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ÉRICO EMED KAUANO

ÁREAS PROTEGIDAS NA AMAZÔNIA BRASILEIRA: ATIVIDADES ILEGAIS, EFICIÊNCIA DE GESTÃO E DESENVOLVIMENTO LOCAL

MACAPÁ, AP
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Orientador: Dra. Fernanda Michalski
Co-Orientador: Dr. Jose M. C. da Silva

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“Dedico este trabalho ao vô Zinho e a vó Clarice (In Memorian).”

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PREFÁCIO

Esta tese está dividida em três artigos, seguindo o formato alternativo proposto pelo Programa de Pós-Graduação em Biodiversidade Tropical (PPGBIO), que segue normas da Ecology para as referências bibliográficas. Todos os artigos foram formatados seguindo estas normas para fins de padronização. O artigo 1 é intitulado "Illegal use of natural resources in federal protected areas of the Brazilian Amazon" e foi publicado no periódico PeerJ (Qualis B2 na área de biodiversidade). O artigo 2 intitulado "Associations between management effectiveness, illegal activities, and deforestation in Brazilian Amazon federal protected areas" foi submetido ao periódico Journal for Nature Conservation (Qualis A2 na área de biodiversidade) e está em fase de revisão. O artigo 3 intitulado "Do protected areas hamper economic development of the Amazon region? An analysis of the relationship between protected areas and the economic growth of Brazilian Amazon municipalities" (Qualis B1 na área de biodiversidade) foi submetido ao periódico Land Use Policy e está em fase de revisão. A tese ainda é composta por uma introdução geral, objetivos gerais, hipóteses gerais, conclusões gerais, e fluxogramas sobre a decisão de uso dos métodos de cada artigo (anexos).

RESUMO

Emed Kauano, Erico. Áreas protegidas na Amazônia brasileira: atividades ilegais, eficiência de gestão e desenvolvimento local. Macapá, 2018. Tese (Doutorado em Biodiversidade Tropical) – Programa de Pós-graduação em Biodiversidade Tropical - Universidade Federal do Amapá.

A estratégia global de estabelecimento de Áreas Protegidas (APs) para a conservação da biodiversidade tem obtido sucesso, mas apesar dos avanços em relação ao aumento do número de áreas protegidas, muito esforço ainda deve ser realizado. A simples criação de um território especialmente protegido não é o suficiente para cessar os processos e atividades antrópicas que afetam negativamente o meio ambiente. O Brasil abriga 70% da Amazônia, a maior floresta tropical do mundo. Nas últimas três décadas, o governo brasileiro implementou uma grande rede de APs que atualmente cobre cerca de 48% da região. As APs da Amazônia brasileira protegem a biodiversidade do país, mantêm a subsistência dos povos indígenas e comunidades locais e fornecem serviços ecossistêmicos como regulação da qualidade do ar e da água, estabilização do solo, prevenção de enchentes e regulação do clima. No entanto, apesar da importância e dos avanços positivos no estabelecimento de APs, o uso ilegal dos recursos naturais na Amazônia brasileira ainda é generalizado, além do estigma de que a expansão de APs em toda a região dificulta o desenvolvimento econômico local. Neste sentido, o presente trabalho busca avaliar a relação entre o uso ilegal de recursos naturais dentro de APs com o tipo de manejo, idade das APs, densidade populacional e acessibilidade; avaliar a relação entre a eficiência de gestão de APs e a redução de duas grandes ameaças à biodiversidade: desmatamento (medida pela perda cumulativa de habitat dentro das APs) e a intensidade das atividades ilegais (medida por registros de infrações ambientais gerados por multas de fiscalização dentro de APs); e avaliar a relação entre o crescimento econômico local e a cobertura de APs em 516 municípios da Amazônia brasileira no periodo de 2004 a 2014.
Palavras-chave: Áreas Protegidas; Atividades Ilegais; Efetividade de Gestão; Crescimento Econômico; Amazônia Brasileira.

ABSTRACT

Emed Kauano, Erico. Protected areas in the Brazilian Amazon: illegal activities, management effectiveness and local development. Macapá, 2018. Thesis (PhD in Tropical Biodiversity) – Postgraduate Program in Tropical Biodiversity - Federal University of Amapá.

The global strategy for the establishment of Protected Areas (PAs) for biodiversity conservation has been successful, but despite advances in increasing the number of protected areas, much work remains to be done. The simple creation of a specially protected territory is not enough to cease anthropic processes and activities that negatively affect the environment. Brazil is home to 70% of the Amazon, the largest rainforest in the world. Over the last three decades, the Brazilian government has implemented a large network of PAs that currently covers about 48% of the region. PAs in the Brazilian Amazon protect the country's biodiversity, maintain the livelihoods of indigenous peoples and local communities, and provide ecosystem services such as air and water quality regulation, soil stabilization, flood prevention, and climate regulation. However, despite the importance and positive advances in the establishment of PAs, the illegal use of natural resources in the Brazilian Amazon is still widespread, in addition to the stigma that the expansion of PAs throughout the region hampers local economic development. In this sense, the present work seeks to evaluate the relationship between the illegal use of natural resources within PAs with the type of management, age of PAs, population density and accessibility; to assess the relationship between PAs management efficiency and the reduction of two major threats to biodiversity: deforestation (as measured by cumulative habitat loss within PAs) and the intensity of illegal activities (measured by records of environmental infractions generated by monitoring fines within PAs); and to evaluate the relationship between local economic growth and PAs coverage in 516 Brazilian Amazonian municipalities from 2004 to 2014.

Keywords: Protected Areas; Illegal Activities; Management Effectiveness; Economic growth; Brazilian Amazon

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1. INTRODUÇÃO GERAL

1. 1. Áreas Protegidas

As Áreas Protegidas (APs) podem ser entendidas como porções da paisagem mais restritivas às atividades humanas (Jenkins and Joppa 2009). A União Internacional para a Conservação da Natureza (International Union for Conservation of Nature – IUCN), define AP como uma superfície de terra e/ou mar especialmente destinada à proteção e manutenção da diversidade biológica, dos recursos naturais e do patrimônio cultural associado (Phillips 2004, Dudley 2013). Originalmente foram concebidas para proteger paisagens icônicas e animais selvagens, mas hoje, alcançam um conjunto cada vez mais diversificado de objetivos, sejam eles de conservação da natureza, sociais ou econômicos (Watson et al. 2014).

O estabelecimento de APs é considerado uma das principais estratégias para a preservação e conservação da natureza (Rodrigues et al. 2004). Avaliações recentes concluíram que na maioria das vezes, quando bem gerenciadas, reduzem as taxas de perda de habitat e proporcionam melhor manutenção dos níveis populacionais das espécies do que outras abordagens de gestão (Watson et al. 2014). As APs também armazenam estoques de carbono terrestre (auxiliando na mitigação e manutenção das mudanças climáticas) e ainda fornecem os meios de subsistência para milhares de pessoas (Bertzky et al. 2012).

As APs podem apresentar diferenças em relação aos objetivos de conservação, formas de gestão, denominação, e restrições de uso, dependendo do arcabouço legal do país onde estão inseridas (Jenkins and Joppa 2009). A IUCN estabelece seis categorias de APs (Tabela 1), que variam conforme a importância ecológica, o nível de antropização atual da área, bem como, um nível de interferência humana que seja aceitável (por exemplo, áreas com atividades como manejo florestal de impacto reduzido, manejo de açaizais, áreas com diversos usos do solo mas que mantem boa parte de suas características naturais e possuem grande importância ecológica, entre outras) (Figura 1).

No Brasil, as APs são constituídas pelas Terras Indígenas, Territórios Quilombolas, e as Unidades de Conservação (UCs), e para viabilizar a manutenção e conservação de todas as APs do território nacional, o governo brasileiro possui várias estratégias políticas, contidas em diferentes instrumentos, como o Sistema Nacional de Unidades de Conservação (SNUC), o Cadastro Nacional de UCs, o Plano Estratégico Nacional de Áreas Protegidas (PNAP) e

programas e projetos de alcance nacional (BRASIL 2000, Brasil 2006, Rylands and Brandon 2005). As UCs estão distribuídas em 12 categorias (Tabela 2) que se diferenciam principalmente em relação ao nível de restrição de uso e ocupação do solo. As UCs podem ser agrupadas em Proteção Integral ou Uso Sustentável, conforme definição dada pela Lei 9985, de 2000, que institui o Sistema Nacional de Unidades de Conservação (SNUC) (BRASIL 2000).

Tabela 1: Categorias de manejo de APs, segundo a IUCN (Phillips 2004, Ravenel and Redford 2005, Dudley 2013)

Categoria	Descrição
Ia - Reserva Natural Estrita	Área protegida para a ciência.
Ib - Reserva de vida selvagem	Área protegida dedicada especialmente à proteção da vida selvagem.
II - Parque Nacional	Área protegida dedicada especialmente à proteção do ecossistema e recreação.
III - Monumento Natural	Área protegida dedicada especialmente à conservação de características naturais específicas.
IV - Área de Manejo de Habitats/Espécies	Área protegida dedicada especialmente à conservação por meio de ações de manejo.
V - Paisagem Protegida Terrestre e/ou Marinha	Área protegida dedicada especialmente à proteção de paisagens terrestres e/ou marinhas e recreação.
VI - Área Protegida com Manejo de Recursos	Área protegida dedicada especialmente ao uso sustentável dos recursos naturais.

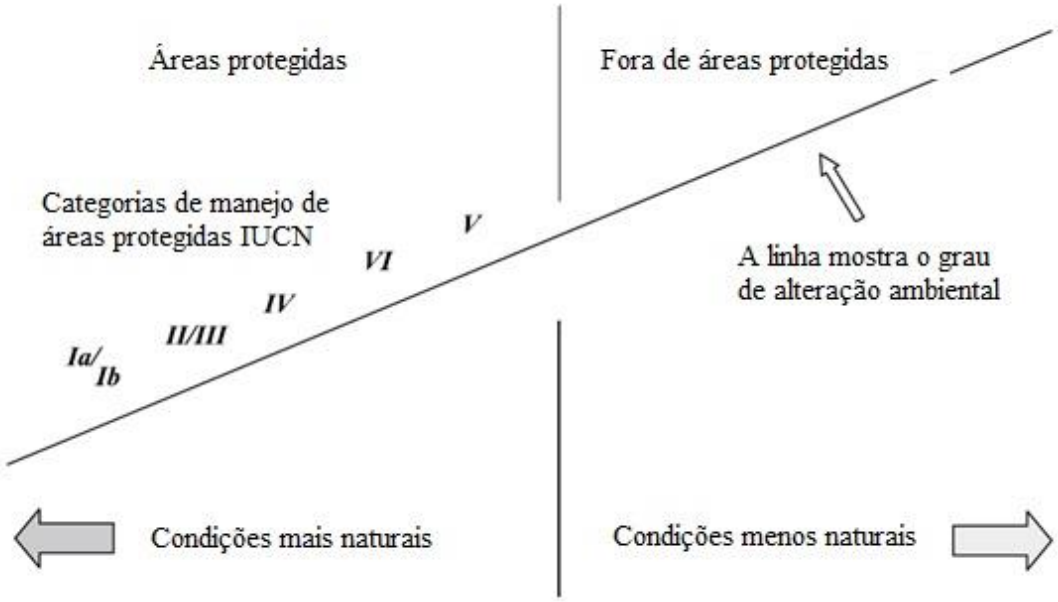

Figura 1: Categorias de manejo de APs, segundo a IUCN, em relação as condições naturais (Phillips 2002).

As Unidades de Proteção Integral têm como objetivo básico a manutenção dos ecossistemas livres de alterações causadas por interferência humana, e permite apenas o uso indireto dos seus atributos naturais. As Unidades de Uso Sustentável, além do objetivo de conservar a natureza, permitem a exploração do ambiente de maneira a garantir a perenidade dos recursos ambientais renováveis e dos processos ecológicos, e também, permitem que populações tradicionais que viviam na localidade antes da criação da UC continuem vivendo nestas áreas (BRASIL 2000).

O Brasil ainda possui as Áreas de Preservação Permanente (APPs), e as Reservas Legais (RLs), que foram instituídas pelo Código Florestal Brasileiro de 1965, e alteradas pelo "Novo Código Florestal" (Brasil 2012). O Plano Nacional de Áreas Protegidas (PNAP) (Freitas 2009) considera as APPs e as RLs como elementos de grande importância na escala da paisagem, que possuem uma função estratégica na conectividade entre fragmentos naturais e as próprias áreas protegidas.

Tabela 2: Tipos de Unidades de Conservação segundo o Sistema Nacional de Unidades de Conservação (SNUC) e sua correlação com o sistema de classificação da IUCN.

Grupo	Categoria	
	SNUC	**IUCN**
Proteção Integral	Estação Ecológica	Ia e Ib
	Reserva Biológica	Ia e Ib
	Parque Nacional, Estadual, Municipal	II
	Monumento Natural	III
	Refúgio de vida Silvestre	Ib
Uso Sustentável	Área de Proteção Ambiental	-
	Área de Relevante Interesse Ecológico	-
	Floresta Nacional	VI
	Reserva Extrativista	VI
	Reserva de Fauna	IV ou VI
	Reserva de Desenvolvimento Sustentável	VI
	Reserva Particular do Patrimônio Natural	II

1. 2. Distribuição das Áreas Protegidas no Brasil e no Mundo

A Convenção da Diversidade Biológica (Convention on Biological Diversity – CBD) estabeleceu a criação de APs como um dos objetivos estratégicos para melhorar a situação da biodiversidade mundial. A meta 11 da CDB prevê que até o ano 2020, pelo menos 17% de áreas terrestres e de águas continentais e 10% de áreas marinhas e costeiras estarão sendo conservados por meio de sistemas de APs ecologicamente representativas, gerenciadas de maneira efetiva e equitativa, e satisfatoriamente interligadas (Convention on Biological Diversity 2010, Woodley et al. 2012).

Atualmente, as APs cobrem 15,4% da superfície terrestre e de águas continentais, 3,4% dos oceanos, 10,9% de áreas costeiras (0 até 12 milhas náuticas) e 8,4% em águas de jurisdição das nações (0 até 200 milhas náuticas) (Juffe-Bignoli et al 2014). Uma avaliação do atual

“estado” da distribuição das APs no mundo (Watson et al. 2014) demonstra haver um déficit de cobertura de APs de ecorregiões terrestres (827 ecorregiões) e marinhas (237 ecorregiões) em relação à meta 11 da CBD (Figura 2a). Até 2014 somente 300 ecorregiões terrestres (36%) possuíam uma cobertura maior do que 17% e apenas 46 (20%) das ecorregiões marinhas possuíam uma cobertura maior do que 10%.

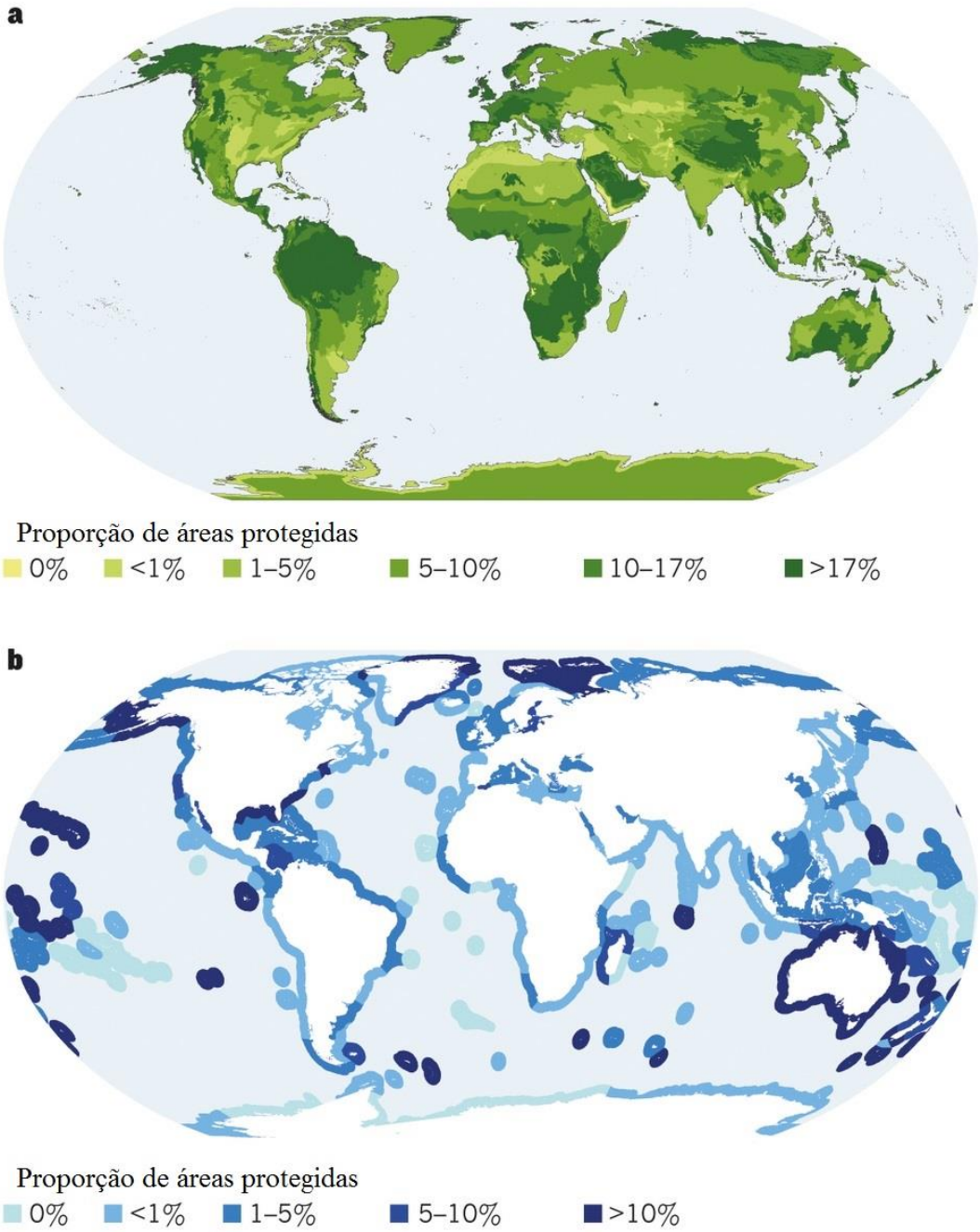

Figura 2: Porcentagem de APs no mundo em relação a cada ecorregião do planeta, terrestres (a) e marinhas (b), no ano de 2014 (Watson et al. 2014).

O Brasil é um dos países que mais avançaram em relação à criação de APs, mais especificamente no estabelecimento de UCs, entre os anos de 2003 e 2008 foi responsável pela criação de 74% das áreas protegidas estabelecidas no mundo (Jenkins and Joppa 2009). Segundo dados do Cadastro Nacional de Unidades de Conservação – CNUC o país possuía até o ano de 2015, 16,9% de sua área continental e 1,5% de sua área marinha em UCs (MMA 2015).

Conforme dados do CNUC (MMA 2015) o Brasil possui 1940 UCs distribuídas no âmbito Federal, Estadual e Municipal, e em sua maior parte (69,8%, n = 1354) são de Uso Sustentável (Tabela 3). Esta maior quantidade de UCs de Uso Sustentável só não é observada no nível municipal que possui mais UCs de Proteção Integral. No âmbito federal existe a maior quantidade de UCs (954) principalmente devido à grande quantidade de Reservas Particulares do Patrimônio Natural – RPPNs, que são particulares, mas são criadas na esfera federal.

Tabela 3: Quantidade de Unidades de Conservação do Brasil e tipos de UCs dentro de cada categoria, na esfera Federal, Estatual, e Municipal, e a quantidade de área correspondente em km² até 2015 (adaptado de MMA 2015).

Tipo/Categoria	**Esfera**						**Total**	
	Federal		**Estadual**		**Municipal**			
Proteção Integral	N°	Área (Km²)	N°	Área (Km²)	N°	Área (Km²)	N°	Área (Km²)
Estação Ecológica	32	74.691	58	47.513	1	9	91	122.213
Monumento Natural	3	443	28	892	11	73	42	1.407
Parque Nacional / Estadual / Municipal	71	252.978	195	94.889	95	221	361	348.088
Refúgio de Vida Silvestre	7	2.017	24	1.729	1	22	32	3.768
Reserva Biológica	30	39.034	24	13.449	6	48	60	52.531
Total Proteção Integral	**143**	**369.164**	**329**	**158.472**	**114**	**372**	**586**	**528.007**
Uso Sustentável	N°	Área (Km²)	N°	Área (Km²)	N°	Área (Km²)	N°	Área (Km²)
Floresta Nacional / Estadual / Municipal	65	163.913	39	136.053	0	0	104	299.966
Reserva Extrativista	62	124.362	28	20.208	0	0	90	144.570
Reserva de Desenvolvimento Sustentável	2	1.026	29	110.090	5	176	36	111.293
Reserva de Fauna	0	0	0	0	0	0	0	0
Área de Proteção Ambiental	32	100.101	185	334.898	77	25.922	294	460.922
Área de Relevante Interesse Ecológico	16	447	24	443	8	32	48	921
RPPN	634	4.832	147	686	1	0	782	5.517
Total Uso Sustentável	**811**	**394.681**	**452**	**602.377**	**91**	**26.131**	**1354**	**1.023.189**
Total Geral	**954**	**763.845**	**781**	**760.848**	**205**	**26.503**	**1940**	**1.551.196**
Área Considerando Sobreposição Mapeada	**954**	**758.733**	**781**	**755.661**	**205**	**26.479**	**1940**	**1.513.828**

Visualmente é possível observar que na Amazônia Legal ocorrem as maiores áreas em tamanho, tanto de UCs como de terras indígenas, em relação às outras regiões do país (Figura 3). De certa forma, este fato também representa o processo de uso e ocupação do solo por atividades antrópicas muito mais estabelecido nas outras regiões, o que reflete uma menor disponibilidade de áreas nas demais regiões e seus ecossistemas (principalmente em relação ao tamanho).

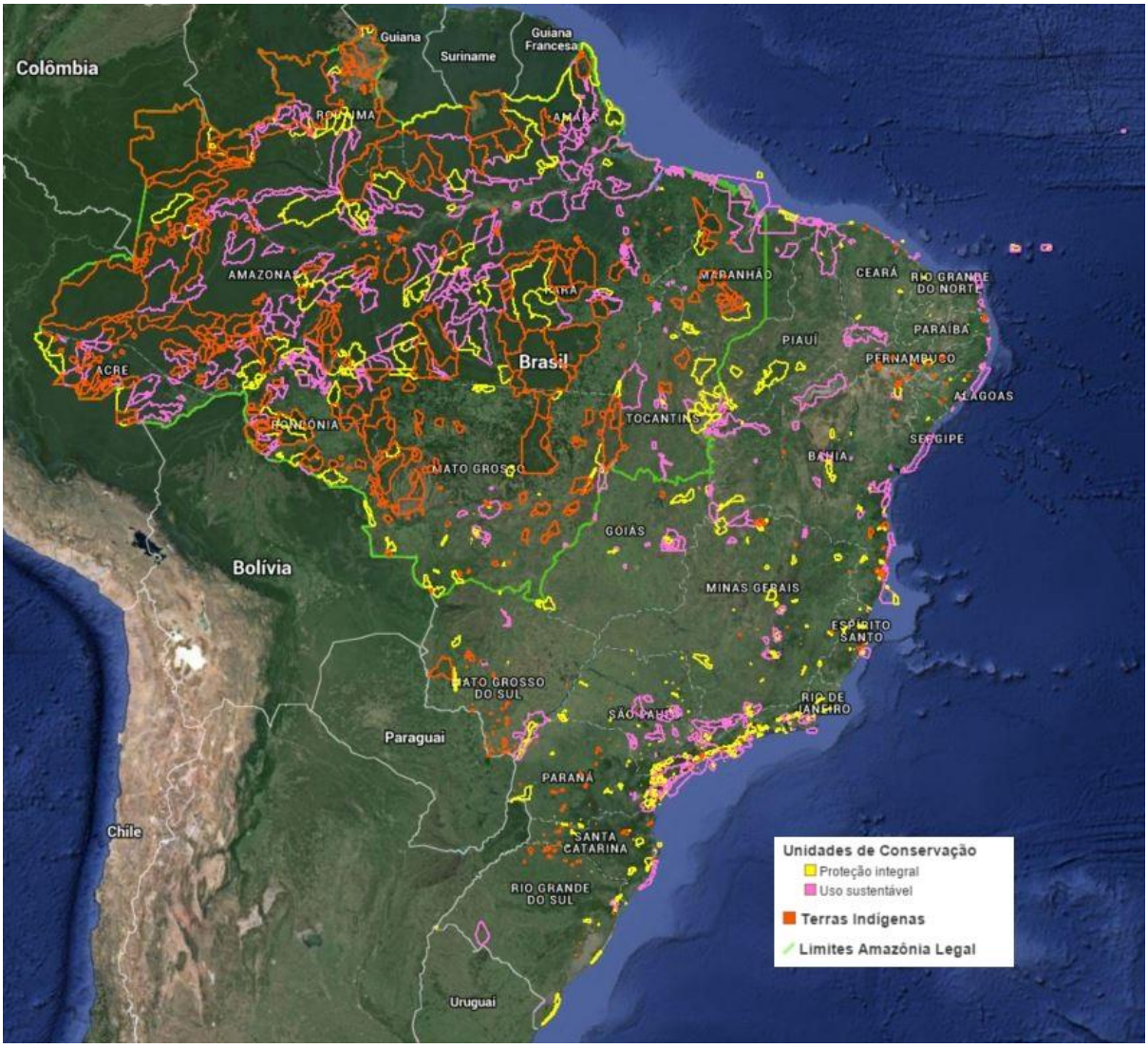

Figura 3: Unidades de Conservação do Brasil (Federais, Estaduais e Municipais) divididas em Proteção Integral (amarelo) e Uso Sustentável (rosa), Terras Indígenas (vermelho), e limites da Amazônia Legal (verde) (adaptado de ISA 2015).

A Amazônia Legal Brasileira possui 137 Unidades de Conservação Federais (Figura 4) totalizando uma área de 638.352,69 de km², sendo que destas áreas protegidas 88 são da categoria de Uso Sustentável (64,23 %) e 49 de Proteção Integral (35,77 %). Apesar de existir uma maior quantidade de Unidades de Conservação de Uso Sustentável, em relação à quantidade de território protegido as duas categorias possuem áreas totais próximas, 329.800,90 km² em Proteção Integral (51,66 %) e 308.551,78 km² em Uso Sustentável (48,34 %).

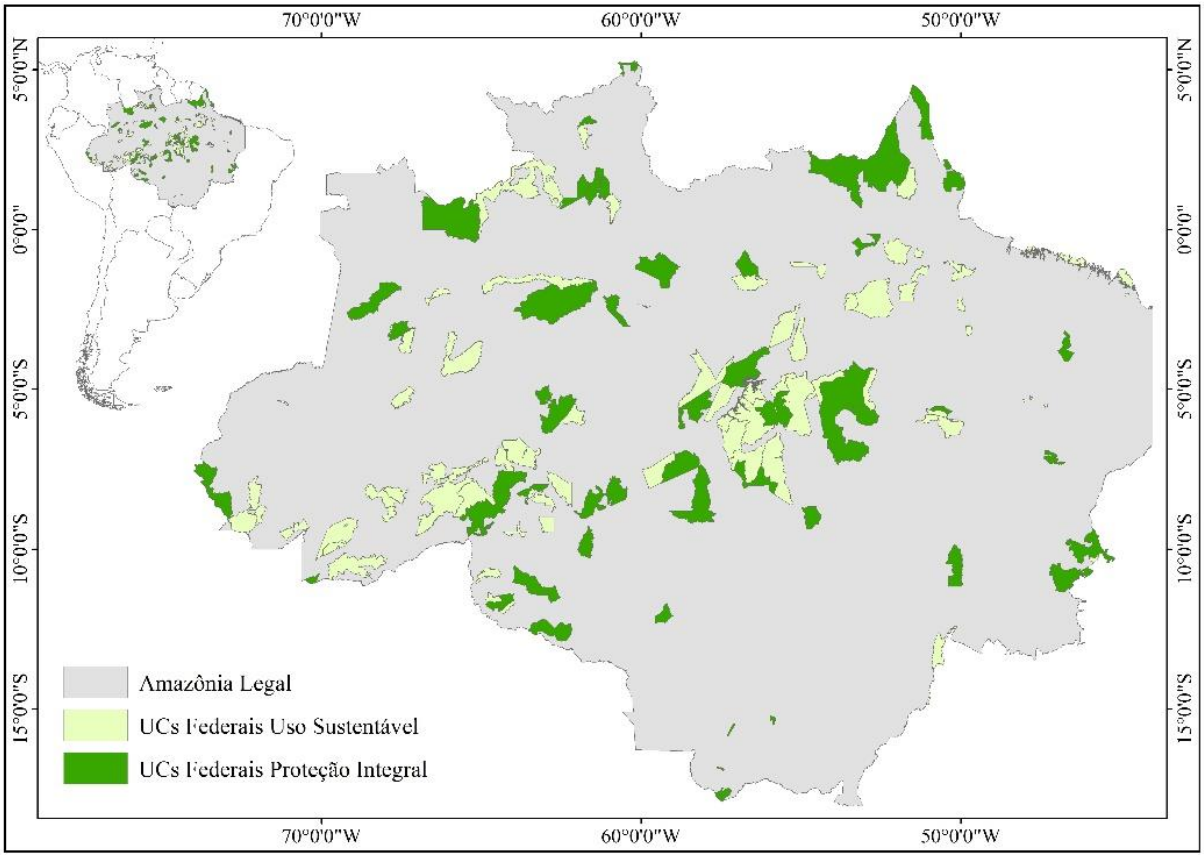

Figura 4: Unidades de Conservação Federais da Amazônia Legal Brasileira.

Tabela 4: Número de UCs na Amazônia Legal em relação à categoria e área correspondente.

Tipo/Categoria	**N°**	**Área (km²)**
Proteção Integral		
Estação Ecológica	15	71.523,42
Reserva Biológica	9	36.381,43
Parque Nacional	25	221.896,06
Total Proteção Integral	**49**	**329.800,91**
Uso Sustentável		
Área de Proteção Ambiental	4	24.642,59
Área de Relevante Interesse Ecológico	3	189,31
Floresta Nacional	32	162.862,85
Reserva de Desenvolvimento Sustentável	1	644,42
Reserva Extrativista	48	120.212,61
Total Uso Sustentável	**88**	**308.551,78**
Total Geral	**137**	**638.352,69**

1. 3. Conflitos de Conservação e Ameaças às Áreas Protegidas

Conflitos de conservação ocorrem quando duas ou mais partes discordam sobre os objetivos de conservação, e quando uma das partes impõe seus interesses em detrimento dos interesses da outra, e podem ser divididos em dois componentes principais: 1) Conflitos gerados pela interação direta entre as pessoas e outras espécies, e 2) Conflitos centrados na interação humana entre aqueles que buscam a conservação de espécies e aqueles com outros objetivos (Redpath et al. 2013). Geralmente, são percebidos como impactos negativos sobre atividades humanas, por meio de impactos diretos e indiretos sobre a pecuária, a agricultura, a silvicultura e a pesca (Milner and Redpath 2013).

Os conflitos entre a conservação da biodiversidade e outras atividades de interesse humano ocorrem em todos os tipos de habitats e podem prejudicar severamente os parâmetros biológicos e sócio econômicos (Young et al. 2010). Atualmente estes conflitos tem tido um

grande aumento, podendo prejudicar a manutenção de espécies a longo prazo (Redpath et al. 2013) e estão sendo documentados dentro e fora das APs na Ásia, África, e também no Brasil (Weladji and Tchamba 2003, Michalski et al. 2006, 2012, Gusset et al. 2009).

Apesar da realização de compromissos globais no sentido de aumentar o tamanho e a eficácia da gestão das APs (ex. CBD), há evidências significativas que alguns governos estão regredindo em seu compromisso de apoiar as APs por meio de grandes cortes de financiamento e/ou orçamento, reduções de pessoal e ignorando as suas próprias políticas. Se este fato representar uma tendência global, muitas APs ficarão seriamente expostas, especialmente no contexto dos níveis preexistentes de orçamentos inadequados e crescentes ameaças para a conservação (Watson et al. 2014).

No Brasil, existe uma tendência de retrocesso em relação à conservação da natureza pelos legisladores, e existem diversos exemplos de alterações de legislação, propostas de alteração de legislação, e posicionamentos de alguns setores do governo brasileiro, que mostram claramente esta inversão de valores dos nossos políticos. O Novo Código Florestal é um caso emblemático, que foi aprovado apesar das evidências científicas contra as alterações (Metzger 2010) e a maior parte da população do país se mostrar contra estas modificações, como pode ser observado em dados de pesquisa do Datafolha mostrando que 79% da população brasileira se manifestaram contra as modificações realizadas (Valera 2014).

Mudanças recentes na política de conservação brasileira têm favorecido projetos de infraestrutura e de conversão de terras agrícolas, mesmo quando estas iniciativas estão em conflito direto com as unidades de conservação já estabelecidas. Diversas mudanças em relação a tamanho (diminuição do tamanho da área das UCs), recategorização (alteração para categorias menos restritivas quanto às alterações ambientais), extinção, estão sendo propostas (Marques and Peres 2014).

Bernard et al. (2014) identificaram 93 eventos desta natureza de 1981 a 2012 e apontam que estes eventos aumentaram em frequência desde 2008, atribuídas principalmente à geração e transmissão de energia elétrica na Amazônia. Em parques e reservas brasileiras, 7,3 milhões de hectares já foram afetados por estes tipos de eventos e projetos de alteração que estão em andamento no Congresso Federal podem reduzir 2,1 milhões de hectares de APs na Amazônia. Segundo (Ferreira et al. 2014), poucas APs estão livres de sofrer influência de redução de tamanho devido à implantação de usinas hidroelétricas.

A Mineração é outra grande fonte de conflitos e ameaças, (Durán et al. 2013), em uma avaliação global, demonstraram que aproximadamente 7% das jazidas dos metais mais explorados no mundo sobrepõem-se diretamente com APs e 27% delas estão em um raio de 10 km da fronteira de algumas APs. Além deste fato, existe a mineração destes metais em 6% das APs no mundo, e 14% das áreas com exploração destes, encontram-se a 10 km dos limites de APs. Dadas as distâncias nas quais os impactos destas atividades podem ter influência, o tempo de persistência dos seus efeitos, e considerando o rápido crescimento da demanda por metais, há uma necessidade urgente para limitar ou solucionar esses conflitos.

No Brasil, o projeto de Lei (PL) 1610/96 pretende possibilitar o desenvolvimento de atividade mineral em UCs de uso sustentável e Terras Indígenas, e o PL 3682/2012 quer determinar que 10% da área de UCs de proteção integral sejam destinadas para a mineração, bem como, proibir a criação de novas UCs em áreas de potencial mineral ou potencial hidrelétrico. (Ferreira et al. 2014), verificaram que estas mudanças podem prejudicar uma grande quantidade de UCs e TIs, o que poderá causar danos irreversíveis.

Ferreira et al. (2014), verificaram que em todo território brasileiro existem 1,65 milhão de km² com alguma forma de interesse de mineração registrada e deste total, 1,01 milhão de km² estão situados na Amazônia. Embora relativamente poucas áreas foram realmente liberadas para exploração mineral, pelo menos 20% de todas as UCs de proteção integral e as TIs se sobrepõem com áreas com registros de títulos minerários, demonstrando o potencial da ocorrência de efeitos negativos generalizados se uma pequena fracção é autorizada. Somente na Amazônia 34.117 km² de UCs de proteção integral (8,3%) e 281,443 km² de TIs (28,4%) se encontram em áreas de interesse mineral.

Outra questão que também é prejudicial à conservação da natureza, pois, produz muitos conflitos no mundo inteiro e muitas vezes uma aversão às APs e aqueles que trabalham em prol da conservação, é a exclusão das pessoas ou determinados grupos que a existência de APs muitas vezes impõe devido aos seus objetivos, restrições de uso ou necessidade de manter um baixo nível de alteração. E também muitas vezes, o radicalismo das partes dos que querem conservar e das pessoas com outros interesses, ou mesmo entre os próprios conservacionistas com diferentes visões ou correntes de conservação que existem. Algumas destas diferentes visões da conservação podem ser observadas em trabalhos científicos (Mace 2014).

1.4. Atividades Ilegais em Áreas Protegidas

Laurance et al. (2012) identificaram que, além do desmatamento, em todos os três continentes tropicais, a extração de madeira, os incêndios florestais e a coleta excessiva (caça e colheita de produtos florestais não-madeireiros) são as principais ameaças à integridade das APs tropicais. Muitas dessas ameaças, diferentemente do desmatamento, são difíceis de detectar (por exemplo, incêndio de superfície, mineração/garimpo de ouro em pequena escala, extração seletiva de madeira) ou indetectáveis (por exemplo, caça e extração de produtos vegetais não madeireiros) mesmo por técnicas sofisticadas de sensoriamento remoto (Peres, Barlow & Laurance, 2006). Nesse sentido, as atividades de fiscalização in loco podem resultar em uma riqueza de informações sobre a magnitude e os tipos de atividades ilegais (atividades lesivas ao meio ambiente) que ocorrem dentro das APs (Gavin, Solomon & Blank, 2010) que não são detectadas pelas técnicas de sensoriamento remoto comumente utilizadas.

No Brasil, as atividades lesivas ao meio ambiente são definidas como atividades ilegais por um conjunto de normas que vem evoluindo ao longo tempo. O paragrafo 3º, do artigo 225, da Constituição Federal do Brasil diz que "as condutas e atividades consideradas lesivas ao meio ambiente sujeitarão os infratores, pessoas físicas ou jurídicas, a sanções penais e administrativas, independentemente da obrigação de reparar os danos causados" (Brasil 1988). A Lei de Crimes Ambientais (Lei n° 9.605, de 1998) (Brasil 1998) dispõe sobre as sanções penais e administrativas derivadas de condutas e atividades lesivas ao meio ambiente. E o Decreto n° 6.514, de 2008 (Brasil 2008), dispõe sobre as infrações e sanções administrativas ao meio ambiente, e estabelece o processo administrativo federal para apuração destas infrações.

O Decreto n° 6.514, de 2008, é o principal instrumento utilizado pelos órgãos responsáveis pela fiscalização de atividades ilegais (atividades lesivas ao meio ambiente) em APs. Segundo o Decreto n° 6.514, de 2008, as infrações ambientais podem ser enquadradas em 68 tipos e agrupadas em 6 grandes categorias: Infrações Contra a Fauna, Infrações Contra a Flora, Infrações Relativas a Poluição e outras Infrações Ambientais, Infrações Contra o Patrimônio Urbano e o Patrimônio Cultural, Infrações Administrativas Contra a Administração Ambiental e Infrações Cometidas Exclusivamente em Unidades de Conservação.

De uma maneira geral, quando uma equipe de fiscalização verifica uma atividade ilegal (por exemplo, caça, pesca irregular, desmatamento), um auto de infração pode ser gerado por um agente de fiscalização. A irregularidade então é enquadrada segundo o Decreto n° 6.514, de

2008, e sanções são aplicadas conforme a necessidade (por exemplo, multa, apreensão de animais, embargo de atividade). O Instituto Chico Mendes de Conservação da Biodiversidade – ICMBio, é órgão do governo brasileiro (vinculado ao Ministério do Meio Ambiente) que desde 2007 administra e fiscaliza as UCs Federais (Brasil 2007).

1.5. Eficiência de Gestão em Áreas Protegidas

A avaliação da efetividade de gestão de uma AP pode ser definida como a avaliação de como a AP está sendo gerenciada, principalmente pela verificação de como ela está protegendo seus alvos de conservação, bem como, atingindo suas metas e objetivos de criação (Hockings et al. 2006). Uma maior efetividade pode ser atingida por meio de testes e avaliações das atividades de gestão, sintetizando os dados disponíveis e relevantes, e a comunicação dos resultados de maneira que as futuras decisões sejam tomadas com base nesses resultados e mudanças necessárias para o alcance dos objetivos da AP possam ser implementados (Keene and Pullin 2011).

Hockings et al. (2000) identificam quatro abordagens gerais para avaliar a efetividade de APs: extensão (tamanho) e localização da AP; avaliações em larga escala (por exemplo, impactos do desmatamento); a eficiência da gestão da AP (Protected Area Management Effectiveness - PAME) e os resultados da AP (um subconjunto mais detalhada do PAME). Essas avaliações podem permitir que os formuladores de políticas e tomadores de decisão, desenvolvam estratégias para a resolução de problemas de gestão, destacando os pontos fracos e ameaças que afetam diretamente o sucesso de APs (Hockings 2000, Ervin 2003).

A eficiência de gestão não é um conceito novo na área da conservação e ferramentas e métodos necessários para coletar e utilizar informações para medir e melhorar a eficiência dos programas, políticas e intervenções específicas, estão sendo estabelecidos dentro e fora do setor ambiental (Stem et al. 2005). Avaliações da eficiência de gestão estão sendo amplamente utilizados por doadores e gestores de projetos de conservação para priorizar, monitorar e avaliar os investimentos de recursos e esforços em áreas protegidas (Nolte and Agrawal 2013). Por exemplo, a Fundação Gordon e Betty Moore, a Fundação de Caridade Doris Duke e outros grupos que contribuem com milhões de dólares para projetos de conservação, estão exigindo cada vez mais que os recebedores destes recursos forneçam evidências de que os resultados

ambientais e sociais propostos estão sendo alcançados, bem como o prazo para o alcance destes resultados (Keene and Pullin 2011).

Em 2000, a Comissão Mundial de Áreas Protegidas da IUCN (World Commission on Protected Areas - WCPA) publicou o “Marco WCPA” para avaliar a efetividade das APs com base na gestão de ciclo de projeto, com seis elementos: de contexto, planejamento, insumos, processos, produtos e resultados de gestão. O trabalho ganhou ampla aprovação na comunidade internacional de conservação e gerou o desenvolvimento e testes de várias metodologias de avaliação (Stem et al. 2005).

A metodologia RAPPAM (Rapid Assessment and Prioritization of Protected Area Management) tem como objetivo fornecer aos tomadores de decisão uma ferramenta que possibilite a priorização de ações de manejo em um conjunto de áreas protegidas em uma escala abrangente, permitindo uma avaliação da eficiência da gestão de um sistema de áreas protegidas de um país ou região (Ervin 2003). Segundo Leverington et al. (2008), a metodologia foi implementada em cerca de 40 países e mais de 1000 áreas protegidas na Europa, Ásia, África e América Latina e no Caribe, tendo sido desenvolvida originalmente para avaliar redes de áreas protegidas pelo World Wild Life Fund - WWF entre 1999 e 2002.

O método RAPPAM pode (1) identificar os pontos fortes de gestão, limitações e fraquezas; (2) Analisar o âmbito, a gravidade, a prevalência e distribuição de uma grande variedade de ameaças e pressões; (3) identificar áreas de alta importância e vulnerabilidade ecológica e social; (4) indicar a urgência e prioridade de conservação de áreas protegidas individuais; e (5) ajudar a desenvolver e priorizar as intervenções políticas adequadas e acompanhamento de passos para melhorar a eficácia da gestão da área protegida. Além disso, proporciona a possibilidade de responder a uma série de questões importantes: Quais são as principais ameaças que afetam o sistema de APs, e quão sério são elas?; Como comparar áreas protegidas umas com as outras em termos de infraestrutura e capacidade de gestão?; Como comparar de forma eficaz produtos e resultados de conservação, como resultado da gestão das APs?; Qual é a urgência de implementação de ações em cada área protegida (Leverington et al. 2008). No entanto, há pouca evidência de que estas avaliações reflitam a capacidade das áreas protegidas em entregar resultados concretos de conservação (Nolte and Agrawal 2013).

1.6. Áreas Protegidas e Desenvolvimento Local na Amazônia Brasileira

A ocupação da Amazônia Brasileira foi realizada em periodos devastadores, ligados à valorização momentânea de produtos no mercado internacional, alternados por longos períodos de estagnação (Becker 2001). Seu povoamento e desenvolvimento foram fundados de acordo com o paradigma de uma economia de fronteira, com o crescimento econômico sendo linear e infinito, e baseado na contínua incorporação de terras e de recursos naturais (Becker 2005). A história da ocupação é uma "história de perda e danos". No início da colonização foi um lugar com muitos índios que podiam servir como escravos. Foi uma fonte de riqueza na época das especiarias do interior. Tornou-se um dos maiores produtores e exportadores de borracha do mundo. E posteriormente e até hoje em dia, tem sido uma extraordinária fonte de minérios, de produção de energia (principalmente hidrelétrica), de fornecimento de madeira, e de fornecimento de terras para a expansão do agronegócio (Loureiro 2002).

As alterações na dinâmica de uso e ocupação do solo da região, tiveram o inicio de sua intensificação a partir de 1950 com implementação de projetos de integração da Amazônia (Tavares, 2011) e inauguração das rodovias Belém-Brasília e Transamazonica nas décadas de 1960 e 1970 (Fearnside 2005, Vieira et al. 2008). Culminando com os Planos Plurianuais de desenvolvimento do governo Brasileiro a partir de 1996 e os Planos de Aceleração do Crescimento (PAC 1 e 2) de 2008 a 2015 (Fearnside & Laurance 2012). Estas alterações transformaram a dinâmica de organização do espaço amazônico que passou do padrão Rio-várzea-floresta para o padrão Rodovia-Terra Firme-Subsolo. O primeiro padrão, predominou na região até a década de 50 do século XX e caracteriza-se pela sua organização às margens dos rios, com a exploração econômica da floresta. Já o padrão Rodovia-Terra Firme-Subsolo tem como caracteristica a ocupação da região ao longo das rodovia, com atividades voltadas para a exploração econômica da terra firme (pecuária e agricultura) e do subsolo (atividades minerais) (Tavares 2011).

Em 2004, o desmatamento da Amazônia brasileira atingiu 27.772 km2, o que levou o governo brasileiro a elaborar um plano de longo prazo para controlar o desmatamento e afastar a região do modelo tradicional de fronteira para um plano de desenvolvimento mais centrado na conservação (Hecht 2012), o Plano de Ação para Prevenção e Controle do Desmatamento na Amazônia Legal (PPCDAm). O PPCDAm combinou um conjunto de iniciativas, incluindo aquelas focadas na expansão de áreas protegidas, o reconhecimento de terras indígenas, e apoio à produção sustentável, incluindo assistência técnica e financiamento para intensificação

agrícola (Silva et al. 2017). O que levou o Brasil a ser um dos países que mais avançou na criação de APs, entre 2003 e 2008 foi responsável pela criação de 74% das áreas protegidas no mundo (Jenkins e Joppa 2009). No período de 2004 a 2007 sobre a influência do PPCDAm, foram criados aproximadamente 20 milhões de hectares de Unidades de Conservação, principalmente em zonas de alta pressão de desmatamento na porção oriental da Amazônia, bem como, 10 milhões de hectares de Terras Indígenas. Estas novas APs funcionaram como uma "barreira verde" para a expansão da agricultura e levou a taxa de desmatamento na Amazônia Brasileira diminuir cerca de 79% no periodo de 2004 a 2015 (Thaler 2017).

Em contrapartida, a expansão de APs significa menos áreas para fins agrícolas e minerais. O que pode ser visto como um obstáculo ao desenvolvimento local, regional e nacional. De fato, a hipótese tradicional é que as APs atrasam o desenvolvimento econômico. De acordo com Loureiro (2002), a biodiversidade da Amazônia foi ignorada, questionada e combatida pelas políticas públicas. Essas políticas estabeleceram uma oposição entre desenvolvimento e conservação ambiental. O desenvolvimento sustentável não integra políticas públicas como condição essencial e quando aparece, é confinado e limitado a alguns programas específicos dos setores e agências ambientais. O que podemos verificar depois dos avanços relacionados ao aumento de areas protegidas, fiscalização, promoção de ações para o desenvolvimento sustentável, e inserção da "conservação" nos ultimos planos de desenvolvimento econômicos, é um sistematico contra ataque por parte dos setores mais "desenvolvimentistas" que vem impondo "agendas" mais aliadas a econômia de fronteira e conseguido retrocessos do ponto de vista da conservação, com a proposição e efetiva alteração de leis, diminuindo e dificultando a criação de novas APs, entre outras ações (Bernard et al. 2014; Fearnside 2016; Marques and Peres 2014).

Os impactos socioeconômicos que as APs podem produzir sobre os territórios onde estão inseridas, pode ser considerado como uma das principais questões relacionadas as políticas de conservação da biodiversidade. Estes impactos podem ser verificados em diferentes escalas (locais ou regionais) e podem ser tanto positivos quanto negativos. De fato, a relação entre desenvolvimento e biodiversidade é muito complexa. Alguns estudos destacam que a proteção e a conservação da biodiversidade contribuem para um dos mais importantes objetivos de desenvolvimento do milênio das Nações Unidas, que é a redução da pobreza. Mas em contraste, outros trabalhos afirmam que as APs ampliam a pobreza local ou que não há um efeito claro entre conservação e desenvolvimento (Castillo-Eguskitza, Rescia, & Onaindia,

2017). Por exemplo, Thaler (2017) verificou que a criação de APs nas áreas de expansão agrícola da Amazonia Brasileira não diminuiu o crescimento da produção agrícola nestas mesmas regiões, e que na verdade, aumentou consideravelmente.

Pullin et al (2013) verificaram que a base de evidências fornece uma série de possíveis caminhos de impacto das APs sobre o bem-estar humano (tanto positivos como negativos) e que o conjunto de pesquisas relatadas até o momento ainda são inadequadas do ponto de vista de informar a elaboração de políticas públicas que possam melhorar o alcance de resultados de ganha-ganha para a biodiversidade e o desenvolvimento. Neste sentido, é necessário que mais estudos procurem avaliar a relação entre APs e desenvolvimento econômico, e em áreas de grande importância ecológica, de dimensões continentais, com grandes diferenças regionais, e uma grande quantidade de APs, como é o caso da Amazônia Brasileira, avaliações econométricas que levem em consideração as relações espaciais podem gerar melhores resultados para o entendimento do crescimento econômico da região, bem como, a influência das APs sobre este crescimento.

2. OBJETIVOS

2.1 Objetivo Geral

O presente trabalho tem como objetivo geral analisar alguns aspectos da relação entre Áreas Protegidas da Amazônia Brasileira e a ocorrência de atividades ilegais, eficiência de gestão, e o desenvolvimento econômico dos municipios da região.

2.2. Objetivos específicos

2.2.1. Artigo 1

Apesar de todos esses esforços recentes para a conservação da Amazônia Brasileira, a degradação dos recursos naturais na região ainda é generalizada e as APs estão sujeitas a várias pressões e ameaças. Quatro fatores principais determinam a intensidade das pressões em um AP: (a) acessibilidade; (b) densidade populacional local; c) a categoria de gestão (proteção integral e uso sustentável); e (d) idade do PA. Desta forma, o primeiro capítulo tem como objetivo avaliar os registros de infrações ambientais gerados entre 2010 e 2015 em 118 unidades de conservação federais da Amazônia Brasileira, relacionar a quantidade de infracão com os 4 fatores que determinam a intensidade das pressões, e assim, obter um melhor entendimento da distribuição geográfica do uso ilegal de recursos nestas áreas protegidas.

2.2.2 Artigo 2

Diversos métodos tem sido propostos para avaliar a eficiência do manejo de uma AP, mas estudos descobriram que altos escores de eficiência de gestão nem sempre estão associados a resultados de conservação (por exemplo, conservação efetiva de espécies ou ecossistemas). O método de Avaliação Rápida e Priorização de Manejo de Áreas Protegidas (RAPPAM) é amplamente utilizado para avaliar a eficiência de gestão de unidades de conservação no Brasil e no mundo, mas poucos estudos examinaram como os resultados desse método se relacionam com a redução das ameaças à biodiversidade. Por este motivo, o estudo teve como objetivo avaliar como o método RAPPAM está correlacionado com atividades ilegais (representadas

pelo número de registros de infrações ambientais de 2010 a 2015) e o desmatamento acumulado (2010 para 2015) em 94 unidades de conservação federais na Amazônia brasileira.

2.2.3. Artigo 3

Setores da sociedade brasileira argumentam que a expansão das APs na região Amazônica dificulta o desenvolvimento econômico local por diminuir a área disponível para atividades econômicas convencionais, como agricultura e agropecuária em larga escala, mineração e geração de energia. Com o objetivo de analisar esta relação conflituosa o estudo avaliou a relação entre o crescimento econômico local e a cobertura de áreas protegidas em 516 municípios da Amazônia brasileira de 2004 a 2014, por meio da modelagem do impacto da cobertura de unidades de conservação de proteção integral, unidades de conservacão de uso sustentável e terras indígenas na taxa de crescimento anual do produto interno bruto per capita em cada município. O trabalho buscou ainda, contribuir para o esforço contínuo de entender as sinergias e as compensações entre áreas protegidas e o crescimento econômico local em diferentes contextos socioeconômicos.

3. HIPÓTESES

3.1. Artigo 1

- A classificação das unidades de conservação em proteção integral e uso sustentável tem gerado uma série de discussões sobre qual categoria é mais eficiente na redução do uso ilegal de recursos naturais. Embora alguns especialistas não acreditem na eficiência da conservação da biodiversidade a longo prazo em unidades de conservação de uso sustentável, outros acreditam que a adoção dessa classe de unidade de conservacão é a uma estratégia de conservação mais eficaz e inclusiva. Neste sentido, testamos a hipótese de que unidades de conservação de uso sustentável possuem menos atividades ilegais por apresentarem menos restrições de uso do que as unidades de conservação de proteção integral;

- A idade de uma unidade de conservação (ou o tempo desde a sua criação) é frequentemente correlacionada com melhores resultados de conservação. Avaliações em reservas marinhas revelam que áreas que estão protegidas a mais tempo apresentam um aumento na quantidade e riqueza de espécies de peixes. No entanto, a relação da idade com os resultados de conservação de uma unidade de conservação pode ser antagônica, com algumas unidades de conservação mais jovens obtendo melhores resultados no combate ao desmatamento. No estudo, consideramos a hipótese de que menos atividades ilegais ocorrem em unidades de conservação mais antigas porque elas têm estruturas administrativas e gerenciamento melhor estabelecidas que as mais recentes;

- Nas florestas tropicais, observa-se uma relação positiva entre o aumento da população humana e a extração de recursos naturais e o desmatamento. No entanto, na Amazônia brasileira, essa relação nem sempre é positiva. Enquanto em algumas regiões a densidade populacional não é uma causa direta do desmatamento, em outros pode ser uma das principais causas. Desta maneira, testamos a hipótese de que unidades de conservação com maior densidade populacional local tendem a ter mais atividades ilegais por causa da maior pressão antrópica;

- A acessibilidade das unidades de conservação pode ser medida pela avaliação de rios navegáveis e estradas que cruzam ou formam os limites de uma determinada área. Alguns autores estimam que grande parte da bacia amazônica no Brasil pode ser acessada a pé a partir do rio ou via funcional mais próxima e que a densidade de espécies preferidas são caçadas em

áreas mais próximas aos pontos de acesso (por exemplo, estradas, rios). Na Amazônia, até 1997, cerca de 90% do desmatamento estava concentrado em áreas dentro de 100 km das principais estradas estabelecidas pelos programas de desenvolvimento do governo federal. Assim, avaliamos se unidades de conservação com maior acessibilidade tendem a ter mais atividades ilegais.

3.2. Artigo 2

- Índices de eficiência de gestão podem estar relacionados com a capacidade da unidade de conservação em identificar atividades ilegais e combater o desmatamento. Neste sentido, consideramos a hipótese de que unidades de conservação com altos valores do índice de efetividade RAPPAM são associadas à alta capacidade de identificar atividades ilegais, e portanto apresentam um número maior de atividades ilegais. Por outro lado, altos valores do índice de efetividade RAPPAM são associadas a uma melhor capacidade de vigilância, o que resulta em uma menor quantidade de desmatamento;

- Na avaliação RAPPAM o contexto, em que uma unidade de conservação esta inserida, é carcterizado pela importância biológica da unidade de conservação, por sua importância socioeconômica, e por sua vulnerabilidade a fatores antrópicos. Assim, testamos a hipótese de que unidades de conservação com contextos mais favoráveis e com baixa vulnerabilidade apresentarão menos atividades ilícitas e desmatamento;

- O RAPPAM possui índices que representam diversos aspectos relacionados ao manejo das unidades de conservação (por exemplo, objetivo e recursos financeiros). Desta forma, consideramos hipóteses de que unidades de conservação com objetivos claros, design adequado, com boa segurança jurídica, sem conflitos fundiários, devidamente sinalizada, e com os recursos financeiros, humanos, e materiais (equipamentos) necessários para realizar a gestão, irão possuir maior capacidade de identificar atividades ilegais e evitar o desmatamento.

3.3. Artigo 3

As APs variam em relação ao nível de restrições de uso, apresentando áreas mais restritivas e outras que permitem diversos tipos de atividades econômicas. Desta forma, APs com grandes restrições de uso nem sempre geram ganhos monetários para as economias locais,

equanto APs com mesmos restrições de uso podem contribuir para o crescimento econômico local. Considerando a legislação Brasileira que limita a exploração de recursos naturais dentro de unidades de conservação de proteção integral e terras indígenas, e que permite a exploração econômica dos recursos naturais nas unidades de conservação de uso sustentável, testamos as seguintes hipóteses:

- A cobertura de unidades de conservação de proteção integral e terras indígenas nos municípios da Amazônia brasileira possuem relação negativa ou não possuem relação com o crescimento econômico destes municípios, pois a presença destas áreas, bem como a porcentagem de cobertura, restringe o uso do território para atividades econômicas mais convencionais (por exemplo, produção de soja, criação de gado e mineração) sem trazer retornos monetários que possam compensar a restrição imposta;

- A cobertura de unidades de conservação de uso sustentável nos municípios da Amazônia brasileira possuem relação positiva com o crescimento econômico destes municípios. Apesar da presença destas áreas e suas porcentagens de cobertura restringirem o estabelecimento de atividades econômicas convencionais, podem trazer retornos financeiros pelo uso sustentado dos recursos naturais renováveis (por exemplo, manejo florestal de impacto reduzido, manejo de açaizais, manejo do pirarucu), e desta forma gerar retornos monetários que possam compensar a restrição.

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ARTIGO CIENTÍFICO 1

Illegal use of natural resources in federal protected areas of the Brazilian Amazon

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Illegal use of natural resources in federal protected areas of the Brazilian Amazon

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ABSTRACT

Background. The Brazilian Amazon is the world's largest rainforest regions and plays a key role in biodiversity conservation as well as climate adaptation and mitigation. The government has created a network of protected areas (PAs) to ensure long-term conservation of the region. However, despite the importance of and positive advances in the establishment of PAs, natural resource depletion in the Brazilian Amazon is pervasive.

Methods. We evaluated a total of 4,243 official law enforcement records generated between 2010 and 2015 to understand the geographical distribution of the illegal use of resources in federal PAs in the Brazilian Amazon. We classified illegal activities into ten categories and used generalized additive models (GAMs) to evaluate the relationship between illegal use of natural resources inside PAs with management type, age of PAs, population density, and accessibility.

Results. We found 27 types of illegal use of natural resources that were grouped into 10 categories of illegal activities. Most infractions were related to suppression and degradation of vegetation (37.40%), followed by illegal fishing (27.30%) and hunting activities (18.20%). The explanatory power of the GAMs was low for all categories of illegal activity, with a maximum explained variation of 41.2% for illegal activities as a whole, and a minimum of 14.6% for hunting activities.

Discussion. These findings demonstrate that even though PAs are fundamental for nature conservation in the Brazilian Amazon, the pressures and threats posed by human activities include a broad range of illegal uses of natural resources. Population density up to 50 km from a PA is a key variable, influencing illegal activities. These threats endanger long-term conservation and many efforts are still needed to maintain PAs that are large enough and sufficiently intact to maintain ecosystem functions and protect biodiversity.

Subjects Biodiversity, Conservation Biology, Ecology, Environmental Sciences, Legal Issues
Keywords Illegal activities, Protected areas, Conservation, Natural resources, Amazon

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Abstract

Background. The Brazilian Amazon is the world's largest rainforest regions and plays a key role in biodiversity conservation as well as climate adaptation and mitigation. The government has created a network of protected areas (PAs) to ensure long-term conservation of the region. However, despite the importance of and positive advances in the establishment of PAs, natural resource depletion in the Brazilian Amazon is pervasive. **Methods.** We evaluated a total of 4,243 official law enforcement records generated between 2010 and 2015 to understand the geographical distribution of the illegal use of resources in federal PAs in the Brazilian Amazon. We classified illegal activities into ten categories and used generalized additive models (GAMs) to evaluate the relationship between illegal use of natural resources inside PAs with management type, age of PAs, population density, and accessibility. **Results.** We found 27 types of illegal use of natural resources that were grouped into 10 categories of illegal activities. Most infractions were related to suppression and degradation of vegetation (37.40%), followed by illegal fishing (27.30%) and hunting activities (18.20%). The explanatory power of the GAMs was low for all categories of illegal activity, with a maximum explained variation of 41.2% for illegal activities as a whole, and a minimum of 14.6% for hunting activities. **Discussion.** These findings demonstrate that even though PAs are fundamental for nature conservation in the Brazilian Amazon, the pressures and threats posed by human activities include a broad range of illegal uses of natural resources. Population density up to 50 km from a PA is a key variable, influencing illegal activities. These threats endanger long-term conservation and many efforts are still needed to maintain PAs that are large enough and sufficiently intact to maintain ecosystem functions and protect biodiversity.

Keywords: Illegal activities; Protected areas; Conservation; Natural resources; Amazon

Introduction

The Brazilian Amazon is one of the world's largest rainforest regions and plays a key role in biodiversity conservation, maintenance of ecosystem services, and storage of terrestrial carbon stocks (Laurance et al. 2001). In recent years, many advances have been made in combating the widespread and illegal use of the region's natural resources. Political actions based on the establishment of new protected areas (PAs), increases in law enforcement, and support for forest-based economic activities have resulted in a significant deforestation reduction in the region (Fearnside 2005, Silva et al. 2005, Nepstad et al. 2009). In 2010, an extensive network of PAs protected about 54% of the remaining forests of the Brazilian Amazon and contained around 56% of its forest carbon (Soares-Filho et al. 2010).

The creation and maintenance of PAs is the most effective way to protect vast areas of tropical forests in the Brazilian Amazon (Soares-Filho et al. 2006, Soares-Filho et al. 2010, Dalla-Nora et al. 2014). Recent studies have indicated that PAs can reduce deforestation and pave the way to a more sustainable use of the region's natural resources (Nepstad et al. 2006, Nepstad et al. 2009, Barber et al. 2012, Nepstad et al. 2014, Pfaff et al. 2015). However, despite all these recent efforts, natural resource degradation in the Brazilian Amazon is still pervasive and thus PAs are subjected to several pressures and threats. Four major factors determine the intensity of pressures on a PA: (a) accessibility; (b) local human population density; (c) management category; and (d) age of the PA.

Accessibility of PAs can be measured by evaluation of navigable rivers and roads that cross or form the boundaries of a given reserve (Peres and Terborgh 1995). Peres and Lake (2003) estimate that much of the Amazon basin in Brazil can be accessed on foot from the nearest river or functional road and found that the density of preferred hunted species tended to decrease in areas closer to access points (e.g., roads, rivers). In Amazonia, until 1997, about 90% of deforestation was concentrated in areas within 100 km of main roads established by federal government development programs (Alves 2002).

In tropical forests, a positive relationship is observed between the increase in both human population and natural resource extraction, and deforestation (Laurance et al. 2002, Lopez-Carr et al. 2009, Lopez-Carr and Burgdorfer 2013). However, in the Brazilian Amazon, this relationship is not always positive. While in some regions population density is not a direct cause of deforestation, in others it may be one of the leading causes (Jusys 2016, Tritsch and Le Tourneau 2016).

The age of the PA (or the time since its creation) is often correlated with better conservation results. Assessments in marine reserves reveal that areas that have been protected for longer show an increase in the quantity and richness of fish species (Claudet et al. 2008, Molloy et al. 2009). However, the relationship of PA age with conservation results may be antagonistic, with some younger PAs in the Brazilian Amazon obtaining better results in relation to reduction or avoidance of deforestation compared with older PAs (Soares-Filho et al. 2010).

The classification of PA classes according to the International Union for Conservation of Nature (IUCN) criteria (Dudley 2008), into strictly protected (I-IV) and sustainable use (or multiple use) management classes (V-VI), has generated several discussions on the efficiency of one category or another in reducing the illegal use of natural resources (Nelson and Chomitz 2011). While some experts do not believe in the efficiency of multiple-use PAs in conserving biodiversity in the long term, others believe adoption of this class of PA will lead to a more effective and inclusive conservation strategy (Schwartzman et al. 2010, de Toledo et al. 2017).

Laurance et al. (2012) identified that in addition to the deforestation, across all three tropical continents logging, wildfires, and overharvesting (hunting and harvest of non-timber forest products) are major threats to tropical PA integrity. Many of these threats, unlike deforestation, are difficult to detect (e.g., surface fire, small-scale gold mining, selective logging) or undetectable (e.g., hunting and exploitation of animal products and extraction of non-timber plant products) even with increasingly sophisticated remote sensing techniques (Peres et al. 2006). In this sense, on the ground enforcement activities can result in a wealth of information about the magnitude and types of illegal activities occurring within PAs (Gavin et al. 2010) that are not detected by commonly used remote sensing techniques.

In this study, we evaluated the illegal use of natural resources within 118 federal PAs in the Brazilian Amazon, through the analysis of 4243 illegal activities (infraction records) obtained from law enforcement activities in the period of 2010-2015. First, we categorized illegal activities to determine the main threats found within PAs. Then, we used the infraction records to evaluate the following hypotheses about the intensity of pressures on PAs from illegal activities: (a) fewer illegal activities occur in sustainable use PAs because they have fewer use restrictions than PAs under integral protection; (b) fewer illegal activities occur in older PAs because they have better established administrative structures and management than newer ones; (c) PAs with higher local population density tend to have more illegal activities because

of greater anthropogenic pressure; and (d) PAs with greater accessibility tend to have more illegal activities.

Materials & Methods

Data sources

The data used as explanatory variables were obtained from the following publicly available sources: a shapefile describing the geographic boundaries of the Amazon biome from Ministério do Meio Ambiente (MMA 2016); a shapefile describing the geographic boundaries of federal PAs (conservation units) from Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio 2016b); shapefiles describing water bodies (water masses) and rivers (multiscale ottocoded hydrographic base 2013) from Agência Nacional de Águas (ANA 2013); a shapefile describing roads at 1:250000, and limits of Brazil and South America from Instituto Brasileiro de Geografia e Estatística (IBGE) (IBGE/DGC 2015); and shapefiles describing the populational “grid” of Brazil from IBGE (IBGE 2016b).

The data on illegal use of natural resources (illegal activities) used were standardized and made available to authors by the Instituto Chico Mendes de Conservação da Biodiversidade/ Divisão de Informação e Monitoramento Ambiental (ICMBio/DMIF 2017). The maps presented in this study (Fig. 1, Fig. S1, Fig. S2) and area calculations were produced in an equal area projection (Projection: Albers Equal Area Conic; Datum: South America 1969). The geographic information system (GIS) environment was created and the elaboration of spatial variables performed based on geographic data obtained from official sources, in ArcGIS 10.2 software (ESRI 2013). The data on illegal activities compiled and formatted for our study are available in Data S1.

Brazilian Amazon

We delimited the Brazilian Amazon (Fig. 1) according to the boundaries of the Amazonia biome as defined by the Instituto Brasileiro de Geografia e Estatística (IBGE 2004). The IBGE’s proposal follows the boundaries laid out in the original extension of the tropical rainforests of northern Brazil (Góes Filho and Veloso 1982), which is inside the tropical moist broadleaf forests biome (Olson et al. 2001). The Brazilian Amazon covers an area of around 4.3 million km², about 50% of the of the country's territory. The region has a population of roughly 21.6 million people, 72% of whom live in cities in nine Brazilian states (Amazonas,

Acre, Rondônia, Roraima, Amapá, Pará, Mato Grosso, Maranhão, and Tocantins) (Silva et al. 2017).

Federal protected areas

We evaluated 118 federal PAs established before 2010 in the Brazilian Amazon, totaling an area of around 600000 km² (Fig. 1, Table 1, Table S1). Of these 118 PAs, 38 are strictly protected (Biological Reserve (Rebio), n = 9, IUCN Ia; Ecological Station (Esec), n = 10, IUCN Ia; and National Park (Parna), n = 19, IUCN II), and 80 are sustainable use (Area of Relevant Ecological Interest (Arie), n = 3, IUCN IV; Environmental Protection Area (Apa), n = 2, IUCN V; National Forest (Flona), n = 32, IUCN VI; Sustainable Development Reserve (RDS), n = 1, IUCN VI; and Extractive Reserve (Resex), n = 42, IUCN VI). Although fewer strictly protected than sustainable use reserves were analyzed, these two major classes of PA have similar total areas (strictly protected: roughly 295000 km² and sustainable use: roughly 305000 km^2). In total, we studied 91.5% of the PAs managed by the federal government in Amazonia, which corresponds roughly 76% of the total territory in federal PAs. Overall, Brazil have 789280 km² distributed in 326 PAs managed by the federal government across the country and 127 PAs in Amazonia (ICMBio 2016a).

All PAs are forested, with a few also featuring grasslands and savannas. Thirteen PAs are coastal/marine reserves. We excluded nine areas established after 2010, because we analyzed the period of illegal activity spanning from 2010 to 2015. In our study, only PAs (conservation unities) managed by the federal government under the Brazilian System of Conservation Units (SNUC) (Brasil 2000) were evaluated. Therefore, for the purpose of this study, we excluded state, municipal and private areas, as well as indigenous lands and quilombola lands (traditional Afro-Brazilian communal territories).

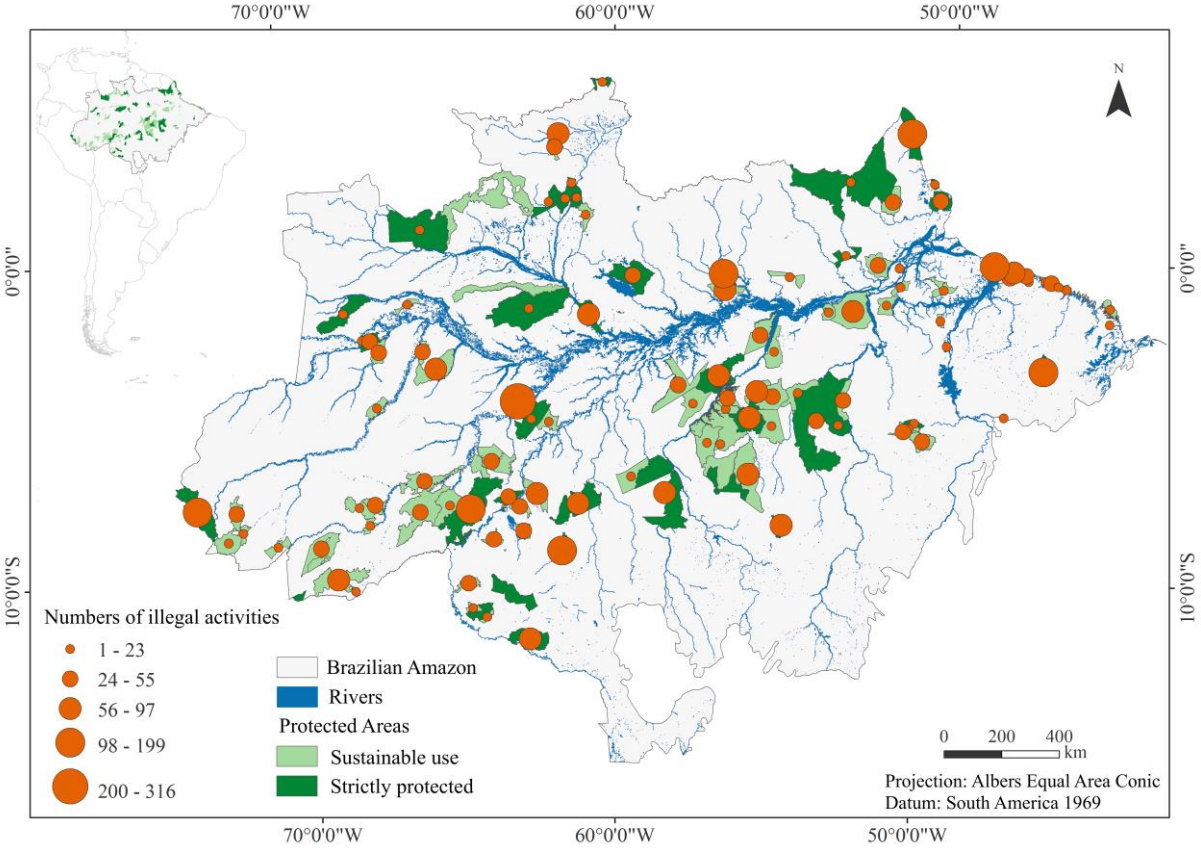

Figure 1. Illegal activities in the Brazilian Amazon Federal Protected Areas. Brazilian Amazon Federal Protected Areas (Sustainable use and Strictly protected), and 4243 occurrences grouped per PA of illegal use of natural resources (illegal activities) in the period of 2010-2015.=

Table 1. Summary of Brazilian Amazon federal protected areas. Overall information about Brazilian Amazon federal PAs, IUCN category correspondence, absolute number of illegal activities and value of fines.

Protected Area Class	Protected Area Category	IUCN	PAs (n)	Area (km²)	Illegal activities (n)	Fines (U$)[a]
Strictly protected	Ecological Station	Ia	10	55,248.94	257	27,594,947.29
	Biological Reserve	Ia	9	36,381.43	963	49,005,094.70
	National Park	II	19	204,324.04	959	67,348,814.39
Subtotal			38	295,954.42	2,179	143,948,856.38
Sustainable use	Relevant Ecological Interest Area	IV	3	189.31	6	13,573.23
	Environmental Protection Area	V	2	20,632.85	5	384,154.04
	Sustainable Development Reserve	VI	1	644.42	3	10,782.83
	National Forest	VI	32	164,262.20	901	54,675,627.21
	Extrative Reserve	VI	42	119,250.50	1,149	25,613,146.15
Subtotal			80	304,979.29	2,064	80,697,283.46
Total			118	600,933.71	4,243	224,646,139.84

[a] All fines were imposed in Brazilian real (R$) and converted to American dollar (US$) by using an exchange rate of R$ 3.168: US $1 for the purpose of comparison with other studies. Dollar quotation on 03/31/2017.

Illegal use of natural resources

Official figures for illegal use of natural resources (hereafter illegal activities) within federal PAs in the Brazilian Amazon were obtained by analysis of 4243 environmental infraction records (Data S1, Table S1). Irregularities are framed according to Federal Decree 6514 (2008), which deals with administrative environmental infractions and penalties (Brasil 2008). For analytical purposes, we considered that each environmental infraction corresponded to an illegal activity.

Due to the large number of types of infraction and considering that the categories presented by the Brazilian Decree are very broad (e.g., hunting and fishing would fall into the same category), a new categorization of illegal activities was proposed. We considered the infraction framework, the number of occurrences of each type of infraction, and the main characteristics of illegal activities (Fig. 2, Table S2).

Protected area accessibility

We defined accessibility (or accessible area) of PAs as the intersection between the total area of a PA with the area of a 10 km buffer adjacent to roads and rivers located within or outside PAs. The definition of accessibility within 10km of rivers and roads takes into consideration that most natural resource exploitation in the Amazon is limited by transportation. Preliminary work conducted in Amazonia suggested that 10 km is the maximum distance local people can travel in order to collect non-timber forest resources and/or hunt (Peres and Terborgh 1995, Peres and Lake 2003).

To measure accessibility (Fig. S1, Table S2), we used the following procedures: creation of 10km buffers around roads and rivers; union of the files produced when applying 10 km buffers; intersection of buffers and PAs (accessibility or accessible area); calculation of the accessible area (km²); and division of the accessible area by the total area of the PA. All roads mapped by the IBGE at 1:250000 were considered (IBGE/DGC 2015). Selection of the main rivers was carried out according to the criteria adopted by the National Water Agency for the characterization of Brazilian rivers, in which main rivers are drainage sections with an area of contribution greater than 20000 km².

Population density

Population density was considered at a distance of 50 km around the PAs. Population density information was obtained from the "Brazilian statistical grid" (IBGE 2016b, a) prepared by IBGE based on the Brazilian population census of 2010 (IBGE 2010, 2011). The "Brazilian statistical grid" contains the amount of the Brazilian population in georeferenced polygons from 1 km² in rural areas and polygons up to 200 m² in urban areas. The grid is more refined than the municipal level data, which is generally used in studies that analyze demographic and socioeconomic factors for the Brazilian Amazon. For visualization purposes, we elaborated a population density map of the Amazon biome from the "Brazilian statistical grid" (Fig. S2).

In order to produce the population density variable (Table S2) in the area surrounding the PAs, we first created a 50 km buffer from the perimeter of each PA; then intersected the 50 km buffer area of each PA with the "Brazilian statistical grid"; and finally divided the population within the buffer area of 50km by its area (km²). Areas located outside the Brazilian territory and in marine areas were excluded. When PAs were located very close to the border of the Amazon biome, a 50km band was considered beyond the limits of the biome, but within Brazilian territory.

Data analysis

A summary of all environmental infractions in the period from 2010 to 2015 allowed assessment of the main illegal uses of natural resources (by verifying the illegal activities that generated the infraction notices), as well as the categorization of these illegal uses (Fig. 2). The temporal trend of the illegal use of natural resources for the study period was evaluated using a linear regression. The total number of illegal activities was also summarized for each PA (Table S1), in relation to management categories (strictly protected and sustainable use) (Table 1). For further analysis, the three categories of illegal activities with the highest number of records and their totals summarized for each PA were used. In order to take in to account differences in the area of PAs and to standardize our variables, the total number of infractions and the total number of the three most common infraction categories were divided by the number of years (n = 6) and the area of the PA (km²). This procedure was performed considering that the PAs have varied sizes and the measure of law enforcement effort that we adopted was the number of infraction records per year.

In order to normalize the data, transformations were applied to the following variables: illegal activities = $\log_{10}$ ((illegal activities × 10^5) + 1); age = $\log_{10}$ protected area age; accessibility = √(accessibility); and population density = $\log_{10}$ (population density × 10^5).

We used Spearman correlation analysis to evaluate the independence between our environmental variables (Table S3). Variables with weak correlations ($r_s < 0.50$) were retained for use in subsequent analyses. The differences in the influence of management classes of PAs (sustainable use or strictly protected), age, accessibility, and population density, on illegal activities occurring in PAs, were analyzed using generalized additive models (GAMs, Gaussian distribution family) (Guisan et al. 2002, Heegaard 2002, Wood 2017). GAMs were run separately for each of the three most recorded illegal activities. In order to verify possible differences in the number of illegal activities in stryctly terrestrial PAs (n=105) and coastal/marines (n=13) ones, we used a Mann-Whitney U test. All analyses were performed in the R environment for statistical computing (R Development Core Team 2016).

Results

Federal protected areas and illegal use of natural resources

Of the 118 PAs evaluated, 107 had at least one infraction reported between 2010 and 2015; only 11 had no records of illegal activities (Fig. 1, Table S1). Overall, there was a decrease in the number of illegal activities within federal protected areas in the Brazilian Amazon for the study period ($R^2 = 0.56$, $p = 0.09$). A total of 4243 occurrences of illegal use of natural resources were evaluated, and these resulted in total fines of US$ 224646139.84 (Table 1). Strictly protected PAs had a relatively higher total fines value (US$ 143948856.38) compared to that of sustainable use reserves (US$ 80697283.46). Similarly, strictly protected PAs presented slightly higher numbers of illegal activities (n = 2179) than sustainable use reserves (n = 2064). The mean number of total illegal activities in each PA was 35 (median 19.50), with 50% of PAs within the range of 8.0 to 47.5. The ten PAs with the highest frequency of illegal activities were Rebio do Abufari (n = 316), Parna Serra do Divisor (n = 199), Parna Mapinguari (n =187), Rebio do Jaru (n = 158), Rebio do Gurupi (n = 137), Resex Marinha de Soure (n = 129), Parna do Cabo Orange (n = 122), Rebio Trombetas (n = 122), Flona do Jamaxim (n = 97), and Resex Chico Mendes (n = 93).

We found 27 types of illegal uses of natural resources that were grouped into 10 categories of illegal activities (Fig. 2, Table S2). The most commonly registered infractions

were related to suppression and degradation of vegetation (37.36%), followed by illegal fishing (27.34%) and hunting activities (18.15%). These three categories together corresponded to 82.85% of all records of illegal activities in the entire study period. Infractions related to the suppression and degradation of vegetation were responsible for the highest total amount of fines among the 10 categories of illegal activities, US$ 188337814.39, which corresponds to around 83% of all fines imposed in the study period. The four PAs with the highest number of illegal activities related to the suppression and degradation of vegetation were the Parna Serra do Divisor (n = 109), Rebio do Gurupi (n = 94), Parna Mapinguari (n = 92), and Resex Chico Mendes (n = 71). For illegal fishing, the Rebio do Abufari (n = 168), the Parna do Cabo Orange (n = 120), the Rebio Jaru (n = 89), and the Esec Maracá (n = 52), had the highest number of infractions. Regarding hunting, the four reserves with the majority of records were the Rebio do Abufari (n = 168), the Parna Serra do Divisor (n = 72), the Rebio Trombetas (n = 46), and the Flona Tefé (n=35).

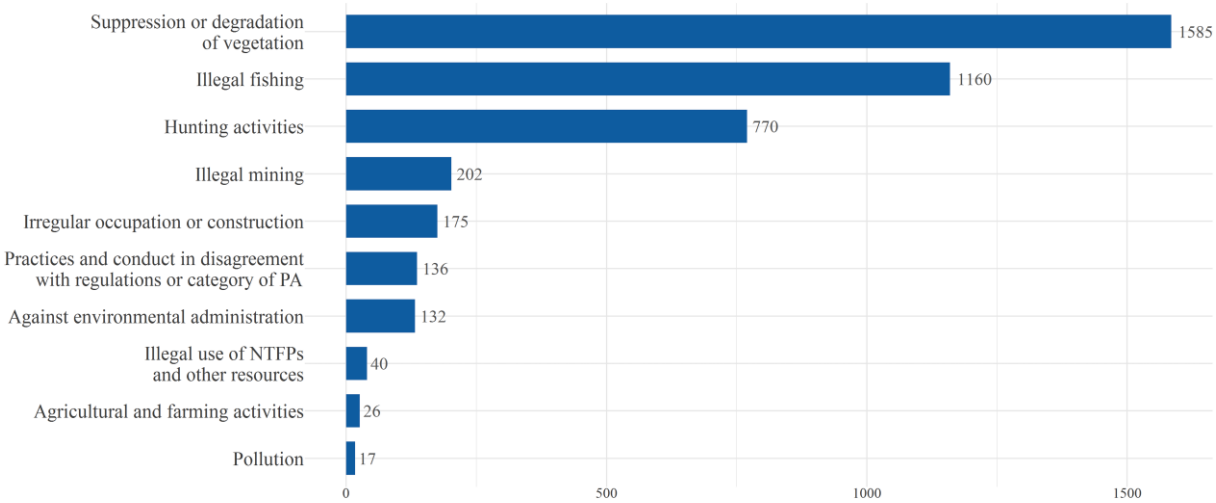

Figure 2. Illegal activities category and total number of occurrences. Official figures for illegal use of natural resources (illegal activities) within federal PAs in the Brazilian Amazon obtained by analysis of 4243 environmental infraction records. Categorization of illegal activities considered the infraction framework, the number of occurrences of each type of infraction (according to the Brazilian Federal Decree 6514 (2008)), and the main characteristics of illegal activities.

Predictors of illegal activities within Federal protected areas

The mean age of federal PAs in the Brazilian Amazon (calculated from 2015) was 18.92 years (median = 14, range = 6-54 years), with 50% of reserves ranging in age from 10 to 26 years. The total mean area of the PAs was 5092.66 km² (median = 2858.73 km²). The reserves ranging from 1209.90 to 6813.01 km² in a 50 km buffer population density around PAs averaged 7.49 inhabitants per km² (median = 1.54 inhabitants/km²), with 50% of the PAs ranging from 0.63 to 4.68 inhabitants per km². The protected area with the lowest population density in the surroundings was the Resex do Xingu with 0.06 inhabitants/km² and the highest density was found in the neighborhood of Parna Anavilhanas with 75.90 inhabitants/km². The overall index of accessibility was on average 43% (median = 33%), and 50% of PAs had accessibility between 15% and 68%. Regarding accessibility, it is important to highlight that 17 PAs presented 100% of this variable, as well as 10 PAs had zero accessibility (Table S1).

The explanatory power of the GAMs was low for all groups (Table 2), with a maximum explained variation of 41.20% (R^2adjusted = 0.39) for total illegal activities, and a minimum of 14.6% (R^2 adjusted 0.12) for illegal hunting activities. From all explanatory variables analyzed in our study, population density was the most important predictor of total number of infractions (Fig. 3), as well as illegal fishing, suppression and degradation of vegetation, and hunting. The second most important predictor of illegal activities was accessibility, which was positively related to all illegal activities (Fig. 4) and to illegal fishing. PA classification was only an important predictor for illegal fishing, with sustainable use PAs having lower levels of illegal fishing. The age of a PA was not a significant predictor for any of the illegal activities analyzed in our study.

In relation to the number of illegal activities and the PA location (coastal/marine or terrestrial), we found a significant decrease in the number of all illegal activities ($p < 0.001$) and a significant increase in the number of illegal fishing ($p < 0.001$) in coastal/marine PAs (Table S4). Illegal activities related with hunting and flora degradation were not significantly different in these two locations of PAs.

Table 2. Generalized additive models (GAMs) results. Parameter (Slope) estimates of explanatory variables from the GAMs on the number of illegal activities in the Brazilian Amazon federal PAs.

	All Illegal activities [a]		Hunting activities [b]		Illegal fishing [c]		Flora degradation [d]	
	Slope (SE)[e]	t value	Slope (SE)[e]	t value	Slope (SE)[e]	t value	Slope (SE)[e]	t value
Intercept	-1.460 (0.521)	-2.80**	-0.909 (0.577)	-1.57	-1.718 (0.643)	-2.67**	-1.318(0.618)	-2.13*
Classes[f] (Sustainable use)	-0.160 (0.159)	-1.00	-0.198 (0.176)	-1.12	-0.476 (0.197)	-2.42*	0.163 (0.189)	0.86
Age[g]	-0.005 (0.007)	-0.67	0.002 (0.008)	0.29	-0.005 (0.009)	-0.53	-0.009 (0.009)	-1.02
Accessibility[h]	0.968 (0.256)	3.85***	0.502 (0.284)	1.77†	0.899 (0.316)	2.84**	0.527 (0.304)	1.73†
Population density[i]	0.574 (0.112)	5.14***	0.317 (0.124)	2.56*	0.508 (0.138)	3.68***	0.449 (0.133)	3.39***
R-square adjusted[j]	0.391		0.116		0.284		0.194	
Model deviance explained (%)[l]	41.20		14.60		27.30		22.10	
Model GCV[m]	0.541		0.665		0.826		0.763	

Notes: Significance values: †p < 0.10, *p < 0.05, **p < 0.01, ***p < 0.001; [a] Includes the total of all illegal activities (illegal activities/protected area size km²/number of years) log transformed ($(\log_{10} +1) \times 10^5$); [b] Includes all hunting activities (hunting activities infractions/protected area size km²/number of years) log transformed ($(\log_{10} +1) \times 10^5$); [c] Includes all illegal fishing (illegal fishing/protected area size km²/number of years) log transformed ($(\log_{10} +1) \times 10^5$); [d] Includes all flora degradation (flora degradation/protected area size km²/number of years) log transformed ($(\log_{10} +1) \times 10^5$); [e] Slopes for variables and Standard Error (SE); [f] Class of protected areas (Sustainable use and Strictly protected); [g] Age of protected area creation (creation until 2015) log transformed ($\log_{10}$); [h] Accessibility of protected area square root transformed; [i] Population density in a 50 km buffer from the perimeter of each PA log transformed ($\log_{10} \times 10^5$); j R-square adjusted for each model; [l] Percentage of Deviance Explained for each model (%); [m] Generalized Cross-Validation score for each model (GCV).

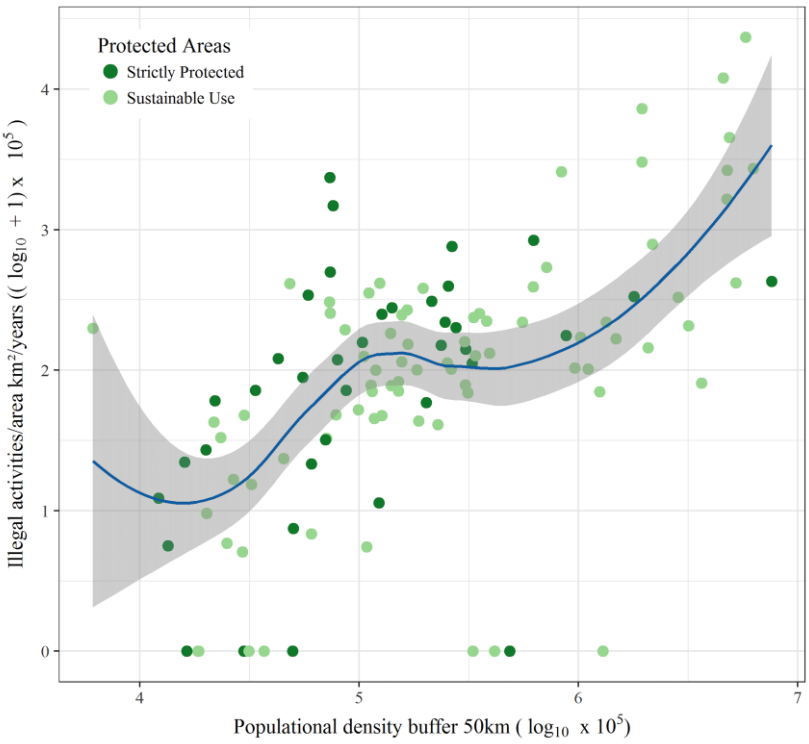

Figure 3. Total of all illegal activities and human population density in a 50km buffer from the perimeter of each protected area.

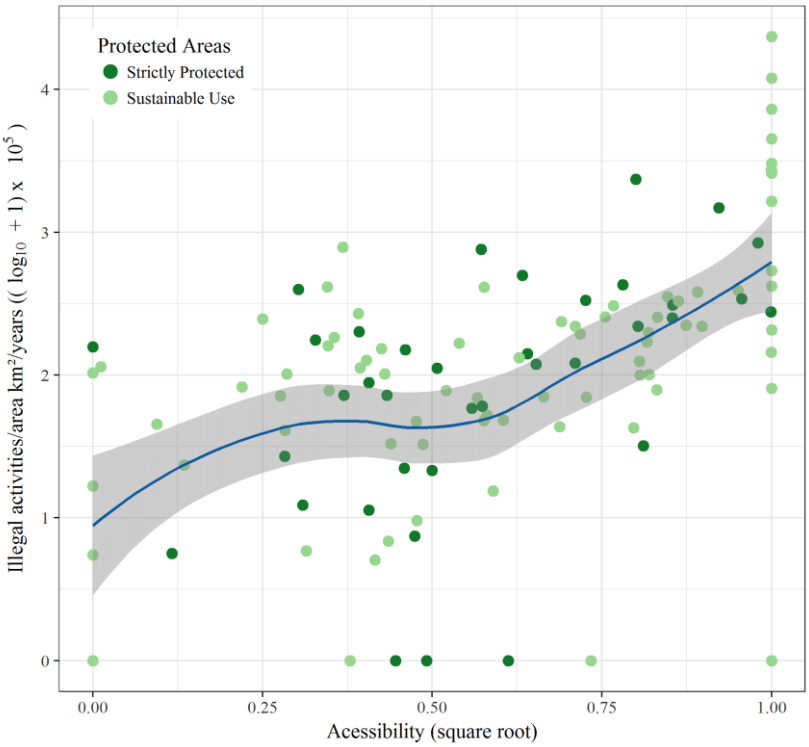

Figure 4. Total of all illegal activities and accessibility of protected areas.

Discussion

Globally, the illegal use of natural resources is one of the biggest threats to biodiversity, and generally threatens the integrity of PAs and the viability of endangered species (Dinerstein et al. 2007, Gavin et al. 2010, Laurance et al. 2012, Conteh et al. 2015). Despite the fact that Amazonian PAs are one of the most important means of reducing deforestation rates in the biome (Kere et al. 2017), PA creation alone is not sufficient to reduce threats to biological diversity.

Our analysis showed that there was a wide range of illegal activities that threatens the biodiversity of Amazonian federal PAs. We found that illegal activities related to suppression and degradation of vegetation, illegal fishing and hunting activities were the most commonly recorded. These three activities have been highlighted in several assessments of biodiversity threats globally: hunting and the illegal wildlife trade (Dudley et al. 2013, Underwood et al. 2013, Sharma et al. 2014, Tella and Hiraldo 2014, Nijman 2015); fishing in prohibited locations, outside permitted periods and in excess of established quantities or sizes (Sethi and Hilborn 2008, Free et al. 2015, Thomas et al. 2015); and illegal logging, deforestation and degradation of vegetation (Curran et al. 2004, Yonariza and Webb 2007, Funi and Paese 2012, Chicas et al. 2017). Although illegal activities related to the suppression and degradation of vegetation, illegal fishing, and poaching activities were those most frequently recorded in Amazonian PAs, it does not mean that other less prominent illegal activities are not of concern.

The population density surrounding PAs was the most important variable in our study, predicting total illegal activities, as well as the suppression and degradation of vegetation, illegal fishing, and poaching activities. This finding is in line with the results of other tropical forest studies that have observed a positive relationship between the growth of human populations and an increase in natural resource extraction and deforestation (Geist and Lambin 2002, Lopez-Carr and Burgdorfer 2013, Laurance et al. 2014, Lewis et al. 2015, Marques et al. 2016).

We found that accessibility was positively related only with the total number of illegal activities and to illegal fishing, while for hunting activities and vegetation suppression and degradation activities this variable was marginally significant. Despite this, it was possible to verify the importance of accessibility in predicting illegal activities within PAs. Roads and highways have a fundamental role in opening the tropics to destructive colonization and exploitation (Laurance et al. 2001). Roads provide access and dispersion of people within

tropical forests and facilitate access for hunters, miners, land speculators, and others into forest core areas (Laurance et al. 2009). For example, the increasing deforestation of the Brazilian Amazon began with the construction of the Belém-Brasília highway in the 1960s (Vieira et al. 2008) and the opening of the Transamazon Highway in 1970 (Fearnside 2005). Barber et al. (2014) observed that until 2006, deforestation in the Brazilian Amazon was higher in areas closer to roads and rivers, with almost 95% of the total deforested area within 5.5 km of roads and up to 1 km from rivers. Recent studies show that populations of aquatic species (e.g., giant otters, alligators) in more accessible areas have collapsed throughout the Amazon basin (Antunes et al. 2016).

We found no relationship between the age of PAs and illegal activities, although the age of a PA is often correlated with conservation results (Claudet et al. 2008, Molloy et al. 2009, Soares-Filho et al. 2010). Our results show that sustainable use PAs decrease the frequency of illegal fishing activities. This relationship can be attributed to the fact that residents of the reserves assist surveillance. Nepstad et al. (2006) verified that sustainable use PAs and indigenous lands hold great importance for the prevention of deforestation and wildfires. This pattern was also observed in a global analysis of the effectiveness of strictly protected and sustainable use PAs in reducing tropical forest fires, where sustainable use PAs were more efficient (Nelson and Chomitz 2011). Porter-Bolland et al. (2012) observed that forests managed by communities presented lower and less variable deforestation rates across the tropics. These findings reinforce the idea that in order to achieve an effective conservation, it is necessary to involve local communities in environmental governance (Dudley et al. 2014, Brondizio and Le Tourneau 2016).

Despite differences found in the decrease in the number of total illegal activities and the increase in illegal fishing activities in coastal/marine when compared with terrestrial PAs, we did not find significant differences for illegal activities of hunting and flora degradation. Overall, a greater number of fisheries-related offenses are expected in coastal marine areas. However, coastal marine PAs that occur in the Brazilian Amazon have also significant portions of forests (mainly mangrove formations). Thus, it is not surprising that illegal hunting and flora degradation were present in these areas in similar levels of terrestrial PAs. On the other hand, the differences presented here indicate the need for a more detailed evaluation of these different locations of PAs, which could be coupled with differences in strategies and conservation actions to be applied to individual areas (Margules and Pressey 2000, Barber et al. 2012).

Conclusions

PAs are fundamental for biodiversity conservation across the Brazilian Amazon, and their establishment and maintenance is a key strategy for protection from the pressures and threats posed by human presence in tropical forests. Nonetheless, PAs are one of the most crucial factors contributing to reductions in deforestation in this biome. We report several threats that may impair long-term conservation and many efforts are still needed to address these issues. The use of enforcement reports generated by official government authorities provides us with a more nuanced view of the illegal activities taking place within PAs in the Brazilian Amazon. We demonstrated that this type of information can be useful as a complement to more sophisticated remote sensing techniques that usually fail to identify threats under the forest canopy. We have showed that the monitoring information helps to identify more problematic PAs in relation to the illegal use of natural resources and in relation to detailed categories of infraction. This can help managers to plan and implement specific conservation actions to individual areas in order to reduce illegal activities. Additionally, information regarding enforcement effort applied in each PA can be better quantified, which would help conservationists and practioners to be able to evaluate and set goals for different PAs under different regimes and locations. Implement management actions in and around PAs are key conservation issues that will need to be addressed to provide the realization of effectiveness goals of *de facto* preservation of the Brazilian Amazon.

Acknowledgements

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Supporting Information

Table SM 1. Amazon Federal Protected Areas evaluated and explanatory variables**.** Amazon Federal PAs evaluated (n=118), Brazilian classification, IUCN classification, age in 2015, total area (km^2), total number of illegal activities recorded (2010-2015), population density in a 50 km buffer from the perimeter of each PA and accessibility of a protected area (accessibility km^2/total area km^2). APA: Environmental Protected Area, ARIE: Area of Relevant Ecological Interest, ESEC: Ecological Reserve, PARNA: National Park, REBIO: Biological Reserve, FLONA: National Forest, RDS: Sustainable Development Reserve, RESEX: Extractive Reserve.

Protected Area	**Class**	**IUCN**	**Age (year)**	**Area (km^2)**	**Illegal activities**	**Population density**	**Accessibility**
APA DO IGARAPE GELADO	Sustainable use	V	26	232.85	0	12.911	1.000
APA DO TAPAJOS	Sustainable use	V	9	20,400.00	5	0.293	0.173
ARIE JAVARI BURITI	Sustainable use	IV	30	131.77	2	3.526	0.692
ARIE PROJETO DINAMICA BIOLOGICA DE FRAGMENTOS FLORESTAIS	Sustainable use	IV	30	31.80	0	3.303	1.000
ARIE SERINGAL NOVA ESPERANCA	Sustainable use	IV	16	25.74	4	8.344	1.000
ESEC DA TERRA DO MEIO	Strictly protected	Ia	10	33,730.00	43	0.160	0.211
ESEC DE CARACARAI	Strictly protected	Ia	33	867.95	13	1.268	0.729

ESEC DE CUNIA	Strictly protected	Ia	14	1,853.14	37	17.932	0.527
ESEC DE JUTAI SOLIMOES	Strictly protected	Ia	32	2,895.14	26	2.361	0.212
ESEC DE MARACA	Strictly protected	Ia	34	1,035.20	92	0.761	0.851
ESEC DE MARACA JIPIOCA	Strictly protected	Ia	34	602.53	10	1.412	0.999
ESEC DO JARI	Strictly protected	Ia	33	2,310.82	8	2.025	0.312
ESEC JUAMI JAPURA	Strictly protected	Ia	14	8,315.32	13	0.200	0.080
ESEC NIQUIA	Strictly protected	Ia	30	2,847.91	15	0.552	0.165
ESEC RIO ACRE	Strictly protected	Ia	34	790.94	0	0.297	0.375
FLONA DE ALTAMIRA	Sustainable use	VI	17	7,249.74	14	0.234	0.193
FLONA DE ANAUA	Sustainable use	VI	10	2,594.03	8	0.993	0.337
FLONA DE BALATA TUFARI	Sustainable use	VI	13	10,800.00	26	2.282	0.080
FLONA DE CARAJAS	Sustainable use	VI	17	3,912.63	40	10.222	0.666
FLONA DE CAXIUANA	Sustainable use	VI	54	3,179.51	13	3.124	0.321

FLONA DE HUMAITA	Sustainable use	VI	17	4,731.59	76	1.656	0.153
FLONA DE ITAITUBA I	Sustainable use	VI	17	2,128.92	6	0.298	0.332
FLONA DE ITAITUBA II	Sustainable use	VI	17	3,977.56	53	3.805	0.764
FLONA DE JACUNDA	Sustainable use	VI	11	2,212.20	55	1.239	0.119
FLONA DE MULATA	Sustainable use	VI	14	2,166.04	10	1.132	0.121
FLONA DE PAU ROSA	Sustainable use	VI	14	9,881.87	28	0.784	0.366
FLONA DE RORAIMA	Sustainable use	VI	26	1,696.29	31	0.731	0.588
FLONA DE SANTA ROSA DO PURUS	Sustainable use	VI	14	2,315.57	2	0.323	0.348
FLONA DE SAO FRANCISCO	Sustainable use	VI	14	211.48	0	0.184	0.000
FLONA DE SARACA TAQUERA	Sustainable use	VI	26	4,412.88	58	5.549	0.505
FLONA DE TEFE	Sustainable use	VI	26	8,651.27	58	2.523	0.155
FLONA DO AMANA	Sustainable use	VI	9	6,825.61	2	0.249	0.099
FLONA DO AMAPA	Sustainable use	VI	26	4,603.59	42	1.668	0.181

FLONA DO AMAZONAS	Sustainable use	VI	26	19,440.00	0	0.314	0.143
FLONA DO BOM FUTURO	Sustainable use	VI	27	973.85	46	21.751	0.136
FLONA DO CREPORI	Sustainable use	VI	9	7,403.96	10	0.451	0.018
FLONA DO IQUIRI	Sustainable use	VI	7	14,730.00	28	0.710	0.237
FLONA DO ITACAIUNAS	Sustainable use	VI	17	1,367.01	29	1.106	0.717
FLONA DO JAMANXIM	Sustainable use	VI	9	13,020.00	97	1.047	0.648
FLONA DO JAMARI	Sustainable use	VI	31	2,221.57	52	6.215	0.904
FLONA DO JATUARANA	Sustainable use	VI	13	5,694.28	2	0.605	0.189
FLONA DO MACAUA	Sustainable use	VI	27	1,763.47	0	0.185	0.000
FLONA DO PURUS	Sustainable use	VI	27	2,561.23	28	1.389	0.126
FLONA DO TAPAJOS	Sustainable use	VI	41	5,306.21	22	12.515	0.529
FLONA DO TAPIRAPE AQUIRI	Sustainable use	VI	26	1,965.06	5	1.868	0.473
FLONA DO TRAIRAO	Sustainable use	VI	9	2,575.29	59	1.956	0.794

FLONA MAPIA INAUINI	Sustainable use	VI	26	3,689.50	1	1.081	0.000
PARNA DA AMAZONIA	Strictly protected	II	41	10,660.00	71	3.277	0.257
PARNA DA SERRA DO DIVISOR	Strictly protected	II	26	8,375.60	199	2.551	0.092
PARNA DA SERRA DO PARDO	Strictly protected	II	10	4,454.13	19	0.871	0.137
PARNA DE ANAVILHANAS	Strictly protected	II	34	3,502.43	90	75.902	0.610
PARNA DE PACAAS NOVOS	Strictly protected	II	36	7,086.70	0	4.857	0.242
PARNA DO CABO ORANGE	Strictly protected	II	35	6,573.28	122	2.138	0.730
PARNA DO JAMANXIM	Strictly protected	II	9	8,598.07	62	0.427	0.505
PARNA DO JAU	Strictly protected	II	35	23,670.00	16	0.122	0.096
PARNA DO JURUENA	Strictly protected	II	9	19,580.00	70	0.220	0.329
PARNA DO MONTE RORAIMA	Strictly protected	II	26	1,167.49	11	1.035	0.000
PARNA DO PICO DA NEBLINA	Strictly protected	II	36	22,530.00	14	1.231	0.165
PARNA DO RIO NOVO	Strictly protected	II	9	5,381.57	0	0.164	0.199

PARNA DO VIRUA	Strictly protected	II	17	2,149.51	4	0.703	0.658
PARNA DOS CAMPOS AMAZONICOS	Strictly protected	II	9	9,613.27	68	0.795	0.427
PARNA MAPINGUARI	Strictly protected	II	7	17,770.00	187	8.764	0.107
PARNA MONTANHAS DO TUMUCUMAQUE	Strictly protected	II	13	38,650.00	15	0.500	0.225
PARNA NASCENTES DO LAGO JARI	Strictly protected	II	7	8,127.53	10	0.605	0.250
PARNA SERRA DA CUTIA	Strictly protected	II	14	2,835.03	0	0.496	0.000
PARNA SERRA DA MOCIDADE	Strictly protected	II	17	3,599.44	1	0.134	0.014
REBIO DE UATUMA	Strictly protected	Ia	25	9,387.32	40	0.337	0.188
REBIO DO ABUFARI	Strictly protected	Ia	33	2,238.67	316	0.735	0.640
REBIO DO GUAPORE	Strictly protected	Ia	33	6,157.76	74	2.757	0.154
REBIO DO GURUPI	Strictly protected	Ia	27	2,712.01	137	6.243	0.960
REBIO DO JARU	Strictly protected	Ia	36	3,468.64	158	2.648	0.328

REBIO DO LAGO PIRATUBA	Strictly protected	Ia	35	3,924.75	33	3.060	0.410
REBIO DO RIO TROMBETAS	Strictly protected	Ia	36	4,077.59	122	0.737	0.401
REBIO DO TAPIRAPE	Strictly protected	Ia	26	992.73	13	2.459	0.646
REBIO NASCENTES DA SERRA DO CACHIMBO	Strictly protected	Ia	10	3,421.96	70	0.586	0.914
RDS DE ITATUPA BAQUIA	Sustainable use	VI	10	644.42	3	3.046	0.690
RESEX ARAPIXI	Sustainable use	VI	9	1,337.12	8	1.831	0.672
RESEX ARIOCA PRUANA	Sustainable use	VI	10	838.17	11	13.402	0.806
RESEX AUATI PARANA	Sustainable use	VI	14	1,469.49	10	1.564	0.000
RESEX BARREIRO DAS ANTAS	Sustainable use	VI	14	1,061.99	1	0.266	0.000
RESEX CHICO MENDES	Sustainable use	VI	25	9,315.43	93	14.837	0.291
RESEX CHOCOARE MATO GROSSO	Sustainable use	VI	13	27.83	20	45.787	1.000
RESEX DE CURURUPU	Sustainable use	VI	11	1,860.57	16	20.772	0.999

RESEX DE SAO JOAO DA PONTA	Sustainable use	VI	13	34.09	48	57.756	1.000
RESEX DO ALTO JURUA	Sustainable use	VI	25	5,379.49	15	1.269	0.227
RESEX DO ALTO TARAUACA	Sustainable use	VI	15	1,509.24	23	0.738	0.569
RESEX DO BAIXO JURUA	Sustainable use	VI	14	1,780.39	44	0.482	0.332
RESEX DO CAZUMBA IRACEMA	Sustainable use	VI	13	7,549.87	37	1.510	0.048
RESEX DO CIRIACO	Sustainable use	VI	23	81.07	22	48.872	1.000
RESEX DO LAGO DO CAPANA GRANDE	Sustainable use	VI	11	3,043.13	14	1.398	0.271
RESEX DO LAGO DO CUNIA	Sustainable use	VI	16	506.04	10	28.448	0.745
RESEX DO MEDIO JURUA	Sustainable use	VI	18	2,869.55	12	1.144	0.441
RESEX DO MEDIO PURUS	Sustainable use	VI	7	6,042.36	36	1.188	0.651
RESEX DO QUILOMBO FLEXAL	Sustainable use	VI	23	93.38	17	19.486	1.000
RESEX DO RIO CAJARI	Sustainable use	VI	25	5,324.05	42	3.929	0.395
RESEX DO RIO DO CAUTARIO	Sustainable use	VI	14	751.25	2	1.171	0.009

RESEX DO RIO JUTAI	Sustainable use	VI	13	2,755.16	32	0.862	0.516
RESEX DO RIO OURO PRETO	Sustainable use	VI	25	2,046.33	29	3.321	0.476
RESEX GURUPA MELGACO	Sustainable use	VI	9	1,455.74	11	3.391	0.162
RESEX IPAU ANILZINHO	Sustainable use	VI	10	558.35	18	7.159	1.000
RESEX ITUXI	Sustainable use	VI	7	7,763.30	4	0.201	0.228
RESEX MAE GRANDE DE CURUCA	Sustainable use	VI	13	366.79	60	62.564	0.999
RESEX MAPUA	Sustainable use	VI	10	937.48	0	4.144	0.000
RESEX MARACANA	Sustainable use	VI	13	301.80	48	47.593	1.000
RESEX MARINHA DE ARAI PEROBA	Sustainable use	VI	10	625.78	3	36.398	1.000
RESEX MARINHA DE CAETE TAPERACU	Sustainable use	VI	10	424.90	42	47.456	1.000
RESEX MARINHA DE GURUPI PIRIA	Sustainable use	VI	10	727.90	9	31.715	1.000
RESEX MARINHA DE SOURE	Sustainable use	VI	14	295.79	129	19.456	1.000
RESEX MARINHA DE TRACUATEUA	Sustainable use	VI	10	278.65	7	52.282	1.000

RESEX RENASCER	Sustainable use	VI	6	2,096.67	20	3.023	0.120
RESEX RIO IRIRI	Sustainable use	VI	9	3,989.98	10	0.217	0.635
RESEX RIO UNINI	Sustainable use	VI	9	8,496.93	0	0.369	0.539
RESEX RIO XINGU	Sustainable use	VI	7	3,030.05	36	0.061	0.670
RESEX RIOZINHO DA LIBERDADE	Sustainable use	VI	10	3,249.06	48	1.565	0.063
RESEX RIOZINHO DO ANFRISIO	Sustainable use	VI	11	7,361.44	31	1.511	0.076
RESEX TAPAJOS ARAPIUNS	Sustainable use	VI	17	6,775.21	41	11.065	0.081
RESEX TERRA GRANDE PRACUUBA	Sustainable use	VI	9	1,948.70	12	9.604	0.000
RESEX VERDE PARA SEMPRE	Sustainable use	VI	11	12,890.00	78	2.627	0.185

Table SM 2. Categories and types of illegal activities**.** Categorization of illegal activities considering the infraction framework, the number of occurrences of each type of infraction (according to the Brazilian Federal Decree 6514 (2008)), and the main characteristics of illegal activities.

Illegal activities categories	**Types of illegal use of natural resources**	**Illegal activities (n)**	**Fines (US$)[a]**
Suppression or degradation of vegetation	To market, carry, or use chainsaw without authorization	106	73,107.01
	Illegal trade in timber	372	4,050,076.70
	Prevent natural regeneration of forests and other types of natural vegetation	122	40,732,903.09
	Production of coal without authorization or in disagreement with that obtained	5	2,209.60
	Suppression or degradation of vegetation (e.g. deforestation, selective logging, logging of endangered species)	937	142,600,414.46
	Make use of fire without authorization or in disagreement with that obtained (e.g. use of fire that could cause forest fires)	43	879,103.54
Subtotal		1,585	188,337,814.39
Illegal fishing	Fishing in strictly protected areas or in prohibited locations, outside the allowed period and above established quantities or sizes in sustainable-use areas	1,160	3,966,355.11
Subtotal		1,160	3,966,355.11
Hunting activities	Hunting in strictly protected areas or for commercial purposes in sustainable-use areas	769	17,688,522.10
	Abuse or mistreatment of animals (e.g. transport of animals in unhealthy conditions)	1	631.31

Subtotal		770	17,689,153.41
Illegal mining	Mining in strictly protected areas and extractive reserves (e.g. sustainable-use areas where the activity is not allowed), and without authorization or in disagreement with the authorization	202	1,107,001.26
Subtotal		202	1,107,001.26
Irregular occupation or construction	Irregularly occupying areas of a protected area for housing or enterprises. Build buildings where it is not allowed, without authorization or in disagreement with the authorization (e.g. to build a hotel in a national park without authorization)	175	7,809,092.17
Subtotal		175	7,809,092.17
Practices and conduct in disagreement with regulations or category of AP	Causes damage to protected area (in case it can not be framed in any other type)	2	631.31
	Realize conduct in disagreement with any specific regulations (e.g., exceed the established limits for visitation)	10	5,145.20
	Entering motorized vehicles in areas not allowed	42	18,686.87
	Enter the protected area without authorization	82	52,714.65
Subtotal		136	77,178.03
Against environmental administration	Presentation of false information	8	648,810.92
	Embargo noncompliance	56	3,088,266.73
	Notification noncompliance	33	617,859.22
	Disrupt or impede enforcement	32	137,310.61
	Conduct research of any nature without authorization	2	7,260.10
	Unauthorized commercial use of image	1	2,367.42
Subtotal		132	4,501,875.00

Illegal use of NTFPs and other resources	Collection of non-timber forest products in strictly protected areas or in disagreement with regulations in sustainable-use areas	40	141,414.14
Subtotal		40	141,414.14
Agricultural and farming activities	Breeding of animals and agricultural crops in strictly protected areas or in disagreement with regulations in sustainable-use areas	17	80,018.94
	Introduction of species for commercial purposes that have great potential for impact or biological invasion (e.g. buffalos, exotic fish)	9	47,348.48
Subtotal		26	127,367.42
Pollution	To construct, renovate, expand, install or operate facilities, activities, works or services users of environmental resources, considered as effective or potentially polluting, without the license or authorization of the competent environmental agencies, in disagreement with the license obtained or contrary to legal norms and regulations	9	848,642.68
	Pollution at inadequate levels (e.g. to cause pollution of any nature at levels that result or may result in damage to human health, or that lead to the death of animals or the significant destruction of biodiversity)	2	6,628.79
	Production, use and storage of toxic or hazardous substances	6	33,617.42
Subtotal		17	888,888.89
Total		**4,243**	**224,646,139.84**

Table SM 3. Spearman correlation results of explanatory variables.

Variables	Classes [a]	Age [b]	Accessibility [c]	Population density [d]
Classes	-	-0.32***	0.10	0.24**
Age	-0.32***	-	0.02	0.15
Accessibility	0.10	0.02	-	0.46***
Population density	0.24**	0.15	0.46***	-

Notes: [a] Class of protected areas (Sustainable use and Strictly protected); [b] Age of protected area creation (creation until 2015) log transformed ($\log_{10}$); [c] Accessibility of protected area square root transformed; [d] Population density in a 50 km buffer from the perimeter of each PA log transformed ($\log_{10} \times 10^5$). Significance values: **$p < 0.01$, ***$p < 0.001$.

Table SM 4. Mann-Whitney U test results between the number of illegal activities in terrestrial and coastal/marine Brazilian Amazon federal PAs. Comparison between the number of illegal activities in the Brazilian Amazon federal PAs, and the PA location (coastal/marine, n=13; or terrestrial, n=105). The test was run separately for all illegal activities, hunting activities, illegal fishing, and flora degradation.

PA's components	**Terrestrial PAs**	**Coastal/marine PAs**	**W[a]**
PAs number	105	13	
PAs area (km²)	584899.07	16044.65	
All Illegal activities	3696	547	232*
Hunting activities	745	25	554+
Illegal fishing	788	1551	56*
Flora degradation	1551	34	649+

Notes: [a] Mann-Whitney U test performed with the total number of illegal activities (all illegal activities, hunting activities, illegal fishing, and flora degradation) divided by the number of years (n = 6) and the area of the PA (km²), and $\log_{10}$ ((illegal activities $\times 10^5$) + 1) transformed; + Not significant; * $p < 0.001$.

Data SM 1. Illegal activities database. Data on illegal activities compiled and formatted for our study**.** **https://doi.org/10.7717/peerj.3902/supp-7**

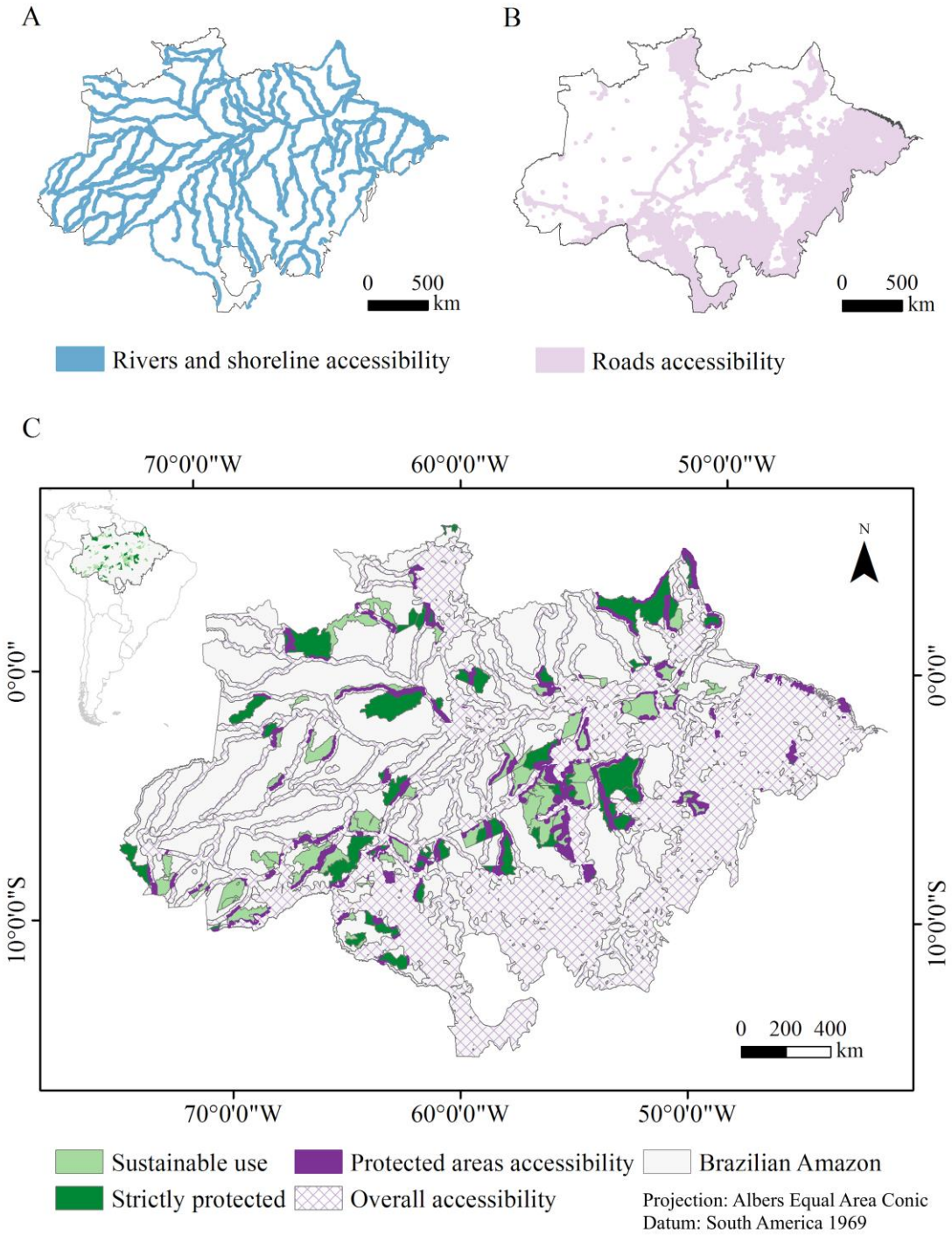

Figure SM 1. Accessibility of the Brazilian Amazon federal protected areas**.** Accessibility of PAs defined as the intersection between the total area of a PA with the area of a 10 km buffer adjacent to roads and rivers located within or outside PAs. A) rivers and shoreline accessibility; B) roads accessibility; and C) overall and PAs accessibility.

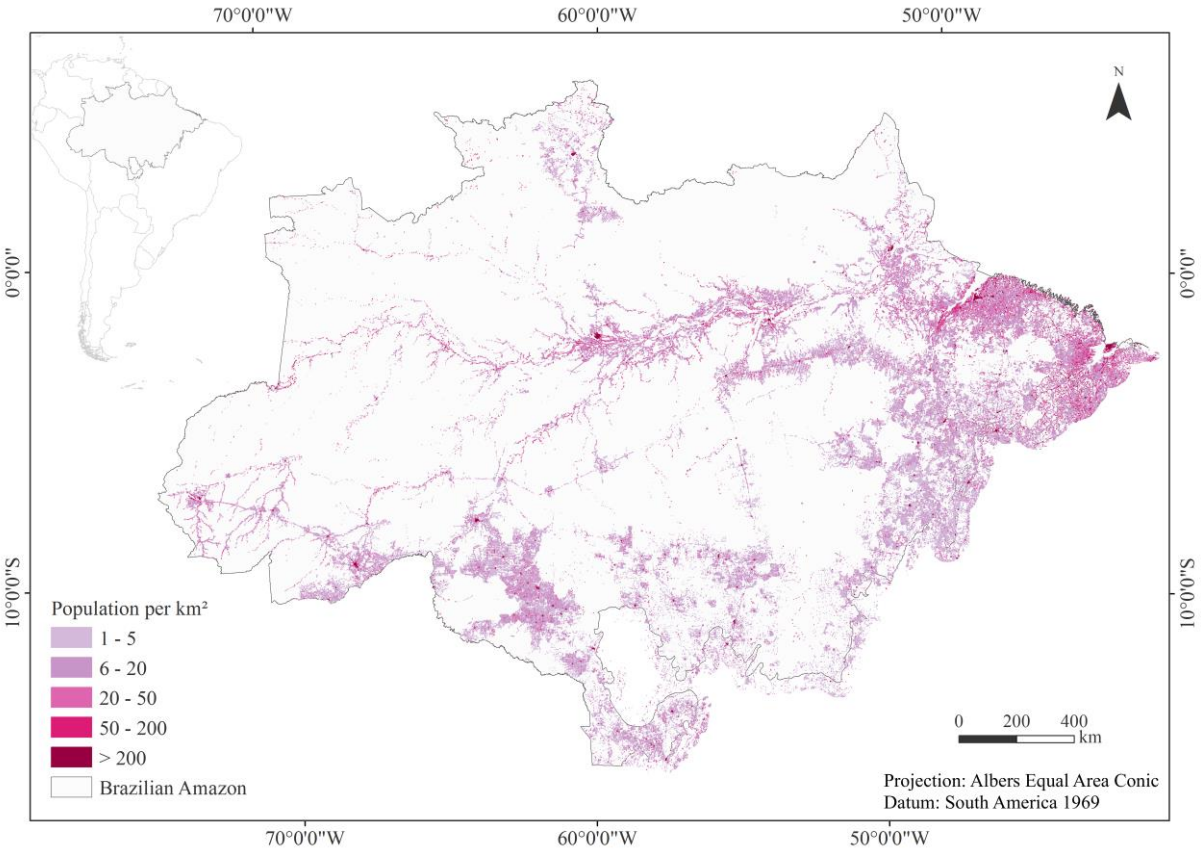

Figure SM 2. Population density of the Brazilian Amazon**.** Population density map of the Amazon biome elaborated from the "Brazilian statistical grid" for visualization purposes.

ARTIGO CIENTÍFICO 2

Associations between management effectiveness, illegal activities, and deforestation in Brazilian Amazon federal protected areas

Artigo submetido ao periódico "Journal for Nature Conservation"

Associations between management effectiveness, illegal activities, and deforestation in Brazilian Amazon federal protected areas

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Abstract

The enactment of protected areas (PAs) is the most common policy tool used by governments worldwide to achieve biodiversity conservation. Several methods have been proposed to evaluate PA's management effectiveness, but studies have found that high management effectiveness scores are not always associated with conservation outcomes (e.g., effective conservation of species or ecosystems). Here, we assessed how one method used to evaluate protected area management effectiveness—the Rapid Assessment and Prioritization of Protected Area Management (RAPPAM) method—correlates with illegal activities (represented by the number of environmental infraction records from 2010 to 2015) and cumulative deforestation (2010 to 2015) in 94 protected areas in the Brazilian Amazon. Using an information-theoretic (IT) approach, we evaluated 8 models (negative binomial generalized linear models) that had illegal activities and deforestation rates as response variables, and the RAPPAM's effectiveness index and several combinations of the RAPPAM's modules scores as covariates. One model (M7), containing the RAPPAM module scores of vulnerability, legal security, communication and information, as well as research, evaluation, and monitoring, explained 25% and 42% of the variation in the number of illegal activities and deforestation inside PAs, respectively. In this model, vulnerability was positively related to both the number of illegal activities and deforestation. In contrast, legal security was negatively related to both the number of illegal activities and deforestation. One group of PAs (i.e., sustainable use) was negatively related to illegal activities but positively related to deforestation. Sustainable-use PAs were approximately 50% less likely to have any illegal activity and 1.7% more likely to have forest loss when compared with strictly protected areas. The PA's size was positively related with deforestation but showed no significant association with illegal activities. For illegal activities, a second plausible model (M3) including three modules (i.e., biological importance, socioeconomic importance, and vulnerability) representing the context of PAs explained 23% of the occurrence of illegal activities. In general, the RAPPAM's effectiveness index and the majority of the modules scores did not show significant associations with illegal activities and cumulative deforestation. Our results suggest that vulnerability, legal security, and PA group are the most important management factors to consider when planning interventions to reduce threats to biodiversity in the PAs of the Brazilian Amazon.

Keywords: Protected area; Illegal activity; Deforestation; Management effectiveness; Brazilian Amazon

Introduction

The enactment of protected areas (hereafter PAs) is considered one of the most effective policy tools for achieving biodiversity conservation (Bruner, Gullison, Rice, & da Fonseca, 2001; Johnson et al., 2017; Watson, Dudley, Segan, & Hockings, 2014). Currently, PAs cover around 15% of the planet's terrestrial areas and 4% of the oceans (UNEP-WCMC & IUCN, 2016). However, the Aichi Target 11 of the Conference of the Parties to the Convention on Biological Diversity requires that by 2020, at least 17% of terrestrial areas and 10% of marine areas should be conserved through effectively and ecologically representative PA systems (Conference of the Parties to the Convention on Biological Diversity, 2010).

Like any public policy, the effectiveness of PAs (e.g., how they contribute to protecting biodiversity) needs to be systematically monitored (Chape, Harrison, Spalding, & Lysenko, 2005; Eklund & Cabeza, 2016). There are four general approaches for assessing the effectiveness of PAs (Hockings, Leverington, & Cook, 2015): (1) PA size and location, (2) large-scale assessments (e.g., impacts of forest clearing), (3) PA management effectiveness (PAME), and (4) PA outcomes (a more detailed subset of PAME). Such assessments are useful because they can identify problems that have the potential to undermine the success of PAs (Ervin, 2003a, 2003b; Geldmann et al., 2015; Hockings et al., 2015). Among these general approaches, PAME is the most commonly used (Geldmann et al., 2015; Hockings et al., 2015; Leverington, Costa, Pavese, Lisle, & Hockings, 2010; Nelson & Chomitz, 2011), and, among all of the PAME methods, one of the most widely applied has been the Rapid Assessment and Prioritization of Protected Area Management (RAPPAM) method (Ervin, 2003a, 2003b), and has been applied in over 1,900 PAs in more than 65 countries (Coad et al., 2015). The RAPPAM methodology was developed by the World Wildlife Fund (WWF) for broad-level assessments and comparisons among PAs that, taken together, comprise a conservation network (Ervin, 2003a; Hockings et al., 2015).

Although RAPPAM has been used worldwide, few studies have examined how the results of this method relate to reducing the threats to biodiversity (Carranza, Manica, Kapos, & Balmford, 2014; Geldmann et al., 2018). The limited literature that exists on this topic is usually focused on cross comparisons of large-scale assessments using deforestation (habitat loss) variables that can be easily detected and monitored based on remotely sensed data (e.g., land cover conversion) (Carranza et al., 2014; Nolte, Agrawal, & Barreto, 2013). However, other human-pressure resources (e.g., illegal hunting, illegal fishing, and illegal logging) that

are not easily detected using remote sensing approaches can also undermine conservation outcomes (Kauano, Silva, & Michalski, 2017; Peres, Barlow, & Laurance, 2006; Peres & Lake, 2003). To our knowledge, there are no studies that evaluate the relationship between RAPPAM's scores and illegal activities within a PA.

In this paper, we evaluate the relationship between RAPPAM's effectiveness index and module scores with the reduction of two major threats to biodiversity: deforestation (measured as the cumulative habitat loss inside the PAs) and the intensity of illegal activities (as measured by environmental infraction records generated by enforcement fines inside PAs). These threats are considered the most important ones across tropical forests and, over time, are able to undermine conservation efforts (Kauano et al., 2017; Kurten, 2013; Schulze et al., 2017; Vieira, Toledo, Silva, & Higuchi, 2008). We tested a set of hypotheses (Table 1) that combine RAPPAM's effectiveness index or module scores in seven different models to evaluate their effects on the number of illegal activities as well as the cumulative deforestation inside the protected areas analyzed. To test our hypotheses, we used a sample of 94 federal PAs (i.e., managed by the federal government) in the Brazilian Amazon, a region that hosts a large fraction of the earth's terrestrial biodiversity (Mittermeier et al., 2003) and sustains around 40% of the world's remaining tropical forests (Hubbell et al., 2008; Laurance et al., 2001).

2. Material and methods

2.1. Brazilian Amazon and federal protected areas

Our definition of the Brazilian Amazon is equivalent to the Amazon biome, defined by the *Instituto Brasileiro de Geografia e Estatistica* (IBGE, 2004) as a region with a total area of around 4.2 million km^2 that covers the states of Amazonas, Acre, Roraima, Amapá, Pará and Rondônia, and parts of Mato Grosso, Maranhão, and Tocantins. The Brazilian Amazon has 137 federal protected areas (FPAs) (called federal conservation units in the Brazilian legislation), covering roughly 638,000 km^2 (ICMBio, 2016b).

Our study was conducted within a subset of 94 PAs of the Brazilian Amazon (Fig. 1, Data B.1). These PAs were represented by 34 strictly protected areas (Ecological Reserve, IUCN category I, n = 9; Biological Reserve, IUCN category I, n = 8; and National Park, IUCN category II, n = 17) and 60 sustainable-use areas (National Forest, IUCN category VI, n = 30; Extractive Reserve, IUCN category VI, n = 29, and Sustainable Development Reserve, IUCN VI, n = 1).

This subset of PAs was chosen because it had both a database about the intensity of illegal activities (environmental infraction records) within the PAs, recorded from 2010–2015 (ICMBio/DMIF, 2017), a recent RAPPAM assessment carried out in 2015 (WWF-Brasil & ICMBio, 2017), and cumulative deforestation data (http://www.dpi.inpe.br/prodesdigital/prodesuc.php). We excluded from the study: (1) PAs created after 2010, because they do not allow full correspondence with the entire period evaluated; (2) PAs that were not evaluated in RAPPAM 2015; (3) marine/coastal PAs and PAs belonging to the categories of Area of Relevant Ecological Interest (IUCN IV), as well as Environmental Protection Areas (IUCN V) due to possible restrictions on RAPPAM methodology (Ervin, 2003a).

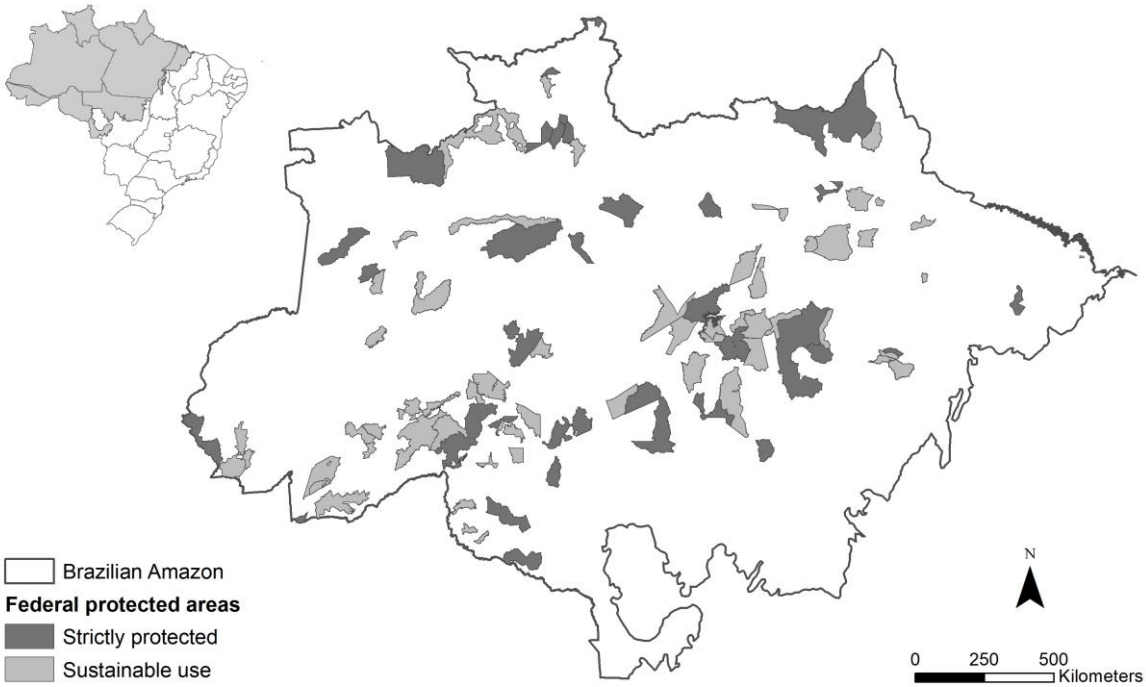

Figure 1. The 94 federal protected areas of the Brazilian Amazon analysed in the study.

2.2. Illegal activities

Official figures for illegal activities within PAs in the Brazilian Amazon were obtained by analyzing 3,603 environmental infraction records from 2010 to 2015 (Data B.1). For analytical purposes, we considered that each environmental infraction record corresponded to one illegal activity. The data on environmental infraction records were obtained from enforcement activities conducted by the *Instituto Chico Mendes de Conservação da*

Biodiversidade – ICMBio (Brasil, 2007, 2008) and were made available to the authors by the *Divisão de Informação e Monitoramento Ambiental* (Division of Environmental Information and Monitoring) of ICMBio (ICMBio/DMIF, 2017). For more information on the illegal activities within FPAs in the Brazilian Amazon (e.g., categories of illegal activities), see Kauano et al. (2017).

2.3. Deforestation

Official figures of deforestation within PAs in the Brazilian Amazon from 2010 to 2015 (Data B.1) were obtained from data from the *Monitoramento da Floresta Amazônica Brasileira por Satélite* (PRODES) (http://www.dpi.inpe.br/prodesdigital/prodesuc.php), conducted systematically by the *Instituto Nacional de Pesquisas Espaciais* (INPE).

2.4. Management effectiveness scores

The PA management effectiveness scores were taken from the RAPPAM assessment carried out with the managers of the FPAs at the end of 2015 (WWF-Brasil & ICMBio, 2017). We used 13 module scores as covariates (i.e., biological importance, socioeconomic importance, vulnerability, objectives, legal security, design and planning, staffing, communication and information, infrastructure, financial resources, management planning, decision making, and research evaluation monitoring) and the RAPPAM effectiveness index. We deliberately did not use the module outputs or the questions that compose the RAPPAM modules individually (Table A.1 presents the set of 96 questions, 14 modules, and 5 elements that compose the RAPPAM assessment).

2.5. Data analysis

Data exploration was applied following a protocol described in Zuur, Leno, and Elphick (2010). Cleveland dot plots were used to assess the presence of outliers, which demonstrated that some PAs had very large areas (> 20,000 km^2, Fig. A.3); therefore, this covariate was log-transformed in the models. Multi-panel scatter plots, Pearson correlations, and variance inflation factors (VIFs) were used to determine the presence of collinearity in the covariates, but there was no strong collinearity (all VIFs < 3) (Table A.2).

Because we have a large number of covariates (13 modules, 1 effectiveness index, and 2 control variables) with a relatively small sample size (94 PAs), we applied an information-theoretic (IT) approach (Burnham & Anderson, 2002) in a set of 8 different models (M1 to M8).

The selected models (Table 1) represent the null model (M1), the RAPPAM effectiveness index (M2), the management elements context (M3), planning (M4), inputs (M5), and management processes (M6). We also evaluated models with a mixture of the modules of the different elements (M7 and M8). In this case, we selected the set of modules that according to our pre-evaluation would be more related to illegal activities and cumulative deforestation. As control variables in all models, we used the PA group (strictly protected and sustainable-use protected areas) and the PA area (log transformed) to control for differences in types of governance and PA size.

Initial analyses using Poisson generalized linear models (GLM) indicated the presence of over dispersion. We therefore applied negative binomial GLMs. Model validation was applied on each selected model, and Pearson residuals were inspected for spatial dependency, outliers, and non-linear patterns (A. Zuur, Leno, Walker, Saveliev, & Smith, 2009). All analyses were performed with the *R* language and environment for statistical computing (R Development Core Team, 2016).

Table 1. A priori candidate models used to investigate the associations between the RAPPAM's effectiveness index and modules scores (covariates) with the number of illegal activities (2010 - 2015) and the cumulative deforestation (2010 - 2015) (response variables) inside 94 Federal Protected Areas in the Brazilian Amazon (PAs).

Model	Expression	Hypothesis
M1	Null model	None of the covariates is associated with the number of illegal activities and the cumulative deforestation.
M2	RAPPAM effectiveness index + PA area + PA governance	High values of the RAPPAM effectiveness index will be associated with high capacity of identify illegal activities, than will present a higher number of illegal activities. On the other hand, the best surveillance capacity will result in a lower quantity of deforestation.

M3	Biological importance + socioeconomic importance + vulnerability + PA area + PA group	This model represents the PAs context. More favourable contexts with low vulnerability will present less illegal activities and deforestation.
M4	Objectives + legal security + design and planning + PA area + PA group	This model represents the overall design and planning of PAs. Then, PAs with clear objectives, better design and with good legal security will have better capacity in identify illegal activities and will present less cumulative deforestation.
M5	Staffing + communication and information + infrastructure + financial resources + PA area + PA group	This model represents the inputs of PAs. The resources needed to carry out management of the PAs. Therefore, with more resources more capacity of identify illegal activities and more capability to avoid deforestation.
M6	Management planning + decision making + research evaluation monitoring + PA area + PA group	This model represents the management processes, which is the way in which management is conducted. High scores will be associated with high capacity of identify illegal activities and prevent deforestation.
M7	Vulnerability + legal security + communication information + research, evaluation and monitoring + PA area + PA group	PAs vulnerable but with a high value of legal security, a good system of communication and information, and a good monitoring system will have a better capacity to identify illegal activities and will have a better performance in avoiding deforestation.
M8	Vulnerability + staffing + infrastructure + financial resources + PA area + PA group	PAs vulnerable but with adequate staff, infrastructure and financial resources, instead the threats, will have a good capacity of identify illegal activities and hamper deforestation.

3. Results

The RAPPAM effectiveness index was high for 46% of PAs (≥ 0.60), medium for 37% (< 0.60 and ≥ 0.40), and low for 17% (< 0.40). The mean number of illegal activities was 38.33 (median = 22.50) (Fig. A.1), with 7 PAs presenting a high quantity of illegal activities: *Reserva Biologica do Abufari* (n = 316), *Parque Nacional Serra do Divisor* (n = 199), *Parque Nacional Mapinguari* (n = 187), *Reserva Biologica do Jaru* (n = 158), *Reserva Biologica do Gurupi* (n = 137), and *Reserva Biologica do Trombetas* (n = 122). The cumulative deforestation across the PAs was low (mean = 9.27 km^2 and median = 1.22 km^2) (Fig. A.2), with no forest reduction in 18% of the PAs during the study period. The 3 highest cumulative deforestation values were for *Floresta Nacional do Jamaxin* (261.83 km^2), *Floresta Nacional de Altamira* (117.74 km^2), and *Reserva Extrativista Chico Mendes* (80.41 km^2).

Table 2. Model selection values of the candidate models of the negative binomial generalized linear model for illegal activities and deforestation across 94 Federal Protected Areas in the Brazilian Amazon (FPAs).

Model	df	AIC	AIC differences	Akaike weights
Illegal activities				
M1	2	873.930	19.213	0.000
M2	5	864.647	9.930	0.004
M3	7	855.350	0.633	0.384
M4	7	864.655	9.938	0.004
M5	8	869.533	14.815	0.000
M6	7	868.670	13.952	0.000
M7	8	854.717	0.000	0.527
M8	8	858.445	3.728	0.082
Deforestation				
M1	2	530.326	44.695	0.000
M2	5	506.963	21.331	0.000
M3	7	493.039	7.408	0.024

M4	7	495.149	9.518	0.008
M5	8	509.739	24.108	0.000
M6	7	512.886	27.255	0.000
M7	8	485.631	0.000	0.967
M8	8	499.200	13.569	0.001

Table 3. Results of the best model (M7) from the negative binomial generalized linear model for PAs number of illegal activities and deforestation.

	Illegal activities[a]		Deforestation[b]	
	Estimate (SE)[c]	t value	Estimate (SE) [c]	t value
Intercept	2.153 (1.030)	2.090*	-3.750 (1.832)	-2.047*
Vulnerability	2.242 (0.577)	3.884***	3.011 (0.980)	3.071**
Legal security	-1.246 (0.616)	-2.022*	-4.573 (1.095)	-4.178***
Communication and information	0.496 (0.525)	0.946	0.017 (0.902)	0.018
Research, evaluation and monitoring	0.197 (0.434)	0.453	0.707 (0.736)	0.960
PA area (log)	0.087 (0.108)	0.810	0.513 (0.195)	2.637**
PA group (Sustainable use)	-0.669 (0.228)	-2.931**	1.658 (0.415)	3.993***
AIC	854.72		485.63	
R-squared	0.247		0.417	

Significance *p < 0.01, **p < 0.001 and ***p < 0.000.

[a] Considering the effect of the PAs number of illegal activities in the model. Dispersion parameter for Negative Binomial (0.9815) family taken to be 1. Null deviance: 147.57 on 93 degrees of freedom. Residual deviance: 111.05 on 87 degrees of freedom.

[b] Considering the effect of PAs deforestation (km^2) in the model. Dispersion parameter for Negative Binomial (0.5212) family taken to be 1.312729. Null deviance: 179.99 on 93 degrees of freedom. Residual deviance: 105.00 on 87 degrees of freedom.

[c] Slopes for variables and Standard Error (SE).

For illegal activities, we found almost no difference between the Akaike information criterion (AIC) values of two models (M7 and M3), which suggests these are the two most plausible models affecting this response variable. The M7 model was able to explain approximately 24.7% of the variation in total illegal activities (Table 3). In this model, PA vulnerability was positively related with the number of illegal activities ($p < 0.001$) but negatively related to legal security and PA group ($p < 0.05$ and $p < 0.01$, respectively) (Figure 2a). Under M7, strictly protected areas had 50% more chance to have an illegal activity when compared with sustainable-use PAs. The M3 model explains 23% of the variation in the intensity of illegal activities among PAs. In addition, M3 showed that the intensity of illegal activities is positively related to vulnerability ($p < 0.001$) and negatively associated with PA group ($p < 0.01$) (Table A.3).

When evaluating deforestation rates within the PAs, model M7 performed better. Model M7 was able to explain approximately 41.7% of the variation in the total deforestation inside PAs (Table 3). Under this model, cumulative deforestation was positively related to PA vulnerability ($p < 0.001$) and PA group ($p < 0.001$) but negatively associated with legal security ($p < 0.001$) (Figure 2b). In general, sustainable-use PAs are 1.7% more likely to suffer forest loss than strictly protected areas.

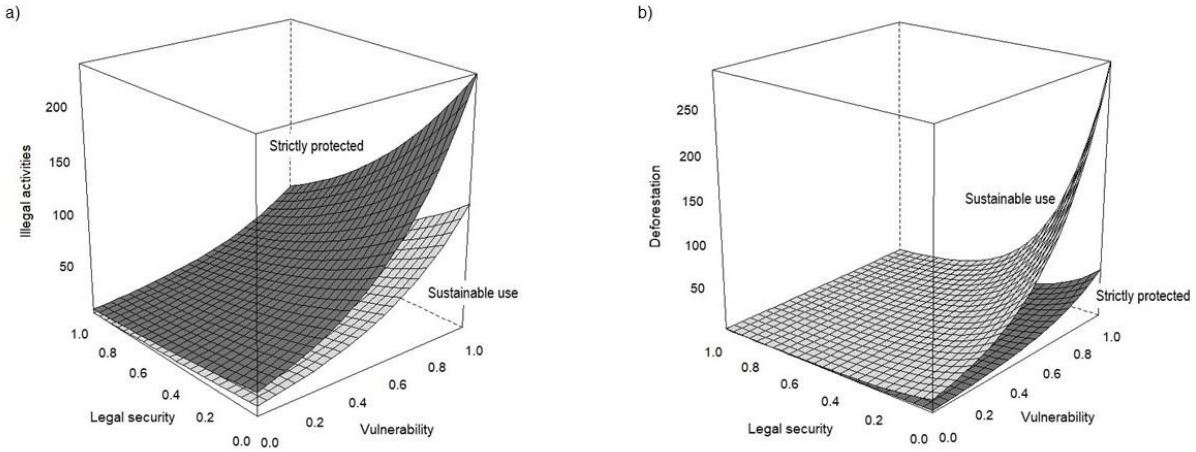

Figure 2. Associations between the RAPPAM modules legal security and vulnerability with the number of illegal activities (a) and cumulative deforestation (b) in the period of 2010 to 2015.

4. Discussion

Our results indicate that vulnerability, legal security, and PA group are good predictors of both illegal activities and cumulative deforestation within protected areas. These results are relevant because they suggest that although these threats have different levels of detectability, their impacts can be predicted by a common set of variables. A potential explanation is that these two types of threat are related, representing a *continuum* in PA degradation, where illegal extractive activities represent the first step of a process, while deforestation represents the end point.

A potential argument against the hypothesis that illegal activities and deforestation represent a continuum in a long-term process of forest degradation within PAs is the fact that, for sustainable-use FPAs, illegal activities were lower but cumulative deforestation was higher than in strictly protected areas. This apparent paradox has a simple explanation that is associated with co-management of these areas by government partners. Brazilian sustainable-use FPAs can be co-managed with local communities (e.g., Extractive Reserves) or with commercial companies (e.g., National Forests). In those PAs co-managed with local communities, the presence of local communities empowered by the government limits the invasion of PAs by outsiders and consequently can constrain illegal activities. On the other hand, such communities have the right to remove forest from some specific areas within protected areas to build houses and other facilities as well as establish family agriculture and sometimes pasture plots (IBAMA, 2006; ICMBio, 2007). Similarly, in FPAs managed for commercial purposes, such as some national forests mining exploration and consequently some vegetation extraction is allowed (IBAMA, 2001; ICMBio, 2016a), which can contribute to deforestation rates within PAs.

In sustainable use PAs co-managed by local communities, demographic growth can lead to more demands for basic infrastructure and, over time, is predicted to increase cumulative deforestation if these demands are incorporated into future versions of the PA management plans. Therefore, deforestation should not be by itself characterized as a PA degradation process but as a consequence of the management required for this specific type of PA. In fact, deforestation within sustainable use PAs should be better investigated and monitored to sort out the proportion of deforestation that is illegal and the proportion that is a consequence of the implementation of management plans.

Our work did not seek to evaluate which type of PAs (sustainable use or strictly protected areas) is the most efficient against deforestation. However, we found that the difference between them is very small. Studies that specifically evaluated the effect of PAs on deforestation have found that both types are effective in combating deforestation but that the strictly protected category obtained superior performance (Nolte, Agrawal, Silvius, & Soares-Filho, 2013; Pfaff, Robalino, Sandoval, & Herrera, 2015). More recently, Jusys (2018) found that designing sustainable use PAs do not currently prevent deforestation, but he did not sort out illegal vs. legal deforestation within this type of PA.

Overall, the vulnerability of PAs has a positive association with both illegal activities and deforestation, and also for the two types of PAs. This association suggests that the geographic context where the PA is inserted matters with regard to whether it can effectively prevent biodiversity loss. In general, PA accessibility has a great influence on both illegal deforestation (Barber, Cochrane, Souza, & Laurance, 2014) and illegal activities such as poaching, fishing, and logging (Kauano et al., 2017).

Legal security in PAs means that there are no disputes regarding land tenure or land rights; that the boundaries of PAs are demarcated and are recognized by outsiders; that staff and financial resources are adequate to conduct critical law enforcement activities; and that conflicts with the local community living inside or outside the PA have been resolved fairly and effectively. These are the most fundamental components of effective PA management and have been demonstrated as bringing effective results for conservation. For instance, Bruner et al. (2001) and Vanclay (2001) found negative associations between conservation outcomes and the demarcation of PA boundaries as well as the prevention and detection of threats and law enforcement. In addition, Vanclay (2001) and Nolte et al. (2013a) found a negative relationship between absence of land tenure conflict and conservation outcomes.

The RAPPAM's effectiveness index and the other module scores (i.e., biological importance, socioeconomic importance, objectives, design and planning, staffing, communication and information, infrastructure, financial resources, management planning, decision making, and research evaluation monitoring) had no significant association with either illegal activities or cumulative deforestation. This evidence shows that there is a mismatch between those indicators selected to measure PA management effectiveness in RAPPAM and those indicators traditionally selected to measure PA biodiversity outcomes. If this mismatch continues unchecked, it can have serious implications for the future of protected areas. Most

protected areas worldwide are underfunded and have limited resources to be invested annually (Leverington, Costa, Pavese, Lisle, & Hockings, 2010). If these already scarce resources are used to improve management processes that contribute very little to the actual PA performance in avoiding biodiversity loss, then PAs will not achieve the goals for which they were enacted. We suggest that an outcome-based approach rather than a process-based approach should guide the management of protected areas in places with limited financial resources.

Our results showed that the RAPPAM's effectiveness index is not a good predictor of the capacity of a PA to constrain illegal activities and deforestation. Instead, we found that only two RAPPAM modules (specifically, vulnerability and legal security) are associated with threat intensity. This result suggests that in the Brazilian Amazon, location, which defines vulnerability, and capacity to carry out boundary control, which defines legal security, are the two major factors influencing threat intensity in FPAs. Because the same model can explain the variation in both illegal activities and deforestation, two types of pressures with different levels of detection, we suggest that both threats represent only a *continuum* of the human pressures that are currently found among PAs in the Brazilian Amazon. We found that the PA group also matters, as strictly protected areas are 50% more likely to have illegal activity when compared with sustainable-use PAs, while sustainable-use PAs are 1.7% more likely to suffer forest loss compared with strictly protected areas. Our results can help decision-makers to prioritize interventions and investments that seek to reduce the current threats to the PA network of the Brazilian Amazon.

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Supplemental Material

Table A.1. The RAPPAM is composed by a set of 96 questions, grouped in 14 modules that covers four management effectiveness elements (planning, inputs, management processes and outputs) and one element representing the context of the PA. The questions use a standard four-point scale (no = 0, mostly no = 1, mostly yes = 3, yes = 5). The 14 modules scores are the arithmetic mean of a subset of questions. The elements are scored as the arithmetic mean of its module scores. And the RAPPAM effectiveness index is the arithmetic mean of four elements scores (planning, inputs, management processes and outputs).

Elements [a]	**Sections** [b]	**Questions**
Context [c]	Biological importance	- The PA contains a relatively high number of rare, threatened, or endangered species; - The PA has relatively high levels of biodiversity; - The PA has a relatively high degree of endemism; - The PA provides a critical landscape function; - The PA contains the full range of plant and animal diversity; - The PA significantly contributes to the representativeness of the PA system; - The PA sustains minimum viable populations of key species; - The structural diversity of the PA is consistent with historic norms; - The PA includes ecosystems whose historic range has been greatly diminished; - The PA maintains the full range of natural processes and disturbance regimes.

Context	Socioeconomic importance	- The PA is an important source of employment for local communities; - Local communities depend upon the PA resources for their subsistence; - The PA provides community development opportunities through sustainable resource use; - The PA has religious or spiritual significance; - The PA has unusual features of aesthetic importance; - The PA contains plant species of high social, cultural, or economic importance; - The PA contains animal species of high social, cultural, or economic importance; - The PA has a high recreational value; - The PA contributes significant ecosystem services and benefits to communities; - The PA has a high educational and/or scientific value.
Context	Vulnerability	- Illegal activities within the PA are difficult to monitor; - Law enforcement is low in the region; - Bribery and corruption is common throughout the region; - The area is experiencing civil unrest and/or political instability; - Cultural practices, beliefs, and traditional uses conflict with the PA objectives; - The market value of the PA resources is high; - The area is easily accessible for illegal activities; - There is a strong demand for vulnerable PA resources; - The PA manager is under pressure to unduly exploit the PA resources; - Recruitment and retention of employees is difficult.
Planning	Objectives	- PA objectives provide for the protection and maintenance of biodiversity; - Specific biodiversity-related objectives are clearly stated in the management plan; - Management policies and plans are consistent with the PA objectives; - PA employees and administrators understand the PA objectives and policies; - Local communities support the overall objectives of the PA.

Planning	Legal security	- The PA has long-term legally binding protection; - There are no unsettled disputes regarding land tenure or use rights; - Boundary demarcation is adequate to meet the PA objectives; - Staff and financial resources are adequate to conduct critical law enforcement activities; - Conflicts with the local community are resolved fairly and effectively.
Planning	Site, design and planning	- The siting of the PA is consistent with the PA objectives; - The layout and configuration of the PA optimizes the conservation of biodiversity; - The PA zoning system is adequate to achieve the PA objectives; - The land use in the surrounding area enables effective PA management; - The PA is linked to another area of conserved or protected land.
Inputs	Staffing	- The level of staffing is sufficient to effectively manage the area; - Staff members have adequate skills to conduct critical management activities; - Training and development opportunities are appropriate to the needs of the staff; - Staff performance and progress on targets are periodically reviewed; - Staff employment conditions are sufficient to retain high-quality staff.
Inputs	Communication and information inputs	- There are adequate means of communication between field and office staff; - Existing ecological and socio-economic data are adequate for management planning; - There are adequate means of collecting new data; - There are adequate systems for processing and analyzing data; - There is effective communication with local communities.

Inputs	Infrastructure	- Transportation infrastructure is adequate to perform critical management activities; - Field equipment is adequate to perform critical management activities; - Staff facilities are adequate to perform critical management activities; - Maintenance and care of equipment is adequate to ensure long-term use; - Visitor facilities are appropriate to the level of visitor use.
Inputs	Financial resources	- Funding in the past 5 years has been adequate to conduct critical management activities; - Funding for the next 5 years is adequate to conduct critical management activities; - Financial management practices enable efficient and effective PA management; - The allocation of expenditures is appropriate to PA priorities and objectives; - The long-term financial outlook for the PA is stable.
Management Processes	Management planning	- There is a comprehensive, relatively recent written management plan; - There is a comprehensive inventory of natural and cultural resources; - There is an analysis of, and strategy for addressing, PA threats and pressures; - A detailed work plan identifies specific targets for achieving management objectives; - The results of research and monitoring are routinely incorporated into planning.
Management Processes	Decision-making	- There is clear internal organization; - Management decision making is transparent; - PA staff regularly collaborate with partners, local communities, and other organizations; - Local communities participate in decisions that affect them; - There is effective communication between all levels of PA staff and administration.

Management Processes	Research, evaluation and monitoring	- The impact of legal and illegal uses of the PA are accurately monitored and recorded; - Research on key ecological issues is consistent with the needs of the PA; - Research on key social issues is consistent with the needs of the PA; - PA staff members have regular access to recent scientific research and advice; - Critical research and monitoring needs are identified and prioritized.
Outputs	Outputs	- Threat prevention, detection and law enforcement; - Site restoration and mitigation efforts; - Wildlife or habitat management; - Community outreach and education efforts; - Visitor and tourist management; - Infrastructure development; - Management planning and inventorying; - Staff monitoring, supervision, and evaluation; - Staff training and development; - Research and monitoring outputs.

[a] The elements are based in the WCPA (World Commission on Protected Areas) framework, and explore the major issues related to the management effectiveness of protected areas. [b] The sections were used like covariates in the study. [c] The element context is not used in the composition of the RAPPAM management effectiveness index, but the sections of context were covariates in analysis.

Table A.2. Variance inflation factors of the covariates.

Covariate	**GVIF**
PA area km2	1.411
PA group	1.778
Biological importance	2.319
Socioeconomic importance	2.035
Vulnerability	1.513
Objectives	2.265
Legal security	1.444
Design planning	1.952
Staffing	1.642
Communication information	2.162
Infrastructure	1.576
Financial resources	1.693
Management planning	2.450
Decision making	2.741
Research, evaluation and monitoring	1.745

Table A.3. Results of model 3 (M3) of the negative binomial generalized linear model for PAs number of illegal activities.

	Illegal activities[a]	
	Estimate (SE)[e]	z value
Intercept	1.8693 (0.906)	2.063*
Biological importance	-0.9861 (0.806)	-1.223
Socioeconomic importance	0.4985 (0.634)	0.786
Vulnerability	2.3197 (0.584)	3.97***
PA area (log)	0.1442 (0.109)	1.316
PA group (Sustainable use)	-0.7406 (0.246)	-3.008**
AIC	855.35	
R-squared	0.229	

Significance *p < 0.01, **p < 0.001 and ***p < 0.000.

[a] Considering the effect of the PAs number of illegal activities in the model. Dispersion parameter for Negative Binomial (0.9534) family taken to be 1. Null deviance: 143.87 on 93 degrees of freedom. Residual deviance: 110.95 on 88 degrees of freedom.
[b] Slopes for variables and Standard Error (SE).

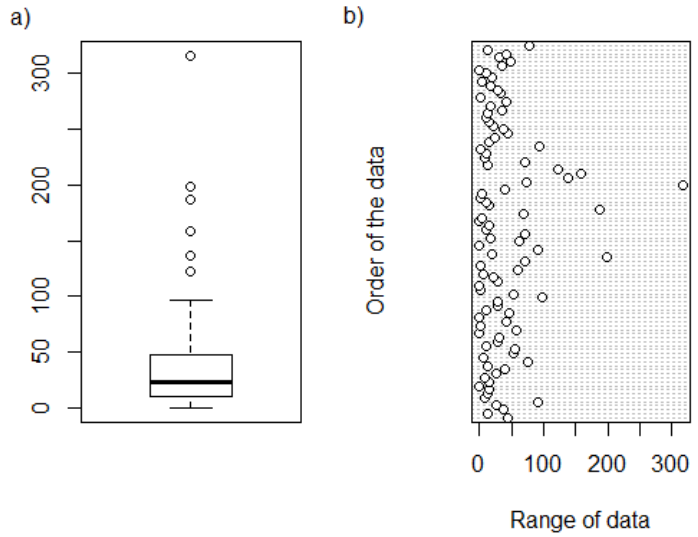

Fig. A.1. Data exploration of the number of illegal activities in the period of 2010 – 2015 in 94 federal protected areas in the Brazilian Amazon (mean = 38.33, median = 22.50, min. = 0, 1st Qu. = 10, 3rd Qu. = 47.50, and max. = 316); a) Boxplot and b) Dotchart for visualization of data distribution. The dots visualized as outliers were considered in the analyses.

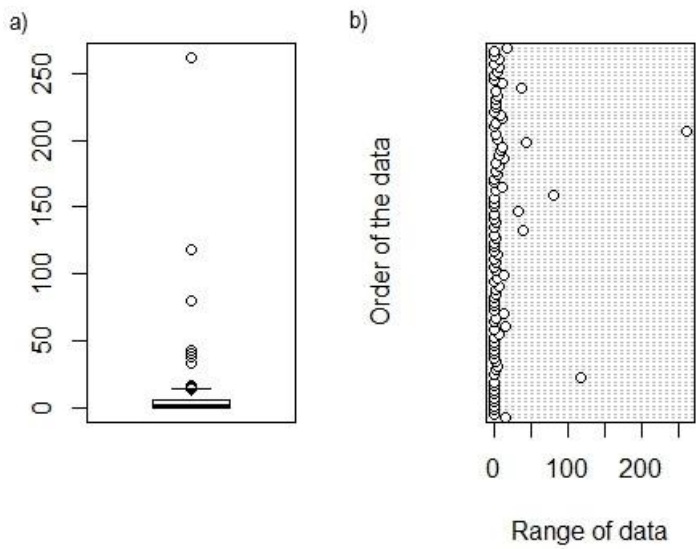

Fig. A.2. Data exploration of the deforestation (km^2) in the period of 2010 – 2015 in 94 federal protected areas in the Brazilian Amazon (mean = 9.22, median = 1.27, min. = 0, 1st Qu. = 0.16, 3rd Qu. = 5.63, and max. = 261.83); a) Boxplot and b) Dotchart for visualization of data distribution. The dots visualized as outliers were considered in the analyses.

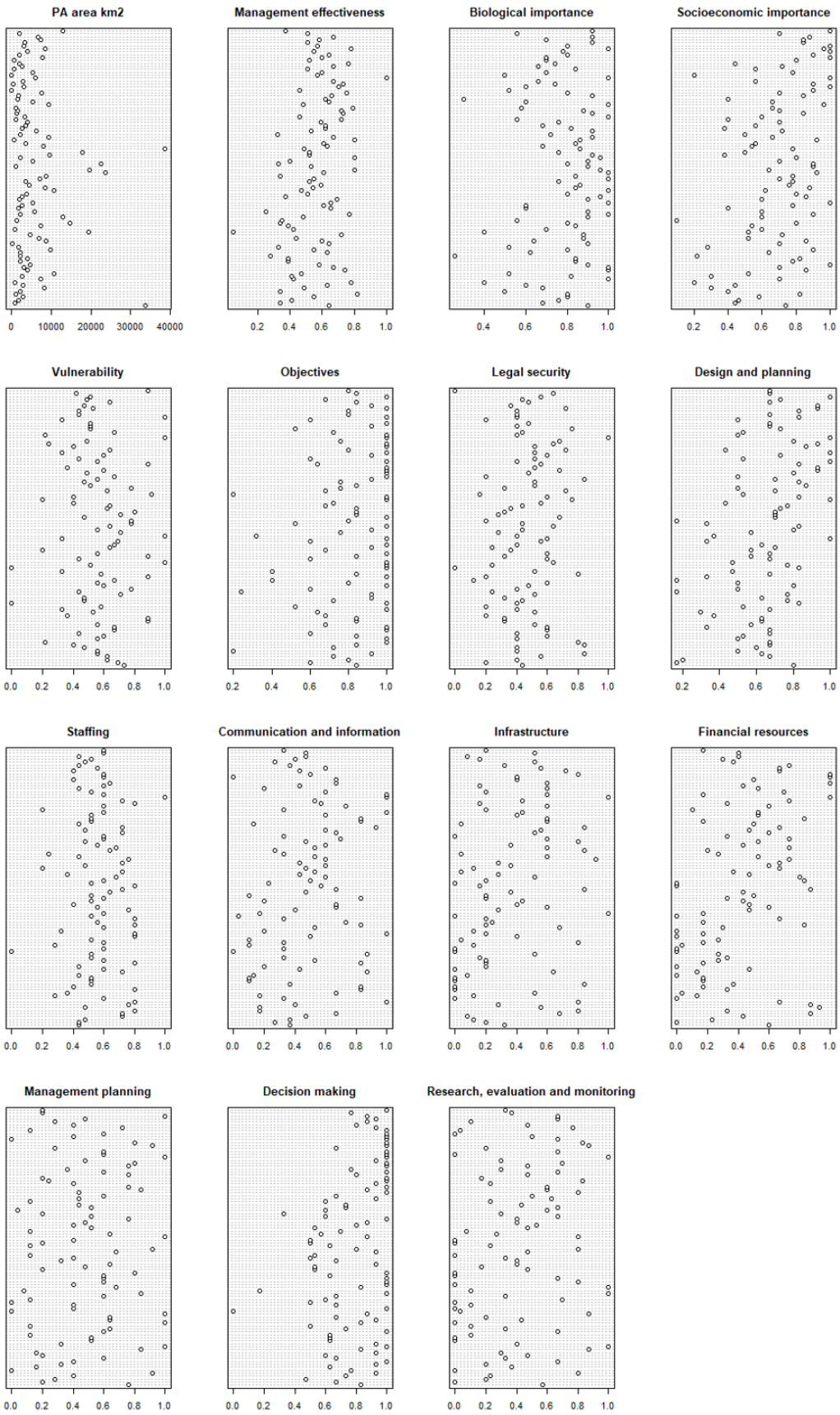

Fig. A.3. Dotcharts for visualization of covariates distributions.

ARTIGO CIENTÍFICO 3

Do protected areas hamper economic development of the Amazon region? An analysis of the relationship between protected areas and the economic growth of the Brazilian Amazon municipalities

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Do protected areas hamper economic development of the Amazon region? An analysis of the relationship between protected areas and the economic growth of Brazilian Amazon municipalities

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ABSTRACT

The Brazilian Amazon harbours 70 % of the world's tropical forests and is essential to the country's economy because it maintains biodiversity, sustains the livelihoods of the indigenous people and local communities, and provides ecosystem services such as water production, soil stabilization, flood prevention, and climate regulation. In the last three decades, the Brazilian government has established a regional protected area (PA) network that currently covers approximately 48 % of the region. Despite their importance, some sectors of the Brazilian society have argued that the expansion of the PAs across the region hampers the local economic development, because they make less area available for non-forest economic activities such as large-scale agriculture, mining, and power generation. In this study, we analysed the relationship between local economic growth and PA coverage in 516 municipalities in the Brazilian Amazon from 2004 to 2014. We modelled the impact of the coverage of the three types of PAs (strictly-protected, multiple-use, and indigenous lands) on the (i) compound annual growth rate (CAGR) of the real gross domestic product per capita (GDP per capita), and (ii) real gross value added per capita (GVA per capita) of the agriculture, industry, services, and government sectors in each municipality. The models also considered the following control variables at the municipal level: area, age, per capita GPD in 2004 (or per capita GVAs in 2004), population growth rate between 2004 and 2014, education index, deforested area outside PA per capita, deforested area inside PA per capita, degraded area outside PA per capita, degraded area inside PA per capita, and presence of illegal mining within PA. We applied spatial Durbin error models (SDEM) to analyse the direct, indirect, and total impacts of the PAs on the local economic growth. We did not find a statistically significant relationship between the local economic growth and PA coverage in any of the three PA groups evaluated. Only the total impact of the GVA per capita of the industry was negatively correlated with the coverage of the strictly-protected PAs. Our findings do not support the arguments used by some interest groups of the Brazilian society that the social and environmental gains generated through the expansion of PAs across the region constrain the overall local economic growth.

1. Introduction

Set aside protected areas (PAs) is considered one of the most effective policies for ensuring biodiversity conservation across the world (Dudley et al., 2014; Johnson et al., 2017; Rodrigues et al., 2004). Recent assessments have concluded that when well-managed, PAs reduce habitat loss and maintain species populations (Watson et al., 2014). PAs also provide livelihoods for millions of people and maintain land carbon stocks, which helps to mitigate and regulate climate changes (Bertzky et al., 2012).

Brazil is one of the countries that most contributed with the recent expansion of PAs coverage around the world. Indeed, 74 % of the

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Do protected areas hamper economic development of the Amazon region? An analysis of the relationship between protected areas and the economic growth of Brazilian Amazon municipalities

'Declarations of interest: none'

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Abstract

Brazil harbors 70% of the Amazon, the world's largest tropical forest. In the last three decades, the Brazilian government has implemented a large regional protected area (PA) network that currently covers about 48% of the region. Brazilian Amazonian PAs protect the country's biodiversity, sustain the livelihoods of indigenous people and local communities, and provide ecosystem services such as air and water quality regulation, soil stabilization, flood prevention, and climate regulation. Despite their importance, some sectors of Brazilian society have argued that the expansion of PAs across the region hampers local economic development, making less area available for conventional economic activities such as large-scale agriculture, mining, and power generation. In this study, we analyzed the relationship between local economic growth and PA coverage in 516 municipalities in the Brazilian Amazon from 2004 to 2014. We modelled the impact of the coverage of the three types of PAs (strictly protected areas, sustainable use areas, and indigenous lands) on the compound annual growth rate (CAGR) of the real per capita gross development product (GDP) in each municipality, while considering information at the municipal level: area, age, per capita GPD in 2004, population growth (rate between 2004 and 2014), and education index. We applied a spatial Durbin error model (SDEM) to analyze the direct, indirect, and total impacts of PAs on local economic growth. We did not find statistically significant relationships between local economic growth and PA coverage in any of the three PA categories evaluated. This finding shows that there is no evidence at the regional level to support the claim that PAs hamper local economic growth across the Brazilian Amazon.

Key words: Conservation police, Tropical rainforest, Strictly protected areas, Sustainable use protected areas, Indigenous lands

1. Introduction

The establishment of protected areas (PAs) is considered one of the most effective policies for ensuring biodiversity conservation across the world (Dudley et al., 2014; Johnson et al., 2017; Rodrigues et al., 2004). Recent assessments have concluded that generally, when they are well-managed, protected areas reduce rates of habitat loss and maintain species population levels (Watson et al., 2014). Protected areas also store land carbon stocks, which helps to mitigate and regulate climate change and provides livelihoods for thousands of people (Bertzky et al., 2012).

Brazil is one of the world's leaders in establishing new PAs. For instance, from 2003 to 2009, the country contributed 74% of the area added to the world's terrestrial PA network (Jenkins and Joppa, 2009). Many of these new PAs were established in the Brazilian Amazon region to limit the negative effects of regional deforestation (Silva, 2005; Walker et al., 2009). Deforestation in the Brazilian Amazon reached its second highest rate in history in 2003, and the cumulative deforested area level reached extremely worrisome levels (Fearnside, 2005; Kirby et al., 2006). From that year until 2014, 845,000 km2 were set aside for PAs, including the formal recognition of 315,000 km2 of indigenous lands. The establishment of PAs, intensification of law enforcement, improvement of monitoring systems, interventions in the soy and cattle supply chain, and support for forest-based economic activities have been identified as major drivers of the decline in deforestation across the region (Arima et al., 2014; Assunção et al., 2015; Le Tourneau, 2016; Nepstad et al., 2014, 2009; Pfaff et al., 2015).

Although political actions that seek to protect the biodiversity in the Brazilian Amazon receive broad support from the national population (Ministério do Meio Ambiente, MMA, 2012), some national interest groups have been orchestrating a systematic campaign to change the country's advanced environmental legislation, including the way the country establishes and maintains PAs (Tollefson, 2018; Veríssimo et al., 2011). One of the most visible outcomes of these actions has been the high number of PAs that have suffered pressure for degazettement, downsizing, or downgrading in the country (Bernard et al., 2014; Marques and Peres, 2015; Pack et al., 2016). In addition, several other policy initiatives in process in the national parliament seek to allow mining within PAs where the activity is currently prohibited (e.g., strictly protected areas, indigenous land, and some sustainable use areas) and to form a parliamentary front in defense of the populations (i.e., mostly farmers from other Brazilian regions, or land grabbers) affected by PAs (Ferreira et al., 2014; Rocha, 2015; Villén-Pérez et

al., 2018). The major argument behind this political movement is that the expansion of the Brazilian PAs network constrains local economic development because PAs take the space that could be occupied by large-scale agriculture, mining, and power generation activities (Ferreira et al., 2010; Miranda, 2009; Rodrigues, 2014).

The socioeconomic impacts of PAs on local economies have been widely discussed in the literature (Andam et al., 2010; Brockington and Wilkie, 2015; Castillo-Eguskitza et al., 2017; Ferraro and Hanauer, 2014; Hanauer and Canavire-Bacarreza, 2015; Oldekop et al., 2016; Sims, 2010; Upton et al., 2007; West et al., 2006). In some regions in Africa, PAs are thought to disrupt local economies by imposing land uses that are not compatible with the traditional practices of local communities (Derman, 1995; Fairhead and Leach, 2012; Gibson and Marks, 1995; Neumann, 1997). In contrast, in Brazil, PAs are one of the most effective tools to ensure land use rights for local communities, protecting them against the negative impacts of the expansion of the economic frontier (Veríssimo et al., 2011). A reason for these differences is the fact that protected areas are not equal, as they can be set aside with completely different management and social goals. The International Union for Conservation of Nature (IUCN) (2008) recognizes six major management categories, ranging from strict protection (categories I to III) to promoting the sustainable use of natural resources (categories IV to VI). From this perspective, PAs with high use restrictions are not always expected to generate gains for local economies. In contrast, PAs with low use restrictions should contribute to local economic growth. The impacts of PAs on local economies are context specific and depend on the country's legal framework for designating PAs. Thus, national or sub-national studies evaluating the relationship between local economic growth and environmental conservation (measured by PA coverage) are essential to fully understand the synergies and trade-offs between these two essential goals of sustainable development (Sachs, 2015).

In this study, we analyzed the relationship between local economic growth and PA coverage in 516 municipalities in the Brazilian Amazon from 2004 to 2014. Because protected areas in Brazil are set aside with different management goals, we modelled the independent impacts of three types of PA (strictly protected, sustainable use, and indigenous lands) on municipal economic growth, as measured by the compound annual growth rate (CAGR) of the gross development product (GDP) per capita, while considering the following variables at the municipal level: (a) area, (b) age, (c) 2004 per capita GPD, (d) population growth (difference between 2004 and 2014), and (f) education index. Brazilian legislation limits the exploration of natural resources within strictly protected areas and indigenous lands. Thus, their coverage area

at the municipal level is expected, on average, to be negatively associated or to show no association with AGR. In contrast, a major goal of sustainable use PAs is the promotion of sustainable use of the natural resources that they contain; therefore, their spatial coverage is expected to be positively associated with AGR.

2. Material and Methods

2.1. Study area

We analyzed a total of 516 municipalities in the Brazilian Amazon and 571 PAs allocated from 2004 to 2014 (Fig. 1). The Brazilian Amazon was delimited according to the boundaries of the Amazonia biome, as defined by the *Instituto Brasileiro de Geografia e Estatística* (IBGE) (IBGE, 2004). This region includes the states of Amazonas, Acre, Roraima, Amapá, Pará and Rondônia, and parts of Mato Grosso, Maranhão, and Tocantins. The Brazilian Amazon covers 4.3 million km^2 and has a population of 21.6 million people, 72% of whom live in urban areas (Silva et al., 2017).

The Brazilian Amazon has a PA network of around 2.2 million km2 (Brazil, 2015), which can be grouped into three main categories: strictly protected areas, sustainable use PAs, and indigenous lands (Brasil, 2006; Rylands and Brandon, 2005). The strictly protected areas (biological reserves, IUCN category I; ecological reserves, IUCN category I; and national parks, IUCN category II) have as a basic goal the protection of ecosystems with minimal human interference, allowing tourism activities only in national parks. The sustainable use PAs (national forests, IUCN category VI; extractive reserves, IUCN category VI; and sustainable development reserves, IUCN category VI) reconcile biodiversity conservation, the sustainable exploitation of natural resources, and the livelihoods of local populations (Brasil, 2000; IUCN, 2008). Finally, the indigenous lands seek to guarantee the right of the Amerindians to the lands historically occupied by them and the maintenance of their livelihoods and cultural heritage (Brasil, 1988).

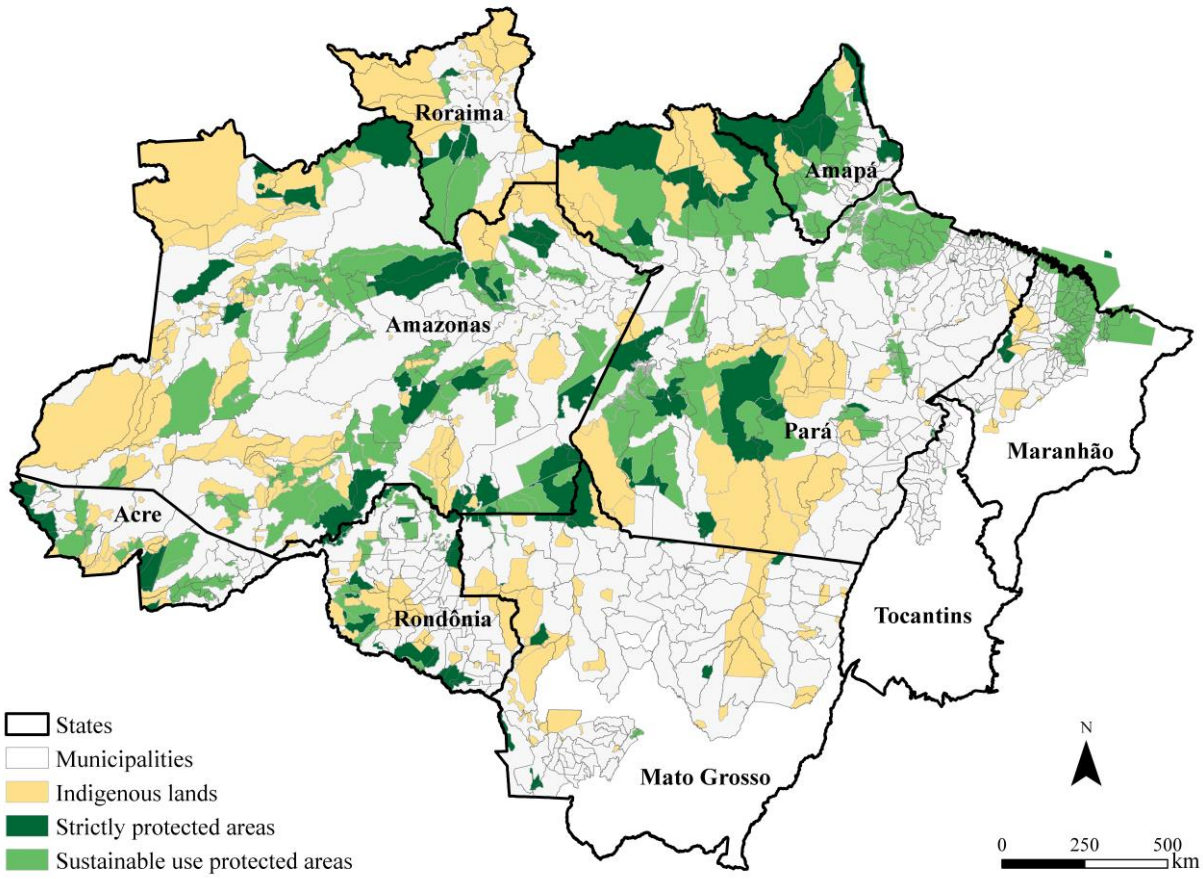

Figure 1: Brazilian Amazon municipalities (n = 516) and protected areas (n = 571) established up to 2014. The protected areas were divided in three main categories: strictly protected areas (n = 80), sustainable use protected areas (n = 185), and indigenous lands (n = 306).

In our study, we analyzed all PAs enacted up to 2014 that are managed at the federal, state, and municipal government levels. Other areas, such as the quilombola lands (Afro-Brazilian communal territories) and private lands with a legally defined environmental conservation function (e.g., riparian forests or private reserves), were not included. When there was a spatial overlap between PAs, we corrected it by excluding the overlapping part of one of the PAs. In these cases, the criteria adopted was to maintain the PA with the most restrictive category by following this restriction order: strictly protected area > sustainable use PA > indigenous land.

2.2. Data sources

All information used in this analysis is available from public sources. Data about the GDP, population, and boundaries (shapefiles format) for each municipality were gathered from the databases of the IBGE (2018a, 2018b, 2010a). Digital maps of PAs (shapefile format) are from the World Database on Protected Areas (WDPA) (UNEP-WCMC, 2017, 2016). The education index, which measures the education dimension of a municipality by combining the number of children and young people in school and the education level of the adult population, was obtained from the 2010 Human Development Index of the Brazilian municipalities (United Nations Development Program, UNDP, 2013).

The spatial data (protected areas and municipalities polygons) were first organized in a Geographic Information System (GIS) environment in ArcGIS 10.6 software (ESRI, 2018). Then, we followed five steps to produce the data required for statistical analyses: 1) We used the maps generated by IBGE to produce the shapefile of the Brazilian Amazon municipalities by overlapping the maps of the Brazilian municipalities with the map of the Brazilian ecological regions (or biomes); 2) we produced a shapefile of Brazilian Amazon PAs from the WDPA data, including the correction for PA overlaps; 3) we intersected the municipality data with the PA data; 4) we calculated the municipality areas, the PA areas, and the proportion of each PA type (strictly protected area, sustainable use area, and indigenous lands) in the municipalities; and 5) we added the information from the GDP (2004 to 2014), municipality populations in 2010, municipality ages, and municipality education indexes. The final shapefile for all analyses as well as Figures 1 and 2 were produced as an equal area projection (Projection: Albers Equal Area Conic; Datum: South America, 1969).

2.3. Analysis

In our model, the dependent variable was local economic growth. It was estimated using the compound annual growth rate (CAGR) of the GDP per capita, a method widely used for comparisons of economic performance (Fagerberg and Verspagen, 1996; Gordon, 2012; Klasen and Lamanna, 2009; Mo, 2001; Romer, 1986; Scully, 1988; Torsten Persson and Guido Tabellini, 1994). We calculated the CAGR for the period between 2004 and 2014 following three steps: 1) we divided the GDP per capita in 2014 (final year) by the GDP per capita in 2004 (initial year); (2) then, we raised the result to the power of 1 divided by the total period length (10 years); and (3) finally, we subtracted 1 from the result. We estimated the GDP per capita in thousands of Brazilian Reais (R$). The 2004 GDP per capita was converted to 2014 GDP per

capita values by considering Brazil's national inflation. As the indicator of national inflation we used the Índice Nacional de Preços ao Consumidor Amplo (IPCA), an official Brazilian inflation index developed by the IBGE (IBGE, 2018c).

The explanatory variables were the percentage of the municipality areas covered by strictly protected areas, sustainable use PAs, and indigenous lands. Because several other factors can influence economic performance at the local level, our models included the following control variables: the municipality's area (log-transformed), age, 2004 GDP per capita (log-transformed), population growth (overall rate from 2004 to 2014), and education index (Table 1).

Table 1: The explanatory variables used to evaluate the associations between the economic growth of Brazilian Amazon municipalities and the proportion of protected areas from 2004 to 2014.

Explanatory variables	Description
Strictly protected areas (%)	Percentage of strictly protected areas in each municipality in 2014. This variable was used to evaluate the hypothesis that strictly protected areas have a negative or no association with the economic growth of Brazilian Amazon municipalities.
Sustainable use PAs (%)	Percentage of sustainable use PAs in each municipality in 2014. This variable was used to evaluate the hypothesis that sustainable use areas have a positive association with the economic growth of Brazilian Amazon municipalities.
Indigenous lands (%)	Percentage of indigenous lands in a municipality in 2014. This variable was used to evaluate the hypothesis that indigenous lands have a negative or no association with the economic growth of Brazilian Amazon municipalities.
Municipality area	Municipality area in square km. Municipality area was included to take into account the differences in municipality sizes in the

	models. This variable was included because larger municipalities are expected to have higher economic growth.
Municipality age	Municipality age in 2014. Municipality age was included to evaluate the prediction that old municipalities have had more time to develop and consequently have greater economic growth.
GDP per capita 2004	GDP per capita in 2004 This variable was utilized because the initial year value is an important factor to consider in growth models. The expectation is that municipalities with a lower initial per capita GDP will have greater economic growth.
Population growth	Population growth was defined as the population of 2014 minus the population of 2004 divided by the population of 2003. The values were log transformed before the calculation: Population growth = (log(population 2014) – log(population 2003))/ log(population 2003). The expectation is that municipalities with higher population growth will have an increase in the work force and consequently will have a greater economic growth.
Education index	The education sub-index variable from the 2010 Municipal Human Development Index was utilized considering that the education level of a population is an important explanatory variable in economic growth models.

We followed the protocol described by Zuur et al. (2010) to explore our data. Box plot and Cleveland dot plots were used to visualize CAGR values. We maintained all values in the analyses even though some municipalities presented some growth rates above or below that of the regional trend (Fig. A.1). We log-transformed the CAGR for the subsequent analysis. We added 1 to the CAGR values due to the presence of negative rates. Cleveland dot plots were also used to visualize the explanatory and control variables. We found that some municipalities had a high GDP per capita in 2004 and that some municipalities had very large areas (Fig. A.2). Therefore, these two variables were also log-transformed. Variance inflation factors (VIFs) were used to determine the presence of collinearity in the explanatory variables. We found no

strong collinearity (all VIFs < 3; Table A.1), thus, all variables were used in the subsequent analyses.

To test our hypotheses, we first used an ordinary least squares regression (OLS) on the relationship between the proportions of different PA types and the economic growth of Brazilian Amazon municipalities from 2004 to 2014 (Table A.2, Fig. A.3). The control variables (Table 1) also include the fitted OLS. Second, we verified the spatial dependence of the residuals of the fitted OLS regression utilizing a Moran's I test and applying Lagrange Multiplier tests. To apply these tests, we constructed a weight list object (Table A.3) developed from a neighboring object (Fig. A.4). The Moran's I test showed significant spatial dependence (Table A.4) and the Lagrange Multiplier test diagnostics indicated that a spatial error simultaneous autoregressive model as more appropriate to deal with the observed spatial autocorrelation (Table A.5). As a consequence, we applied the spatial error model (SEM) and a spatial Durbin error model (SDEM), using the same weights list object as the spatial dependence evaluation. A likelihood ratio test between the SEM and the SDEM was used to verify if the spatial autoregressive error specification was internally consistent (Arbia, 2014). The SEM model (Table A.6) was fitted only for evaluating the error specification, considering that the SDEM improved our interpretation because it considers the autocorrelation of variables in the neighboring municipalities. This procedure is relevant because it enables an evaluation of the neighboring impacts, in which indirect impacts (spatial spillovers) interact with direct impacts (own municipality), producing a total (overall) impact (e.g., an indirect impact may nullify a significant positive direct impact on growth level and produce an insignificant or negative total impact) (LeSage and Fischer, 2008). For all models (OLS, SEM, and SDEM), we tested for normality using a Jarque-Bera test and for heteroskedasticity using a studentized Breusch-Pagan test. Finally, we evaluated the SDEM impacts (direct, indirect, and total) by generating 1,000 simulations in a Markov chain Monte Carlo (MCMC) process. All the analytical procedures used here were based on spatial econometrics methods described by Le Sage and Fischer (2008), LeSage and Pace (2009), Bivand et al. (2013), and Arbia (2014).

We used the R-platform (R Core Team, 2018) for all statistical analyses. Some of the R scripts used were adapted from Zuur et al. (2010), Bivand et al. (2013), Bivand and Piras (2015) and Arbia (2014). The R packages used in our study were: rgdal (Bivand et al., 2018), sp (Pebesma and Bivand, 2005), lattice (Sarkar, 2008), spdep (R. Bivand et al., 2013; Bivand and Piras, 2015), coda (Plummer et al., 2006), tseries (Trapletti and Horninik, 2018), lmtest (Zeileis and Hothorn, 2002), and ggplot2 (Wickham, 2016).

3. Results

The GDP per capita (for all region) ranged from R$ 1,910 to R$ 94,820 (mean of R$ 8,170) in 2004 and from R$ 3,770 to R$ 86,600 (mean of R$ 13,400) in 2014 (Table A.7). The regional population was 17,962,134 in 2004 and 21,282,131 in 2014 (Table A.7). Over the entire study period, the yearly CAGR ranged from -5.51% to 23.66% (mean = 5.56%) (Table A.8, Fig. 2b). The PA coverage in 2014 (in relation to all regions) was 47.99%, of which 9.65% were strictly protected areas, 16.04% were sustainable use areas, and 22.30% were indigenous lands (Table A.8, Fig. 2a). Most of the municipalities (72.48%) had some PA coverage in their territories.

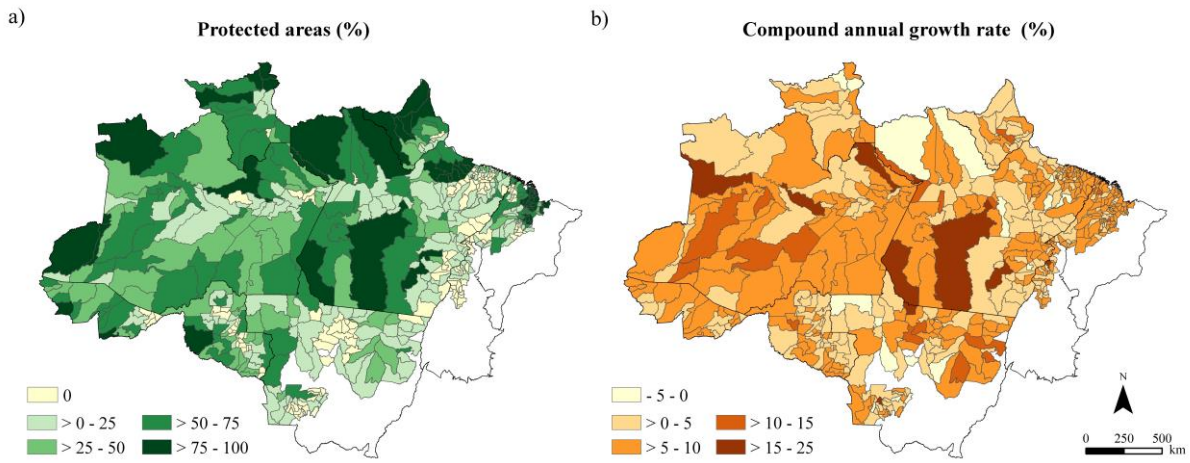

Figure 2: (a) Percentage of protected areas up to 2014 in the Brazilian Amazon municipalities; (b) percentage of compound annual growth rate (CAGR) of the local gross development product (GDP) per capita from 2004 to 2014.

The SDEM presented an R2 of 0.35 (adjusted R2 = 0.33), indicating a good fit between the data and the model. We did not find any statistically significant relationship between the economic growth of Brazilian Amazon municipalities and the coverage of strictly protected areas, sustainable use PAs, and indigenous lands (Table 2). The evaluation of the impacts (direct, indirect, and total) also did not present any significant relationship with the coverage of any PA category (Table 3). As expected, the control variables were statistically significantly associated with the CAGR, with the exception of the municipality's age. The area, per capita

GDP in 2004, and education index of the municipalities were positively related with the CAGR, while their population growth was negatively related.

Table 2: Spatial Durbin error model (SDEM) results. Parameter (slope) estimates of exploratory variables from the SDEM on the log of compound annual growth rate (CAGR) of the gross development product (GDP) per capita in Brazilian Amazonian municipalities from 2004–2014.

	Estimate	Std. Error	z-value	Pr(>|t|)	
Intercept	0.01520	0.02059	0.7381	0.4605	
Strictly protected areas	-0.00017	0.00014	-1.1945	0.2323	
Sustainable use PAs	-0.00003	0.00007	-0.4575	0.6473	
Indigenous lands	-0.00004	0.00008	-0.5342	0.5932	
Municipality area (log)	0.00486	0.00166	2.9300	0.0034	**
Municipality age	-0.00002	0.00002	-0.7403	0.4591	
GDP per capita 2004 (log)	-0.02835	0.00305	-9.2943	< 2.2e-16	***
Population growth (log)	-0.02726	0.00366	-7.4565	8.88E-14	***
Education index	0.06348	0.01807	3.5125	0.0004	***
lag.Strictly protected areas[a]	0.00006	0.00025	0.2544	0.7992	
lag.Sustainable use PAs[a]	0.00015	0.00010	1.4156	0.1569	
lag.Indigenous lands[a]	0.00015	0.00014	1.0416	0.2976	
lag.Municipality area[a]	0.00120	0.00223	0.5414	0.5882	
lag.Municipality age[a]	-0.00006	0.00004	-1.5338	0.1251	
lag.GDP per capita 2004[a]	0.00604	0.00482	1.2533	0.2101	
lag.Population growth[a]	-0.00196	0.00706	-0.2778	0.7811	
lag.Education index[a]	0.01588	0.03020	0.5258	0.5990	
Multiple R-squared	0.35	0.00604			
Adjusted R-squared	0.33				
Log likelihood	1175.68				

AIC	-2313.40

Significance: *p < 0.05, **p < 0.01, and ***p < 0.001
Lambda: 0.1756, LR test value: 6.7962, p-value: 0.0091
Asymptotic standard error: 0.0643
z-value: 2.7311, p-value: 0.0063
Wald statistic: 7.4586, p-value: 0.0063
ML residual variance (sigma squared): 0.0006, (sigma: 0.0247)
Jarque-Bera test: X-squared = 1181.8, df = 2, p-value < 2.2e-16
studentized Breusch-Pagan test: BP = 19.506, df = 16, p-value = 0.2433
[a] lag."variable name" is the form for the spatially lagged explanatory variables

Table 3: Impacts of the spatial Durbin error model (SDEM) results on the log of the compound annual growth rate (CAGR) of the gross development product (GDP) per capita in the 516 Brazilian Amazonian municipalities from 2004 to 2014. The impacts were obtained by a Markov chain Monte Carlo (MCMC) process using 1000 randomizations.

	Direct			Indirect		Total		
	Estimate	Std. Error		Estimate	Std. Error	Estimate	Std. Error	
Strictly protected areas	-0.00017	0.00015		0.00006	0.00026	-0.00010	0.00024	
Sustainable use PAs	-0.00003	0.00007		0.00015	0.00011	0.00012	0.00008	
Indigenous lands	-0.00004	0.00009		0.00015	0.00015	0.00010	0.00014	
Municipality area (log)	0.00486	0.00174	**	0.00120	0.00234	0.00606	0.00197	**
Municipality age	-0.00002	0.00002		-0.00006	0.00004	-0.00008	0.00005	
GDP per capita 2004 (log)	-0.02835	0.00321	***	0.00604	0.00507	-0.02232	0.00475	***
Population growth	-0.02726	0.00384	***	-0.00196	0.00742	-0.02922	0.00801	***
Education index	0.06348	0.01900	***	0.01588	0.03175	0.07935	0.03191	*

Significance: *p < 0.05, **p < 0.01, and ***p < 0

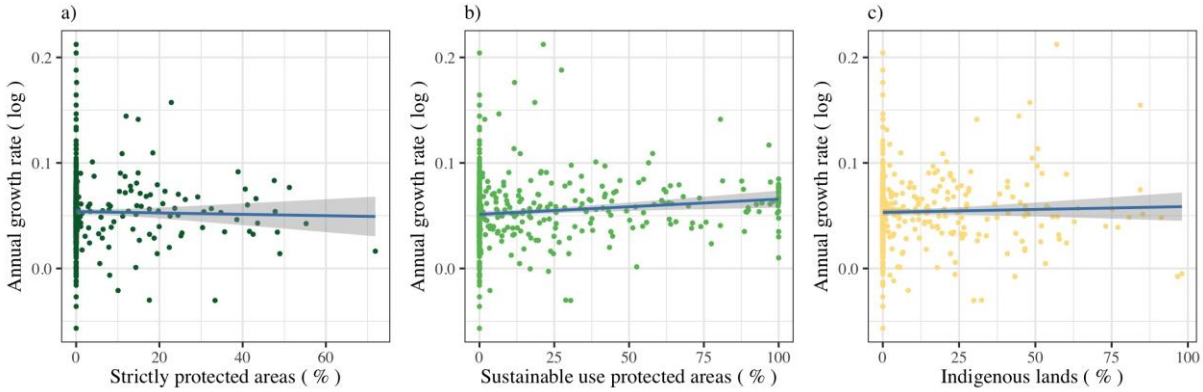

Figure 3: Associations between protected areas and economic growth in Brazilian Amazon municipalities from 2004 to 2014. Linear associations between the compound annual growth rate (CAGR) of the gross development product (GDP) per capita and the percentage of the municipality area covered by strictly protected areas (a), sustainable use protected areas (b), and indigenous lands (c). PAs coverage did not have a statistically significant relationship with the CAGR.

We found that heteroskedasticity was not a restriction for the SDEM (studentized Breusch-Pagan test; BP = 19.50, df = 16, p-value = 0.24). In contrast, the SDEM residuals were not normally distributed (Jarque-Bera test; X2 = 1181.8, df = 2, p-value < 0.001). The SDEM was able to deal with the spatial dependence observed on the OLS residuals (Global Moran's I, observed = - 0.0016 and p-value = 0.9906; Table A.9). The likelihood ratio test between the SEM and the SDEM demonstrated that the spatial autoregressive error specification was internally consistent (Table A.10).

4. Discussion

We found that PAs do not hamper local economic growth across the Brazilian Amazon. By collecting the best evidence available, using reliable spatial econometric methods, and considering key control variables, we demonstrated that the coverage of strictly protected areas, sustainable use PAs, and indigenous lands did not constrain economic growth at the municipality level across the Brazilian Amazon from 2004 to 2014. Therefore, our results do

not support the arguments used by some sectors of Brazilian society to undermine the social and environmental gains generated from the expansion of PAs across the region.

Although our aim was not to identify the major drivers of local economic growth across the Brazilian Amazon, our models suggest that local economic growth is better explained by the GDP per capita in 2004 (i.e., the initial condition). This result indicates that there is a negative relationship between initial GDP per capita and CAGR, supporting the general hypothesis that poor local economies tend to grow faster than rich ones (Barro and Sala-i-Martín, 2003). This convergence pattern seems to be pervasive across the region, as it has also been reported in other econometric studies in the Brazilian Amazon that analyzed temporal changes in the local human development index (Caviglia-Harris et al., 2016; Silva et al., 2017).

We used the best official information available to model the relationship between PA coverage and economic growth. However, it is important to highlight that the GDP per capita measured by official sources only represents part of the total local economy. In fact, an important share of the economic activities at the local level in the Brazilian Amazon is informal and, therefore, is not captured by the official indicators (Silva et al., 2017). Informal economic activities in rural Brazilian Amazon include the illegal use of natural resources (e.g., illegal mining, commercial hunting, illegal logging, and illegal fishing) and even land grabbing, a common practice in the region. Informal economies also include several activities that the Brazilian state does not yet have the capacity to control, such as small-scale fisheries that supply most of the local markets, and extraction and commercial use of non-timber forest products (Almeida et al., 2001; Antunes et al., 2016; Cleary, 1993; Kauano et al., 2017; Simmons et al., 2007). The impact that setting aside PAs has on local informal economies still needs to be assessed, but some predictions can be made. In municipalities where the informal economy is based on the illegal extraction of natural resources, the intensity of the informal economic activities is expected to decline with the expansion of PAs. The main reason is that the designation of PAs brings more and better law enforcement by governments, which consequently limit illegal activities (Kauano et al., 2017). On the other hand, PAs can also foster informal rural economic activities. For instance, in those municipalities where the informal economy is currently limited due to lack of land security and government support, new PAs can increase local informal economies by ensuring that local populations have the right to use their lands, are protected against newcomers, and have access to social programs (Pinho et al., 2014; Simmons, 2004; Veríssimo et al., 2011).

Although our findings did not show any statistically significant negative associations between local economic growth and the coverage of strictly protected areas and indigenous lands, they also did not show significant positive relationships between local economic growth and sustainable use PAs. We suggest that these results are a consequence of the high spatial concentration of local economies across the region associated with the lack of PA implementation.

The high spatial concentration of economic activities at the municipal level is due to three factors: large municipal areas, low human density, and high urbanization. In fact, most of the municipalities across the region are large (76% are above 1,000 km2, while the mean size of municipalities in other Brazilian states is roughly 716 km2), had low human densities in 2014 (85% of them had a human density below 29 people/km2), and had a high urbanization ratio (72% of the population was living in urban areas in 2010). In the last four decades, the regional population has shifted from mostly rural to mostly urban areas (IBGE, 2010b). This trend continues, and it is expected that by 2030, at least 80% of the regional population will be living in cities, which is close to the United Nations (2018) estimate of 89% urbanization for Brazil. Excluding the municipalities in the southern Brazilian Amazon, whose economy is based on commercial agriculture, this fast and chaotic urbanization process is leading to a high concentration of economic activities around relatively small urban areas (Becker, 2005). As a consequence, setting aside PAs, even large ones, far away from major urban centers has little or no impact on local economies.

Even when located far away from the urban centers, Amazonian PAs could become engines of economic growth if they are fully implemented (Dias et al., 2016). The effective management of a PA requires goods and services that can only be supplied locally. Therefore, the simple implementation of a PA could bring additional financial resources to municipalities and thus benefit formal local economies. Flows of tourists and researchers could also increase the demand for goods and services at a local scale and could generate economic benefits (Lima and Peralta, 2017). In addition to protecting biodiversity, sustainable use PAs are also expected to enable sustainable commercial exploitation of natural resources and, consequently, to help local economies (Brasil, 2000). However, the lack of relationships between sustainable use PA coverage and local economic growth suggests that sustainable use PAs are not fulfilling some of their goals.

In the Brazilian Amazon, sustainable use PAs include two major groups: 1) extractive reserves + sustainable development reserves; 2) national or state forests. The first group is designated to protect the livelihoods and culture of traditional extractive populations. Governments develop community projects in these areas to improve the quality of life of the local people. These projects include a wide range of activities, such as the control of zoonoses, the development of productive chains of natural products, support for ecotourism, and sustainable forest management, among other initiatives (Fraga et al., 2015; ICMBio, 2018, 2016, 2014). The second group is designated for the multiple use of forest resources with an emphasis on sustainable forest management. It may involve forestry concessions and, in some cases, mining activities, which can have a large positive local and regional impact (Veríssimo et al., 2002). Regardless of PA type, PAs need to be fully implemented to achieve their goals. However, implementation is a major gap across all Brazilian Amazon PAs. The most recent assessment of the management quality of federal PAs in the region indicated that few of them could be considered as meeting the minimum requirements to be considered fully operational (WWF, 2017). A recent audit by the Tribunal de Contas da União (TCU) pointed out that only 4% of the federal and state PAs in the Brazilian Amazon were considered to have a high degree of implementation and management. The audit also found suboptimal use of the economic, social, and environmental potential of the areas (e.g., national parks without public use, national forests without community forest management or forest concessions, biological reserves without research) (TCU, 2013). Dias et al. (2016) demonstrated that in the state of Amapá, the potential economic benefits of PAs outperform their management costs, indicating that, from an economic viewpoint, PAs can foster strong local economies if they are fully implemented.

Studies on the relationship between PAs and local economic growth have found mixed outcomes. In Costa Rica, establishing PAs with tourism activities helped reduce rural poverty (Ferraro and Hanauer, 2014). In the western United States, non-metropolitan areas with national parks, wilderness, and other forms of protected public lands improved their economic performance (Rasker et al., 2012). In southwestern Australia, protected areas stimulated the local housing development sector, encouraged local business growth, and received local government finances (Heagney et al., 2015). On the other hand, other studies found that PAs can increase local poverty or that there was no clear effect between conservation and development (Castillo-Eguskitza et al., 2017). Our study contributes to the ongoing effort to

understand the synergies and trade-offs between PAs and local economic growth in different socio-economic contexts. We found no evidence that PAs hamper local economic growth across the Brazilian Amazon. We suggest that this result is possibly a consequence of the spatial concentration of local economic activities around urban centers and the lack of implementation of PAs. Based on the studies so far, we believe that PAs can be engines of local economic growth in the Brazilian Amazon if and only if they are fully implemented.

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Appendix A. Supplemental Material

Table A.1: The variance inflation factors (VIF) of the explanatory variables. All variables, VIF < 3.

Variable	VIF
Strictly protected areas	1.175
Sustainable use PAs	1.376
Indigenous lands	1.386
Area	1.233
Age	2.062
GDP per capita 2004	2.139
Population growth	1.145
Education index	1.799

Table A.2: Ordinary Least Square (OLS) regression results. Parameter estimates of exploratory variables from OLS on the log of compound annual growth rate (CAGR) of the gross development product (GDP) per capita in Brazilian Amazonian municipalities from 2004–2014.

	Estimate	Std. Error	t-value	Pr(>|t|)	
Intercept	0.019420	0.012120	1.603	0.1095	
Strictly protected areas	-0.000145	0.000124	-1.169	0.2431	
Sustainable use PAs	0.000009	0.000046	0.196	0.8444	
Indigenous lands	0.000001	0.000074	0.014	0.9887	
Municipality area (log)	0.006352	0.001139	5.578	3.97E-08	***
Municipality age	-0.000036	0.000021	-1.736	0.0831	
GDP per capita 2004	-0.025110	0.002525	-9.945	< 2e-16	***
Population growth	-0.028150	0.003565	-7.897	1.79E-14	***
Education index	0.077400	0.016680	4.639	4.47E-06	***
Multiple R^2	0.32				
Adjusted R^2	0.31				
AIC	-2314.00				
Log likelihood	1167.00	(df=10)			

Significance: *p < 0.05, **p < 0.01 and ***p < 0.001.
Residual standard error: 0.0254 on 507 degrees of freedom.
F-statistic: 30.13 on 8 and 507 DF, p-value: < 2.2e-16
Jarque Bera Test: X-squared = 1208, df = 2, p-value < 2.2e-16
Studentized Breusch-Pagan test: BP = 14.361, df = 8, p-value = 0.0728

Table A.3: Weights constants summary of weights list object of the study area.

W	n	nn	S0	S1	S2
Moran's I	516	266256	516	209.7786	2152.3440

Number of regions: 516
Number of nonzero links: 2760
Percentage nonzero weights: 1.036596
Average number of links: 5.348837
Weights style: W

Table A.4: Global Moran's I of residuals from Ordinary Least Square (OLS) regression on the log of compound annual growth rate (CAGR) of the gross development product (GDP) per capita in Brazilian Amazonian municipalities from 2004–2014.

	Observed	Expected value	Variance	Standard deviate	p-value
Moran's I	0.07574	-0.00814	0.00076	3.04570	0.00232

alternative hypothesis: two.sided

Table A.5: Lagrange multiplier diagnostics for spatial dependence of residuals from Ordinary Least Square (OLS) regression on the log of compound annual growth rate (CAGR) of the gross development product (GDP) per capita in Brazilian Amazonian municipalities from 2004–2014.

	Observed	df	p-value
Lagrange multiplier (lag)	3.8679	1	0.05
Robust Lagrange multiplier (lag)	0.6294	1	0.43
Lagrange multiplier (error)	7.2805	1	0.01
Robust Lagrange multiplier (error)	4.0421	1	0.04
SARMA	7.9099	2	0.02

Table A.6: Spatial Error Model (SEM) results. Parameter (Slope) estimates of exploratory variables from SEM on the log of compound annual growth rate (CAGR) of the gross development product (GDP) per capita in Brazilian Amazonian municipalities from 2004–2014.

	Estimate	Std. Error	z-value	Pr(>|z|)	
Intercept	0.025148	0.01280	1.9646	0.0495	*
Strictly protected areas	-0.000146	0.00013	-1.1382	0.2550	
Sustainable use PAs	-0.000005	0.00005	-0.1084	0.9137	
Indigenous lands	-0.000005	0.00008	-0.0672	0.9464	
Municipality area	0.006047	0.00122	4.9507	7.40E-07	***
Municipality age	-0.000029	0.00002	-1.3921	0.1639	
Annual growth rate	-0.025617	0.00264	-9.7000	< 2.2e-16	***
Population growth	-0.028085	0.00358	-7.8446	4.44E-15	***
Education index	0.072439	0.01722	4.2065	2.59E-05	***
Multiple R^2	0.34				
Adjusted R^2	0.32				
Log likelihood	1170.57				
AIC	-2319.10				

Significance: *p < 0.05, **p < 0.01 and ***p < 0.001.
Lambda: 0.1796, LR test value: 7.1282, p-value: 0.0076
Asymptotic standard error: 0.0642
z-value: 2.7994, p-value: 0.00512
Wald statistic: 7.8367, p-value: 0.0051
ML residual variance (sigma squared): 0.0006, (sigma: 0.0249)
Number of observations: 516
Number of parameters estimated: 11
Jarque Bera Test: X^2 = 1290.5, df = 2, p-value < 2.2e-16
Studentized Breusch-Pagan test: BP = 12.67, df = 8, p-value = 0.1237

Table A.7: Summary of the number of the Brazilian Amazon municipalities per state, as well the population in 2004 and 2014, and the gross development product (GDP) per capita in 2004 and 2014. The GDP per capita values are in thousands *Reais* (R$).

States	Municipalities number	Population in 2004	Population in 2014	GDP per capita in 2004				GDP per capita in 2014			
				Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
Acre	22	630,328.00	790,101.00	7.47	2.26	4.59	14.06	12.59	3.10	9.23	22.46
Amazonas	62	3,138,726.00	3,873,743.00	5.10	4.41	2.47	27.33	9.42	6.08	4.30	37.77
Amapá	16	547,400.00	750,912.00	9.13	1.82	7.08	13.63	14.76	5.16	10.19	28.44
Maranhão	94	3,399,547.00	3,834,049.00	3.77	2.25	1.91	15.45	6.77	3.74	3.77	25.66
Mato Grosso	83	1,109,233.00	1,320,975.00	15.97	13.23	5.81	94.82	25.39	15.83	7.46	83.85
Pará	143	6,850,181.00	8,058,583.00	7.19	7.38	2.02	60.38	11.46	10.68	4.69	86.60
Rondônia	52	1,562,085.00	1,748,531.00	9.92	2.82	4.84	17.95	15.86	4.30	9.93	31.57
Roraima	15	381,896.00	496,936.00	9.03	2.47	5.57	15.13	13.57	3.42	9.29	23.35
Tocantins	29	342,738.00	408,301.00	7.99	4.12	3.69	21.19	14.01	8.22	6.38	47.46
All region	516	17,962,134.00	21,282,131.00	8.17	7.96	1.91	94.82	13.40	10.96	3.77	86.60

Table A.8: Summary of the number of the Brazilian Amazon municipalities per state, as well the municipalities area (km^2), the percentage of protected areas (strictly protected areas (SPs), sustainable protected PAs (SUs), and indigenous lands (ILs)), and the compound annual growth rate (CAGR) of the gross development product (GDP) per capita.

States	Municipalities number	Municipalities area (km^2)	Protected areas (%)				Compound annual growth rate (%)				
			SPs	SUs	ILs	Total	Median	Mean	SD	Min.	Max.
Acre	22	164,123.02	9.80	19.28	14.05	43.14	5.58	5.49	1.38	1.95	7.97
Amazonas	62	1,559,172.72	9.95	16.38	24.67	51.00	4.37	6.74	3.25	1.13	19.27
Amapá	16	142,829.40	33.50	29.21	8.12	70.83	6.17	4.63	2.55	1.41	11.51
Maranhão	94	118,551.93	2.31	26.34	11.16	39.81	6.29	6.18	2.47	0.58	15.18
Mato Grosso	83	590,801.94	3.77	0.32	18.63	22.72	4.94	5.11	4.15	-5.51	22.65
Pará	143	1,247,966.16	10.23	21.97	22.55	54.75	5.51	5.38	3.86	-2.99	23.66
Rondônia	52	237,591.84	13.98	9.07	15.71	38.76	4.73	4.88	1.89	1.41	11.58
Roraima	15	224,302.47	5.25	15.71	45.53	66.49	4.46	4.25	2.48	-0.76	8.81
Tocantins	29	34,668.49	0.00	0.95	0.10	1.04	5.66	5.68	2.60	2.30	15.77
All region	516	4,320,007.98	9.65	16.04	22.30	47.99	5.52	5.56	3.28	-5.51	23.66

Table A.9: Global Moran's I of residuals from Spatial Durbin Error Model (SDEM) on the log of compound annual growth rate (CAGR) of the gross development product (GDP) per capita in Brazilian Amazonian municipalities from 2004–2014.

	Observed	Expected value	Variance	Standard deviate	p-value
Moran's I	-0.0016	-0.0019	0.0008	0.0118	0.9906

alternative hypothesis: two.sided

Table A.10: Test on common factory hypothesis. Likelihood ratio for spatial linear nested models: unconstrained Spatial Durbin Error Model (SDEM) and constrained Spatial Error Model (SEM).

	Observed	df	p-value
Likelihood ratio	10.219	8	0.25
sample estimates:			
Log likelihood of Spatial Durbin Error Model	1175.68		
Log likelihood of Spatial Error Model	1170.57		

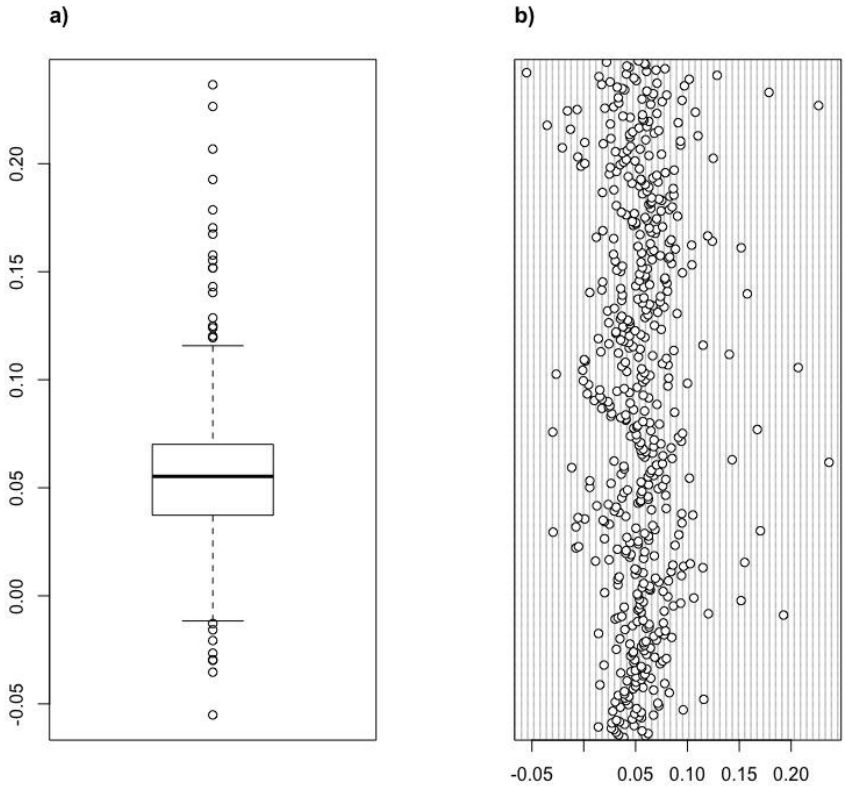


Fig. A.1: Data exploration of the of compound annual growth rate (CAGR) of the gross development product (GDP) per capita in 516 Brazilian Amazonian municipalities from 2004 to 2014 (mean = 0.0556, median = 0.0553, min. = - 0.0551, 1st Quartile. = 0.0373, 3rd Quartile. = 0.0701, and max. = 0.2365). Box plot (a) and Cleveland dot plot (b) for visualization of CAGR values.

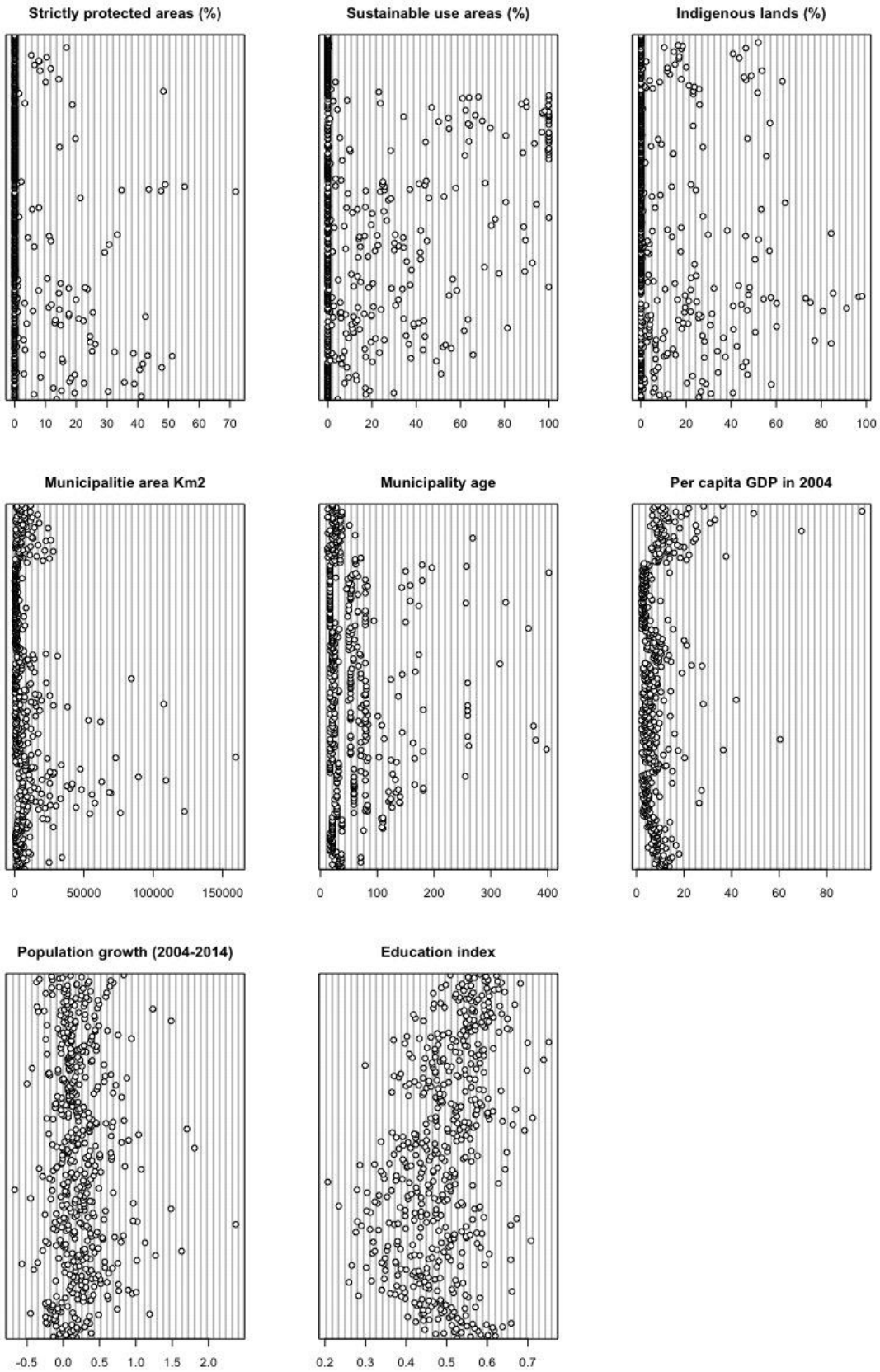


Fig. A.2: Cleveland dot plots for visualization of explanatory variables distributions. The gross development product (GDP) per capita in 2004 values are in thousands *Reais* (R$).

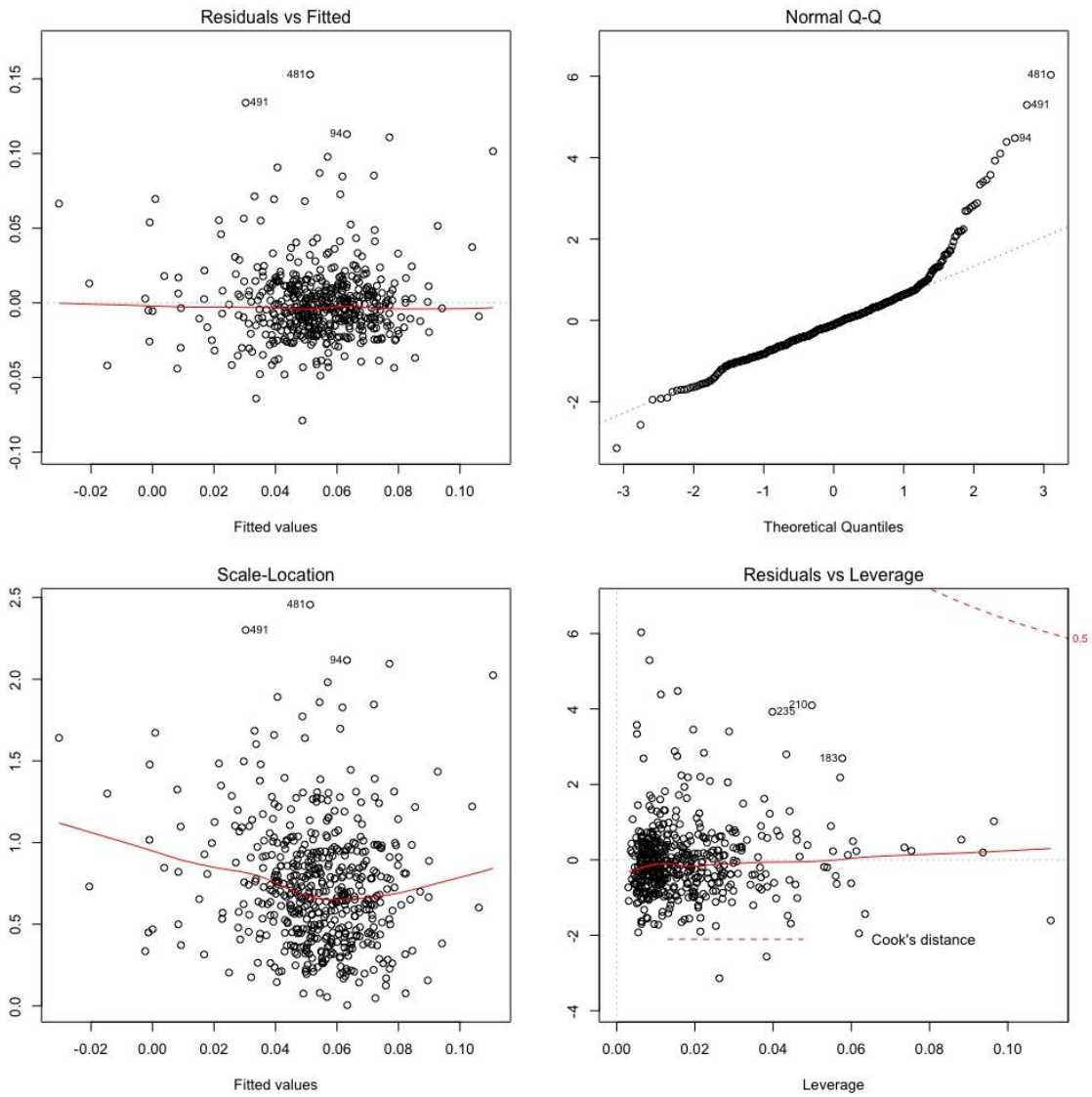


Fig. A.3: Residuals plot from Ordinary Least Square (OLS) regression on the log of compound annual growth rate (CAGR) of the gross development product (GDP) per capita in Brazilian Amazonian municipalities from 2004–2014.

Fig. A.4: Contiguity neighbours' graph (queen-style) of 516 municipalities in the Brazilian Amazon.

5. CONCLUSÕES

O uso de autos de infração ambientais gerados em atividades de fiscalização mostrou a existência de diversos tipos de usos ilegais dos recursos naturais que podem prejudicar a conservação da natureza a longo prazo nas UCs estudadas e indicam que muitos esforços ainda são necessários para resolver esses problemas. As infrações fornecem uma visão diferenciada e mais clara das atividades ilegais que ocorrem nas APs na Amazônia brasileira, e ajudam a identificar áreas mais problemáticas em relação ao uso ilegal de recursos naturais. Isso pode ajudar os responsáveis pelo manejo das UCs a planejar e implementar ações de conservação específicas para áreas individuais e desta forma apresentar resultados mais efetivos. Além disso, as informações sobre o esforço de fiscalização aplicado em cada UC (por exemplo, dias de fiscalização) podem ser melhor registrados, o que ajudaria os gestores e pesquisadores a avaliar e estabelecer metas para UCs sob diferentes regimes de manejo, locais e contextos.

A avaliacão da efetividade de gestão de UCs em relação a quantidade de infrações ambientais e desmatamento acumulado mostrou que o índice geral de efetividade RAPPAM e a maior parte dos módulos utilizados (objetivos, planejamento, recursos humanos, comunicação, infraestrutura, recursos financeiros, plano de manejo, tomada de decisão e monitoramento de avaliação de pesquisa) não são bons preditores da capacidade de uma AP em restringir atividades ilegais e desmatamento. Apenas dois módulos RAPPAM (vulnerabilidade e segurança legal) estão associados à quantidade de atividades ilegais e desmatamento acumulado registrados no período. Esse resultado sugere que, na Amazônia brasileira, a localização e o contexto regional, que estão relacionados com a vulnerabilidade e a capacidade de realizar o controle dos limites, regularização fundiária e resolução de conflitos, atributos relacionados com a segurança jurídica, são os dois principais fatores que influenciam a intensidade dos impactos nas UCs.

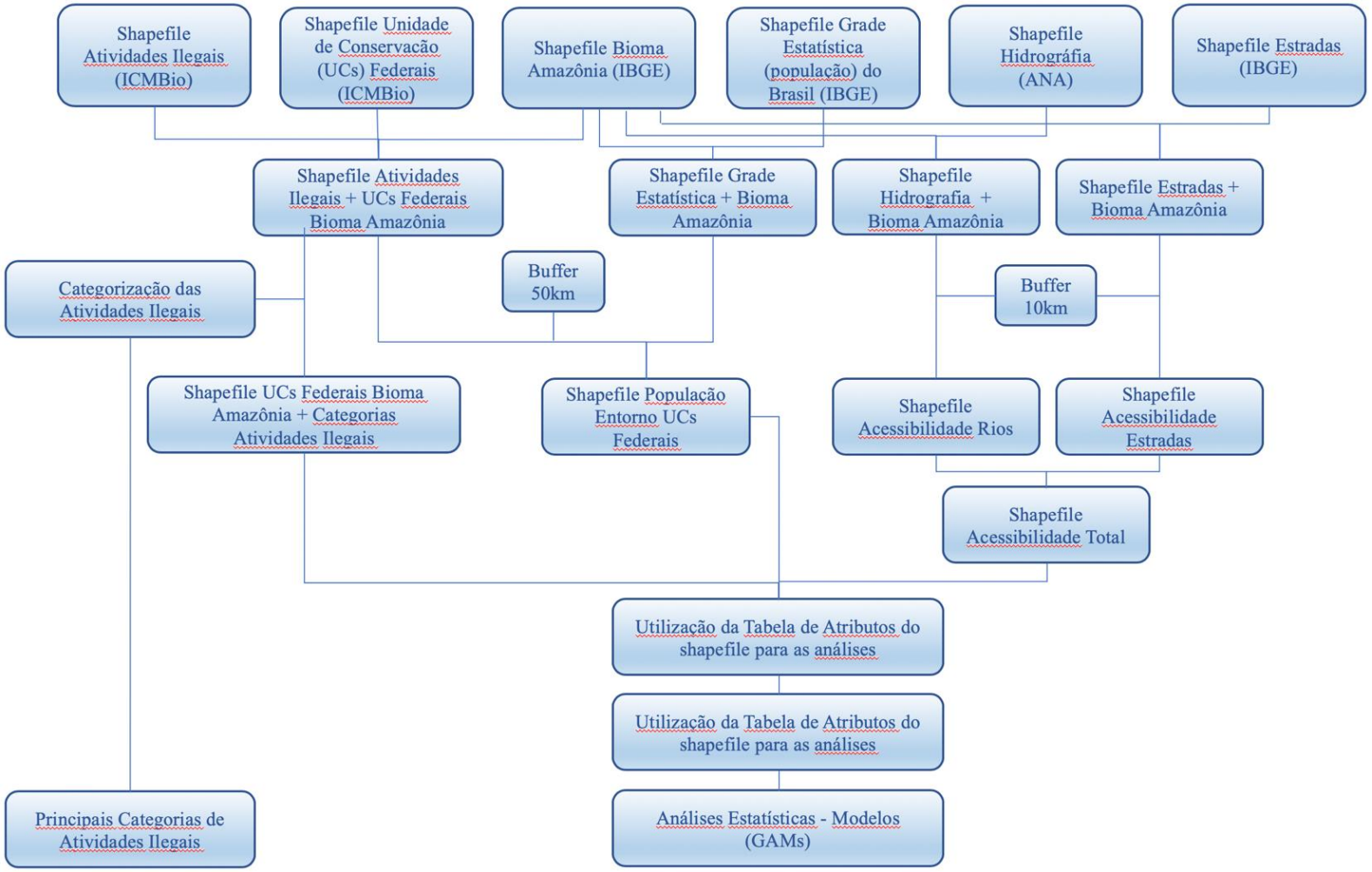
Como o mesmo modelo foi capaz de explicar a variação tanto das atividades ilegais quanto do desmatamento, dois tipos de pressões com diferentes níveis de detecção, sugerimos que ambas as ameaças representam um continuum das pressões humanas atualmente encontradas nas APs na Amazônia brasileira. Sugerindo que se for possível a realização de ações no inicio do continuum a proteção será muito eficaz. Nossos resultados podem ajudar os tomadores de decisão a priorizar intervenções e investimentos que buscam reduzir as ameaças atuais ao sistema de APs da Amazônia brasileira. Mostrando que ações focadas em questões básicas (mas não necessariamente de fácil resolução e/ou gestão) como vulnerabilidade,

regularização fundiária, e resolução de conflitos podem trazer melhores resultados de conservação.

A modelagem do impacto da cobertura de APs e a taxa de crescimento anual do produto interno bruto per capita dos municípios da Amazonia brasileira não mostrou evidências de que as APs estejam influenciando o crescimento econômico destes municípios. Diferente de nossas hipóteses iniciais a cobertura de UCs de proteção integral e terras indígenas não apresentou relação negativa com o crescimento econômico municipal, e a cobertura UCs de uso sustentável apresentou relação positiva. Desta forma, os resultados obtidos não apoiam os argumentos de que as APs atrapalham o crescimento econômico dos municípios da Amazônia, como frequentemente é difundido por alguns setores da sociedade brasileira para minar os ganhos sociais e ambientais gerados pela expansão das APs em toda a região.

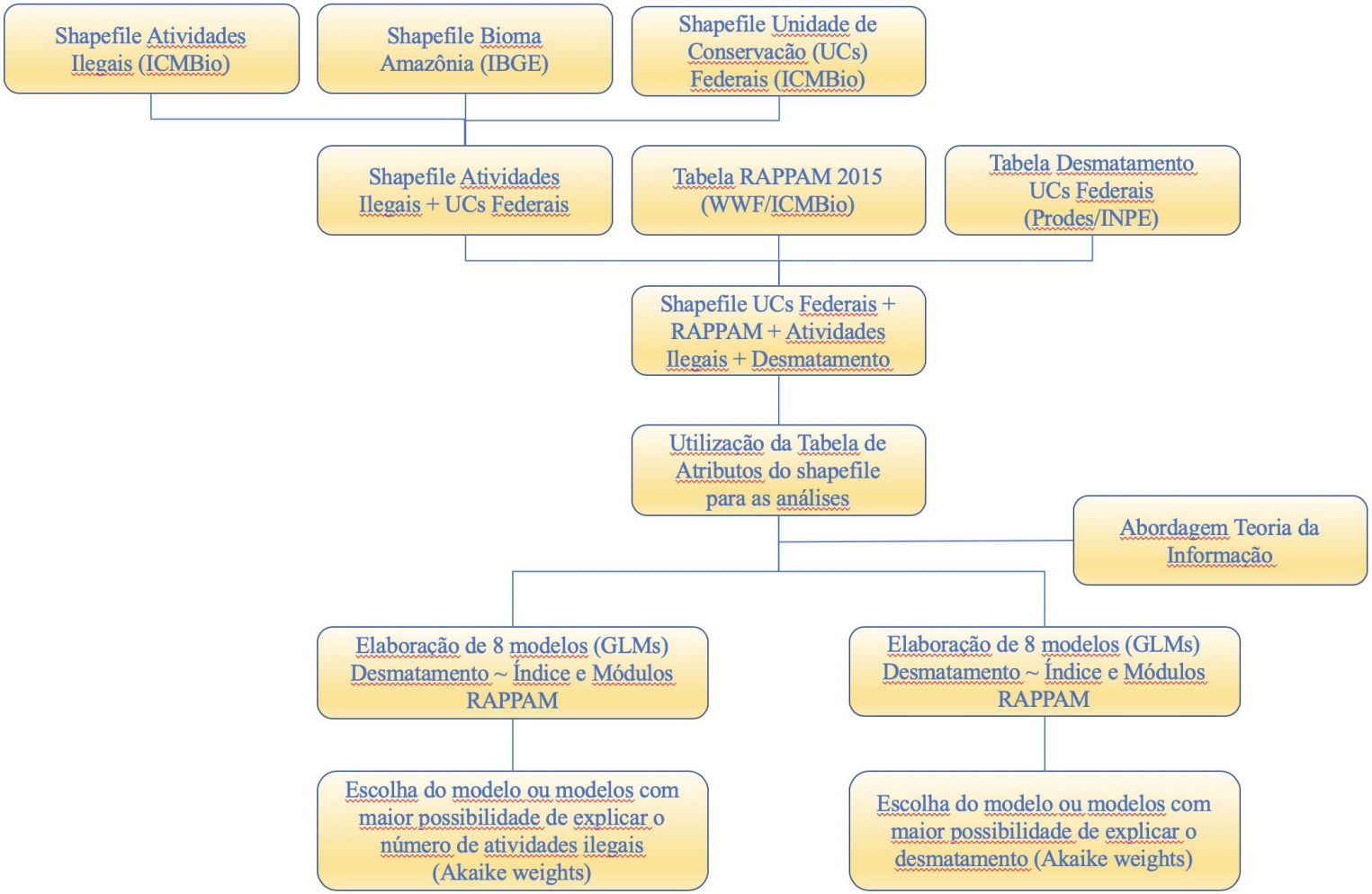
A falta de influência das APs sobre o crescimento econômico dos municípios da Amazonia brasileira são possivelmente conseqüência da concentração espacial das atividades econômicas locais em torno dos centros urbanos, pela existência de diferentes contextos socioeconômicos na região e devido a falta de implementação das APs. O manejo efetivo de uma AP exige bens e serviços que só podem ser fornecidos localmente, portanto, a simples implementação de uma AP poderia trazer recursos financeiros adicionais para os municípios e, assim, beneficiar economias locais formais. Fluxos de turistas e pesquisadores também poderiam aumentar a demanda por bens e serviços em escala local e gerar benefícios econômicos. E além de proteger a biodiversidade, espera-se que as UCs de uso sustentável possibilitem a exploração comercial sustentável dos recursos naturais e, consequentemente, ajudem as economias locais. Desta forma, é possível observar que existem bons indicativos de que as APs podem ser motores do crescimento econômico local se forem melhor implementadas.

FLUXOGRAMA ARTIGO 1



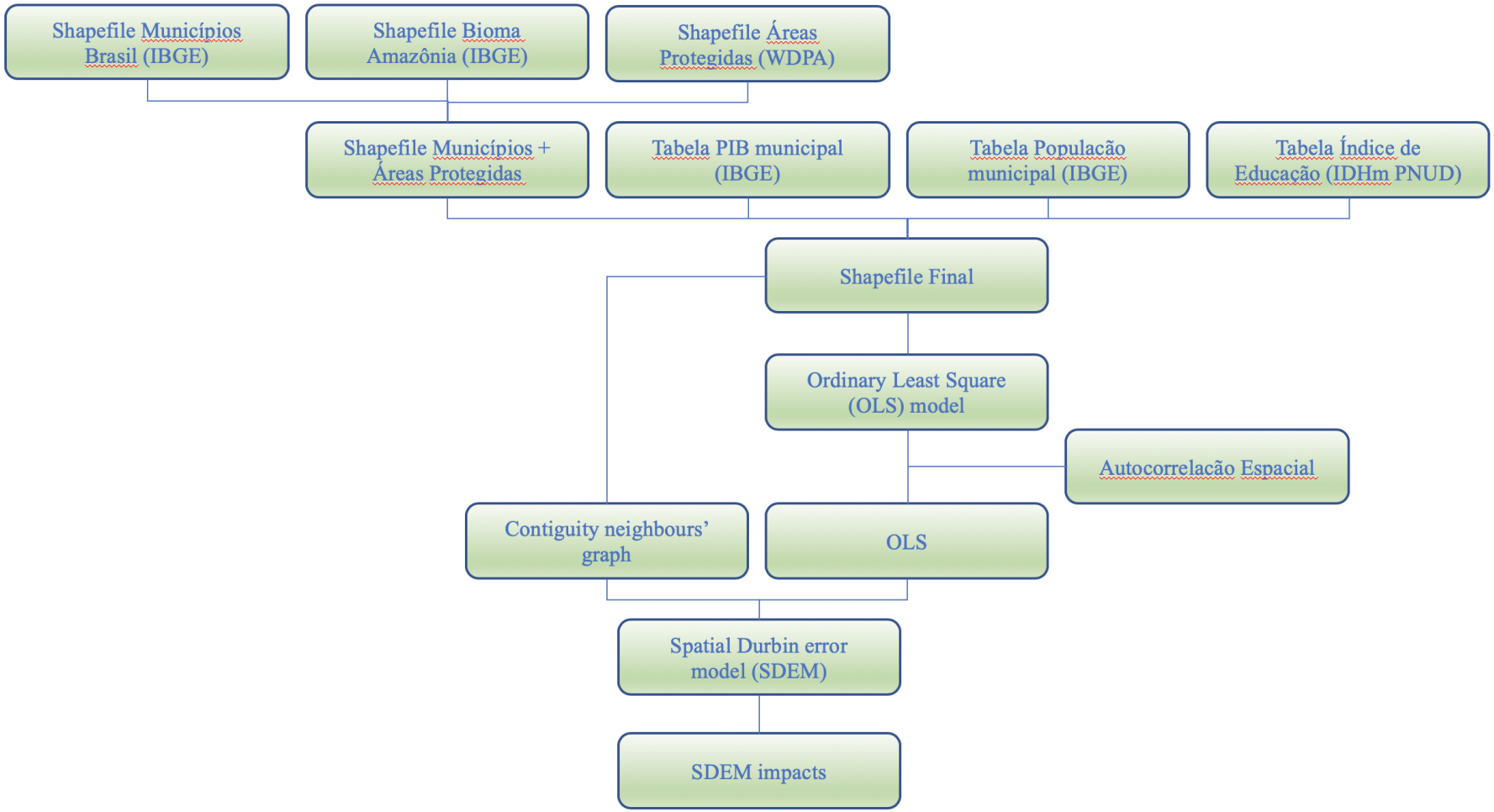
Fluxograma 1: Sequência dos principais passos metodológicos para a elaboração artigo 1.

FLUXOGRAMA ARTIGO 2



Fluxograma Artigo 2: Sequência dos principais passos metodológicos para a elaboração do artigo 2.

FLUXOGRAMA ARTIGO 3



Fluxograma Artigo 3: Sequência dos principais passos metodológicos para a elaboração do artigo 3.