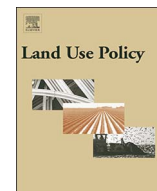




Contents lists available at ScienceDirect

Land Use Policy

journal homepage: [www.elsevier.com/locate/landusepol](http://www.elsevier.com/locate/landusepol)

## Towards zero deforestation and forest restoration in the Amazon region of Maranhão state, Brazil

Danielle Celentano<sup>a,\*</sup>, Guillaume X. Rousseau<sup>a,b,c</sup>, Francisca Helena Muniz<sup>a,b,c</sup>, István van Deursen Varga<sup>d,c</sup>, Carlos Martinez<sup>e,b</sup>, Marcelo Sampaio Carneiro<sup>f</sup>, Magda V.C. Miranda<sup>g</sup>, Márcia N.R. Barros<sup>g</sup>, Luciana Freitas<sup>h</sup>, Igor da Silva Narvaes<sup>i</sup>, Marcos Adami<sup>i</sup>, Alessandra Rodrigues Gomes<sup>i</sup>, Jane C. Rodrigues<sup>i,k,c</sup>, Marlúcia B. Martins<sup>l,b,c</sup>

<sup>a</sup> Agroecology Graduate Program (PPGAgroecologia), State University of Maranhão (UEMA), Campus Universitário Paulo VI, s/n, Têrirical, 65054-970, São Luís, MA, Brazil

<sup>b</sup> Biodiversity Research Program (PPBIO) Amazônia Oriental, Ministry of Science, Technology, Innovation and Communication (MCTI), Brazil

<sup>c</sup> Member of the Advisory Council of the Biological Reserve of Gurupi, Maranhão, Brazil

<sup>d</sup> Health and Environment Graduate Program (PPGSA), Federal University of Maranhão (UFMA), Campus do Bacanga, Av. dos Portugueses, s/n, 65.000-000, São Luís, MA, Brazil

<sup>e</sup> Biology Department, Federal University of Maranhão (UFMA), Campus do Bacanga, Av. dos Portugueses, s/n, 65.000-000, São Luís, MA, Brazil

<sup>f</sup> Social Sciences Graduate Program (PPG Ciências Sociais), Federal University of Maranhão (UFMA), Campus do Bacanga, Av. dos Portugueses, s/n, 65.080-805, São Luís, MA, Brazil

<sup>g</sup> Fundação de Ciência, Aplicações e Tecnologias Espaciais (FUNCATE). Av. Dr. João Guilhermino, 429, 11° Andar, Centro, 12.210-131, São José dos Campos, SP, Brazil

<sup>h</sup> Chico Mendes National Institute of Biodiversity Conservation (ICMBIO). Reserva Biológica do Gurupi, BR 222, km 12, Pequiá, 65.930-000, Açailândia/ MA, Brazil

<sup>i</sup> National Institute for Space Research (INPE). Centro Regional da Amazônia (CRA). Parque de Ciência e Tecnologia do Guamá. Av. Perimetral, 2651, 66077-830, Belém, PA, Brazil

<sup>j</sup> Maranhão State Secretary of Environment and Natural Resources (SEMA), Av. dos Holandeses, 4, Calhau, 65071-380, São Luís/ MA, Brazil

<sup>k</sup> Socio-spatial and Regional Development Graduate Program, Federal University of Maranhão (UFMA). Campus do Bacanga, Av. dos Portugueses, s/n, 65.000-000, São Luís/ MA, Brazil

<sup>l</sup> Zoology Coordination, Museu Paraense Emílio Goeldi (MPEG). Campus de Pesquisa. Av. Perimetral 901, Terra Firme, 66040-170, Belém, PA, Brazil

### ARTICLE INFO

#### Keywords:

Amazonia  
Zero deforestation  
Restoration  
Secondary forests  
Ecological-economic zoning

### ABSTRACT

The Amazon forest in the state of Maranhão ensures ecosystem services that directly and indirectly affect the life quality of its population and economy, via hydrologic and climatic regulation, among other benefits. Currently, only 25% of the original forest cover (24.7 thousand km<sup>2</sup>) remains while illegal deforestation persists in a violent process that provokes visible social, economic and environmental harm. Simultaneously, Maranhão has seen record levels of burning, faces a water shortage and fights against the worst social and economic indicators in the country. Conversely, secondary vegetation covers 19.9 thousand km<sup>2</sup> (27% of deforested area) and is completely unprotected. Contrary to the international commitments assumed by Brazil to combat deforestation and restore forests, some of the political representatives of Maranhão have sought legal mechanisms to further diminish forest cover in public and private areas. To promote the conservation and restoration of Maranhão Amazon Forest, a multi-institutional network of researchers was established in 2015. This viewpoint paper aims to draw attention to this endangered region of the Brazilian Amazon and give science-oriented recommendations to policy makers in order to avoid more setbacks. We argue that Maranhão state must urgently establish a policy of Zero Deforestation, protect secondary forests and comply with the national forest restoration policy, thus ensuring long-term economic sustainability.

\* Corresponding author.

E-mail addresses: [danicelentano@yahoo.com.br](mailto:danicelentano@yahoo.com.br) (D. Celentano), [guilroux@yahoo.ca](mailto:guilroux@yahoo.ca) (G.X. Rousseau), [fhmuniz@yahoo.com](mailto:fhmuniz@yahoo.com) (F.H. Muniz), [ivarga@uol.com.br](mailto:ivarga@uol.com.br) (I.v.D. Varga), [nyctic@yahoo.com](mailto:nyctic@yahoo.com) (C. Martinez), [mdscarneiro@uol.com.br](mailto:mdscarneiro@uol.com.br) (M.S. Carneiro), [magda.miranda@funcate.org.br](mailto:magda.miranda@funcate.org.br) (M.V.C. Miranda), [marcia.barros@funcate.org.br](mailto:marcia.barros@funcate.org.br) (M.N.R. Barros), [luciana.freitas@icmbio.gov.br](mailto:luciana.freitas@icmbio.gov.br) (L. Freitas), [igor.narvaes@inpe.br](mailto:igor.narvaes@inpe.br) (I.d.S. Narvaes), [marcos.adami@inpe.br](mailto:marcos.adami@inpe.br) (M. Adami), [alessandra.gomes@inpe.br](mailto:alessandra.gomes@inpe.br) (A.R. Gomes), [janecrodrigues@gmail.com](mailto:janecrodrigues@gmail.com) (J.C. Rodrigues), [marlucia@museu-goeldi.br](mailto:marlucia@museu-goeldi.br) (M.B. Martins).

<http://dx.doi.org/10.1016/j.landusepol.2017.07.041>

Received 6 March 2017; Received in revised form 23 July 2017; Accepted 23 July 2017  
0264-8377/ © 2017 Elsevier Ltd. All rights reserved.

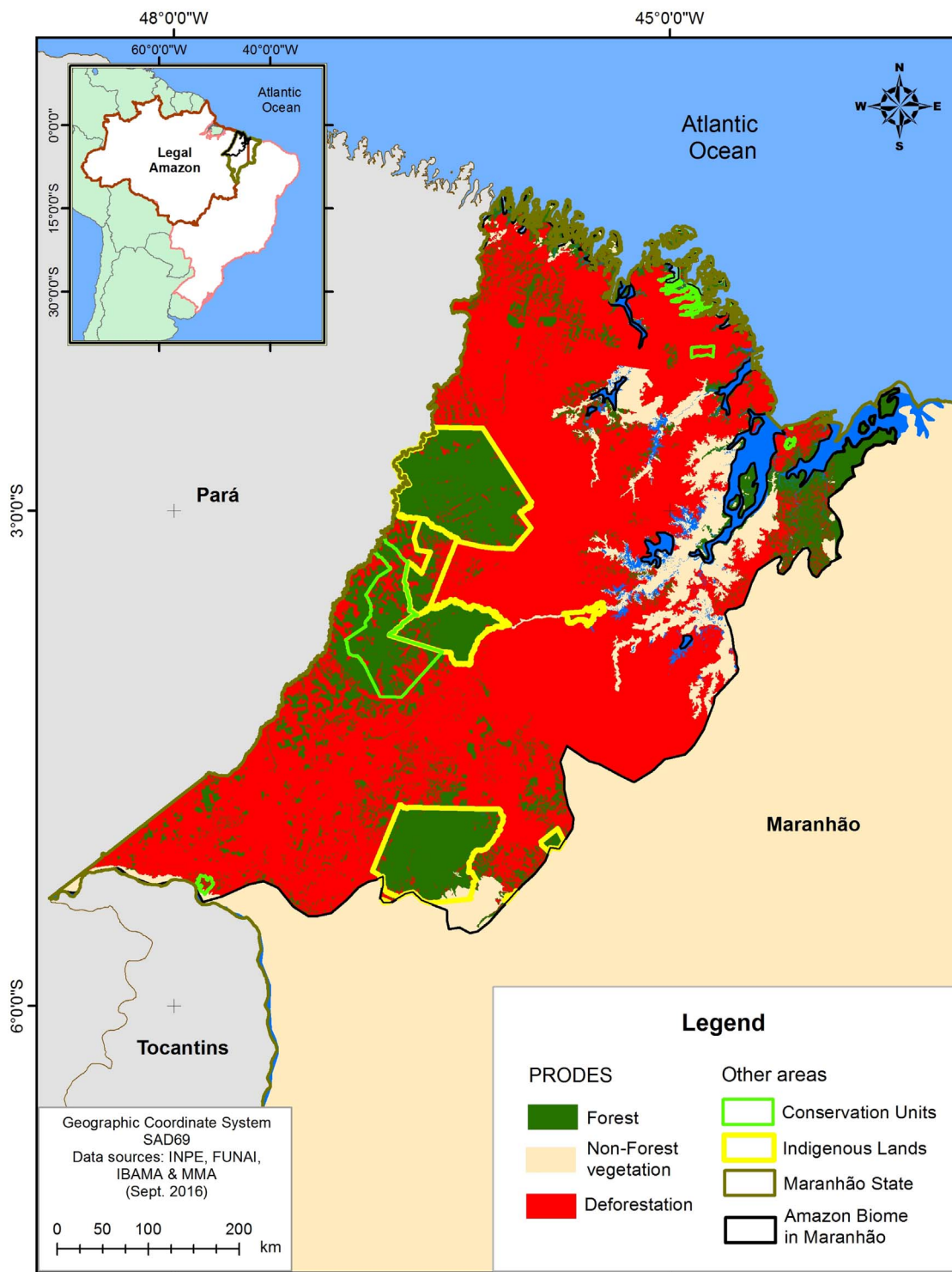


Fig. 1. Deforestation in the Amazon Biome in the state of Maranhão (INPE, 2016).

## 1. Introduction

The Amazon is the largest tropical forest on the planet with recognized importance in conserving biodiversity and in providing essential ecosystem services such as regulating the water cycle (Aragão, 2012) and climatic aspects (Malhi et al., 2008), among other benefits. In Brazil, the Amazon biome occupies 4.2 million km<sup>2</sup>, an area that extends into nine Federative states, and includes part of the state of Maranhão. Originally, 110.4 thousand km<sup>2</sup> of Maranhão was covered by the Amazon biome, but 75% of forest cover was cleared to provide

space mainly for agriculture and cattle ranching (INPE, 2016).

Amazon deforestation in Maranhão state was always justified politically by the search for the “economic development dream”, but the socioeconomic liability from this process is highly negative, reinforcing the thesis that deforestation does not result in better living conditions for the local population, but rather provokes social, economic and environmental harm (Celentano et al., 2012). In fact, Maranhão has historically ranked among the states with the worst social and economic indicators in Brazil (IBGE, 2016) while the municipalities within its Amazonian region are even poorer (UNDP, 2013). The Amazonian

region of Maranhão registers severe human rights violations associated with deforestation, such as recurrent cases of persons in a work regime analogous to slavery (Gulnara, 2010; Moura et al., 2011), land conflicts and the assassination of peasants and indigenous people (CIMI, 2016; CPT, 2017), including young members of the Awa tribe (CIMI, 2012), who are considered the most threatened indigenous group on the planet (Survival International, 2015).

In December of 2015, during the COP-21 in Paris, Brazil made an international commitment to cut Amazon illegal deforestation to zero and restore 12 million hectares of forest by 2030. In December of 2016, the country strengthened this commitment by adhering to the Bonn Challenge. In January of 2017, Brazil launched its National Policy for the Recovery of Native Vegetation (Decree n°8.972, Brazilian Federal Government, 2017) with the objective of promoting programs and actions for forest restoration. Besides the ecological benefits, these actions have positive effects on the economy. Indeed, markets are increasingly more demanding about the origin of products, especially commodities such as beef and soy (Nepstad et al., 2006; Rudorff et al., 2011), that together with eucalyptus are the main products of Maranhão Amazonian soils (Carneiro, 2016). However, these issues have not yet been fully considered by local politicians.

Not only the Amazon forest of Maranhão itself, but also its people and biodiversity are endangered. To promote the conservation and restoration of this region, a multi-institutional group of researchers first gathered in 2015. The so-called ‘Maranhão Amazon Forest Conservation Network’ seeks bases to support conservation and restoration policies in the state. The network consolidated a database of environmental and social data, and mapped deforestation, forest fires and secondary growth. This viewpoint paper is the first product of the network, and its objectives are to draw attention to this endangered region of the Amazon and give science-based recommendations to policy makers in order to avoid more setbacks.

### 1.1. Deforestation in the Amazon region of Maranhão

Large-scale deforestation in the Maranhão Amazon forest began in the 1960s, when the military government promoted the occupation of this territory through the construction of highways and the incentivizing of large farming projects on public lands (Arcangeli, 1987; Kohlhepp, 2002). Along with this came the development of many logging centers (Asner et al., 2005). In the 1980s, with the implantation of the largest iron mining project in the world in the neighboring state of Pará (Carajas Project), the railroad that links the mine to the port in Maranhão was built and many pig iron facilities were installed in the Maranhão Amazon region, demanding large quantities of vegetal charcoal (Carneiro, 1997), which increased the pressure on forest resources (Oren, 1988).

Since 1988 deforestation in the Brazilian Amazon has been monitored by the National Institute for Space Research (INPE) through satellite images. In the last 30 years of monitoring, a total of 24.6 thousand km<sup>2</sup> of the Amazon forest of Maranhão was clear-cut, which represents 33% of total deforested areas whereas 77% had been deforested previously (INPE, 2016). Currently, only 25% of the original forest cover (24.7 thousand km<sup>2</sup>) remains (INPE, 2016; Fig. 1), of which 70% is inside protected areas (Indigenous lands and Conservation Units), 10% is on agrarian reform settlements (Alencar et al., 2016) and about 20% is dispersed on rural properties. The remaining forests, including those legally protected, continue to disappear rapidly due to the illegal logging, burning and conversion of lands to cattle ranching. Fire in agriculture and cattle ranching is still utilized extensively in the state. In 2015 alone, 30,137 heat foci were detected in the Amazon region of Maranhão (INPE, 2016), fires that often burn out of control and reach forested areas.

Forests, whether in public or private areas, are of interest to the state. The scientific literature is replete with evidence on the importance and benefits of forests, but only their roles in regulating the

water cycle (Aragão, 2012; Makarieva et al., 2014) and the climatic cycle (Houghton et al., 2000; Malhi et al., 2008) justify their conservation and restoration needs. This effect of the Amazon forest is particularly important in Maranhão, where the precipitation rates have diminished (INMET, 2016) and where the climatic models predict an increase in temperature and important diminution of precipitation (IPCC, 2014; Almeida et al., 2016). In fact, recent studies indicate that Maranhão is among the states most vulnerable to disaster risk and climate change in Brazil (Almeida et al., 2016).

### 1.2. Forest threats in the Amazon region of Maranhão

Contrary to the ecological importance of the Amazon forest in the state and to the international commitments assumed by Brazil, part of Maranhão’s government has sought mechanisms to diminish protection of forests in public and private areas. Some politicians have tried to overturn the status of the principal protected area in the region, the Biological Reserve of Gurupi (Legislative Decree Project n°914/2013; LDP, 2013); the legislative project was declined in the same year but the intent was not abandoned. Created in 1988, this Reserve is the only integral protection conservation unit in the ‘Endemic Area of Belém’ and protects a rich diversity of biota, including many endemic species that are threatened with extinction (Martins and Oliveira, 2011), such as *Cebus kaapori*, which is among the 25 primate species at the greatest risk of extinction in the world (Schwitzer et al., 2016). Illegal deforestation and violence happen together in this area. In 2015, Mr. Raimundo dos Santos Rodrigues, a member of the advisory council of the Biological Reserve of Gurupi was murdered inside the reserve by persons engaged in illegal logging (The Washington Post, 2015). Unfortunately, it is not an isolated case as Brazil is the country that registers the most deaths of ecologists in the world, almost half of whom are indigenous (Global Witness, 2016). Only in 2016, nine indigenous people of Maranhão Amazon reserves were murdered (CPT, 2017).

On private lands, the political intention is to reduce protection, forgive environmental liabilities and further diminish demands to recover native vegetation of illegally deforested areas. In Brazil, the forest conservation on rural properties is regulated by the Native Vegetation Protection Law (NVPL; Law n°12,651/2012; Brazilian Federal Government, 2012), which replaced the Forest Code from 1965 (Law n°4.771) in a controversial process (Soares Filho et al., 2014). In common with the previous law, NVPL requires partial dedication of rural properties for conservation in: (1) Areas for Permanent Preservation (APP) to protect critical environments such as riparian vegetation, springs, steep slopes and hilltops; and (2) Legal Reserves (LR) that are an area dedicated to the sustainable use of natural resources and biodiversity conservation, but where economic activities that do not cause deforestation are permitted. However, the new law has brought critical setbacks.

Brançalion et al. (2016) detail the environmental setbacks of NVPL, such as the removal and reduction of protection of fragile areas, concession of amnesty for illegal deforestation, and the reduction and annulment of recovery requirements.<sup>1</sup> NVPL also allows the deduction of APPs (conserved or under recovery) from LR required area. Indeed, the new law considerably diminishes the environmental liability of rural landowners. Compared to the former law, Soares Filho et al. (2014, SM) estimated that NVPL reduces 76% of riparian preservation areas debt (a proxy for APP) and 61% of LR debt in the Amazon region of Maranhão.

Additionally, the law permits the reduction of LR restoration

<sup>1</sup> Setbacks of NVPL includes: (1) the removal of protection of intermittent springs and small lentic water bodies (< 1 ha); (2) reduction of riparian vegetation buffer; (3) legalization of farming and infrastructure in APPs; (4) amnesty of fines for illegal deforestation until 2008; (5) annulled restoration requirements in degraded APPs such as hilltops and steep slopes; (6) annulled restoration requirements of LR on “small” properties (220–300 ha depending on the municipality of the Amazonian region of Maranhão). Details in Soares Filho et al. (2014) and Brançalion et al. (2016)



requirements from 80 to 50% in the Amazonian Biome. This reduction is allowed in municipalities predominantly occupied by protected areas, and also in areas that are zoned for agricultural development in the State Ecological-Economic Zoning (ZEE, in Portuguese, at 1:250,000 scale; [Brazilian Federal Government, 2002](#)) and that are not considered a priority area for biodiversity and hydrological conservation. Even though the Brazilian Supreme Court is still adjudicating this and other points of the NVPL that had its constitutionality questioned,<sup>2</sup> in 2016 the Governor of Maranhão requested LR reduction for the Ministry of Environmental using the existent Macro-ZEE (1:1,000,000 scale) of the state ([FIEMA, 2017](#)). This demand was denied by the Attorney General of Brazil (AGU, in Portuguese) as the zoning scale does not meet law requirements. The discussions about the ZEE process in the Amazonian region of Maranhão were initiated in 2015, but only in 2017 did the mapping processes start prioritizing municipalities that can benefit from RL reduction.

Another mechanism of the NVPL that necessitates proper regulation at the state level is the compensation of LR liabilities. Rural properties that have forest debt in LR can recover it on-farm, or compensate for it through forest areas leaseholds, purchasing forest areas off-farm or buying the Environmental Reserve Quotas (ERQ), including in other states within the same biome. The compensation options are attractive mechanisms to rural producers with forest debt since they diminish implementation and opportunity costs ([Silva and Ranieri, 2014](#)). However, to ensure ecosystem services and biodiversity conservation, the LR compensation must occur as close as possible to the degraded area, preferably in the same watershed ([Brançalion et al., 2016](#)). In the neighboring state of Pará, [Nunes et al. \(2016\)](#) indicate that most of LR compensation can take place in the same municipality, thus maximizing ecological benefits. The liability of LR in Maranhão Amazon region is estimated in more than 10 thousand km<sup>2</sup> ([Soares Filho et al., 2014](#)), and only with proper regulation the compensation of this debt will guarantee ecological benefits to the state.

Derogations of the APP and LR areas in rural properties greatly reduces the need for restoration in the state and enables additional deforestation ([Soares Filho et al., 2014](#)), which is contrary to the global commitments of forest conservation and restoration assumed by Brazil.

### 1.3. Zero deforestation in the Amazon region of Maranhão

The Amazon forest deforestation rate has dropped since 2008 in Maranhão ([Fig. 2](#)) and most of recent forest loss is due to illegal logging, including clearing of Protected Areas ([ICMBIO, 2015; ISA, 2017](#)). However, according to the NVPL (Law n°12,651/2012), some forestlands on rural properties are yet available for legal deforestation.<sup>3</sup> [Soares-Filho et al. \(2014, SM\)](#) estimated 771 km<sup>2</sup> of Amazon forest surplus in Maranhão (against about 11.7 thousand km<sup>2</sup> of deficit). Considering the status of Amazon forest in Maranhão (refers to [Fig. 1](#)), we argue that no additional deforestation can take place in the state. According to [Turner and Corlett \(1996\)](#) review, in highly deforested areas, even a small forest fragment can play a critical role in biodiversity conservation and restoration.

In 2015 during COP-21, Brazil committed to achieve “Zero Illegal Deforestation” by 2030 (Ministry of Environmental Ordinance n°76/

2016), whereas two Amazonian States (Mato Grosso and Acre) made this commitment by 2020. This is a timid promise that evidences the inability of the country to enforce the existent law. In 2012, during the Rio + 20, the neighboring state of Pará committed to achieve the “Net Zero Deforestation” by 2020. Net deforestation is the difference between forest loss (deforestation) and forest gains (restoration and/or tree plantation) in a period of time ([Brown and Zarin, 2013](#)). Another proposal – “Zero (absolute) Deforestation” in which no forest destruction is permitted- was made by an organized group from civil society and was delivered in 2015 at the Brazilian National Congress together with 1.4 million signature petition ([Greenpeace, 2015](#)). The ‘Maranhão Amazon Forest Conservation Network’ considers this more restrictive proposal as the most appropriate to the current situation in Maranhão state.

It is time for the state of Maranhão to recognize the importance of their forests and to create effective mechanisms to protect them, by enacting a state policy of “Zero Deforestation”, and at the same time, by promoting agricultural practices without the use of fire and restoring the degraded areas to promote the “Forest Transition” in the state.

### 1.4. Forest restoration in the Amazon region of Maranhão

The degraded areas of the Maranhão Amazon region can and must be restored. The simplest and cheapest manner of restoration is removing the source of perturbation to allow the forest to recuperate naturally by natural succession. The time necessary to restore the forest biomass may vary from 30 to 80 years, with an average of 66 years ([Poorter et al., 2016](#)), depending on the state of degradation. The secondary forests (in regeneration) play a fundamental role both in conserving biodiversity and in providing ecosystem services such as atmospheric carbon fixation ([Poorter et al., 2016; Marin-Spiotta et al., 2007](#)), as long as it is protected from further deforestation. Indeed, conservation value of secondary forests increases with age ([Finegan, 1996](#)). According to the [INPE and EMBRAPA \(2014\)](#), 19.9 thousand km<sup>2</sup> of Amazon biome in Maranhão are covered by secondary forests, which equates to 26.8% of the area deforested up through 2014 ([Fig. 3](#)). However, these secondary forests are completely unprotected in Maranhão state.

Recognizing the importance of Secondary Forests, NVPL (Law n°12,651/2012) permits compensation of Legal Reserve in areas with “secondary vegetation in any stage of regeneration or reconstitution”. In this sense, Maranhão must urgently create norms to protect its secondary forests and regulate their conversion as exemplified by the neighboring state of Pará, which created norms to safeguard the secondary vegetation in the state (Normative Instruction n°8/2015; [Pará State Government, 2015](#)). In the Maranhão Amazon region, secondary forests play a key role in nature conservation and must be preserved. Other countries have provided examples of the biological importance of protected secondary forests, such as the Guanacaste National Park in Costa Rica created in areas with secondary vegetation ([Janzen, 2002](#)).

The restoration of highly degraded areas requires more intense human interventions. There are many methods to achieve this ([Lamb and Gilmour, 2003; Lamb et al., 2005; Holl et al., 2011](#)), while the choice of the most appropriate technique depends on the degradation state, on the desired results and on the financial capital available ([Chazdon, 2008](#)), besides the legal and sociocultural context. According to [Lamb et al. \(2005\)](#), the major challenge of restoration is to move from the site scale to the landscape scale, since only at the landscape scale it is possible to balance the restoration and agricultural production. In 2005, a more holistic concept of restoration was proposed, the ‘Forest Landscape Restoration’ (FLR) that aims to restore ecological integrity and improve human-well-being in deforested landscapes ([ITTO and IUCN, 2005; Mansourian et al., 2005](#)), which is desirable in Maranhão where rural poverty and environmental degradation are strongly correlated. FLR considers the complex interactions between persons, natural resources and soil uses and suggests a set of

<sup>2</sup> The Brazilian Supreme Court is adjudicating four points of the NVPL through ‘Direct Actions of Unconstitutionality’ (ADI, in Portuguese): Reduction of LR (ADI 4901) as also detailed in [Sterzi \(2016\)](#), Amnesty for illegal deforestation in LR (ADI 4902) and in APP (ADI 4903), and LR compensation mechanisms (ADI 4937). The Brazilian scientific community positioned itself against environmental setbacks of NVPL ([Nader and Palis, 2015](#)) and the State Court of both Minas Gerais and Mato Grosso states already considered amnesty of deforestation to be unconstitutional. Maranhão can correct some of the environmental setbacks of the NVPL through a judicial decision, but also by establishing more rigorous regulations at the state level.

<sup>3</sup> Legal deforestation is allowed on rural properties with an excess of LR in areas without further restriction. [Nunes et al. \(2016\)](#) present relevant details about deforestable surplus and the importance in conserving these areas.

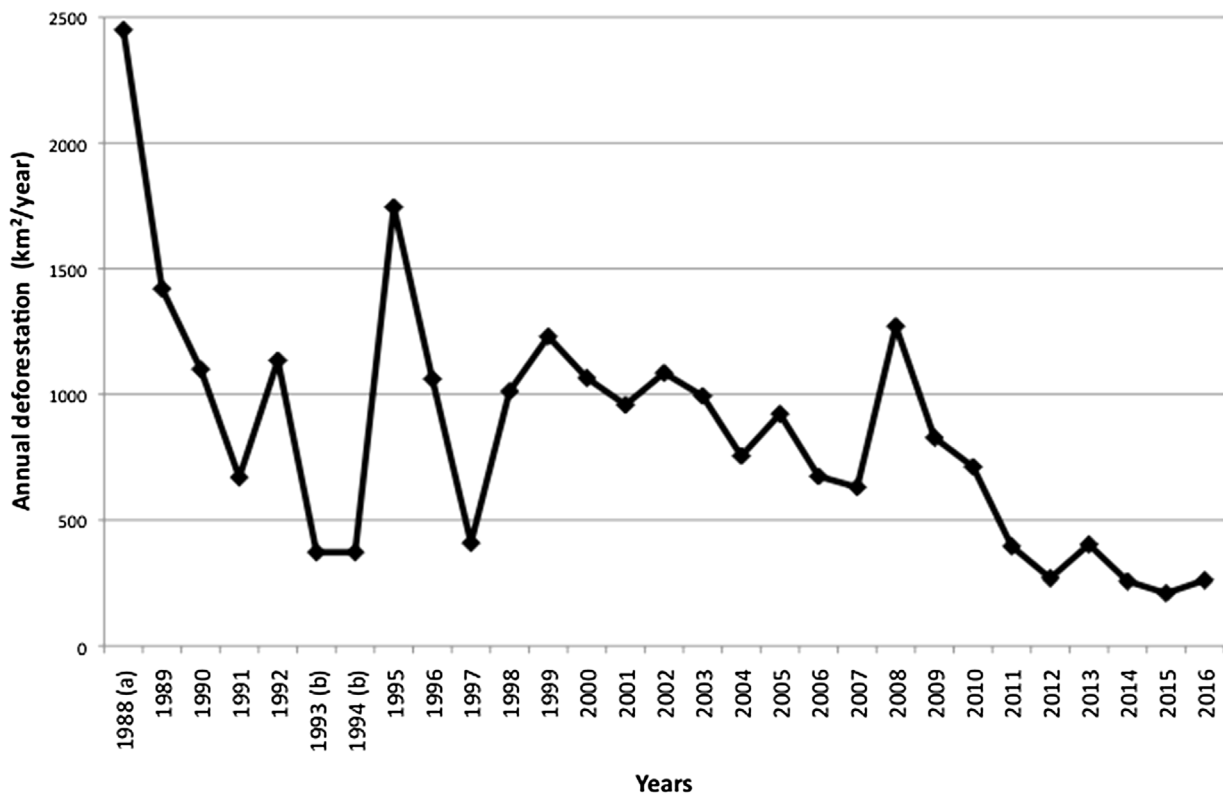


Fig. 2. Annual deforestation rate of the Amazon forest in Maranhão (INPE, 2016). (a) Average rate between 1977 and 1988; and (b) average of 1993 and 1994.

complementary practices of agriculture, restoration and forestry.

The costs of restoration techniques vary widely and given that they constitute a large investment for rural producers, the use of species of economic interest is one option that can provide an economic return and create space for large-scale restoration in agricultural landscape (Latawiec et al., 2015). The Agroforest Systems (the consortia of annual agricultural plants with trees) are also an attractive alternative for restoration (Vieira et al., 2009), mainly to guarantee food safety to the small farmers.

The greatest challenge for development in the Maranhão Amazon region is to harmonize the conservation and restoration of nature with the improvement of agricultural production and life quality. Besides restoration, there are several more efficient crop and cattle ranching practices that can reconcile production with conservation on different scales (UN, 2010). The ‘Maranhão Amazon Forest Conservation Network’ considers the protection of secondary forests, promotion of no-fire agricultural practices and the Agroforest Systems as the priority restoration actions to be supported by the state in Maranhão. In the poorest region of the country, restoration costs must not only be minimized but also bring direct social and economic benefits.

#### 1.5. Recommendations for the Amazon region of Maranhão

At this moment, the state government of Maranhão has a unique opportunity to change the development paradigm in the Amazon region. Instead of seeking mechanisms to diminish forest cover, the ZEE of the Amazon Biome that is being elaborated could serve as a landmark, if scientific precepts are taken into account in its elaboration, such as an instrument that ensures the sustainability of crop and cattle ranching production and the provision of essential ecosystem services for society. In this sense, we present some recommendations for decision-makers and for the team that is elaborating the ZEE, so that this instrument may fulfill its function of “securing environmental quality of water and soil resources and conserving biodiversity” (Art. 2° of Federal Decree n°4,297/2002), thus assuring fulfillment of the Brazilian Federal

Constitution itself, which in article 225 imposes on both the Public Power and on the collective the obligation to defend and preserve an equilibrated environment for the present and future generations:

1–Conserve all the remaining forests in the Amazon Biome in Maranhão. Create protection mechanisms for both primary and secondary vegetation and establish a restrictive state policy of “Zero Deforestation” with mechanisms and incentives for the conservation and restoration in public and private areas;

2–Maintain 80% of the Legal Reserve in the Amazon Biome, and incentivize a compensation system of the Legal Reserve that generates environmental benefits in the state of Maranhão, preferentially in the same watershed;

3–Define new Conservation Units, both indirect and of sustainable use for the recovery of secondary vegetation creating ecological corridors to connect the biggest remaining forest areas;

4–Incentivize and regulate the development of silvicultural, crop and cattle ranching good practices, as Agroforestry Systems, without the use of fire and integrated into the landscape scale to ensure protection of soil and water;

5–Establish and implement a state policy of forest restoration. Develop mechanisms for stimulating forest restoration with fiscal incentives and payments for environmental services, with special attention to municipalities that have logging and charcoal-producing activity as an economic base.

In conclusion, Maranhão state needs to take a giant step forward in the Amazon region to guarantee human life and natural resources protection. Illegality and violence must be countered with command and control by both state and federal forces. The recommendations presented herein have a high political cost because they threaten strong economic forces in the state, and rely on governmental incentives. However, they are demonstrably in the public interest and are the only way to ensure long-term economic sustainability and quality of life in the state. The ‘Maranhão Amazon Forest Conservation Network’ is open to dialogue with all sectors of society and assists the state to find the best options for the Amazon region from a scientific perspective.

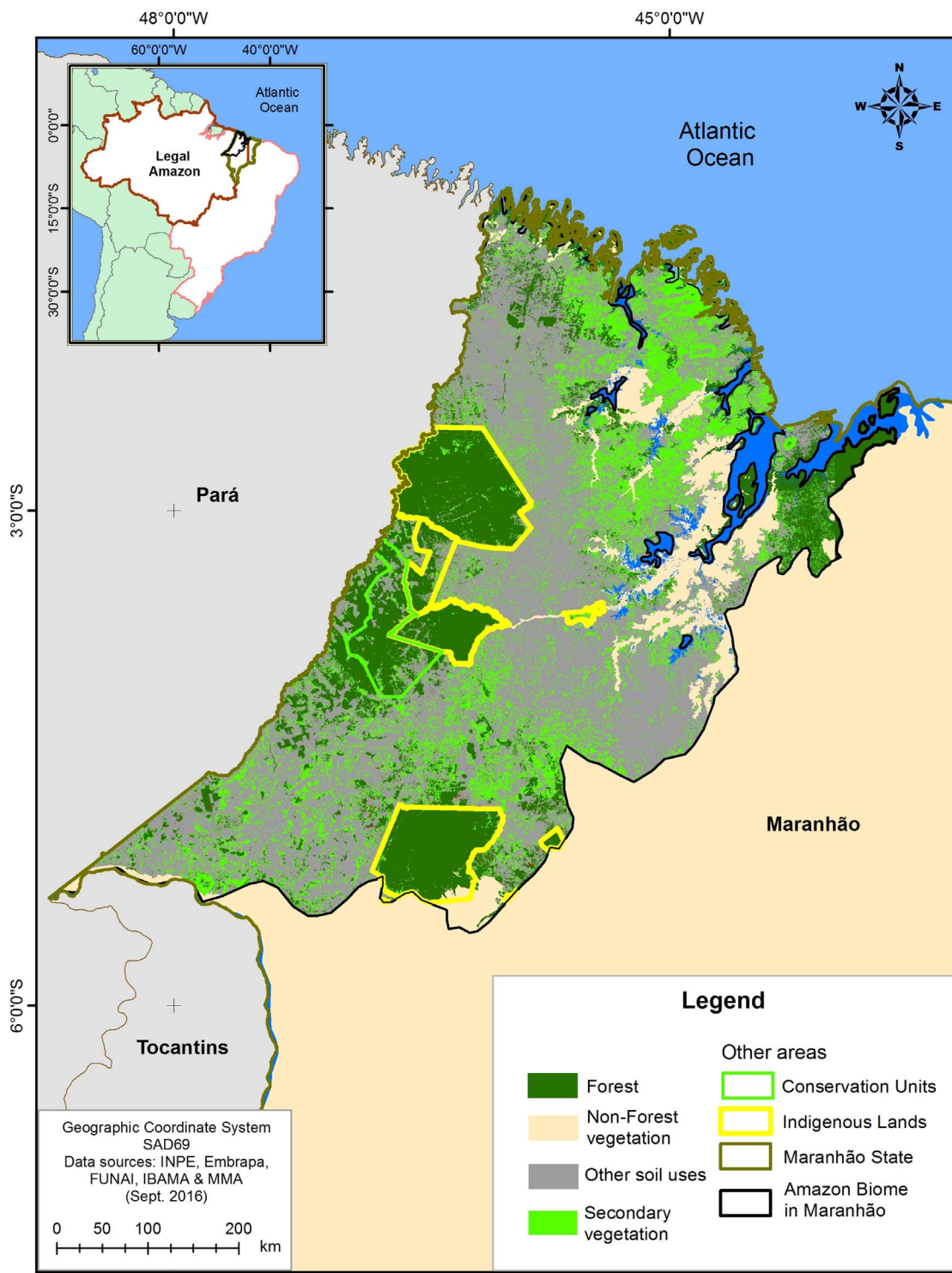


Fig. 3. Secondary Forests in the Amazonian Biome in the State of Maranhão (INPE and EMBRAPA, 2014).

## Acknowledgements

The authors are grateful for the support of the Foundation for Scientific and Technological Research and Development of Maranhão (FAPEMA), of the Coordination for the Improvement of Superior Level Personnel (Capes), of the National Council for Scientific and Technological Development (CNPq), of the Program for Biodiversity Research (PPBio), of the Program for Protected Areas of the Amazon (ARPA), of Maranhão State University (UEMA), and of the INCT Biodiversity and Land Use Project of CNPq. We thank James Welsh for

language editing.

## References

- Alencar, A., et al., (2016) Desmatamento nos Assentamentos da Amazônia: Histórico, Tendências e Oportunidades. Brasília: IPAM, 93p. Available at: <http://ipam.org.br/wp-content/uploads/2016/02/Desmatamento-nos-Assentamentos-da-Amaz%C3%B4nia.pdf>.
- Almeida, L.Q., Welle, T., Birkmann, J., 2016. Disaster risk indicators in Brazil: a proposal based on the world risk index. *Int. J. Disaster Risk Reduct.* 17, 251–272.
- Aragão, L.E.O.C., 2012. The rainforest's water pump. *Nature* 489, 217–218.



- Arcangeli, A., 1987. O mito da terra: uma análise da colonização da Pré-Amazônia maranhense. EDUFMA, São Luís.
- Asner, P.G., et al., 2005. Selective logging in the Brazilian Amazon. *Science* 310, 480–482.
- Brançalon, P.H.S., et al., 2016. A critical analysis of the native vegetation protection law of Brazil (2012): updates and ongoing initiatives. *Natureza & conservação. Braz. J. Nat. Conserv.* 14, 1–15.
- Brazilian Federal Government. 2002. Federal Decree n.4.297, from 10 July 2002. Available at: [http://www.planalto.gov.br/ccivil\\_03/decreto/2002/d4297.htm](http://www.planalto.gov.br/ccivil_03/decreto/2002/d4297.htm).
- Brazilian Federal Government. 2012. Federal Law n.12.651, from 25 May 2012. Available at: [http://www.planalto.gov.br/ccivil\\_03/ato2011-2014/2012/Lei/L12727.htm](http://www.planalto.gov.br/ccivil_03/ato2011-2014/2012/Lei/L12727.htm).
- Brazilian Federal Government. 2017. Federal Decree n. 8.972, from 23 January 2017. Available at: [http://www.planalto.gov.br/ccivil\\_03/\\_ato2015-2018/2017/decreto/D8972.htm](http://www.planalto.gov.br/ccivil_03/_ato2015-2018/2017/decreto/D8972.htm).
- Brown, S., Zarin, D., 2013. What does zero deforestation mean? *Science* 342, 805–807.
- CIMI - Conselho Indigenista Missionário. 2012. Lideranças denunciam assassinato de criança Awá-Guajá na Terra Indígena Araribóia. Available at: [http://www.cimi.org.br/site/pt-br/?system=news&conteudo\\_id=6037&action=read](http://www.cimi.org.br/site/pt-br/?system=news&conteudo_id=6037&action=read).
- CIMI - Conselho Indigenista Missionário. 2016. Relatórios de Violência Contra os Povos Indígenas. Brasília: CIMI. Available at: <http://www.cimi.org.br/site/pt-br/?system=publicacoes&cid=30>.
- CPT. 2017. Conflitos no Campo Brasil 2016. Brasília: Comissão Pastoral da Terra. Statistics available at: <https://www.cptnacional.org.br>.
- Carneiro, M.S., 1997. Do latifúndio agropecuário à empresa latifundiária carvoeira: a Estrada de Ferro Carajás e a propriedade da terra no Oeste maranhense. In: Coelho, M.C.N., Cota, R.G. (Eds.), 10 anos da Estrada de Ferro Carajás. UFPA/NAEA, Belém, pp. 223–250.
- Carneiro, M.S., 2016. Mercado e contestação: a atuação da crítica social e as transformações nas estratégias das empresas siderúrgicas de Carajás (1988–2012). *Política e Sociedade* 15 (33), 282–313.
- Celentano, D., et al., 2012. Welfare outcomes and the advance of the deforestation frontier in the Brazilian Amazon. *World Dev.* 40, 850–864.
- Chazdon, R.L., 2008. Beyond deforestation: restoring forests and ecosystem services on degraded lands. *Science* 320, 1458–1460.
- FIEMA. 2017. ZEE, Resex de Tauá-Mirim e Turismo são pautas de audiência da FIEMA com Ministro do Meio Ambiente. Available at: <http://www.fiema.org.br/noticia/21874110/ze-resex-de-taua-mirim-e-turismo-sao-pautas-de-audiencia-da-fiema-com-ministro-do-meio-ambiente&pagina=3> (Access April, 2017).
- Finegan, B., 1996. Pattern and process in neotropical secondary rain forests: the first 100 years of succession. *Trends Ecol. Evol.* 11 (3), 119–124.
- Greenpeace. 2015. Projeto de lei do Desmatamento Zero é entregue no Congresso. Available at: <http://www.greenpeace.org/brasil/pt/Noticias/Projeto-de-lei-do-Desmatamento-Zero-e-entregue-no-Congresso/>.
- Gulnara, S., 2010. Report of the Special Rapporteur on Contemporary Forms of Slavery, Including Its Causes and Consequences. Addendum: Mission to Brazil, New York: United Nations (UN) Available at: <http://www.refworld.org/docid/4c96ff682.html>.
- Holl, K.D., Zahawi, R.A., Cole, R.J., Ostertag, R., Cordell, S., 2011. Planting seedlings in tree islands versus plantations as a large-scale tropical forest restoration strategy. *Restor. Ecol.* 19, 470–479.
- Houghton, R.A., et al., 2000. Annual fluxes of carbono from deforestation and regrowth in the Brazilian Amazon. *Nature* 302, 301–304.
- IBGE—Brazilian Institute of Geography and Statistics, 2016. Contas Nacionais. Available at: <http://www.ibge.gov.br/>.
- ICMBIO – Chico Mendes Institute of Biodiversity Conservation. 2015. Relatório de Análise multitemporal da dinâmica do uso e cobertura do solo nas TI Caru, Awá e Alto Turiaçu. Belém: ICMBio.
- INMET. 2016. Instituto Nacional de Meteorologia. Dados históricos. Available at: <http://www.inmet.gov.br/portal/>.
- INPE and EMBRAPA, 2014. Projeto TerraClass: Levantamento de informações de uso e cobertura da terra na Amazônia. São José do Campos: Instituto Nacional de Pesquisas Espaciais. Available at: <http://www.inpe.gov.br>.
- INPE National Institute for Space Research. 2016. Monitoramento da cobertura florestal da Amazônia por satélites – sistemas Prodes, Deter, Degrad e Queimadas. São José do Campos: INPE. Available at: <http://www.inpe.gov.br>.
- IPCC, 2014. Climate change 2014: synthesis report. In: Pachauri, R.K., Meyer, L.A. (Eds.), Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team. IPCC, Geneva Switzerland 151 pp.
- ISA. 2017. Monitoramento de Áreas Protegidas. Data available at: <https://www.socioambiental.org/pt-br/o-isa/programas/monitoramento-de-areas-protegidas> (Access April, 2017).
- ITTO and IUCN, 2005. Restoring Forest Landscapes: An Introduction to the Art and Science of Forest Landscape Restoration. International Tropical Timber Organization, Yokohama.
- Janzen, D.H., 2002. Tropical dry forest: area de conservación guanacaste, northwestern Costa Rica. In: Perrow, M.R., Davy, A.J. (Eds.), Handbook of Ecological Restoration, Volume 2, Restoration in Practice. Cambridge University Press, Cambridge, UK, pp. 559–583.
- Kohlhepp, G., 2002. Conflitos de interesse no ordenamento territorial da Amazônia brasileira. *Estudos Avançados* 16, 37–61.
- LDP 2013. Projeto de Decreto Legislativo de Sustação de Atos Normativos do Poder Executivo n.914/ (Deputado Weverton Rocha) que: "Susta os Efeitos do Decreto nº 95.614 de 12 de Janeiro de 1988, que Cria a Reserva Biológica do Gurupi e dá Outras Providências" 2013; Available at: <http://www.camara.gov.br/proposicoesWeb/fichadetramitacao?idProposicao=579217>.
- Lamb, D., Gilmour, D., 2003. Rehabilitation and Restoration of Degraded Forests. International Union for Conservation of Nature and Natural Resources (IUCN) and The World Wide Fund for Nature (WWF) 122 p.
- Lamb, D., Erskine, P.D., Parrotta, J.A., 2005. Restoration of degraded tropical forest landscapes. *Science* 310, 1628–1632.
- Latawiec, A.E., et al., 2015. Creating space for large-scale restoration in tropical agricultural landscapes. *Front. Ecol. Environ.* 13, 211–218.
- Makarieva, A.M., et al., 2014. Why does air passage over forest yield more rain? Examining the coupling between rainfall, pressure, and atmospheric moisture content. *J. Hydrometeorol.* 15, 411–426.
- Malhi, Y., et al., 2008. Climate change, deforestation and the fate of the Amazon. *Science* 319, 169–172.
- Mansourian, S., Vallauri, D., Dudley, N., 2005. Forest Restoration in Landscapes: Beyond Planting Trees. WWF and Springer, New York 437p.
- Marin-Spiotta, E., Ostertag, R., Silver, W.L., 2007. Long-term patterns in reforestation of tropical pastures: plant community composition and aboveground biomass accumulation. *Ecol. Appl.* 1, 828–839.
- Martins, M.B., Oliveira, T.G., 2011. Amazônia Maranhense: Diversidade E Conservação. MPEG, Belém.
- Moura, W.C., et al., 2011. In: Martins, M.B., Oliveira, T.G. (Eds.), A Reserva Biológica Do Gurupi Como Instrumento De Conservação Da Natureza Na Amazônia Oriental. Amazônia maranhense: diversidade e conservação, Belém: MPEG, pp. 24–31.
- Nader, H.B., Palis, J., 2015. Retrocessos Da Nova Lei Florestal: Uma Carta Aberta Da SBPC E Da ABC Para Apoiar a Análise Do STF Sobre as ADINs.
- Nepstad, D.C., Stickler, C.M., Almeida, O.T., 2006. Globalization of the Amazon soy and beef industries: opportunities for conservation. *Conserv. Biol.* 20 (6), 1595–1603.
- Nunes, S., Gardner, T., Barlow, J., et al., 2016. Compensating for past deforestation: assessing the legal forest surplus and deficit of the state of Pará, eastern Amazonia. *Land Use Policy* 30 (57), 749–758.
- Oren, D., 1988. Uma reserva biológica para o Maranhão. *Ciência Hoje* 8 (44), 36–45.
- Pará State Government. 2015. State Normative n.8, from 28 October 2015. Available at: <https://www.sem.spa.gov.br/2015/11/03/instrucao-normativa-no-08-de-28-de-outubro-de-2015/>.
- Poorter, L., et al., 2016. Biomass resilience of Neotropical secondary forests. *Nature* 530, 211–226.
- Rudorff, et al., 2011. The Soy Moratorium in the Amazon Biome Monitored by remote sensing images. *Remote Sens.* 3, 185–202.
- Schwitzer, C., et al., 2016. Primates in Peril: the World's 25 Most Endangered Primates 2014–2016. Arlington: IUCN SSC Primate Specialist Group (PSG), International Primatological Society (IPS). Bristol Zoological Society (BZS).
- Silva, J.S., Ranieri, V.E.L., 2014. The legal reserve areas compensation mechanism and its economic and environmental implications. *Ambiente Soc.* 17 (1), 115–132.
- Soares Filho, B., et al., 2014. Cracking Brazil's forest code. *Science* 344, 363–364.
- Sterzi, R.S., 2016. A inconstitucionalidade da redução da área de reserva legal prevista no novo Código Florestal. *Âmbito Jurídico* 153. Available at: [http://www.ambito-juridico.com.br/site/?n\\_link=revista\\_artigos\\_leitura&artigo\\_id=17950&revista\\_caderno=5](http://www.ambito-juridico.com.br/site/?n_link=revista_artigos_leitura&artigo_id=17950&revista_caderno=5).
- Survival International. Awá: Earth's most threatened tribe. Londres: Survival International. Available at: <http://www.survivalinternational.org/awa> > .
- The Washington Post. 2015. Why are Brazil's environmentalists being murdered? By Michael E. Miller (August 27, 2015) Available at: <https://www.washingtonpost.com/news/morning-mix/wp/2015/08/27/why-are-brazils-environmentalists-being-murdered/>.
- Turner, I.M., Corlett, R.T., 1996. The conservation value of small, isolated fragments of lowland tropical rain forest. *Trends Ecol. Evol.* 11 (8), 330–333.
- UN. 2010. Promotion and protection of all human rights, civil, political, economic, social and cultural rights, including the right to development. Report submitted by the Special Rapporteur on the right to food, Olivier De Schutter. Human Rights Council. General Assembly. UN: New York . 21p.
- UNDP. 2013. Atlas do Desenvolvimento Humano no Brasil. Brasília, DF: PNUD, IPEA e FJP. Available at: <http://www.atlasbrasil.org.br/2013/>.
- Vieira, D.L.M., Holl, K.D., Peneireiro, F.M., 2009. Agro-successional restoration as a strategy to facilitate tropical forest recovery. *Restor. Ecol.* 17, 451–459.
- Global Witness, 2016. On dangerous ground. 2015's Deadly Environment: the killing and criminalization of land and environmental defenders. Global Witness, Londres.