. Moreover, when these data uncertainties are combined with trying to map traditional livelihood territories at their differing grains and extents, the complexity increases.

6.3.4 – METHODS, DATA AND MAPPING

6.3.4.1 – OVERVIEW

Our approach to mapping the five defined traditional communities and livelihoods included a complex set of data sources from government institutions, reputable nongovernmental institutions, and using identified proxy variables supported by the literature, and using defining legal parameters (**Box 1** and **SM1**) to arrive at the spatially explicit input variables for each of the five traditional communities and livelihoods. Just as the five focus livelihoods and communities' geographic patterns of land occupation occur at different scales, and thus hold different grain and extent, so too did the input data. Even for spatial input variables for a specific livelihood, differences in scale were the norm. A defined list of the spatial data used to arrive at the input variables for each of the livelihood categories is listed in detail in **SM2**.

Step 1 – All Geospatial analyses were conducted using ArcGIS v10.4.1 (ESRI, 2016). All input data was projected to IBGE's standard Albers Conic Equal Area projection (IBGE, 2015) and all final input variables for modeling the index were produced in raster format with a spatial resolution of 250 meters^2 and covered Brazil's entire continental territorial extent, independent of any original input vector data's or input raster data's scale, resolution or geographic extent. Due to the spatial scale differences across our data sources, we determined that the best way forward for dealing with spatial coverage and data uncertainties was to perform a pairwise comparison of our level of uncertainty for the data sources and variables using the Analytical Hierarchy Process (AHP) as defined by Saaty (1980). The AHP was performed for each of the livelihoods and the input variables that we could find or generate spatially explicit data for. We gave higher weights to the data sources we felt most confidently had high accuracy and lower weight to data sources we believed had questionable accuracy.

Step 2 – Using basic map algebra functions, once the weights were determined for each input variable, they were applied to the corresponding the input raster data variables. With the weighted variable rasters at hand, each livelihoods' variables were added together using the map algebra simple addition function. This resulted in a pre-normalized raster surface for each of the livelihoods. For each of the five pre-normalized raster sets, each was normalized creating an individual livelihood index ranging from zero (the absence or lowest amount of that individual livelihood's diversity) to 100 (the highest encountered amount of that individual livelihood's diversity).

Step 3 – Once each of the individual livelihood's diversity indices were generated at the national extent, the next step involved putting them together to generate the overall traditional livelihoods' diversity index. However, given that high levels of biodiversity and cultural diversity tend to occur in the same ecosystems, landscapes and at similar spatial extents (LOH; HARMON, 2005), we felt that it would be appropriate to measure the livelihood diversity at the biome level. This is because we felt that it would be unwise to hold the highest levels of biodiversity in the Pampas to the same standards as the highest levels of biodiversity in the Amazon. Under this same rational, as traditional communities and their associated TEK have developed within distinct environments, holding the highest levels of traditional livelihood diversity in the Pampas to the same standards of the highest levels of traditional livelihood diversity in the Amazon would be like comparing apples to oranges.

Step 3A – With these considerations in mind, each of the specific normalized individual livelihood indices from step 2, were added together, using the basic addition function of map algebra, and was then cut for each specific biome using the biome limits developed by Project Mapbiomas (ROSA; PROJECT MAPBIOMAS, 2016). Then the resulting cut rasters for each biome underwent a second by biome separate normalization, and thus generating six Biome Specific Traditional Livelihood Indices with values ranging from zero (the absence of lowest amount of a specific biome's overall traditional livelihood diversity) to 100 (the highest encountered amount of a specific biome's overall traditional livelihood diversity). Thus, traditional livelihood diversity could be analyzed at the biome specific level with an Atlantic Forest Traditional Livelihood Diversity Index, an Amazon Traditional Livelihood Diversity Index, a Caatinga Traditional Livelihood Diversity Index, and the same for the Cerrado, Pampas and Pantanal.

Step 3B – With the Biome-Specific Traditional Livelihood Indices Generated, in order to create a national level Traditional Livelihood Indices, each of the Biome-Specific Traditional Livelihood Indices were simply mosaiced together and given that they were already normalized to the same scale of zero to 100, no further normalization was required.

6.3.4.2 – STEP 1: THE AHP PROCESS

While there are some spatial data available for mapping the extent (polygons) of traditional livelihoods such as indigenous lands, quilombola communities, and agrarian reform settlements; in the case of small scale family farming and PCTs (such as, but not limited to: Extractivists, Ribeirinhos, Caiçaras among the 23 other legally defined PCT groups), we could not find any spatial data that indicated to high levels of certainty the specific geographic locations of some or any of these livelihoods below the county level. Therefore, for small scale family faming and other PCTs we had to estimate their locations and extents using proxy variables. Moreover, for the indigenous and quilombola livelihoods, we could find spatial data that indicated at least some of these livelihoods' geographic extent; however, we still felt that it was an incomplete picture of their locations. Thus, we decided to supplement the spatial data that we could find with additional proxy data that might help indicate additional undocumented occurrences of their geographic extents. We describe the methodological approach for each individual type of livelihood as follows:

6.3.4.2.1 – INDIGENOUS LIVELIHOOD VARIABLES AND AHP WEIGHTS

For indigenous livelihoods we were able to find 6 different data sets from three different sources that indicate their locations and to which we assigned different confidence weights via AHP crosswise comparison (**Table 1**). In this process (see **SM1** for more explanation) we assigned higher weights to data from sources that hold higher legal authority, higher weights to data with metadata categories indicating the legal status of an indigenous territory (TI, Portuguese for *Terra Indigena*), higher weights to data that was originally in polygon format (as opposed to point format). For the indigenous territories for which the location was given in point data, we incorporated a 30km buffer around the point.

From FUNAI we used two polygon datasets which separated completely regularized TIs (those theoretically having full legal/constitutional protections) and non-regularized TIs which are mapped lands that have been deemed to belong to indigenous peoples through anthropological studies, but that have yet to be administratively recognized by the federal government (FUNAI, 2018). Additionally, from FUNAI, we used a point dataset which includes the general location of self-declared indigenous lands undergoing anthropological studies for possible recognition from the federal government (FUNAI, 2018). From IBGE we used spatial point data derived from the 2010 census, that indicate the locations of 'indigenous villages' whether within or outside of any regularized, non-regularized, or understudy TI (IBGE, 2010). Finally, we incorporated polygon and point data from UNEP's World Datadase of Protected Areas (WDPA) (UNEP-WCMC, 2018), both including possible unrecognized TIs that do not exist in official government datasets. As the WDPA also includes many of the same TIs included in official government datasets, only the spatial data that did not duplicate government identified TIs was included in our model. Lower weights were assigned to WDPA data given that dataset does not hold any official status in Brazil.

AHP Variable Weights – Indigenous Livelihood Variables AHP Certainty	
Data Source and Variable	**AHP Weight**
FUNAI – Regularized TIs (Polygons)	62.90%
FUNAI – Unregularized TIs (Polygons)	13.20%
IBGE – Indigenous Villages (Points with 30km buffer)	7.90%
FUNAI – TIs under study ((Points with 30km buffer)	6.90%
WDPA – Indicated TIs (Polygons)	6.00%
WDPA – Indicated TIs ((Points with 30km buffer)	3.10%

Table 1 – Indigenous Livelihood Sub-Category AHP Results

6.3.4.2.2 – QUILOMBOLA LIVELIHOOD VARIABLES AND AHP WEIGHTS

For quilombola livelihoods we were able to find five different datasets/variables from three primary sources: INCRA (2018a), the Palmares Cultural Foundation (FUNDAÇÃO CULTURAL PALMARES, 2019) and the Pastoral Land Commission (CPT, Portuguese for *Comissão Pastoral da Terra*) (CPT, 2018). For variables from Palmares and CPT, the data was spatialized with the aid of additional secondary input sources from IBGE (see **SM2**). These five generated input variables were assigned different confidence weights via AHP crosswise comparison (**Table 2**). In this process (see **SM1** for more explanation) we assigned higher weights to data from sources holding higher legal authority, higher weights to data with metadata categories indicating the legal status of title holding of quilombola communities, higher weights to data that define territorial boundaries at the local scale, and then lower weights to variables that could only be spatialized at the county scale and depending on how well the data could or could not indicate the actual presence of a territory or multiple territories within the country boundaries.

AHP Variable Weights – Quilombola Livelihood Variables AHP Certainty	
Data Source and Variable	**AHP Weight**
INCRA – Titled Demarcated Quilombola Lands	41.85%
INCRA – Untitled Demarcated Quilombola Lands	26.25%
Palmares – Number of Certified Quilombola Communities within a County	15.99%
CPT – Number of Quilombola Communities Involved in Land Rights Disputes within a County	9.73%
Palmares – Number of Quilombola Families within a County	6.17%

Table 2 – Quilombola Livelihood Sub-Category AHP Results

6.3.4.2.3 – OTHER PCT (TRADITIONAL PEOPLES AND COMMUNITIES) VARIABLES AND AHP WEIGHTS

For PCT livelihoods we were able to find and generate five different input variables based on data from five primary sources, some being spatialized with the aid of additional secondary input sources (see **SM2**). The main input variables and the primary data sources include:

(i) Self-declared and demarcated PCT territories (polygon format at the local scale) from the Brazilian Forest Service's (2018) (SFB, Portuguese for *Serviço Florestal Brasileiro*) National Rural Environmental Registry (SICAR, Portuguese for *Sistema Nacional de Cadastro Ambiental Rural*) (see **SM2**);

(ii) As a proxy for extractivistism, a generated Extractivism Simpson Diversity Index (Extractivisim SID) using IBGE's (2017a) county level extractivism and silviculture data (see **SM2**);

(iii) CPT's documented conflicts related to PCT groups per county (see **SM2**);

(iv) Extractivism Reserves, Sustainable Development Reserves, and National Forests which are Sustainable Use Conservation Unit categories commonly associated with and designed for PCTs and traditional livelihoods from MMA's (2018) National Conservation Unit Registry (see **SM2**);

(v) and counties included in MMA's (2012) National Plan for the Promotion of Socio-Biodiverse Product Supply Chains (see **SM2**);

These five generated input variables were assigned different confidence weights via AHP crosswise comparison (**Table 3**). In this process (see **SM1** for more explanation) we assigned higher weights to data that we believed mapped the presence of PCTs at the finest scale or with a higher incidence probability. For example, self-declared PCT territories in the SICAR database were demarcated and submitted to SFB by the community itself or by an NGO or government institution representing a PCT group. Interestingly, we felt that the county scale Simpson Diversity Index of Extractivism activities and CPT's counties with land conflicts involving PCTs would likely indicate the presence of PCT peoples at a higher level than the three Sustainable Use Conservation Unit categories associate with PCTs and traditional livelihoods, as these UCs would likely coincide with high extractivism diversity and are commonly involved in land conflicts. However, these three UCs groups by themselves are limited in geographic coverage and location and likely do not cover a substantial amount of land belonging to PCTs in Brazil.

AHP Variable Weights – PCT Livelihoods Variables AHP Certainty	
Data Source and Variable	**AHP Weight**
SFB SICAR – Self-Declared and Demarcated PCT Territories	43.77%
IBGE – County Level Simpson Diversity Index of Extractivist Products	22.60%
CPT – Number of PCT Groups Involved in Land Rights Disputes within a County	13.73%
MMA's CNUC – Sustainable Use Conservation Units Associated with PCTs and Traditional Livelihoods (RESEXs, RDSs, FLONAs)	13.43%
MMA's SocioBioiverse Supply Chains Program – Number of SocioBiodiverse Products associated with the Program's Counties	6.45%

Table 3 –PCT Livelihoods Sub-Category AHP Results

6.3.4.2.4 – SMALL SCALE FAMILY FARMING LIVELIHOOD VARIABLES AND AHP WEIGHTS

For small scale family farming we were able to generate 3 input variables based on data from three primary sources and using legally defining parameters as well as the aid of additional secondary spatial data to generate the final spatialized input variables (see **SM2**). These variables and primary data sources include:

(i) Registered Rural Properties with and area of four fiscal modules or less from INCRA's (2018c) National Rural Registry System (SNCR, Portuguese for *Sistema Nacional de Cadastro Rural*);

(ii) We spatialized the percentage of all registered farms per county participating in the National Program for Strengthening Family Agriculture (PRONAF, Portuguese for *Programa Nacional de Fortalecimento da Agricultura Familiar*) via proof of PRONAF Eligibility Certification (DAP, Portuguese for *Declaração de Aptidão ao Pronaf*) from IBGE's (2018) 2017 Agricultural Census;

(iii) and, as a proxy variable, we generated a combined Extractivism and Agricultural Production Simpson Diversity Index (Extrativisim-Agricultural SID) using IBGE's (2017a, 2017b) county level extractivism and silviculture data as well as its county agricultural production data (see **SM2**).

We assigned different confidence weights to these variables via AHP crosswise comparison (**Table 4**). In this process (see **SM1** for more explanation) we assigned higher weight to INCRA's SNCR data as it was already spatially defined at the local scale. We weighted IBGE's PRONAF/DAP agricultural census information higher than the Extrativisim-Agricultural SID, as the former is a primary source data and the latter is a proxy variable. Our justification for using Extrativisim-Agricultural SID as a proxy is that we assumed the premise that agribusiness tends to intensify and homogenize the local production systems. We therefore assumed that the counties that were located in areas where a diversified set of agricultural production systems still exist are more likely to be associated with small scale family farming.

AHP Variable Weights - Family Farming Livelihood AHP Variables Certainty	
Data Source and Variable	**AHP Weight**
INCRA's SNCR - Properties at 4 Fiscal Modules or Less	69.4%
IBGE's 2017 Agricultural Census – Percent of All Farms that are PRONAF/DAP qualified farms	17.4%
IBGE – County Level Simpson Diversity Index of Extractivist and Agricultural Products	13.2%

Table 4 – Family Farming Livelihood Sub-Category AHP results

6.3.4.2.5 – AGRARIAN REFORM SETTLEMENT LIVELIHOOD VARIABLES AND AHP WEIGHTS

For agrarian reform settlements, we generated five input variables based on one specific spatial dataset from INCRA (2018b). The five input variables are based on the current status level of each settlement project's administrative process at the date of spatial data download. We weighted agrarian reform settlements at the beginning process of project formation and settlement creation higher, than settlement projects that are finished and completely settled (**Table 5**). We justify this under the premise that settlements are significantly more vulnerable to outside interference, land grabbing, and deforestation in the early stages of settlement than once the settlement is completed and all infrastructure is installed (see **SM2**).

AHP Variable Weights – Agrarian Reform Settlement Livelihood AHP Variables Certainty	
Data Variables	**AHP Weight**
Created Settlement (Stage 1)	51.28%
Settlement in Installation (Stage 2)	26.15%
Settlement in Structuring (Stage 3)	12.89%
Settlement in Consolidation (Stage 4)	6.34%
Settlement Condolidated (Final Stage)	3.33%

Table 5 – Agrarian Reform Settlement Livelihood Sub-Category AHP Results

6.3.4.3 – NORMALIZATON OF INDIVIDUAL LIVELIHOOD INDICES

As mentioned at the beginning of this section and by using basic map algebra functions, the AHP weights were applied to the input variable raster surfaces. Then a preliminary raster surface was generated for each of the five livelihoods and from that an individual livelihood index, normalize to a scale of 0 to 100, was generated for each livelihood. **Figures 1** to **5** show the five sub-indices for individual livelihood types.

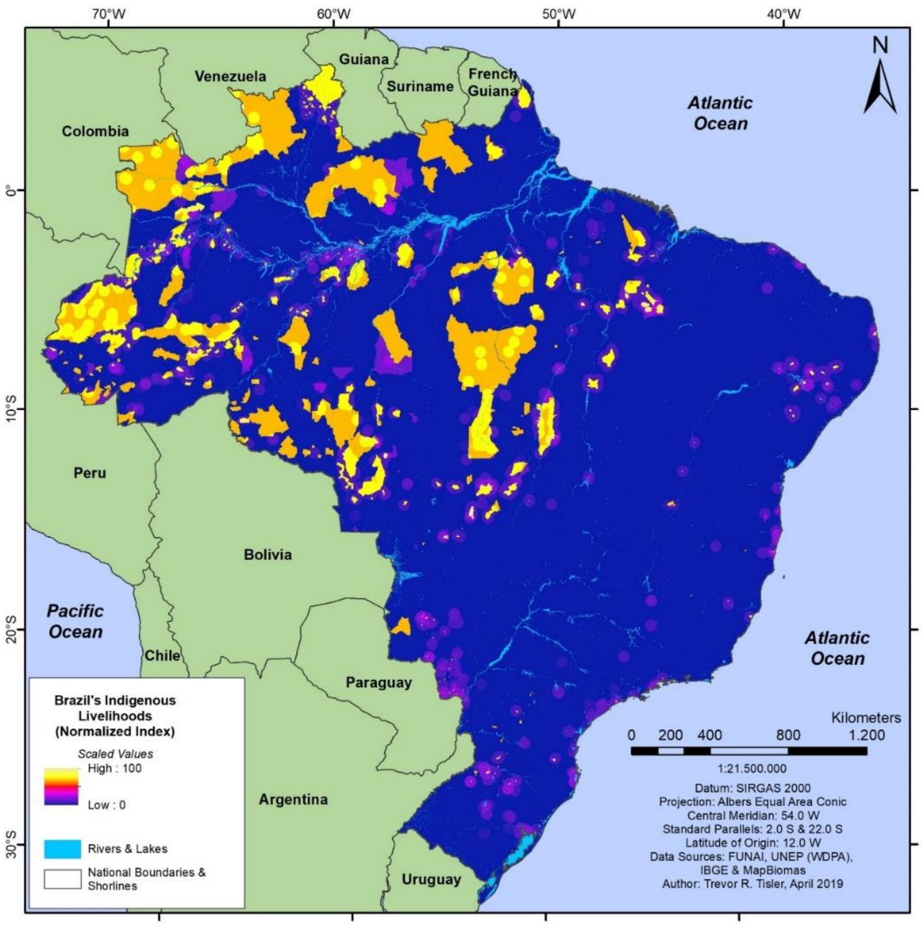

Figure 1 – Indigenous Livelihood Sub-Category

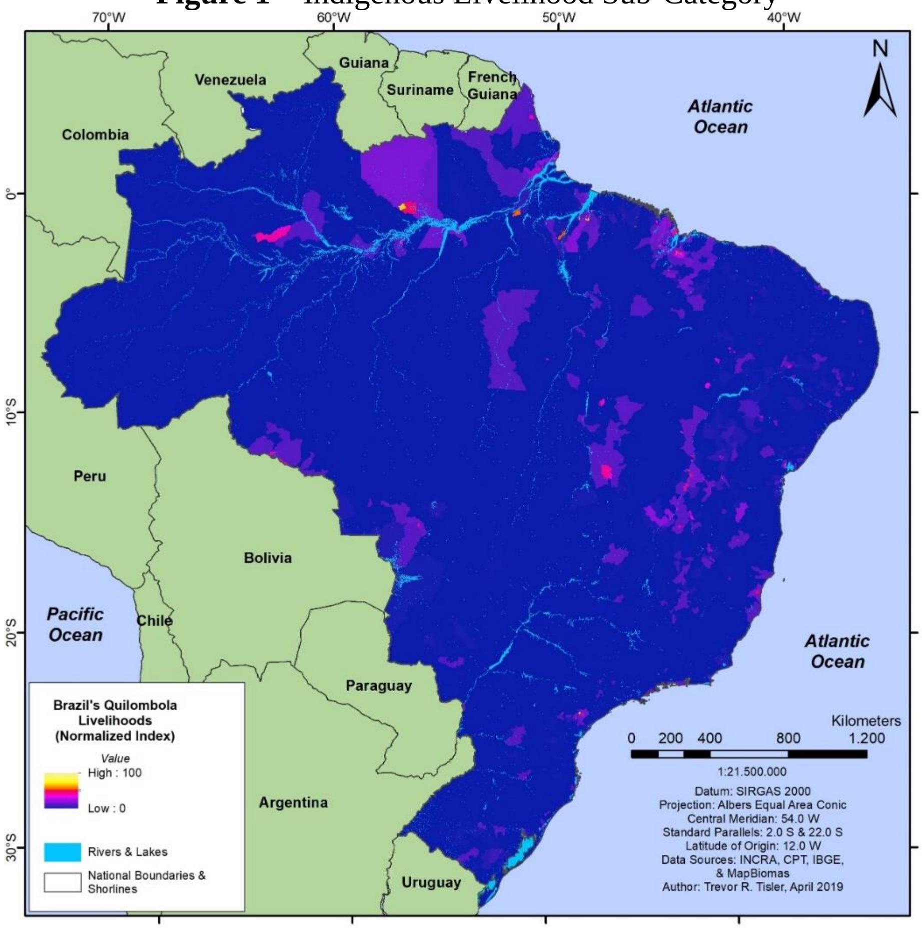

Figure 2 – Quilombola Livelihood Sub-Category

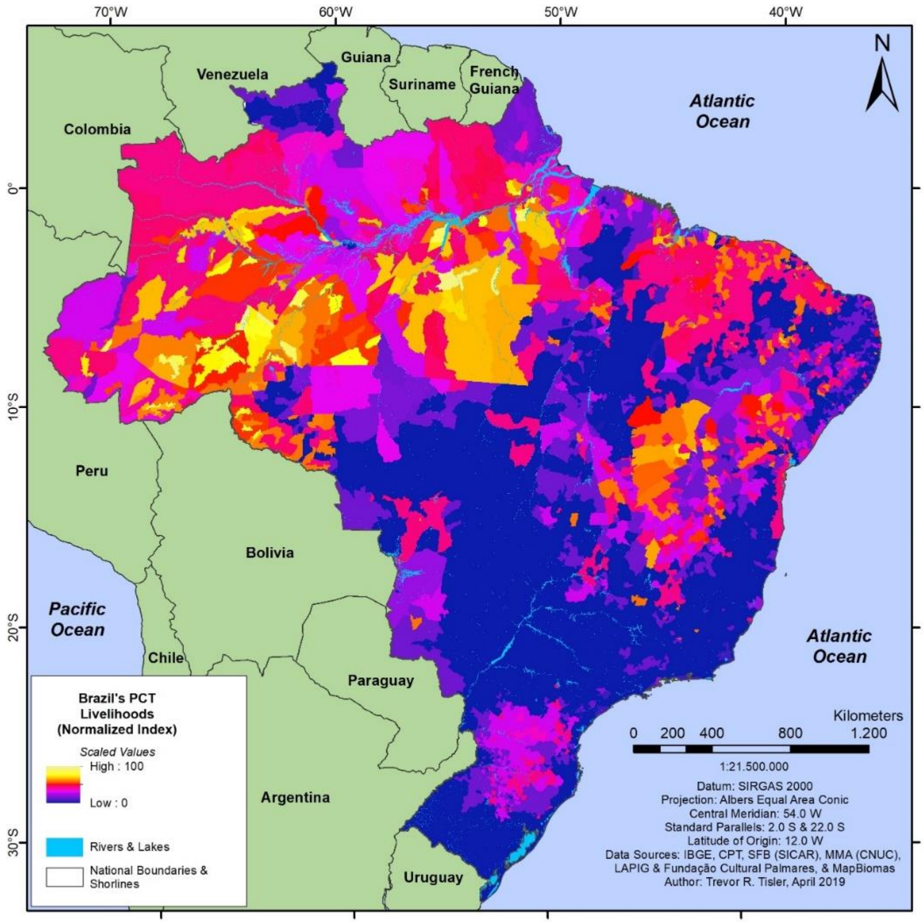

Figure 3 – PCTs Livelihood Sub-Category

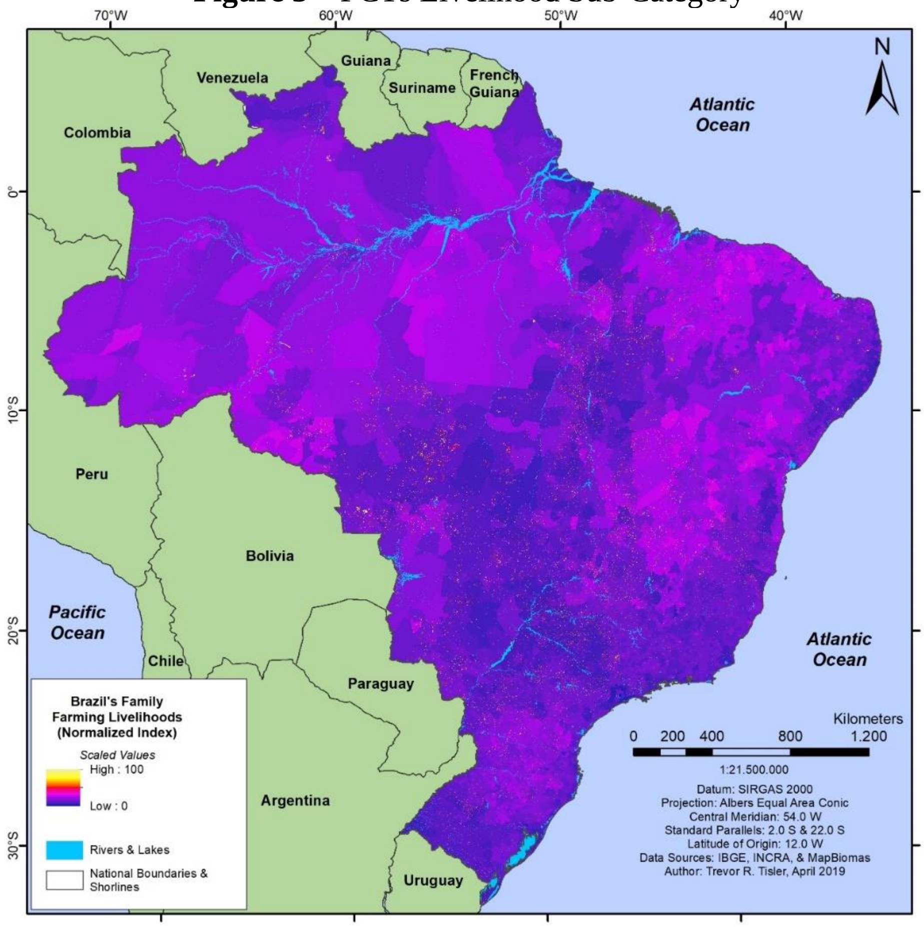

Figure 4 – Small Scale Family Farming Livelihood Sub-Category

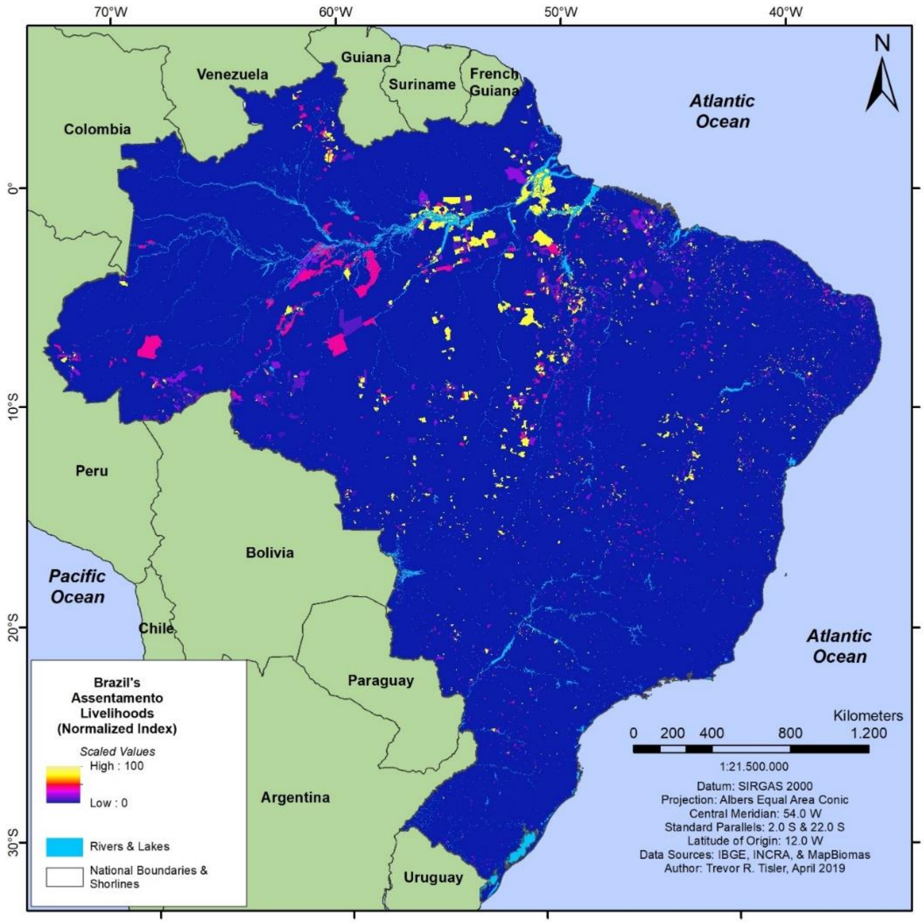

Figure 5 – Agrarian Reform Settlement Livelihood Sub-Category

The results of our sub-indices show that the scale, grains and extents are fairly unique for each of the five livelihoods when considered at the national level. The indigenous livelihood sub-index (**Figure 1**) shows that livelihood occupancy being predominantly located in northern and inland areas of the Brazilian Amazon at larger extents; while, finer grained hotspots are scattered across the country, particularly along Brazil's coast lines and southern boarders. These small grained hotspots represent either smaller indigenous territories, documented indigenous villages, or unrecognized but self-declared TIs that have been documented by NGOs. As far as the quilombola livelihood sub-index (**Figure 2**) is concerned, higher extents are located in Amazon and Cerrado Biomes and finer grained instances are also found in large numbers in the Atlantic Forest biome. The PCT livelihood sub-index (**Figure 3**) shows that the 'other' PCTs likely occupy a large share of Brazilian mainland and occur in diverse regions throughout the country. **Figure 4** demonstrates the finer grained nature of small-scale family farming livelihoods and that they are likely more 'evenly' distributed throughout Brazil's mainland than the other four livelihoods. Finally, for Brazil's Agrarian Reform Settlement Livelihoods, **Figure 5** shows that the livelihood occurs throughout the country; however, the extent and grain vary significantly depending on the region of the country.

6.3.4.4 – BIOME LEVEL AND NATIONWIDE TRADITIONAL LIVELIHOOD INDICES

To complete the Traditional Livelihoods Index, the individual livelihood sub-indices were combined, using basic map algebra addition function. This preliminary stage was then cut per each of Brazil's six biomes and normalized at the biome level on a scale of 0 to 100 (by dividing for the highest value). Then the individual Biome Level Traditional Livelihood sub-indices were mosaiced back together (all with the same normalized value scale of 0 to 100) to generate the final National Level Traditional Livelihoods Index. The Biome Level Sub-Indices are show in **Figures 6** to **11** and the final National Level Traditional Livelihoods Index is show in **Figure 12**.

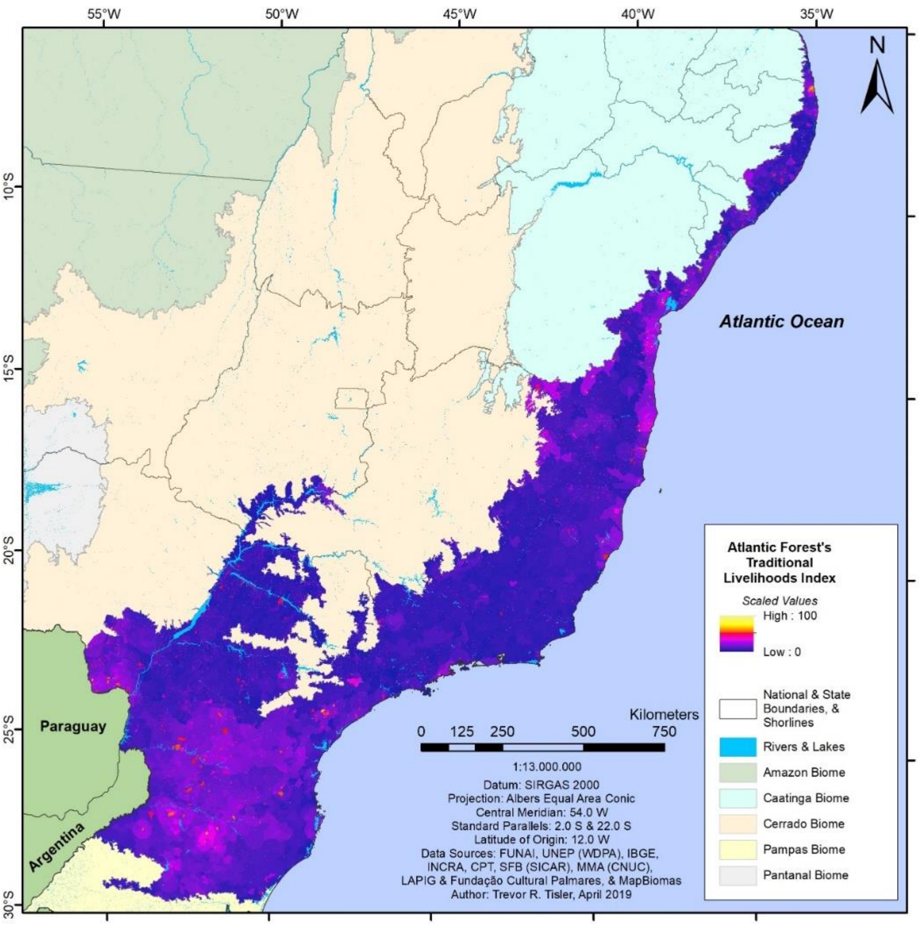

Figure 6: Atlantic Forest's Traditional Livelihood Index

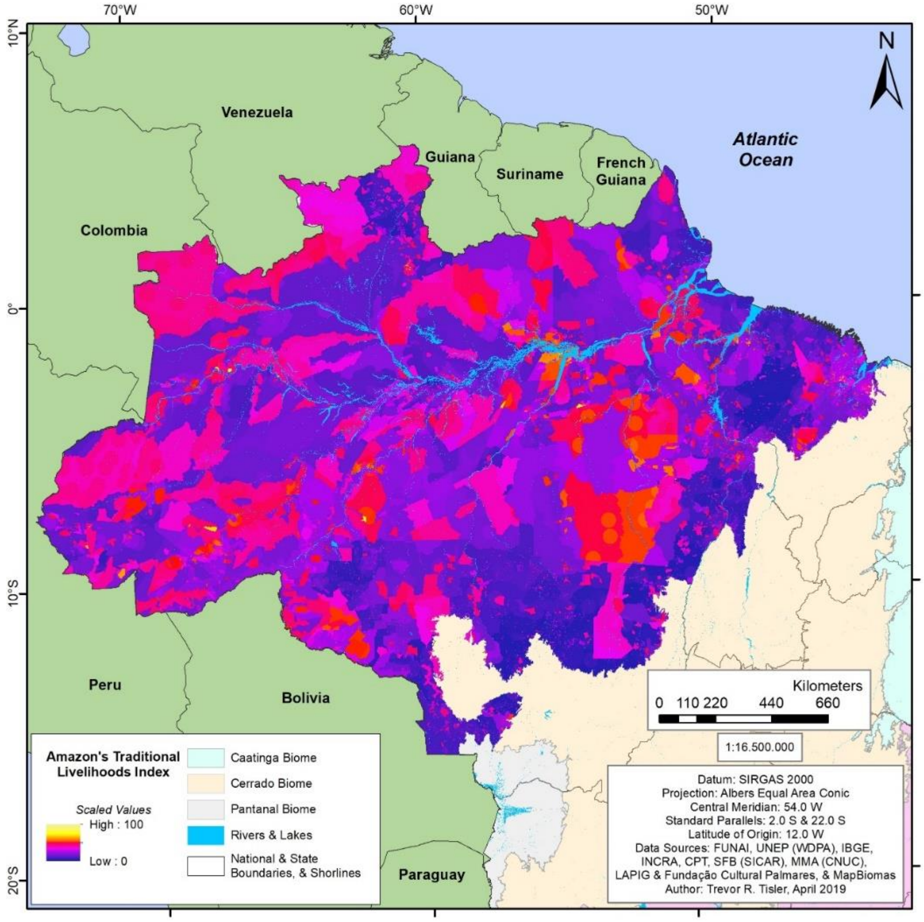

Figure 7: Amazon’s Traditional Livelihood Index

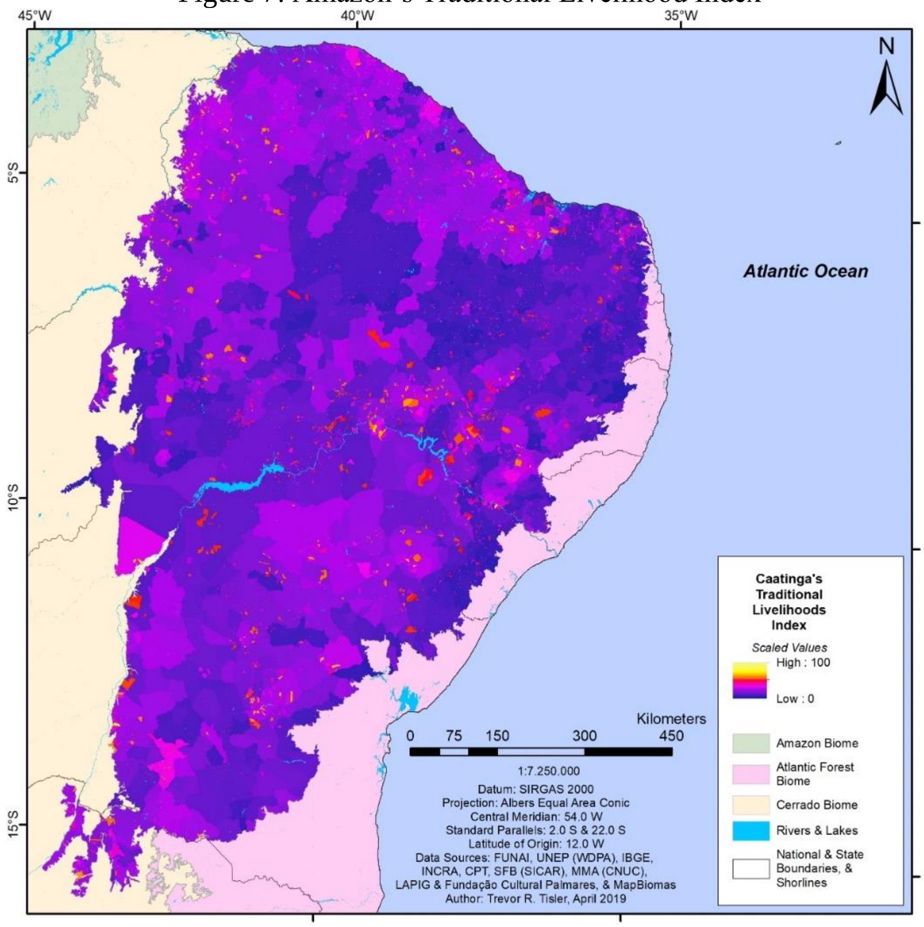

Figure 8: Caatinga’s Traditional Livelihood Index

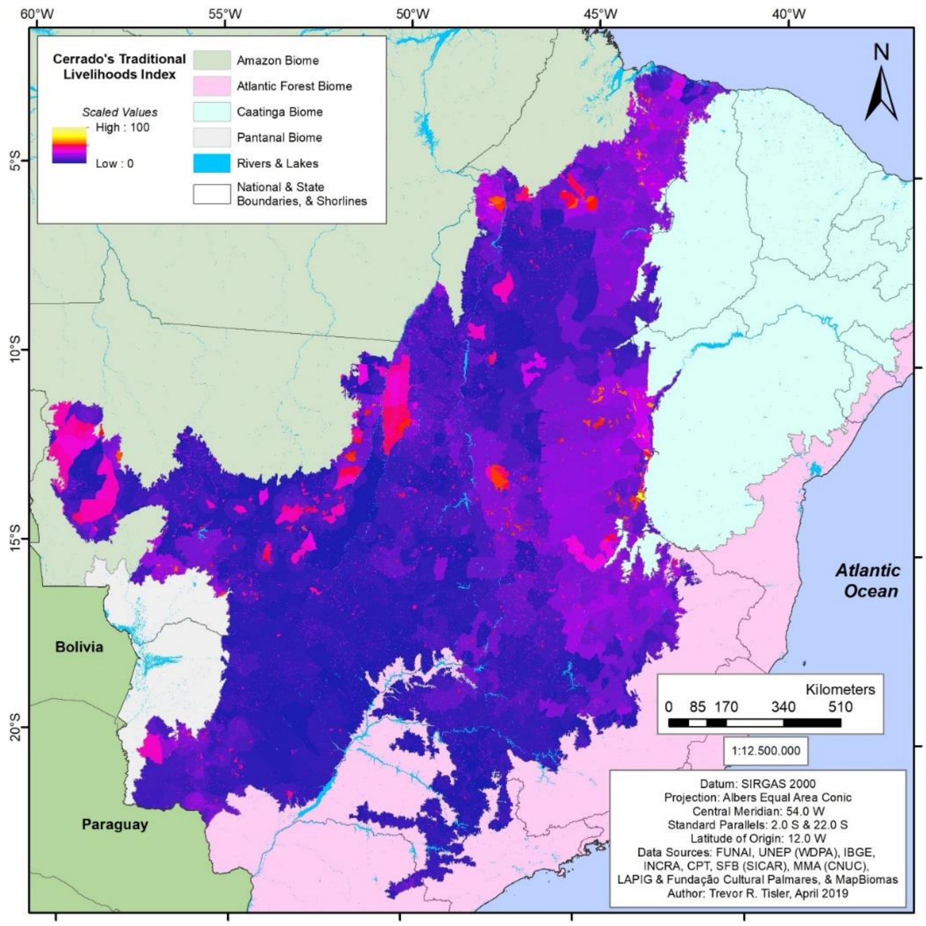

Figure 9: Cerrado's Traditional Livelihood Index

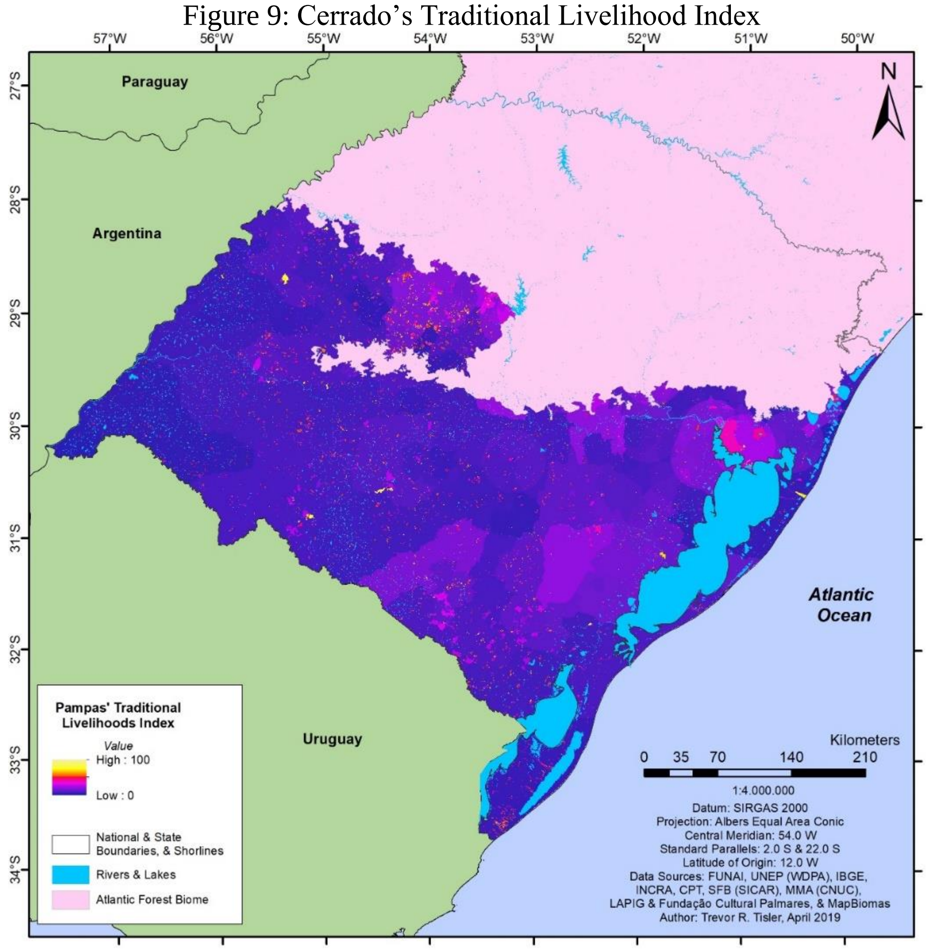

Figure 10: Pampa's Traditional Livelihood Index

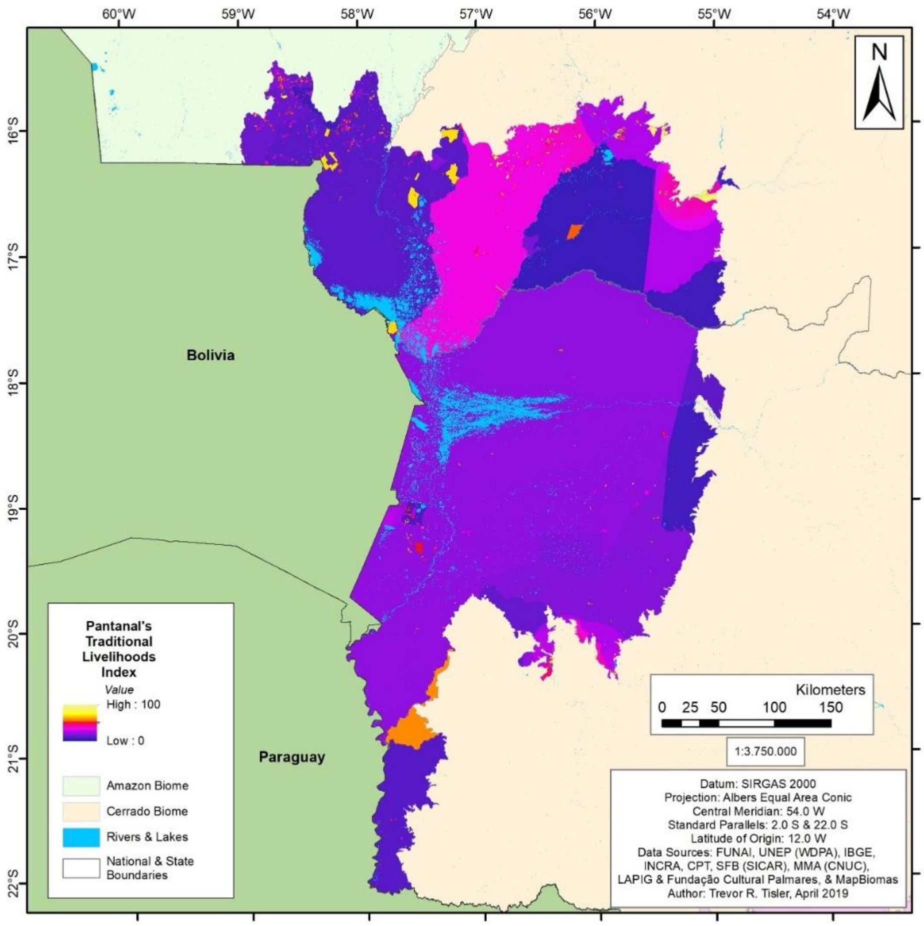

Figure 11: Pantanal’s Traditional Livelihood Index

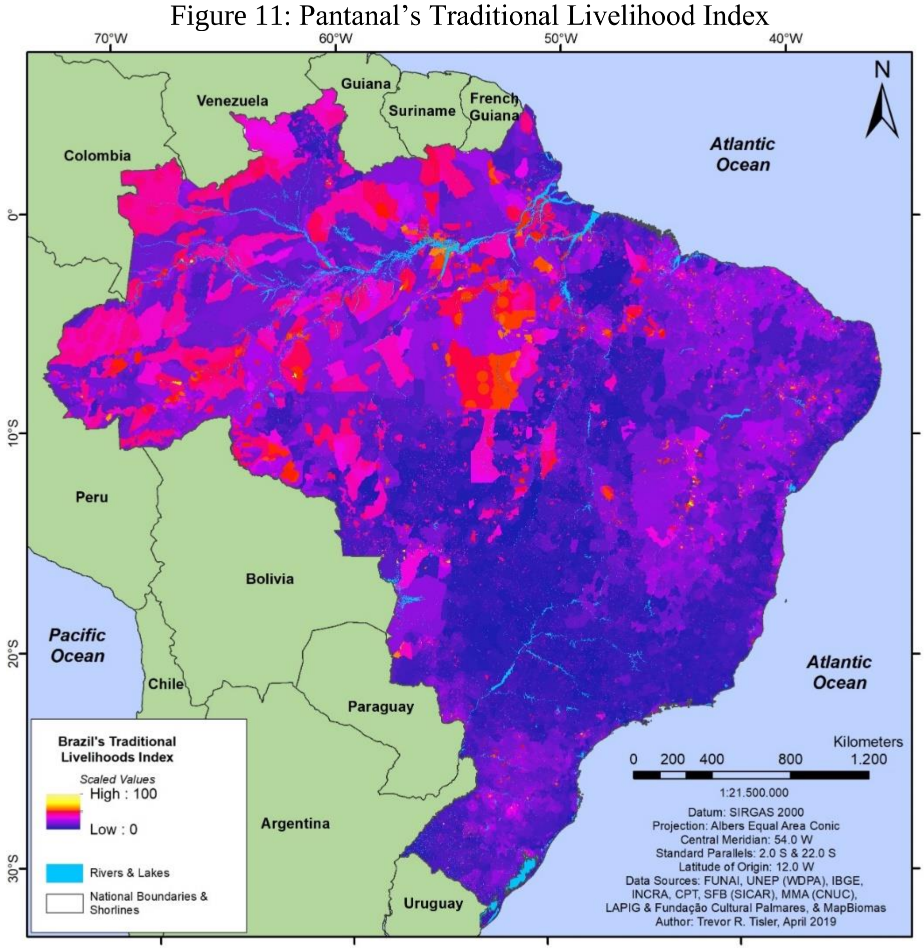

Figure 12. National Livelihood Index (Normalized per Biome and then re-joined together)

6.3.5 – RESULTS

We assumed the premise that Brazil's six biomes should be not have their traditional livelihood diversity compared to one another when arriving at the final index because, just as these biomes are biologically different, the majority of the traditional communities, their cultures and TEK would be a reflection of the biodiversity within their specific biome. In addition to the differences in management strategies for particular biome ecosystems, Brazil's biomes have also been impacted differently throughout history by different inflow migrant groups with different backgrounds. Moreover, the pre-colonization indigenous peoples of these different biomes have been contacted, impacted, 'integrated', or wiped out by mainstream society differently. We suppose that separate normalization per biome was necessary so that the differences in the biome specific socio-biological potentials are fairly considered. While this may come across as slightly environmental deterministic, the past investigations into the concept of biocultural diversity have shown that the world's most bio-culturally diverse areas are located in world's remaining Equatorial Tropical Rainforests (LOH; HARMON, 2005).

Once the final Traditional livelihood index (**Figure 12**) was composed and although we acknowledge that there are still legal and data issues involved with our approach, we were able to make the following observations. Firstly, we estimated spatial patterns of occupancy of traditional communities and livelihoods with two different confidence levels: 1 – higher confidence can be associated to estimates of indigenous (2 million km^2), quilombolas (2.8 million km^2) and agrarian reform settlers (435 thousand km^2); while, 2 – lower confidence is attributed to the estimates of the other PCT groups, which may possibly be located in 1633 of Brazil's 5,500+ counties, which cover an approximate area of 6 million km^2; and small scale farmers, which we were able to associate with all of Brazil's counties. The areas ranking at 20 or higher on the Traditional Livelihoods Diversity Index represent approximately half of the Brazil's continental territorial extent (**Figure 12**).

6.3.6 – DISCUSSION AND CONCLUSION

Traditional livelihoods and communities are important stakeholders in all land biomes in Brazil. For centuries, traditional communities in all 6 of Brazil's biomes have been using natural resources as part of their livelihoods (LEVIS et al., 2017; SCOLES; GRIBEL, 2015). In Brazil, even with acknowledged rights by the Brazilian Constitution (FC88) and federal legislation (**BOX 1**), and support from public policies from federal ministries and agencies, the values of traditional communities have hardly ever been included in a comprehensive and cross-sectoral way, at least by government actors, into a multi-scale governance framework. Moreover, there has been historic discrimination and disdain for traditional communities in past land management governance frameworks (DAYRELL, 2000; TEIXEIRA, 2005). In parallel, Brazil's contemporary cattle ranching, agro-business, and mineral extraction focused development paradigm has been infused with the country's prevailing political ideological discourse on all sides of the political spectrum, and as such has also been profoundly transforming traditional livelihoods (GOMES, 2009; GOMES; VADJUNEC; PERZ, 2012).

Despite a widespread agreement on the important role of traditional livelihoods in land management and while traditional communities are protected by the law (**Box 1**), we were unable to find other comprehensive attempts to map the diversity of livelihoods in Brazil. Moreover, there are scant examples in the literature of attempts to map multiple traditional livelihoods or communities at the state, biome or national levels. To our knowledge, based on our extensive background research into data sources, there is no comprehensively organized database that has organized spatial data for multiple traditional livelihoods in Brazil.

The results mapped in **Figure 12** show a first attempt at mapping the spatial patterns of occupancy for the diversity of actors and associated livelihoods, such as indigenous, maroons (quilombolas) and other traditional peoples and communities (e.g. extractivists, riberinhos, caiçaras, etc), small-scale family famers and agrarian reform settlers. We conducted this multi-scale analysis from 250m^2 pixels to the county scale throughout Brazil. Our work shows that this assessment is methodologically very challenging. Much of the data from the publicly available geospatial datasets used in creating the Traditional Livelihood Diversity Index in Brazil are managed by different institutions and are thus organized differently and mapped at different scales, which contributed to difficulties for this assessment. In addition to the data issues, the spatial pattern of occupancy is different among the different types of livelihoods. While indigenous lands do seem to have the appropriate scale (see **Figure 1**) for influencing large scale conservation initiatives (GARNETT et al., 2018), this may not be as easily the case for other livelihood types such as small-scale family farming (see **Figure 4**). We encourage the academic community to investigate ways forward for putting Brazil's traditional communities on the map. This will likely include publishing spatial data that better documents their occupancy locations in a comprehensive manner, whether for previously undocumented communities or for captured communities but with finer scales and more information. Finally, we highlight the necessity for this to be done with support of a publicly available database with strict data organization standards.

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