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The ethanol industry and its impact on land use and biodiversity. A case study of São Paulo State in Brazil.

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The ethanol industry and its impact on land use and biodiversity.

A case study of São Paulo State in Brazil.

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Bachelor thesis in Physical Geography and Ecosystem Analysis

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Preface

This is a bachelor thesis of 15p in Physical Geography and Ecosystem Analysis. It is a literature study highlighting the problem with the ethanol industry in Brazil.

Ängelholm, May 27, 2011
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Abstract

During the last decades, it has become increasingly clear that the extensive use of fossil fuels may severely threaten the environment. As the awareness of negative environmental impacts of fossil fuels has increased, the interest of alternative fuel sources has developed. Ethanol is a renewable fuel made from biomass that has attracted growing attention during the last 40 years. Ethanol has lower energy efficiency than gasoline but the combustion of ethanol is cleaner since it contains oxygen and this lowers the emissions of toxic substances. Ethanol is produced worldwide, with the largest producers being the United States and Brazil. In Brazil ethanol is produced from sugarcane and São Paulo State account for more than 50% of Brazil's production of both sugar and ethanol. The main concern about ethanol production is that it requires large land areas since it is produced from biomass and this could shift land use and affect biodiversity. For example, within the state of São Paulo almost all of the original area of the Atlantic Forest has been deforested as a result of the increased ethanol production during the last decades. The Atlantic Forest and the large savanna called Cerrado are precious ecosystems in Brazil that are associated with very high levels of species richness and the increased cultivation of sugarcane within Brazil during the last decades has led to the fragmentation of these habitats, followed by a decrease in biodiversity. Much of the biodiversity value of forest and savanna habitats depends on the preservation of the remaining fragments and to a sustainable planning of the future cultivation of sugarcane. Not only does the increased sugarcane cultivation cause fragmentation of forest and savanna habitats, it also changes the pattern of cultivation. The variety of crops in São Paulo State has decreased and large areas of monocultures with sugarcane are spreading. Monocultures gives higher yields but are vulnerable to diseases since it share the same genetics, so if a disease should occur the entire harvest fails. This in turn increases monocultures dependency on pesticides.

The purpose of this study is to highlight the impact the growing ethanol industry in São Paulo State (Brazil) has on land use and biodiversity as well as look into how air, water and soil quality are affected by production. The primary results are that sugarcane cultivations in São Paulo State have increased since the 1970s. At first the expansion took place on other agricultural land but recent expansion is taking place on pastures, making cattle move to new areas which causes indirect effects on biodiversity. It is concluded that sugarcane plantations in São Paulo State have increased during the last 40 years and depending on where ethanol is produced the impact on land use and biodiversity differs in severity. Ethanol from sugarcane has a high production yield and the process of making ethanol from sugarcane show some signs of being sustainable. However, the methods used for harvesting the crop have the biggest impact on air, water and soil quality and could be improved.

Keywords: geography, physical geography, sugarcane, deforestation, Cerrado, expansion, habitats

Sammanfattning

Under de senaste decennierna har det blivit allt tydligare att den omfattande användningen av fossila bränslen är dåligt för miljön. I och med att kunskapen om hur fossila bränslen påverkar miljön har ökat, så har också intresset för alternativa bränslen ökat. Etanol är ett förnyelsebart bränsle som framställs av biomassa och användningen av etanol har ökat under de senaste 40 åren. Etanol ger mindre energi än bensin och har med andra ord en lägre energieffektivitet, men förbränningen av etanol är renare eftersom den innehåller syre och detta minskar utsläpp av giftiga ämnen. Etanol produceras över hela världen och de största producenterna är USA och Brasilien. I Brasilien produceras etanol från sockerrör och São Paulo State står för mer än 50 % av Brasiliens produktion av både socker och etanol. Den största farhågan med produktionen av etanol är att det kräver stora markområden eftersom det framställs av biomassa och detta skulle kunna ändra på nuvarande markanvändning och påverka den biologiska mångfalden. Ett exempel på detta finnes i delstaten São Paulo där nästan hela det ursprungliga området av Atlantskogen har blivit avverkat som en följd av den ökade etanolproduktionen. Atlantskogen och den stora savannen vid namn Cerrado är värdefulla ekosystem i Brasilien som är förknippade med hög artrikedom och den ökade odlingen av sockerrör i Brasilien har under de senaste decennierna lett till en fragmentering av dessa habitat, följt av en minskning av den biologiska mångfalden. Sockerrörs odling orsakar inte bara fragmentering av habitat, det förändrar också mönstret för odling. Mångfalden av grödor i delstaten São Paulo har minskat och monokulturer med endast sockerrör breder ut sig. Monokulturer ger högre avkastning, men är sårbara för sjukdomar eftersom växterna delar samma gener, så om en sjukdom skulle inträffa misslyckas hela skörden. Detta i sin tur ökar monokulturers beroende av bekämpningsmedel.

Syftet med denna litteraturstudie är att belysa de effekter den växande etanolindustrin i São Paulo State (Brasilien) har på markanvändning och biologisk mångfald samt att se hur luft, vatten och mark kvalitet påverkas av produktionen. De primära resultaten är att sockerrörs-odlingar i São Paulo State har ökat sedan 1970-talet. I början skedde expansion främst på andra jordbruksmarker, men den senaste tidens expansion sker på betesmarker, vilket medför att boskap får flytta till nya områden vilket orsakar indirekta effekter på den biologiska mångfalden. Slutsatsen är att sockerrörsplantage i São Paulo State har ökat under de senaste 40 åren och beroende på var etanolen produceras skiljer sig produktionens påverkan på markanvändning och biologisk mångfald. Etanol från sockerrör har en hög avkastning och tillverkningsprocessen av etanol från sockerrör visar några tecken på hållbarhet. Dock kan de skördemetoder som används förbättras då de har störst inverkan på luft, vatten och mark kvalitet.

Nyckelord: geografi, naturgeografi, sockerrör, avskogning, Cerrado, expansion, habitat

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1. Introduction

With the debate about fossil fuels impact on the environment and the growing concern for global warming the demand of alternative fuels has increased. Biofuels, like ethanol, are produced from food crops such as corn, sugarcane, soybeans, and palms (Fargione et al, 2008). A result of the production is that land in undisturbed ecosystems or already occupied agricultural lands is being converted in order to increase the production of biofuels.

Brazil is the largest producer of ethanol from sugarcane and the second largest producer of ethanol in the world. During the last 40 years, Brazil has expanded the production of ethanol from sugarcane, which has caused extensive changes in land use. São Paulo State is the area where sugarcane cultures are most prevalent and it supplies approximately 60% of Brazil's ethanol. This literature study wants to review the land use alterations made in the state.

The aim of this literature study is to research the impacts on land use and biodiversity implicated by the ethanol industry in Brazil. The focus lies on São Paulo State and the following shall be analyzed:

- How air, water and soil quality in São Paulo State is affected by the emissions from the cultivation of sugarcane and the process of ethanol production
- What impact the sugarcane industry have on land use in São Paulo State
- What impact the sugarcane industry have on biodiversity in São Paulo State

Furthermore, the study investigates possible areas of expansion of the industry.

2. Background

2.1 Ethanol: raw material, producers and the market

Since the oil crisis in the 1970s the ethanol production has strongly increased worldwide (Mussatto et al., 2010). The market grew from less than a billion liters in 1975 to more than 39 billion liters in 2006 and is expected to increase over the years. The United States is the largest producer of ethanol in the world and is closely followed by Brazil, as can be seen in table 1. The United States and Brazil are not only the largest producers, they are also the largest consumers of ethanol (Mussatto et al., 2010). Brazil is on the other hand the largest exporter, while the United States and Europe are the largest importers. In the European Union the largest importers in 2006 were the Netherlands and Sweden.

Table 1. Worldwide production of ethanol in 2008, modified from Mussatto et al. (2010).

Country	Production	
	Megalitres (10^6 l)	% of the total
United States	34 070	52
Brazil	**24 500**	**37**
China	1 900	3
France	1 000	2
Canada	900	1
Germany	568	1
Thailand	340	1
Spain	317	-
Colombia	256	-
India	250	-
Poland	200	-
Hungary	150	-
Australia	100	-
Slovakia	94	-
Paraguay	90	-
Others	627	1
Total	**65 362**	**100**

For decades Brazil was the world leader in ethanol production, but in 2006 the United States overcame this production due to increased investments to reduce their dependence of oil and consequently the ethanol industry in the US has gained fast growth and development. (Mussatto et al., 2010). USAs ethanol production increased from 1.63 billion gallons in 2000 to 9 billion gallons in 2008, giving them a 5.5-fold increase. As shown in table 1 ethanol is produced in several countries but they have a lower production scale. Ethanol production is without a doubt a growing market and the interest for the industry has increased worldwide.

The energy equivalent of ethanol is 68 % of petroleum fuel, but the combustion of ethanol is cleaner since it contains oxygen and this lowers the emissions of toxic substances (Mussatto et al., 2010). By replacing the use of fossil fuels with biofuels the emissions from fossil fuels are avoided and the CO_2 content of fossil fuels remains stored in the ground.

The production of ethanol can be achieved in three ways (Zuurbier & Van de Vooren, 2008:11):

1. By fermentation (see appendix 1) of sugar from sugarcane, sugar beet and sorghum
2. By saccharification (see appendix 1) of starch from maize, wheat and manioc
3. By hydrolysis (see appendix 1) of cellulosic materials

Corn is the main product for ethanol production in the United States while in Brazil it is sugarcane (Mussatto et al., 2010). Of the raw materials used for ethanol production, sugarcane provides the lowest production costs and is easier to process. The reason for the lower production cost is the utilization of the residue known as bagasse, which is created when sugarcane is crushed (Zuurbier & Van de Vooren, 2008:11). This residue can be burned to produce enough bioelectricity to provide for the mill. The production cost is also lower because input of fossil fuels in form of fertilizers and pesticides are small. When producing ethanol from maize and other feed stocks the need of external energy is considerably higher. Most of it comes from fossil fuels and does therefore only reduce the greenhouse gas (GHG) emissions marginally. Sugarcane produces approximately 7000 liters/hectare while corn produces just about 4000 liters/hectare (Mussatto et al., 2010). All these reasons make ethanol production in Brazil cheaper than in Europe or the United States. The production cost of ethanol in Europe is three times higher than in Brazil and twice as high as in the United States.

2.2 The ethanol history of Brazil

Sugarcane plantations were introduced in Brazil shortly after the country became colonized by the Portuguese in the 16th century (Wells, 2009). Parts of the country have conditions that are favorable to large scale farming of sugarcane. These conditions are an excellent combination of latitude, soil, topography and climate and the State of São Paulo is where the production has been concentrated for a long time. The production of sugarcane into alcohol was not a new thing for the country when they decided to expand their market (Wells, 2009). They have a long tradition of making Cachaça which is an alcoholic drink with 40 % alcohol. In 1927 Brazil pioneered with a program to produce alcohol for automobiles, but the market was slow (Mussatto et al., 2010). However, due to the oil crisis in the 1970s and the low prices on the international sugar market, the fuel ethanol market was revived and in 1975 the government created the National Alcohol Program (Proálcool) in Brazil. This program intended to phase out fossil fuels by reducing the oil imports and favor large scale production of biofuel in the country. Thanks to the governmental intervention to increase the supply and demand for ethanol, Brazil has developed the capacity and technology to use large scale renewable energy.

In the 1980s Brazil made an attempt to designing cars that ran entirely on ethanol, but the project was confronted with several setbacks (Wells, 2009). It was not until the flex-fuel cars appeared on the market in 2003 that the interest for ethanol as a fuel for cars increased once again. Today, almost all Brazilian cars use ethanol, either in pure form or in mixture of 25% ethanol and 75% gasoline (Mussatto et al., 2010). In March 2008 the ethanol consumption in Brazil exceeded the gasoline consumption, which made Brazil the only country in the world where the renewable fuel is the main source of energy and the fossil fuel is the alternative one (UNICA, 2009).

2.3 The spatial distribution of ethanol production in Brazil

Figure 1a illustrates in which states sugarcane cultivations are located and figure 1b display the worldwide production of sugarcane and Brazil can easily be recognized as the number one producer of sugarcane in the world (UNICA, 2011). Sugarcane fields represent about 2% of all arable soil in Brazil; in 2007 this number was equivalent to 7.8 million hectares. The South-Central area of Brazil is the main production region, which account for almost 90% of the total production (see figure 1c, South-Central + São Paulo State). The remaining sugarcane fields are located in the Northeast. The location of sugarcane cultures are visualized in figure 2. Brazil produces sugar and ethanol throughout the year with two harvests per year and the cane can be cut every harvest without being replanted for up to seven years.

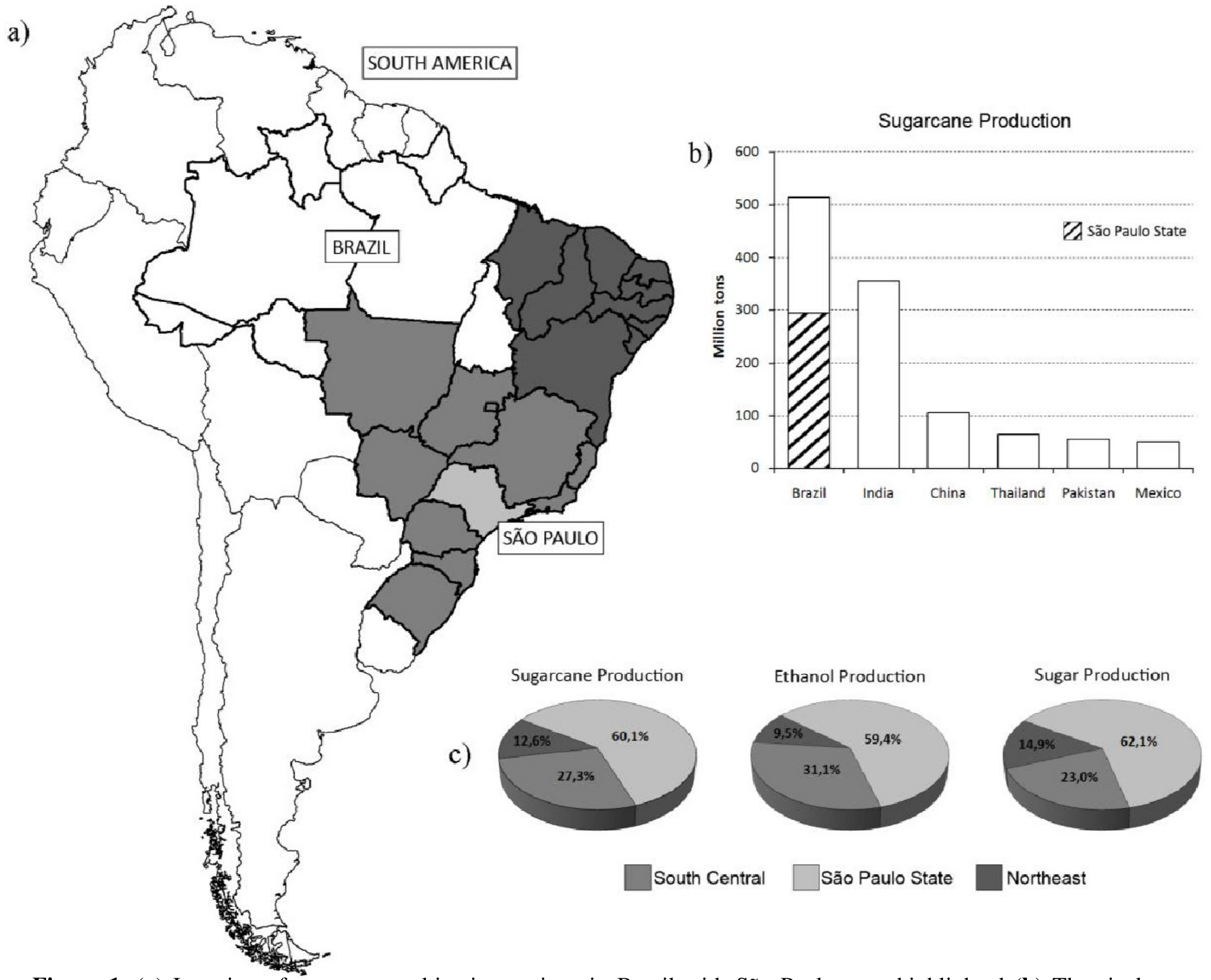

Figure 1. (**a**) Location of sugarcane cultivation regions in Brazil with São Paulo state highlighted (**b**) The six largest sugarcane producers in the world for the 2007/08 crop year, (**c**) Percentage of sugarcane, sugar and ethanol production from the Northeast and South-Central regions, with São Paulo's contribution featured separately (Rudorff et al., 2010).

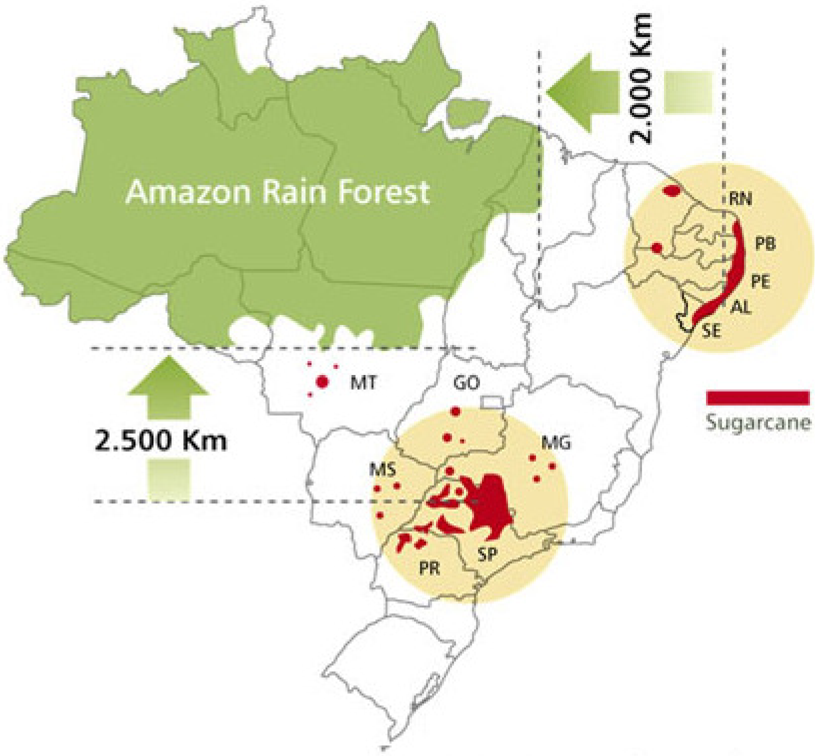

Figure 2. Red areas on the map indicate where sugarcane plantations and ethanol plants are located. SP stands for the state of São Paulo and it is easily recognized as the largest manufacturer of sugarcane. Modified from UNICA, 2011.

Sugarcane is a perennial crop with C_4 (4 carbon) photosynthetic pathway (Fischer et al., 2008: 48). It has its best productivity under conditions of high temperatures and its revenue is located in the stem as sucrose. Sugarcane is most effective in tropical lowland and warm subtropical climates, as well as dry zones under irrigation. The crop requires warm, sunny conditions and appropriate soil moisture. It prefers deep, well-drained, well structured and ventilated loamy to clayey fertile soils, with an ideal pH of 5.5 to 7.5. Brazil has regions with two distinct seasons which stages an ideal climate for crop growing (Nascimento et al., 2010). These seasons are: hot and humid, which favor germination (see appendix 1) and growing and cold and dry, which favor the crops to reach maturity and to accumulate sucrose in the stem. Other regions, like the Amazon, are to humid and does not favor good productivity. A state with high productivity is São Paulo, which has an area of 245 338 km^2 (FAO, 2011).

The State of São Paulo has a long tradition of agriculture and is the wealthiest region of Brazil and also one of the most populated (Wells, 2009). The region has the highest concentration of research and development and has advantageous natural factors, such as latitude, climate, soil, water (rainfall) and topography, which favor sugarcane cultivation. The ethanol production in the state has grown from 7.5 million m^3 in 1990/91 to 13 million m^3 in 2007/08 and was in 2007/08 accounting for 62% of the Brazilian production and 26% of the global production of ethanol. The land area devoted to sugarcane has increased by approximately 7% per year since 2000 and has for the most part been replacing grazing areas (Wells, 2009).

2.4 The production process of ethanol from sugarcane

There are more than 600 varieties of sugarcane in Brazil and the varieties planted are chosen to correspond with local climate and soil conditions to increase productivity and resistance to diseases (UNICA Virtual Mill, 2011). Fertilizers are limited since solid residues, like filter cake, from sugarcane processing are restored and used in the fields as a natural fertilizer. Another important residue from the production is vinasse. It is rich in potassium and other nutrients and is used as an organic fertilizer, which reduces the use of petroleum-based fertilizers. To further reduce the use of industrial chemicals natural enemies to sugarcane, like pests and diseases, are introduced to create a resistance.

Harvests take place in the dry season between April to December (UNICA Virtual Mill, 2011). There are two ways of harvesting: mechanized and manual. Mechanized harvesting accounts for more than 55% in São Paulo state and is carried out by machines that separate the straw from the cane. Manual harvesting is performed by agrarian fieldworkers and before they can cut the straw the field is burned to make it easier to cut the cane but also to repel snakes and other poisonous animals. São Paulo state government and the sugarcane industry have signed an agreement to put an end to manual harvesting in the state by 2017.

Once the cane has been cut it is very vulnerable because it starts to decompose and if it is not processed in a mill as soon as possible it will lose much of its sugar content (UNICA Virtual Mill, 2011). Because of that the distance to the mill cannot be more than 70 kilometers (Zuurbier & Van de Vooren, 2008:20). Manually harvested cane must first be washed to remove impurities before it gets chopped into pieces and crushed; the water used is then treated and reused (UNICA Virtual Mill, 2011). Cane that is harvested by machines does not need to be washed and it is also already cut into small pieces by the harvester. When the cane is crushed a fiber residue called bagasse is all that is left of the cane stalk, this is burned to generate bioelectricity.

The juice that results from crushing the cane is used to produce sugar and ethanol and the different processes to produce sugar and ethanol are illustrated as a flow chart in figure 3 (UNICA Virtual Mill, 2011). The juice for sugar production must first be purified and then it submits to evaporation and boiling procedure. At this stage the sucrose is crystallized and the crystals are isolated from molasses in a centrifuge, they are then moved to driers and filtered and stored. The molasses can later on be fermented to produce ethanol. One ton of sugarcane can produce 120 kg sugar.

Ethanol is produced from the sugarcane juice in a fermentation and distillation process (UNICA Virtual Mill, 2011). First the juice is purified in different filtering processes and is then fermented and mixed with yeast when it is ready. At this stage of the process the liquid is called fermented wine and the alcohol contained in the wine is recovered in distillation and rectification columns. At this point hydrous ethanol is produced; this type of ethanol is used in flex-fuel cars in Brazil. Anhydrous ethanol, which is blended with gasoline, is acquired by an additional process: dehydration. One ton of sugarcane yields about 85 liters of ethanol.

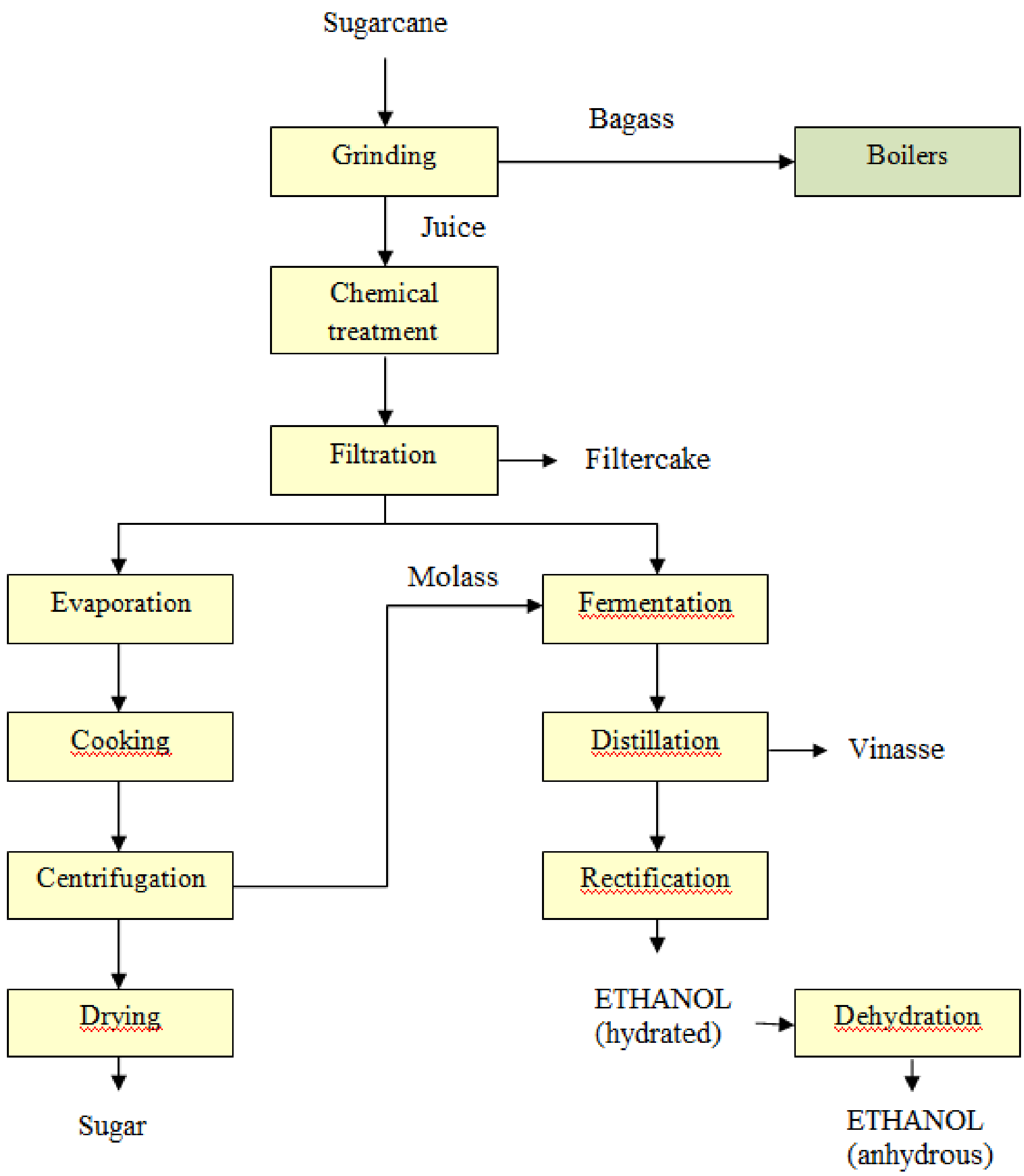

Figure 3. Flow chart illustrating the various processes needed to produce sugar and ethanol from sugarcane. Modified from Nascimento et al. (2010).

Bagasse is as earlier mentioned a fibrous residue from sugarcane crushing. One ton of sugarcane produces around 250 kg bagasse, which can be used to generate bioelectricity or become a second generation cellulosic biofuel (UNICA Virtual Mill, 2011). The bagasse is transferred to boilers where it creates vapor and the vapor then powers turbines that generate electricity. This makes all mills self sufficient in energy and the surplus is sold to other companies to light up cities in Brazil. The ethanol and bioelectricity from sugarcane is hence an important energy extractor and it is also considered the cleanest in the world.

3. Emissions from the production of sugarcane ethanol

Ethanol is not climate neutral and contributes to emissions, however ethanol from sugarcane does not lead to significant net emissions of greenhouse gases, especially regarding CO_2 (carbon dioxide) (Goldemberg et al., 2008). This can be motivated by CO_2 that is released by burning ethanol and bagasse is reabsorbed in the photosynthesis when sugarcane for the next season grows. In addition to this the electricity that is needed for the production is provided by the bioelectricity from bagasse. Emissions from the consumption of fossil fuels are limited to utilization in harvesting machines, transportation trucks and usage of fertilizers.

In a study by Ometto et al. (2009) the lifecycle assessment of ethanol fuel in Brazil is discussed. The study was carried out in northeastern São Paulo and details regarding the limitations can be found in their report. They analyzed emissions from nine steps in the ethanol production chain. The nine steps are: "(1) soil preparation; (2) sugarcane plantation; (3) chemical application; (4) harvesting; (5) fuel ethanol industrial process; (6) electrical energy cogeneration; (7) irrigation; (8) ethanol distribution; (9) use of fuel ethanol in cars" (Ometto et al, 2009). For details on emissions, see tables in Ometto et al. (2009).

- Ethanol consumes less energy that its own production
- The largest quantities of emissions emitted to the atmosphere in the ethanol production is substances of: carbon dioxide (CO_2), nitrogen oxide (NO_x), carbon monoxide (CO) and methane (CH_4)
- Diesel is used in the sugarcane plantation, harvesting and transportation to and from the mill as well as transportation within the country for distribution of the product. Emissions from diesel should because of this also be taken into account. For example, emissions to water are due to the diesel production and wastes from the production of phosphate fertilizers.
- The burning of sugarcane fields for manual harvesting releases emissions of CH4, NOx and PM (particulate matter, see appendix 1). This process also requires more water since sugarcane needs to be washed after the burning process.
- When ethanol is used in cars as a 100% fuel this leads to NO_x emissions.

To summarize, the burning practice and usage of diesel in machines show the greatest threats toward a sustainable production, since these two particular factors have the greatest emission output (Ometto et al., 2009).

3.1 Emissions impact on air, water and soil quality in São Paulo State

3.1.1 Emissions from the sugarcane and ethanol production

The air emissions from ethanol production process come from the bagasse boilers (Goldemberg et al., 2008). The emissions are mainly PM and NO_x and are controlled by the

São Paulo State Environmental Agency (CETESB). There is also a limit for these pollutants established by the National Council for the Environment.

The emissions to air from sugarcane production essentially come from the manual harvesting where sugarcane fields are burned (Goldemberg et al., 2008). The burning weakens the stalks and chase away poisonous animals, but burning of the cane can also harm the cell tissue and consequently increase the risk of diseases, cause nutrients loss, destroy organic matter and soil structure because of increased drying and hence increase the risk of soil erosion. Sugarcane burning also has direct negative impact on health, mainly respiration disorders among children and elderly (Fischer et al., 2008:43). Emissions released from burning are: CO, CH_4, PM and non-methane organic compounds (see appendix 1) (Goldemberg et al., 2008). The burning is also responsible for increasing troposphere ozone concentration in sugarcane producing areas. Manual harvesting is on the other hand being phased out with mechanized harvesting, whose main negative effect towards air quality is the utilization of gasoline in the machines and the emissions caused by this.

3.1.2 Emissions from ethanol combustion

By removing lead from gasoline and adding ethanol the emissions of CO, hydrocarbons and sulfur related with transport has decreased significantly (Goldemberg et al., 2008). Sulfur emissions in pure ethanol cars are completely eliminated. The hydrocarbons from ethanol feature lower atmospheric reactivity and hence are less toxic then those from gasoline. The disadvantage of pure ethanol combustion in relation to gasoline is the increased emissions of aldehydes. However the emission from ethanol is primary acetaldehydes while in gasoline it is formaldehydes. On the contrary Goldemberg et al. (2008) states that aldehyde emissions (acetaldehyde and formaldehyde) from diesel vehicles are higher than E22 vehicles. Another negative concern from ethanol combustion compared to gasoline, are the increased concentrations of peroxyacetyl nitrate (PAN, see appendix 1). This is a byproduct of the combustion and is eye irritant and noxious to plants. Many studies investigating ethanol blends' impact on air quality have been conducted, all giving different results, making this a debatable problem with increased need for research.

3.1.3 Water pollution

Water is used in two ways during the production: as irrigation in sugarcane plantations and in the process of converting sugarcane to ethanol (Goldemberg et al., 2008). Compared to other producers of sugarcane in the world, irrigation is a minor problem in Brazil. Crop irrigation is used to a small extent due to climate conditions, it is mainly used in the northeastern region of Brazil. In the rest of Brazil sugarcane cultivations are mainly rain-fed and major parts of São Paulo utilize none to minimal irrigation. However, water is used to a larger extent in ethanol conversion. Water is used for washing the burned cane, as a condenser in evaporation, fermentation cooling and alcohol condenser cooling, but most of the water is recycled.

There has not been reported any environmental problems related to water quality from irrigation in São Paulo state, which can be explained by the low need for irrigation in the state (Goldemberg et al., 2008). The negative causes of irrigation could be increased run-off, transporting both nutrients and pesticides off the plantations, hence causing erosion and possible damage to the environment in the catchment.Water pollution used to be a severe problem in sugarcane production regions until early 80’s when laws against direct discharge of vinasse into rivers were implemented (Fischer et al., 2008:43-44). 30 years ago vinasse polluted the water each harvesting season where it was released (Goldemberg et al., 2008).

3.1.4 Soil degradation

There are suggestive implications regarding soil degradation. Goldemberg et al. (2008) says that soil erosion is not a large issue, while Fischer et al. (2008) present valid reasons for soil erosion. According to Goldemberg et al. (2008) several standards and restrictions are set up for protection to avoid vulnerable soils, especially regarding management of vinasse. The sugarcane cultures have a low rate of soil erosion loss, particularly when it is compared to corn and soybean. Prevention of soil erosion and nutrient depletion is possible through careful management procedures such as, avoiding to plant sugarcane on vulnerable soils and slopes with high inclination, monitoring soil quality and nutrient balance. On the other hand Fischer et al. (2008:43) state that soil degradation by erosion and compaction of soils is a problem in sugarcane cultures that are cultivated intensely and harvested by machines. The heavy machines compress the soil, which result impairs erosion due to reduced soil porosity that decreases water infiltration and increases water run-off. In that sense, anytime the soil remains bare it is exposed to the erosive forces of wind and water. Throughout Brazil there is a practice of soil recovery; every harvesting season 20% of the sugarcane crop is removed and replaced with other crops (Goldemberg et al., 2008).

4. Land use changes in São Paulo State

4.1 Deforestation

During the last century São Paulo has been in the process of deforestation, which has been pursued to clear land for pastures and agriculture (Goldemberg and Lucon, 2010). Figure 4 illustrates how the forest cover has changed over the years by deforestation and what remains in 2000 is the Atlantic rainforest, a biodiversity sanctuary (further explained in chapter 5). Between the years of 1963 and 1992 the vegetation coverage has decreased from approximately 7.3 million hectares to 3.3 million hectares.

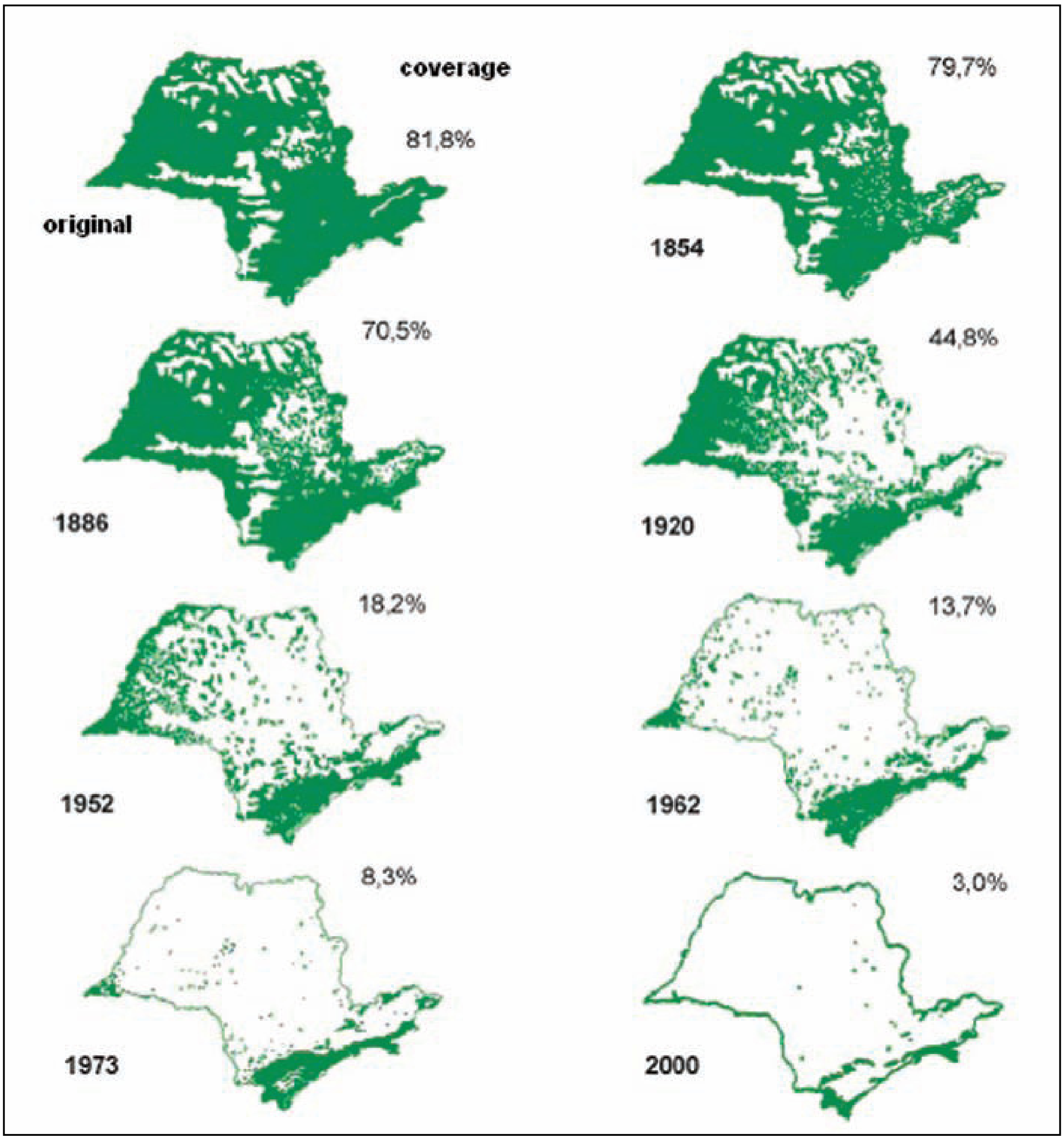

Figure 4. Historical deforestation in the state of São Paulo (Goldemberg and Lucon, 2010).

4.2 Alterations of crops in agriculture

Along with deforestation the production of sugarcane crops has expanded as a response to the demand for sugar and ethanol (Rudorff et al., 2010). In the beginning of Proálcool in the 1970s to 1980s, ethanol caused a shift in land use patterns from food crops to sugarcane (Goldemberg et al., 2008). The planted area of maize and rice in São Paulo declined with 35% and most of the sugarcane expansion replaced food crops. Between 1995 and 2007 the area used for sugarcane cultures in São Paulo state expanded by 70% (Fischer et al., 2008:40). As a result of the expansion, sugarcane crops have replaced pasture and other agricultural lands in the same extent as when they replaced forests (Rudorff et al., 2010). With continuous demand for ethanol in the future, São Paulo state will still be the region where most of the land use change into sugarcane cultivations is expected to take place (Fischer et al., 2008:40). Figure 5 shows the spatial distribution of sugarcane cultivations in São Paulo for the year of 2008/09.

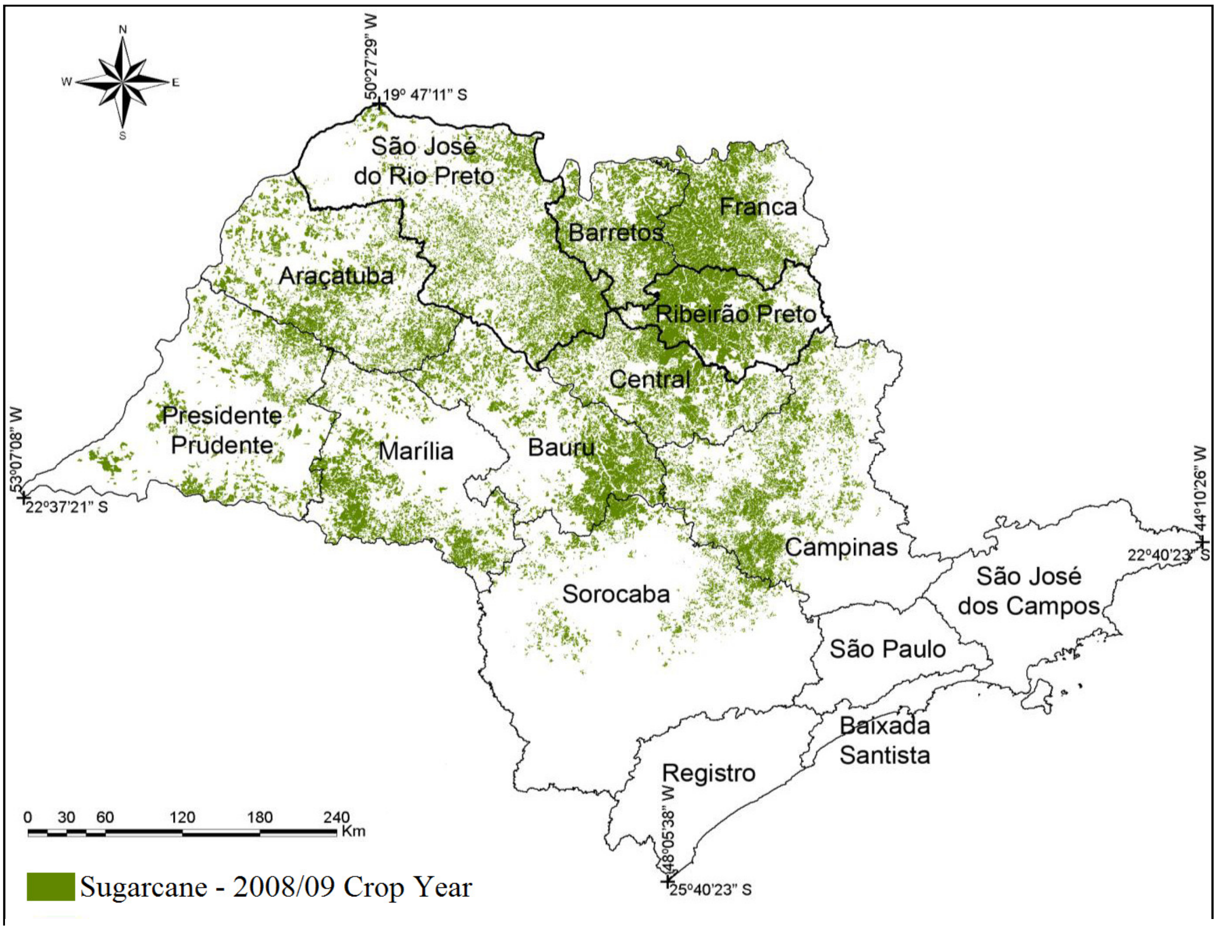

Figure 5. Cultivated sugarcane areas in São Paulo state for the 2008/09 crop year. Modified from Rudorff et al., 2010.

However, looking at agricultural land in 2006, sugarcane does not seem to have an impact on crop production, since the area for food crops has not decreased. Recent expansion in São Paulo State is therefore taking place on pasturelands. Fischer et al. (2008:57) agrees with this and states that sugarcane expansion has mainly intruded on cultivated areas and pasturelands. According to Goldemberg et al. (2008) there were plans to increase the sugarcane plantations in the state by 50% until 2010, though continuous data could not be found for this survey. Nevertheless, Goldemberg et al. (2008) states that there could be enough space for such expansion without extensive environmental impacts. If infrastructure and urban areas are not included there are 220,000 km^2 land distributed as shown in table 2.

Table 2. Distribution of land use in São Paulo State year 2006, not including infrastructure and urban areas. Modified from Goldemberg et al., 2008.

Land use (thousand km^2) in São Paulo State, 2006		
Sugarcane	43,4	19,70%
Other cultures	35,7	16,21%
Subtotal cultures	*79,1*	*35,91%*
Natural forests	32,0	14,53%
Reforesting	11,4	5,17%
Subtotal forests	*45,4*	*19,70%*
Pasture land	97,8	44,39%
Total	***220,30***	***100,00%***

Since the early 80's until 2005 the area of main grain crops has decreased by 0.9 million hectares in the state of São Paulo, while sugarcane area has expanded with almost 1.7 million hectares (Fischer et al., 2008:44-45). On a national level the total area of major crops is around 50 million hectares. This makes the land use changes in São Paulo quite small on a larger scale, but for the state the change is significant. In comparison, the rapid expansion of soybeans in Brazil measured from less than 10 million hectares in the 1980s to approximately 23 million hectares in 2005, which represents more than a third of all agricultural land. Figure 6 shows the harvested areas of selected crops in São Paulo between the years of 1983 to 2008.

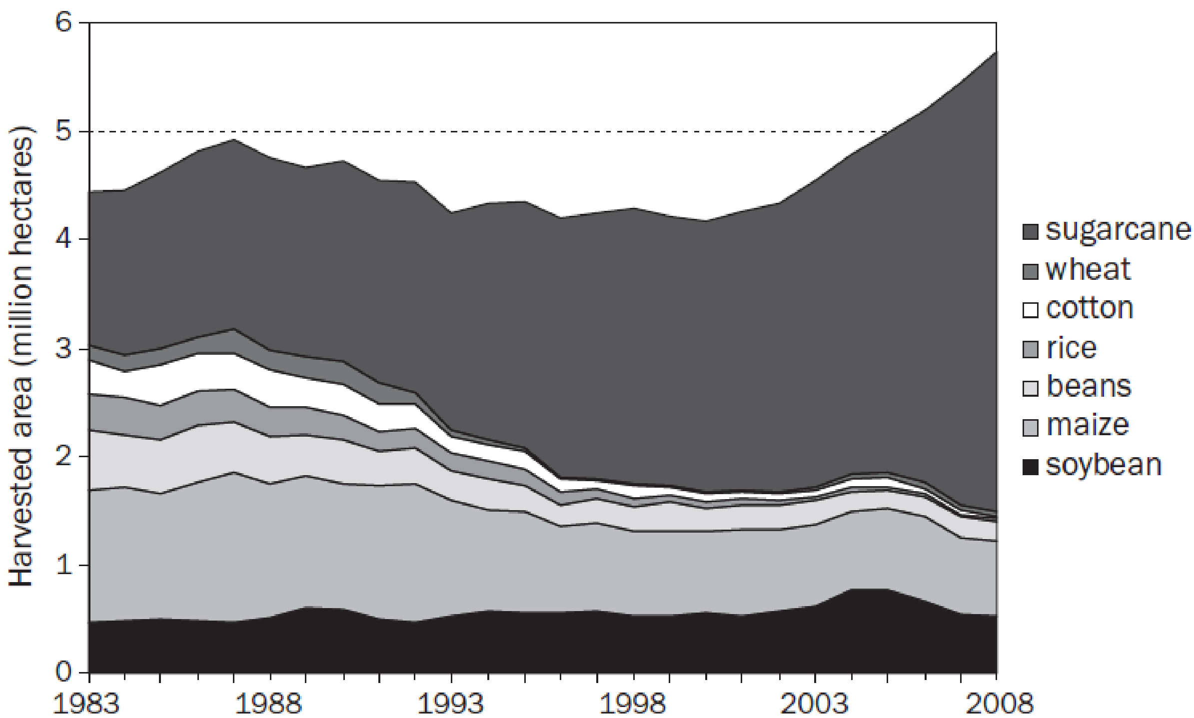

Figure 6. Harvested areas of selected crops in São Paulo State. The expansion of sugarcane in the state is easily recognized (Fischer et al., 2008:45).

Furthermore there are other concerns, apart from effects on land use. One of the greater concerns about the expansion of sugarcane is its' threat towards food security (Fischer et al., 2008:44-45). The rapid expansion could compete for availability of arable land for cultivation of food crops. This would reduce the supply of food crops and increase the food prices, due to a higher demand. In the 1970s the expansion had a short-term impact on regional food supply and prices, particularly maize and rice. However, in the 1990s the expansion of sugarcane has not compromised the production of food crops, since the majority of the expansion has intruded on grazing areas.

4.3 Livestock and sugarcane

In a study by Novo et al. (2010) the competition of land use between the livestock production and sugarcane in São Paulo state is analyzed. The dairy production has decreased, while the sugarcane industry has expanded. The result states that several factors need to be addressed to determine the reasons behind the land use change, but most of all it is an issue of governmental support and historical development.

> The relationship between biofuel and beef/dairy is not simply a result of recent global market demand but has been strongly mediated by strong, long-term government support for the biofuel chain and a corresponding lack of support for small-scale dairy farming. While historically the biofuel sector has been supported by a range of government policies (regarding research and development, tax benefits, import controls, regulations regarding blending of ethanol with gasoline), government policies for the dairy sector were much less directed toward the development of the sector and basically served other interests such as control of inflation (Novo et al., 2010).

Due to less competition in the dairy farming industry in São Paulo many farmers decided to stop specialize in this practice and sold or rented their lands to the sugarcane sector. This new opportunity attracted many farmers since the sugarcane industry offered high rents for their land. Between the years of 2001 to 2006 the land cost in São Paulo State increased on average 113.66% and in some regions of the state the price rose with 160-170% (Goldemberg et al. 2008).

5. Impacts on biodiversity in São Paulo State

5.1 Fragmentation of the Atlantic forest

The Atlantic rainforest is a moist tropical forest located on the south-eastern edge of Brazil (see figure 7) and it is a home to 2 200 species of birds, mammals, reptiles and amphibians and 20 000 plant species (The Nature Conservancy, 2010). In 1990 only 8% of its original cover remained, shattered into thousands of forest fragments (Ranta et al., 1998). The habitat fragmentation causes isolation of remaining habitat patches, local extinctions and "may have long term effects on populations through changes in ecological processes such as pollination, predation, territorial behavior and feeding habits" (Ranta et al., 1998). Fragmentation also has impact on microclimate, such as changes in humidity, solar radiation and wind pattern. It also creates edge zones of the forest, which is different from the interior habitat. The result of all these changes leaves a fragmented ecosystem that fails to support the species living in it like it did when the ecosystem was intact.

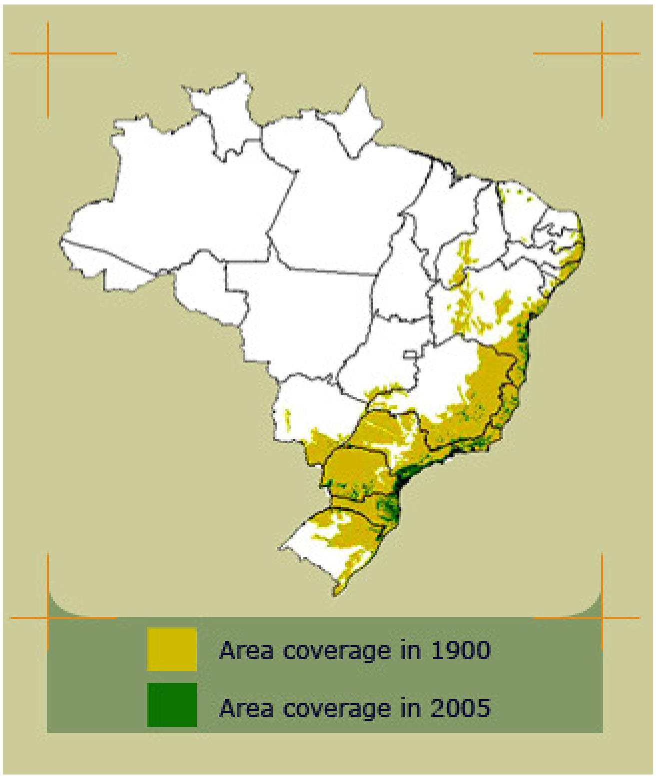

Figure 7. The Atlantic Forest of Brazil (A Rocha, 2011).

A survey by Ranta et al. (1998) investigated the fragmentation of the Atlantic forest in the southeastern corner of the State of Pernambuco, an area covering 2 674 km^2. They found that around 48% of the fragments are less than 10 ha and only 7% are greater than 100 ha. However, methods enforcing restoration of the Atlantic forest with riparian forests (see appendix 1) and biodiversity corridors are set in motion (Rodrigues et al., 2011). One program is The Atlantic Forest Restoration Pact, which aims to recover 15 million ha of the Atlantic Forest by 2050.

5.2 Fragmentation and biodiversity

Habitat loss caused by fragmentation may change species composition and diversity (Lyra-Jorge et al., 2008). Species that require large territories and have small populations are particularly vulnerable to habitat fragmentation. Very little of the native vegetation remains in São Paulo State and it is today a mosaic of small fragments of Cerrado, semi-deciduous forest surrounded by crop plantations (mainly sugarcane), eucalyptus silviculture (see appendix 1) and pastures, as well as developed urban areas (Lyra-Jorge et al., 2008). Lyra-Jorge et al.

(2008) recorded large carnivore species (by 21 camera traps and 21 track plots) in a 50 000 ha mosaic landscape (see figure 8) during 18 months to evaluate species richness, diversity and frequency for large carnivores. They recorded ten species, some locally threatened to extinction, and found that the carnivores explored the whole study area regardless of the vegetation cover, the eucalyptus plantations were even used as the native environment.

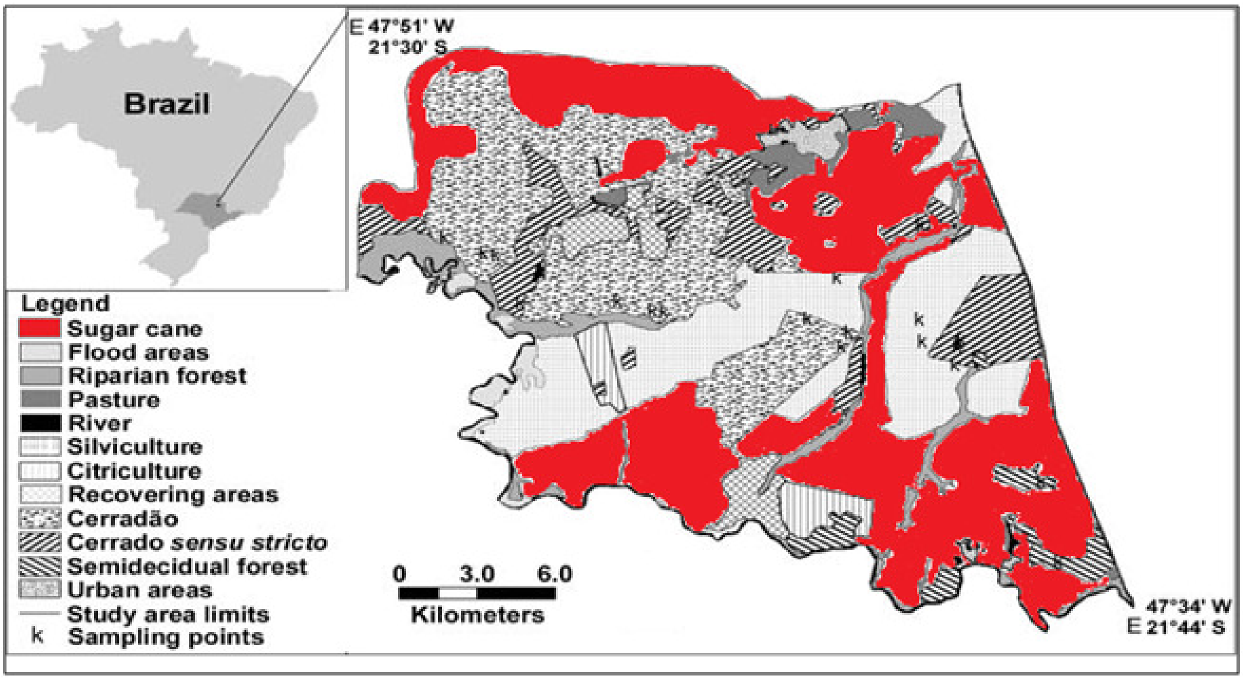

Figure 8. Study area of biodiversity changes in a mosaic landscape in Northeastern São Paulo State, Brazil. Modified from Lyra-Jorge et al., 2008.

An earlier survey of biodiversity was carried out by Chiarello (2000) in a semi-deciduous forest fragment of 150 ha in São Paulo State. 49 bird species and 20 mammal species (not including bats and small mammals) were confirmed in the area, among them were some rare and endangered species such as mountain lion and maned wolf. The fauna recorded was in general habitat generalist species, which have a high ability to adapt to different types of forest cover (Chiarello, 2000). The study was carried out in Ribeirão Preto a region of intensive agriculture in São Paulo State where few forest patches remain. The region lost 60% (~ 410 000 ha) of its original cover between 1962 and 1992, which requires species to adapt or migrate in order to survive. The land use changes are plausible reasons to why some species like jaguar, tapirs and giant anteater no longer live there, they require very large home ranges (preferably fragments larger than 20 000 ha) or have special diets and are in that sense vulnerable to fragmentation. Chiarello (2000) concludes that "the result demonstrate that forest fragment of this size are refuges for native fauna in a region dominated almost exclusively by sugar-cane plantations" and continues to stress the importance of these fragments for further studies regarding species preservation.

5.3 Land use change and biodiversity

Land use changes have direct and indirect impact on biodiversity. Smeets et al. (2006) explains that direct impacts on biodiversity by sugarcane production are limited, since many of the new crop plantations are constructed on pasturelands or are replacing food crops. The plantations are also far away from important biomes such as the Amazon Rain Forest, Panatal and Cerrado. However the indirect impacts by sugarcane production could be significant. Those indirect impacts implicate that livestock production (and perhaps food crops) are moving to other parts of Brazil, which result in alternation of that land cover or biome and this are resulting in further impacts on biodiversity.

In São Paulo State there are recovery projects that require the crop plantations to guarantee a minimum of 20% forest cover of native or reforested native trees (Goldemberg, et al., 2008). Maintenance of riparian forests is also required in the state.

6. Expansion of the sugarcane industry in Brazil

The cultivation of sugarcane for ethanol production in Brazil is increasing the pressure on agricultural land and the expansion has replaced pasturelands and small farms of varied crops (Goldemberg et al., 2008). The sugarcane production in São Paulo State takes place far away from important biomes like the Amazon Rain Forest (see figure 2), Cerrado, Caatinga and Pantanal (Smeets et al, 2006). Consequently it also takes place far away from abundant biodiversity reserves, however parts of the Cerrado are located in São Paulo State. The Cerrado and Amazon will be the only ecosystems discussed in this section, since the Atlantic Forest has already been discussed and the Panatal and Caatinga are less likely to be primarily affected by the sugarcane industry.

The expansion of sugarcane could increase the rate of deforestation in two ways, either direct or indirect (Fischer et al., 2008:41). Direct deforestation is caused by encroaching on natural areas of unprotected forest and indirect deforestation is caused by forcing other land uses, such as other cultivations and livestock farming, to move to new areas (hence making them responsible for the act). This brings a great threat of irreversible conversion of virgin ecosystems (Goldemberg et al. 2008). As mentioned in chapter 5, deforestation leads to fragmentation of habitats and causes extinction of species and loss of ecosystem functions. Also if forest are disturbed in a larger scale this could affect the regional hydrological cycle and climate, causing reduced precipitation and higher temperatures.

The following key concerns with sugarcane expansion are presented by Fischer et al. (2008:57).

- It causes deforestation and habitat loss.
- It increases land competition with food production.
- It causes indirect effects of land conversion due to expansion of sugarcane plantations that compete with other crop and livestock activities, which in turn encroach on natural habitats.
- It causes water pollution and eutrophication.
- It causes soil erosion and soil compaction (increases if the soil is bare, on steep slopes or if there is relatively high rainfall)
- It causes air pollution (mainly through burning of sugarcane before harvest)

Of the 264 million ha of agriculture land in Brazil, almost 200 million ha are pastoral lands (Fischer et al., 2008:41). Successful areas of expansion are areas that combine good soil quality, high amounts of precipitation and good logistic (or potential to improve it) (Goldemberg et al. 2008). When it comes to soil the sugarcane is not very selective, it adapts decently to soils of meduim fertility and high porosity/permeability-sandier soils. The major part of the Amazon is not suitable for agricultural practice and expanding there would also require deforestation. The main problem with expansion is the indirect outcome it has on existing agriculture or livestock keeping in those areas.

6.1 Potential areas for sugarcane expansion

The most threatened habitats are those that lie close to current production areas (Fischer et al., 2008:56). The environmental consequences of the expansion might range from somewhat acceptable, with conversion of pastures and crop lands, to very negative effects, with direct or indirect alteration of unprotected areas. The unprotected areas have native vegetation with high biodiversity. The threats to biodiversity and native ecosystems can be avoided by better environmental regulation and to perform agricultural policies that support intensification of the industry (Fischer et al., 2008:57).

6.1.1 Amazonas

One of the potentially threatened ecosystems is the Amazon rainforest, which is the largest rainforest in the world (Goldemberg and Lucon, 2010). It has, as stated before, a low suitability for sugarcane production and is because of that not directly threatened by sugarcane expansion (Fischer et al., 2008:41). The deforestation of the Amazon region is mainly caused by expansion of soybean production and conversion to pastoral lands for livestock production. 15% of the forest had disappeared in 2003 and models estimate that by 2050, the losses will be reaching 40% (Goldemberg and Lucon, 2010). A study by Fearnside (2005) investigates the causes of deforestation in the Brazilian Amazon and (Fischer et al., 2008:41) explains out of that study, that the sugarcane expansion is too scarce to cause either direct or indirect reallocation of pasture and soybeans intrusion northwards. Fischer et al. support this theory by explaining that between "1988 to 2007 the average rate of expansion of sugarcane was 0.14 million ha/year when rates of Amazon deforestation ranged from ~1.1 to 2.9 million ha per year".

6.1.2 Cerrado

The Brazilian Cerrado, a savannah region, is a biodiversity hotspot and it is the ecosystem that is most threatened by the sugarcane expansion (Fischer et al., 2008:42). The cerrado covers 2 million km^2 or 21 % of Brazil and it is a home to more than 1 600 species and several plant species are endemic to the Cerrado (WWF, 2011). Only 20% of the original vegetation is still untouched and less than 3% of the area is protected by law. The major threats to this area are agricultural expansion and unsustainable agricultural activities, particularly soy production and cattle ranching.

6.2 Prospects

During the entire process of sugarcane plantation and processing there is a risk of environmental degradation (Fischer et al., 2008:46). The lack of implementation of better management practices and ineffective legalization and control has caused negative impacts. However looking at São Paulo State there are examples of improvement of the process for the last three decades. Nevertheless, further improvements are still necessary to make the industry more environmentally sustainable. Even though more effective and less environmentally harmful techniques are available, it is still at the risk of affecting biodiversity. Fischer et al. (2008) emphasize the use of stricter regulation and enforcements to protect environmental losses. One example of protection is to guarantee protection and recovery of specific biomes such as the Cerrado and riparian forests.

If the sugarcane ethanol program expands the Brazilian government is required to address several issues related to social and environmental impacts of the ethanol production and allocation cycle (Goldemberg and Lucon, 2010). The issues regarding air pollution and technical trade barriers are particularly important. The environmental objectives comprise:

- To phase-out sugarcane crop burning practices and to put pressure on the rate at which this is being carried out today
- Increased water conservation and protection of water bodies
- To protect the remaining forests
- To help the recovery of riparian areas and biodiversity corridors
- To reduce the emissions to air, water and soil
- To prevent soil erosion
- To increase acceptable management of agrochemical use
- To enforce fair labor management and promote environmental education and public consciousness

7. Biofuel: carbon debt or carbon savings?

Soils and plant biomass contain around 2.7 times more carbon together than the atmosphere and is hence the two greatest biological active terrestrial carbon stores (Fargione et al., 2008). In that sense, conversion of native habitats into croplands results in disturbance of the carbon storage and releases CO_2. After the land has been cleared there is a prolonged period of GHG release from remnants of the cleared land as they decay. Fargione et al. (2008) define the carbon debt as ”the amount of CO_2 released during the first 50 years” of land conversion. Biofuels can, in course of time, repay this carbon debt if their production and combustion have less net GHG emissions than the emissions from fossil fuels, which they displace. In fact, biofuels from converted lands have greater GHG impact than the displaced fossil fuels, until the carbon dept is refunded.

In a study by Farginone et al. (2008) the question whether biofuels production offer carbon savings or increase carbon released to the atmosphere is raised. The answer depends on what biofuel is produced from and where; on abandoned pasture or agriculture lands or by converting forests to new croplands? For their research they calculated how large the carbon debts for conversion of six different habitats (impact in 2008 of biofuels) and how many years it would take to refund the debt, these habitats are represented in figure 9. The conversion of Brazilian Cerrado to sugarcane ethanol is the one that is particularly interesting for this report.

The carbon debts were estimated by calculating the quantity of CO_2 released from ecosystem biomass and soils, for full details see their report (Fargione et al., 2008). Their result demonstrates that conversion of native ecosystems to production of sugarcane results in large carbon debts, which is illustrated in figure 9A. The sugarcane expansion was focused on the Cerrado sensu stricto, which is moister and more productive. Their results state that for this particular conversion it would take approximately 17 years to refund the carbon debt, which is somewhat acceptable compared to those 319 years it would take to refund carbon debts from soybean biodiesel produced on converted Amazonian rainforest.

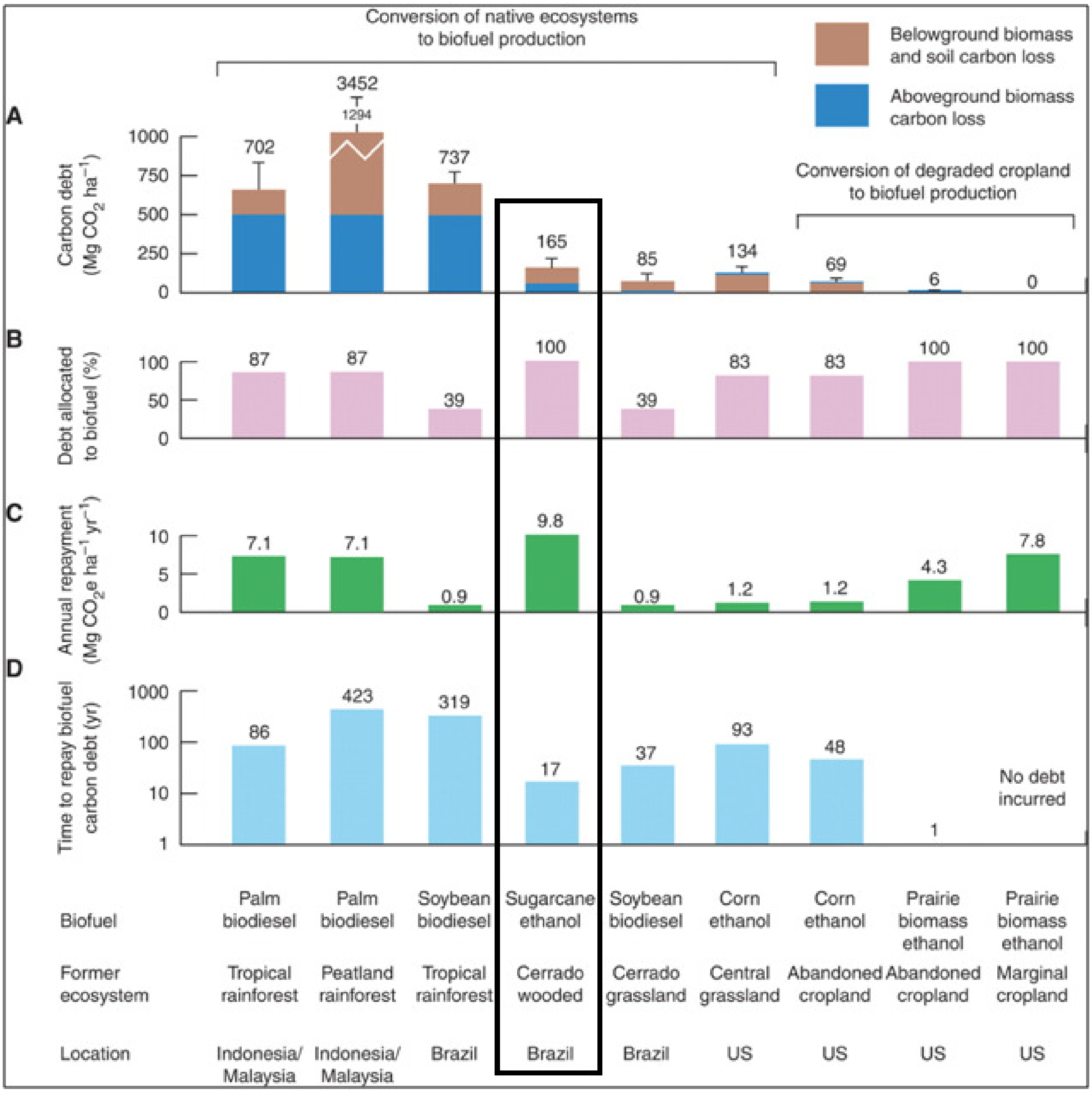

Figure 9. Nine scenarios of carbon debt from land conversion in order to produce biofuels and the estimated years it would take to refund the debt. **(A)** Carbon debt, including CO_2 emissions from soil and above- and belowground biomass from habitat conversion. **(B)** The proportion of total carbon debt in percent allocated to biofuel production. **(C)** How much of the debt that is refunded per year, including displaced fossil fuels and soil carbon storage. **(D)** How many years it takes to repay the carbon debt after the land conversion, relative to the fossil fuels they replace (Fargione et al., 2008).

As can be seen in figure 9 all but two land conversions, Cerrado to sugarcane ethanol and Cerrado to soybean biodiesel, generates greater GHG emissions for at least 50 years before they repay their carbon debt (Fargione et al., 2008). The results by Fargione et al. (2008) thus propose that if biofuels are produced on converted lands, they will be a larger emitter of GHG (for decades to centuries) than the fossil fuels they aim to displace. Fargione et al. (2008) suggests that biofuels need to be produced where the carbon storage is disrupted to the smallest extent possible like for example on degraded and abandoned agricultural land.

8. Discussion

8.1 Impact on air, water and soil quality

The production of ethanol from sugarcane shows some signs of being superior to ethanol production from other crops. However, I cannot state that without some uncertainty since sugarcane ethanol is the only origin of ethanol that is surveyed in this paper (apart from the short notice about corn ethanol in 2.1). Nevertheless, the sugarcane ethanol production itself shows a fairly sustainable implementation, but it has room for improvements. Emissions are hard to avoid, so what is most unsustainable in my opinion is the procedure of what methods that are used to produce ethanol and where.

Sugarcane ethanol is superior to other ethanol productions thanks to the beneficial qualities from byproducts. Bagasse reduces the energy costs of the production and can provide enough energy for the mill. Vinasse reduces the need for fertilizers, since application of this to the field does the same trick. In additions to this sugarcane yield more liter ethanol per hectare than other crops. São Paulo State is extra fortunate since the need for irrigation is minimal and this results in further reduction of production costs.

The parts of the production that can be improved to make it more environmentally sustainable is to remove the practice of manual harvesting and to implement machines and trucks that run on ethanol as well. The burning of sugarcane cultivations has negative effects on soil and human health, but this is about to change according to UNICA; manual harvesting shall be completely phased out in São Paulo State by 2017. The machines used for mechanized harvesting are so far running on gasoline and since the ethanol industry wants to promote its fuel I cannot see why they use diesel themselves? I am clearly not an expert on the area and perhaps it is not possible to run heavier vehicles on ethanol, but I definitely think is it something worth investing in to reduce gasoline emissions and to market themselves. In Ometto et al. (2009) it became clear that emissions from harvesting had the biggest impact on global warming and this was due to sugarcane burning and the high consumption of gasoline in vehicles.

Emissions to air are hard to avoid since anything that interacts with another will result in rest products (emissions) and in this matter one has to take the good with the bad. Good because if ethanol is used instead fossil fuels, emissions otherwise emitted can be avoided and bad because the production of ethanol still causes emissions of CO_2. What partly counterbalance the bad is that CO_2 is reabsorbed in the photosynthesis when sugarcane grows for the next season. The main problem with air emissions is however that it has a global effect, while emissions to soil and water are directly linked with the source of pollution. On the other hand this does not mean that São Paulo does not have problems linked with air emissions. The concentration of Greenhouse gases in São Paulo state might be above average and cause respiratory problems from smog etc. Which would make this a local problem in the state, but as earlier stated those concentrations will also blend with the atmospheric concentration and contribute to global warming, hence making it a global problem.

Water pollution and soil degradation are the biggest concerns to consider. The location of São Paulo State is very fortunate since the region has very little need for irrigation and this decreases the water consumption. Other areas in Brazil, like sugarcane cultures in the northeastern part of the country are not as lucky. With little need for irrigation there are fewer concerns about water availability within the state also the cost of investing in irrigation can be neglected. Water pollution used to be a severe problem in the state until disposal of vinasse into rivers was banned 30 years ago. Rivers and river basins can still be affected in other ways though, for example by water runoff with nutrients and pesticides and sediments from soil erosion that deposits into rivers.

Soil erosion is a natural occurrence but human activities speed up the process by exposing the soil, making it vulnerable to rainfall and wind. It also accelerates by compaction of the soil as stated by Fischer et al. in 3.1.4. Harvest takes place two times a year and replanting occurs once every six years. There are attempted methods for soil recovery, with 20% of the sugarcane crop being replaced by another crop every harvesting season. I am not sure how effective that method is, perhaps it is better to let it lie in fallow? Soil erosion has serious direct impact in situ and it causes long term problems with sustainability due to removal of the most fertile top soil which decreases soil productivity. The hazard for erosion also increases with the inclination of slopes, which is why cultivation on steep slopes should be avoided, especially if it is harvested by machines. It is better to leave slopes for crops that is better suited or let it remain as natural vegetation. As earlier mentioned, sediments from soil erosion must also end up somewhere causing further problems elsewhere.

A comparison of pros and cons of sugarcane ethanol and gasoline would require another study since this report does not intend to compare the two. Therefore the magnitude of emissions from the sugarcane ethanol production and the emissions from ethanol combustion cannot be fully understood since they need to be put in relation to another emission source. Also direct and indirect impacts of pollution from the industry needs to be further investigated as this study has only scratched the surface.

8.2 Land use changes in São Paulo State and expansion into virgin ecosystems

Land use in São Paulo State has clearly changed since the 1970s. The increased use of sugarcane in the state has fueled smaller farms to migrate into new areas or to sell their land. It is hard to determine how extended the displacement of other agricultures or livestock farming is, but the general picture is that sugarcane cultures have expanded since 1975 and other crops have decreased as shown in figure 6. Looking at table 2, sugarcane represented almost 20% of the area in the state in 2006, while other crops represented slightly more than 16% and pastures represented 44%. This means that there are still areas where sugarcane cultures could expand without causing grand negative environmental impacts within the state. Since São Paulo has great natural benefits for sugarcane cultivation, here would be the best place to perform the practice. Planting on pastures is better than deforesting precious ecosystems, on the other hand there are also indirect effects to consider like displacement of other industries.

To consider figure 9 expansion into Cerrado is bad, but not as bad as expanding into the Amazon. The Amazon is on the other hand not the first choice for expansion since it does not have good natural qualities for sugarcane cultivation. Only 20% of the Cerrado is left untouched today and I hope for the sake of biodiversity and ecosystem functions that those 20% will be left untouched. Deforestation of the Atlantic Forest in order to expand urban areas, roads, industries, pastures for livestock and arable land for agriculture has shattered the forest into small fragments and only 8% of the forest cover remains. It would be a shame to see this being repeated in the Cerrado, even if parts of that scenario already are set in motion.

Land use changes in Brazil cannot only be blamed on sugarcane, after all it “only” covers 2% of the arable soil in Brazil. Other crops like cocoa and soybean are also produced in Brazil and should be taken into consideration. For example the production of soybean has just like sugarcane increased rapidly since the 1980s and soybeans pose a threat on both Cerrado and Amazon. Soybean production in Brazil would make a great subject for future surveys.

Where sugarcane is cultivated and what methods that are practiced for the production is very important when the carbon cycle are considered. Needless to say, plantation on pastures is to prefer over untouched ecosystems or any forest without exceptions. Rainforest and pastures work as carbon sinks when they convert CO_2 to organic forms of carbon which is stored in their tissue through photosynthesis. The carbon in the plants can then be transferred to the soil through the roots or decomposition of the plant. Soils are in other words rich in carbon and regardless of where sugarcane expands some of it will be released into the atmosphere. Cultivation must in that sense be executed were it does least harm and is most suited for the crop.

Consequently, I think the best place for expansion is on the pastures in São Paulo State for a number of reasons. To begin with, the state is located in a climate that sugarcane enjoys and there is no need for large scale irrigation, which lower the production costs. Secondly, if expansion occurs on pastures the land is already cleared so there is no need for deforestation. Deforestation would not only affect the biodiversity more, but it would also cost more to remove the forest: both in money and carbon storage. Thirdly, São Paulo is a highly developed state so mills, roads and other necessities already exist and this also reduces production costs as well as more alteration of the landscape to build new roads etc. Fourthly, the state already has a high productivity which makes it favorably to expand in the state. All of the above favors São Paulo to have a high productivity but low production costs, however when expansion occurs it should not be rushed into like in the beginning of Proálcool. The people in the industry should know better ways to produce sugarcane and ethanol by now. For starters, there should be strong laws that protect the remaining 8% of the Atlantic Forest and the sugarcane industry should do their best to produce in ways that attempt to restore parts of the forest. To reduce the fragmented parts and try to restore them via biodiversity corridors is one way to go. All pastures in São Paulo shall of course not go to sugarcane plantation, parts of the pastures can be left as they were or restored into forests. The bottom line is to not make the same mistakes as before.

Giving pastures to sugarcane cultivations does however not solve any problems, there are still indirect impacts of land use changes. Displaced livestock farming will also make impacts on land use, the choice is to either move or give up the cattle farming and start a new career. It is not only land use and biodiversity that is affected, this has socioeconomic impacts as well. Regardless of who migrates, agriculture or livestock, the impacts on land use and biodiversity are just as bad. With that in mind I think it is better to let sugarcane expand within the state, where the productivity is high, instead of moving to a new area and perhaps get lesser harvests. There is no real solution to this, the world is not a chessboard where the outcast players are eliminated if you move to their area.

8.3 Impact on biodiversity

Ethanol from sugarcane is a renewable fuel unless it is harvested faster than it is replenished. In other words, ethanol is a renewable fuel if sugarcane absorbs CO_2 during its photosynthesis in the same amount (or more) than is released into the atmosphere when it is harvested. I doubt that sugarcane cultivations can compete with virgin ecosystems in uptake of CO_2. If the ecosystem is burned and CO_2 is released it would take several decades for sugarcane cultivations to replenish that and in my opinion it still would not suffice because it is not the same habitat as before. Hence, ethanol has the possibility to be a renewable fuel, as long as it is produced on already degraded land and harvested in a sustainable way.

The Atlantic Forest almost covered the entire state of São Paulo in the past and now only small areas remains (see figure 7). The location of the forest is quite unfortunate, since it is right by the Atlantic Ocean and was most likely disturbed by settlers from Portugal that needed timber for houses and harbors. Since then urban sprawl and deforestation has been preformed to produce sugarcane and other crops, as well as cattle production. Now only 8% of the entire forest remains, shattered into small fragments making it hard for larger mammals to live there. What has happened in the Atlantic Forest cannot be blamed solely on sugarcane, there are more to the events to this than sugarcane expansion since it has been going on since the 16^{th} century.

Biodiversity has been affected and endemic species are in a danger zone but more studies are definitively needed in this area. Also a closer look at Brazil's laws and constitution is necessary to fully understand how grave the problems are in the state and to get a better view on what is done for the environment.

8.4 Sources of error

The main source of error is not being able to find or understand primary sources. When reading I found great sources in the text, but when I looked for the source myself it was written in Portuguese. Therefore I had to refer to the text I had and be happy with that. This was especially bad for some figures I found and wanted to use, but since I did not fully understand the context I could not use them. I found a web page from the government of São Paulo (http://www.ambiente.sp.gov.br/) regarding environmental questions in the state and I looked for English text, but I did not find any. I think that site could have helped me so it is a shame I do not speak Portuguese.

9. Conclusion

With the ethanol industry I mean the whole process from planting sugarcane up to combustion of the finished product.

The ethanol industry's impact on air, water and soil quality

- The main impact on both air and soil comes from the harvesting techniques:
  - In the manual harvesting technique sugarcane fields are burned and this causes nutrients loss, destroys organic matter and soil structure which increases the risk for soil erosion. Burning has also negative impact on health and it releases emissions of carbon monoxide and methane to the atmosphere.
  - In the mechanized harvesting technique soil in intensely harvested sugarcane fields are compacted by harvesters, which reduces the soils porosity, decreases water infiltration and increases water run-off. All this makes the soil less resistant to soil erosion. Emissions to air come from the machines used in the production, they run on diesel which lets out emissions of carbon dioxide.
- Water pollution is no longer a severe problem in the state but if erosion occurs and water runs off with nutrients and pesticides there will be impacts on water quality.

9.2 The ethanol industry's impact on land use

- Deforestation occurred before sugarcane expanded to fulfill today's need so it is not necessarily sugarcane that has caused deforestation in the past in São Paulo State. However sugarcane can be a working force that causes future direct or indirect deforestation by displacing other agricultures.
- When sugarcane in São Paulo State began to expand in the 1970s, it primarily replaced other food crops, but current expansion in the state is taking place on pasturelands.
- The Amazon is not threatened by deforestation from the sugarcane ethanol industry, since it has a low suitability for sugarcane production and the sugarcane expansion is to scarce to either cause direct or indirect reallocation northwards.
- The Cerrado is in the direct risk zone of being converted into sugarcane cultivations and is also in the indirect risk zone of being converted into agricultures displaced by sugarcane cultivations.

9.3 The ethanol industry's impact on biodiversity

- Not much of the Atlantic forest remains today and this makes it harder for the ecosystem to support species living in it as it did before. Animals with large home ranges have been more affected by land use changes than animals that can adapt to smaller habitats.

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Appendix 1

Glossary

Fermentation is an anaerobic cellular process in which organic foods are converted into simpler compounds and chemical energy (ATP) is produced (Biology Online, 2011).

Germination is the stage in which a germ (seed) or a living thing starts to sprout, grow and develop (Biology Online, 2011).

Hydrolysis is the process of splitting a compound into fragments with the addition of water, like for example to break down starch into glucose (Biology Online, 2011).

Non-methane organic compound is a volatile organic compound (vOC) (Biology Online, 2011). Which are organic compounds that exist as gases in the atmosphere and some of them cause pollution (Miller and Spoolman, 2009:474). Some examples are methane (CH_4), isoprene (C_3H_8) and terpenes ($C_{10}H_{15}$).

Particulate Matter (PM) is small parts of air pollutants (Air Info Now, 2011). It could be for example smoke, dirt and dust from factories, farming and roads. It can also be mold, spores, pollen, toxic organic compounds and heavy metals.

Peroxyacetyl nitrate (PAN) is a product of combustion that has negative effects on plants (Britannica, 2011).

Riparian area is an ecosystem that is transitional between land and water ecosystems, typical examples are riversides, lake borders, and marshes (Biology Online, 2011). Riparian vegetation is "a reservoir of biodiversity and a buffer against sedimentation of water bodies" (Fischer et al., 2008:42).

Saccharification is the process of breaking a complex carbohydrate (as starch or cellulose) into its monosaccharide components (Biology Online, 2011).

Silviculture is the practice of controlling forest establishment, composition, and growth (Britannica, 2011).

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