Historical Land Use Change in China, the US and Germany

An overview of anthropogenic land cover changes over time

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Abstract

This research thesis gives an overview of existing data on historical land use changes in China, the United States of America, and Germany. For this purpose, this research paper mainly focuses on growth in cropland cover over time for these three countries. This thesis gives an overview of the reconstruction of data on land use change that is available for each of the three countries, and gives an overview of the driving factors of the historical land use change per country. Reconstruction of historical land use changes is essential for making estimations of the anthropogenic greenhouse gas emissions prior to the industrial period. Therefore, this thesis has compared existing literature on historical land use changes for three specific countries with estimations retrieved from an existing land use and land cover change (LUCC). This database, the HYDE 3.1, is one of the most used databases of global LUCC. The results of the comparison show that precise and accurate data on historical LUCC is not yet available for every country, and there is still some dissent on what the best method is to calculate global LUCC over time.

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Introduction

The Anthropocene is a term currently well-known by most in the academic world. In recent years, however, new theories have been proposed as to when the Anthropocene began exactly. In the traditional definition, the start of the Anthropocene is placed at around 1850 AD, when the industrial revolution began, and human-made machines started to emit greenhouse gasses that affected the composition of the atmosphere. However, several years ago a new theory implied that the Anthropocene, in the broader meaning of the influence that humans have had on the global climate and atmosphere, started thousands of years before the industrial era had begun. One of the most prominent supporters of this theory is William F. Ruddiman, who defended this theory in a study published in 2003 (Ruddiman, 2003).

Ruddiman pointed to the anomalies in the historical methane and carbon dioxide emissions records, that started around 8000 years ago. The trends in atmospheric greenhouse gasses can be calculated according to orbital time scales, but starting at 8000 BP, the trend showed anomalies in the levels of these greenhouse gasses. Ruddiman proposed the explanation for these anomalies to be anthropogenic land use changes. Pointing to evidence that human populations started deforesting and cultivating the earth around 8000 BP, Ruddiman calculated the deviating carbon dioxide and methane flux between the earth and the atmosphere, and matched this deviation with the possible excesses in emission that anthropogenic deforestation could cause (Ruddiman, 2003).

Since this theory has been proposed, this phenomenon has been studied more elaborately. Besides making changes in the atmospheric composition, anthropogenic land use change can also affect regional climates through changes in surface energy and water balance, and affect biospheres with anthropogenic nutrient inputs (Foley *et al.*¸ 2005). For this reason, making reconstructions of land use changes in the past can be crucial to study the effect of anthropogenic land use change on the global environment. Information on historical land use changes can aid in making estimations on how much and how long humans have already affected the atmospheric composition (Ruddiman, 2003). Several studies have already focused on the topic of anthropogenic land use change (Foley *et al.*, 2005, Kaplan *et al.*, 2010, Arneth *et al.*, 2017). These studies often address the difficulty of establishing an accurate database of historical land use change per country, since modern technologies that keep track of such changes have not existed for more than a century. Therefore, databases that do contain data on historical land use change prior to the industrial revolution, often consist of estimates of land use change made per country, based on different techniques to make such estimates (Kaplan *et al.*, 2010).

This research thesis will attempt to make an overview of reconstructed land use change over time for three major countries. These countries are China, the United States of America and Germany. They were chosen as the object of this research thesis because these countries are all relatively large and all located on different continents, and therefore my expectation is that they have developed different patterns of land use change over time. The three vegetation types that will be discussed in this research thesis are the cropland cover, the grassland cover and forest cover of each of these three countries over time. The focus in this research thesis will be on cropland cover, since this is one of the most intensively used forms of vegetation (Brown *et al.*, 2005). The results of this data for the total cropland area growth will then be compared to the HYDE 3.1 database, an already existing database that covers global land use change estimates over the past 12,000 years per country.

The research question of this paper is:

“What are the differences in historical land use change, and their driving forces in China, the United States, and Germany, and how does the data available on cropland growth in these three countries compare to the estimates of the HYDE 3.1 database?”

To answer this question, I will first give an overview of the methods that have been used to establish data on historical land use change in these three countries, and I will give a description of the relevant terms used in this paper. In the results section, I will reconstruct the information that is available on the land use change histories of the three countries, and the different driving factors that have been suggested to cause these land use changes. In the discussion section, I will discuss the LUCC patterns for cropland of these three countries, and compare the results to the cropland change estimates made in the HYDE 3.1 database. Then will use the comparison between the HYDE 3.1 database and the literature review numbers for cropland to show the different results that different methods of estimating historical land use change can produce. Finally, I will make some concluding remarks.

1. Methods

This research thesis will provide an overview of data that is already in existence. By reviewing papers, I have reconstructed past land use changes for Germany, the United States and China, so far as there was information available on the three countries. I have used the original figures from the papers I reviewed.

I have compared the results from the literature review to the land use change estimates retrieved from the HYDE 3.1 database. The HYDE 3.1 is a database of global historical land use change estimates. The estimates in this database are based on a combination of historical population estimates and the implementation of allocation algorithms with time-dependent weighting maps for cropland and grassland. The period covered in the HYDE 3.1 database is from 10,000 BC to 2000 AD.

The papers that have been reviewed in this research thesis contain some important terms that need additional explanation.

The most important term is the 'land use and land cover change', often abbreviated to LUCC. Variations of this term include LULC (Land Use and Land Cover Change) and ALCC (Anthropogenic Land Cover Change). The abbreviation that will be used in this paper is LUCC.

Three other important terms that will be used throughout this research thesis are cropland cover/area, forest cover, and grassland area. With cropland is meant the arable land that is solely used to cultivate for the purpose of growing food, so farmlands with grazing animals are excluded from the total cropland area of a country. The forest cover is the size of land that is still or again covered in tree canopy. The term 'forest transition', which is also mentioned briefly in this research thesis, refers to the abandonment of farmland, and the subsequent regrowth of forest cover, also called 'afforestation'. The opposite of afforestation is 'deforestation', meaning the removal of forest cover. Grassland area is a vegetation type that includes grass or low bushes. Grassland area can be used for animal grazing, but is mostly seen as 'original' vegetation of a certain area, since it is not a vegetation type that is used intensively by humans.

2. Results

2.1 China

China's mainland has a total land area of approximately 956 million ha (He *et al.*, 2015). This area excludes Hong Kong, Macao and Taiwan. Due to many years of political instability, the borders of the People's Republic of China and those of the provinces within the country have not always been the same as they currently are. Especially in times of political instability, the government often did not store data on the land use in every region. It is for these reasons that most papers concerning land use and land cover changes (LUCC) in China focus on specific regions or provinces in China. There are however, a few studies to be found that attempt to reconstruct the LUCC of every province in mainland China over the past 300 years or even further back in time (He *et al.*, 2015, Miao *et al*, 2016, Ge *et al.*, 2004, Liu *et al*, 2010, Li *et al.*, 2015). The methods that are most often used to reconstruct these data are archival material, satellite images, remote sensing (RS) or other techniques. In this section, 'cropland' will refer to both dry cropland and paddy field.

2.1.1 LUCC and Spatial Patterns

The study by Ge *et al.* (2004) shows an increase in total area of cultivated land in China's Interior 18 provinces from 53.2 million ha to 82.7 million ha between 1661 and 1933. Their study does not include results after 1933, and therefore does not show the results of political instabilities in China on the land use change in the 20th century.

In the figure below, we can see that Li *et al.* (2015), taking into account nearly all provinces of mainland China, have displayed data that point to a large increase in the total cropland area in the past three centuries. According to Li *et al.* (2015), the total cropland area in China increased from 55.59 million ha in 1661 to 130.09 million ha in 1996. This amount roughly corresponds with the data outcome of He *et al.* (2015), who mention a total increase of 79,45 million ha from 1661 until the 1980's. The annual growth rate (abbreviated by Li *et al.* as AGR) was 0.25% over this time period. However, what also becomes clear from this figure below and from other studies on the historical LUCC in China, like Liu *et al.* (2010), Liu *et al.* (2014) and He *et al.* (2015), is that a peak in the total cropland area in China appears to have been reached in the mid-1900's. After this peak, accordingly around the year 1949 (Ge *et al.*, 2004), the total cropland area stagnated and even started decreasing steadily.

Miao *et al.* (2016) distinguish three different periods of cropland growth. The first period, ranging from 1650 until 1949, saw a rapid growth in cropland area and a decrease in total forest cover. The second period, from 1949 until the 1980s was an unstable period, with large variations in land use. Finally, the third period, starting in the 1980s and continuing to the present saw a steady decrease in cropland area, and a slow increase in forest cover. This final increase is due to government policies protecting and reclaiming forests in China (Miao *et al.*, 2016). He *et al.* (2015) point out that the approximate decrease of forest cover has been 89.73 million ha over the past 300 years and that the grassland cover decreased with 40.00 million ha in this same period. Of the decrease in forest cover, however, most is confirmed to have occurred before the 1960s. Between the 1960s and 1998 the total forest cover increased again by 73.42 million ha .

Looking into more recent years, Liu *et al.* (2014) suggest that the total amount of cropland stayed roughly the same between 1990 and 2010, but the spatial distribution of the cropland changed drastically within these twenty years, with an increase of cropland in the north and a decrease of cropland in the southern part of China. Of the cropland that was lost between 1990 and 2010, roughly 50% was converted into built-up land. Losses of cropland in parts of China were made up for in other parts by the conversion of woodland and grassland to cropland (Liu *et al.*, 2014).

The large increase only took off after 1873. This increase did contain some fluctuations. An increase in cropland area took place between 1873 and 1933, after which the cropland decreased until 1950. After 1950 it rapidly increased again, only to come to a halt around 1980. The different stages of growth of cropland can clearly be seen in figure 1, taken from Li *et al.* (2015).

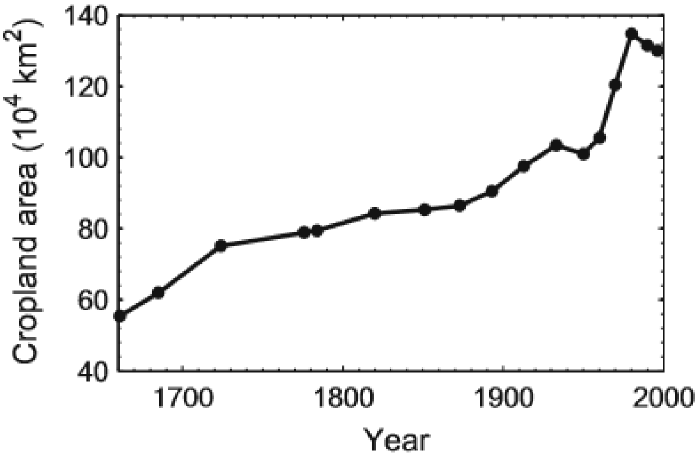

Figure 1 from: Li et al. (2015) displaying the total cropland area of mainland China for 1661-1996 in 104 km2 (million ha).

Concerning the spatial distribution of the variation in land use, we can see in the figure by Li *et al.* (2015) below that the prevalence of cropland gradually spread from the northeastern part of China to other regions in the country, and additionally the cropland coverage became more dense in the northeastern part as well. Ge *et al.* (2004) mention that at the time of publication of their research, about 13.3% of the total land area in China was used for cropland. Of this total area, the northeastern regions were highly cultivated and the western provinces were lightly cultivated. They ascribe this distribution to the occurrence of highly fertile farmland in the northeastern parts of the country. Additionally, Ge *et al.* (2004) mention that the cultivation in the eastern provinces was quite slow after 1724, since these provinces were already highly cultivated. He *et al.* (2015) add that the largest increases in croplands occurred in border areas and hilly areas, where cultivation is more challenging than in the plains. In additional research, urbanization is indicated as an important cause of loss in croplands (Jiang *et al.*, 2013, Deng *et al.*, 2015, Liu *et al.*, 2014).

In the 1990's, urban areas of China increased by almost 25% (Jiang *et al.*, 2014). In 2012, the urbanization rate was 52.6%, meaning that over half of the population in China lived in urban areas (Deng *et al.*, 2015). For this reason, croplands made place for built-up land rapidly in especially the densely populated areas like the Huang-Huai-Hai Plain, the Yangtze River Delta, the Pearl River Delta and the Sichuan Basin. This provides another explanation why cultivation in the northeastern, densely populated areas, was not high. In contrast, the provinces in the western part of China that were not as densely populated and that did not have a high urbanization rate saw an increase in the total amount of cropland area (Liu *et al.*, 2014). In figure 2 from Li *et al.* (2015), the spatial pattern of the growth in cropland area can clearly be seen.

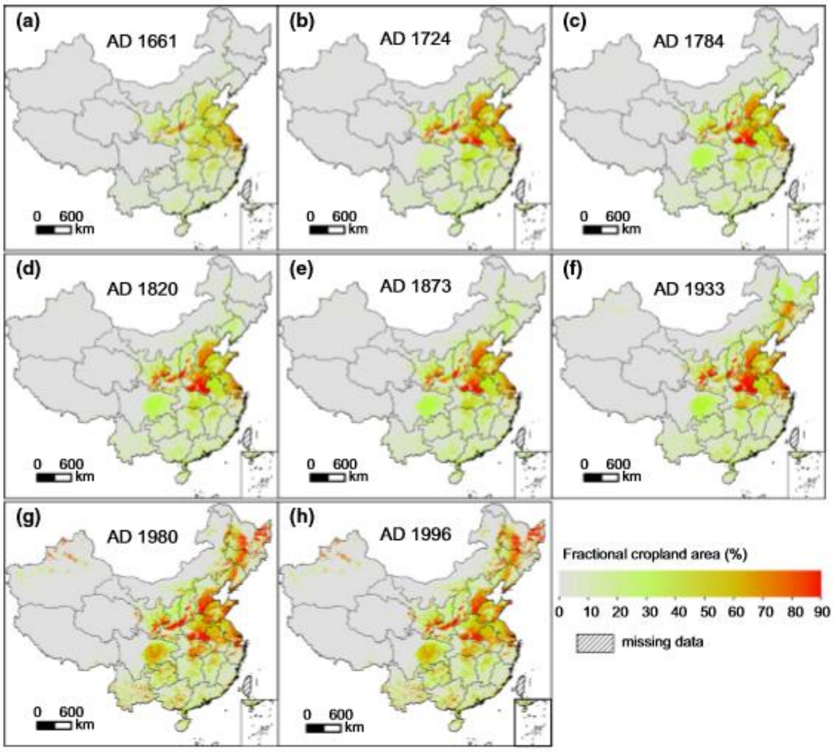

Figure 2 from: Li et al. (2015) displaying the spatial distribution of cropland cover of mainland China for 1661-1996 in percentages.

2.1.2 Driving factors

Over the past three centuries, China has seen much political and socioeconomic turmoil. Since the impacts of human activities on the physical environment are deemed as the most important impacts, it is no wonder that this turmoil has resulted in dramatic variations in land use in China over time. Most papers name the same prominent driving forces of cultivation and reclamation over time. For example, Miao *et al.* (2016) name population growth as a crucial factor influencing LUCC. They summarize the population growth over time by mentioning the fast and stable growth between 1724-1852, the decrease in population between 1852-1870 which might have been related to pestilence and famine, the Taiping Rebellion (a civil war that lasted from 1850 to 1864), and the Second Opium War (a war between China and the British and French empires that took place between 1856 and 1860), all of which occurred in this twenty-year period (Miao *et al.*, 2016). Additionally, the years between 1870 and 1960 saw a steady growth in population. In recent years, the growth rate has slowed down due to the implementation of the "one-child policy". These changes in population growth roughly coincide with the variation in cropland area over time, indicating that population growth is the most defining driving factor of LUCC (He *et al.*, 2015).

As a second driving factor, agricultural technology and intensification has been influential in the Since agricultural technology became more efficient, the decrease of cropland per capita did not mean a lack of food availability when the population began to grow. Increase of yield per unit land that resulted from the agricultural intensification therefore allowed for the slow increase of cropland area when the population was growing much steeper, and even allowed for the decrease in total cropland area in recent decennia (Miao *et al.*, 2016).

Another driving force is climate change and interactions between ecosystems. As the yield of agricultural land is influenced by fluctuations in temperature, precipitation and other environmental factors, it is logical that slightly longer-term climatic factors influence the amount of land area that is used for cropland (Miao *et al.*, 2016).

A final factor that can be connected to the LUCC in China are the national policies. The most well-known examples of Chinese national policies concerning land use are those that were introduced under the rule of Mao Zedong starting in 1949. These were introduced during the Great Leap Forward, the grain-first campaign and the Cultural Revolution. These historic events led to an enormous increase in agricultural area at the cost of wetland and forest land (Miao *et al.*, 2016). After 1979, when Mao's rule had ended, these policies also ended and made way for a national policy towards ecological restoration. These policies, combined with the slight stagnation in population growth after the introduction of the "one-child policy" and the intensification of agricultural technologies allowed for the decrease in total agricultural area in China beginning in the 1980's (Miao *et al.*, 2016).

2.2 United States

The United States has a total land area of 983 million ha. The part of the United States that excludes Hawaii, Alaska and other American offshore territories is called the Conterminous or Contiguous United States. The total land area of the contiguous USA is approximately 766 million ha, and is often referred to in studies of the land use change in the United States. The land use and land cover change history of the United States is unique since large scale settlement occurred at a late stage in human history, resulting in an extremely rapid growth and spread of cropland throughout the country. Since the location of the first settlers also determined the spatial patterns of land use change in the United States, the growth in cropland area was highly directional (Brown *et al*, 2005). The United States only became an independent nation after 1776, so data on LUCC before this period is difficult to find and can be quite inaccurate (Houghton *et al.*, 1999). For that reason, studies on LUCC over time in the United States commence their time period around 1800 or later (Ramankutty *et al.*, 2010, Waisanen and Bliss, 2002, Ramankutty and Foley, 1999). The study by He *et al.* (2015) however, compares land use and land cover change over the past 300 years for China and the US, and thus has obtained a data set starting around 1700. Since the United States did not exist before that period, the country borders moved westward, and so did the spread of land used for crops. This is therefore a unique case of rapid deforestation and land reclamation to use for cropland (He *et al.*, 2015). Techniques used by these studies to construct a data set of LUCC over time include remote sensing, archival material and the US national Census bureau.

2.2.1 LUCC and Spatial Patterns

A general consensus by the studies by He *et al.* (2015), Waisanen and Bliss (2002), Ramankutty and Foley (1999), Ramankutty *et al.* (2010) and Clawson (1979) shows that between 1700 and the mid-1900s, the amount of total cropland area in the United States of America increased steeply. He *et al.* (2015) distinguish three different periods of growth of cropland area. They indicate the first period, between 1700 and 1800, as the period of slow but steady growth in total cropland area. This century saw an annual growth rate (AGR) of 10.6%. The period between 1800 and 1930 was the period of most rapid growth, with an AGR of 24.3%. The final period, ranging from 1930 to 2000 was characterized by a stable growth with some fluctuations (He *et al.* 2015). He *et al.* (2015) estimate the total cropland area to be 630,000 ha in 1700. According to their study, the total cropland area grew to a total area of 191.50 million ha in 1950. Ramankutty and Foley (1999) propose that a peak in the growth of cropland over time can be distinguished around 1950, after which the growth in total cropland area comes to a halt. He *et al.* (2015) place this peak a decade earlier, in 1940. In addition, He *et al.*'s study shows that after 1940, the cropland area continues to grow. Contrarily to their study, Waisanen and Bliss (2002) show a slight decline in total cropland area in the United States after 1940. Ramankutty and Foley (1999) argue that the total cropland area neither declined nor increased after 1950. They suggest that the apparent decline shown in other papers is an artefact of the changes in definitions of agricultural land over time. When corrected, they show that the cropland data shows no decline after 1940 (Ramankutty and Foley, 1999). The US Bureau of Census also shows fluctuations from 1940 onward, with no clear decline in total cropland area (US bureau of Census: Agriculture). Brown *et al.* (2005) have studied only the LUCC in the US between 1950 and 2000, and include metropolitan growth in their research. They claim that the period from 1950 to 1970 was a period of metropolitan growth, resulting in cropland abandonment throughout the country, but that a rural population turnaround took place in the 1970s, resulting in an increase in cropland cover and a migration flux from metropolitan to non-metropolitan counties (Brown *et al.*, 2005). Data from Sleeter *et al.* (2013) however, shows a decline in the total farmland area in the US from 1970 to 2000. In summary, even with new technologies to detect land use change, there is still dissent on the most recent cropland cover growth in the US.

The increase in cropland area has resulted in the loss of other forms of vegetation types in the US. Since the United States have a relatively short agricultural history, this means that the agricultural land area that was gained over the past 300 years was reclaimed from ‘natural’ or ‘original’ land, meaning the vegetation type that was present prior to European settlement on the North American continent (Clawson, 1979). Forests and grasslands are the two vegetation types that have lost the greatest amount of land area due to reclamation for agricultural purposes. He *et al.* (2015) claim that the total forest coverage in the US was 444.18 million ha in 1700, which was at the time 57.97% of the total land area of the country (He *et al.*, 2015). This amount decreased to around 307.2 million ha in 1950 according to their estimations. The most rapid decrease occurred between 1850 and 1950. According to the estimates of He *et al.* (2015), the total area covered by grassland decreased from 277.84 million ha in 1700 to 140.86 million ha in 1990. Since 1907, the forest extent has been stabilized, and no significant regrowth has taken place (Ramankutty *et al.*, 2010). Ramankutty and Foley (1999) add that since 1850, 168 million ha of original savannas, grasslands and steppes have been cleared, and that 140 million ha of all original forests and woodlands have been cleared. They distinguish grassland and steppe as the vegetation types to have lost the greatest land cover area.

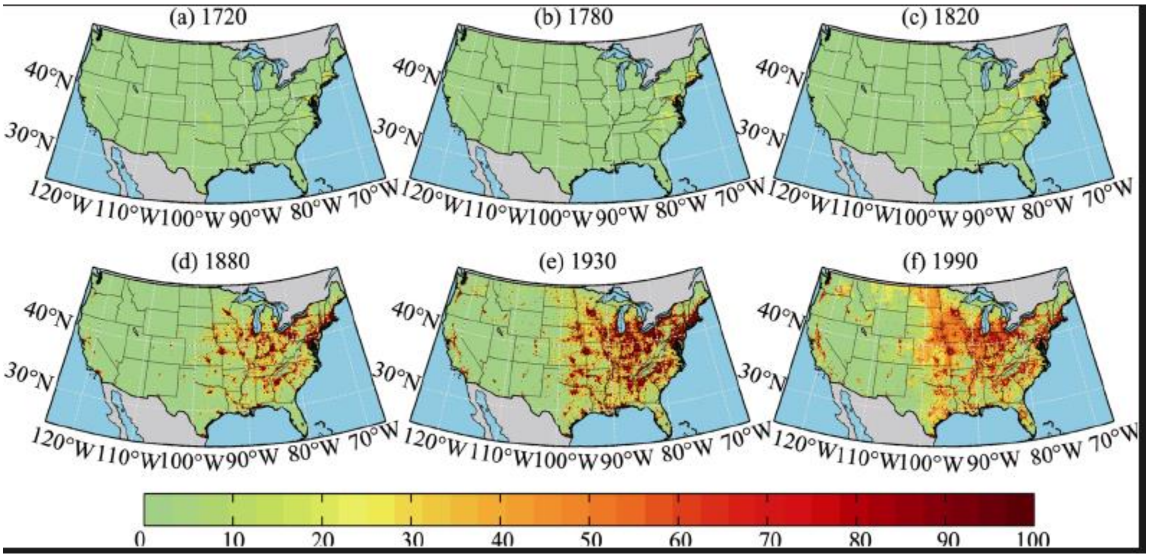

Figure 3 from: He et al. (2015). Spatial distribution of cropland area from 1720 to 1990

Spatial models of LUCC over time can provide more details as to what areas saw an increase or a decline in total cropland area. The cropland area gradually moved from mainly the eastern coastal states before 1776 to the Midwest during the two centuries following the American independence (He *et al.*, 2015, Ramankutty *et al.*, 2010, Ramankutty and Foley, 1999). The Appalachians formed a geographical barrier for early settlers, but gradually the expansion of cropland area crossed the Appalachians and covered the Great Lakes Plains and the Gulf Plains. This phenomenon is often referred to as the Westward movement, and corresponds to knowledge we have of the movement of the frontier to the western region of the North American continent (He *et al.*, 2015). Ramankutty *et al.* (2010) discuss whether the forest transition theory - the theory that agricultural clearing in the 1800s was followed by agricultural abandonment and subsequent afforestation – holds for the conterminous United States as well. They conclude that this theory only holds for the northeast and north central parts of the United States like Pennsylvania, New York, Michigan and Ohio, since these areas have regained forest cover in the past century. In other regions of the United States, like Texas, California, Arkansas and Florida, the forest cover has still significantly declined in recent decades. The result of these spatial changes in deforestation is that overall, the forest extent stabilized in 1907, and no significant regrowth of forests has occurred in the United States (Clawson, 1979, Ramankutty *et al.*, 2010).

2.2.2 Driving Factors

In the case of the United States, the land use changes over time correspond with the country's settlement history. Before the independence in 1776, the cropland cover mainly occurred at the eastern coast, in the European colonial districts. The cropland cover began to increase drastically after the declaration of independence (He *et al.*, 2015). From the beginning, land reclamation was encouraged by the government through different policies. One of the first of these governmental policies was the Land Ordinance of 1785, which introduced a mechanism for selling land. These policies helped accelerate the land reclamation from an early stage. The constant immigrant flux into the United States also aided in the process of land reclamation from East to the Midwest (He *et al.*, 2015).

For the past centuries, some severe droughts hindered the growth of cropland area in the United States. One of these was the drought in 1860, resulting in cropland abandonment for a brief period (Waisanen and Bliss, 2002). In 1862, the Homestead Act was introduced by the government. This act opened up the possibility to own land for anyone willing to cultivate the land for at least five years (Ramankutty and Foley, 1999). The Homestead Act, combined with the termination of the Civil War, caused a strong increase in land reclamation, and this resulted in the period of rapid growth in cropland area starting in the 1860s and lasting until the mid-1900s (Ramankutty and Foley, 1999). A second drought in 1860 caused a brief pause in the cropland growth rate again (Waisanen and Bliss, 2002), but in general the total cropland area growth maintained stable throughout this century, as the Westward Movement proceeded (He *et al.* 2015). In the 1930s, a period of severe dust storms called the Dust Bowl occurred in the High Plains area of the United States. These dust storms occurred in several waves during the decade. They greatly damaged the agricultural areas and caused large scale farmland abandonment (Ramankutty *et al.*, 2010). This resulted in a sharp decline in cropland area for a brief period around 1940 (Waisanen and Bliss, 2002). After the 1930s, new governmental policies were introduced to protect the soil from erosion and to prevent such droughts and storms from recurring (He *et al.*, 2015). These policies also aimed at protecting and re-growing forest cover. How this affected the deforestation rate or the growth rate of cropland cannot be determined exactly, as some uncertainty on the number of afforestation and cropland abandonment after the 1930s still exists (Waisanen and Bliss, 2002, Ramankutty and Foley, 1999, He *et al*., 2015).

These events that occurred in the past two centuries correspond to the small fluctuations that are described by He *et al.* (2015). In the case of the United States, the government policies played a crucial role in the land use and land cover changes over the past three centuries. In addition, influx of immigrants, natural disasters like droughts, and natural geographic barriers such as mountain ranges, determined the spatial pattern of land use change in the conterminous United States over the past three centuries.

2.3 Germany

Germany currently has a total land area of 35,7 million ha (Destatis, 2017). As of 2015, the country was covered for 30.6% by forest, and 51.7% of the total land area was used for agricultural purposes. The remainder consists of buildings, transport area, recreational areas and areas with other uses (Destatis, 2017). Over time, the ratios of vegetation cover have varied since early in the history of human settlement in Europe. Unlike the other two countries studied in this paper, the largest part of the deforestation in Germany took part several centuries ago, and therefore the historic land use in Germany can be reconstructed with much less certainty and precision (Bork and Lang, 2003). The referenced studies have used several methods to construct the historic account of land use in Germany.

Bork and Lang (2003) extract information from soil formation and soil translocation processes, since soils preserve information about the conditions of their formation. From this information, the original land use of the area during formation can be determined. Kaplan *et al.* (2009) have developed a model to determine prehistoric and preindustrial land use change in Europe using human population size, intensity of land use, and suitability for agriculture and pasture as indicators for rates of deforestation. Bender *et al.* (2005) focus on a sector in Bavaria, Germany, and can therefore use regional registers to reconstruct landscapes in the past. Enters *et al.* (2008) also study a smaller section within Bavaria, and use pollen analysis to determine land use change in the area.

2.3.1 LUCC and Spatial Patterns

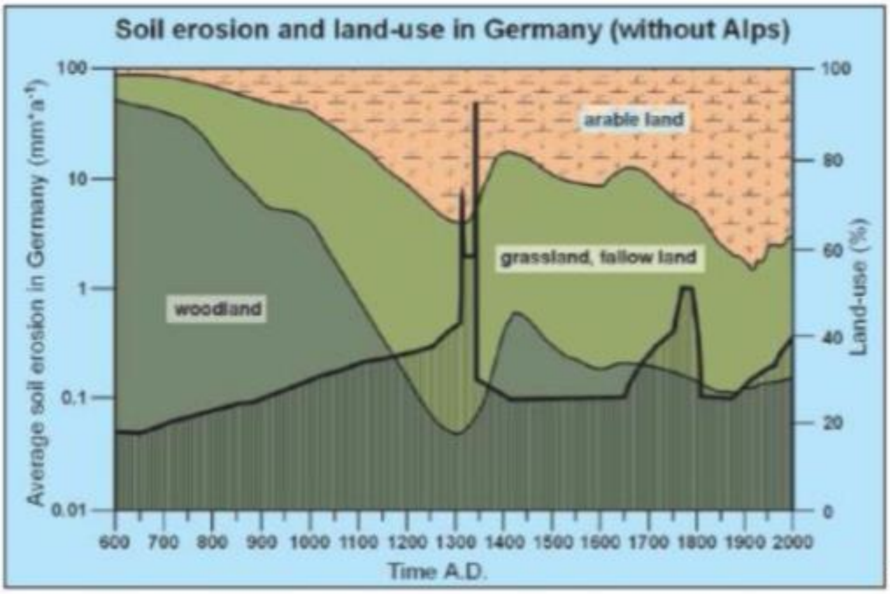

Figure 4 from: Bork and Lang. (2003), showing the percentages of the total area of Germany (excluding the Alps) that were used for cropland, grassland and fallow land, or woodland.

In figure 4, retrieved from Bork and Lang (2003), the division between arable land, grassland/fallow land and woodland is clearly distinguished. This graph leaves out the area that is part of the Alps, since the vegetation is quite different in these mountainous areas (Bork and Lang, 2003). Since it is unclear exactly how much area is left out in this graph, the percentages have not been calculated into the amount of hectares they refer to, to avoid the possibility of inaccuracies. It is for that reason that numbers on the total area of cropland cover over time are not included in this section, as this data was not available in any of the (English) studies on historical LUCC that have been reviewed for this research thesis.

The percentage of arable land in Germany starts at close to zero in 600 AD, and can therefore be neglected. From this century onwards the total arable land gradually begins to increase, coming to its first peak around 1300 AD. At this peak, the percentage of arable land of the total German land area is around 35%. Following this peak, the percentage of arable land decreases until around 1430, when it is approximately 20% of Germany's total land area. Following 1430, the arable land in Germany steadily increased, with slight fluctuations and another slight setback around 1600. The second peak, around 1920 AD, shows that over 45% of the total area was arable land. After 1920 it gradually decreased to the current share of approximately 37%

The grassland and fallow land percentage shows less variation than the arable land cover does. From 600 AD the grassland and fallow land increased from 5% to approximately 50% of total land area in Germany. From 1300 to around 1430, the grassland and fallow land decreased to 35% of available land area in Germany. It continued to gradually decrease until 1900, when the percentage was around 27%. At 2000 AD, it was around 32%.

As is shown in figure 4, the total forest cover in Germany has decreased severely since 600 AD, with the share of forest cover going from well over 90% of the total land area to merely 30%. Between 600 and 1300 AD, a steep decrease in forest cover area percentage took place, during which the forest cover declined to its lowest point of 20%. In the period of the early 1400s, afforestation took place, and the forest cover increased to over 40% of total land area. Following this period, the forest cover decreased with a small rate until 1900, when the percentage of forest cover was slightly under 30, after which it increased again to the current percentage of slightly over 30 (Lang *et al.*, 2000).

Kaplan *et al.* (2009) show a similar pattern of variability of forest cover over the centuries, although their percentages of forest cover are much lower. This might be due to the fact that they give the forest cover as a percentage of the total land that is usable for clearing for agriculture. This would therefore exclude the forest land that would not be usable for clearing for agriculture. Also, the information in Kaplan *et al.* (2009) does not mention excluding the Alpine area, which could also be an explanation for the difference in numbers. Kaplan *et al.* start their timeline at 1000 B.C., setting their percentage of forest cover at 71.8%. This gradually declines to 29.1% in 1000 AD, and hits a low at 9.9% in 1350. In 1400 it picks up again to the percentage of 15.0, after which it decreases again to the all-time-low of 3.0% in 1850. Since this paper only discusses the land use changes in Europe prior to the industrial era, the timeline stops here. This differs quite a lot from the 27% it is said to have been in 1850 by Bork *et al.* (1998). As mentioned before, this difference might be due to the differences in definitions of the percentage of forest cover in Germany.

Since Germany has not been a unified country for more than a couple of decades, it is useful to look at land use change over time in the larger region of Central Europe. Since most European areas have a high suitability for crops and pasture, deforestation in Europe has been significant throughout the past 3000 years. However, as Kaplan *et al.* (2009) show in their research, the 14th century was the greatest period of deforestation in Europe. This corresponds to the values of deforestation that have been found for Germany. Another fluctuation that is present throughout most parts of Central Europe is the decline in used land and the period of afforestation that starts in the early 1300s. As Kaplan *et al* (2012) confirm, in 1960 most of the forest cover throughout Europe was extremely low, after which a period of modest afforestation began (Kaplan *et al.*, 2012).

As the deforestation and transition to arable land began at a much earlier stage in the region that is now Germany than in the USA and China, there is little information available on the spatiotemporal distribution of the land use change in Germany. The first settlers are likely to have settled in the most fertile areas of Germany, mainly the areas covered by the highly fertile loess sediment. These areas were in the southernmost parts of Germany, and also in the loess belt near the present-day city of Hannover in the north. This is said to have happened around 5500 BC (Dotterweich, 2008). The first acts of deforestation must therefore have taken place around these areas. During Roman times, only the southern part of Germany which was part of the Roman Empire, had cultivated lands. According to historical documents, everything north of the Roman borders was still covered with woodlands (Dotterweich, 2008). After the 6th century, when deforestation was increasing, the woodlands were cleared first in the western parts of Central Europe, and later in the eastern parts. After this, the distribution of croplands in Germany was supposedly different throughout time, depending on the population density in the different areas of the region that is nowadays Germany (Dotterweich, 2008).

2.3.2 Driving Factors

Until a few centuries ago, the rate of deforestation was directly correlated with the rate of population growth in the area that is now Germany (Kaplan *et al.*, 2009). The first stages of deforestation in Germany were caused by the first settlers, over 7000 years ago. The arable land grew steadily and the forest cover declined. There was a local maximum in forest cover at the end of the Western Roman Empire, in the 5th century AD. The period between 400 and 600 AD is called the 'Migration Period', since the fall of the Western Roman Empire caused political unrest and migration patterns throughout Europe. This resulted in a brief pause in deforestation in Germany, and even afforestation in some parts of Germany (Kaplan *et al.*, 2009, Büntgen *et al.*, 2011). In the 13th century, the population in German areas grew steeply. This period is referred to as the Settlement Boom (Büntgen *et al.*, 2011). In this century, the deforestation increased heavily as well. In the mid-1300s, a clear rise in Germany's forest cover area can be seen, as well as a decline in arable land. Several studies have explained this phenomenon to be a consequence of the Black Death, the deadly plague that spread throughout Europe in the first half of the 14th century and is estimated to have wiped out at least 25% of the European human population, and about a third of the population in Germany (Kaplan *et al., 2009,* Kaplan *et al.*, 2012, Büntgen *et al.*, 2011, Schmidtchen *et al.*, 2003). Since the human population severely decreased during this period, many of the cropland areas in use were abandoned, and a short period of afforestation followed in the decades after the plague (Kaplan *et al.*, 2012). Dotterweich maintains that there are other possible causes for this sudden decline in arable land cover, like famines, urbanisation and socio-economic and political reasons that also took place in the first half of the 14th century (Dotterweich, 2008). The population had recovered to pre-plague levels by 1450 AD, and so had the forest clearance levels by this time (Kaplan *et al.*, 2009). Between 1618 and 1648, the Thirty Year's War broke out in Central Europe, which was a series of very destructive wars. This period correlated with a small pause in deforestation, and a small decline in arable land cover in Germany (Kaplan *et al.*, 2009). After this period, the direct relation between population growth and the rate of deforestation became less distinct, as technological advances were applied in agriculture, and thus the intensity of cultivation increased. By 1850, when the industrial era had begun, this correlation was no more in Central Europe (Kaplan *et al.*, 2009). After 1850, a period of forest transition began, in which agricultural lands were abandoned, and forest cover started to grow again slightly. This is a result of the changes in technologies and some governmental policies within the area (Kaplan *et al*., 2012).

3. Discussion

The three countries show different land use change patterns. In existing literature on land use change history of the United States and China, most studies mainly give estimates on LUCC for the past 300 years. Therefore, these results are quite different from the results that the literature review of German LUCC has shown. The timeline of the German LUCC studies show that much of the fertile lands in Germany had already been reclaimed from forest cover centuries before the timeline of the studies on the LUCC in the US and China had even started. This makes it quite difficult to determine the spatial patterns of cropland growth over time. The LUCC of the United States and China can be compared quite well. The period of rapid growth of cropland area started slightly earlier in China than did the rapid growth-period in the United States. Since the driving forces causing the LUCC patterns differ between these two countries, it is logical that their LUCC patterns do not coincide. However, it can be concluded that for both China and the US, governmental policies have been very influential in shaping the historic LUCC over the past century. In the US, it was the most important driving factor, while in China the booming population growth was the most important driving factor of LUCC over the past three centuries.

In this section, the outcomes for total cropland area of the literature review will be compared to the estimates of the HYDE 3.1 database. The countries will be discussed in the same order as in the previous section. After the comparing of the data of China, the United States and Germany, possible explanations for the differences in outcome will be discussed.

For China, the data retrieved from the literature review roughly coincides with the data collected in the HYDE 3.1 database. In the section on China, different outcomes were discussed. The study by Ge *et al.* (2004) estimates a total cropland area of 53.2 million ha in 1661, which, according to their estimates, increased to 82.7 million ha in 1933. The study by Li *et al.* (2015) estimates an increase in cropland area from 55.59 million ha in 1661 to an area of 130.09 million ha in 1996. The estimates made in the HYDE 3.1 database suggest a total cropland area of 56.69 million ha around 1600, and a cropland area of 103.3 million ha in 1930. The HYDE 3.1 estimate for 1990 is a total cropland area of 131.4 million ha.

In the previous section, the study by Ge *et al.* (2004) was discussed to be incomplete. The data outcomes of the study by Li *et al.* (2015) coincide quite well with the HYDE 3.1 estimates, with an error of about 3.5 million ha for the period of the 1600s.

For the United States, the data from the literature review are also similar to the estimates made in the HYDE 3.1 database. He *et al.* (2015) start with an estimate of 0.63 million ha in 1700 AD. This grew to 7.34 million ha in 1800, and reaches a peak at 185.64 million ha in 1930. A second peak took place in 1950, when the overall cropland area was at 191.5 million ha (He *et al.*, 2015). Waisanen and Bliss (2002) show similar cropland cover estimates, their estimate for the year 1997 being 172 million ha. Their study does show higher numbers for total cropland area in the early 1900s, however. The HYDE 3.1 estimate for 1850 AD is an area of 41.67 million ha. The HYDE 3.1 estimates for 1900, 1950 and 2000 are 144.22 million ha, 189.75 million ha and 178.07 million ha respectively. For 1930, the HYDE 3.1 estimate is 184.42 million ha. This number differs from the He *et al.* (2015) estimate by only 1.22 million ha. the HYDE database is slightly higher than the He *et al.* (2015) estimate for 1700 AD, and stays above the estimates by He *et al.* (2015) until the mid-1900s, when they started becoming quite similar.

The data for Germany are a bit more complicating to compare. Since the literature review did not yield any specific numbers, but only percentages, these cannot be compared to the HYDE 3.1 database estimates. Additionally, the percentages in the graph referred to the total arable land, and the HYDE 3.1 database estimates only concern cropland areas. However, we can compare the pattern of growth of cropland area that the literature review yields to the pattern of growth of cropland area that can be distinguished from the HYDE 3.1 database.

The HYDE 3.1 estimates for Germany are 807.000 ha, then grow steadily to 12.9 million ha in 1300, after which the cropland area declines to 6.9 million ha in 1400 AD. After 1400 AD, the cropland area resumes its steady growth once again, with a small and temporary decrease to the value of 8.9 million in 1700, but reaching a total value of 16.1 million ha in 1900. In the 20th century, the total cropland area declines again to the value of 12 million ha in 2000 AD.

These fluctuations since the year 600 AD coincide with the fluctuations that are distinct in the graph by Bork *et al.* (1998). The same short periods of decrease in the 1300s and in the latter half of the 1600s can be distinguished. Therefore, we can conclude that the estimates retrieved from the HYDE 3.1 database and the growth pattern for cropland in the graph by Bork *et al.* (1998) show approximately the same pattern.

Although slight differences between the HYDE 3.1 database and the results from the literary review exist, they follow the same pattern of cropland growth during most of the time period that was studied. The differences that do exist can be accounted for by the different methods that several studies have used to reconstruct historic land use change.

The HYDE 3.1 database bases its estimations on reconstructions of global population growth and population density. The HYDE 3.1 database includes the land use per capita (in order to measure land use intensity) in its calculations. As Kaplan *et al.* (2010) and Hurtt *et al.*, (2006) mention however, the HYDE 3.1 estimations are based on a nearly linear relationship between population and area of land under agriculture, and therefore shows little variation in per capita land use. This could result in estimations of cropland growth for specific countries that deviate from other studies executed on the cropland growth in this particular country. Kaplan *et al.* (2010) suggest an alternative, namely to make the assumption that humans use land more intensively in all regions of the world with increasing population density and land scarceness (Kaplan *et al.*, 2010). He applies this assumption in the KK10 scenario, which is another LUCC database. Despite the existence of other approaches to make historical LUCC scenarios, the HYDE 3.1 is one of the most used databases on global historical land use change (Gaillard *et al.*, 2010). For this reason it is quite logical that the data from the literature reviewed in this research thesis should coincide with the estimations retrieved from the HYDE 3.1 database, since many studies will probably use the HYDE database as one of their prime sources.

Conclusion

The research question formulated in the introduction was:

“What are the differences in historical land use change and their driving forces in China, the United States, and Germany, and how do they compare to the estimates of HYDE 3.1 database?”

I have answered this research question by giving an overview of the data on historical LUCC in China, the United States and Germany that are currently in existence. This data was subsequently compared to the estimates on historical LUCC retrieved from the HYDE 3.1 database. For each of the three countries, similar cropland growth patterns coincided, although for example for China, there were slight differences in the total amount of cropland area between the HYDE 3.1 results and the results from the other literature.

Based on the different studies discussed in this research thesis, we can conclude that there is still some disagreement on the outcomes of historical LUCC in these three countries, as well as on the way the estimations should be calculated. Since the topic of the anthropogenic land use changes and its effect on the atmosphere is such a new field of research however, further research in the near future can be expected to get more precise results on the historic land use changes for China, the US and Germany.

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