Master Thesis in Geographical Information Science nr 129

Dynamics of net primary production and food availability in the aftermath of the 2004 and 2007 desert locust outbreaks in Niger and Yemen

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2021

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Emma Bylund (2021). Dynamics of net primary production and food availability in the aftermath of the 2004 and 2007 desert locust outbreaks in Niger and Yemen.

Master degree thesis, 30 credits in Geographical Information Systems (GIS)
Department of Physical Geography and Ecosystem Science, Lund University

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Master thesis, 30 credits, in *Geographical Information Sciences*

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Abstract

The knowledge of desert locust plagues goes back to biblical times but it is just as relevant in 2020 with an ongoing outbreak in East Africa and the Middle East. The locusts pose a threat to agriculture, and by extent food availability, due to their high appetite, diverse diet and ability to migrate long distances in large swarms. More knowledge of the aftermath is required by the international donors to motivate their continued funding for locust control to prevent and fight future outbreaks. As many countries in the affected areas lack the economic resources to fund full-scale control measures, monetary contributions from donors are crucial. This master thesis aims to contribute to this topic by investigating the impact the 2004 and 2007 locust outbreaks had on net primary production (NPP) and food availability in Niger and Yemen, which are two of the poorest countries in the region. This is done with the use of a comparative and exploratory approach using geographical information systems, remotely sensed images and statistical methods. Key datasets in this thesis includes information on known locust locations, livelihood zones as well as food availability indices.

The result shows a decrease in NPP within both croplands alone and within all land cover types combined during the years of the outbreaks. The decrease was larger in Niger 2004 than in Yemen 2007. A reduction in NPP was also observed within all livelihood zones in Niger and almost all in Yemen. It can be seen that the decrease was greater closer to the known locust locations, which implies that the locusts did have an impact. Food indices in Niger 2004 showed an overall decline in food availability at the time, possibly in relation to the outbreak. The result of food indices in Yemen was less prominent as the country imports 75% of its food and is therefore more resilient against decreased food availability from national production compared to Niger.

Factors other than locusts could be the reason, or partly the reason, for the decreases in NPP and food related indices seen in the result. However, the incidents coincide in time and space and a relationship between them is possible. That said, the results of this thesis constitute a step towards generating knowledge about the consequences of the locust outbreak and presents a foundation for such research to be continued and improved upon. This is particularly relevant in light of the fact that donors often require more evidence of the negative impacts caused by locusts as a condition for receiving additional funding to combat future outbreaks.

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1. Introduction

Knowledge of locust plagues goes back to biblical times (Anyamba et al. 2005) and despite their small size, desert locusts (*Schistocerca gregaria*) can cause havoc when they gather in swarms. The desert locust is one of the most common species of locusts in Africa, the Middle East and Asia, and is a threat to agriculture due to its large appetite, diverse diet and ability to migrate long distances in swarms (Latchininsky 2013). Over 60 countries, covering 30 million square kilometers, are at risk of food insecurity during an outbreak where locust swarms could completely ruin millions of hectares of crops within hours (Renier et al. 2015).

Ample rainfall and subsequent vegetation provide favorable conditions for the desert locusts to breed and lays the foundation for an outbreak to arise (Roffey and Magor 2003, Anyamba et al. 2005). A preventive control strategy is to monitor areas where these conditions exist to enable early intervention and treating locusts in the field before they have the chance to multiply. Still, many countries become overwhelmed by locust upsurges and need international assistance (Magor et al. 2008). Several of the affected countries are amongst the world´s poorest and lack economic resources to finance full-scale locust controls. Instead, they rely on international donors and assistance to fund necessary measures to control the swarms. Lecoq (2001 & 2003) describes that the long and calm recession periods in between outbreaks weaken the control capacity and lower donors’ interest in terms of support and response time. For example, an early warning system noticed that a possible outbreak was about to emerge in West Africa in 2004, but Ceccato et al. (2007) argues that the action from the community and donors was too slow and too late to be able to prevent an outbreak from happening. This outbreak eventually became the worst in over 10 years where more than 12 million hectares of land were infested and caused significant losses within the agricultural sector of several West African countries (Anyamba et al. 2005).

Studies of the damage and costs of locust outbreaks have been considered too outdated and inexact (Lecoq 2001), and donors require more accurate estimates that can justify their funding (Lecoq 2003). Cressman (2013) also argues that even though the techniques for monitoring and managing locusts have advanced, the geopolitical and financial aspects remain a challenge to reach a sustainable preventive control. In my literature research for this thesis, I have come across several studies focusing on the reasons for outbreaks or on control methods (e.g. Ceccato et al., 2007; Cressman, 1998; Showler, 2002), and fewer studies (e.g. Thomson and Miers 2002) on their actual consequences. However, if there are more peer-reviewed studies that assess the negative impact of outbreaks on agricultural production and food availability, it is plausible that there would be more interest and resources in monitoring locusts and counteracting the damage they cause.

The intention behind this thesis was to help fill this knowledge gap by using a different approach than what has been done before. I will perform an exploratory and comparative study on two different outbreaks and focus on two of the most affected countries. I will use statistical analysis to investigate the link between the outbreaks and the aftermath in terms of net primary production and effect on food availability. I will focus on the two massive outbreaks of 2004 and 2007 within the two geographically separate countries of Niger and Yemen. The outbreaks and countries are spatiotemporally unconnected to each other and if a link can be discerned between their aftermaths, it could give us a good indication of the possible outcomes of future outbreaks. With a massive desert locust outbreak in East Africa as recently as spring 2020 (Johanson 2020), I believe that this topic is as important and relevant as ever.

To accomplish this investigation, I will make use of geographical information systems (GIS) and remote sensing, which have proven to be useful tools in other locust studies due to the possibilities of efficiently examining large areas (Anyamba et al. 2005, Liao et al. 2013). Livelihood zones from Famine Early Warning Systems Network (FEWSNET), as well as food indices from the Food and Agriculture Organization of the United Nation´s statistical database (FAOSTAT), will also be incorporated in the study to connect the results to food availability.

1.2 Aim

The overarching aim of this master's thesis is to investigate, through an exploratory approach, the consequences the 2004 and 2007 desert locust outbreaks had on net primary production (NPP) and food availability. The study region is limited to the countries Niger and Yemen and the study period is between 2001 and 2010.

1.3 Research questions

- RQ1: How did the locust outbreaks affect the countries' NPP, particularly of croplands?
- RQ2: Has there been any strong reduction in NPP within livelihood zones?
- RQ3: Can a link between food availability and locust outbreaks be determined?

1.4 Expected result

I expect to find a distinguishable effect on each country's NPP due to the locust swarm's appetite for crops, and by extension an effect on food availability.

2. Background

2.1 Study area

The study area is limited to the countries of Niger, located in West Africa, and Yemen, located in the Middle East. They are considered Least Developed Countries according to the United Nations. With a broad agricultural activity, consisting mainly of local self-supporting farmers, they are in a precarious situation with respect to locust outbreaks (FAO 2019, Ventura 2019). Both countries were highly affected by the 2004 and 2007 outbreaks, Niger especially in 2004 (Chongwang 2017) and Yemen in 2007 (FAO 2009a).

A large part of Niger is classified as hot arid (Köppen-Geiger climate classification: BWh), while the southern part is classified as hot semiarid (BSh). Yemen is mostly arid, where a large proportion of the country is classified as hot arid (BWh) and the highlands in the west are classified as cold arid (BWk) (Kottek et al. 2006). The average monthly temperature in Niger lies between 17 to 33 degrees Celsius with an average monthly rainfall between 0 to 75 mm, mostly falling between June and September. In Yemen, the average monthly temperature lies between 18 to 28 degrees Celsius with an average monthly rainfall between 5 to 28 mm falling during the rain seasons in April-May and July-Sept (The World Bank 2019).

Both countries rely highly on agriculture. In Niger, the most important cash crops are millet followed by sorghum and cowpeas. The most important crop types in Yemen are sorghum followed by wheat and millet (FAOSTAT 2019).

Figure 1 on the following page shows the geographical placement of the study area, included for localization purposes. The figure also presents the elevation in each country, where it visible that Yemen has a much more mountainous and varied landscape compared to Niger.

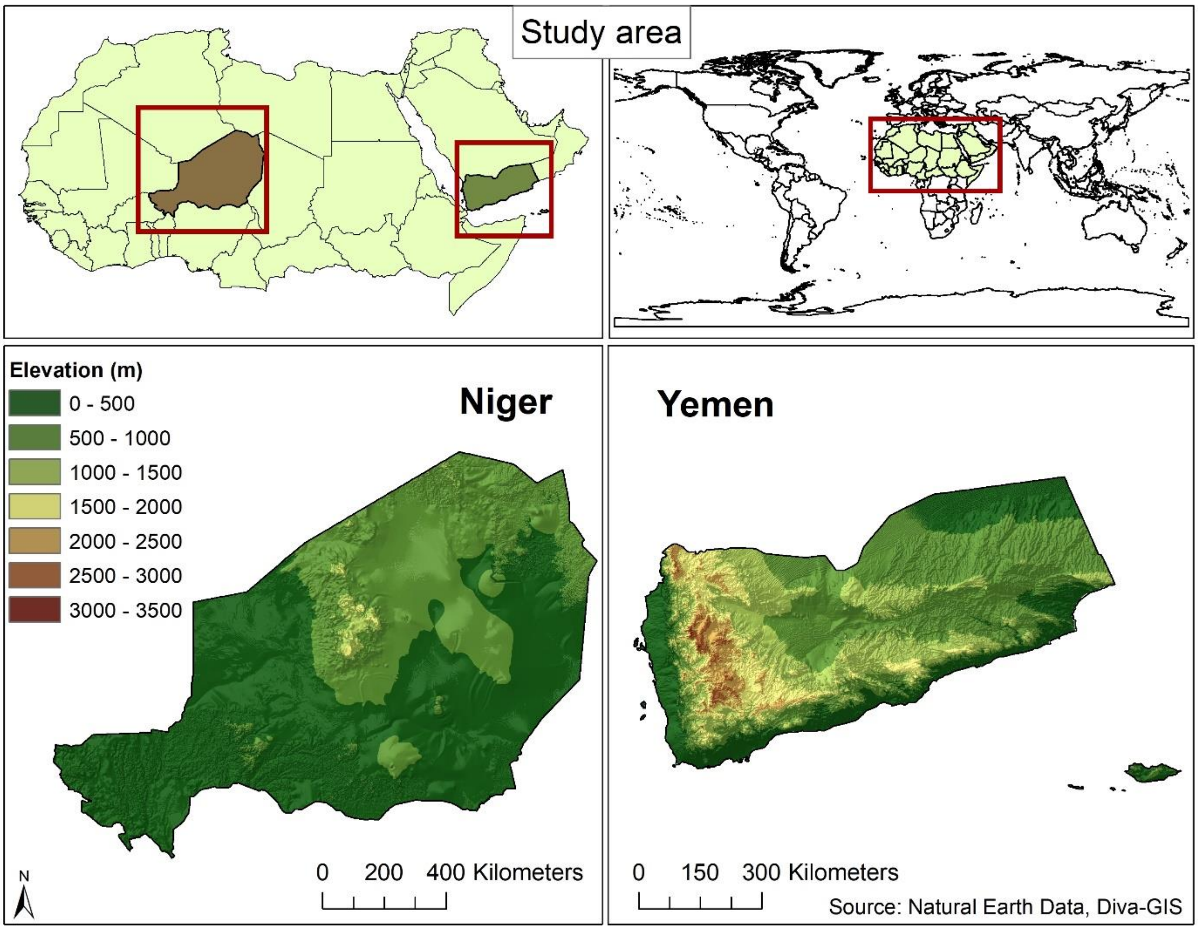


Figure 1. Geographic location of Niger and Yemen relative to northern Africa & the Middle East (top left) and to the world (top right). Bottom maps show the elevation in each country

2.2 Study period

The study period is limited to the years 2001 to 2010. A range of ten years is chosen to be able to compare data from the years of the outbreaks with the other surrounding years to see if any anomalies could be distinguished. This particular period was chosen as it includes data three years before the 2004 outbreak as well as three years after the 2007 outbreak. The study period is, in other words, centered around the years of interest.

2.3 Desert locust

Desert locust (*Schistocerca gregaria*) is a species of short-horned grasshopper (FAO 2009b). Unlike other grasshoppers, desert locusts have the ability of so-called density-dependent phase polyphenism (Renier et al. 2015). This means that changes in population density can in turn lead to change in phase in the locust lifecycle, which affects their behavior, physiology and morphology. There are two particular phases for a desert locust: solitarious and gregarious. The solitarious locust exists when populations are low and is characterized by camouflaging and a life on its own, avoiding others. The gregarious phase, on the other hand, exists when population density is high (caused by favorable conditions leading to higher breeding) and is characterized by the formation of large groups that have the ability to migrate either as marching bands or flying swarms (Simpson and Sword 2008, Renier et al. 2015). A swarm can fly up to 100 kilometers along the prevailing winds in one day, while a marching band can move up to 1.5 kilometers per day (Showler 2002). That capacity to mass-migrate long distances into unprepared areas, along with its high appetite on crops, makes a locust invasion a devastating and an unwanted pest that threatens agricultural resources (Magor et al. 2008, Renier et al. 2015). A desert locust can eat as much as its own weight of vegetation in one day and the FAO (2009b) makes the comparison that a 40 million locust-swarm, existing on 1 square kilometer, eats an equal amount of food as 35,000 people per day.

Over time, the desert locusts have adapted to very harsh dryland environments that have little precipitation, high temperatures and sparse vegetation. Their ability to quickly transform between phases when the conditions are more or less favorable gives them a higher chance of survival, asdoes their ability to migrate to areas with more food and away from possible predators. A desert locust lives around 3 to 5 months and includes the three life-stages of egg, hopper and adult (Cressman 1998). A female lays up to around 150 eggs at a time (depending on phase) and can lay up to three times in one lifetime. They lay their eggs in pods 10 to 15 centimeters below surface in moist sandy or clayey soils (FAO 2009b). In order to start the breeding process, they need specific ecological conditions. The most important factor is rainfall that provides moisture for their eggs to develop as well as contributes to more food through increased vegetation growth. Other factors that play a role are soil type, temperature (affects egg development), amount of vegetation for food and shelter and topography (which affect the rainfall pattern and its runoff) (Tappan et al. 1991). The number of locusts can increase ten times in just one generation (FAO 2004), and if the conditions are favorable, high breeding can lead to outbreaks which can mean devastating consequences for agricultural communities.

2.4 Locust outbreak

The phenology of the desert locust alters between times of low numbers, called recessions, and times of very high numbers, called outbreaks or a plagues (Magor et al. 2008). During recessions, the locusts are mainly present in about 30 countries around eastern Africa and south-west Asia that receive less than 200 mm of rainfall per year. Those 30 countries cover approximately 16 million square kilometers, while a plague could influence an area of over 30 million square kilometers within 60 countries, and through that affect one tenth of the world's total population. As mentioned in the previous section, an outbreak can occur when the conditions (in terms of rainfall, soil and vegetation) are favorable and cause the locusts to increase due to rapid breeding, high concentrations in one area as well as through gregarization (Cressman 2013). One swarm of desert locusts can contain 40 to 80 million adults per square kilometer and can cover an area up to hundreds of square kilometers (FAO 2009b). A plague can in turn include hundreds or thousands of swarms grouped together (Showler 2002). They eat all types of vegetation and a large invasion can cause severe damage to agricultural production of crops that can lead to negative consequences regarding food availability as well as on the environment caused by the chemical pesticides used against them (Lecoq 2003, Lazar et al. 2015). Lecoq (2003) also writes that damage to crops could lead to people abandoning their fields and induce rural migration. Less food for livestock, local desertification and a decreased total biomass are other potential consequences.

2.5 Locust outbreaks in 2004 and 2007

The specific outbreaks that were chosen to study in this thesis occurred in 2004 and 2007. The desert locust spread during those years can be observed in Figure 2. Niger was one of the most affected countries in 2004, with locusts present within most of the non-desert areas. Yemen was in turn one of the most affected countries in 2007, with locusts present across the entire country.

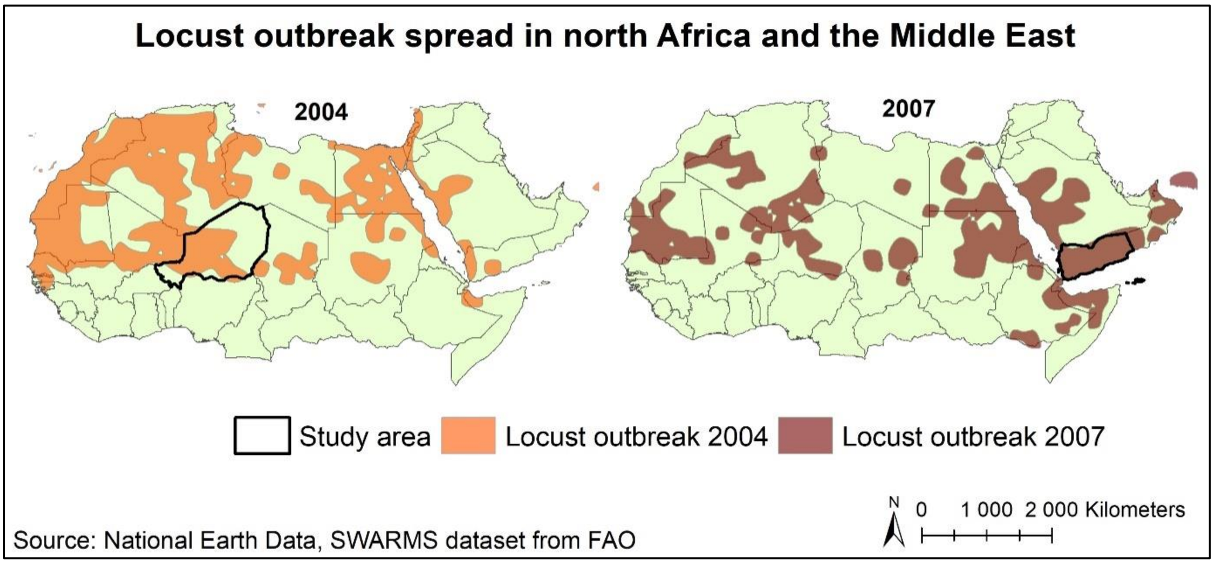


Figure 2. Spatial extents of the desert locust outbreaks in North Africa and the Middle East in 2004 and 2007

2.5.1 Locust outbreak 2004

Already in the autumn of 2003, four different locust outbreaks existed in different parts of north Africa, one of them being Niger (Cressman 2013). The following winter of 2003 and spring of 2004 had unusually heavy rainfall in northwest Africa leading to higher vegetation cover in the Sahel compared to the years before (NASA Earth Observatory n.d). Remote sensed imagery even showed that the limit of vegetation had moved 100 km further north than in earlier years (Cressman 2013). Several successful generations of locusts were possible and formed the basis for swarms and large infestations to develop in late summer. Three to four million hectare of land were infested by October (NASA Earth Observatory n.d). An early warning system existed but the affected countries had insufficient resources to respond to the invasion, and help from donors came much later when the situation was picked up by international news outlets (Cressman 2013). In the end, over 13 million hectares of land needed to be treated to stop the invasion (Lazar et al. 2015), and more than eight million people were affected in west Africa. About 80-100% of the harvest was ruined in some places, and the rate of food insecurity increased (Renier et al. 2015).

2.5.2 Locust outbreak 2007

Higher than average rainfall fell during March and May in Yemen which created favorable conditions for the desert locusts to breed and gregarize. Many swarms came in April and a breeding area of 31 square kilometers formed and was the beginning of the worst outbreak the country had faced over the previous 15 years (FAO 2008). Hopper bands developed in May, whose own eggs hatched in July and formed new bands and swarms (FAO Locust watch 2007). By August, high density swarms had invaded a larger part of the country and the Ministry of Agriculture and Irrigation warned that the outbreak had turned into a dangerous phase and is a threat to crops. They treated land through spraying pesticides but it took time before the invasion was under control (Reliefweb 2007). Some of the obstacles that hampered control strategies included difficulties to monitor the spread over the large, remote areas with harsh terrain as well as lack of adequate equipment (FAO 2008), and locals concerned about the effect of pesticides on them (Reliefweb 2007).

2.6 Locust control and the role of GIS and remote sensing

Unless the desert locusts are monitored in some way, there is always a risk for bands or swarms to develop and lead to potentially devastating outbreaks. The control strategies have gone from being just curative in the past to being more and more preventive, with emphasis on finding and taking care of the threat before swarms have the chance to form. GIS and remotely sensed imagery have been a part of this preventative strategy since the 1980s (Cressman 1998). As the locusts themselves cannot be detected on satellite imagery, the images could instead assist in locating areas of favorable ecological conditions where locusts are likely to breed and gregarize. Two of the most important and influential factors are green vegetation and rainfall leading to moist soils. Remotely sensed imagery can provide continuous data in near real-time and on a large scale (Pekel et al. 2011). The desert locusts are very hard to control as they are highly mobile and spread over extremely large, often remote, areas with difficult access due to rough terrain and underdeveloped infrastructure (Hemming et al. 1979). Narrowing down potential locust locations with satellite images aids the survey and control teams on the ground who are responsible for early detection and prevention. Some recent research has incorporated several ecological factors and implemented machine learning methods to effectively detect potential breeding sites (e.g. Gómez et al. 2019, Kimathi et al. 2020).

Other reasons for difficulties in locust control are the socio-political uncertainty that exist in some of the countries that are at risk of becoming affected. Armed conflicts makes it difficult to maintain ground surveys and monitor locust sites in time, which Meynard et al. (2020) discusses as a reason for the 2020 outbreak in the Horn of Africa to became so severe. Lack of periodicity in outbreaks also makes them hard to predict, and lack of finances and resources makes them hard to monitor and treat. The FAO is the only centralized transnational service when it comes to locust monitoring. They collect data from affected countries and analyze together with satellite imagery to produce forecasts and warnings and coordinate national control centers that perform the field surveys (FAO 2009b).

A GIS is not only useful in the preventive control strategies but it can also combine data of different types and from different sources, making it possible to effectively analyze large areas. It is also an effective tool for studying the ecological consequences of a locust outbreak and plays an important part in visualizing important information (ESRI n.d). A GIS together with remotely sensed imagery is a central tool in this thesis.

2.7 Locusts and climate change

Current literature discusses how much influence climate change has had in the rise of the 2020 outbreak and will have on future outbreaks. UNEP (2020) makes the connection that this outbreak happened after five years of higher temperatures than normal and that rain falling during late 2019 in parts of Africa were up to four times higher and linked to climate changes. Warmer temperatures improve the development of eggs, and a study of historical locust outbreaks detected that they tended to be more severe in times of hotter climate (Yu et al. 2009). With many of the African countries warming faster than the world average (Bishop 2017), that could mean more devastating outbreaks in the future within countries that already have weak economies. A possible future climate change scenario is also that rainfall in the Sahel area will increase and lead to more frequent outbreaks as more vegetation and moist soils means increased breeding opportunities and higher survival rate (Tratalos et al. 2010). A changed future climate could thereby mean both more frequent and severe outbreaks, which means that further research in potential incidence and mitigation scenarios, as well as continued funding are of high importance.

3. Data and Methods

3.1 Data

The datasets used in the analysis is listed in Table 1 below. The more specific datasets containing locust locations, NPP, Livelihood zones and food availability indictors are also described in more detail.

Datasets	**Type**	**Spatial resolution**	**Temporal resolution**	**Source**
Country borders	Polygon shapefile	-	-	Natural Earth Data
Land cover	Raster	300 m	Annual, 2004/2007	ESA CCI (2018)
Locust locations SWARMS	Point shapefile	-	Annual, 2004/2007	FAO Desert Locust Information Service
NPP (MOD17A3)	Raster	5 km	Annual, 2001-2010	NASA Earth Data (2019)
Livelihood zones	Polygon shapefile	-	2011	FEWS NET (2010)
Rainfall	Raster	27 km	Monthly, 2001-2010	PERSIANN (2019)
Population	Raster	2.7 km	2010	Worldpop (2019)
Food availability indictors	Comma-separated values	-	Annual, 2001-2010	FAOSTAT (2019)

Table 1. List of data used in the analysis

3.1.1 SWARMS dataset

The *Schistocerca* WARning Management System (SWARMS) is a geographical information system that includes data of the distribution of desert locusts since the mid-1900 and makes it possible to study their population dynamics over time. It became operational in 1996 and can also, in combination with other geographical layers, be used in decision making as a tool for risk analysis and investigating different control strategies against the locusts. The data are gathered by researchers or locust organizations and added to the GIS for viewing, exploring or downloading. Apart from when and where the locusts were located, also information about e.g. their life stage and surrounding ecological conditions are found in the database (Magor and Pender 1997). In this study, data from SWARMS containing the yearly desert locust distributions during the outbreak years was used. The data includes the life stages of hoppers, adults, bands and swarms.

3.1.2 Net primary production data

Net primary production (NPP) is the net carbon gained by vegetation over time. It is depending on factors as water, light, CO_2 and nutrients, where precipitation is the most limiting one in the study area. The measurement of NPP could be used for analyzing the amount of biomass on earth as well as changes over time (Chapin and Eviner 2007). As locusts consume vegetation and large outbreaks causes a loss in biomass, NPP could be an appropriate measurement to use in this study. Vegetation mass, in particular crops, are also highly related to food availability whereas NPP could contribute to the connection between locust outbreak and changes in food availability. NPP is most commonly calculated annually, which also was the temporal resolution chosen in this study to be able to compare the result with the yearly food availability indicators. The NPP data is captured by MODIS (Moderate Resolution Imaging Spectroradiometer) onboard NASA's Terra and Aqua satellites (Running et al. 2015).

3.1.3 FEWSNET livelihood zones

The Famine Early Warning Systems NETwork (FEWSNET) provides information on *market and trade*, *agroclimatology*, *livelihoods* and *nutrition*, all of which are connected to food security. They save this information in a knowledge database and have continuous monitoring of current food security, which they later use for analyzing and making forecasts of future outcomes. Next, they make food insecurity classifications of the anticipated future which are used as a support for decision makers in their work to prevent famine (FEWSNET n.d-b).

In this study, the FEWSNET livelihood zones (LHZ) are incorporated as a way to connect the results to food security in terms of availability of food. The countries are geographically divided into zones based on general livelihood patterns where the people share similar ways to earn their income and to access food. The differences in work opportunities and access to food also makes them differently vulnerable to crises, as for example caused by a locust outbreak. The coping mechanisms can also differ between the zones (FEWSNET n.d-a). Maps of the LHZ in Niger and Yemen respectively can be seen in Figures 17 and 18 in the appendix.

3.1.4 Food availability indictors from FAOSTAT

The statistical database of the Food and Agriculture Organization of the United Nations (FAOSTAT) provides free access to data containing statistics of various factors related to food and agriculture, divided by country. Examples that will be used here is statistics of yield and production of the most important crop types in each country around the years of the outbreaks. Also, food balance factors as annual import, export, stock variation and domestic supply quantity of cereals will be used as indicators of how the outbreaks may have impacted the countries food availability. The stock variation includes all variables that effect the quantity and shows net increases (minus sign) or net decreases (no sign) in the country's total stock per year. The domestic supply quantity includes production, import, export and changes in stock (either increase or decrease) combined and gives a good indication of the total supply to utilize (FAOSTAT 2017).

Food availability indictor	Description
Import	Annual import of cereals
Export	Annual export of cereals
Stock variation	Net changes in total stock of cereals per year. Includes all factors that affects the stock
Domestic supply quantity	Total annual supply of cereals available to utilize. Includes import, export, production and stock changes combined

Table 2. List of food availability indictors

3.2 Methods

3.2.1 Introduction to method

The method used and steps performed in this study are described in this section. Since there are not many previous studies on the aftermath of locust outbreaks using geospatial methods, an exploratory approach was chosen for this thesis. Several steps have thereby been undertaken to look at the problem from different angles where the result of one step led to the choice of the next. The software ArcGIS has been used for the geographical analysis and visualizations throughout the project. Below follows a chart of the workflow including the main steps performed. After a visualization of the known locust locations in relation to the land cover, the NPP Z-scores based on the study period were calculated for continued use for timeseries within croplands and the location of areas with strong changes. The NPP Z-scores were also used to compute time series of changes within LHZ and within different buffer zones around the known locust locations. This was followed by an investigation of how many people who live in the most affected zones and how food availability indictors as food balances and agricultural production changed around the outbreaks.

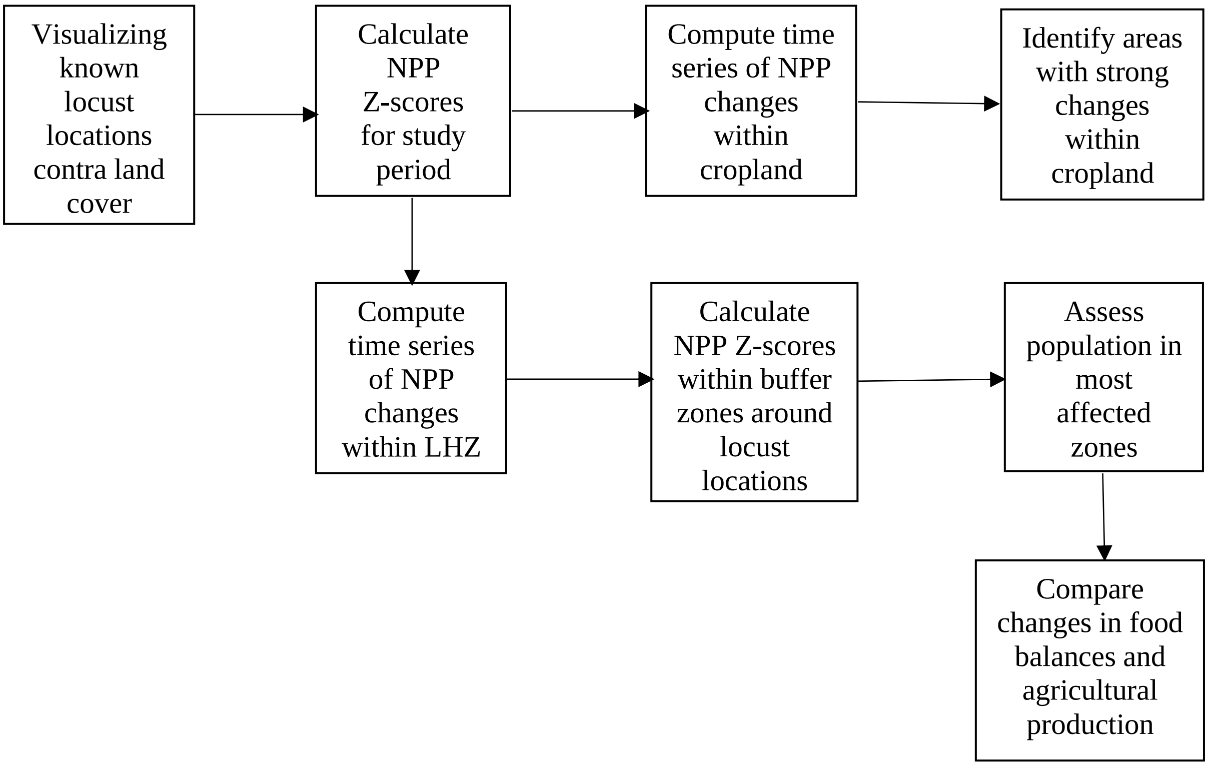


Figure 3. Workflow of the study

3.2.2 Research question 1

3.2.2.1 Visualization of locust locations and land cover

First, the known locations of locusts were compared against land cover type. This was done for locusts found during 2004 in Niger and during 2007 in Yemen. The land cover data used was from ESA CCI website (https://www.esa-landcover-cci.org/). The locust data used are the SWARMS dataset, and it is divided by the different phases of adults, hoppers, bands and swarms spotted during the entire year of 2004 and 2007 respectively. These visualizations are shown in Figure 4 and 5 and give a general idea of the presence of locusts' contra the land cover type.

3.2.2.2 Calculating NPP Z-scores for study period

NPP is a widely-used indicator of the amount of biomass. In this thesis, change in NPP was examined over several years to see whether any differences could be detected around the years of the locust outbreaks. This was done through the use of Z-scores which enables increases or decreases of NPP to be detected.

Standardized anomalies (Z-scores) are a statistical method used to present normalized data. A Z-score shows a value in relation to the sample/population mean which makes the value meaningful standing alone, as well as makes it possible to easily compare data of different distributions or units with each other. Z-scores are computed through converting the original data-scores to the standard deviation from their mean value through the formula:

$$Z = \frac{x - \mu}{\sigma}$$

where, x is the raw score; μ is the population mean value; σ is the population standard deviation. Z-scores follow the normal distribution and always have a mean value of 0, a standard deviation corresponding to 1, and have no unit of measurement (Abdi 2007).

It is common to use thresholds of -1.96 and +1.96 to indicate a strong change compared to the population. A Z-score below -1.96 indicates a strong decrease while a Z-score above +1.96 indicates a strong increase. When applied to this specific study, Z-scores with these thresholds were used to investigate if any change in NPP has occurred around the years of the locust outbreaks. To accomplish this, the NPP layers were clipped according to the country borders and the Z-scores calculated according to the formula above, where the population mean and standard deviation is based on the 10-year study period. The resulting Z-scores were then used as the foundation for all the following analysis in the thesis.

3.2.2.3 Computing NPP anomalies within all land cover and croplands alone

As the objective of this analysis was to see what the locusts' impact were on vegetation loss during and after an outbreak, the time series of Z-scores were plotted in charts. This was done both for all land cover types combined and for only croplands alone to see whether croplands were more affected compared to other land cover types. The ESA CCI land cover defined as *rainfed cropland, irrigated cropland, cropland (>50%) & natural vegetation (<50%)* and *natural vegetation (>50%) & cropland (<50%*) were extracted and classed as cropland in this thesis. The NPP Z-scores were clipped based on areas of cropland and plotted in a separate chart. The same analysis was made for both Niger and Yemen for the 10-year study period.

3.2.2.4 Locating areas of strong change in NPP within all land cover and croplands alone

The next step was to locate the areas where a strong change in NPP occurred during the years of the outbreaks. The areas of strong decrease (Z < -1.96) or increase (Z > +1.96) were located in Niger year 2004 and in Yemen year 2007. The result are changes in NPP within all land cover types and is presented in a map. As the thesis has a specific focus on croplands, which can be linked to food availability, it would be interesting to also investigate the changes within croplands alone. The areas of change in NPP were therefore crossed against the areas previously defined as cropland to see whether a relation could be distinguished. The result of areas with strong change are presented in maps, overlaying the land cover for localization purpose. The areas of strong change within croplands are show in Figure 19 in the appendix.

3.2.3 Research question 2

3.2.3.1 Computing NPP anomalies within livelihood zones

LHZ from FEWSNET were incorporated as the areas defined as cropland are quite small and many small-scale farmer will be missed. Another reason for using these zones is that they enable the link to food availability. The dataset was downloaded from FEWSNET webpage (https://www.fews.net/livelihoods) and analyzed in ArcGIS. The mean NPP Z-scores previously calculated were then clipped according to each LHZ for all ten years in the study period. There are 15 LHZ in each country of Niger and Yemen, although the types of zones differ, and one chart showing the changes in NPP were made for each of them.

3.2.3.2 Computing NPP Z-scores within buffer zones around known locust locations

A next step in the analysis of the NPP Z-scores was to study the values co-located with the known locust locations. If the locusts have a clear relation to decreased NPP, it would be logical to find that there is a significant decrease in NPP in the areas around the locations where locusts have been spotted. As they are highly mobile and can cover a large area, it could be interesting to study several different buffer zones surrounding the known points. Buffer zones with a radius of 2, 5, 10, 15, 20, 25, 50, 75 and 100 kilometers were therefore made around each known location of adults, hoppers, bands and swarms. This was done for the year 2004 in Niger and for year 2007 in Yemen. The buffer-zones with the same radii were then merged together and dissolved before clipping them according to the livelihood zones. The NPP Z-scores for the year of interest were then clipped based on the new areas of different buffer distances within each LHZ. The mean NPP Z-score as well as the standard deviation was calculated for each field and noted in tables. The majority land cover types within each field were also noted.

3.2.4 Research question 3

3.2.4.1 Calculating the population affected

It was of interest to know how many people lived in the most-affected zones in order to connect the locust outbreaks to food security through its impact on food availability. Population data of Niger and Yemen from year 2010 were downloaded from WorldPop's website (https://www.worldpop.org/) and analyzed in ArcGIS. The population data were divided based on the boundaries of each LHZ and the population within each zone was summed up. The mean NPP Z-score, as well as the standard deviation, for these LHZ were also included to provide context.

3.2.4.2 Changes in food balances and agricultural production

Food balance and the agricultural production were explored to see whether any anomalies could be detected around the years of the outbreaks. FAOSTAT provides measurements of food balance indicators as import, export, stock variation and domestic supply quantity as well as the amount of production and yield that each country has for each year. These six measurements were downloaded for the period of 2001-2010 for both Niger and Yemen and explored in Excel.

Regarding the annual production and yield, only the three most important crop types in each country were studied.

3.2.5 Investigating the relationship between NPP and rainfall

It is known that rainfall is a critical factor when it comes to how well vegetation grows in dryland systems (Abdi et al. 2017). Thus, the impact of rainfall must be ruled out in order to be able to draw any conclusion about the role of the locusts in the decline of vegetation. To accomplish this, Z-scores for annual rainfall during the study period were calculated in the same way as described in section 3.2.2.2. These new Z-scores were then used together with the NPP Z-scores for all ten years for both countries. As it would be logical that the NPP increases when the rainfall does (and vice versa), the two variables were plotted side by side to see if they follow the same pattern. A regression analysis was also performed to see how much of the changes in NPP that could be explained by changes in rainfall.

4. Result

4.1 Research question 1 – NPP changes within croplands

4.1.1 Visualization of locust locations in relation to land cover

Land cover types and the documented locust locations in Niger year 2004 and in Yemen year 2007 are shown in Figure 4 and 5, respectively. Both countries have large bare areas (desert) and areas of sparse vegetation. Niger also has large areas of grassland. Areas of cropland can mainly be found along the southern parts of Niger, and in Yemen they are found close to the western coast and in the central inland regions of the country. The documented locusts are divided by type: swarms, bands, adults and hoppers. In Niger, the locusts are concentrated in areas dominated by bare/sparse vegetation and grassland close to the northwestern border. In Yemen, the locusts are relatively spread out along the coast and in the inland, with various land cover dominating. Many of the known swarms are located around an area of rainfed cropland in the central inland.

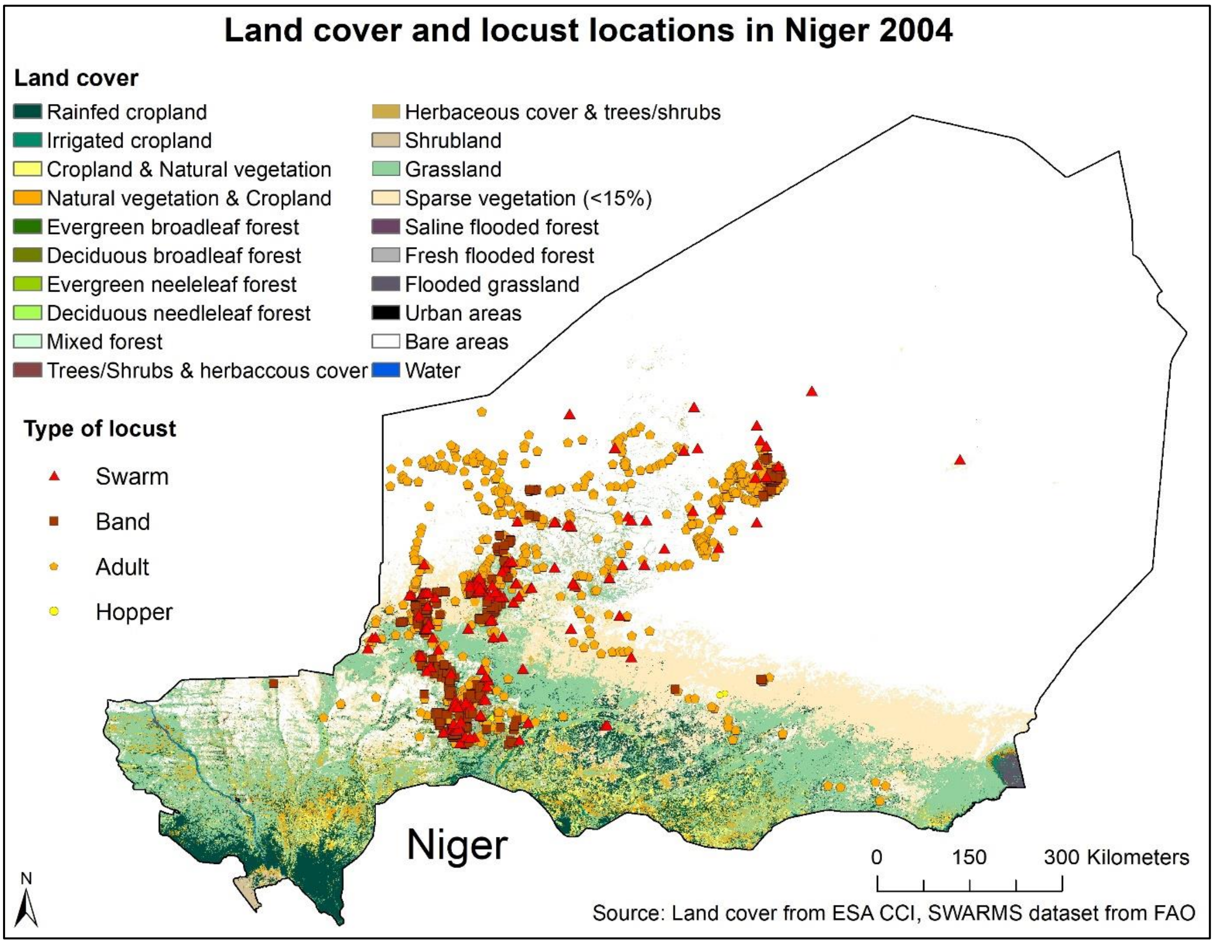


Figure 4. Land cover and documented locust locations in Niger 2004

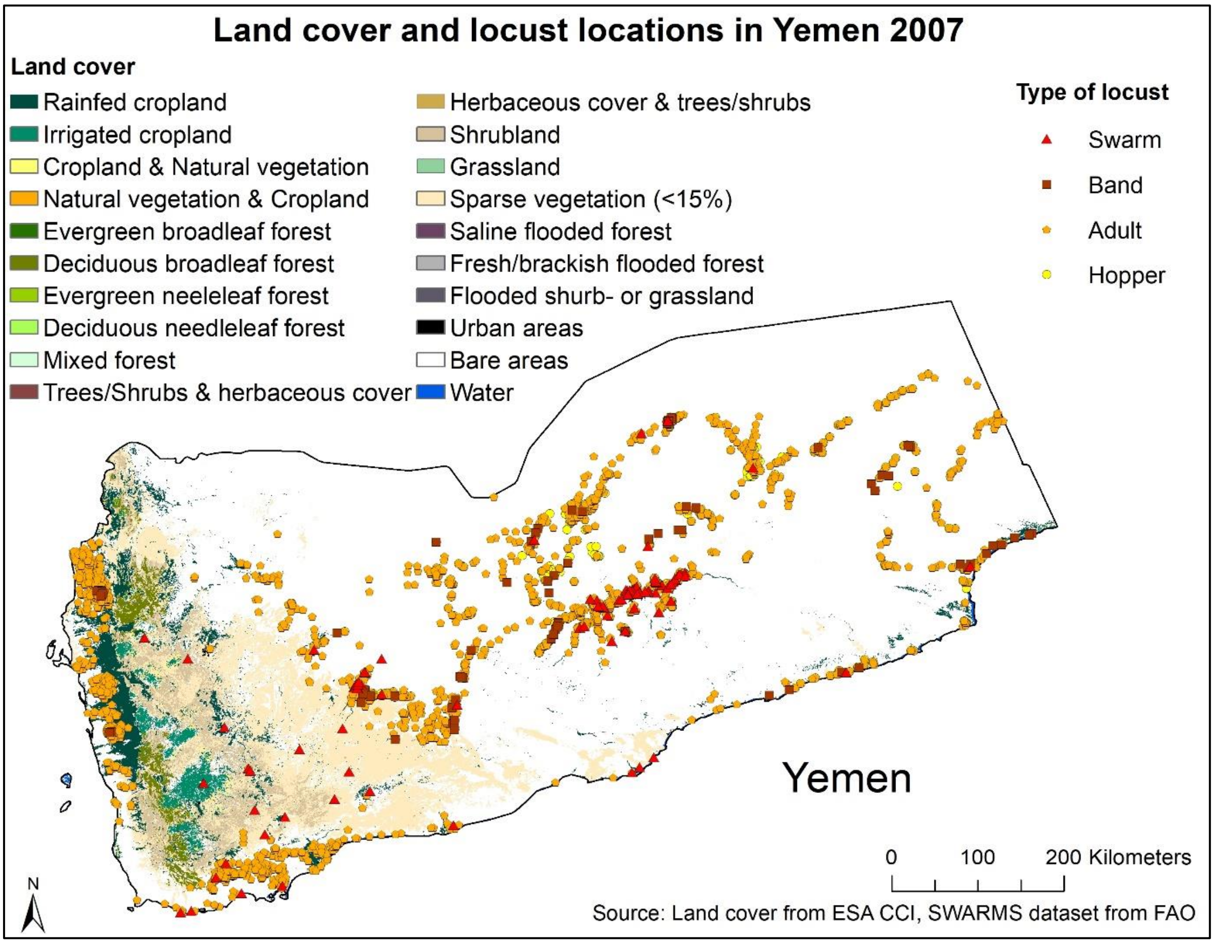


Figure 5. Land cover and documented locust locations in Yemen 2007

4.1.2 NPP Z-scores within croplands and all land cover types

Figure 6 and 7 show time series of the mean NPP Z-scores within croplands alone, as well as within all land cover types combined, in Niger and Yemen respectively. It is apparent that the mean NPP Z-score within croplands follow the same pattern as for all land covers combined. It is also distinguishable that cropland in general shows slightly larger anomalies compared to the total land cover. A large decrease in NPP can be seen from year 2003 to 2004 in Niger which coincides with the locust outbreak. Only a small decrease in NPP can be seen around the outbreak of 2007 in Yemen.

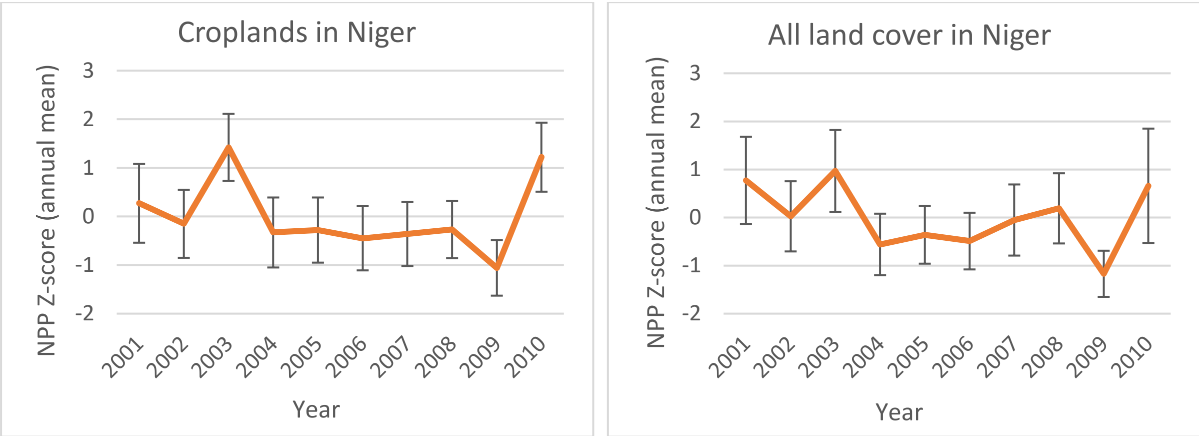


Figure 6. Mean NPP Z-scores within croplands and all land cover in Niger. The error bars denote one standard deviation.

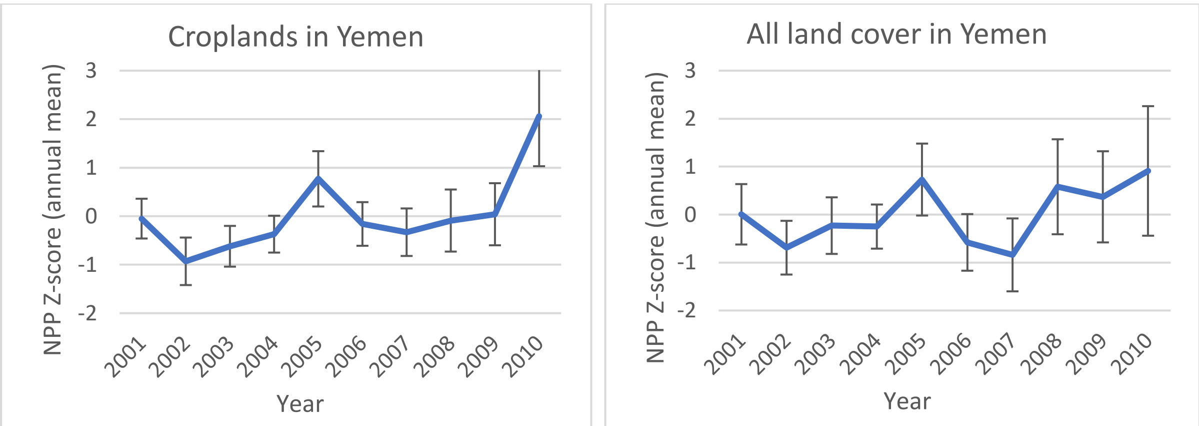
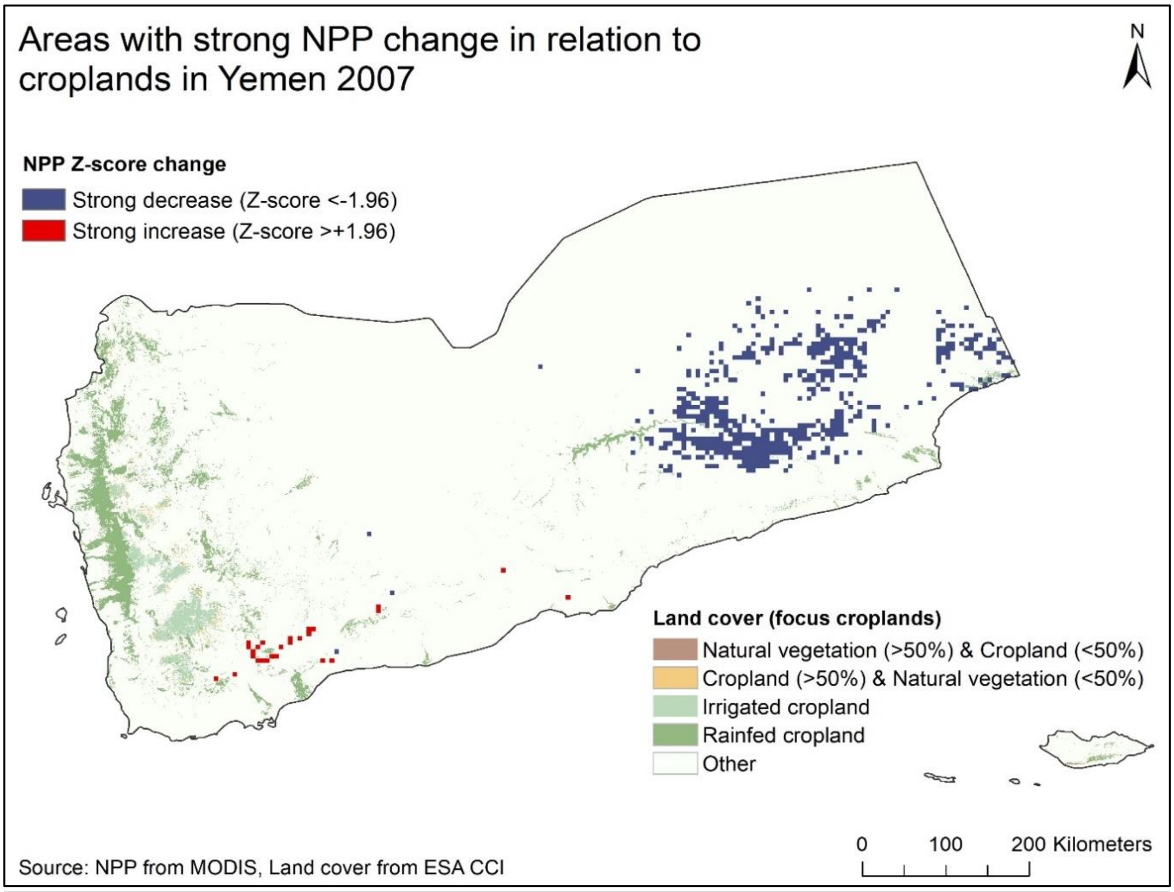


Figure 7. Mean NPP Z-scores within croplands and all land cover in Yemen. The error bars denote one standard deviation.

4.1.3 Areas with strong changes in NPP

Areas with strong changes in NPP in Niger 2004 and in Yemen 2007 (compared to the study period) are shown in relation to croplands in Figure 8. A strong decrease in NPP ($Z < -1.96$) is presented in blue while a strong increase in NPP ($Z > +1.96$) is presented in red. A very limited number of areas show a strong decrease in NPP in Niger, and even less show a strong increase. A larger area in Yemen's eastern inland has experienced a strong decrease in NPP, while a limited number of areas experienced an increase.



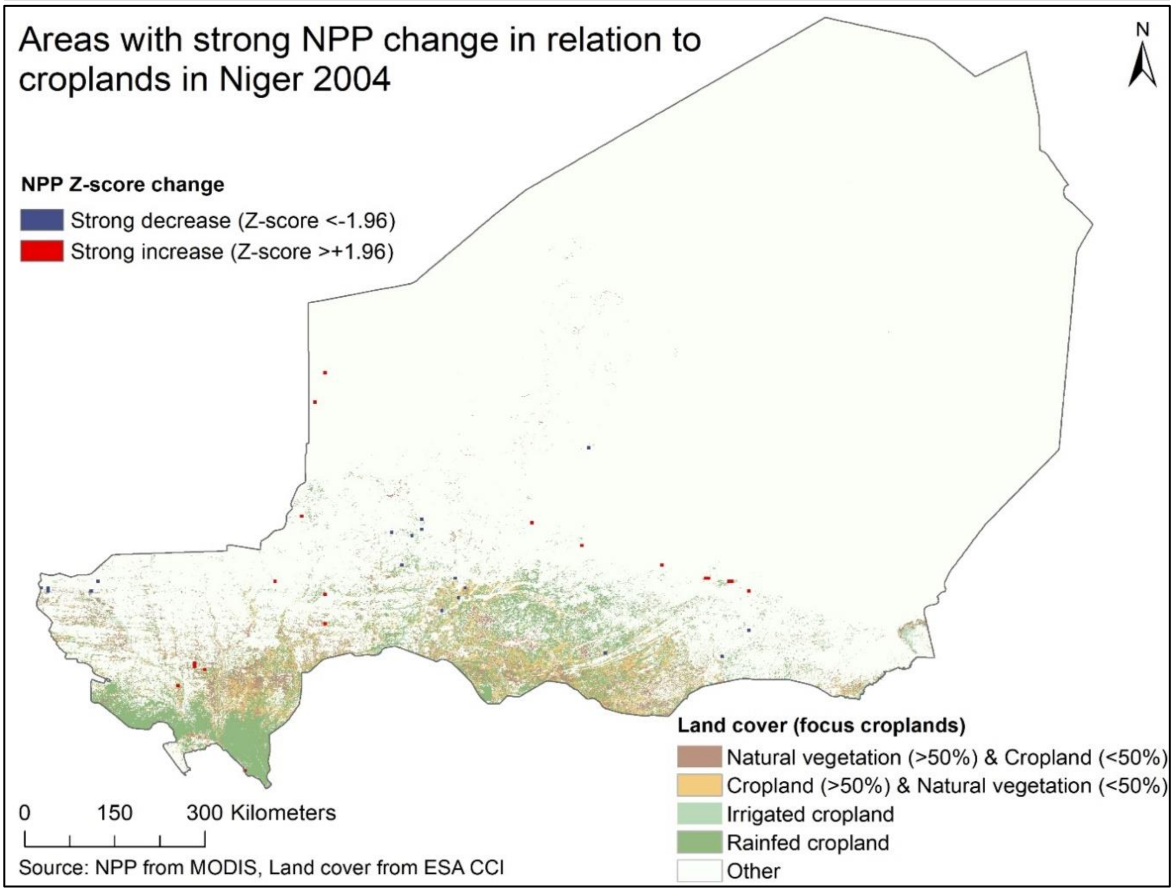


Figure 8. Areas with strong NPP change in relation to croplands in Niger 2004 and in Yemen 2007

4.2 Research question 2 - NPP changes by livelihood zone

4.2.1 Timeseries of mean annual NPP Z-score within LHZ

Mean annual NPP Z-score within four of the largest and most important LHZ in Niger 2004 and Yemen 2007 are shown in Figure 9 and 10, respectively. All four LHZ in Niger show the same pattern, with a high NPP in 2003 and a significant drop in 2004. The LHZ NPP in Yemen also follows a similar general pattern, with a NPP high in 2005 and a very small decrease around the outbreak 2007. Charts for the remaining LHZ can be found in the appendix.

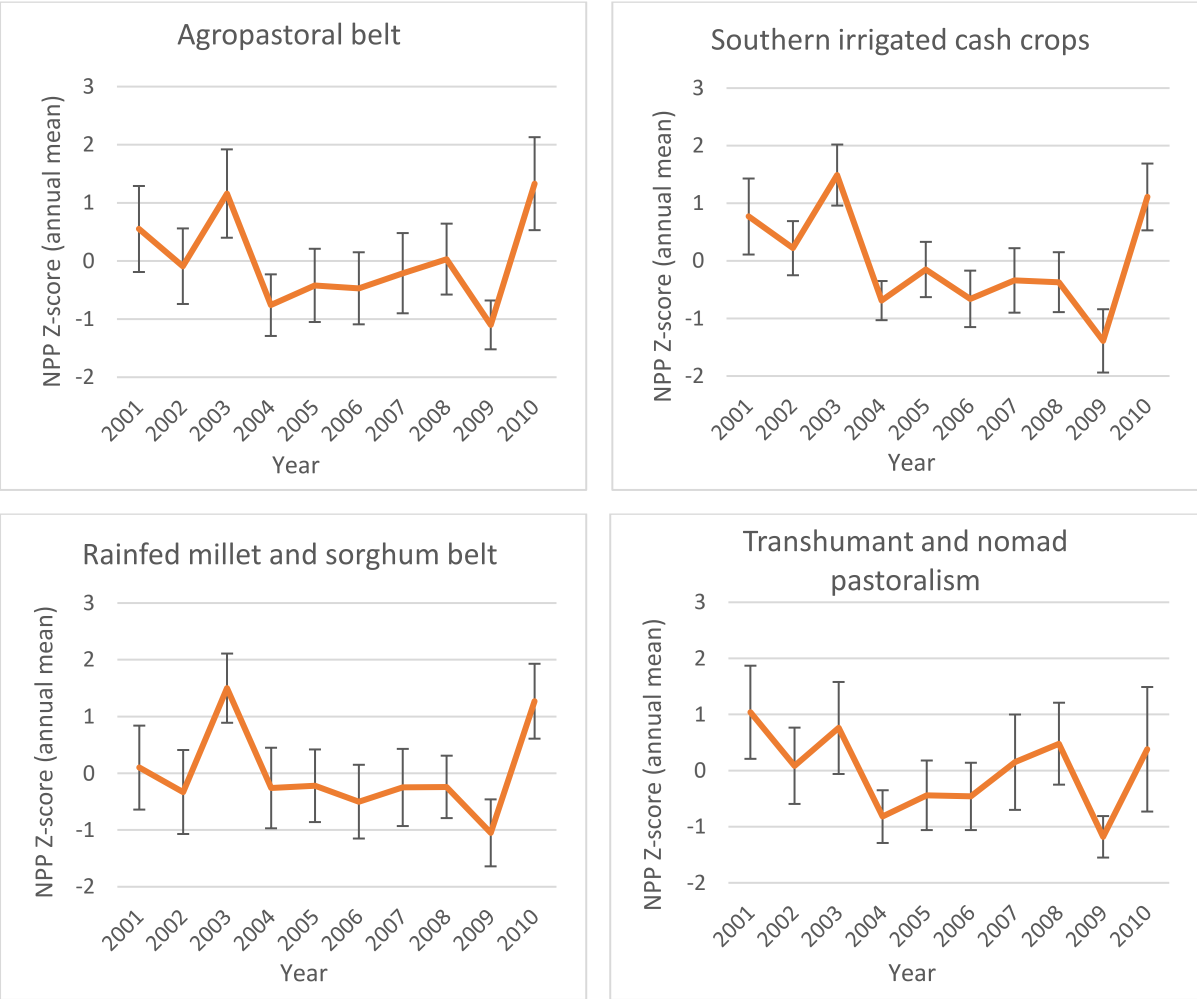


Figure 9. Mean annual NPP Z-scores in four LHZ in Niger. The error bars denote one standard deviation

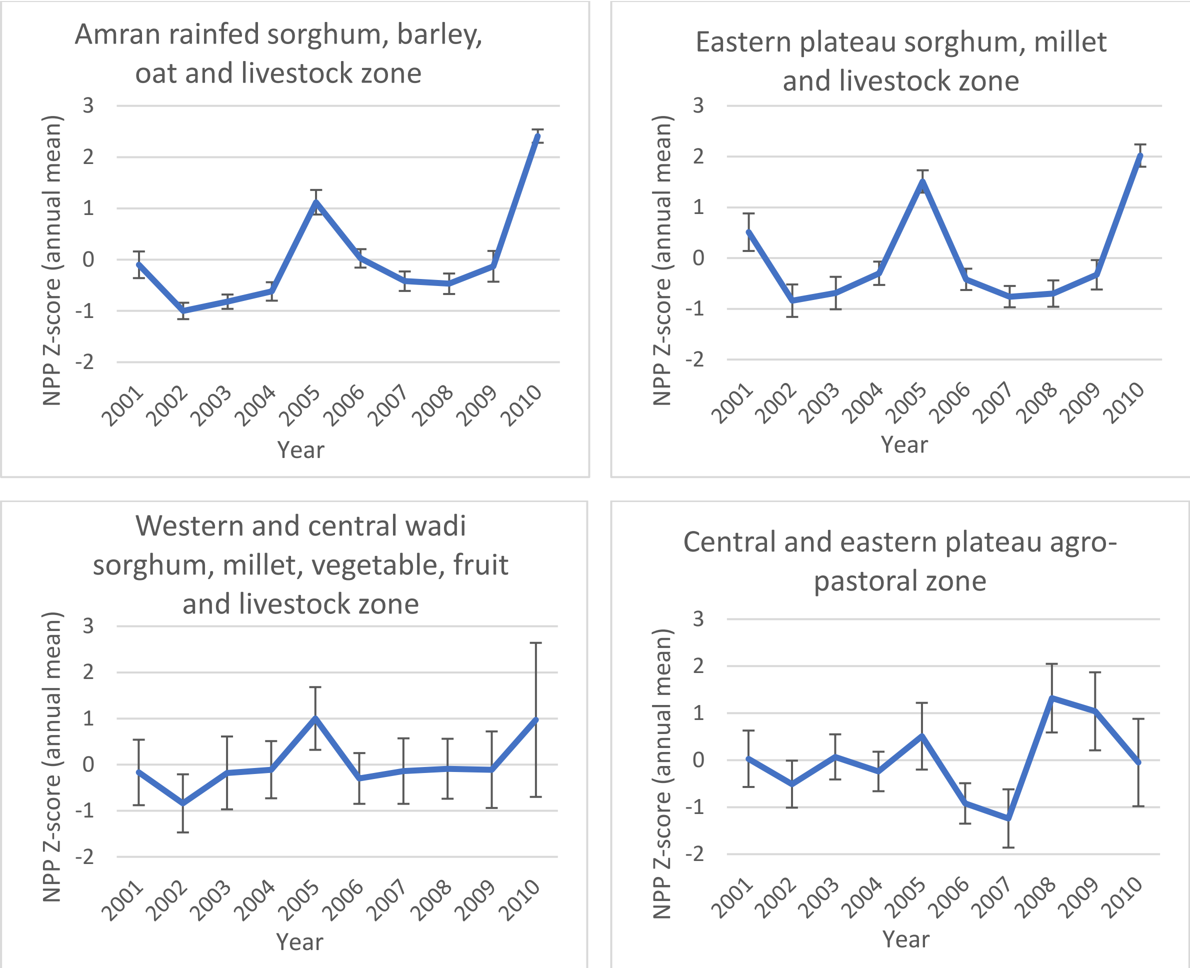


Figure 10. Mean annual NPP Z-scores in four LHZ in Yemen. The error bars denote one standard deviation.

4.2.2 Mean NPP Z-scores within buffer zones around known locust locations, divided by LHZ

Tables 3-6 and 7-10 show the mean and standard deviation of NPP Z-scores within different buffer zones around known locust locations in Niger 2004 and Yemen 2007, respectively. The four most important LHZ in each country are presented here, the rest are found in the appendix. All of these eight LHZ experienced a decrease in NPP in the years of interest, compared to the study period as a whole. The decrease in NPP is in general larger in the buffer-zones closest to the documented locust locations and is reduced with increased distance. The standard deviation is in general smaller in the narrower zones and increases with distance.

3. Agropastoral belt

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	-1.08	0.46	Grassland
5	-1.03	0.42	Grassland
10	-0.90	0.49	Grassland
15	-0.86	0.51	Grassland
20	-0.84	0.53	Grassland
25	-0.84	0.55	Grassland
50	-0.76	0.56	Grassland
75	-0.73	0.55	Grassland
100	-0.72	0.54	Grassland

4. Rainfed millet and sorghum belt

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	-0.96	0.23	Grassland
5	-0.98	0.25	Grassland
10	-0.99	0.28	Grassland
15	-0.96	0.30	Grassland
20	-0.93	0.31	Grassland
25	-0.90	0.32	Grassland
50	-0.72	0.45	Grassland
75	-0.60	0.52	Grassland
100	-0.61	0.52	Grassland

5. Southern irrigated cash crops

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	-1.05	0.36	Grassland
5	-1.05	0.37	Grassland
10	-1.00	0.38	Grassland
15	-0.94	0.34	Grassland
20	-0.92	0.33	Grassland
25	-0.89	0.33	Grassland
50	-0.79	0.32	Grassland
75	-0.73	0.31	Grassland
100	-0.73	0.31	Grassland

6. Transhumant and nomad pastoralism

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	-0.99	0.37	Bare areas
5	-0.98	0.41	Bare areas
10	-0.96	0.41	Bare areas
15	-0.94	0.41	Bare areas
20	-0.91	0.42	Bare areas
25	-0.90	0.42	Bare areas
50	-0.85	0.46	Bare areas
75	-0.84	0.46	Bare areas
100	-0.82	0.48	Bare areas

Table 3-6. Mean NPP Z-score within different buffer zones around locust locations in Niger 2004

7. Amran rainfed sorghum, barley, qat & livestock zone

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	-0.40	0.11	Bare areas
5	-0.37	0.17	Bare areas
10	-0.36	0.16	Bare areas
15	-0.33	0.13	Bare areas
20	-0.36	0.14	Bare areas
25	-0.37	0.13	Bare areas
50	-0.43	0.17	Bare areas
75	-0.42	0.18	Bare areas
100	-0.42	0.18	Bare areas

8. Western and central wadi sorghum, millet, vegetable, fruit & livestock zone

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	-0.03	0.80	Bare areas
5	-0.06	0.86	Bare areas
10	0.03	0.81	Bare areas
15	0.02	0.76	Bare areas
20	0.04	0.76	Bare areas
25	-0.18	0.72	Bare areas
50	-0.14	0.71	Bare areas
75	-0.14	0.71	Bare areas
100	-0.14	0.71	Bare areas

9. Eastern plateau sorghum, millet & livestock zone

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	-0.78	0.18	Bare areas
5	-0.75	0.22	Bare areas
10	-0.70	0.20	Bare areas
15	-0.74	0.21	Bare areas
20	-0.76	0.21	Bare areas
25	-0.76	0.21	Bare areas
50	-0.76	0.21	Bare areas
75	-0.76	0.21	Bare areas
100	-0.76	0.21	Bare areas

10. Central and eastern plateau agro-pastoral zone

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	-1.27	0.58	Bare areas
5	-1.32	0.55	Bare areas
10	-1.32	0.58	Bare areas
15	-1.32	0.58	Bare areas
20	-1.29	0.59	Bare areas
25	-1.25	0.60	Bare areas
50	-1.21	0.61	Bare areas
75	-1.23	0.62	Bare areas
100	-1.24	0.62	Bare areas

Table 7-10. Mean NPP Z-score within different buffer zones around locust locations in Yemen 2007

4.3 Research question 3 - Relation between locust outbreak and food *availability*

4.3.1 Population affected in the four most affected LHZ

Table 11 presents the number of people living in each of the four most important and affected LHZ in Niger, as well as the mean NPP Z-score for the affected year of 2004. These zones together represent 79.1% of the entire population. Worth noting is that these are some of the largest zones in area**.**

LHZ in Niger 2010	Population	Percentage (%)	Mean NPP Z-score (2004)
Agropastoral belt	2 445 828	15.8	-0.76 ± 0.53
Rainfed millet and sorghum belt	7 086 011	45.7	-0.26 ± 0.71
Southern irrigated cash crops	2 116 958	13.6	-0.69 ± 0.34
Transhumant and nomad pastoralism	626 413	4.0	-0.82 ± 0.47
Total population in Niger in 2010: 15 512 000			

Table 11. Population living in four of the most affected zones in Niger, and the mean NPP Z-score

Table 12 below presents the number of people living in each of the four most important and affected LHZ in Yemen, as well as the mean NPP Z-score for the affected year of 2007. These zones together represent 9.6% of the total population. Three of these are geographically relatively small.

LHZ in Yemen 2010	Population	Percentage (%)	Mean NPP Z-score (2007)
Amran rainfed sorghum, barley and livestock zone	544 155	2.3	-0.42 ± 0.19
Western and central wadi sorghum, millet, vegetable, fruit and livestock zone	968 229	4.1	-0.14 ± 0.71
Eastern plateau sorghum, millet and livestock zone	48 886	0.2	-0.76 ± 0.21
Central and eastern plateau agro-pastoral zone	730 850	3.0	-1.24 ± 0.62
Total population in Yemen in 2010: 24 132 999.			

Table 12. Population living in four of the most affected zones in Yemen and the mean NPP Z-score

4.3.2 Variation in food balances and agricultural production

4.3.2.1 Niger

Figure 11 shows the variation in the food balance factors of import quantity, export quantity, stock variation and domestic supply quantity of cereals in Niger during the study period. It is visible that the import quantity of cereals increased in 2004-2005, while the export instead decreased a little between the same years. Regarding stock variation, a positive value means a decrease in stock and it can be seen that the stock decreased significantly from 2003 to 2004. The domestic supply quantity (production, import, export and stock combined) shows a slight increase in the years around the outbreak 2004.

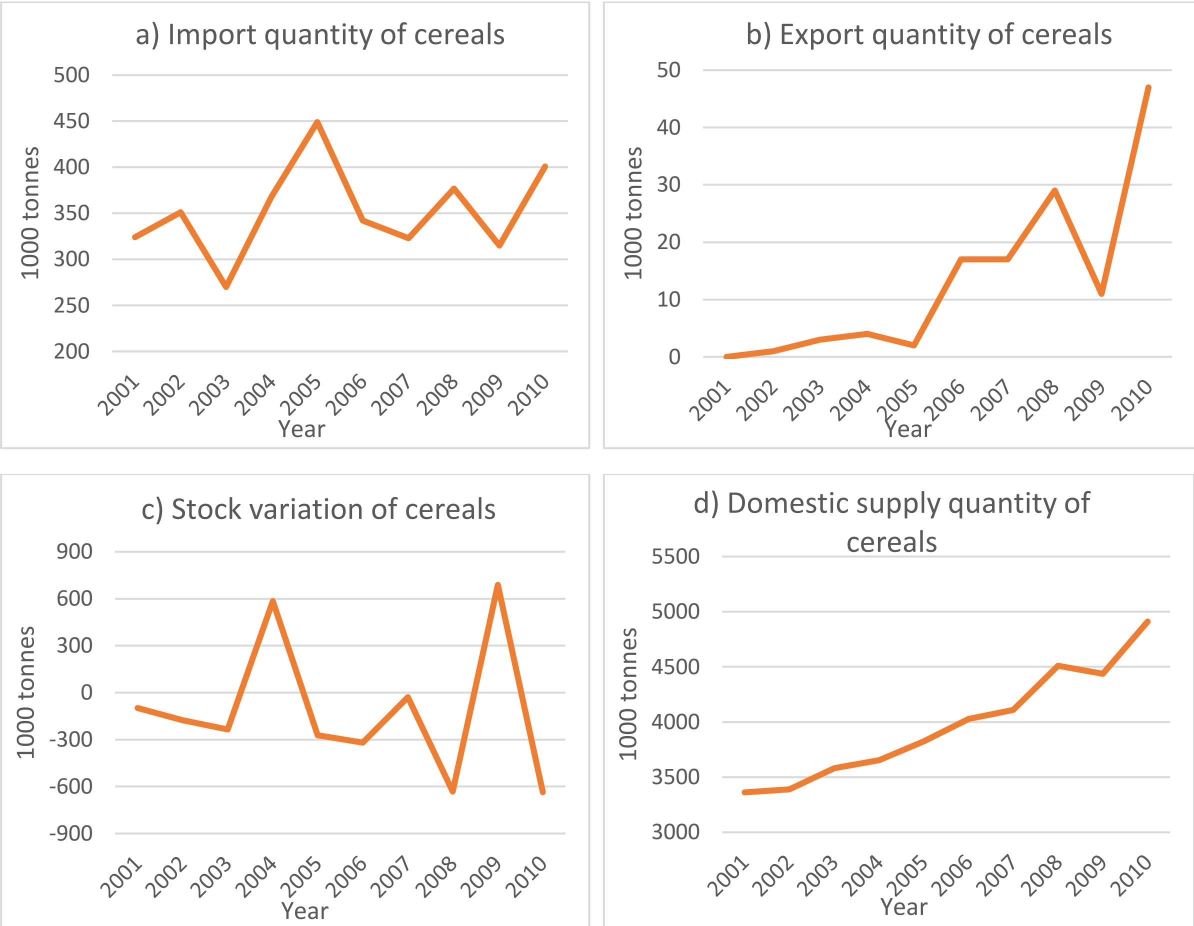


Figure 11. Variation in import (a), export (b), stock variation (c) and domestic supply quantity (d) of cereals in Niger. See section 3.1.4 for descriptions of these terms

Variation in yield and production of the three most important crop types in Niger, as well as the mean NPP is shown in Figure 12. It is clear that all three crops decreased from 2003 to 2004 both in yield density and in amount of production. Millet, the most important of them all, decreased the most.

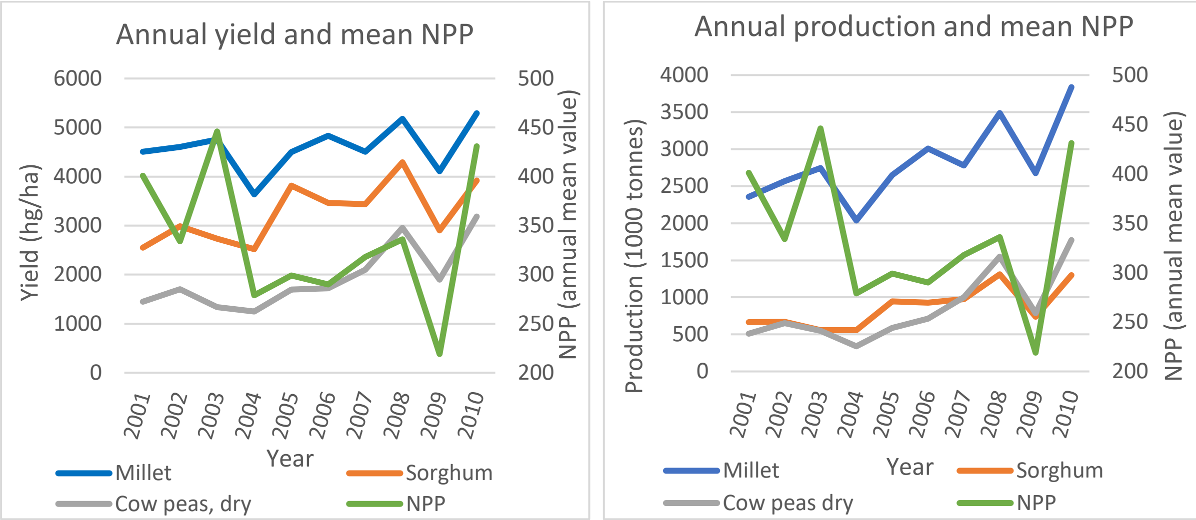


Figure 12. Mean annual NPP and the variation in yield and production of the three most important crop types in Niger

4.3.2.2 Yemen

Variation in the food balance factors of import quantity, export quantity, stock variation and domestic supply quantity of cereals in Yemen between 2001-2010 is shown in Figure 13. It is clear that the import quantity of cereals is unchanged between 2006-2007 and decreased a little from 2007 to 2008. The export decreased between 2006-2007 and then increased again to 2008. Regarding stock variation, the stock in Yemen increased slightly 2006-2007 and then dropped significantly from 2007 to 2008. The domestic supply quantity shows a slight increase in the years around the outbreak 2006-2007 and a slight decrease 2007-2008.

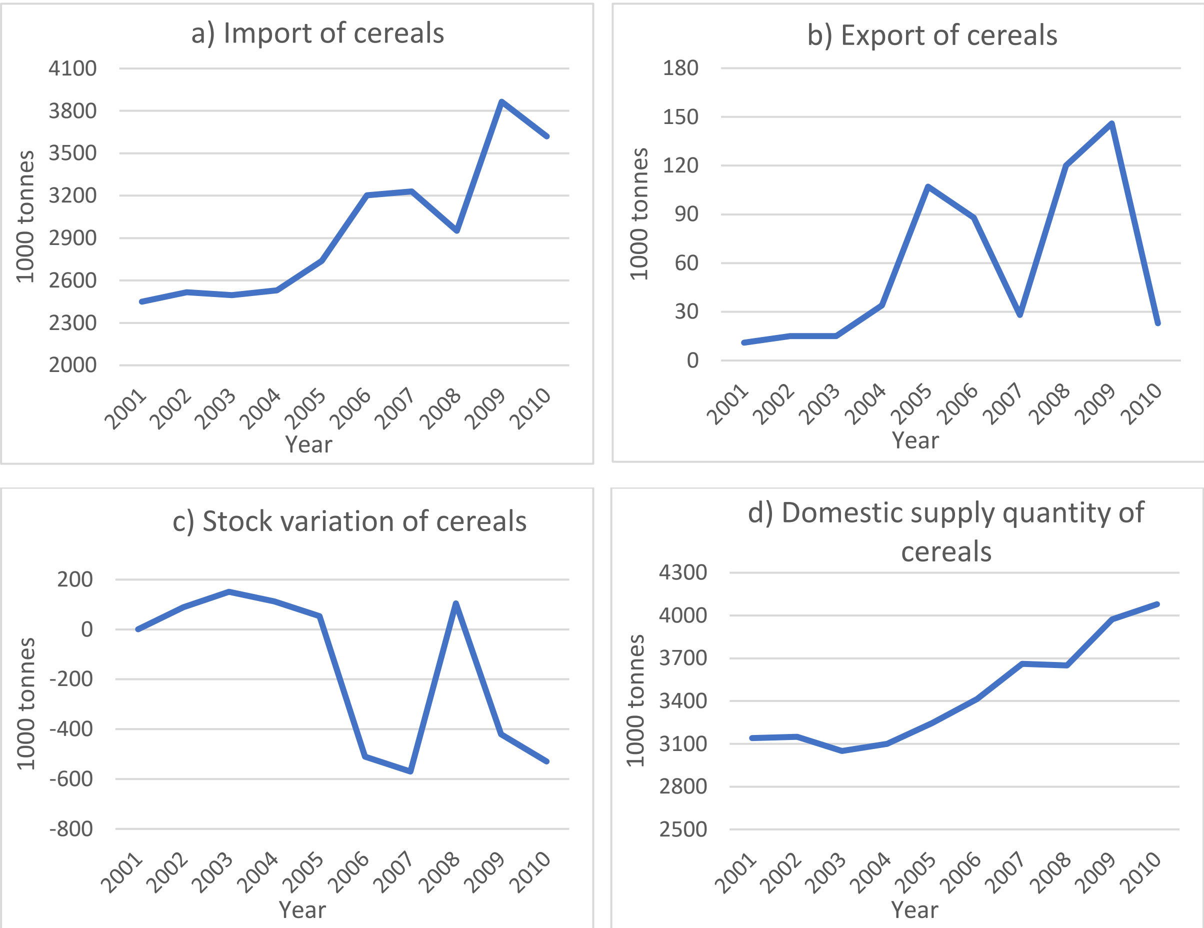


Figure 13. Variation in import (a), export (b), stock variation (c) and domestic supply quantity (d) of cereals in Yemen. See section 3.1.4 for descriptions of these terms.

Variation in yield and production of the three most important crop types in Yemen: sorghum, wheat and millet are shown in Figure 14. NPP is included for comparison. It is clear that all three crops decreased slightly from 2007 to 2008 in yield density and in amount of production. Sorghum, the most important of them all, decreased the most in production.

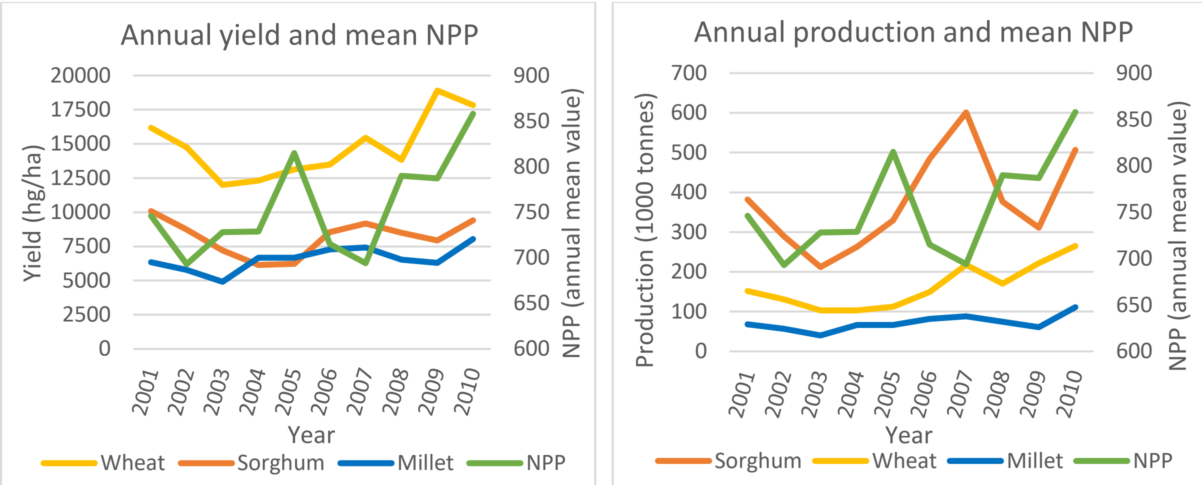


Figure 14. Mean annual NPP and the variation in yield and production of the three most important crop types in Yemen

4.4 Relation between NPP and rainfall

The relationship between Z-scores of NPP and rainfall in Niger is shown in Figure 15. Both variables were first plotted side by side to see if they follow the same pattern and then plotted against each other in a regression analysis to see how much of the changes in NPP that could be explained by changes in rainfall. The graph to the left shows that NPP and rainfall follows the same pattern the first years, less in the latter and that both are low in the year of interest 2004. The graph to the right does not show any strong relation between the two factors, only 13.4% of the changes in NPP can be explained by changes in amount of rainfall.

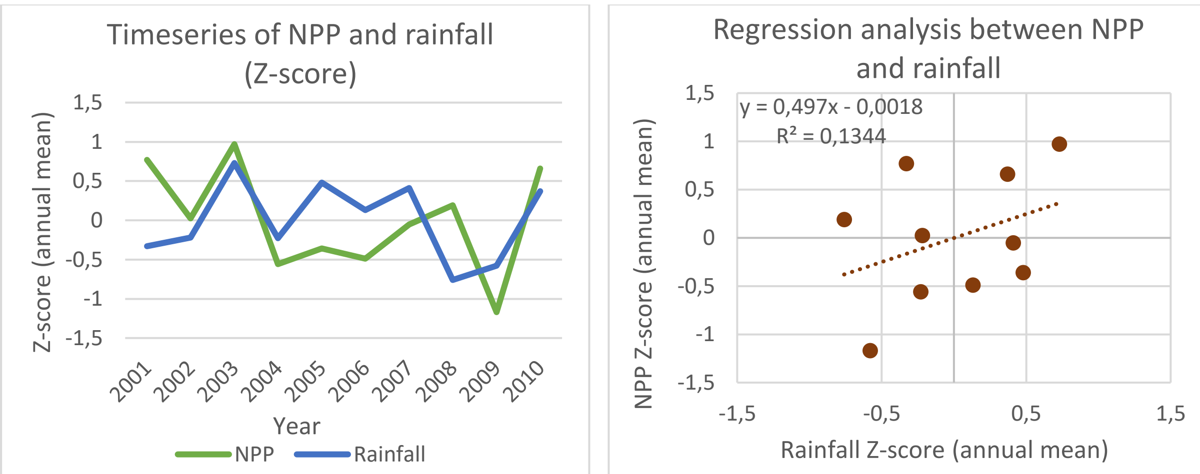


Figure 15. Relation between NPP and rainfall in Niger

Figure 16 shows the relation between NPP and rainfall in Yemen, in the same way as Figure 15. In the graph to the left, the two factors do not follow the same pattern very well and in the most interesting year of 2007, the rainfall was high and the NPP low. The graph to the right does not show any strong relationship between changes in NPP and rainfall. Still, a small negative relation exists where 15.7% of the changes in NPP can be explained by changes in amount of rainfall.

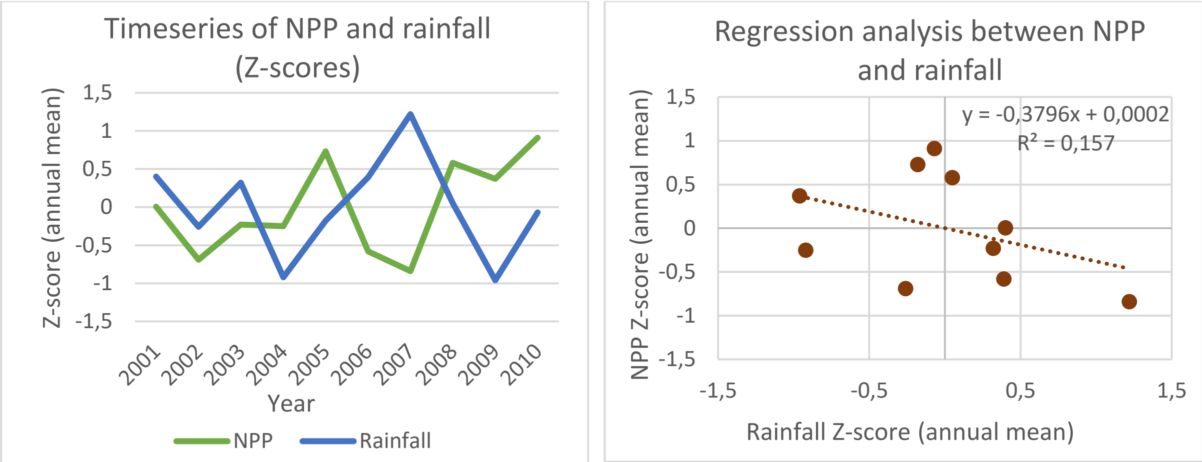


Figure 16. Relation between NPP and rainfall in Yemen

5. Discussion

In this part of the thesis, the results of the study will be discussed in relation to the three research questions stated. There is one section per question followed by a discussion of the method and proposals of how this study could be improved in the future.

5.1 Research question 1

The first question that this study aimed to answer was how the locust outbreaks affected the study area NPP, with a specific focus on croplands. At the start of this project, I began with visualizing known locust locations in the years of interest in comparison with the land cover (see Figure 4 and 5). The objective was an overview of the localization of the locusts, with emphasis on the swarms, and whether they were found around a particular type of land cover. Worth noting is that the countries are large, and some fields are very small, meaning that it can be difficult to distinguish between land cover types, and that small-scale farming may go unnoticed. In Niger, no particular pattern could be visually discerned. The most interesting observation in Yemen was the band of swarms found in the interior of the country that coincided with croplands located in the mountains. The coincidence raises the question of whether the locusts prefer croplands in these highlands, and if so, whether the decrease in NPP is higher in croplands relative to other vegetation types. This leads to the analysis of the time series of NPP Z-scores within all land cover types and for croplands alone. The most prominent result in Niger (Figure 6) is that NPP was high in 2003 and that a large decrease occurred in 2004. As the decrease coincides with the large outbreak, a connection between them could be possible. NPP continues to be low in the following years, with a dip in 2009, which could be due to other factors. Indeed, for 2004, factors other than locusts may have caused the decrease in NPP as well. But if the vegetation in 2004 was significantly consumed by locusts, it would have an effect on NPP in the time after the outbreak as well. A slower recovery and build-up of new vegetation would in turn mean lower NPP. This could perhaps explain some of the low numbers in the following years but not the low values in 2009. Previous research has seen that one consequence of locusts ravaging crops is rural migration and local farmers abandoning their destroyed fields (Lecoq 2003), which also might lead to reduced agricultural production in the years thereafter.

In Yemen, there was only a very small decrease in NPP compared to the study period as a whole within both croplands and all land covers (see Figure 7). Even if there is a small decrease, nothing can really be said about a potential connection between that and the locust outbreak. It is clear that in both countries NPP follows the same pattern within croplands alone and within all land cover combined. This means that croplands are affected in the same way by other factors (both positive and negative) as other vegetation. Such factors could be amount of rainfall, temperature or locust outbreaks for example. However, it is distinguishable that the croplands generally show slightly larger anomalies compared to all land cover. That could point to that croplands are more impacted (also positively or negatively) by other factors, but as croplands are managed land there are also other factors involved such as direct human activities.

Mapping the areas that had experienced a strong change in NPP in the years of the outbreaks in relation to the study period resulted in very few pixels (see Figure 8). Starting with Niger, very limited areas showed any strong change (i.e. $-1.96 < Z < +1.96$). However, there were more areas with strong decreases in NPP than increases. Much larger areas in Yemen experienced a strong decrease in NPP in 2007 and it is noteworthy that a large area in the interior of the country is coincident with visible locations of several swarms. This area also coincides with a string of croplands, but when extracting the pixels within croplands that show strong change, very few were left (see Figure 19 in the appendix). A similar outcome is visible in Niger and means that it is difficult to state that any strong decline in NPP was caused by the outbreaks. Also worth noting is that many areas could have experienced a large decrease in NPP but were below the thresholds set in this analysis. Another source of potential influence is that a large proportion of the population that works in the agricultural sector in these countries are small-scale farmers. This means that their croplands may not become categorized in a large-scale land cover map and the impact on NPP goes unnoticed. Therefore, to sum up the analysis connected to the first research question: decreases in NPP in the years of the locust outbreaks are visible but a conclusive link to the locusts as the cause could not be established. Some areas did experience a strong decrease, especially in Yemen, but very few of them were classified as croplands.

5.2 Research question 2

The second question was whether any strong reduction in NPP can be discerned in the different livelihood zones during the outbreak years. When looking at the resulting time series in Niger (see Figure 9 in the result and Figure 20 in the appendix), almost all LHZs follow the same pattern with a NPP high in 2003 followed by a large decrease to 2004. The exceptions are *Water*, *Desert* and *Aïr Massif irrigated gardening* (close to desert), which seems logical since they have no, or very limited, amount of vegetation. The rest have vegetation and are named after the dominant type of vegetation or crop. The LHZs that experienced the largest drop and had the lowest Z-score were the *Agropastoral belt*, *Southern irrigated cash crops* and *Transhumant and nomad pastoralism.* Their large geographical coverage and their name implies a strong agricultural connection. Also, the fact that all of the vegetation-covered LHZ show this large decrease in 2004, the same year as the locust outbreak, could indicate that the two are related. However, similar to the cropland NPP discussed above, the subsequent years exhibited Z-scores below zero, which could be attributed to other factors.

The time series in Yemen shows that the NPP in all LHZs follows a similar pattern (see Figure 10 in the result and Figure 21 in the appendix). NPP peaked in 2005 and a very small decrease could be observed from 2006 to 2007 when the outbreak occurred. All LHZ show a negative NPP Z-score in 2007, based on the 10-year study period, and it is the *Central and eastern plateau agro-pastoral zone, Eastern plateau sorghum, millet and livestock zone* and *Amran rainfed sorghum, barley, oat and livestock zone* that had the largest decrease and lowest negative Z-score. As these are some of the largest LHZ that are connected to agriculture, it implies low production and could have a possible connection to the outbreak. However, we cannot be sure and no conclusion of such a relation can be drawn based on this result.

The next analysis was to look at different buffer zones around each known locust location in the years of the outbreaks. It is clear that all buffer zones within all LHZs in Niger experienced NPP decrease in 2004 compared to the study period as a whole (see Table 3-6 in the results and Table 13-16 in the appendix). However, none experienced a strong decrease ($Z < -1.96$). The larger and agriculture-focused LHZs had the highest decrease with a Z-score around -1 in the narrowest buffer zones. The fact that the smaller zones, closest to the known locust locations generally had the largest decrease is logical if the locusts do have a negative effect on the annual NPP. This result might therefore be the strongest evidence of that connection so far in this study.

Almost all LHZs in Yemen experienced a negative NPP Z-score in 2007 and thereby a decrease compared to the total period (see Table 7-10 in the result and Table 17-26 in the appendix). The Z-score varied considerably between the zones, but the *Central and eastern wadi palm, wheat, vegetable & livestock zone* had the largest decrease with a value of -1.42 in the narrowest zone. NPP decrease was generally larger closer to the known locust location, which indicates a relationship. In the tables for both countries, the standard deviation increased with distance, which is an expected result as a larger area has more variation and uncertainty. I also included the dominant land cover class within each zone to get an indication of what types that are most effected. The result showed *grassland* in Niger and *bare areas* in Yemen in most cases. There are three plausible reasons for this: (1) croplands are not as affected as other types of land cover, (2) the agricultural area is too small to be classified as cropland, or (3) there is inherent misclassification of croplands in the global land cover dataset that was used (Fritz et al. 2013, Liu et al. 2018).

5.3 Research question 3

The third research question was whether a link between food availability and the locust outbreaks could be distinguished. As food security is a multidimensional question, I have chosen to focus my thesis on one important part of it: the availability of food. Here, one important factor to consider is how many people that are at risk of becoming affected by decreased food availability caused by locusts (see Table 11 and 12). In Niger, 79.1% of people live in four of the most affected LHZs, while in Yemen that proportion is 9.6%. The LHZs in Niger are relatively large in areal extent but 79.1% is still a considerable number of people that inhabit zones that exhibit the highest NPP decrease at the time of the outbreak. Furthermore, future projections indicate a risk of NPP demand exceeding supply in the Sahel. This is particularly relevant in light of the fact that sustainable development goals for eliminating hunger in the Sahel are at risk of failure (Sallaba et al. 2017). Yemen, on the other hand, is considerably more mountainous than Niger (see Figure 1), which leads to a different spatial arrangement of LHZs with often smaller and more patchy zones. That might make it harder to make a comparison, but there is a much lower percentage of people living in the four most affected zones. That said, Yemen were less affected overall than Niger. Also, worth noting is that Yemen has a smaller area but larger population than Niger.

The amount of food available for human consumption is a central factor strongly related to overall food security. Food balance indices from FAO were downloaded to get an idea whether they changed during the years of locust outbreaks. Import, export, stock variation and domestic supply quantity were chosen to get a general idea of the situation in the two countries. In Niger, the result in Figure 11 showed that the amount of cereals imported increased strongly from 2003 to 2004 and on to 2005. If the locusts ravaged crops during the outbreak in 2004, it would be logical that the country had to import more cereals that year. That would possibly have an effect the year after as well if the stocks from previous years were lower than normal.

The amount of cereals exported from Niger was low in all years in the first half of the study period, which makes it hard to make any assumptions. Export slightly decreased between 2004 to 2005, possibly due to less cereals to spare that year. The stock variation (which includes all variables that effect the quantity) shows a strong decrease the year of the outbreak which could be due to the stock being used to ease the impact of the locusts. The domestic supply quantity (the total supply for direct consumption) shows a continued slight increase during this period. Since the domestic supply quantity also includes imports, the increase in this quantity could be an explanation for the domestic supply to increase even though the other indices decrease. It is clearly discernible in the graphs presenting the amount of yield and production of the three most important crop types that they all decreased in 2004 (see Figure 12). By far the most important crop, millet, had the largest decrease, which must have had an impact on the population (especially local farmers) that are dependent on it for food. These graphs follow the mean NPP fairly well, indicating that the vegetation followed the same pattern. Thus, with increased import, decreased export and stock variation, it can be inferred that Niger experienced a fall in food availability in 2004, which could in turn impact food security. The fall did coincide with the locust outbreak, but we cannot infer a direct causal link.

The same food balance indices in Yemen (see Figure 13) show that the quantity of cereals imported were practically unchanged between 2006 to 2007. However, that amount is quite high compared to the first years. The quantity of exported cereals decreased considerably from 2006 to 2007, indicating there was less to spare. The stock variation had a slight increase 2006 to 2007, followed by a large drop to 2008. Either this indicator was not influenced by the outbreak, or the reaction was delayed. The domestic supply quantity had a steady increase during the whole study period except for 2007 to 2008 when it flattens out. This could be due to a late response to the outbreak.

The graphs of the yield and production of the three most important crop types in Yemen show a decrease from 2007 to 2008 rather than the year before (see Figure 14). The most important crop type, sorghum, decreased the most, probably influencing food availability for those dependent on it. Interestingly, the time series of the crops does not follow that of the NPP mean indicating that perhaps the signature from crops is too small to be captured in the NPP data. Another observation is that the food balance indices are considerably higher for Yemen compared to Niger. The amount of cereals imported to Yemen are in the range of 2.5 – 4 million tons while imports of cereals in Niger range between 250 and 450 thousand tons, i.e. around 1000 times less. At the same time, Yemen’s production of crops is around 1000 times less then Niger’s. This indicates that Yemen is less dependent on domestic production and more dependent on imported food, meaning that their food availability would be less fragile against locust outbreaks. This observation is shared in a report by Reliefweb (2007) stating that Yemen imports 75% of its food and that crop damage will not result in a food crisis. However, there could be consequences for livelihoods, for example, the decline of agricultural opportunities can trigger migration of farmers from rural to urban areas as has happened in other parts of the Middle East (Eklund et al. 2017). Furthermore, abandonment of farmland can influence global land cover products through misclassification as other classes (Alcantara et al. 2013).

5.4 Relationship between NPP and rainfall

The results indicate lower NPP and decreased food availability in the period following the locust outbreaks, especially in Niger. But one cannot state with certainty whether there is a direct relationship to the locust outbreaks. It is well-known (e.g. Puigdefábregas and Pugnaire 1999) that an important limiting factor for vegetation growth in arid environments is water. Therefore, I chose to investigate the rainfall pattern during the same period to see whether a connection between the amount of rain and the variation in NPP exists. If not, one could at a minimum conclude that it was not lack of rainfall that caused the decrease and the probability that it was the locusts would be higher. In Niger (see Figure 15), the amount of rainfall and NPP followed the same pattern the first years of the study period, and they both show a decline in 2004. Thus, even if only 13.4% of the changes in NPP could be explained by changes in rainfall (based on the whole period) it is difficult to state that the low NPP in 2004 was not caused or influenced by that year's limited rainfall. In Yemen (see Figure 16), rainfall and NPP do not follow each other very well and in the year of interest 2007, the amount of rain was high but the NPP low. Again, Yemen's rugged topography may alter the vegetation-rainfall relationship in this region as it does in neighboring Oman (Ball and Tzanopoulos 2020). The relationship between the two factors is low also here, with only 15.7% of the changes in NPP that could be explained by changes in rainfall. Something other than rainfall might therefore have influenced the decrease in 2007. However, the fact remains that rainfall still cannot be ruled out as the cause of the overall decrease in NPP.

5.5 Perspectives on the methodology

Here, I present a discussion about the method used in this study, including factors that may have influenced the result and recommendations on how the research could be continued in the future.

In the literature review phase of this thesis, I found several studies on the conditions that lead up to a rise of locust outbreaks. There were considerably fewer studies on the consequences of the locust outbreaks. In particular, there was a scarcity of peer-reviewed research and available information was instead based on news articles and reports from non-governmental organizations. Thus, there was not much to base my approach on, and an exploratory method was chosen. In this method, I addressed an integrated problem using a sequential approach. The intention was that one result could lead to the next step, thus forming a methodology that evolves throughout the process. As a result, the research questions are broad, which allows for the use of different strategies to answer them.

Other remotely sensed estimates of vegetation could have been used to investigate changes over time. For example, the Normalized Difference Vegetation Index (NDVI) is commonly used but was not chosen because NPP is a more comprehensive measurement that takes several components into consideration (such as climatic and environmental factors). NPP also results in an actual measured value and not just a unitless index that produces metrics that can be related to, among other things, food availability (e.g. Abdi et al. (2014), Haberl et al. (2014)). Using annual NPP instead of only the months of the growing season (which might seem logical) was a conscious choice. Both due to the fact that the locusts were present during a larger part of the year and the SWARMS data are an annual record, as well as to be able to compare the result with the food availability indices which are provided at annual intervals.

Standardized anomalies were chosen as the only statistical measurement. Regular anomalies were also used initially but were discarded for the sake of consistency. As the result showed few areas with strong change in NPP, future studies may opt to use measurements with a broader scale of change (e.g. low-high) to make better inferences. Oikonomopoulos (2020) used standardized anomalies of remotely sensed vegetation productivity indices, together with field observations of locusts in the Sahel during the 2004 outbreak, to develop a locust outbreak mapping tool. The results indicated decreased productivity during the upsurge, but the decrease was not statistically significant. Even if the method and indices used differed from this study, those findings corresponded well and neither study could establish a definite connection between the locusts and decreases in vegetation indices. Either there really is no clear relationship, or the methods are not sufficient to establish it.

The choice of the data used in the study is based upon content, accesses and resolution. It is possible that other datasets would give slightly different result but probably not by much. There are, for example, several datasets of land cover that are based on different classification criteria and could thereby possibly show different areas of cropland. For the sake of specificity, I chose the datasets with the highest resolution. The datasets used have different spatial resolutions however, which could affect the result if they were combined. However, in my analysis I do not combine any raster data, but rather analyze them separately. Also, the annual mean of the entire countries is used for the NPP and rainfall comparison, meaning that different resolutions have no impact.

There was only one available dataset with information of known locust locations (SWARMS), but there are several ways that the information within it could be used. For example, it would be interesting for future studies to make use of the information on the size of the swarms. It would also be interesting to incorporate other factors that influence vegetation growth to be able to rule them out as possible factors for the observed decrease in NPP. Here, I only used rainfall as it was shown to be an important driver for vegetation growth (Puigdefábregas and Pugnaire 1999, Merbold et al. 2009, Abdi et al. 2017).

I have not come across any other studies that incorporate LHZs to assess locust impact on livelihoods. This approach presents a new way to connect the result to food security in terms of food availability. However, it is difficult to draw clear conclusions from it other than the fact that some LHZ were slightly more affected than others. The LHZs are generalized and are named after the most dominant livelihood, but the livelihood type is not generalizable to the entire population living within them.

Niger and Yemen were chosen as case studies because they were amongst the most affected by outbreaks in their respective regions and are socioeconomically fragile due to their limited economical resources. The rugged and diverse topography of Yemen might influence the results, e.g. inaccurate land cover classification and small-scale farms that might be overlooked. They also have a relatively small agricultural production and instead import the majority of their food. As I focused on croplands, Yemen might therefore not have been the most representative country. In retrospect, another target that is more complementary to Niger would have been a better choice. The locust outbreak in 2007 also seem to have been under control sooner which led to less negative consequences. This makes it somewhat less representative within the scope of this study as a larger outbreak with more impact would probably have given a clearer result.

The chosen study period from 2001 to 2010 also affects the result as the Z-scores presented here are based on this specific period. Choosing a different period could thereby result in different statistical significances. Although, data from a longer period would consume more time and resources, the additional data points could increase the statistical power of the results. A longer study period would also include the long-term effects of other factors such as climatic variations or land use (Mechiche-Alami and Abdi 2020) to be more pronounced. This could potentially dilute the signal of the locust infestation. Thus, a ten-year period centralized around the two outbreaks was chosen as appropriate within the frame of a master’s project.

6. Conclusion

The result of this study shows that there was a decrease in NPP in the years of the locust outbreaks with a larger decrease in Niger 2004 than in Yemen 2007. The decrease can be observed within all land cover types. Some areas experienced a strong decrease, especially in Yemen, but very few could be found within croplands. There is some uncertainly in linking decrease in NPP in the years of the outbreaks and the outbreaks themselves. Other factors can be responsible, or at least partly influence, the observed decrease. For example, the limiting factor of rainfall cannot be ruled out as a contributing factor in Niger as the amount of rain falling in 2004 was low. In summary, for the first research question of this thesis, a decrease in NPP can be observed both when considering only croplands and across all land cover types during the outbreak years, but a conclusive causal relationship cannot be proven.

When dividing the countries by FEWSNET LHZs, almost all zones experienced a decrease in NPP in the years of the outbreak compared to the whole study period. The zones that showed the largest decrease are the ones that have a strong agricultural component, which might indicate that the population that depends on agriculture is potentially susceptible to the impact of the locusts. This is particularly true in Niger, while Yemen is harder to interpret due to many small and patchy LHZs. The largest NPP decreases could be observed in the narrowest buffer zones around the locust points, which implies that the locusts do have a localized negative impact on NPP. In summary, for research question 2, almost all LHZs experienced a decrease in NPP and the agricultural ones were the most affected.

The resulting time series of food indices showed that the import of cereals increased while the export and stock variation decreased in Niger 2004. The three most important crop types also decreased that year, which altogether implies a decreased food availability at the time, and a possible relation to the outbreak. A majority (79.1%) of the population also lives within four of the most affected LHZ. In Yemen, the most distinguishable result was that the export of crops dropped and the domestic supply quantity paused its progress in 2007, possibly due to the locust outbreak. However, as Yemen imports 75% of its food, the country is much less dependent on domestic production. In summary, for research question 3, the observed food indices imply an overall decline in food availability in Niger in 2004, while the results in Yemen 2007 were less prominent.

Although decreases in NPP and food related indices were observed in the years of the outbreaks, this study cannot conclusively prove that it actually was the locusts that caused it. What is clear is that the incidents coincide in time and space and that a relationship is possible. That said, the result of this thesis is a step towards generating knowledge about the consequences of the locust outbreak and it presents a foundation for such research to be continued and improved upon. This is particularly relevant in light of the fact that donors often require more evidence of the negative impacts caused by locusts as a condition for receiving additional funding to combat outbreaks and restore livelihoods.

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8. Appendix

8.1 Livelihood zones in Niger

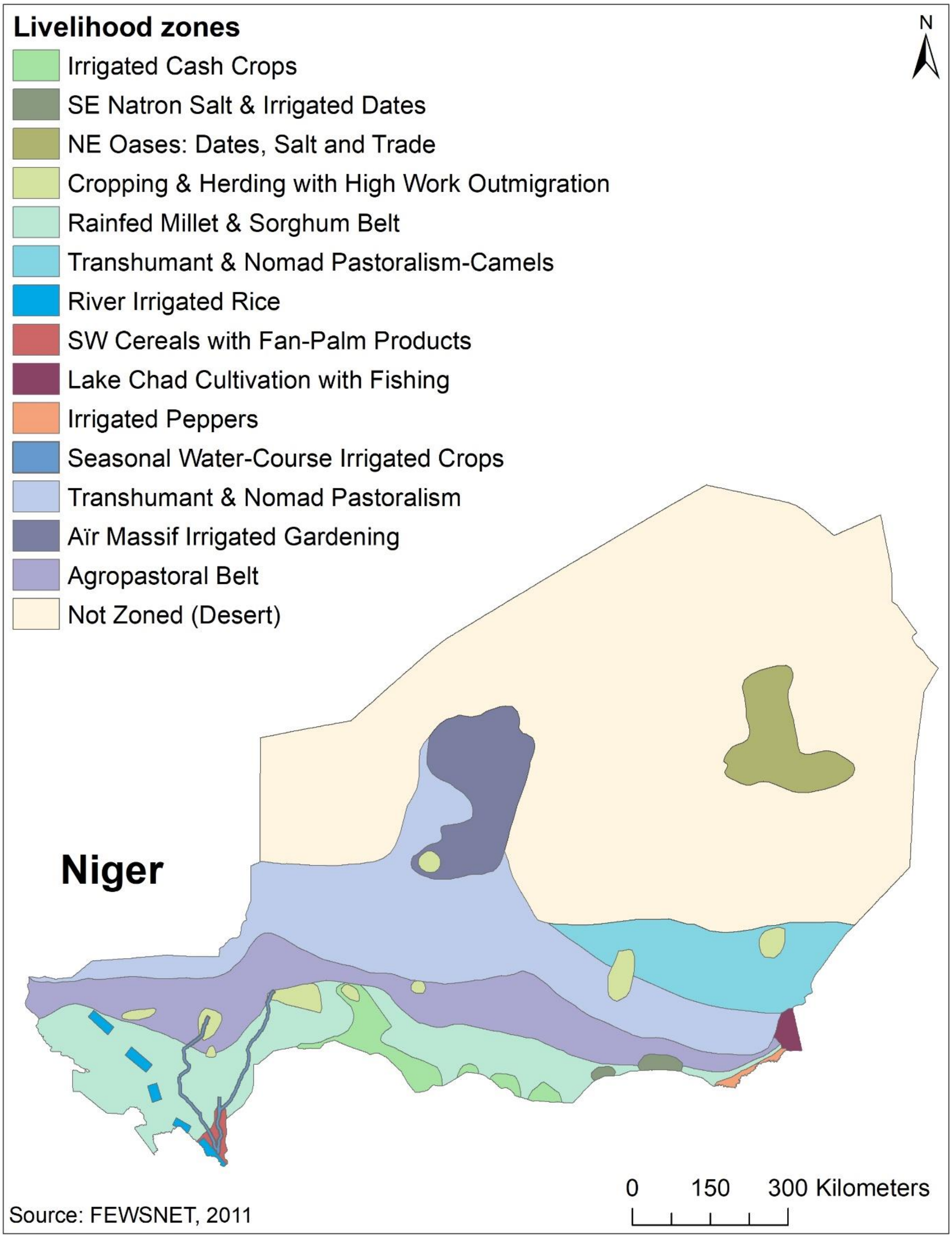


Figure 17. Livelihood zones (LHZ) in Niger

8.2 Livelihood zones in Yemen

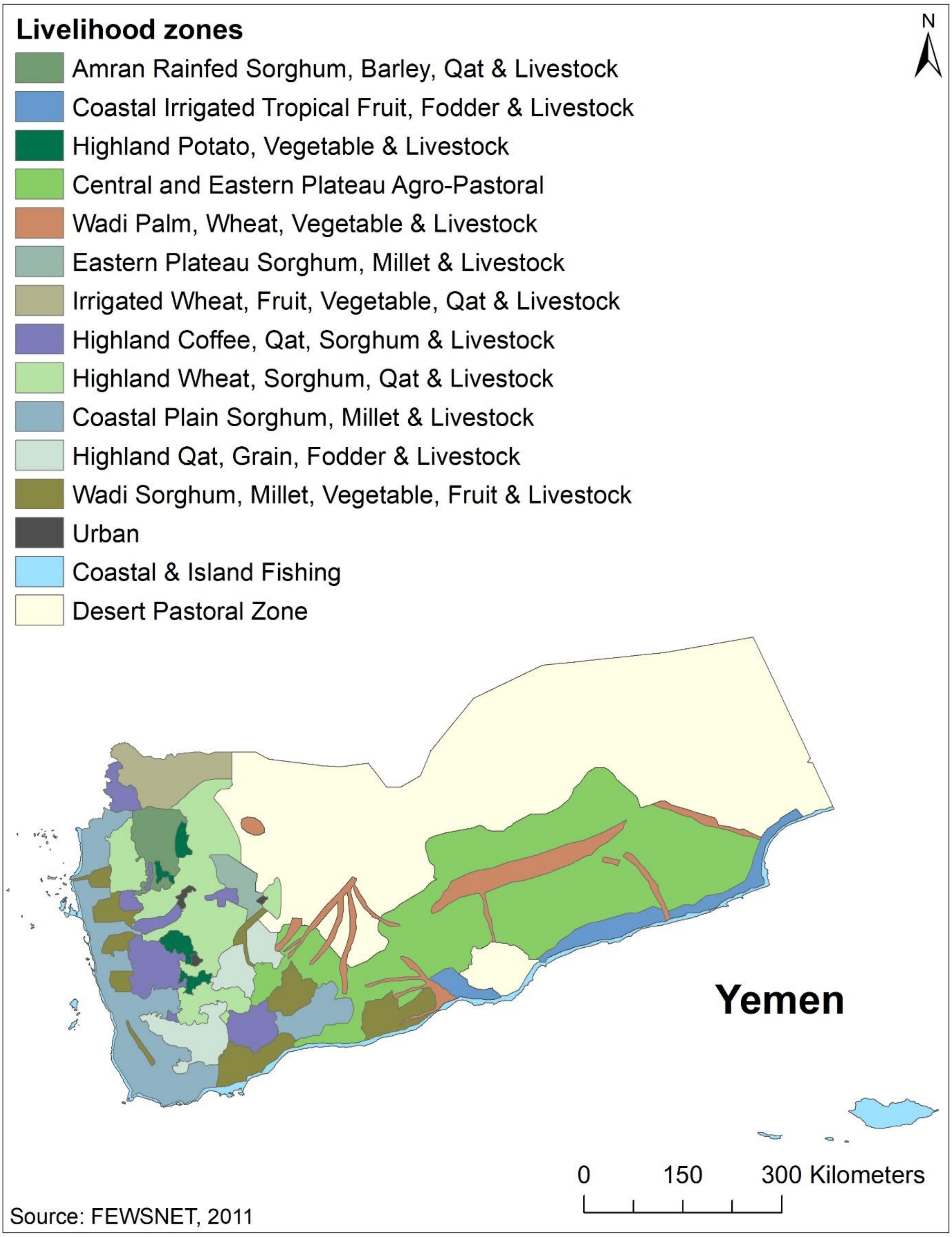
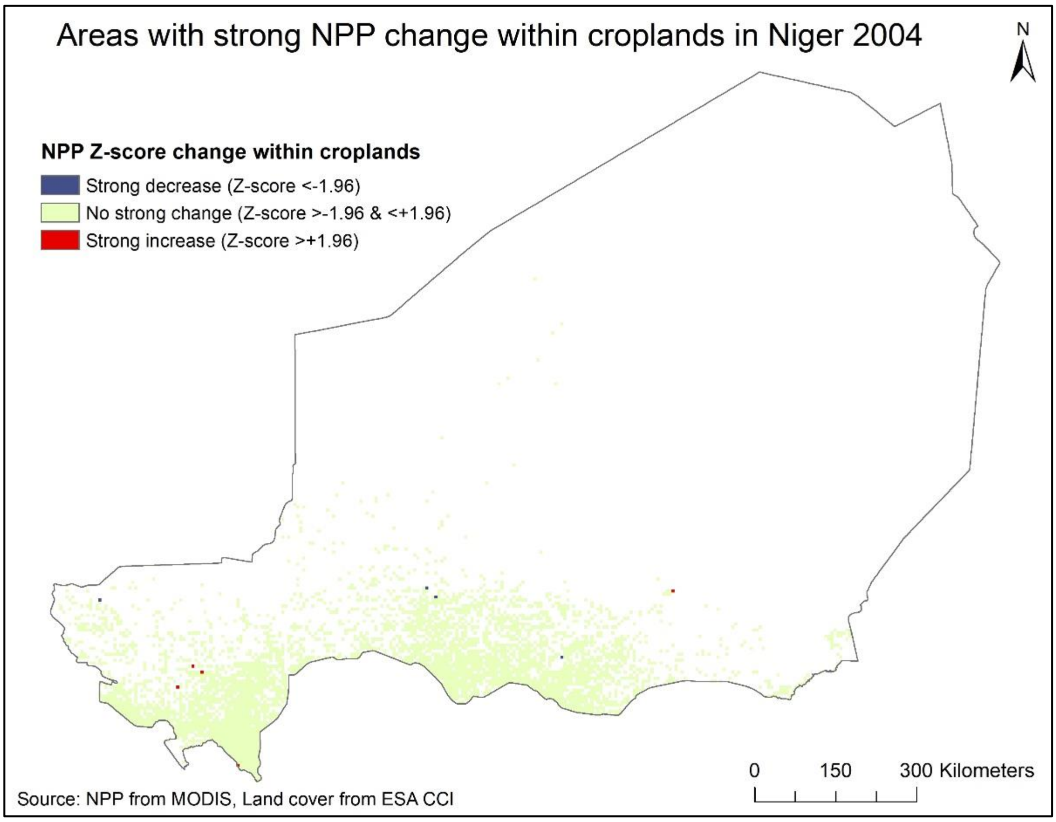


Figure 18. Livelihood zones (LHZ) in Yemen

8.3 Areas with strong NPP Z-score changes within croplands

Figure 19 shows areas with strong changes in NPP within croplands in Niger 2004 and in Yemen 2007. A very limited number of areas experienced a strong decrease in NPP within both countries, these are found in the south of Niger and the eastern coast of Yemen.



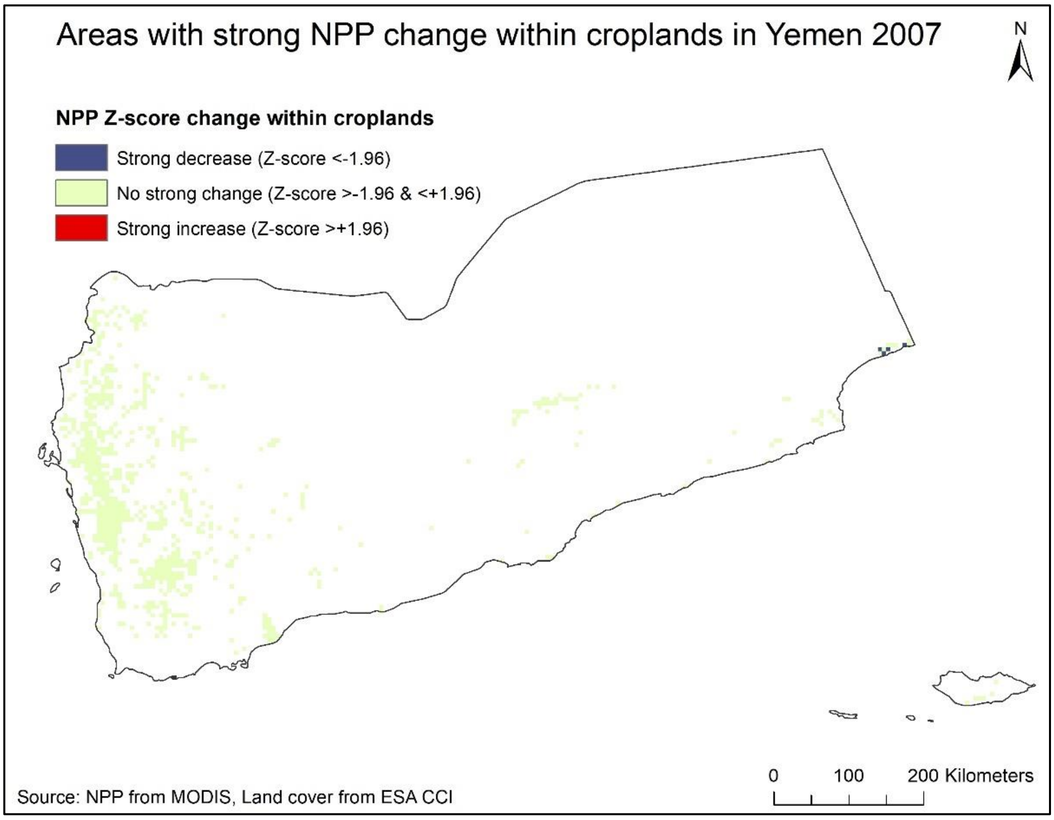
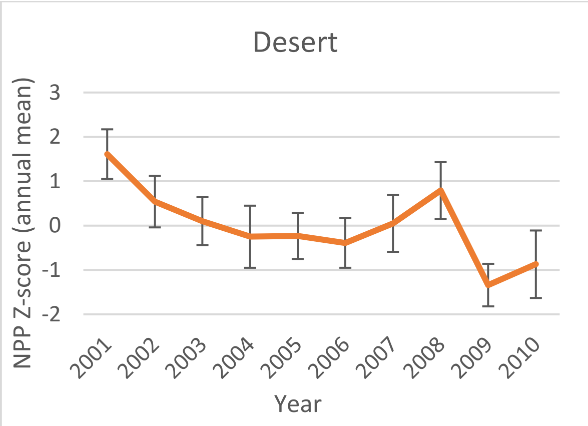
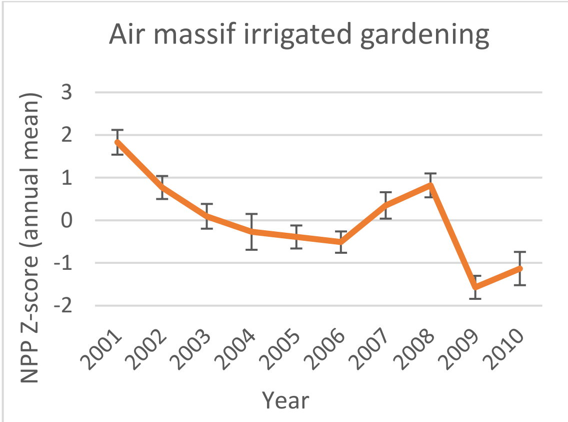


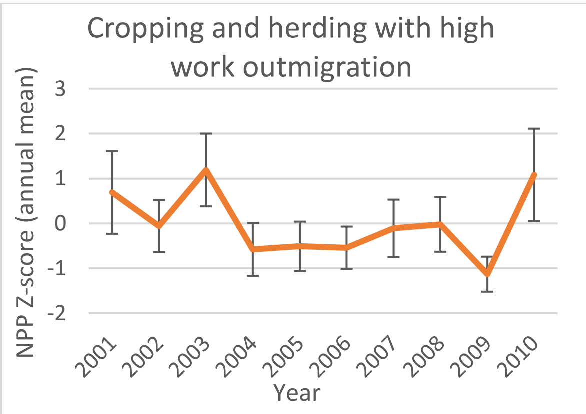
Figure 19. Areas of cropland with a strong change in NPP in Niger 2004 and in Yemen 2007

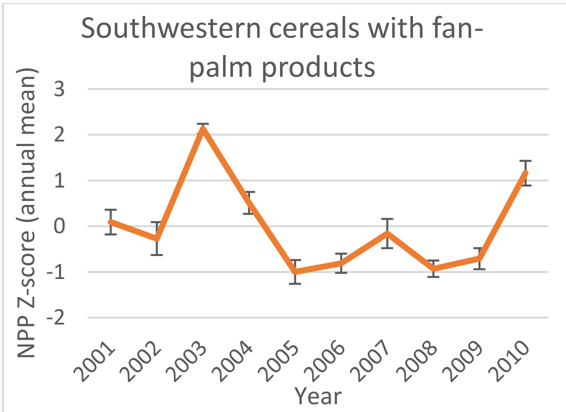
8.4 Timeseries of mean annual NPP Z-score within LHZ

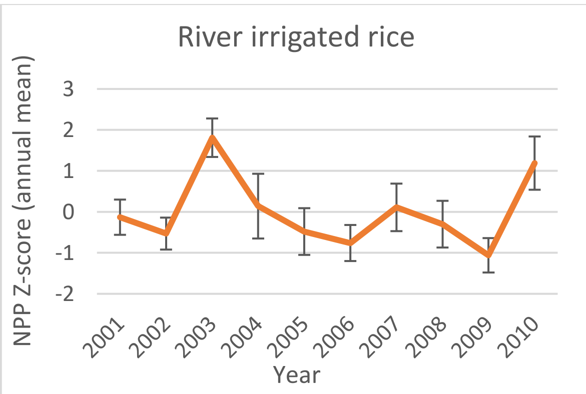
Figure 20 and 21 show the mean annual NPP Z-score within all LHZ in Niger 2004 and Yemen 2007 respectively, apart from the four most important ones in each country that are found in section 4.2.1. Most LHZ in Niger show the same pattern, with a NPP high in 2003 and a significant drop in 2004. The more specific LHZ connected to water or desert (with less vegetation) have a slightly different pattern but did also experience a small decrease between 2003 to 2004. The NPP follow the same pattern in general also in most of the LHZ in Yemen, with a NPP high in 2005 and a very small decrease around the outbreak 2007. It is the more specific zones connected to water/coast that stands out with a different pattern here as well.

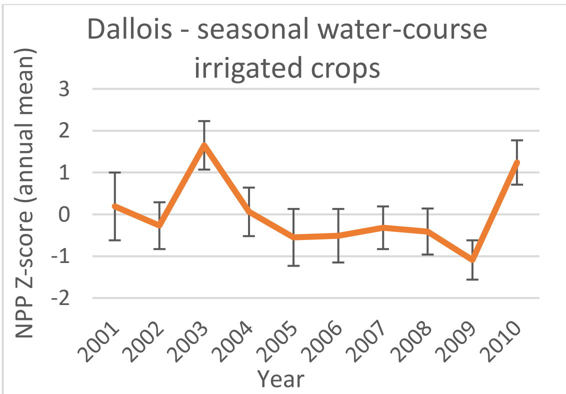












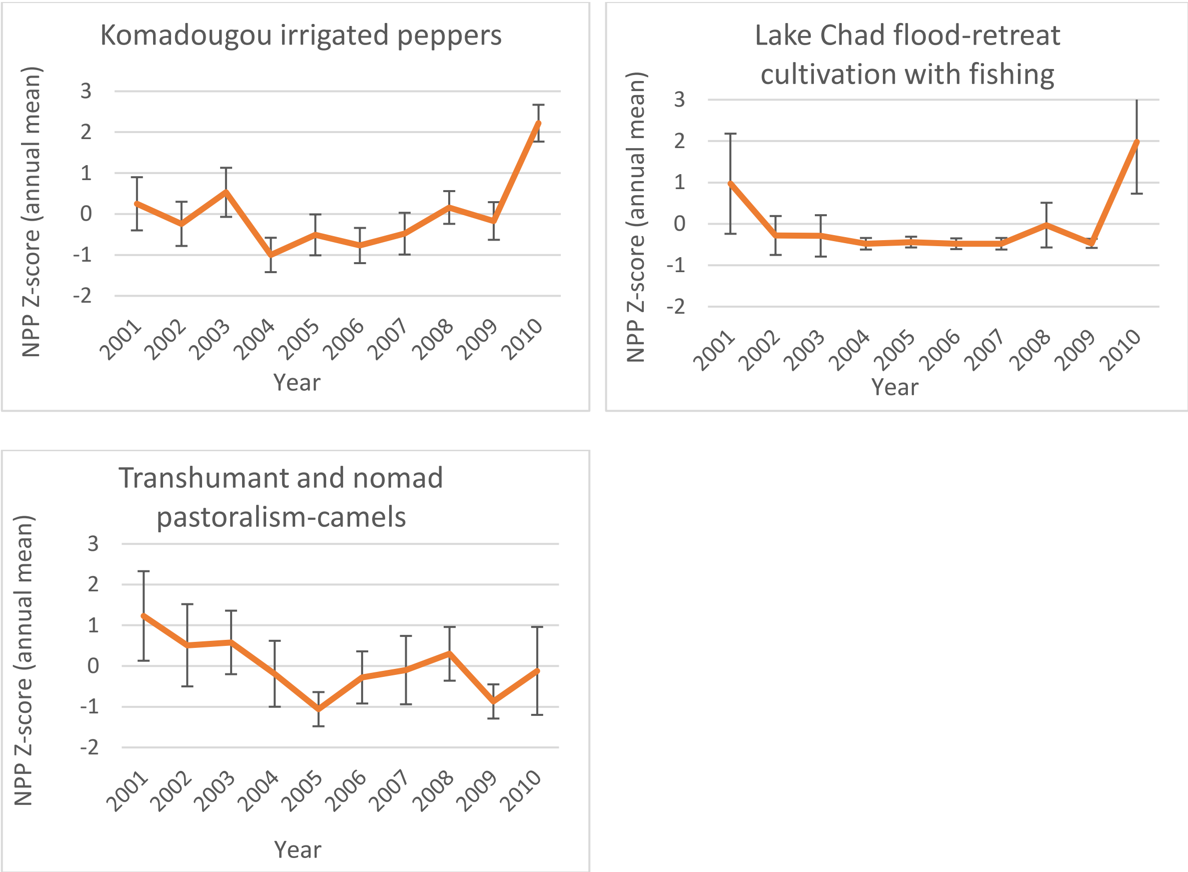
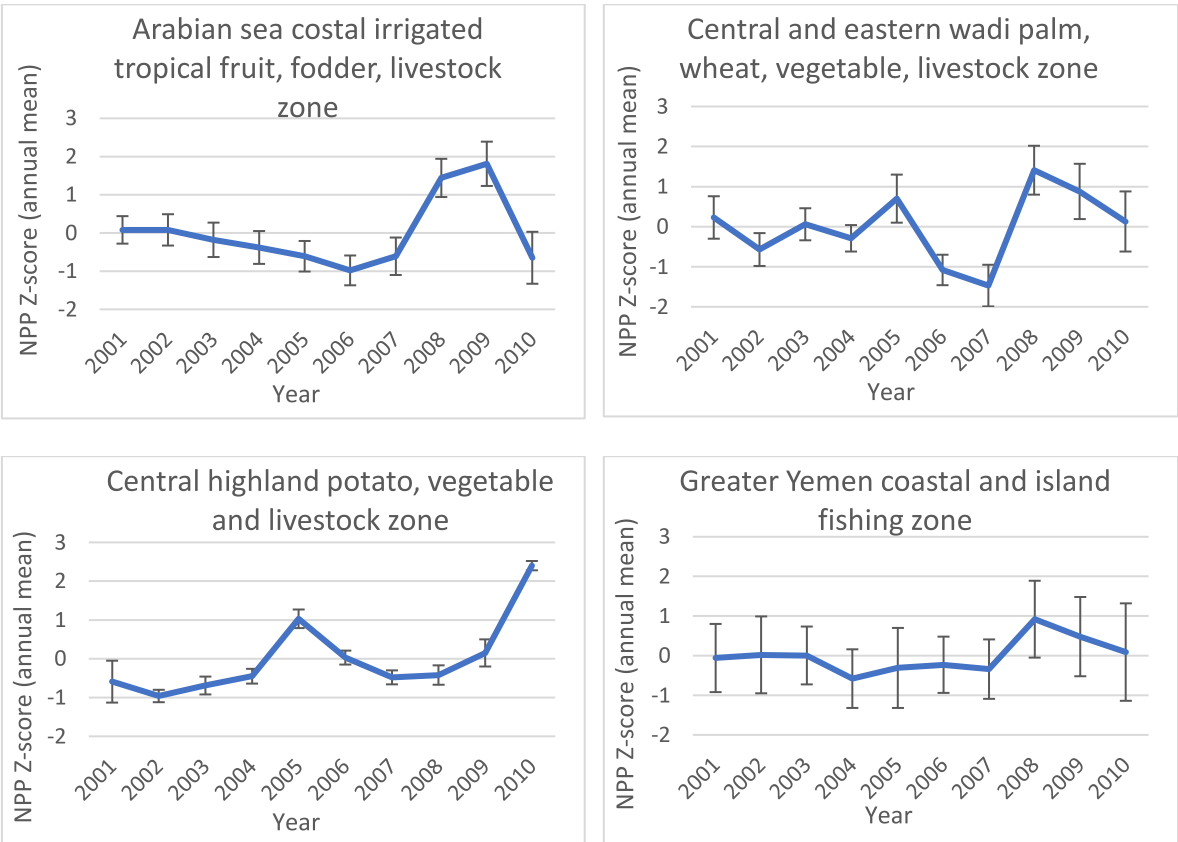


Figure 20. Mean annual NPP Z-scores within LHZ in Niger. The error bars denote one standard deviation.



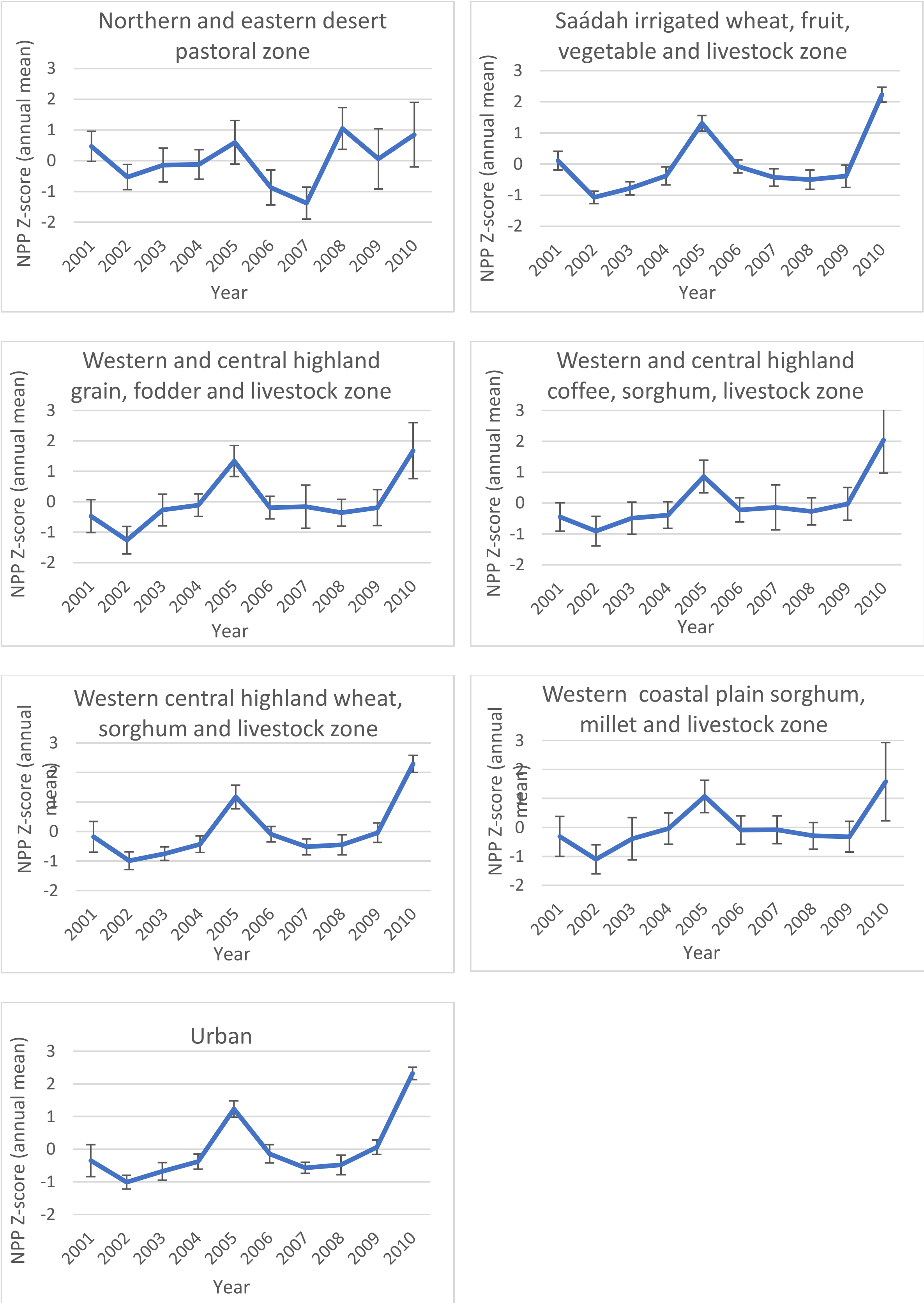


Figure 21. Mean annual NPP Z-scores within LHZ in Yemen. The error bars denote one standard deviation.

8.5 Mean NPP Z-scores within buffer zones around known locust locations, divided by LHZ

Tables 13-16 and 17-26 show the mean and standard deviation of NPP Z-scores within different buffer zones around known locust locations in Niger 2004 and Yemen 2007, respectively. The four most important LHZ in each country are instead presented in section 4.2.2, and the LHZ that are missing did not have any documented locusts in the years of interest according to the SWARMS dataset. All four LHZ in Niger experienced a decrease in NPP in 2004 compared to the study period as a whole. The decrease in NPP is larger in the buffer-zones closest to the documented locust locations and is reduced with increased distance. Almost all LZH in Yemen experienced a decrease in NPP in 2007 compared to the whole study period. Table 22 and 23 did instead show an increase in NPP within some of the buffer zones.

13. Desert

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	-0.53	0.62	Bare areas
5	-0.50	0.58	Bare areas
10	-0.50	0.59	Bare areas
15	-0.50	0.60	Bare areas
20	-0.50	0.60	Bare areas
25	-0.49	0.60	Bare areas
50	-0.44	0.62	Bare areas
75	-0.42	0.63	Bare areas
100	-0.37	0.65	Bare areas

14. Air massif irrigated gardening

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	-0.45	0.43	Bare areas
5	-0.43	0.42	Bare areas
10	-0.41	0.42	Bare areas
15	-0.39	0.41	Bare areas
20	-0.37	0.41	Bare areas
25	-0.35	0.40	Bare areas
50	-0.29	0.41	Bare areas
75	-0.27	0.42	Bare areas
100	-0.27	0.42	Bare areas

15. Cropping/Herding with high work outmigration

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	-0.78	0.28	Grassland
5	-0.78	0.24	Grassland
10	-0.77	0.27	Grassland
15	-0.78	0.28	Grassland
20	-0.75	0.34	Grassland
25	-0.74	0.35	Grassland
50	-0.68	0.46	Grassland
75	-0.57	0.58	Sparse veg.
100	-0.56	0.59	Sparse veg.

16. Southern natron salt & small basin irrigated dates

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	-0.92	0	Sparse veg.
5	-0.41	0.72	Grassland
10	-0.28	0.43	Grassland
15	-0.47	0.55	Grassland
20	-0.65	0.51	Grassland
25	-0.79	0.56	Grassland
50	-0.76	0.57	Grassland
75	-0.73	0.62	Grassland
100	-0.67	0.61	Grassland

Table 13-16. Mean NPP Z-score within different buffer zones around locust locations in Niger 2004

17. Arabian sea coastal irrigated tropical fruit, fodder and livestock zone

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	-0.62	0.55	Bare areas
5	-0.61	0.55	Bare areas
10	-0.62	0.53	Bare areas
15	-0.63	0.49	Bare areas
20	-0.63	0.46	Bare areas
25	-0.63	0.44	Bare areas
50	-0.61	0.49	Bare areas
75	-0.61	0.49	Bare areas
100	-0.61	0.49	Bare areas

18. Central and eastern wadi palm, wheat, vegetable & livestock zone

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	-1.42	0.42	Bare areas
5	-1.43	0.39	Bare areas
10	-1.46	0.41	Bare areas
15	-1.48	0.43	Bare areas
20	-1.48	0.46	Bare areas
25	-1.48	0.47	Bare areas
50	-1.48	0.50	Bare areas
75	-1.47	0.52	Bare areas
100	-1.47	0.52	Bare areas

19. Central highland potato, vegetable & livestock zone

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	-0.41	0.00	Bare areas
5	-0.35	0.09	Bare areas
10	-0.36	0.07	Bare areas
15	-0.41	0.10	Bare areas
20	-0.45	0.15	Bare areas
25	-0.47	0.15	Bare areas
50	-0.48	0.18	Bare areas
75	-0.48	0.18	Bare areas
100	-0.48	0.18	Bare areas

20. Greater Yemen coastal and island fishing zone

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	-0.35	0.62	Bare areas
5	-0.38	0.67	Bare areas
10	-0.39	0.72	Bare areas
15	-0.41	0.72	Bare areas
20	-0.41	0.72	Bare areas
25	-0.40	0.71	Bare areas
50	-0.38	0.71	Bare areas
75	-0.38	0.71	Bare areas
100	-0.38	0.70	Bare areas

21. Northern and eastern desert pastorial zone

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	-1.38	0.36	Bare areas
5	-1.36	0.41	Bare areas
10	-1.39	0.39	Bare areas
15	-1.41	0.41	Bare areas
20	-1.41	0.41	Bare areas
25	-1.42	0.42	Bare areas
50	-1.41	0.50	Bare areas
75	-1.38	0.51	Bare areas
100	-1.38	0.52	Bare areas

22. Western and central highland qat, grain, fodder & livestock zone

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	0.40	1.4	Sparse veg.
5	0.28	1.1	Sparse veg.
10	0.19	0.98	Sparse veg.
15	0.18	0.97	Sparse veg.
20	0.10	0.93	Sparse veg.
25	0.03	0.86	Sparse veg.
50	-0.16	0.70	Sparse veg.
75	-0.16	0.70	Sparse veg.
100	-0.16	0.70	Sparse veg.

23. Western central highland coffee. qat, sorghum & livestock zone

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	-0.50	0.00	Sparse veg.
5	0.37	0.71	Sparse veg.
10	0.45	1.04	Sparse veg.
15	0.50	1.06	Sparse veg.
20	0.37	0.99	Sparse veg.
25	0.24	0.92	Sparse veg.
50	-0.07	0.77	Sparse veg.
75	-0.12	0.74	Sparse veg.
100	-0.13	0.73	Sparse veg.

24. Western central highland wheat, sorghum, qat & livestock zone

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	-0.56	0.40	Bare areas
5	-0.50	0.38	Bare areas
10	-0.43	0.34	Bare areas
15	-0.42	0.31	Bare areas
20	-0.46	0.30	Bare areas
25	-0.48	0.28	Bare areas
50	-0.50	0.27	Bare areas
75	-0.52	0.27	Bare areas
100	-0.52	0.77	Bare areas

25. Western coastal plain sorghum, millet & livestock zone

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	-0.23	0.43	Bare areas
5	-0.17	0.43	Bare areas
10	-0.14	0.43	Bare areas
15	-0.12	0.45	Bare areas
20	-0.10	0.47	Bare areas
25	-0.09	0.48	Bare areas
50	-0.08	0.49	Bare areas
75	-0.07	0.48	Bare areas
100	-0.07	0.49	Bare areas

26. Urban

Buffer distance (km)	NPP Z-score		Majority land cover
	Mean	St.dev	
2	-0.68	0.36	Bare areas
5	-0.65	0.21	Bare areas
10	-0.61	0.19	Bare areas
15	-0.59	0.19	Bare areas
20	-0.59	0.18	Bare areas
25	-0.58	0.18	Bare areas
50	-0.57	0.18	Bare areas
75	-0.57	0.18	Bare areas
100	-0.57	0.18	Bare areas

Table 17-26. Mean NPP Z-score within different buffer zones around locust locations in Yemen 2007

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