

RESEARCH PROJECT REPORT

Anthromes – How Humans shaped the Earth through Land Use Change in the Past 10,000 Years

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Abstract

The beginning of the Holocene (10,000 BCE) marked the point of increased agricultural activity as humans started to settle down. This progress was accompanied with an increase in greenhouse gas emissions, like methane and carbon dioxide. Furthermore, excessive deforestation and land clearings changed the land cover due to adaptations in land use. This has severe consequences on the Earth's climate. The concept of the anthromes represents a different perspective, where humans are viewed as part of the natural ecosystem. The attempt to explain the complex interaction between food availability, which relies on agricultural activity and population growth, has been made by numerous scientists already. The Boserup Theory is based on a positive feedback loop, as a raise in population density leads to an increase in productivity of agricultural production, which again results in a rise in population number due to innovational ideas and industrial development. The HYDE database, version 3.2 provides data on historical land use derived from the concept of the anthromes and on global population density for the time period of the Holocene. The aim of this research project is to test the Boserup Theory throughout the time of the Holocene on a global scale by analyzing the results of the HYDE database v. 3.2. The results of this study revealed that in regions of steady population growth a direct correlation between an increase in population number and a change in land use is given. A pattern in land use change was derived which applies globally, apart from arid regions. When remote and populated woodlands make up the original land cover, they are changed to residential woodlands, which again are substituted by rainfed croplands followed by rainfed villages, before mixed settlements and urban dense areas arise. However, geographic location, including climatic conditions and initial surface cover play an important role regarding the early agricultural development. Therefore, spatial and temporal divergences from the pattern can be observed.

key concepts: Land use change, HYDE database version 3.2, Anthromes, Boserup Theory

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1. Introduction

Land use change, often accompanied by land cover change is a severe threat to the terrestrial biosphere (Ramankutty & Coomes, 2016). Land cover change, on the one hand, refers to any kind of restructuring of the Earth's surface. For example, forests, agricultural areas or any kind of water bodies. Land use change, on the other hand, shows restructuring of the Earth's surface with anthropocentric origin. The beginning of the Holocene (10,000 BCE) marked the point of concentrated land use change caused by a rise of agricultural activity as humans started to settle down. A change in lifestyle from a nomadic culture, based on hunting and gathering for living, to constructing first settlements and growing plants, as well as keeping livestock, was the essential shift (Ellis, 2011; Klein Goldewijk et al., 2017a).

1.1 Land Use Change due to Agriculture

The intensification of agricultural activities also increased the impact on the global climate (Foley et al., 2005). This is caused by changes in land cover, such as deforestation (Foley et al., 2005; Salinger, 2007). Today, humans are changing the land cover to adapt it to their needs, because croplands, plantations and pasture lands guarantee a stable and reliable food source. However, more than half of the agricultural land is negatively impacted by soil degradation, because bare soils are exposed to precipitation and wind (Copernicus, 2019). Furthermore, land use change is driving biodiversity loss, due to destruction and reorganization of ecosystems (Millennium Ecosystems Assessment, 2005). Additionally, the challenge is that the global population is still expanding and growing, and the agricultural sector needs to keep up producing food to accommodate the demand (FAO, 2017). Moreover, an increase of agricultural activity entails a rise of greenhouse gases (e.g. methane (CH₄) and carbon dioxide (CO₂)), which are well known drivers for global warming, as they contribute largely to the greenhouse gas effect (Salinger, 2007; Ramesh et al., 2017). Finally, changes in the Earth's surface cover have severe consequences on the Earth's climate, as vegetation covers support to maintain a balanced climate (Ramankutty & Coomes, 2016). These two components are an interacting system, which affect each other's development. Dynamics in local land use have impacts on global scales (Ramankutty & Coomes, 2016). However, when changes in climate occur, such as an increase of dry periods, adaptations in agriculture need to be performed. Climate is a complex system and numerous variables are essential to keep it in balance. For example, decrease in albedo caused by land cover adaptations alter the heat flows on Earth, due to shifts in the radiative forcing (Myhre & Myhre, 2003). However, biogeochemical cycles are further manipulated when natural ecosystems are not only removed, but also replaced by anthropocentrically constructed areas for agricultural purposes, such as grazing lands or croplands (Smith et al., 2014).

1.2 Anthromes & the HYDE database

Ellis and Ramankutty (2008) have approached the topic of land use change from a different and new perspective. On 75 % of the Earth's land surface, excluding regions permanently covered with ice, humans left traces of land use transformed for their purposes, which led to permanent transitions of ecosystems (Ellis & Ramankutty, 2008). From their point of view, the influence of humans on the natural environment needs to be admitted and accepted. Humans are not affecting natural systems by land use, but rather humans' influence on natural systems is accepted as the basis for this approach and builds up on it. This coined the term "Anthropocentric Biomes" or short "Anthromes". By performing a cluster analysis, a classification scheme of 21 different biome classes was derived, based on dense settlements, villages, croplands, rangelands, forests and wildlands for the year 2000. 18 of these are based on anthropocentric biomes and three on wild and untouched biomes (Ellis & Ramankutty, 2008). Table 1 displays all anthrome classes which are included in this project.

Table 1: Anthromes classes used as input data for the HYDE database, version 3.2 (Klein Goldewijk et al., 2017a).

Classification of the Anthrome classes for the HYDE database, version 3.2:	
Dense settlements	Rangelands
11. Urban settlements	41. Residential rangelands
12. Mixed settlements	42. Populated rangelands
	43. Remote rangelands
Villages	Seminatural
21. Rice villages	51. Residential woodlands
22. Irrigated villages	52. Populated woodlands
23. Rainfed villages	53. Remote woodlands
24. Pastoral villages	54. Inhabited treeless & barren lands
Croplands	Wildlands
31. Residential irrigated croplands	61. Wild woodlands
32. Residential rainfed croplands	62. Wild treeless & barren lands
33. Populated croplands	63. Ice, uninhabited
34. Remote croplands	

A recent study had the aim to apply the concept of anthromes on the latest version of the HYDE (History of the Global Environment) database, version 3.2 for the entire time period of the Holocene, visualizing the development of the anthrome biomes on a global basis alongside with the trend of population number and density (Ellis et al., 2020; Klein Goldewijk et al., 2017b). As described above, the beginning of the Holocene is the starting point of increased agricultural and moreover, anthropocentric activities. Therefore, this time period is specifically important for scientists, with social and natural science backgrounds including archaeologists, anthropologists and historians, in order to understand the shifts in climate development, induced by human impact.

1.3 Development Theories

Numerous development theories were introduced by economists and scientists throughout history, with the aim to explain the interaction between food availability and population growth. Ester Boserup published her theory about how the rise of population density and agricultural intensification are interlinked in 1965 (Boserup, 1965). Her approach challenged the popular and often discussed development theory of Thomas Malthus, which was first released in 1789. Malthus warns of the point, when the maximum carrying capacity is reached and the availability of finite resources is exhausted, as it might lead to a collapse of the population (Malthus, 1789/1990). In contrast, Boserup introduces the hypothesis that population growth and agriculture can be explained with a positive feedback loop. In her opinion, innovational ideas and industrial development prevent stagnation or even collapse of population growth. Therefore, a rise in population density results in an increase of farm productivity (Boserup, 1965).

1.4 Problem Definition & Knowledge Gap

A great number of research institutes and scientists have tackled the topic of land use and land cover change in the past years, as natural land and soils make up the basis of survival for humans and any other terrestrial species. The consequences land use change has on climate change is alarming and therefore, this is a frequently studied and discussed topic. The importance of the issue related to land use change and its effects on climate are also reflected in one of the 17 Sustainable Development Goals (SDGs), published by the United Nations in 2015 (UN, 2020a). Goal number 15 deals with the topic of 'life on land' and the main targets of this goal are the protection and conservation of natural ecosystems. Moreover, it aims to reduce desertification and biodiversity loss (UN, 2020b).

Until today, no comparable data like the output of the HYDE database, version 3.2 which covers the entire time period of the Holocene, has been published. Even though, some authors such as Salinger (2007), Ellis et al. (2010) and Klein Goldewijk (2017), have already dealt with the topic of the influence of agriculture during this time period, nobody has based their analysis on the dataset, which results from running the HYDE database, version 3.2. Furthermore, the Boserup Theory has never been used as a base of analysis for this dataset. Therefore, this project has the aim to close this knowledge gap and provide more information regarding land use change patterns in the epoch of the Holocene.

1.5 Research Aim & Scientific Relevance

The objective of this study is to identify development patterns based on the Boserup Theory throughout the time of the Holocene on a global scale by analyzing the results of the HYDE

database, version 3.2. Transitions in land use change patterns are therefore the focus of this work. Based on these ideas, the following research questions were derived:

1. Where can land use change patterns according to the Boserup Theory be detected based on the anthromes concept for the time period of the Holocene?
 - a. During this time of development, which pattern of land use change can be observed?
 - b. What regional and temporal differences can be discovered?

Besides the scientific relevance of this study, this topic is also interesting from an ecological point of view. Therefore, these results are not only of importance for the scientific communities. Also, other stakeholders are interested in research about anthropocentrically caused changes in climate and land use. Actors in the agricultural sector, like policy makers and agricultural enterprises can benefit from it. They can work more goal oriented, cost efficient and sustainable. New findings on land cover change can give evidence for wildlife protection and conservation of endangered ecosystems.

2 Methods

This section of the report introduces the research process and explains the used methods and well as the methods and techniques.

2.1 Basis of the Research Process

In order to perform this research project, the HYDE database, version 3.2 serves as main data source. The HYDE model itself provides data on historical land use, as well as historical and current population density as an open access dataset (Ellis et al., 2020). The model is derived from present statistical and historical records, which are updated regularly, as well as “land use allocation algorithms” (Klein Goldewijk, 2017b), combined with satellite imagery with a high geometric resolution (Klein Goldewijk, 2017b). The generated output is on a 5 arc-minute resolution grid for the entire time period of the Holocene. The anthrome classification is generated by applying a decision tree, which performs a cluster analysis. By running the data through it, specific anthrome classes are assigned (see Table 1), which can be presented as a gridded time series and are used for further processing. In order to guarantee the most convenient visualization, the temporal resolution is not consistent throughout the given time period. 1000-year time steps are used for the period up to 0 CE. The temporal resolution until 1700 is 100 years and from 1700 until 2000, the data is available for each decade. Finally, the years up to 2015 can be accessed annually (Klein Goldewijk, 2017a).

Besides the analysis of the HYDE database, version 3.2 data output, a literature research on development theories, land use and land cover change patterns, as well as on historical agricultural development was conducted. This has the purpose to understand the dynamics and results, which can be identified during the data analysis. The analysis of the HYDE database results was conducted in QGIS and Excel. QGIS is an open source Geographic Information System software that supports editing and analyzing geospatial data (Qgis.org, 2020). As a great number of the data output of the HYDE database are .asc-files, which contain information in raster format, it is convenient to process them in QGIS. For further statistical analysis the results were exported to Excel.

To start with the analysis of the data, the era of the Holocene was divided into five individual time periods, with the aim to analyze these periods globally due to their land use and population density development. This decision was based on the following criteria. Firstly, the varying temporal resolution throughout the dataset played an essential role. This is because in the more recent years the data have a higher input based on statistical figures, which guarantee a higher accuracy. Secondly, the agricultural development occurred in different phases, which are of importance when analyzing the evolution of land use as a result of agricultural activities. The

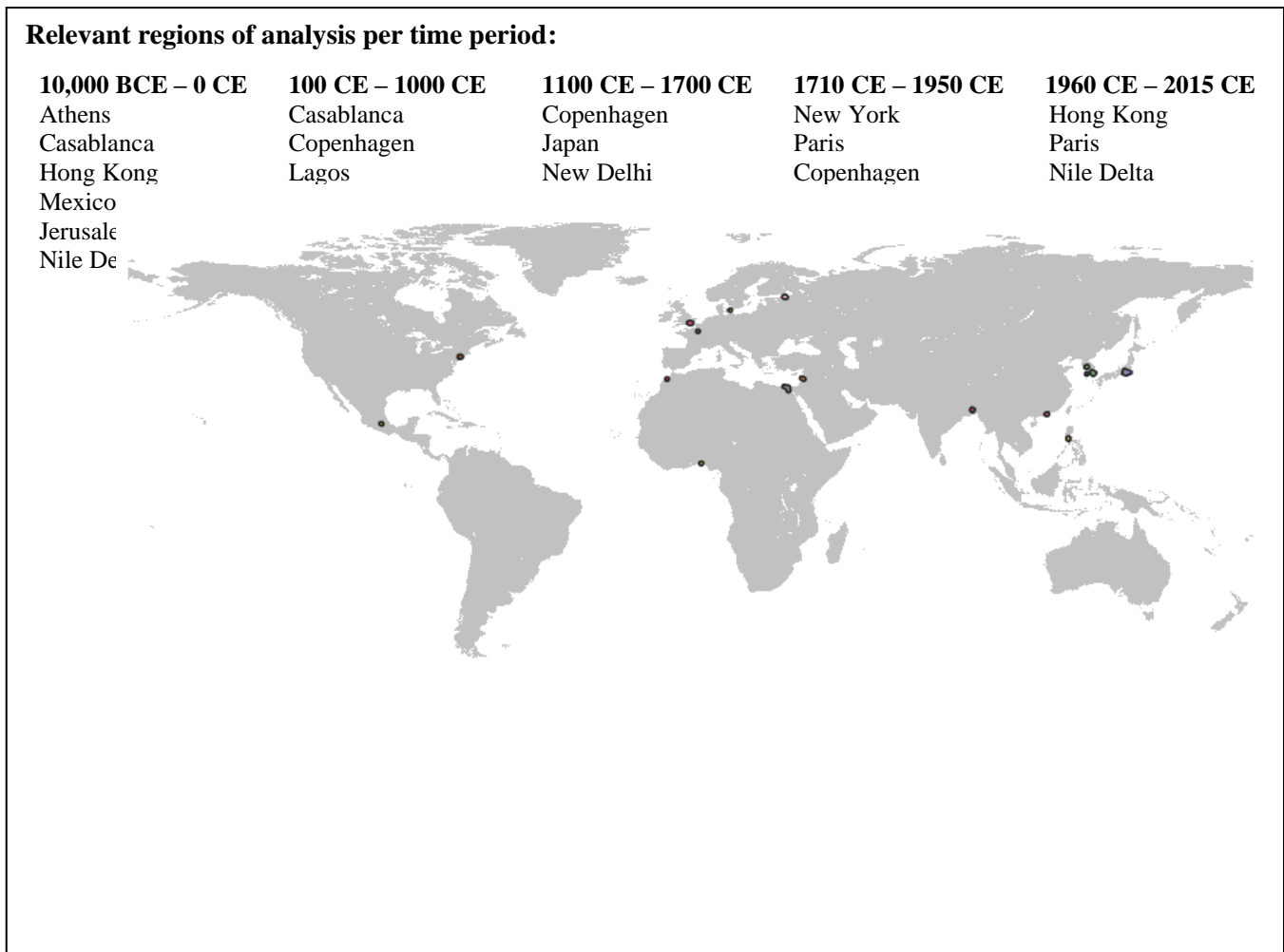
first agricultural phase ended with the beginning of the Holocene, when humans started to settle down (Klein Goldewijk et al., 2017a). The second phase is often called the “Neolithic Revolution” (Diamond, 1999). This agricultural period lasts until the beginning of the Industrial Revolution in the early 18th century. With the start of the Industrial Era severe changes to farming practices were made in a short span of time. As urbanization increased, the farming processes needed to become more efficient and profitable to feed the expanding global population. This development started in England and spread rapidly across the world (Masson, 2018). Inventions and adaptations during the war years of the 20th century led to improvements in machineries and fertilizers. These resulted in today’s intensive farming techniques with comparatively high productivity and efficiency. However, with even more severe consequences on the environment compared to earlier agricultural activities (Pinilla, 2012). For the above-named reasons, the data was split into the periods 10,000 BCE to 0 CE, 100 CE to 1000 CE, 1100 to 1700, 1710 to 1950 and the final time span lasts from 1960 to 2015.

2.2 Data Analysis of the HYDE Database

In order to derive the most relevant regions for each time period of this project’s analysis, the global population density maps, which are part of the HYDE data results, were consulted. For each of the above-mentioned time periods, the provided population density maps were added, and a new raster layer was produced in QGIS to obtain the change in population density for the single time periods. To highlight the regions with the most severe changes in population density throughout these time periods, contours displaying the population density were put on top of the maps. Then it was possible to choose the regions, which were most affected by a rise in population density during the selected time periods. This is of interest for this project, because the Boserup Theory is based on the assumption that a rising population density results in more productive agriculture. Which regions were selected for each time span and an overview where they are located is elucidated in Table 2. Next, a buffer was created to also consider the surrounding of the most effected regions, because as more people started to live in urban districts, the agricultural areas were moved outside the residential areas. These buffers are of the same radius for all defined regions. However, the overall size of the buffered polygons differs, as the highlighted area of high density consists of a varying pixel number depending on the region. These buffers were used as overlay masks to acquire the statistical data for these regional extracts. More precisely, besides population density and absolute population numbers, the anthromes making up the land cover of these regions were derived. This was the final step of the QGIS analysis, all further statistical analyses were conducted in Excel, such as the investigation of regional and temporal differences concerning patterns of land use change.

To distinguish the individual regions, they are named after the largest city within the polygon, if the region comprises more than two distinctive cities, it is named after the entire country, where it is located. The splitting of data into time periods had the purpose to find regions, where a comparatively high increase in population density has already occurred earlier in history and not only after the beginning of the Industrial Revolution. However, this classification is not considered anymore during the statistical analysis, because the overall timespan gives a better overview

Table 2: Chosen regions per time period for the analysis of this project.



3 Results

A statistical analysis was conducted in Excel in order to produce the results that are presented as bargraphs below in this section. Each displays the development of the anthromes and the population for a region. One communal legend is located at the bottom of the bargraphs.

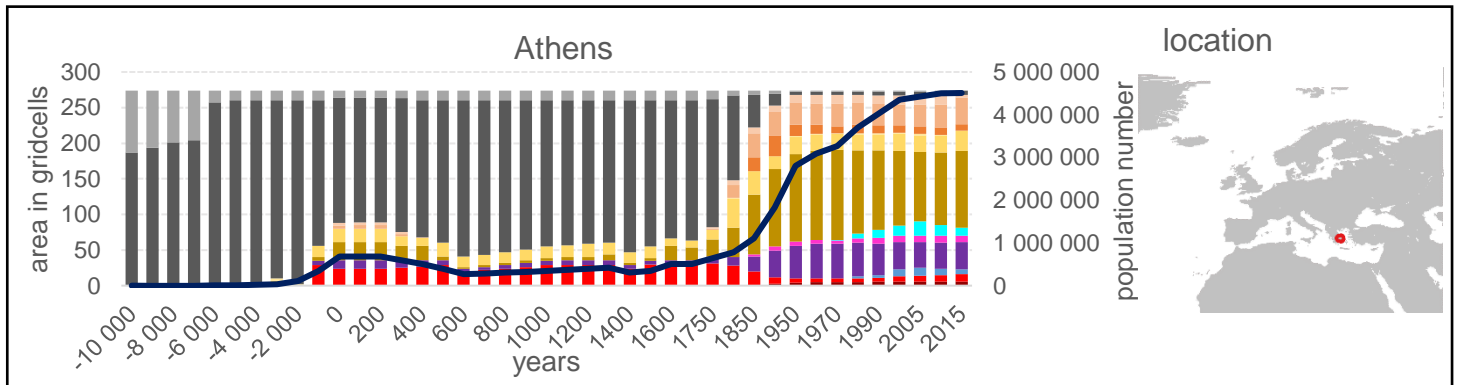


Figure 1: Anthromes development and population numbers for the period of the Holocene for the region of Athens, Greece (own representation).

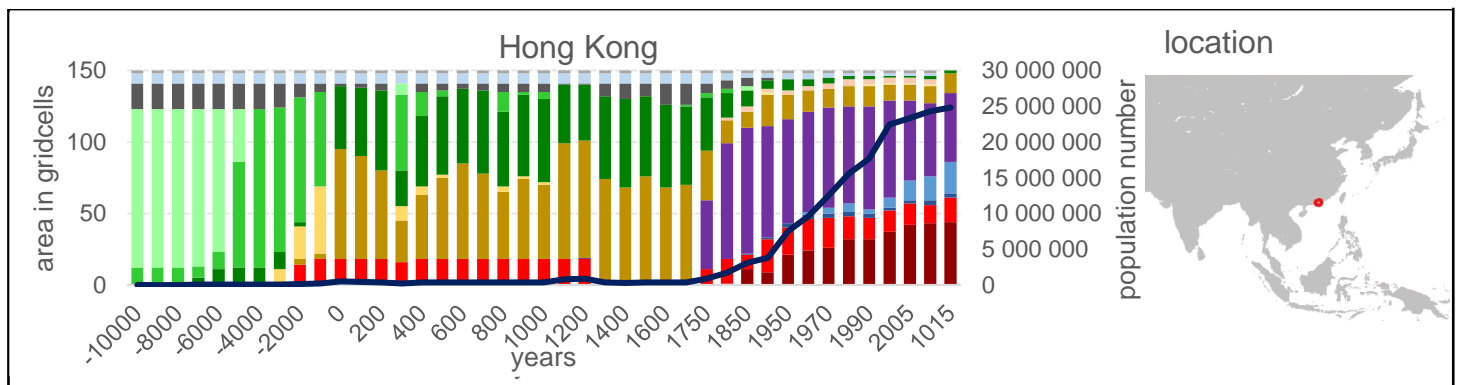


Figure 2: Anthromes development and population numbers for the period of the Holocene for the region of Hong Kong (own representation).

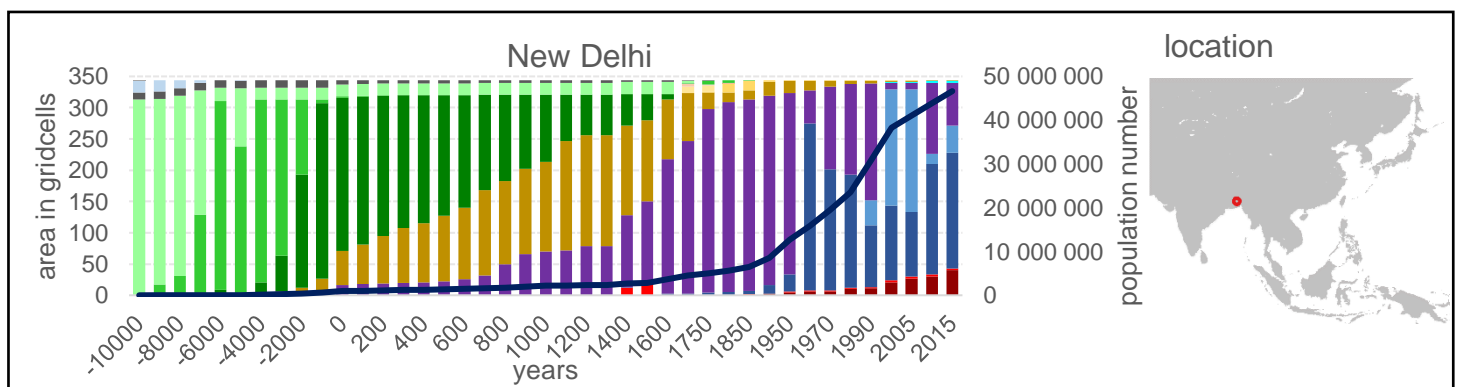


Figure 3: Anthromes development and population numbers for the period of the Holocene for the region of New Delhi, India (own representation).

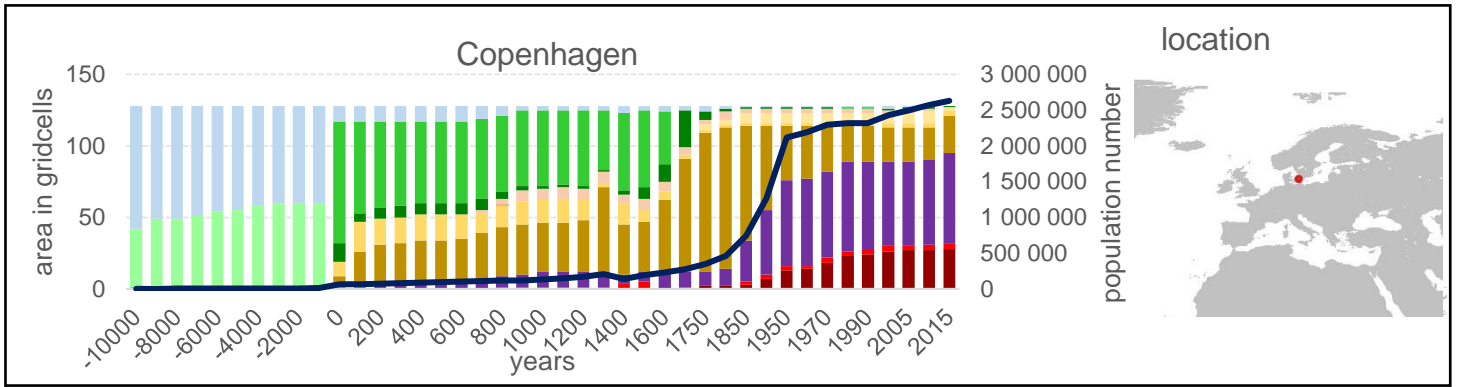


Figure 4: Anthromes development and population numbers for the period of the Holocene for the region of Copenhagen, Denmark (own representation).

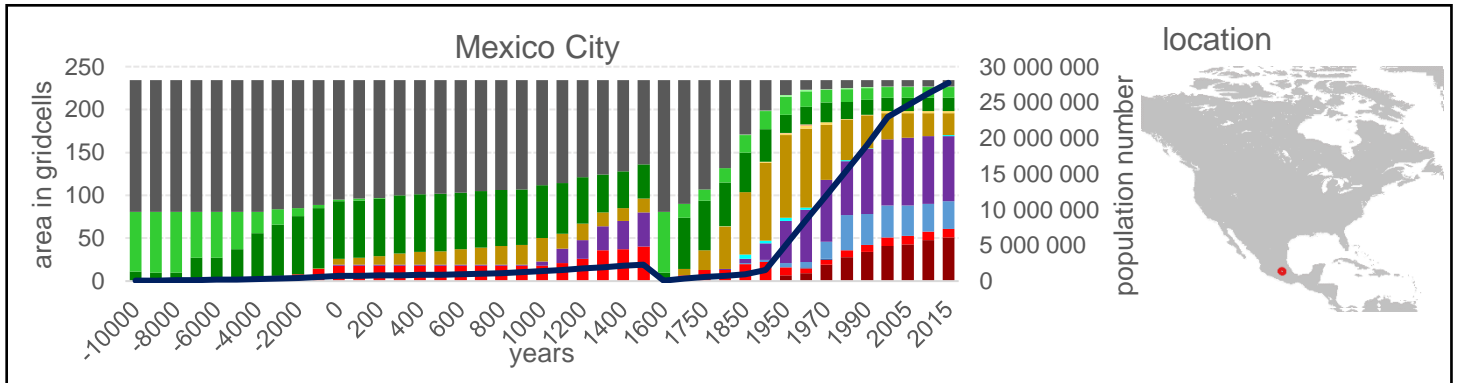


Figure 5: Anthromes development and population numbers for the period of the Holocene for the region of Mexico City, Mexico (own representation).

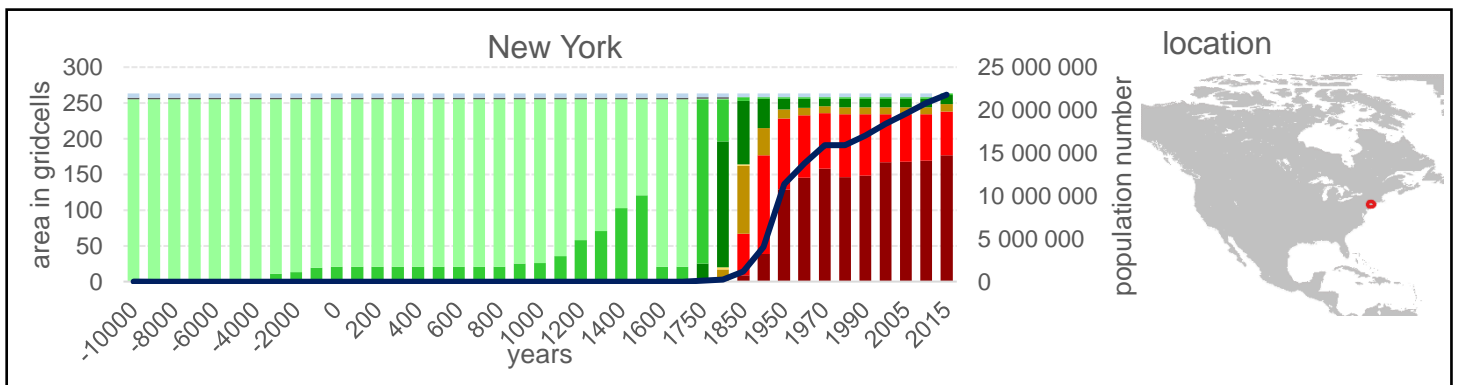


Figure 6: Anthromes development and population numbers for the period of the Holocene for the region of New York, United States (own representation).

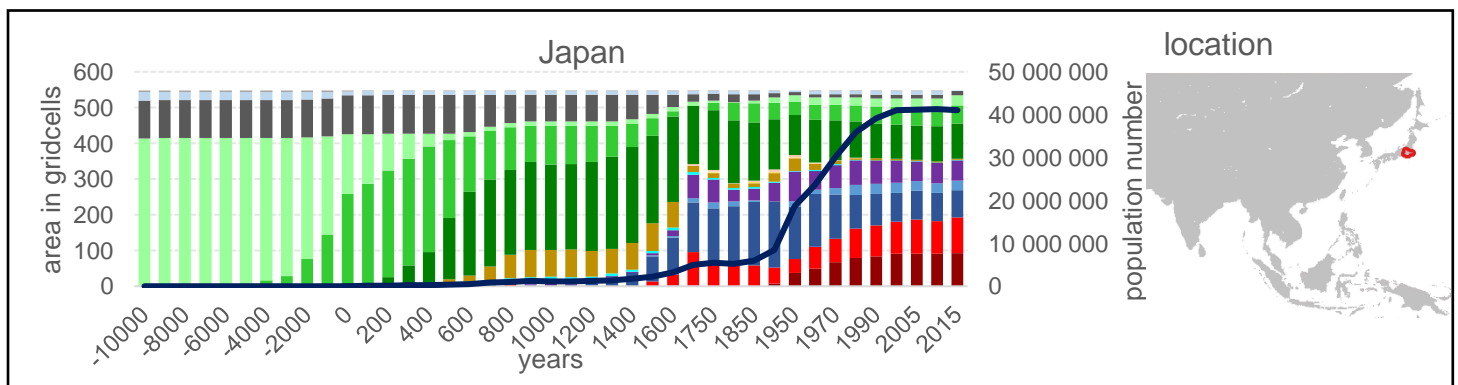


Figure 7: Anthromes development and population numbers for the period of the Holocene for the region of Japan (own representation).

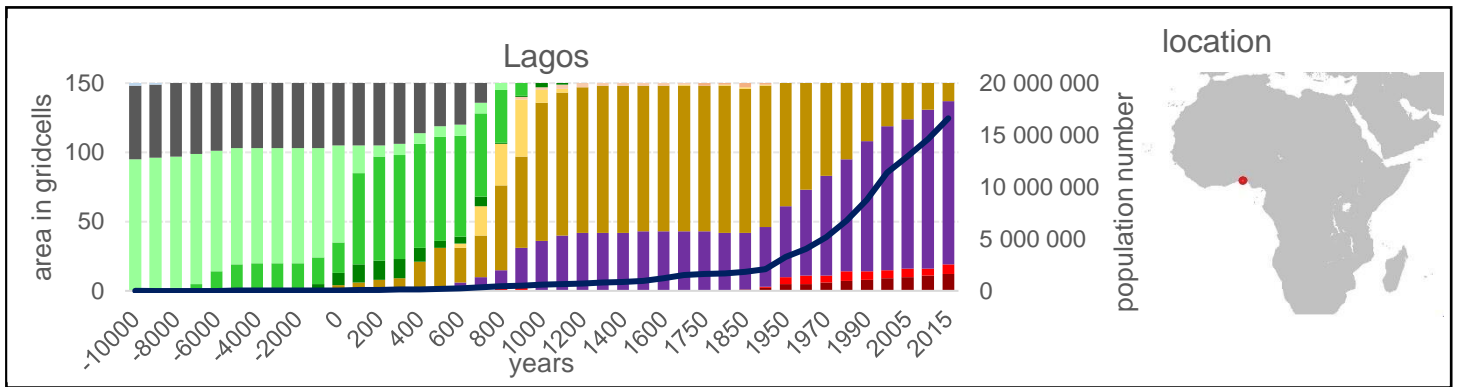


Figure 8: Anthromes development and population numbers for the period of the Holocene for the region of Lagos, Nigeria (own representation).

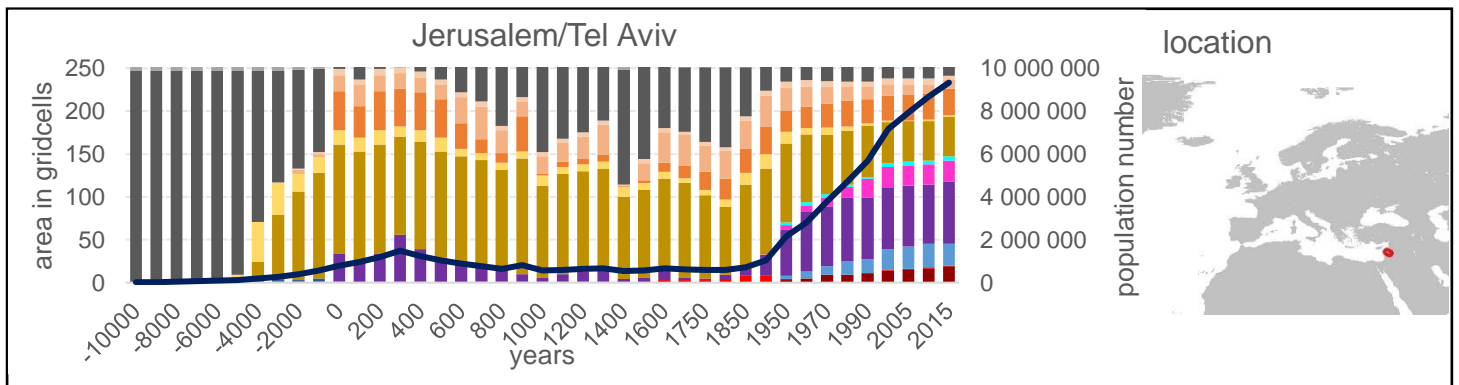


Figure 9: Anthromes development and population numbers for the period of the Holocene for the region of Jerusalem/Tel Aviv, Israel (own representation).

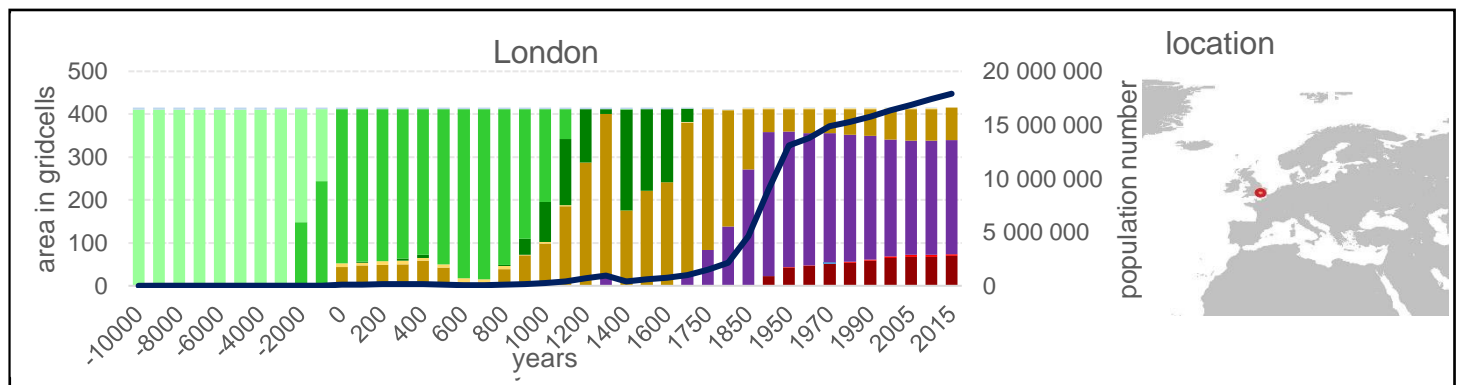


Figure 10: Anthromes development and population numbers for the period of the Holocene for the region of London, United Kingdom (own representation).

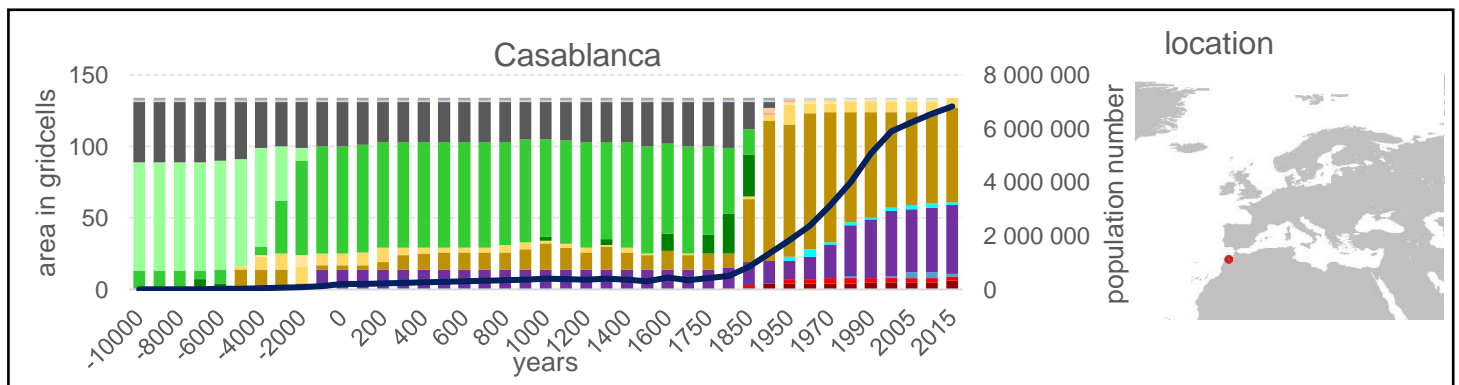


Figure 11: Anthromes development and population numbers for the period of the Holocene for the region of Casablanca, Morocco (own representation).

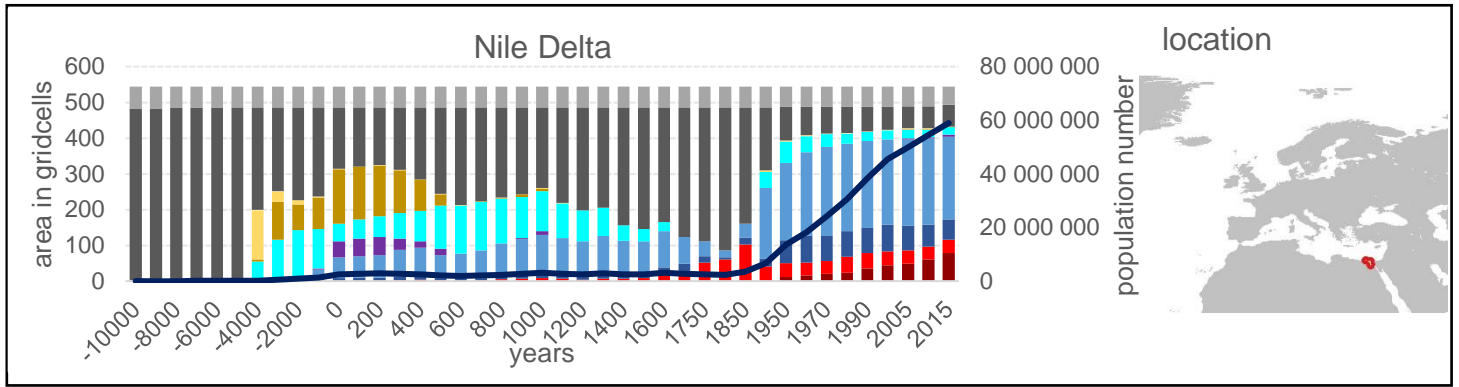


Figure 12: Anthromes development and population numbers for the period of the Holocene for the region of Nile Delta (own representation).

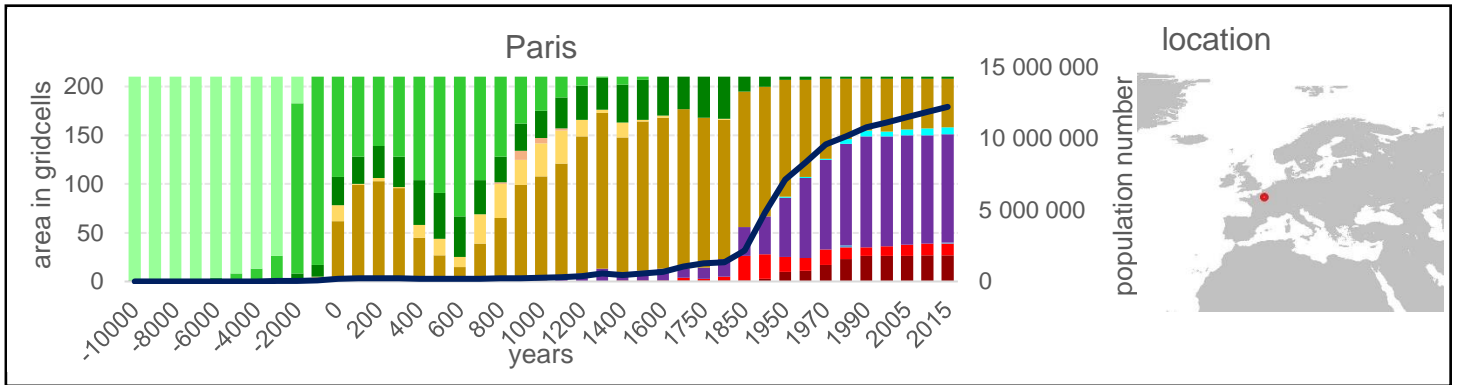


Figure 13: Anthromes development and population numbers for the period of the Holocene for the region of Paris, France (own representation).

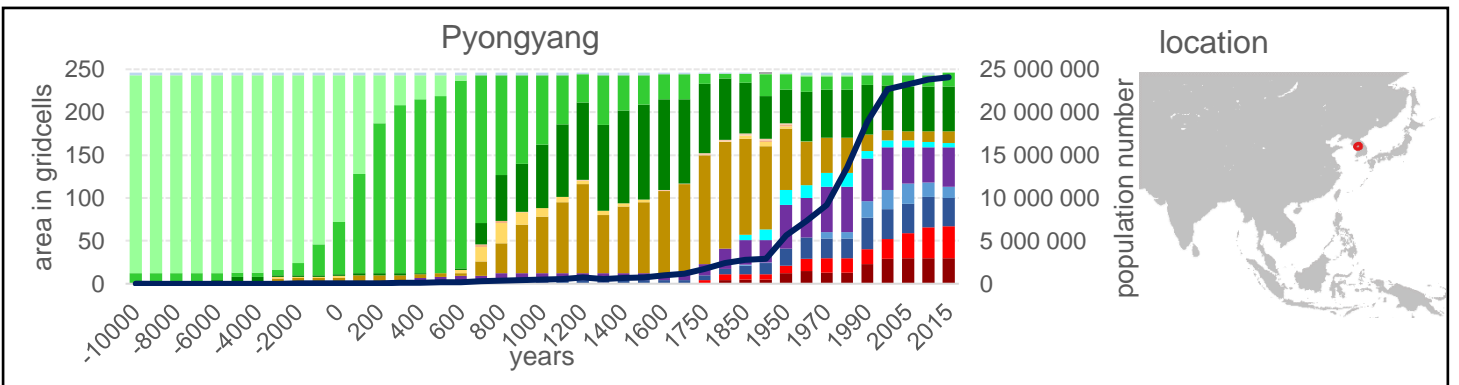


Figure 14: Anthromes development and population numbers for the period of the Holocene for the region of Pyongyang, North Korea (own representation).

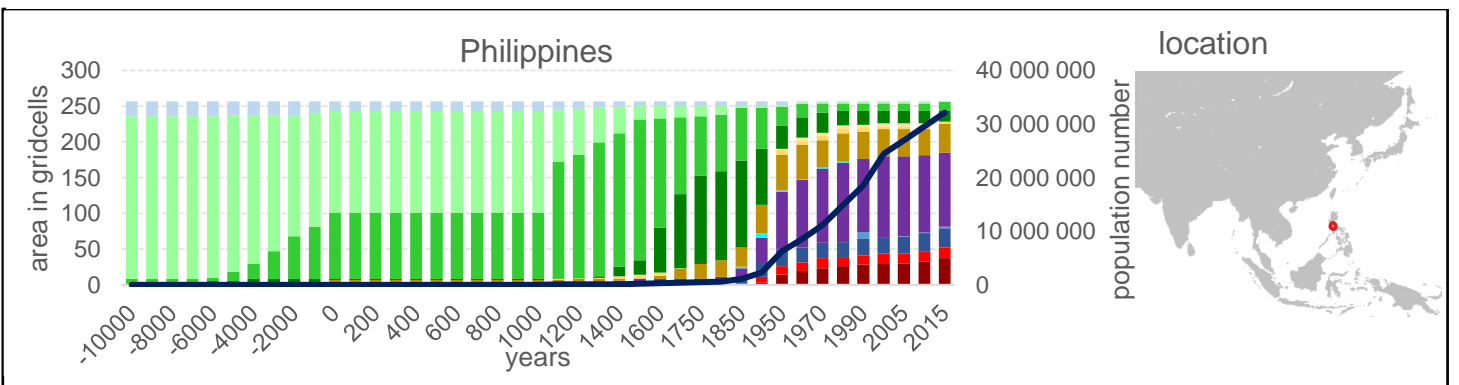


Figure 15: Anthromes development and population numbers for the period of the Holocene for the region of Philippines (own representation).

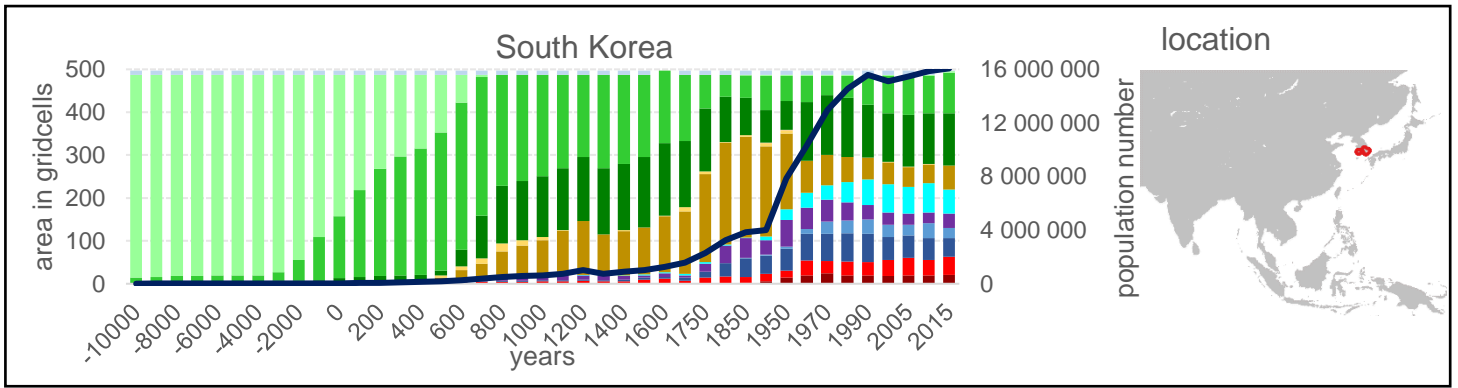


Figure 16: Anthromes development and population numbers for the period of the Holocene for the region of South Korea (own representation).

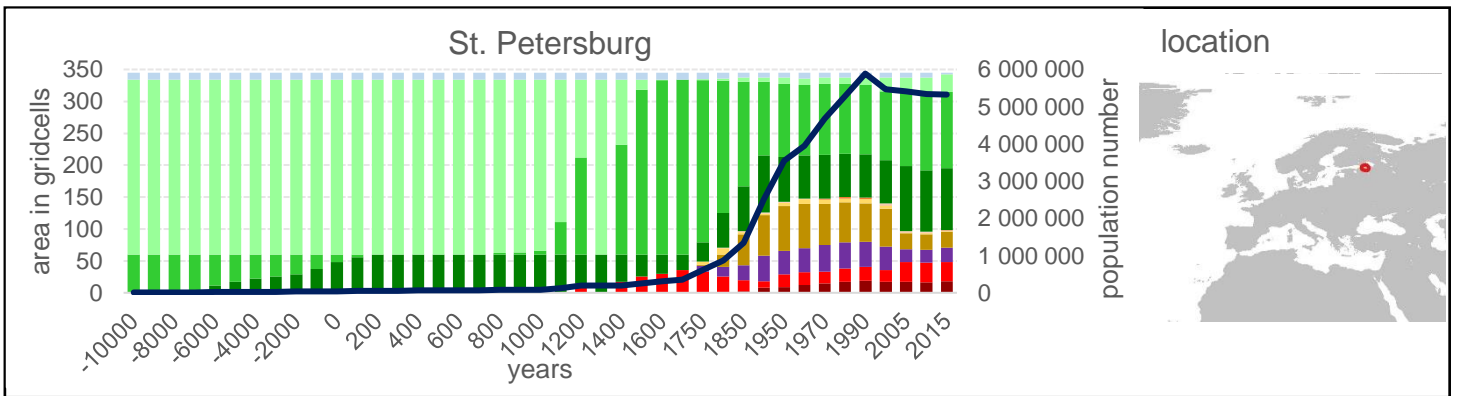


Figure 17: Anthromes development and population numbers for the period of the Holocene for the region of St. Petersburg, Russia (own representation).

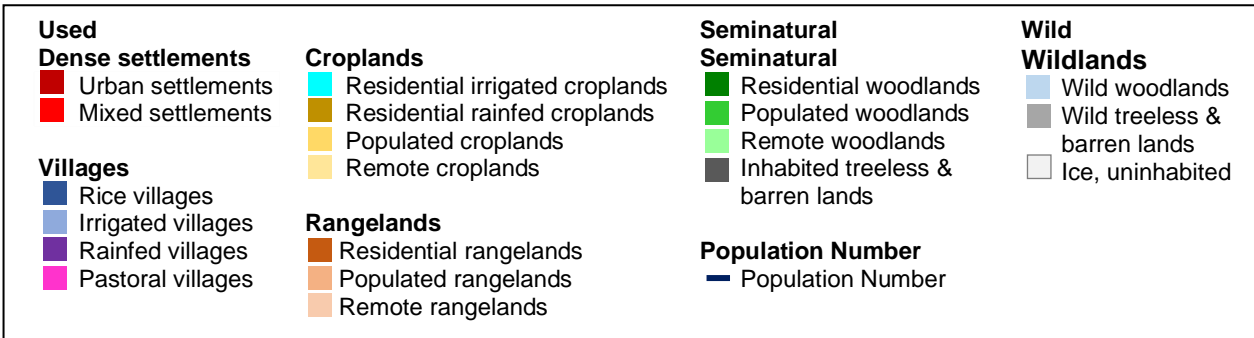


Figure 18: Legend of Figures 1-17 (Ellis et al., 2020).

By analyzing the data, it was possible to detect a pattern in land use change and in this case in a transformation of anthrome classes. This pattern occurs in a great number of the selected areas on a global basis.

The main observed pattern shows the following. The initial anthrome cover mainly consists of remote woodlands and inhabited treeless and barren land. If the population number is increasing at a consistent rate, areas of remote woodlands are over time substituted by populated woodlands and later residential woodlands. Next, residential rainfed croplands occur, followed by rainfed villages. Finally, mixed settlements and urban dense areas arise. According to the

results, areas of inhabited treeless and barren land are substituted much later than various kinds of woodlands. This pattern can clearly be observed in Figures 2-8, Figures 10 and 11, as well as Figures 13-17. In most of the selected regions this development starts with the beginning of the Holocene. Even though not all identified regions have the same surface area, the radius around the high-density areas is consistent throughout the individual polygons and the size of the polygons ranges between 128 and 544 pixels, but the land use change pattern can still be observed.

Temporal differences which show a specifically early change in anthrome classes can be observed in regions where prehistoric settlements were located. These regions could already register a rise in population numbers at the beginning of the Holocene. Examples are Athens, Hong Kong, Mexico City, Jerusalem/ Tel Aviv, Casablanca and the Nile Delta (see Figures 1, 2, 5, 9, 11 and 12). Furthermore, regions like New York (see Figure 6) where development took place in a short period of time, temporal differences can be seen.

Spatial differences from the regular pattern can be seen in regions where rice production makes up a great part of the agricultural activity. In Hong Kong, New Delhi, Japan, Pyongyang, the Philippines, and South Korea the rice villages can be detected in the Figures 2 and 3 as well as Figures 7 and 14-16 from on average, the 16th century onwards. Strong deviations from the main land use pattern can be observed in regions of arid climate. Of the selected areas these are featured by Athens, the Nile Delta and Jerusalem/Tel Aviv. These three regions do not have woodlands, which makes up the major base of the other selected regions of this project. Instead inhabited treeless and barren land is the predominant anthrome, as it is depicted in Figures 1, 9 and 12. No similar pattern between these three plots can be detected when comparing them with each other.

4 Discussion

The Boserup Theory has been investigated for specific regions on Earth by numerous researchers in the past already (Grigg, 1979; Netting, 1993; Turner & Shajaat, 1996). Codjoe and Bilsborrow published their findings in 2011, which revealed that agricultural practices in the sub-Saharan region of Ghana developed according to the ideas of Ester Boserup. So, an increase of agricultural activity corresponding to a rise in population density could be detected, which makes it possible to conclude that a direct correlation between these two factors is given. Also, the results of this research reveal that a steady increase in population number leads to a transformation of wildlands into seminatural or used areas, as named in the anthromes concept (Ellis et al., 2020). A pattern of land use transformation can be observed and derived when analyzing the data. This pattern emerges in numerous areas of the selected regions all over the world with only some exceptions.

4.1 The Main Development Pattern

The course of appearance of each anthrome in the main pattern, which was described in detail in the result section, depends on the development of the individual regions. Nevertheless, it can be generalized that in case of a stagnation in population numbers, also changes in landcover slow down. Even if a decrease in population occurs, this is also represented in a decline of the land use change pattern development. In some cases, like Casablanca (see Figure 11) residential rainfed villages persist from 5000 BCE until today according to the data output of the HYDE database 3.2. In Japan and Pyongyang, in contrast, residential rainfed villages are almost entirely substituted by alternative anthromes. However, it can be collectively said, if an increase in population number occurs, rainfed villages develop. Furthermore, in all cases an increase in urban dense areas can be recorded after the beginning of the Industrial Revolution, when urbanization started to rise (Sachs, 2015).

4.2 Divergences from the Development Pattern

Also, spatial and temporal divergences from this main pattern can be detected. This can be explained by the fact that geographic location, including climatic conditions and initial surface cover, as well as the beginning of augmented human settlement play an important role regarding the early agricultural development.

Temporal differences are caused by early prehistoric cultures and can be found in regions, where they settled down before 0 CE. A condensed and shortened sequence of this pattern can be observed in New York. New York's first settlements are registered by the Dutch in 1609 (Miller, 2009). Since then, there has been a steady and fast increase in population number and density. This resulted in a very fast transformation of the anthromes. Even in this case, the

above-described pattern can be observed, but due to the extreme increase in population density no rainfed villages were constructed after the anthrome class residential rainfed cropland occurred, but rather mixed settlements and urban dense areas emerged.

Areas where rice is produced show spatial divergences from the main land use change pattern. 90% of the World's rice is produced in South-East Asia (GRiSP, 2013) and this is also represented in the selected regions of this project. An exception makes up Japan, where rice villages can already be seen in 1300 with a peak in 1700. However, according to literature, rice was already introduced to Japan at approximately 100 BC, which does not align with the results of the HYDE database, version 3.2. Furthermore, China is also known for its rice agriculture, but in the regions of Hong Kong only little rice is planted. This corresponds to the results of the HYDE database.

Regions of arid climate, which are characterized by the fact that potential evapotranspiration is exceeding precipitation values on a long-term basis (European Commission, 2019) are the only areas which do not show the above-described land use change pattern (see Figures 1, 9 and 12). Even though the development of Jerusalem/Tel Aviv and Athens are represented with a similar surface area and they both had a small peak in population number between 0 CE and 300 CE, no similarity except for their preconditions can be observed. However, it can be concluded that irrigation has a higher priority in these regions, especially in the Nile Delta. In these regions residential irrigated croplands and irrigated villages already occur from 4000BCE onwards, as the Nile works as the perfect irrigation source. Israel has a very diverse climate, but mostly focuses on non-irrigated dry farming methods and therefore irrigated villages can only be found sparsely, like it is also represented in the Figure 9 (Seligman et al., 1997).

The analysis of the data revealed a clear development in land use change over the time period of the Holocene, particularly in regions with steadily rising population numbers. The knowledge which anthrome class follows the other, when an increase in population numbers occurs, can be of great importance for regions, where less development has taken place yet and simpler farming methods are still applied. It is possible to analyze, which land use scheme is most established in further developed countries with similar preconditions, based on geographic and climatic, as well as demographic preconditions. By doing this, less developed countries do not need apply farming methods, which have also been used by more developed countries in the past but abandoned after a certain period of application. This process could help less developed countries to generate a more efficient and sustainable land use system. However, this must be regarded critically, because it is not confirmed that the process developed countries are

undergoing now is the optimal method and current concepts might be abandoned in the future again.

4.3 Accuracy and Limitations of this Project and the HYDE database

When observing the results, it needs to be remembered that the HYDE data, version 3.2 is based on collected historical evidence and statistical data. The data input is not consistently precise, and algorithms are used to complete and produce the global dataset. The full data set is updated on a regular basis to improve the database and its output (Klein Goldewijk, 2017a), but still the database needs to be viewed as a project in process (Ellis et al., 2020). It is known, based on archeological and historic evidence that in several regions around the world, intensive agriculture occurs comparatively late in the HYDE database, version. 3.2 (Stephens et al., 2019; Ellis et al., 2020). Furthermore, this dataset is planned as a global dataset and used by scientists for long term climate models such as CO₂ models. Therefore, its primary purpose is not to look at specific small-scale regions and this needs to be kept in mind when analyzing the data for this project. Still, the detected pattern, which can be found in regions with an increase in population number, throughout the entire Holocene on a global basis can still be seen as a reliable result, even though it needs to be handled with care.

The HYDE database, version 3.2 does not imply a reason for changes in anthrome cover. Therefore, it needs to be remembered that, for example deforestation can be the result of various activities, with not only agricultural purposes. For sudden changes in development of population number and anthrome cover reasons like war, natural disasters and epidemics need to be considered. For example, The Black Death could be the reason for the fall in population number in Europe between 1300 and 1400 (Howard, 2019), as this was the time when this plague reached Europe (see Figures 4, 10 and 12). In some cases, a decline in population number also leads to a negative progress in the observed land use change pattern. In Figure that shows the development of Mexico, the fall of the Aztec Empire in 1521 can clearly be seen (Hernández, 2018) in a drop in population numbers between 1500 and 1600. Also, the anthrome development collapsed and shows only populated and residential woodland for 1600, but a fast transition in anthrome classes follows when the Spanish rebuilt Mexico City.

5 Conclusion

Land use change and land cover change are frequently seen as extremely harming for the environment. These processes are often caused by agricultural activities, which increased at the beginning of the Holocene when humans started to settle down first (Ramankutty & Coomes, 2016; Ellis, 2011; Klein Goldewijk et al., 2017a). The approach of the anthromes admits and accepts the influence of humans on the natural environment. Based on this idea 21 anthrome land cover classes could be derived (Ellis & Ramankutty, 2008). These are also the base of the HYDE database, version 3.2, which applies the approach of the anthromes on the entire time period of the Holocene alongside with the development of population numbers (Ellis et al., 2020; Klein Goldewijk et al., 2017b). By analyzing the results of the HYDE database, version 3.2 in QGIS and Excel, it was possible to answer the main research question and its subquestions, which are stated in the introduction.

The Boserup Theory supports the assumption that the interaction between food availability and population growth can be explained with a positive feedback loop. This means that innovational ideas and industrial development support a rise in population growth. When analyzing the results of this study, it is possible to conclude that a direct correlation between an increase in agricultural activity and a rise in population growth is given. Similar land use change patterns can be observed on a global basis in regions, where a steady increase in population growth is persistent. The main sequence of anthrome classes is consistent. Areas of remote woodlands and populated woodlands are changed over time into residential woodlands. These are again substituted by rainfed croplands followed by rainfed villages before mixed settlements and urban dense settlements develop. However, the geographic preconditions and the population's growth rate influence the pace of the pattern. Furthermore, for areas of arid climate this pattern does not apply. This could be due to the special climatic conditions and nutrient poor soil (Schultz, 2016).

Also, other minor regional divergences of the above described pattern were detected in the course of this study. For example, in regions of South East Asia, where rice production is a predominant agricultural activity, rice villages emerge concurrently or shortly after rainfed villages. Moreover, temporal differences in development can be observed. Late developing regions like New York in North America run through the pattern in a comparatively short time period of 400 years, because of a vast increase in population numbers and because European settlers already had the knowledge and skills to produce agricultural products.

However, as only certain regions, which show an increase in population numbers, have been analyzed in detail in the course of this project, it would be of interest if any other land use

change patterns exist in different regions. Future research could also concentrate on what population number or density needs to be reached that a new land use concept is applied. As little changes in anthrome classes can be observed when there is a stagnation in population growth, but from a certain growth rate onwards, also anthrome classes develop.

The findings of this research project are not only of importance for scientists, the results can be of high value to contribute to more sustainable anthropocentrically induced land use change. Regions could use the most suitable agricultural cultivation methods which support and suit their demographic development best. This approach could help to reduce emissions globally, because more sustainable farming and land use methods can be applied and also a more even, global distribution of agricultural products could be targeted. However, to accomplish this the HYDE database, version 3.2 can work as a primary data source, but the uncertainty in the dataset needs to be handled with care.

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Appendix A: Log Book Entries

Entry 1 - April 24th, 2020

This week's aim was to get more familiar with the provided HYDE database data in Excel and QGIS. I also started to design a schedule for this project with a timeframe of 10 weeks. The end result will be included in next week's logbook entry.

This Wednesday the first peer group meeting was held. It was very interesting to hear about the different projects and their aims. I am sure that we can help each other productively, because we all come from different study backgrounds and have different skills, which can be helpful for others. I believe that working in peer groups is a very nice approach to learn from other students and ask them for advice. As a group we decided to communicate via a WhatsApp group and hold further video meetings in MS Teams. When we discussed the expectations everyone has for this course, we came up with different expectations. However, we agreed that this course is a great practice to write our thesis next year and we expect it to be a guided research course that means that we can ask each other and our supervisor for help in case we are struggling with the assignment. Furthermore, we discussed that this course is a great opportunity to practice for future situations, when we might work in teams and should ask our colleagues for help, advice or their opinion. All in all, I am looking forward to this course, my project and future team group meetings.

Entry 2 – May 1st, 2020

This week I finished the time planner for this project, which can be found in the attachment and I also set up a document for the report. Furthermore, I continued to investigate the HYDE database data in Excel and QGIS. Everything is working well so far!

Entry 3 – May 8th, 2020

During the past week I continued to work with the data of the Hyde database. Specifically, comparisons of changes in anthrome classes in specific regions. Due to other activities I could not progress as much as hoped, but everything is working well!

Entry 4 – May 15th, 2020

This week I tried to put two focuses. Firstly, I tried to continue with the analysis of the HYDE database results, where I encountered some troubles because of the huge amounts of data, which I solved by removing all the HYDE data output, which I do not need for the current research from my laptop to an external storage. Secondly, I continued the writing process of the final report. Except for minor challenges, where I learned a lot by solving them, everything is working well.

Entry 5 – May 22nd, 2020

After doing preparational work with the data in the past weeks I finally reached the point to overlap the population data with the anthromes data sets and I am looking forward to the results I will hopefully discover. Furthermore, I continued with the writing process of the report. Finally, I had a Skype meeting with Kees on Wednesday the 20th of May to discuss the progress of the project and ask him for feedback. Everything is progressing fine!

Entry 6 – May 29th, 2020

This week I managed to produce the first results for the years between 0 and 1700AC, which felt successful after the work of the past weeks. Furthermore, I know that I can apply the same procedure and work steps on the rest of the data as well. In the end it turned out a bit more complicated and work consuming than expected, because in order to achieve the final results I had take a lot of steps in QGIS. I am looking forward to the rest of the results and the conclusions I might be able to draw.