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# Deforested and degraded land available for the expansion of palm oil for biodiesel in the state of Pará in the Brazilian Amazon

Carolina Monteiro de Carvalho [a,*], Semida Silveira [b], Emilio Lèbre La Rovere [c], Allan Yu Iwama [d]

[a] Universidade Federal do Rio de Janeiro UFRJ, Centro de Tecnologia, Bloco C, Sala 211, Cidade Universitária, Ilha do Fundão, Rio de Janeiro, RJ, Brazil
[b] KTH Royal Institute of Technology, School of Industrial Engineering and Management, EGI/Energy and Climate Studies, Brinellvägen 68, SE-100 44 Stockholm, Sweden
[c] Universidade Federal do Rio de Janeiro UFRJ, Centro de Tecnologia, Bloco C, Sala 211, Cidade Universitária, Ilha do Fundão, Rio de Janeiro, RJ, Brazil
[d] Embrapa Monitoramento por Satélite, Centro Nacional de Pesquisa e Monitoramento por Satélite, Campinas, SP, Brazil

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ABSTRACT

This paper maps the availability of deforested and degraded land in the state of Pará in the eastern Amazon and discusses the feasibility of using this land for the expansion of palm crops for biodiesel production. The ultimate objective is to highlight land that is suitable for palm oil and its availability/distribution, so that the palm oil expansion envisaged by the Brazilian Government's Sustainable Palm Oil Program can be achieved in a sustainable way. The analysis is developed with the support of geoprocessing techniques that pull data together from different sources, including the Agroecological Zoning (ZAE) developed for palm oil in Brazil and degraded land data. The analysis identifies some of the challenges faced when planning and monitoring the expansion of palm oil in the Amazon, including the need for an operational concept to identify and use degraded land.



**Contents**



## 1. Introduction

Biofuels are a suitable option to replace the fossil fuels used in transport while also contributing to the mitigation of greenhouse gas (GHG) emissions, the reduction of energy poverty, and social development [1] [1,2]. However, these outcomes depend strongly on how the biofuels are produced from the planting of crops to the production, distribution and use of the biofuel. If biofuel production chains are not properly monitored, GHG emissions resulting from fuel substitution may end up being similar or even higher than the emissions from fossil fuels [3–6].

Brazil and the USA account for nearly 80% of global biofuel production, mainly ethanol, and Brazil has been the largest producer of sugarcane-based ethanol and a major user of biofuels since the 1970s. Today, the Brazilian energy matrix is largely based

* Corresponding author. Tel.: +55 12 9 91556590.
*E-mail addresses:* carvalhocm@gmail.com (C. Monteiro de Carvalho), semida.silveira@energy.kth.se (S. Silveira), emilio@ppe.ufrj.br (E.L.L. Rovere), allan.iwama@gmail.com (A.Y. Iwama).

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on renewable resources, and it relies on hydropower and biomass as a result of development policies that have been pursued for many decades. The oil price shocks of the 1970s provided incentives for the development of ethanol production and the use and modernisation of bioenergy in Brazil. Today, Brazil's achievements in the ethanol industry are well documented not least as it was a pioneering effort to introduce renewable fuels in transport [7–12]. Large-scale ethanol production from sugarcane was established in the 1970s under the Brazilian Ethanol Program (Programa Nacional do Álcool, PROALCOOL), which aimed at reducing oil imports following the first oil crisis [13,14]. Since then, the sugar–ethanol industry has become a major development engine in Brazil, now moving towards second generation fuel production and biorefinery concepts. Energy derived from sugarcane amounts to 19% of the total energy supply in the country, most of it in the form of ethanol and partly in the form of heat and power [15]. Sugarcane plantations continue expanding as ethanol trading opportunities arise. Meanwhile, although the potential for biodiesel production was identified decades ago, its actual development has occurred much more recently [16–18]. Still the development of the biodiesel industry in Brazil has profited from decades of experience with the development of ethanol fuel [17]. In 2013, biodiesel amounted to 7.4% of the diesel utilized in the country [15].

In less than 10 years, Brazil has developed biodiesel production based on oil seeds through programs and incentives supported by the government, such as the National Biodiesel Program [19]. The program's main goal is to produce biodiesel in a sustainable way by meeting the national biodiesel demand while mitigating GHG emissions and pursuing social inclusion and regional development through the creation of jobs and income. Brazil is a country of continental dimensions and great and diverse potential for the production of oil seeds. Palm oil, one of the most productive oil seeds in the world, can be grown in the Amazon region, and this has been viewed as an opportunity to produce more biodiesel to meet the domestic and international demand. This insight has come particularly with the ZAE and the Sustainable Palm Oil Program releases in 2010. From 2010 to 2012, palm oil sector presented an impressive increase, from 1090 km$^2$ to almost 1400 km$^2$ in Pará state, the largest producer, due to bioenergy sector growth with new producers, Vale/Biopalma and PBIO/Galp [20]. Since then, palm oil programs have received more investments from private sector and incentives for production. For example, the Pronaf Eco Dendê (Palm) provides technical assistance, credit lines and funding for small farmers production, and because of that, potential integration between small farmers and companies has intensified. In fact, companies producing oil with small farmers are eligible for tax reductions [21]. However, it is also understood that, if not properly managed, the present development could pose a threat to Amazon forests. Therefore, sustainability criteria for palm oil production should become part of this expansion model [20].

The production of palm oil in Brazil began approximately 30 years ago, and particularly since 2000, the domestic demand for palm oil has increased for both food and biodiesel production [22]. However, Brazilian production is still incipient compared to the major producing countries, such as Malaysia and Indonesia; in fact, it does not even meet the current domestic demand [23]. Throughout the country as a whole, the land devoted to Brazilian palm oil production covers only 1400 km$^2$ [24], which contrasts with sugarcane plantations that covered 55,000 km$^2$ in São Paulo state alone and 90,000 km$^2$ in Brazil in 2012 [25,26].

An expansion of up to 3300 km$^2$ of palm oil plantations by 2020 is currently being envisaged by producers and the government in the state of Pará to increase biodiesel production [24]. As mentioned above, Pará is the major producer of palm oil in Brazil with up to 95% of the crop area and palm oil production in the country, followed by the state of Bahia. Therefore, expansion is presently focused on Pará. The ZAE identified the most suitable areas for this crop, and the Sustainable Palm Oil Program maintained that palm oil crops should be established in the deforested and degraded land that had been mapped as of 2008. Deforestation for palm oil production was forbidden [27,28], but no regulatory framework is yet in place regarding the potential areas for palm oil expansion, which poses social and environmental risks, particularly to sensitive areas of the Amazon region.

According to [29–31], crops aimed for bioenergy are less controversial if developed on degraded land because these lands are unsuitable and economically unattractive for agricultural production. Thus, palm oil expansion on deforested and degraded lands in the Amazon region could bring environmental and socioeconomic benefits, such as reduced importation of diesel, creation of jobs and income, restoration of deforested and degraded land, increased biodiversity and improved energy security [32]. Cleared land and land that currently has a low carbon stock and low biodiversity are considered degraded land in Indonesia, a country that is now reviewing palm oil expansion to avoid continued deforestation [33]. In the Brazilian context, land that is considered suitable for palm oil is primarily deforested land. Within this classification, land that is not suitable for agricultural uses are mapped and classified as Abandoned Pasture [34]. However, while these lands may not be of economic value for agriculture, they can provide basic resources for local communities. It is important to note that the definition of degraded land and its location are important factors that need to be considered in the context of each country [33]. No studies of the use of degraded land for palm oil have been previously conducted in the region, and no major attempts have been made to find an operational definition of degraded land to guide the current crop expansion; this study provides new insights into this topic, by mapping the availability of deforested and degraded land in the state of Pará in the eastern Amazon and discusses the feasibility of using this land for palm crops based on its extent, location and geographic distribution in the region. The potential social and environmental impacts are also considered.

## 2. Objectives and methodologies

This research assesses and quantifies the deforested and degraded land available and suitable for palm oil expansion in the state of Pará. The ultimate objective is to highlight land that is suitable for palm oil and its availability/distribution, so that the current plan for palm oil expansion for biodiesel can be achieved in a sustainable way. The analysis was developed with the support of geo-processing techniques. As a first step, a review of the concepts of degraded land and palm oil development was done based on the available literature. This is presented in Sections 3 and 4 and serves to contextualise palm oil in world and in Brazil (Fig. 1 presents the palm oil production worldwide) and the potential uses of and issues surrounding degraded land in the Amazon. For this paper, we assume that the degraded land suitable for palm oil is land that has been cleared of natural vegetation and now has a low level of biodiversity as well as being unsuitable for agricultural activities [5,29–31,33,35,36]. This definition corresponds to the Abandoned Pasture land classification mapped by the TerraClass project, which will be described in further detail.

As a second step, an analysis was developed with the support of geo-processing techniques. Data on degraded and deforested land were collected from the TerraClass project [37]. PRODES project [38] detects areas in the early stages of deforestation and has been

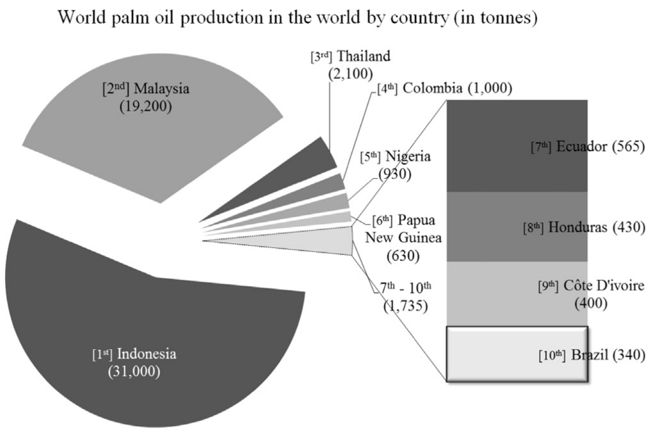


**Fig. 1.** World palm oil production by country (in tonnes) estimated for 2013. Adapted from Index Mundi (based on 39).

updated annually since 2004. The TerraClass project further classifies the land mapped by PRODES as Forest, Secondary forest, Not forest and Deforestation 2008, Agriculture, Agriculture and cattle, Pasture, Abandoned pasture, Recovering forest with pasture, Pasture with exposed soil, Mining, Urban area, Other uses and areas Not observed. Abandoned pasture is the land class that has been identified for palm oil expansion and is considered to be deforested and/or degraded land, according to the Sustainable Palm Oil production Program. These lands were mapped using satellite imagery and specific algorithms that highlight deforestation and features of degradation in the Amazon. The data are provided in a shape-file format that can then be introduced into GIS software. Using GIS, land classes are presented as polygons that can be counted and measured.

The TerraClass data were overlaid on the state map of Pará, which allowed for spatial analysis. The state map of Pará was downloaded from the IBGE (Instituto Brasileiro de Geografia e Estatística) website [39]. All data were cross-checked in ArcGIS 10 to provide a comprehensive picture of the land that is actually available and can possibly be used for palm oil plantations.

Maps were produced and are presented in Section 5. The first map (Fig. 2) shows the degraded land available in the state of Pará and provides a general view of the distribution of these lands throughout the state as well as in the palm oil producing municipalities. This basic information is necessary to plan the expansion of the crops in the region. A table is presented in the Appendix containing land areas in the municipalities that currently produce palm oil. The theoretical yield for available land is calculated, which thus allows for an analysis of palm oil production. A second map (Fig. 3) presents the land degradation process from deforested land stage until the degraded land stage that is considered suitable for palm oil. A third map (Fig. 4) shows the distribution of deforested and degraded land in Pará state, cross-checked with ZAE, in ranges of extent from 0–5 km$^2$, 5–50 km$^2$, 50–100 km$^2$ and $>100$ km$^2$. The ZAE data were added over the TerraClass data for Pará state to finally determine the available land within the classifications provided by the ZAE, but only the preferred and regular zones are considered. These maps provide a spatial representation of the availability of the degraded land and its extent and can contribute to a better understanding of the pattern of its distribution. Table 1 summarizes this map.

Finally, the maps were used to evaluate the potential for palm crop expansion in municipalities that are already producing palm oil and to assess the potential for new producers. This analysis serves to illustrate that the actual potential for palm expansion may be much smaller than anticipated, which would require more careful analysis and monitoring of the palm expansion in the state.

## 3. Palm oil and the Brazilian biodiesel program

Palm oil trees come from the west coast of Africa, and there are two species of commercial interest: *Elaeis guineensis* and *E. oleifera*, the latter being a native of Latin America. Two types of oil can be extracted from the palm, one from the fruit and the other from the seed. Palm oil trees have a 25-year life cycle and can reach up to twenty meters in height [40]. They are widely grown in Indonesia and Malaysia, and these countries are responsible for approximately 90% of the palm oil production worldwide [41] (Fig. 1). However, the two countries have been criticised due to the high environmental impact of their palm oil expansion, including inappropriate land management and deforestation of native forest, which has led to the loss of local biodiversity and increased social pressures on the local populations [42]. Brazil is the 10$^{th}$ largest producer in the world although its contribution is still very marginal.

Global palm oil production has expanded rapidly in recent years and is likely to continue growing. The environmental, economic and social impacts attached to this expansion prompted the creation of the RSPO (Roundtable on Sustainable Palm Oil), an international, multi-stakeholder organisation, in 2006. The RSPO develops criteria for palm oil production that incorporate sustainability along with economic use values [43].

Palm was introduced in the state of Bahia in Brazil in the 16th century, and in 1947, it was introduced in the Amazon, including in the state of Pará [22]. Palm oilseed is promising because of the potential oil yield that can be accrued per hectare, approximately 368 t of oil/km$^2$, which is the highest among the various oilseeds. In contrast, soy produces only 42 t of oil/km$^2$ [44]. Palm oil is well adapted to the Amazon region, and it is a perennial crop that could be used to promote the social inclusion of small farmers and to help recover degraded lands. In addition, once biodiesel production is in place in the region, palm oil can also be used as a substitute in diesel generators and boats, which are widely used for local and regional transport. According to [45], the state of Pará has favourable environmental conditions for palm crops, including rainfall of 2500 mm/yr, 2000 h of sunlight that are well distributed throughout the year, temperatures between 24 °C and 28 °C and humidity between 75% and 90%.

In 2004, the Brazilian government launched the National Biodiesel Program (PNPB) to increase energy security through the sustainable production of biodiesel from oilseeds. The program focused on social inclusion and regional development with an emphasis on job and income generation and the sustainable use of various oilseeds. The program also hoped to reduce GHG emissions. Financial incentives were provided to foster the production of various crops. The mixing of 2% biodiesel into the fossil diesel began in 2008 (B2), and in 2010, this amount was raised to 5%; there are plans to increase the mix to 20% in 2020 [19]. At present, the biodiesel mix is at 7.6% (15). In this context, palm oil is an attractive crop due to the high oil yields that can be achieved, its potential to adapt to climate change, and the opportunities it presents to promote social inclusion and sustainable development [46].

Another feature of the National Biodiesel Program was the creation of the Social Fuel Label, which is granted to biodiesel producers that use oilseeds produced by small farmers. When a certain amount of oilseeds originating from small-scale producers are used, the biodiesel producer is entitled to tax reductions. The minimum amount of raw material from small farmers required to obtain the tax benefits varies among the country's macro-regions: 30% in the Northeast, Southeast and South Regions and 15% in the North and Central-West Regions. In addition, the contracts made with small farmers should be intermediated by small farmer representatives, and the producer company must provide technical assistance and training to the farmers [47].

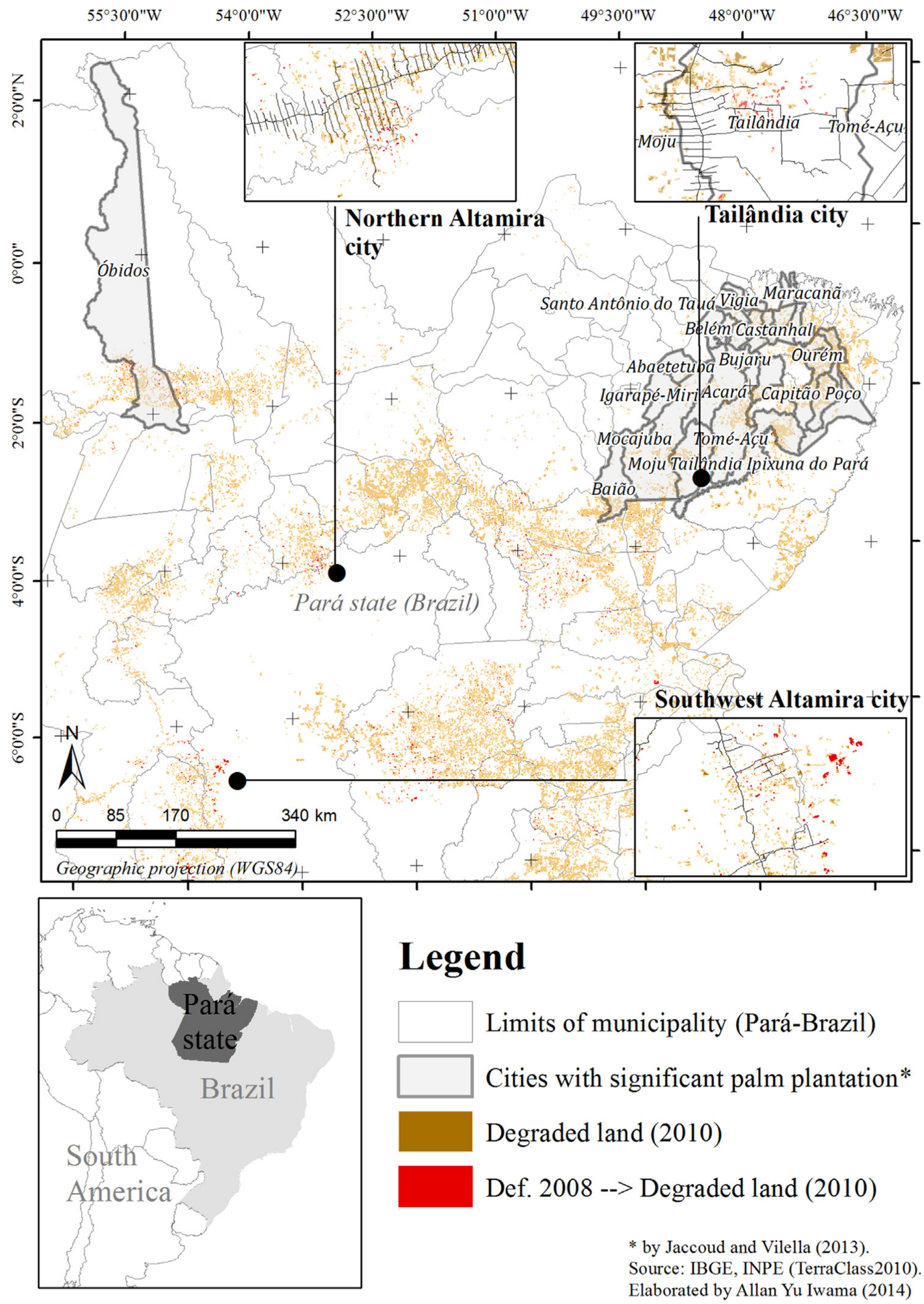


**Fig. 2.** Location of the available deforested and degraded land in Pará.

In the beginning of the PNPB program, soy and animal fats comprised most of the source material for biodiesel, indicating that the potential of various crops was not being fully explored despite increasing oil seed production [17]. Brazil has a diversity of potential feedstocks, such as castor beans, palm oil, soy, *Jatropha*, sunflower and others as well as a significant amount of available land. To explore this diversity, a solid structure for the production of various feedstocks and the distribution of program benefits needs to be implemented under the PNPB [46]. The PNPB can currently be considered to be a successful program in terms of production targets as it did achieve the proposed 5% biodiesel mix, which amounts to the production of no less than 2.4 billion litres of biodiesel per year. Moreover, the production of oil seeds has increased continuously over the years. However, from the social and environmental point of view, there is still a lot to be done because the inclusion of small farmers in the program has been limited, the diversity in the sources of oilseeds has not been fully achieved, and environmental controls, especially those under the application of the Social Fuel Label, have been inadequate [17,18,48].

As previously mentioned, 1400 km$^2$ of land in Brazil are currently being cultivated, and there are plans to expand palm oil crop production to a total of 3300 km$^2$ in Pará by 2020. This expansion can bring economic, social and even environmental benefits to the region, however, negative impacts can be also expected, such as deforestation [20,24,49]. Native forest is cleared to make room for crops, releasing GHG emissions and reducing biodiversity and ecosystem services in addition to affecting local

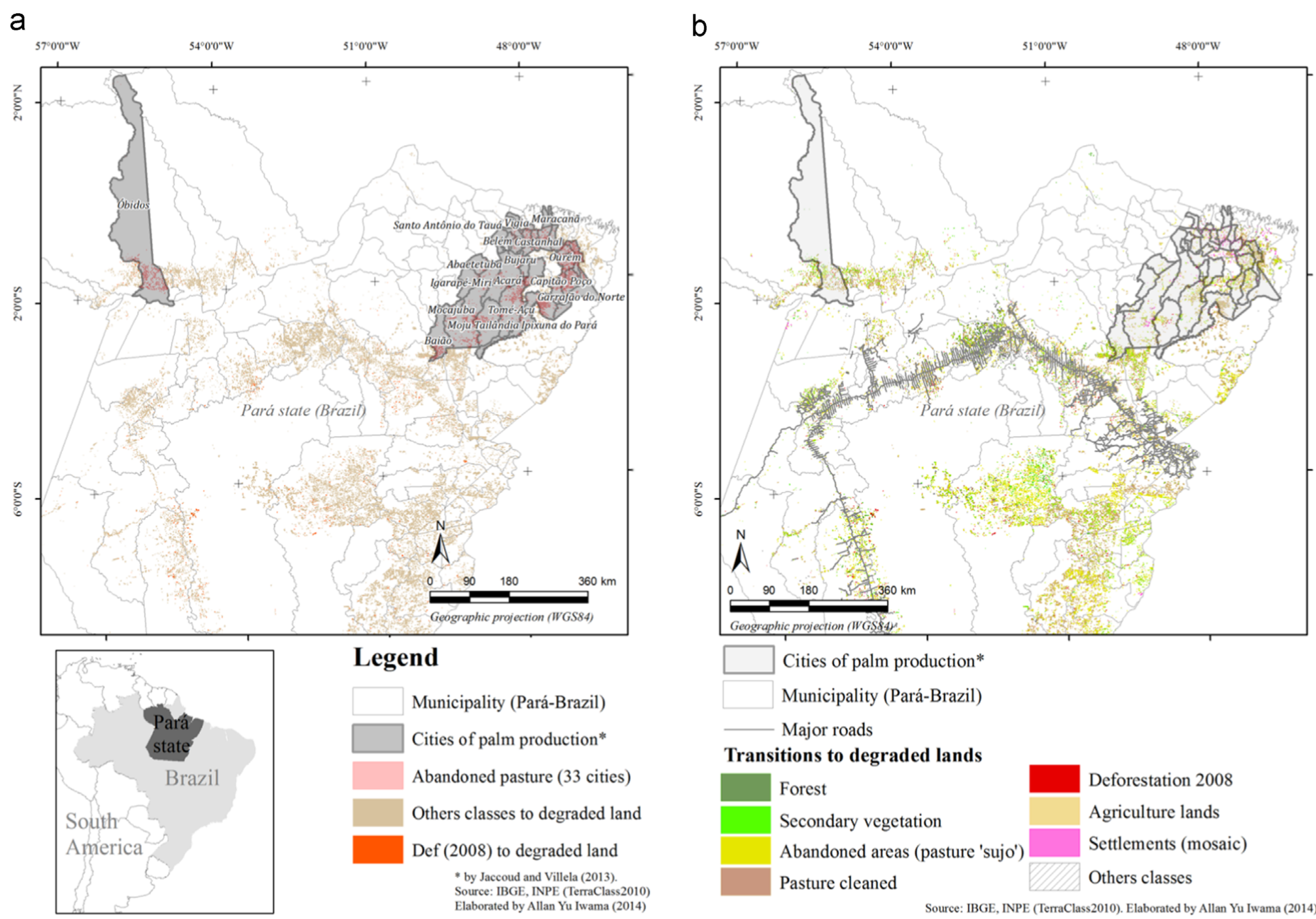


**Fig. 3.** Land degradation transitions in Pará state.

communities that depend on forest resources. Palm oil expansion should be carefully conducted. Because of that, the ZAE and the Sustainable Palm Oil Program were launched to regulate this expansion. The ZAE provides the basis for pursuing social, economic and environmental sustainability in the expansion of palm oil crops and indicates what land is most suitable for growing palm by taking into account soil characteristics, topography, climate and crop-specific environmental factors. It has identified approximately 130,000 km$^2$ of deforested land that is potentially available for palm oil expansion in Brazil, excluding forested areas, Indian reservations and protected areas. Based on that information, it is possible to identify the areas with the highest potential for palm crops and monitor the expansion to avoid negative environmental impacts. ZAE classifies land according to its palm oil potential: preferred (high potential), regular (medium to high potential), marginal (low potential), not suitable (no potential) and not mapped (native forest and protected areas). The ZAE was developed to account for two levels of crop management: level B is the adoption of farming practices that reflect an intermediate degree of technological inputs with modest capital investment, and level C reflects agricultural practices incorporating a high level of technology, including mechanisation [28]. The ZAE has concluded that as a perennial crop, palm oil has the potential to generate income, protect the soil against erosion and degradation, and provide a high rate of carbon sequestration [27].

The Sustainable Palm Oil Program was launched after the ZAE and aim to regulate the expansion of palm oil production, restrict it to degraded lands and areas that were deforested before 2008, and support the recovery of these degraded areas. The deforestation of native vegetation for the purpose of planting palm oil is strictly forbidden [27]. Therefore, this is an opportunity to recover degraded land and related environmental and social benefits, since these directives are followed. To achieve that, a more deep analysis regarding degraded land are needed.

## 4. Degraded land for bioenergy

There are several definitions and concepts about what should be considered “degraded land”. According to the FAO (Food and Agriculture Organisation) [35], areas that were cleared of their natural vegetation cover and now contain low levels of biodiversity and stocks of carbon are considered to be degraded land. UNEP [36] defines degraded land as land that has lost its capacity for sustaining ecosystem services and functions due to disturbance (natural or unnatural) and, therefore, cannot recover naturally. Similar to the FAO, the POTICO project considers cleared land and land that currently has a low stock of carbon and low biodiversity to be degraded [33]. We therefore assume that degraded land is land that has been cleared of its natural vegetation and currently presents low levels of biodiversity and is also considered unsuitable for agricultural purposes.

There are some initiatives underway to promote bioenergy production on degraded land in Europe, such as the European Commission on Renewable Energy Directive, which gives a GHG emission credit for biofuels produced on degraded and/or heavily contaminated land [50]. The above-mentioned Roundtable for Sustainable Palm Oil (RSPO) promotes the use of degraded and idle land for biofuel/palm oil production. In addition, the Global Bioenergy Partnership (GBEP) [51], which is coordinated by the UN, proposes the use of degraded land for biofuels production. Similarly, according to the Brazilian Sustainable Palm Oil Program, degraded and deforested land should be used to grow palm. For the palm oil program to succeed, stakeholders must have a complete understanding of the meaning of deforested and degraded land.

The sustainable expansion of palm oil will strongly depend on the accurate assessment of degraded lands, first through the database and field measurements and then through the management and monitoring of their conversion. According to [2,52], the definition of degraded land should be clarified through a methodology for identifying degraded land that is suitable for bioenergy production, which can be accomplished by reviewing the current use and functions of the land.

It is therefore remarkable that the Brazilian Palm Oil Program does not specify levels of land degradation to be considered when determining land availability. The lack of an official definition as well as accurate data and mapping of the available degraded land are obstacles to achieving the sustainable expansion of palm oil.

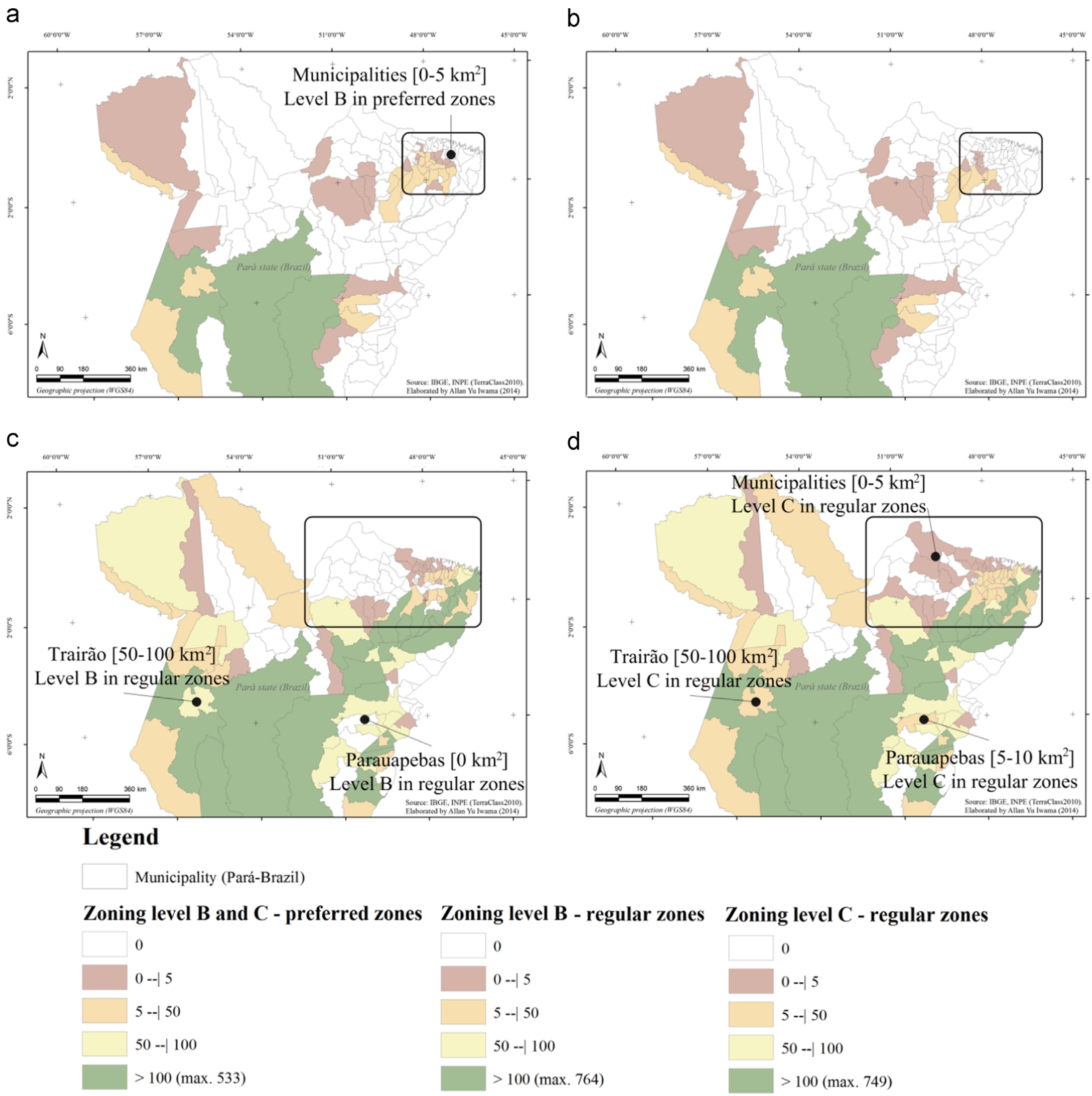


**Fig. 4.** The distribution of deforested and degraded land in Pará state, crosschecked with ZAE (preferred and regular zones), in ranges of extent from 0–5 km$^2$ (brown), 5–50 km$^2$ (orange), 50–100 km$^2$ (yellow) and > 100 km$^2$ (green). (a) Land in the preferred zone of ZAE level B, (b) land in the preferred zone of ZAE level C, (c) land in the regular zone of ZAE level C and (d) land in the regular zone of ZAE level C. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

**Table 1**
Percentages of degraded and deforested land in Pará state that are within the ZAE classes.

| Zoning (Embrapa) | Aband. pasture in Zon B ($km^2$) | Aband. pasture in Zon B (%) | Aband. pasture in Zon C ($km^2$) | Aband. pasture in Zon C (%) |
|---|---|---|---|---|
| Preferential (P) | 1.166 | **6.1** | 1.029 | **5.4** |
| Regular (R) | 7.628 | **39.8** | 7.351 | **38.4** |
| Total (aband. pasture in P and R zoning) | 8.794 | **45.9** | 8.380 | **43.7** |
| Total abandoned pasture | 19.156 | **100.0** | 19.156 | **100.0** |

This situation indicates the need for more careful research to assess land availability and the feasibility of its use for sustainable bioenergy production on the one hand and the need for actions to counteract deforestation and social conflict on the other [52].

The conversion of native forest into palm oil plantations, as has been observed in Indonesia and Malaysia, leads to negative impacts, including the release of large amounts of $CO_2$ into the atmosphere and a potential carbon debt. In contrast, the conversion of degraded land into palm oil plantations results in improved $CO_2$ balances [2,3,5,50,53,54]; calculations of $CO_2$ emissions based on (38) show that the conversion of degraded land into palm oil plantations results in 2049 t $CO_2/km^2$ and that native forest conversion into palm oil results in a release of 44,414 t $CO_2/km^2$. This happens because soils are a carbon reservoir, and their capacity to retain carbon strongly depends on land use. Native forests have a larger amount of stored carbon than degraded vegetation, and if land is converted to another use, carbon is released into the atmosphere, contributing to the greenhouse effect.

According to [52], producing bioenergy on degraded land can avoid GHG emissions due to land use change and the accompanying decline in biodiversity and ecosystem services, especially when native forest is converted to palm crops [2,5]. Using degraded land for the expansion of palm oil also has the potential to recuperate the productive capacity of the land as well as its function as an ecosystem service provider. This may lead to positive environmental impacts, such as the recovery of biodiversity [55]. In addition, small and scattered areas of degraded land could be used by small farmers thereby improving livelihoods in rural areas through social and economic benefits [2,56].

Meanwhile, it is important to address the particular difficulties that may arise from the use of degraded land. For example, it may be more difficult to grow palm oil in degraded land than in virgin or agricultural land; more fertilisers may be required as well as more time to achieve high yields. Land ownership issues may also arise and become a problem when incorporating degraded land into production [2,52]. In addition, as noted by [57], degraded lands are like "holes" in the forest, meaning that they are not large enough for commercial-scale crops, which could result in more deforestation as individual patches of land are connected to establish large plantations. This would further increase the barriers to the participation of small farmers in the program and possibly exacerbate negative social conditions, leading to the expulsion of these small farmers [58].

## 5. Degraded land available in Pará—Brazilian Amazon

Pará is located in the eastern part of the Amazon and is the second largest state in Brazil with a total area of 1248,000 $km^2$ (almost double the size of France) divided into 144 municipalities. The main economic activities are mining, logging, livestock and agriculture. The municipalities where palm oil activities are found are characterised by the presence of local communities [59], and land ownership issues are a problem in Pará and are commonly associated with social conflicts. In recent years, some improvement has been achieved through the creation of protected areas and the cancellation of false land ownership titles. However, a significant amount of land lacks formal title. According to research conducted by IMAZON (Instituto do Homem e do Meio Ambiente na Amazônia), 39% of the state has pending titling processes, and 71% of the deforested and degraded areas do not have regularised titles [59]. Land ownership deeply affects local communities, not least in a context of palm oil expansion because many families live on land without formalised ownership. This means that they can easily end up displaced by newly arriving palm oil companies because they lack the means and knowledge to defend their interests. This has been observed in Indonesia and Malaysia and has been observed in Brazil until now. Thus, land ownership issues can affect the process of palm oil expansion on degraded land in Pará.

Fig. 2 shows the distribution of deforested and degraded land throughout Pará state.

Fig. 2 shows a total of 8264 $km^2$ of degraded land scattered throughout the state that was mapped by TerraClass in 2008 and 3653 $km^2$ inside the producing municipalities for a total potential yield of 1344,304 $t/km^2$. The theoretical potential production value was calculated based on the available degraded land area and the palm oil yield per hectare, which is 368 $t/km^2$ [44]. According to [60], companies collectively plan to achieve the production of approximately 900,000 t of palm oil by 2020.

High concentrations of land are mainly found in the northeast and southeast parts of Pará, and the northeast region corresponds to the current production of palm oil. For each municipality, deforested land was identified using tables available on the official TerraClass website (Appendix). The southeast region is a large area with high levels of deforestation due to intensive human activities that have been carried out in the past few decades. Thus, the degraded land could possibly be used for palm oil plantations and serve to restore the productivity of the land. However, there is currently no activity related to palm oil in that region, so infrastructure would have to be developed to make the activity feasible, not least to improve accessibility.

There is enough degraded and deforested land inside the current producing municipalities in the state of Pará alone to meet demand, at least at first glance. However, the map shows that the land is comprised of areas of different sizes that are scattered in different regions. It is therefore necessary to evaluate the degraded and deforested lands in the field as part of the development of the country's palm oil expansion to determine whether they are eligible for conversion into palm oil plantations or whether they should be rehabilitated with native vegetation. Using scattered areas of degraded and deforested land is not an easy task because the fragmentation of the plantations may have various implications. Maintaining small plantations can be costly, and deforestation is a threat because companies might be tempted to clear the area between two or three nearby plots to improve logistics and reduce production costs. On the other hand, if the palm oil program is implemented in a way that promotes inclusion, it could provide an opportunity for small farmers. Programs specifically focused on this group of producers will then be required, so a criterion will need to be developed to determine the use of these degraded lands. To avoid negative social and environmental impacts, one option would be to use only areas larger than 0.05 $km^2$.

According to [3], 4200 $km^2$ of palm crops would be necessary to meet domestic demand until 2020, and 10,000 $km^2$ would be enough to meet domestic demand by 2030 [20]. Therefore, additional land needs to be incorporated for future crop expansion. However, once again, it will be important to carefully investigate how the land is distributed, how it can be incorporated for palm oil expansion, and how it can be used in a sustainable way.

An important point in the definition and discussion of degraded land in Brazil that is tracked in this research is that the TerraClass project counted 19,156 km$^2$ of degraded land (Abandoned pasture) in 2010. However, 52.8% of this land comes from pasture land, particularly land that is far from roads and therefore less accessible. In addition, 19.1% of these lands were in the process of abandonment between 2008 and 2010, and 3.3% were being deforested in 2008. Lands degraded after 2008 are not eligible for palm oil development according to the Sustainable Palm Oil Program. However, this analysis for 2010 shows that the Abandoned Pasture land class comes about from other land degradation processes, such as deforestation, abandoned agricultural activities and pasture. This is important because some land that is considered degraded is the result of deforestation and should not, perhaps, be used for palm oil but recovered instead. There are no TerraClass data before 2008 to enable this type of analysis of the land eligible for palm oil. Fig. 3 illustrates this process of transitioning land degradation.

Fig. 4 shows how the deforested and degraded land is distributed throughout the palm oil producing municipalities and the whole state, taking the ZAE classification into account. As mentioned earlier, the ZAE mapped the most suitable places for palm oil plantations according to a classification system that ranged from preferred to not-mapped (see Section 3). Only the preferred and regular zones are suitable for palm oil.

The land data were crosschecked with the preferred and regular zones of the ZAE to determine the land area in the most favourable zones for growing palm oil. Fig. 4a and b shows the extent of degraded land inside the ZAE level B and C preferred zones with a focus on the producers, and the range of the extents of degraded land vary from only 0–50 km$^2$. We can see that the number of potential degraded areas of more than 100 km$^2$ that are inside the regular zones increases substantially in northeast Pará (Fig. 4c and d). This area presents the highest numbers of 100 km$^2$ spots, but there are also areas ranging from 0–5 km$^2$ and 5–50 km$^2$ that are favourable to production by small farmers. We can also see the potential land in the south of Pará, specifically in the following municipalities: São Félix do Xingu (533 km$^2$), Itaituba (123.3 km$^2$), Altamira (106.3 km$^2$) and Tucumã (106.2 km$^2$).

Table 1 shows the percentage of degraded and deforested land in Pará state that are inside the ZAE classes for levels B and C. With this calculation, it is possible to assess the amount of land that is available in the preferred and regular classes, which are the only classes attractive to the development of palm oil plantations in the region. In Pará, only 45.9% of the degraded and deforested land that was identified is in the preferred or regular class in ZAE level B, and 43.7% is in level C.

The potential for palm oil expansion for biodiesel is obvious in Pará in terms of the available degraded and deforested land. Meanwhile, the patterns of land availability, the lack of clear land ownership, the lack of supervision, the precarious state of the infrastructure in many parts of the Amazon, and the lack of specific models for the development of small-scale palm oil production are important issues of concern. These problems further support the need for solid land policies for planning and monitoring the expansion of palm oil as well as the need to further scrutinise the quality of the areas that can be potentially used in the state.

## 6. Concluding remarks

We have identified 8264 km$^2$ of degraded and deforested land that is available for palm oil expansion in the state of Pará, according to the TerraClass project, and 3653 km$^2$ in the palm oil producing municipalities, proving that there is enough degraded land for palm oil expansion. The theoretical potential oil yield in Pará state amounts to 3016,360 t/km$^2$, and in the 33 municipalities, the yield is 1344,304 t/km$^2$. Besides, the degraded lands correspond to thousands of areas that are scattered randomly throughout the state, mainly in the northeast and southeast regions. Some of the degraded land areas are smaller than 0.05 km$^2$ and were not considered in this research due to their unsuitability for palm crops. This distribution can represent extra costs for producers, increases the risk of deforestation in adjacent areas, and contribute to the expulsion of local people.

However, when the available degraded and deforested land is compared with the Agroecological Zoning maps, we observe that 45.9% of the degraded and deforested land in Pará is of the preferred or regular class in ZAE level B, and 43.7% is in level C. Inside the producing municipalities there are 175.1 km$^2$ of degraded land in preferred class (level B) and 101.3 km$^2$ in preferred class (level C), while there are 1526 km$^2$ in regular class (level B) and 1557.7 in regular class (level B). This analysis shows that there is not enough land in preferred and regular class inside the producers for the planned expansion. Other areas should be used, in order to meet the 3300 km$^2$ by 2020. If palm oil crop area increase more than this, other areas of the state will have to be used if present targets are to be met. The deforested and degraded land inside the preferred and regular zones in the producing municipalities should be used first followed by lands outside of the producers that are also in preferred and regular zones. Lands near main roads are more likely to be used, since transport and infrastructure are a prerequisite for palm oil production. However, land occupation depends on secure ownership as well as access to roads and infrastructure, so field work should be carried out before crops are established to ensure sustainable land use.

This paper clarifies the degraded land concept and the palm oil context in Brazil. It quantifies and provides a spatial analysis of the distribution of the deforested and degraded land available for palm oil expansion throughout Pará state and in the municipalities that are currently producing palm oil for the next few years. It also refines the previous ZAE by mapping only the 2008 degraded and deforested land data inside the ZAE preferred and regular zones. This assessment of degraded land can support the development of land use policies to prevent negative environmental impacts and social conflicts and gives an idea of the true palm oil production potential and whether this production can meet the target demand in a sustainable way and contribute to climate change mitigation.

The analyses and discussions in this paper have shown the importance of finding an operational definition for degraded lands as well as analysing the characteristics of the available degraded land in terms of location, extent and socio-economic conditions. To pursue the expansion of palm oil plantations in a sustainable way, additional research regarding the status of degraded land in Brazil is necessary as is research on the social, economic and environmental implications of using these lands.

The ZAE and Sustainable Palm Oil rules are not enough to guarantee sustainable palm oil production. Intense supervision of land use management is urgently needed as producers and small farmers may lack a complete understanding of the degraded land concept and what is considered degraded land and what is not. Different models for palm oil production and oil extraction need to be considered in conjunction with development programs aimed at social inclusion. With such programs in place, national policies combined with international mechanisms can provide a real opportunity for local development. The Sustainable Palm Oil Program, if operated in synergy with other initiatives, represents a great opportunity for Brazil to show its commitment to sustainability and climate change mitigation while also becoming a major global producer of sustainable palm oil.

## Appendix

Deforested/degraded land available in the producing municipalities of palm oil.

| Municipality | Available area ($km^2$) | Municipality | Available area ($km^2$) |
|---|---|---|---|
| Abaetetuba | 49.36 | Moju | 191.07 |
| Acará | 85.86 | Nova Esperança do Piriá | 190.01 |
| Baião | 56.36 | Nova Timboteua | 39.18 |
| Benevides | 2.81 | Óbidos | 52.43 |
| Bonito | 2.42 | Ourém | 54.23 |
| Bujaru | 28.88 | Santa Bárbara do Pará | 6.20 |
| Capitão Poço | 315.15 | Santa Isabel do Pará | 0 |
| Castanhal | 108.58 | Santa Luzia do Pará | 91.51 |
| Concórdia do Pará | 85.10 | Santa Maria do Pará | 17.90 |
| Garrafão do Norte | 249.20 | Santo Antônio do Tauá | 49.76 |
| Igarapé-Açu | 42.83 | São Domingos do Capim | 155.64 |
| Igarapé-Miri | 19.97 | São Francisco do Pará | 45.23 |
| Inhangapi | 48.30 | Tailândia | 140.44 |
| Ipixuna do Pará | 200.39 | Terra Alta | 11.38 |
| Maracanã | 11.85 | Tomé-Açu | 246.23 |
| Mocajuba | 2.41 | Vigia | 12.72 |

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