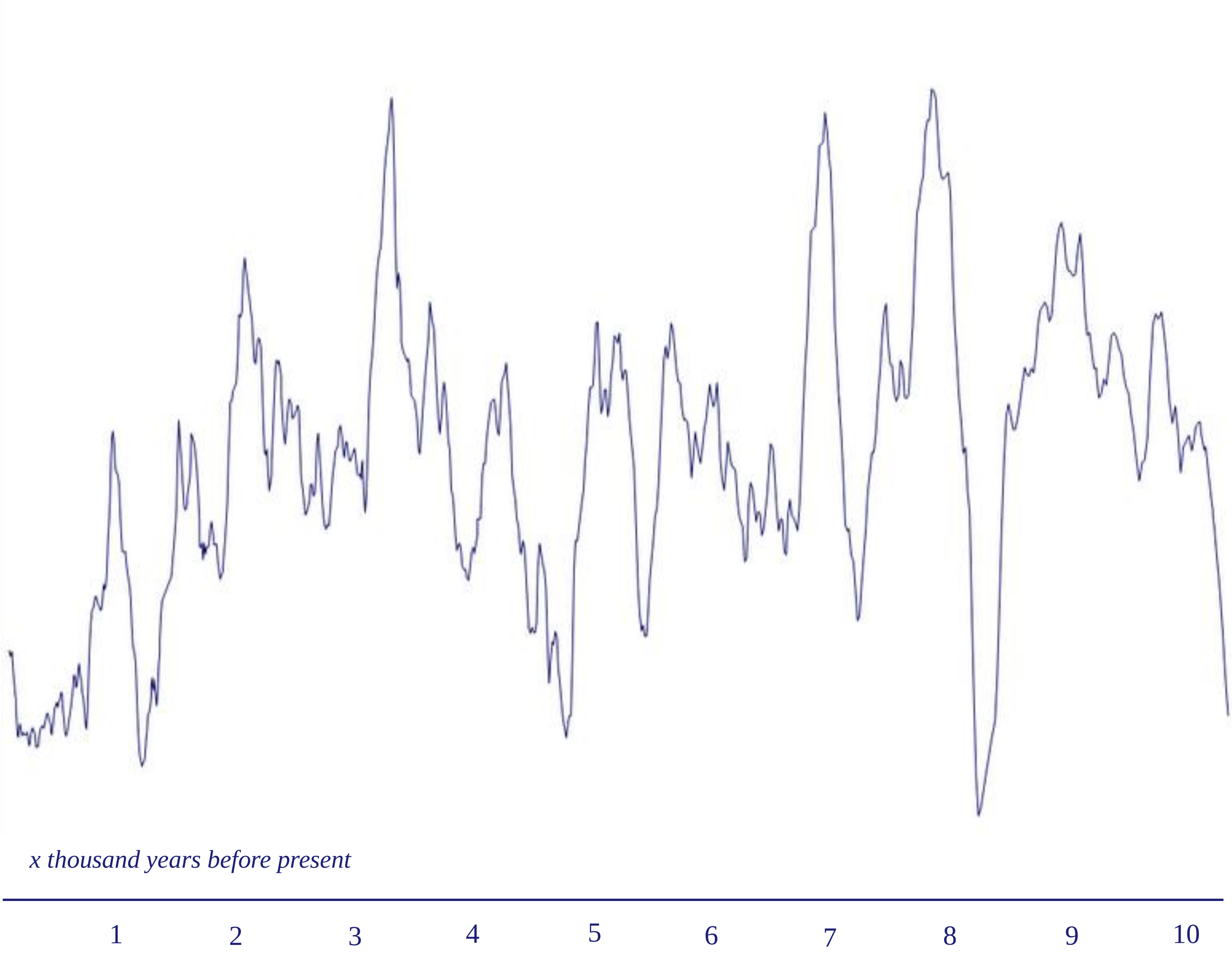
Universiteit Leiden

Ecosystem resilience in the context of the 8.2 ka cooling event

A study on the effects of the 8.2 ka event on the natural environment of Tell Sabi Abyad, Syria, and its significance for research on the characteristics of ecosystem resilience.

S.A. van der Horn



Ecosystem resilience in the context of the 8.2 ka cooling event

A study on the effects of the 8.2 ka event on the natural environment of Tell Sabi Abyad, Syria, and its significance for research on the characteristics of ecosystem resilience.

- Master thesis -

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1. Introduction

> *“While some forecasters believe the cooling and dryness is about to end, others predict a new ice age or a global drought, leaving policy makers and the public highly uncertain about the future climate and what to do, if anything. Is this merely a “blip” of little importance or a fundamental change in the Earth's climate requiring an urgent massive human response?” (Schwarts and Randall 2003)*

Over the past decades climate change has become a topic of global concern. The 2003 Pentagon report on climate change has played an significant role in drawing world-wide attention to climate issues by presenting a worst case scenario with possible environmental and socio-economic consequences of on-going climate forcing (Schwarts and Randall 2003). With the current level of atmospheric CO_2 concentration the debate is rising on the sustainability of the world's climate and ecosystems. Alarming reports have been published on the consequences of the on-going, most likely human induced, changes that are taking place in the global climate (Rose 2010; Schwarts and Randall 2003; Stover 2001). Predictions vary from famines and droughts to natural catastrophes and massive extinctions (Alley 2000; Salam and Noguchi 2005; Schwarts and Randall 2003).

However, climate change is not just something of the current era. There have always been fluctuations in the climate throughout history, some much more far-reaching than current developments. Past climate fluctuations vary from large, more or less regular climate shifts, like the large ice ages, to smaller and more abrupt climate anomalies, like the 8.2 ka event and the Little Ice age (von Grafenstein *et al*., 1998; Rose, 2010). Though these events look rather small in relation to other climate fluctuations in history, they certainly had a visible impact on global temperature and CO_2 levels, as well as other climate variables (Alley and Ágústdóttir 2005; Richerson *et al.* 2001).

1.1 The 8.2 ka event and Tell Sabi Abyad

In the research on climate change and the efforts to get a clearer picture of climate developments in the future, research on climate events in the past plays an important role. Ice core analysis has shed light on long-term climate variability (Rose, 2010), but also serves to gain insight in the environmental consequences of abrupt or short-term climate fluctuations. This is done through research on more recent climate anomalies, like the Younger Dryas, the 8.2 ka event, and the Little Ice age, (Alley and Ágústdóttir 2005; Russell 2010).

The 8.2 ka event in particular has received much attention for this purpose (a.o. Akkermans 2004; Alley and Ágústdóttir 2005; Russell 2010; Wiersma and Renssen 2006). This cooling event was most likely triggered by a sudden drainage of the Laurentide lakes (lake Agassiz and Ojibway) as a result of increased melting of the Laurentide ice sheets. Consequently, this led to a freshening of the North Atlantic and a subsequent slow-down of the Thermohaline Circulation.

The disruption of the North Atlantic conveyor belt caused a major change in the climate on the northern hemisphere, and also affected the southern hemisphere, though more research is needed on the extent of the impacts in the southern regions. The impact of the disrupted Thermohaline Circulation varied all over the world. Most regions generally became colder, while the lower latitudes, like Africa, the Near East, and a large part of Asia, showed also an increased aridification and a decrease in precipitation (Alley and Ágústdóttir 2005; Wiersma and Renssen 2006).

A great deal of research has been done and is on-going in Tell Sabi Abyad, Syria, where a large amount of archaeological material has been found dating back to the time period in which the 8.2 ka event took place (Akkermans 2004). It has been argued that the 8.2 event had significant consequences for the late Neolithic farmers in the Near East, especially for the communities that were located in marginal areas with relatively low precipitation. As agriculture and pastoralism are both highly dependent on water availability, a reduced precipitation could be devastating for farmers (Akkermans 2004; Russell 2010). However, there is still much debate on the extent to which the 8.2 event played a role in this, and to what extent other factors were involved (Akkermans 2004).

1.2 Research questions

Despite the public concern and on-going research, there is much uncertainty about how a changing global climate influences living conditions for humans and natural ecosystems. It is difficult to predict in what way and to what extent the world's ecosystems will be affected by possible climate change in the future. The influence of climate fluctuations on ecosystem functioning is related to the resilience of ecosystems against climate forcing. Presently little is known about the extent to which ecosystems can cope with climate fluctuations and at what level of climate forcing (the 'tipping point') an ecosystem collapses.

As much archaeological data is available on climate variability in the past, and with directed research presumably even more valuable data would be found, archaeology could form a valuable asset to the research on climate variability and ecosystem resilience.

The aim of this research is therefore to determine which factors play a role in the resilience of ecosystems, which methods are needed to research this, and how archaeological research can contribute to this. The research on the influence of the 8.2 event on the natural environment of Tell Sabi Abyad serves as a case study for larger-scale research on ecosystem resilience.

In relation to the previously described problem definition, the following central research question was formulated:

To what extent has the 8.2 ka event affected the natural environment of Tell Sabi Abyad, and how do these observations contribute to the research on ecosystem resilience?

Subsequently, the research question was sub-divided into nine sub-questions, which together lead to the answer to the central research question:

1. What factors play a role in ecosystem resilience?
2. What factors play a role in ecosystem resilience in the area of Tell Sabi Abyad in specific?
3. In what way has the 8.2 ka event affected the natural environment of Tell Sabi Abyad, according to archaeological research and climate models?

4. Which indicators for ecosystem resilience can be found in the archaeological record of Tell Sabi Abyad?
5. In what way can archaeological material contribute to the research on ecosystem resilience?
6. How do the results found on the 8.2 event in Tell Sabi Abyad relate to ecosystem resilience globally?

2. Methodology

The research questions presented here cover a variety of topics. To maintain clarity the research has been subdivided into three different sections, which are described below. Data collection for this research was done through a literature review and interviews with experts.

1. Literature review (chapters 3-5)

First, a literature study had been done to obtain insight in ecosystem functioning and to create a model of climate-ecosystem interactions. Furthermore, literature and experts were consulted in order to obtain a basis of knowledge on the characteristics of the 8.2 event, the climate and geographical characteristics of Tell Sabi Abyad, and the archaeological research done in that region.

2. Data analysis (chapters 6-8)

In the second part of the research, an assessment was made of the effects of the 8.2 event in Syria, and in Tell Sabi Abyad specifically. Subsequently, results of climate models were assessed, in order to enable comparisons with archaeological data. Finally, the results were used for an evaluation on the resilience of ecosystems during the 8.2 event in Syria, and these results will be placed in a broader context of global ecosystem resilience.

3 Synthesis (chapter 9)

The results found in the first two parts of the research were used for an evaluation of the possibilities for the use of archaeological data in determining ecosystem resilience. This was done by making an assessment of the types of archaeological data that are useful for this purpose, and by describing in what way different types of archaeological data can contribute to research on ecosystem resilience.

3. Factors influencing ecosystems

3.1 Introduction

Before analysing the specific case of Tell Sabi Abyad, it is necessary to create a knowledge base on the factors that play a role in ecosystem functioning in general. This is needed in order to view the situation of Tell Sabi Abyad, which will be discussed in chapter 6, in a broader context of global climate-ecosystem interactions.

When it comes to describing the complex subject of climate-ecosystem interactions, a large variety of influential factors needs to be discussed. These factors are mainly related to temperature, the hydrological cycle, and the carbon cycle. Though the direct effects of each of the involved factors differ, eventually most of their influence comes down to moisture availability. Water deprivation in an ecosystem will lead to a reduction in vegetation growth, and in the long run to vegetation die-back. On the other hand, an excess of water can lead to suffocation of plants as their roots become devoid of oxygen. Changes in the hydrological cycle have a direct influence on the water availability in an ecosystem. Temperature and the carbon cycle play mainly an indirect role in this, but also have some direct influences.

In addition, there are a number of factors that influence vegetation growth and ecosystem survival directly, without having a major direct influence on the hydrological cycle. These factors are related to the variety and types of species that are present in an ecosystem.

It needs to be stressed that all factors that play a role in ecosystem functioning are strongly interconnected. Therefore it is impossible to ascribe a certain climatic development to one factor. Rather a variety of factors or a complex loop of interrelated feedback mechanisms play a role.

In this chapter, an overview is given of the main factors that influence ecosystem functioning directly or indirectly, and their characteristics are discussed. Eventually a model has been made which shows how these factors are interlinked. The chapter concludes with a description of how ecosystems respond to climate change.

3.2 Meteorological parameters

The sun is the primary factor of influence on the earth's meteorological characteristics. The way in which meteorological features are affected, might be through changes in solar activity and irradiance (van Geel *et al*. 2003), as well as major natural disasters that are not related to solar influence, like volcanic eruptions and forest fires, or through anthropogenic influences.

The influences of temperature variations are most prominent in regions with extreme temperatures, like the northern and southern high latitudes with low temperatures, and the Sahel region with high temperatures (Dekker *et al*. 2010). By using climate-vegetation interaction models Dekker *et al*. (2010) have discovered that in northern and southern high latitude regions variations in sea surface temperature (SST) show a positive correlation with vegetation growth. Thus, if temperature increases, biomass accumulation increases as well. This is possibly related to the fact that photosynthetic production is hampered at lower temperatures.

On the other hand, at low and mid-latitudes, especially in Central Africa, a negative correlation was seen between vegetation growth and changes in temperature (Dekker *et al*. 2010). This phenomenon is related to the strong effects of SST anomalies on vegetation growth in those regions. The case of the Sahel is a complicated one, as here SST changes seem to have a much larger effect on precipitation and thus on ecosystems as in many other places in the world (Dekker *et al*. 2010; Paeth and Friederichs 2004; Rietkerk *et al*. 2011). The main reason SST plays such an important role here is that the African vegetation is strongly dependent on a monsoon climate (Foley *et al*. 2003). As changes in SST alter the monsoon system, they have a strong effect on precipitation patterns (Foley *et al*. 2003).

Other influences related to temperature variations are albedo effects and cloud formation. Regarding albedo, it is generally assumed that higher temperatures lead to a reduction in albedo (due to vegetation growth and snow melt), which in turn results in further temperature increase. However, this seems to be not always the case. Dekker *et al*. (2010) have observed that an albedo reduction in Central Africa due to vegetation build-up leads to a temperature decrease as a result of increased evapotranspiration from the vegetation. Also, Blok *et al*. (2011) did not find a strong correlation between albedo and temperature in their study on Arctic ice cover and vegetation growth. Therefore, the effect of albedo on temperature remains disputable.

Cloud formation is a result of increased sea surface temperature, which can prevent heat from escaping the atmosphere, thus leading to a further temperature increase. However, it is not certain to what extent cloud formation leads to increased temperatures, if at all. Though water vapour can result in the formation of high, thin clouds that prevent heat from leaving the earth, it is also possible that low, thick clouds are formed, which have a cooling effect on the earth as they reflect sunlight (Alley 2000).

These observations show that temperature variations are strongly connected to the hydrological cycle. Changes in temperature affect evapotranspiration, which in turn plays a crucial role in precipitation patterns (Rietkerk *et al*. 2011). Due to feedback mechanisms within the hydrological cycle, changes in precipitation and evapotranspiration can have strong effects on ecosystems.

Also, wind plays an important role in precipitation patterns. Low and high pressure areas are created through temperature differences and the rotation of the earth. This results in a typical pattern of atmospheric cells around the world (figure 1). The wind patterns resulting from this have an effect on humidity, and are responsible for precipitation patterns around the world, like the Asian and African monsoons (Kafando *et al*. 2008; Li and Zhang 2009), and the European westerlies (sometimes called European monsoons) (Visser 1953). Though precipitation is generally determined by the earth's wind patterns, on a more regional level the precise development of precipitation patterns is dependent on a number of other factors as well. For example, the relief of a landscape (e.g. presence of mountains, hills or plains) can have a huge effect on precipitation. Furthermore, measurements of average precipitation can be misleading, as changes in precipitation intensity throughout different seasons partly determine the possibilities for vegetation growth and faunal diversity.

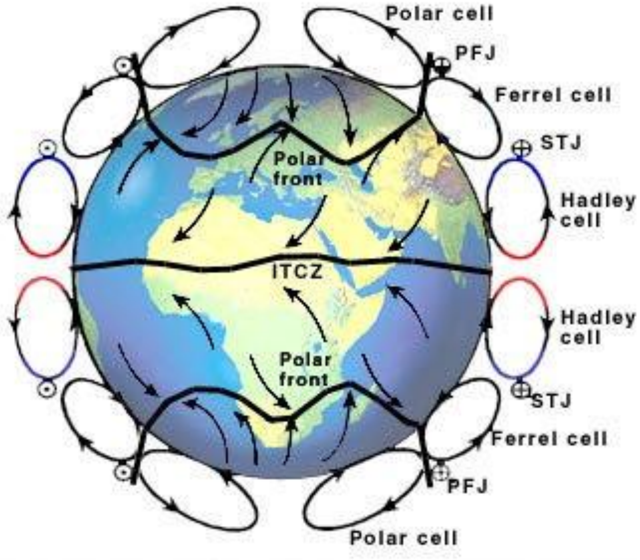

Fig. 1: The distribution of wind circulation patterns over the world, showing Hadley cells, Ferrell cells, polar cells, the polar front jets (PFJ), the subtropical jets (STJ), and the inter tropical convergence zone (ITCZ) (source: http://webarchive.nationalarchives.gov.uk).

3.3 The carbon cycle

As stated before, the carbon cycle is strongly connected to temperature and the hydrological cycle. The level of atmospheric CO_2 is positively correlated with temperature, since CO_2 is a greenhouse gas. Additionally, if temperature increases, this leads to an increase of atmospheric CO_2 levels, as higher SST allows lower amounts of CO_2 to be dissolved into the ocean (Kimball *et al*. 1993). In this way temperature and atmospheric CO_2 levels form a positive feedback-loop.

Changes in CO_2 levels have an effect on temperature and the hydrological cycle, and thus an indirect effect on ecosystems. In addition, CO_2 also has direct effects on ecosystems. A rise in CO_2 in the air will lead to increased plant growth, as more carbon is available (Kimball *et al*. 1993). Similarly, a reduction in atmospheric carbon will slow down plant growth.

Changes in CO_2 levels can be caused by for example a rise in temperature, or through natural disasters like forest fires. Also anthropogenic forcing is possibly a factor of influence on the carbon cycle, through active deforestation, fuel combustion and agriculture. Though it is generally assumed that the effects of anthropogenic activities on the climate started with the industrial era, there are signs that humans had a visible influence on climate and ecosystems already since the agricultural revolution (Hajar *et al*. 2010).

3.4 Internal factors

Besides the above described factors that play a role on a global and regional scale, there are also factors influencing ecosystems from within the system itself. These internal factors are related to and dependent on the different characteristics of each ecosystem.

For a long time it has been assumed that ecosystems were for their functioning mainly dependent on solar input and meteorological influences. However, there is growing evidence that influential factors within an ecosystem could ultimately play a crucial role in the maintenance or collapse of that ecosystem (Dekker *et al*. 2007; Foley *et al*. 2003; Guthrie 1990; Rietkerk *et al*. 2011; Tchernov 1982). Guthrie (1990), in his research on the Mammoth Steppe, found that one of the reasons why this biome stayed intact for such a long time throughout the Pleistocene was because of the large mammals that inhabited it. These herbivores were responsible for the vegetation to remain open and steppe-like, as they were feeding on the shoots of arboreal plants. Forests would therefore not have any chance to develop, while grasses, which easily recover from grazing, could grow in abundance. In this way, the landscape remained open, allowing steppe vegetation to flourish (Guthrie 1990).

Another example of species variety preserving an ecosystem is the Amazone rainforest. It has been argued that currently the climatic conditions in the Amazone region are no longer optimal for a rainforest ecosystem. However, the forest is preserved because of a so-called 'demographic inertia' (Malhi *et al*. 2008). This phenomenon is related to the long life times of the plant species present in the forest, which is responsible for a slow vegetation turnover (Malhi *et al*. 2008). In addition to that, it has been hypothesized that the typical, deep-rooted and dense vegetation of the Amazon rainforest may prevent other plant species to enter the ecosystem. In that way the ecosystem persists, according to Malhi *et al*. (2008), even if the climate shifts to savannah conditions.

Furthermore, Dekker *et al*. (2010) discovered that the amount of vegetation plays a role in the development and resilience of ecosystems. Through modelling vegetation developments in relation to climate they showed that with a globally low vegetation density at the starting point, ecosystems would develop in such a way that an equilibrium would be reached with relatively low vegetation densities. This effect was strongest when initial vegetation was specifically low in northern and southern high latitudes. On the other hand, if initial vegetation density was high, an equilibrium would be reached with relatively high vegetation densities. Even when perturbations were included in the model that would reduce the amount of vegetation to that of the model with initial low vegetation density, the equilibrium would always end up higher than that of the model with initial low vegetation density. This shows that small-scale, local climate-vegetation feedbacks are of crucial importance for the survival of ecosystems.

3.5 Summary: a climate-ecosystem interaction model

The above description of factors influencing ecosystems is a very concise one, and serves mainly to give an impression of the different elements that play a role when it comes to researching ecosystem resilience, as well as to show the complexity of the subject. An overview is given of the important factors that directly or indirectly influence ecosystems, and of their interactions. This is seen in the simplistic overview in figure 2.

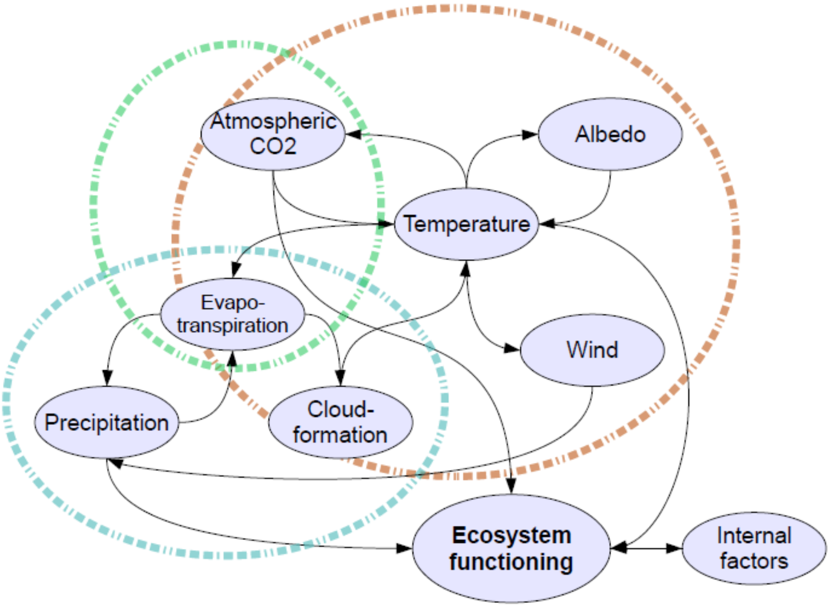

Fig. 2: Simplistic overview of climate-ecosystem interactions.
Red: Temperature-related factors; Blue: factors related to hydrological cycle; Green: factors related to carbon cycle.

It is important to realise that the factors influencing ecosystems have different levels of impact at different places in the world. This was already shown by the examples of temperature influences varying with latitude, and the influence of vegetation types and densities varying globally.

3.6 Floral and faunal responses to environmental change

The way in which ecosystems respond to influential factors from outside or inside varies with region and type of ecosystem. Tchernov (1982) gives a good description of the way in which ecosystem resilience is organized within ecosystems. First, he argues that any community consists of three main types of species:

- Unchanged survivors: these are the animal and plant species that are extremely flexible when it comes to climate and ecosystem changes, and can survive in differing and fairly extreme circumstances. Examples in the Middle East are the house mouse (*Mus musculus*), and the gazelle (*Gazella gazella*), which have been present since respectively the early Middle Pleistocene and the Eemian Interglacial.
- Transformed survivors: these species have been able to adapt to their changing environment and have become resilient against considerable climate variability.
- Species added by indigenous speciation and immigrated elements: species that have not been present in the ecosystem for a long time and therefore are more vulnerable to any changes that may occur. These are generally the first ones to go extinct when climate changes and competition in their ecological niches increases.

In these different categories of species, genetic diversity plays an important role, as does the species-specific physiological and ecological range in respect to abiotic factors. The larger the genetic diversity within a species, or the larger the range of physiological and ecological adaptability, the more likely it is the species will be able to survive changes in its environment.

As a result of the different types of species that are present in ecosystems, the response to environmental change is not uniform among species. Tchernov (1982) argues that each species within an ecosystem should be viewed separately in order to understand the full influence of external or internal stress on ecosystems. In general, Tchernov discerns four different ways in which environmental change affects ecosystems as a whole:

In the first scenario, harsh environmental alterations lead to massive extinctions within an ecosystem, influencing the natural environment to such an extent that it exceeds the limit of resilience that an ecosystem possesses against climate forcing.

The three other scenarios comprise more moderate changes that either affect the internal structure of a community, leading to morphological alterations within species as a means of adapting to the environmental changes, or result in the development of small refuge areas within a changed environment. In these three cases the situation is different from the first one, in the sense that ecosystem resilience is strong enough to retain (part of) the original ecosystem.

The question is to what extent of species extinction and alteration in species variability is 'acceptable' until an ecosystem can no longer be considered intact. This question is related to the question whether the demise of ecosystems always comes in the form of a sudden collapse, as soon as a crucial 'tipping point' has been reached, or if the transition from one ecosystem to another can also take place gradually. In the latter case, it is difficult to pin-point the exact moment at which this transition is definite. Both types of ecosystem transition can occur. A sudden transition from one ecosystem to another could for example be triggered by a sudden climate shift or a natural disaster. An example of a gradual shift from one ecosystem to another is the so-called 'succession', which takes place in newly developing areas where fast spreading pioneer species are gradually replaced with more tolerant species with a higher resilience.

It is also possible that a succession of minor changes trigger an abrupt ecosystem shift. An example is the Sahara and Sahel regions. Up to 5500 years ago these regions were characterised by wet environmental conditions with ample vegetation, lakes and wetlands (Foley *et al.* 2003). These favourable conditions came to a sudden end around 5500 years ago, when the vegetation and wetlands made place for the largest hot desert in the world. According to Foley *et al.* 2003) this change was caused by millennial-scale changes in the earth's orbit. However, a final and sudden collapse of the existing ecosystem cannot be solely explained by millennial-scale changes, as these are very gradual. Hence, Foley *et al.* (2003)

argue that the direct cause for the abrupt ecosystem transition has to be found in a deteriorating resilience within the ecosystem. Due to internal factors the resilience of the Sahara and Sahel regions decreased, and was at some point that low that only a slight change in the earth's orbit was enough to lead to a collapse of the entire ecosystem.

As Tchernov (1982) observed, the different types of floral and faunal responses that take place within an ecosystem in order to adapt to climate change can be seen in the alterations that take place in species diversity and morphology. Thus variations in any species within an ecosystem can already be an indicator for environmental change and changing ecosystem resilience.

4. The 8.2 ka climate event

4.1 Background

The sudden climate event that took place around 8200 BP was first observed in oxygen isotope records from Greenland ice cores (e.g. Johnson *et al.* 1992; Alley *et al*. 1997) (figure 3). After this discovery studies have been done on the global and regional impacts of the event, and it was found that climate proxy records from several other places in the world showed a similar climate anomaly around 8200 BP (e.g Germany: von Grafenstein *et al*. 1998; the tropical Atlantic region: Hughen *et al*. 1996; the Eastern Mediterranean: Bar-Matthews *et al*. 1999).

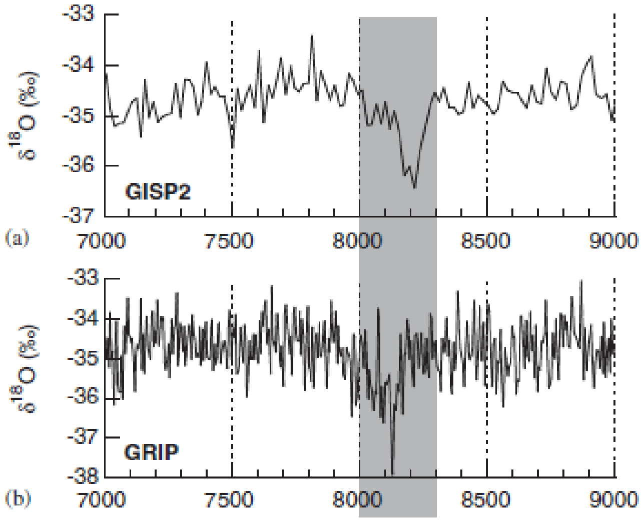

Fig. 3: Oxygen isotope records from two Greenland ice cores showing the 8.2 event (source: Wiersma and Renssen 2006).

The climate shift recorded around 8200 BP was characterized by a reduction in annual temperature in the northern hemisphere, as well as increased seasonality (Wiersma and Renssen 2006). This event was most likely a result of the disrupted Thermohaline Circulation of the northern Atlantic (e.g. Alley and Ágústdóttir 2005; Barber *et al*. 1999; Wiersma and Renssen 2006).

It is assumed that this disruption of the Atlantic conveyor belt was caused by a sudden drainage of the Laurentide meltwater lakes (figure 4). The event was a consequence of an increased melt-down of the Laurentide ice sheets, as a result of increased temperatures during the Holocene. This led to the breakthrough of the ice dam that used to cut the freshwater lakes off from the northern Atlantic (Rohling and Pälike 2005; Wiersma and Jongma 2010).

The exact timing at which this sudden meltwater outburst took place is debated upon. Currently, one of the most reliable dating results is provided by Rasmussen *et al*. (2007), who dated the event based on oxygen isotope records from three Greenland ice cores. According to their results, the cooling event took place between approximately 8300 BP and 8140 BP. Thus, the weakened oceanic conveyor belt was only of a short-lived nature and lasted for about 160 years before the climate turned back to previous conditions (Rasmussen *et al*. 2007). Other efforts to date the 8.2 event are often unreliable because of dating biases. This will be discussed in the third paragraph of this chapter.

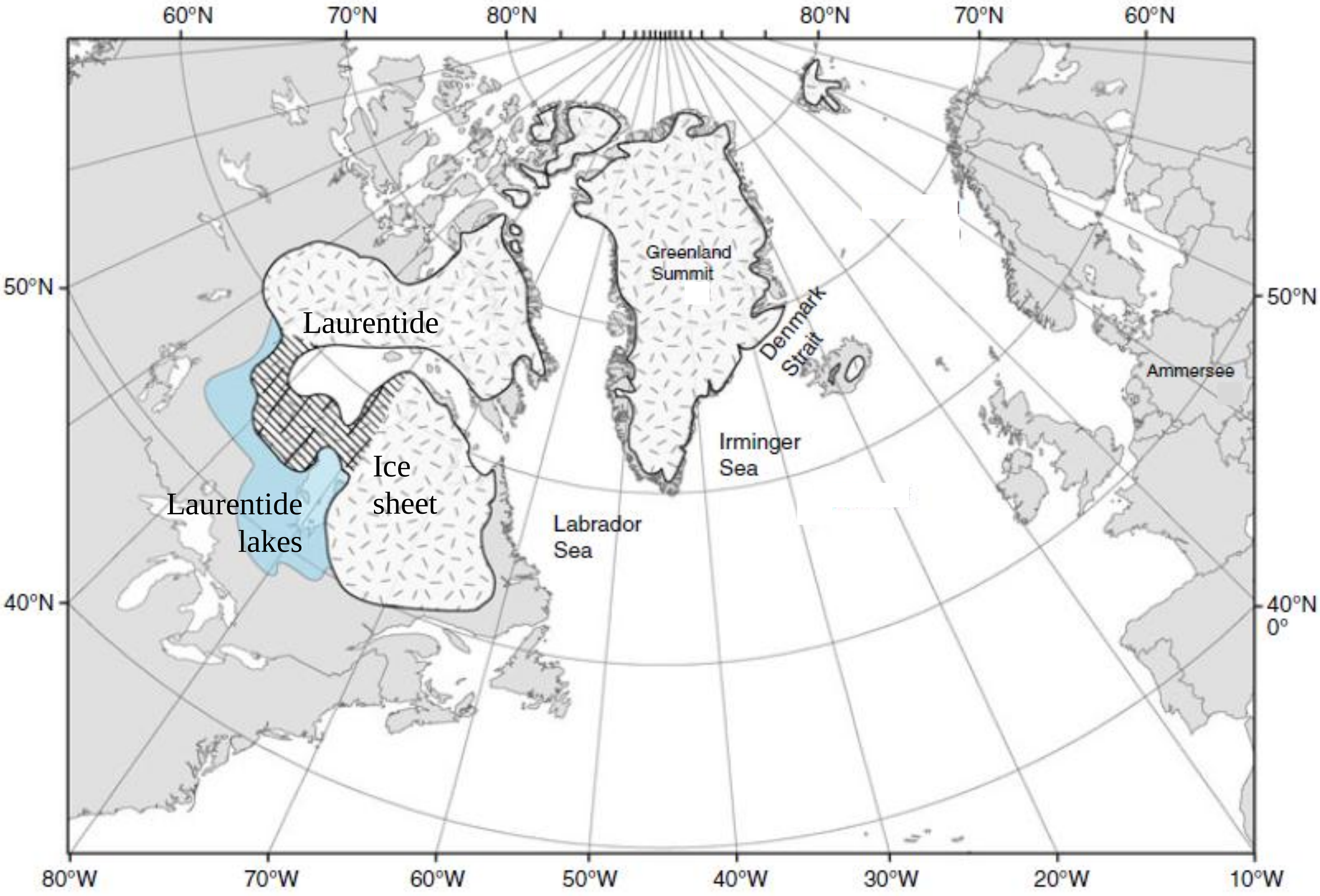

Fig. 4: The Laurentide ice sheet just before the 8.2 event, closing off the Laurentide lakes. During the 8.2 event the ice dam in the middle breaks through and releases the contents of the freshwater lakes (source: Wiersma and Jongma 2010).

Though it was first believed that the drainage of the Laurentide lakes was a single event, it has recently been argued by Wiersma (2008) that the meltwater burst took place in two separate instances, dated about 200 years apart (Wiersma *et al*. 2011). The second outburst would then have been the strongest one and responsible for the anomaly found in the Greenland ice cores (Wiersma 2008).

The duration of the process leading to the Laurentide meltwater water pulse is unknown. Though the 8.2 event is regarded as a sudden, short-term climate anomaly, it has been suggested that the event could be related to a more long-term climate fluctuation, which took place approximately between 8600 BP and 7900 BP (Rohling and Pälike 2005). However, strong evidence for this theory has not yet been found.

4.2 Effects of the 8.2 event

The effects of the 8.2 event were of a global scale, but were strongest in the northern hemisphere (Wiersma 2008). In general, annual temperatures decreased all over the northern hemisphere, while some places, mainly in Africa and Asia, became drier. Alley and Ágústdóttir (2005) give a good overview of the world-wide effects of the 8.2 event, which is shown in figure 5.

The largest effects of the disrupted Thermohaline Circulation were seen in the northern Atlantic region (Alley and Ágústdóttir, 2005), which is closest to the location where the event started. In Greenland, an average temperature drop of 6 °C has been observed (Alley and Ágústdóttir 2005), with strongest relative temperature changes in winter months (Alley and Ágústdóttir 2005)) In the rest of the world this temperature variation was lower, ranging from 1 to 3 °C reduction in annual temperature (Alley and Ágústdóttir 2005).

Alley and Ágústdóttir (2005) observed that Asia and Africa were not so much affected by a temperature drop as a result of the 8.2 event, but by an increased drought and aridity. They mention the possibility that the climate anomaly disrupted the monsoon systems on those continents, resulting in weaker and drier precipitation periods. This change in Asian and African climate has been observed in the floral and faunal records from those regions (Bar-Matthews *et al*. 1999), as well as in a short-term drop in methane levels in Greenland and Arctic ice cores, which indicate drying of tropical wetlands (Alley and Ágústdóttir 2005).

Fig. 5: Overview of the world-wide effects of the 8.2 event
(Source: Alley and Ágústdóttir 2005).

In Europe, the climate event resulted in an overall cooling of approximately 1 °C, and increased dryness (Alley and Ágústdóttir 2005). Also increased seasonal differences were observed in records dating back to the event (Baldini *et al*. 2002). These differences can most likely be attributed to increased winter anomalies (Alley and Ágústdóttir 2005). In addition, the event is associated with increased rainfall seasonality (Baldini *et al*. 2002).

In the Mediterranean region, the 8.2 event took place within a period of enhanced precipitation and an increased deposition of organic material (Wiersma 2008). This period is known as the youngest sapropel 1 (S1). Within the thick S1 sedimentation layer, a short-lived break in organic depositions has been observed that corresponds with the timing of the 8.2 event. This deposition break was presumably caused by cool and dry conditions that could be a result of the 8.2 event (Wiersma 2008).

In contrast to the cooling the 8.2 event brought in the northern hemisphere, some evidence has been found indicating a warming response in certain parts of the southern hemisphere, suggesting a bipolar seesaw effect (Wiersma *et al*.

2011). However, the northern hemisphere has been studied much more thoroughly: additional research is needed on the exact changes in the southern hemisphere.

4.3 Uncertainties regarding the effects of the 8.2 event

Many climate fluctuations all over the world that date back to the time around 8200 BP have been ascribed to the 8.2 event. However, this comes with a great deal of uncertainty about how much influence the 8.2 event really had, and to what extent other factors played a role. A critical view on the climate research related to the 8.2 event is therefore necessary.

First, there are uncertainties with respect to determining the exact date at which the 8.2 event took place. The most reliable records are the ones that enable a reconstruction of an annual time scale. Rasmussen *et al*. (2007) have done this for three Greenland ice cores. Also speleothem (Baldini *et al*. 2002) and tree ring records provide data with such high accuracy. Frequently used proxy records however, are based on marine and lake sediments, which are subject to several age uncertainties (Wiersma and Renssen 2006). First, such records are usually based on a series of radiocarbon dates, which come with a certain error margin. Second, when using marine and lake records, the carbon samples need to be corrected for a time delay related to exchange rates between atmospheric CO_2 and oceanic or lake bicarbonate, which, as studies have shown, is likely to change during climate events (Wiersma and Renssen 2006). Additionally, these models rely on assumptions on sedimentation rate. Daley *et al*. (2011) give a good overview of the age uncertainty related to current proxy records from different places in the world. Despite dating errors and uncertainties, Daley *et al*. (2011) found that in almost all records the duration of the event was more or less the same, about 160 years.

Related to the age uncertainties from climate proxy records are the uncertainties regarding the extent to which the Laurentide meltwater pulse influenced global climates. Alley and Ágústdóttir (2005) warn for 'Anomaly hunting': the ease with which local environmental changes are sometimes associated with the 8.2 event. Incorrect sampling and dating errors can result in an anomaly erroneously correlating with other recorded anomalies. This makes it difficult to give an exact overview of the environmental changes related to the 8.2

event (Alley and Ágústdóttir 2005).

An example is the observed increased periods of drought in Africa between 8.5 and 7.8 ka BP (Gasse and van Campo 1994). It has been suggested that this drought, which caused a water level reduction in several lakes in Africa, was related to the 8.2 event. However, this phenomenon has not been observed in all African lakes that were studied, so the extent of the influence of the 8.2 event is debatable (Alley and Ágústdóttir 2005). Furthermore, it was shown that the onset of the dry period, as well as its duration varied between the lakes. Therefore, it is not certain if this overall dry period in Africa can be ascribed to the results of the Laurentide meltwater outburst, or if multiple factors played a role. Perhaps the long-term climate anomaly that Rohling and Pälike (2005) have found could have played a role in the non-synchronous changes that took place in Africa, but this correlation has not been evidenced. A sudden reduction in humidity, that would be expected if only the 8.2 anomaly had had an influence, has not been observed from lake records in Africa.

In Asia, similar timing uncertainties have been observed in some climate anomalies that were attributed to the 8.2 event (Alley and Ágústdóttir 2005). An example is the lower Yangtze river area of China, where pollen records indicated a reduced extreme flooding in the Ning-Zhen mountains in the period between 8.2 and 7.6 ka BP. This possibly indicates a dry event resulting from the 8.2 event, but, as Alley and Ágústdóttir (2005) observed, the time resolution is not very high. It is therefore difficult to conclude with any certainty that the drying event found in China was indeed related to the north Atlantic disturbance at 8.2 ka.

Even if a climate shift can be dated with precision and corresponds with the timing of the 8.2 event, it is still not certain that the two are related. This is for example the case for a drying event recorded in speleothem data from Oman. Though a clear shift is seen in the oxygen isotope record, which is dated at the time of the 8.2 event, it was also observed that similar shifts took place throughout the Holocene with similar magnitude (Alley and Ágústdóttir 2005).

Then there are also examples of studies that revealed no significant influence of the 8.2 event at all. For example, Eastwood *et al*. (2007) record no significant impact from the 8.2 event in south-western Turkey and the Taurus mountains, nor in east Turkey. Similar results were found from botanical remains in Lebanon. According to Hajar *et al*. (2008), no significant evidence for a climate deterioration around 8200 BP was found in pollen records from that region. However, it must be stressed that these studies rely respectively on lake sediment records and pollen records, the dates of which are not always accurate enough and thus of limited reliability (Budja 2007). For a more extensive description of timing uncertainties related to studies on the impacts of the 8.2 event, and of the studies that lack significant evidence for a climate impact, I refer to Alley and Ágústdóttir (2005).

5. Tell Sabi Abyad: the excavations and climate characteristics

> *"… we see a streak of green ahead – it is the vegetation bordering the river. A vast Tell looms up.*
> *Max says ecstatically: 'The Balikh – Look at it! Tells everywhere!'*
> *The Tells are indeed imposing – Large, formidable, and very solid-looking." (Agatha Christie Mallowan, 1946)*

5.1 Background

Tell Sabi Abyad ('Mound of the White Boy') is located in northern Syria, 30 kilometers from the Turkish border. The site forms part of a cluster of mounds that are located in the Balikh valley, between the Eufrates and Tigris rivers (figure 6).

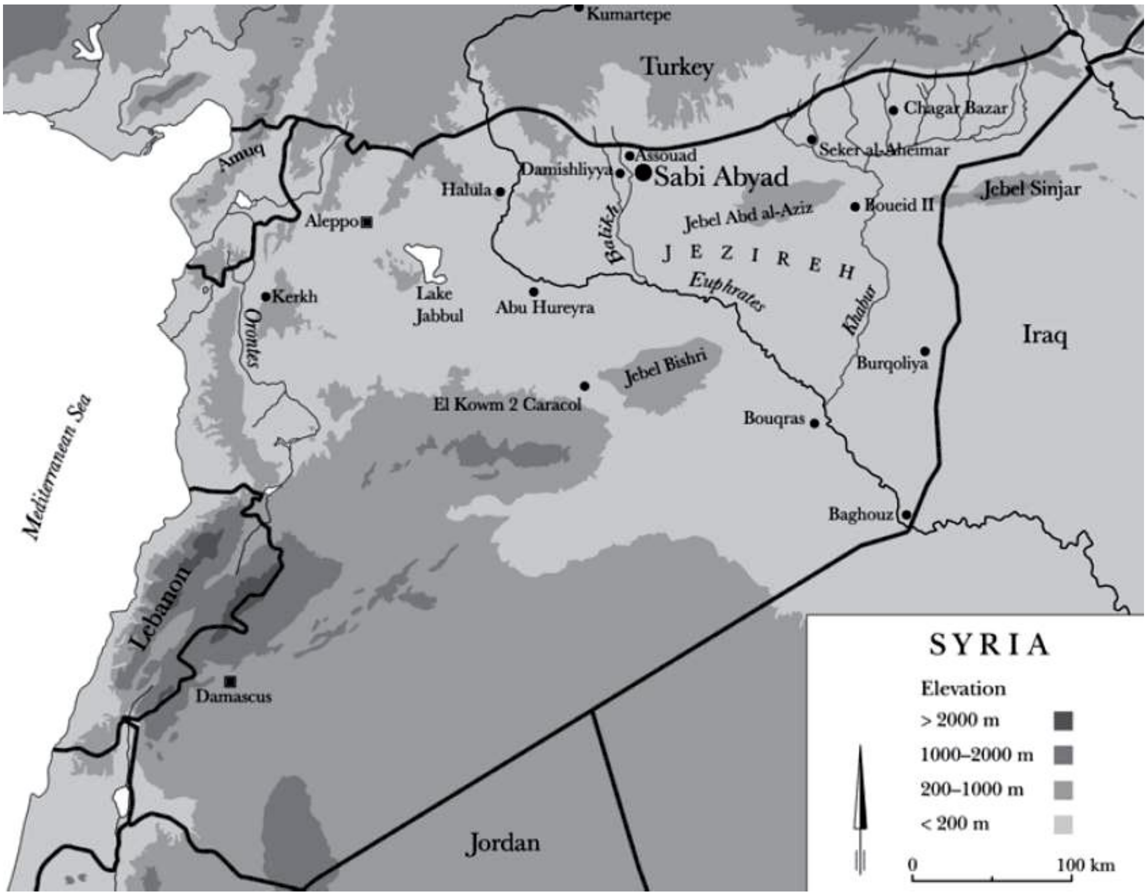

Fig. 6: Location of Tell Sabi Abyad (source: Akkermans et al. 2006).

Tell Sabi Abyad dates back to the 7th and 6th millennium BC, covering the Pottery Neolithic to Halaf periods (Russell 2010). The location of the site at the basin of the Balikh river offered the inhabitants profitable conditions for agriculture and livestock farming, due to relatively high moisture availability in comparison with the rest of the Balikh (Mulders 1969).

Because the site dates back to a period where much was happening in terms of altering subsistence strategies, and changing cultures (Akkermans 2006; Russell 2010), the area became an interesting place for archaeologists. The first to discover the historical value of northern Syria was Sir Max Mallowan, who, on an expedition in the 1930s, found pottery, beads and figurines with uniform characteristics (Akkermans and le Mière 1992). These characteristics, and the typical round houses (tholoi) that were found were from then on associated with the Halaf culture, which extended from Anatolia to the Zagros mountains (Akkermans and le Mière 1992).

The first excavation at Tell Sabi Abyad after Sir Mallowan's expedition in the 1930s, took place in 1986. Since then, many excavation seasons have followed (Akkermans 1996). Much research has been done on the botanical and zoological remains of Tell Sabi Abyad (Cappers, forthcoming; Cavallo 1996; Russell 2010; van Zeist and Waterbolk-van Rooijen 1996). These have been used for studies on plant and animal husbandry, subsistence patterns, and climate studies (Akkermans 2004; Russell 2010).

Additionally, much has been speculated on the finds in botanical and zoological records and their relation to the 8.2 event. It has been argued that the 8.2 event led to a change in subsistence opportunities, which was a cause for changes in agriculture, livestock farming, and even cultural characteristics (Akkermans 2006; Russell 2010).

In this chapter, the climate characteristics of the Tell Sabi Abyad region will be described. Subsequently, the archaeological finds from the site will be discussed, and a link will be made with the 8.2 event. This information will form a basis for a comparison with climate models, which can be found in chapters 6 and 7.

5.2 Climate and geographic characteristics of Tell Sabi Abyad

The geographical location of Tell Sabi Abyad is from a climatological perspective an interesting one. First, the site is located at a river basin of an elevated region in northern Syria, the Jazirah plain (Russell 2010). This has implications for moisture availability, as higher altitudes are generally more arid. The Jazirah plain is characterized by a north-south precipitation gradient, with relatively high precipitation levels in the north and low precipitation levels in the south. As Tell Sabi Abyad is located in the northern part of the area, the site does not show extremely arid characteristics, and can therefore be considered semi-arid (Mulders 1969). Because the northern part of the valley is more humid than the southern part, this region in the Balikh is a more attractive place for human occupation.

Currently the climate of Tell Sabi Abyad is characterized by a Mediterranean seasonality: summers are generally dry and warm, and most of the precipitation falls in winter, which is wet and mild (Wigley and Farmer 1982). As stated before, the area is semi-arid, and is located in an area of high variation, with aridity increasing southward. It is assumed that during most of the Holocene, the aridity around Tell Sabi Abyad has been similar to or higher than it is now (Russell 2010).

The site is influenced by three large climate systems (Wigley and Farmer 1982):

1) The mid-troposphere westerlies: a westerly flow that is created by the temperature difference between high and low latitudes, and by the rotation of the earth. The circulation pattern reaches further south during the winter, reaching 9-12 degrees N in January, and remains more north in the summer months, 22-25 degrees N in July.

   This circulation pattern creates the mid-tropospheric trough, which reaches from Novaya Zemlya in the north of Europe to the central Mediterranean. The longitudinal reach of the southern edge of the trough is highly variable, and ranges from 10 degrees W to 30 degrees. It has been observed that this through is connected to winter rainfall patterns in the eastern Mediterranean.

   Related to these mid-troposphere westerlies are the so-called jet streams: high windspeed zones in the upper troposphere. There are two of these jet streams: the mid-latitude polar front jet (PFJ), extending from the north, and the subtropical jet (STJ), which is located to the south of the PFJ. The position of the PFJ is highly variable, as well as the direction of its wind streams, which usually run from east to west, but can change direction towards a north-south direction.

2) A south-western influence through mid-latitude subtropical high pressure systems, which reach the Middle East from the Sahara and have their strongest influences in the southern regions of the Middle East.
3) The South-Asian and East-African monsoon climate, which also mostly influence the southern regions of the Middle East.

For a more extensive description of the characteristics and influences of these climate systems in the eastern Mediterranean and Middle East, I refer to Wigley and Farmer (1982), who describe the circulation patterns in that region in detail.

The climatic spatial inhomogeneity around Tell Sabi Abyad is not only caused by the different climate systems that are present in the region and the strong precipitation gradient, but also by the geographical characteristics of the area play a role. In particular the Taurus and Kurdistan mountains are an important factor in the climate characteristics in the region (van Zeist and Bottema 1991). Also, the distance from the sea, and continental influences from the east and the north are decisive for the climate (van Zeist and Bottema 1991).

5.3 Ecosystem pressure factors in Tell Sabi Abyad

Though the climatic conditions during the mid-Holocene were a bit wetter in the Middle East and thus more favourable than they are today (Eastwood *et al.* 2007; van Zeist and Bottema 1982), the climate in northern Syria was an exception as the area was characterised by a strong precipitation gradient with low precipitation in the north. It is assumed that the area has been prone to considerable environmental change if a shift would have taken place in precipitation gradient or in the climate systems that influence the region. The Mediterranean could be an important factor of influence here, since it is a source and sink of heat and moisture (Wigley and Farmer 1982): if temperature changes, the evaporation rate at the Mediterranean might change, and thus precipitation.

Due to the aridity of the region, precipitation is the most important limiting factor in Tell Sabi Abyad. Temperature fluctuations are considered to have little influence on the environment, as slight temperature variations remain within acceptable limits for most of the species present in the region. Indirectly, temperature does have an influence on ecosystems: an increase in temperature generally leads to a decrease in precipitation, and vice versa (Wigley and Farmer

1982). However, Wigley and Farmer (1982) have observed that in the Near East the correlation between temperature and precipitation is not strong.

Other factors play a more important role in precipitation variability. These are related to the wind circulation patterns that have been described above. First, the mid-troposphere westerlies, with the mid-tropospheric trough and the PFJ and STJ have been observed to have an effect on precipitation in the Middle East (Wigley and Farmer 1982). The upper westerlies are thought to be responsible for the onset of the rainy season in winter. In addition, the PFJ is characterized by a highly variable southern border which overlaps with the northern border of the STJ. According to Wigley and Farmer (1982), this point of overlap could have implications for the environment in the region where it occurs, and its surroundings. Considering the variability of the southern border of the PFJ, the influence of this wind-speed zone could vary over time, and might have affected the environment of northern Syria as well in the past.

Additionally, changes in the Indian monsoon system could have significant effects on precipitation in the Middle East. Under normal circumstances the monsoon leads in the Middle East to increased precipitation in the north and increased aridity in the south (Wigley and Farmer 1982). A reduction in the monsoon strength is associated with increased aridity, while a strong monsoon is associated with increased precipitation. However, the effects of the Asian monsoon are more visible in the south-eastern part of the Arabian peninsula, and seem to have a lower impact on the northern regions (Wigley and Farmer 1982).

Not only external factors are of importance for the survival of ecosystems in the Middle East, internal factors play an important role as well. Sabi Abyad is located in a region with an unstable climate, which has on the long run been responsible for pushing species towards the limit of their resilience (Tchernov 1982). This means only a slight change in environmental conditions would be enough for existing ecosystems to collapse. It is not certain how much resilience was left within the Near Eastern ecosystems during the 8.2 event, but it has to be taken into account that the natural environment of Sabi Abyad might have been more heavily affected by a climate anomaly than some other regions in the world.

Another important factor of influence is human activity (Bottema 1989; Clason and Clutton-Brock 1982). Currently, Tell Sabi Abyad is located in a region with a steppe-forest vegetation. South of the site starts a steppe landscape, which does not allow forest growth due to low precipitation levels (Bottema 1989; Roberts and Wright 1993). Though the northern Balikh allows tree growth, in the past decades the vegetation has deteriorated due to over-grazing of livestock, and has been showing more and more signs of a steppe landscape (Bottema 1989). Clason and Clutton-Brock (1982) have argued that not only present-day agriculture affects ecosystems, but also past human interactions with nature had visible effects on the natural flora and fauna. For one, the domestication of especially goats and, to some extent, sheep could have led to a considerable landscape change. While wild caprines used to live in the mountains, the domesticated animals were brought to the plains to graze, and were protected against predators. This possibly allowed the development of a different niche-distribution in the region, which could very well have affected the natural environment (Clason and Clutton-Brock 1982).

6. Impacts of the 8.2 event in Tell Sabi Abyad

6.1 Introduction

Tchernov (1982) argues that, when the right information is available, climate change in the past and ecosystem resilience in relation to changing climates can be observed in the zoological and botanical repertoire of the period of research. Tchernov focused on the Levant for his research, and explained the changes in flora and fauna throughout the Holocene with adaptation strategies against climate change and differences in tolerance level between species. This together formed a picture of the resilience of a whole ecosystem.

Here, the zoological and botanical records of Tell Sabi Abyad will be discussed, as well as other archaeological finds that are indicative for a perturbation in the natural environment of the region. An overview will be given of the results that indicate climate forcing on the environment of Tell Sabi Abyad. This will be used for assessing the resilience of the natural environment of Sabi Abyad in chapter 7.

6.2 Developments in the Balikh around 8200 BP

As was said before, Tell Sabi Abyad dates back to a time where many changes took place in subsistence strategies and cultural characteristics. It is generally assumed that many of these changes can be directly linked to the climate influences of the 8.2 event. The changes that are related to the climate anomaly around 8200 BP do not only date back to the specific time period in which the 8.2 event is centred. According to Russell (2010), a series of continuous environmental and cultural changes already started around 8600 BP, and showed a peak around 8200 BP. This observation is consistent with the time frame in which the prolonged climate anomaly took place that ultimately led to the 8.2 event, as suggested by Rohling and Pälike (2005).

The 8.2 event has been connected with changes in cultural characteristics and relocation of communities in the Near East. These developments were most prominent in the Levant and Mesopotamia (Russell 2010). In those regions, many sites were abandoned between 6300 BC and 6200 BC, presumably as a result of impaired agricultural production due to decreased precipitation. In the Balikh valley at least ten settlements were abandoned (Akkermans 2004). This massive migration throughout the Middle East has been suggested as an important factor in the neolithisation of south-eastern Europe (Budja 2007).

Tell Sabi Abyad is one of the few sites that appears to have had continued occupation throughout the climate event (van der Plicht *et al*. 2011). Though other sites were deserted, Akkermans (2004) has argued that many of those sites were re-occupied shortly after they had been abandoned. After a number of decades new communities entered the landscape and re-occupied the tells at the Balikh (Akkermans 2004). The new inhabitants built their settlements next to the old deserted settlements, and introduced new subsistence strategies, possibly as a way to adapt to the changed environmental conditions. This shows that the migration of a society does not necessarily imply a definite collapse of that society (Akkermans 2004). Though it is known that several decades after the 8.2 event took place many communities returned to their homeland, it is difficult to determine whether there were societies that had completely disappeared. In any case, the restricted occupation possibilities in regions like the Balikh and the changes shown in the archaeological records indicate a changing environment.

6.3 Specific changes observed in archaeological records from Tell Sabi Abyad

As Tell Sabi Abyad revealed a great deal of archaeological material dating back to the time of the 8.2 event, the site has been thoroughly studied with regard to this climate anomaly (Akkermans 2004; Russell 2010). In particular one mound of the cluster located at Tell Sabi Abyad, named Tell Sabi Abyad I, contained much relevant material.

The archaeological finds from Tell Sabi Abyad I revealed that some significant changes had taken place during and after the timing of the 8.2 climate event in comparison with the archaeological finds from before 8300 BP. These changes include:

- Changes in architecture. After the return of the migrated societies, new villages were built in the vicinity of the old settlements. In these villages large, rectangular buildings were erected containing a large amount of small rooms. These buildings are referred to as 'warehouses' (Verhoeven 1999). It has been argued that these warehouses were built in the effort to cope with a deteriorating climate: food storage became more important as future food production became uncertain (Verhoeven 1999). Another new architectural feature are the 'tholoi': small, round buildings that were most likely residential houses (Akkermans 1988). These houses were only for temporary use and were periodically replaced (Verhoeven 1999).

- The appearance of seals and sealings. Sealings were used to certify personal possessions. The appearance of sealings after the 8.2 event implies that food storage became important in this time. Furthermore, it has been suggested that the sealings were used to distinguish possessions from different families that shared a warehouse (Duistermaat 1996). What is important to note is that the use of sealings shows that personal possessions seem to have gained importance (Duistermaat 1996). According to Verhoeven (1999), the seals were used predominantly by nomadic people. Thus, these seals might be a sign of increased mobility, a phenomenon that was not uncommon in the Middle East at that time in history, as it has also been observed in Israel by Bar-Yosef and Khazanov (1992).
- Social stratification. The appearance of sealings with which personal possessions were distinguished, indicates that social stratification increased. Another development that suggests this is the increased mobility starting around 6200 BC (e.g. Bar-Yosef and Khazanov 1992). An increase in mobility implies that an improved interaction between communities and cultures was possible. It is assumed that this change is accompanied by an increase in social stratification, since an advance in trading practices allowed for the development of a surplus of certain products. For the first time there are signs of people with private property and people who owned a surplus in comparison to others (Akkermans 2004).
- Changes in livestock. Around 8200 BC a temporary reduction in cattle has been observed in Tell Sabi Abyad (Russell 2010). In the same period, pigs disappear from the archaeological record, and the share of domestic goat and sheep increase (Russell 2010). It has been argued that after 8200 BP the environment had been deteriorating and was soon desiccated to such an extent that it seemed no longer possible to keep pigs, as they require humid environments (Russell 2010). Moreover, the share of cattle diminishes around the same time, and that of sheep and goats increases.

This development too could be explained by differences in water demand among species: sheep and goats require less water than cattle (Russell 2010).

- Changes in livestock use. An increased mobility is observed in animal husbandry from around the time of the 8.2 event, with an increased amount of shepherds leading a nomad life (Bar-Yosef and Khazanov 1992; Verhoeven 1999). This could also be a sign for a deteriorated environment: nutritious grasslands were harder to find. From the same time it was seen that people became more efficient with the use of their livestock: the first proof for milk consumption dates back to around 6200 BC, as well as wool production and the use of animal traction (Russell 2010).

6.4 Discussions on archaeological studies

Similar to the uncertainties concerning studies on the 8.2 event, interpretations of archaeological data are often clouded in uncertainties and assumptions. A number of examples will be mentioned here that play a role in the discussion on the level of environmental deterioration and climate change around 8200 BP.

The first topic of concern is the reliability of dating methods. In archaeology much use is made of radiocarbon dating, which comes with some level of uncertainty and often with a low time resolution. Thus, if interesting material is dated between for example 8300 BP and 7800 BP, it is tempting to place it in the context of the 8.2 event. Again, the pitfall of 'anomaly hunting' emerges: observed oddities in archaeological material are easily attributed to the 8.2 event, while other possible factors do not receive sufficient attention.

An interesting observation is that before the 8.2 climate anomaly became well known (which was after around the year 2000), no significant environmental deterioration was mentioned from studies on zoological and botanical material from the Middle East dating back to the time of the climate event (e.g. de Moulins 1997; van Zeist and Bottema 1982). Only after the 8.2 anomaly was detected in several oxygen isotope records, corresponding results were recorded from archaeology (Akkermans 2004; Budja 2007; Rietkerk *et al*. 2011; Russell 2010). However, the absence of evidence before the discovery of the 8.2 event could be attributed to a lack of interest for that particular time period, and thus a limited availability of relevant archaeological material and a lack of sufficient botanical and zoological samples for the discovery of any significant results (Akkermans 2004). After the discovery that a major climate event took place around 8200 BP, archaeological research on that period intensified, and thus the likeliness of finding relevant results. Still, one must keep in mind that, like Akkermans (2004) observed, climate has quite often been used as a 'Pandora's box' in being designated as the factor behind changes in society that are detrimental for humans.

Moreover, though convincing evidence has been found that points to a climate deterioration around 8.2 ka BP, there are also studies that do not show a significant influence of the 8.2 event, or that do not show convincing records to be able to attribute environmental change to the 8.2 event with any certainty. Examples have been mentioned in paragraph 4.3. Relevant examples for Tell Sabi Abyad include:

- Lack of evidence for influence of the 8.2 event in lake records from south-western Turkey, the Taurus mountains and east Turkey (Eastwood *et al*. 2007). This observation could have implications for research on Tell Sabi Abyad, due to its close vicinity. However, it is known that the Taurus mountains have a strong influence on their surrounding environments, and therefore it is difficult to compare a region north of the Taurus mountains directly with a region located to the south of the mountains.
- Lack of evidence for a climate deterioration around 8200 BP from pollen records in Lebanon (Hajar *et al*. 2008).
- Uncertainties regarding the intensity of a dry period in Africa, found in lake records (Gasse and van Campo 1994).
- Lack of evidence for a vegetation shift at Sabi Abyad during the 8.2 event. According to most recent analyses of botanical samples form Sabi Abyad, no significant changes were observed in crop cultivation in this area (Cappers, forthcoming). However, this does not necessarily mean that there was no influence of the 8.2 event. Though perhaps the choice for crops remained the same, people could have chosen to increase irrigation, in order to retain the crops in a deteriorating environment. If the 8.2 event indeed impacted the vegetation at Sabi Abyad, changes would have to be found in records of wild plants, as the development of wild vegetation has most likely not been modified by humans. Unfortunately, research at Sabi Abyad has so far focused mostly on domesticated species, and few

samples of wild species have been collected. Furthermore, to detect vegetation shifts, research must be done in a consistent manner and on material of good quality that enables determination on a species level. Such a research is often not possible, as it is generally difficult to find botanical material of such a quality that makes determination on a species level possible. In addition to this, detecting shifts in vegetation requires data over a longer time period, as the response of plants to a climate deterioration is always delayed and it can take a long time before the total response (for example a shift in the share of C3 and C4 plants) is visible in an ecosystem. Though no effects of the 8.2 event have been recognised in the botanical data of Tell Sabi Abyad, a report of Pross *et al*. (2009) on the Eastern Mediterranean does show a vegetation shift during the timing of the 8.2 event.

7. Climate models

7.1 Introduction

In an attempt to shed a different light on the topic, and to possibly find more data on the influences of the 8.2 event in Sabi Abyad, climate modelling studies were consulted. Though computer simulated climate models do not always represent reality, if performed with enough data they can provide a good reflection of an actual climatic situation. Therefore, a comparison of the archaeological results from Tell Sabi Abyad with climate models of the region could be useful for assessing the actual influences of the 8.2 event. In this chapter relevant climate models will be discussed, as well as the expected influences from the 8.2 event in northern Syria resulting from the models.

The results of several climate modelling studies focusing on the effects of the 8.2 event have been consulted. These include: LeGrande *et al*. 2006; Renssen *et al*. 2007; Wiersma and Renssen 2006; Wiersma *et al*. 2011. It must be stated first that the existing models simulating the impacts of the 8.2 event have all been made to reflect influences on a global scale. It is therefore not possible to draw conclusions with any certainty on the expected impacts in a small region like northern Syria. Nevertheless, a few remarks can be made on observed climatic changes in the Middle East and Eastern Mediterranean.

7.2 An assessment of several climate models

The Mediterranean Sea was influenced to quite some extent by the fresh water perturbation from the Laurentide lakes (Wiersma *et al*. 2011). This led in the Eastern Mediterranean to a temperature reduction of about 1 °C (Renssen *et al*. 2007; Wiersma and Renssen 2006; Wiersma *et al*. 2011). Figure 7 shows the global changes in annual mean surface temperature as a result of the event.

Besides a decrease in temperature, a reduction in precipitation was observed (LeGrande *et al*. 2006; Wiersma and Renssen 2006). The model by Wiersma and Renssen (2006) (figure 8) suggests that the Middle East and north Africa were characterised more by increased dryness in summer months than in winter months, while south-eastern Europe shows a slightly stronger dry impact during winter, in comparison to summer precipitation changes. This is related to a

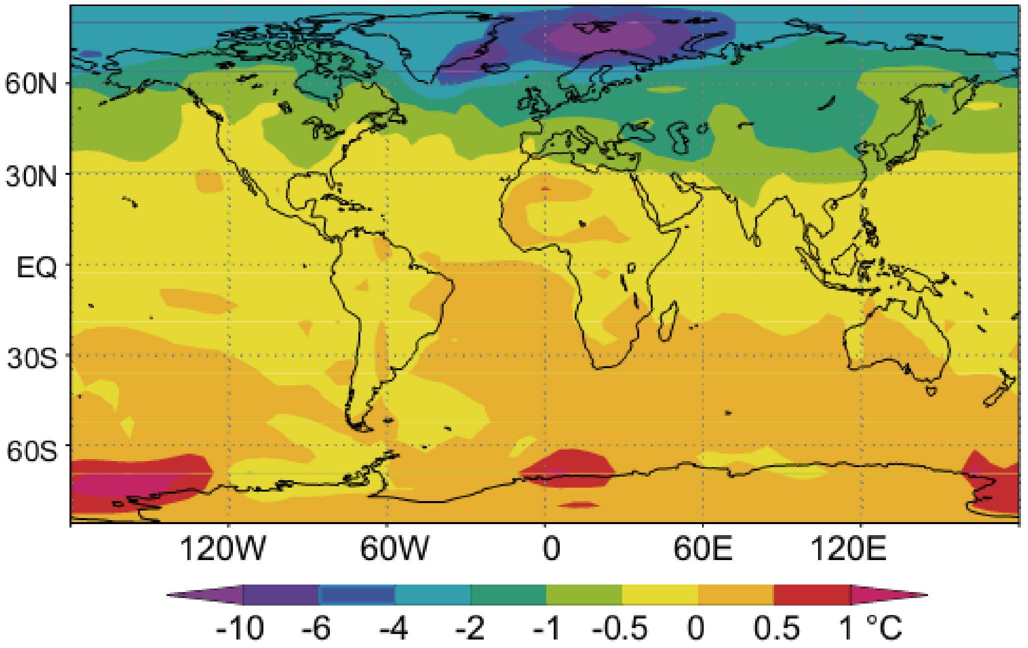

Fig. 7: Changes in annual mean surface temperature resulting from a freshwater perturbation (source: Renssen et al. 2007).

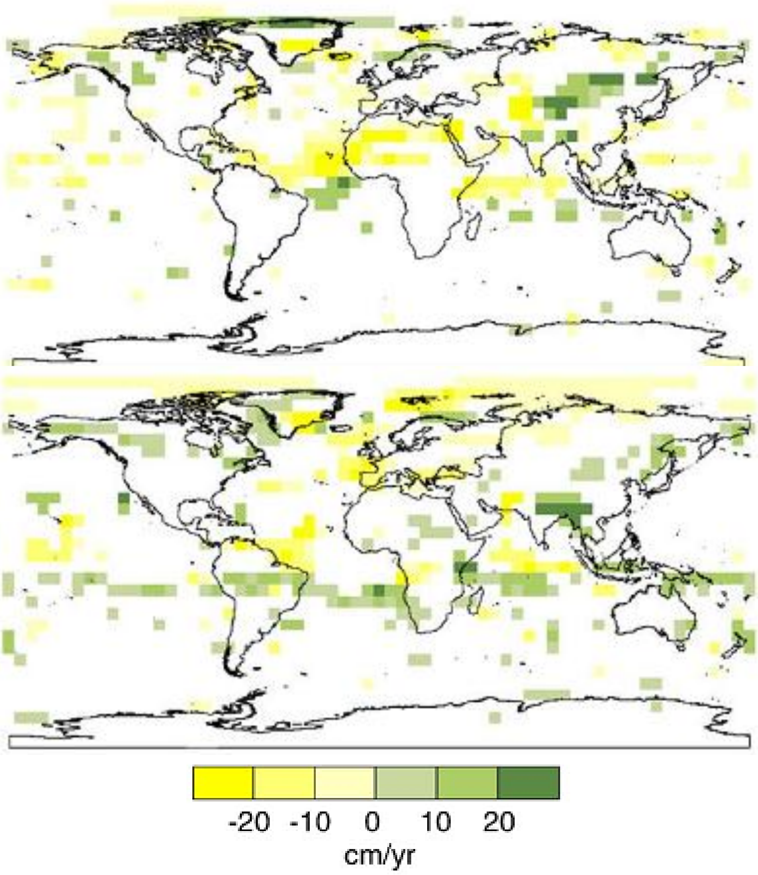

Fig. 8: Changes in precipitation as a result of the 8.2 event. Above: January precipitation changes. Below: July precipitation changes (source: Wiersma and Renssen 2006).

northward shift of the westerlies and a weakening of the westerlies in the south of the continent (Wiersma and Renssen 2006). Depending on the expected level of influence from north Africa, the eastern Mediterranean and south-eastern Europe, this has implications for precipitation in northern Syria. As Europe plays the most important role in winter precipitation (see paragraph 5.3), it could be expected that a reduction in precipitation in south-eastern Europe leads to reduced winter precipitation in northern Syria. Similarly, the reduced precipitation seen in north Africa implies a weakened monsoon system, which could have led to reduced summer precipitation in the Near East.

7.3 Expected influences of climate change in Tell Sabi Abyad

According to the models of Renssen *et al*. (2007) and Wiersma and Renssen (2006), the effects of the 8.2 event led to a dryer climate in Africa and Europe, which most likely affected the Near East in a similar way. Hence, it is expected that the event caused a deterioration of the climate in that region. Wiersma and Renssen (2006) show in a simulation of March precipitation patterns of a location in the Near East that the influence of a freshwater perturbation is largest around 50 years after the onset of the event (figure 9). After that it takes about 250 years before ocean circulation is recovered and precipitation patterns are back to normal.

If the effects of the 8.2 event were strong enough to influence subsistence strategies or cause vegetation changes is hard to tell from the available climate models. In the first place, because current climate models are not detailed enough to give specific information on a small region, second, because the model data do not contain information on ecosystem resilience and therefore need to be compared to archaeological records.

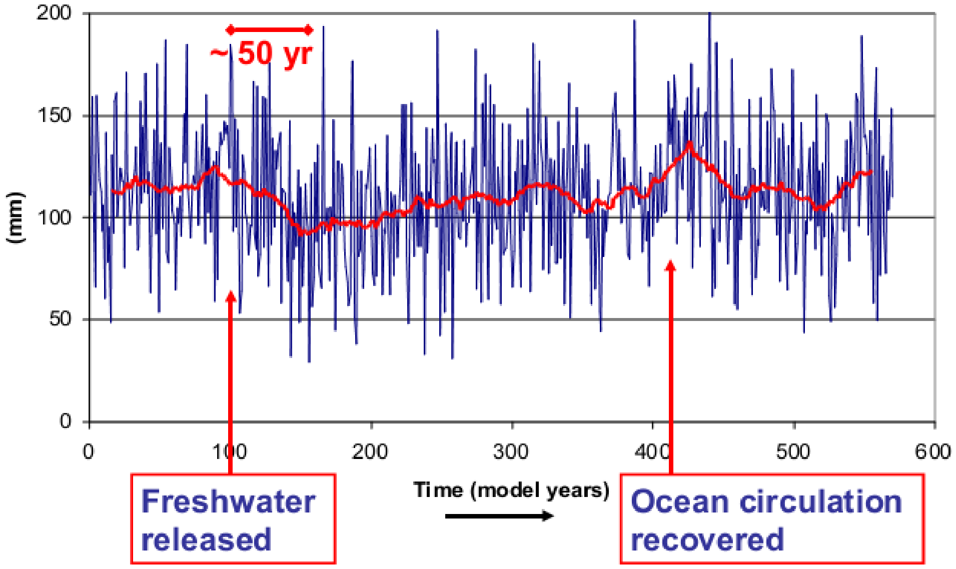

Fig. 9: March precipitation at 40 °N and 40 °E (Wiersma and Renssen 2006).

8. Assessing the influences of the 8.2 event in Tell Sabi Abyad

8.1 Comparison of climate models with archaeological research

We have looked at the characteristics of the 8.2 event according to climate models and at the results of archaeological research on material from Tell Sabi Abyad dating back to the period in which global climates were influenced by the event. Zoological data from the site have revealed significant changes in the faunal record at Sabi Abyad starting between 6300 BC and 6200 BC. These changes coincide with changes in culture, as well as a short interruption of human occupation in the Balikh and other areas in the Near East.

The results from archaeology indicate a certain environmental deterioration, the timing of which corresponds with the timing of the 8.2 event. If these developments were indeed a result of climate change, this could mean that the communities in the Balikh were for a short time unable to cope with the changes induced by the climate event.

The climate models described in chapter 7 seem to support these findings from archaeology. It has to be taken into account, though, that although these models do give some insight in overall climatic changes in the Near East and Eastern Mediterranean, it is difficult to make statements about changes in northern Syria specifically. However, if the climate models indeed imply a lowering in winter precipitation in the Near East, this would correspond with the results from archaeological studies which indicate that the existing subsistence strategies were no longer profitable. Because agriculture mainly took place in the winter months (Akkermans 2004), reduced precipitation during that time of the year would have impeded the possibilities for securing a livelihood. Still, this is a rather blunt conclusion drawn from the climate models studied here. More research on climate models is required in order to obtain information that will form a valuable contribution to a study on local effects of the 8.2 event.

8.2 Ecosystem resilience

Based on the results described in chapters 6 and 7, some statements can be made regarding ecosystem resilience. First, it is clear that the climate perturbation resulting from the North Atlantic fresh water pulse had not left the Near East unaffected. The 8.2 event had a temporary effect on the global climate. Greenland ice cores and climate models show that the global climate was only affected for about 160 years, after which it returned to its original state. Such a sudden and short-term change is also seen in ecosystems in the Near East. For example, a study of Pross *et al.* (2009) indicates that the vegetation of the Eastern Mediterranean shifted to a prevalence of more steppe species for about 200 years at the most. Subsequently, the vegetation returned to its original state and the presence of temperate tree species increased slowly, indicating that the existing ecosystem resumed its original state.

However, such changes have not been observed everywhere in the Near East, as has been indicated by studies from Turkey and Lebanon (Eastwood *et al.* 2007; Hajar *et al.* 2008). Hence, the actual effects of the 8.2 event on Near Eastern ecosystems remain uncertain.

The same can be said for Sabi Abyad. So far no vegetation changes have been detected that indicate a clear effect of the 8.2 event. Nevertheless, though botanical data do not show signs of an ecosystem collapse, faunal data seem to indicate otherwise. Research on zoological remains from Sabi Abyad has shown that indeed a change has taken place in the composition of livestock between 6300 and 6200 BC. From that time goat and sheep become more important, and the share of pigs is reduced. During the same period many cultures move away from the Balikh valley. However, according to the reports these developments took place between 6300 and 6200 BC, which is slightly earlier than the expected onset of the 8.2 event (around 6200 BC) or the moment of highest impact (dated 50 years after the fresh water pulse) as suggested by the models of Wiersma and Renssen (2006).

Hence, the cause of the changes in the Balikh should perhaps be sought elsewhere. Changes in livestock, as well as other changes in subsistence strategies and culture of the population living in the area at that time, could possibly be a result of anthropogenic influences or cultural change instead of climatic influences. Hence, though changes in livestock have been observed, similar changes may not have taken place in the repertoire of the wild fauna.

The changes in culture and practices in the communities living in the Balikh, though possibly triggered by the 8.2 event, may eventually be a consequence of human development instead of being a result of climate change. In the light of ongoing developments during the Neolithic, the 8.2 event could have spurred Neolithisation to a certain extent, but the observed development, or at least a similar development, would probably also have taken place without the occurrence of a short-term climatic shift.

Therefore, when it comes to ecosystem resilience, it is very likely that the natural environment of Tell Sabi Abyad had at the time of the 8.2 event a level of resilience that was high enough to cope with the sudden effects of the climate perturbation.

Comparing this with a sudden ecosystem transition like the one that took place in the Sahara and Sahel around 5500 years ago, it becomes clear that the intensity of an external perturbation is not proportional to the level to which it affects ecosystems. The internal resilience of an ecosystem at the timing of a climatic event is of essential importance for the response of an ecosystem to this event. This level of resilience differs between ecosystems. Though Tchernov (1982) believed the ecosystems in the Near East were close to their limit of resilience and thus close to a tipping point, research on the 8.2 event shows that the resilience of ecosystems in the Near East was still strong enough to recover from a major climatic impact. Thus, their resilience must have been higher than assumed by Tchernov (1982). This might have been different at other places in the world where the resilience of ecosystems was lower.

9. Discussion: the value of archaeology for research on ecosystem resilience

Archaeology, though currently not much involved in research on ecosystem resilience, could provide a valuable contribution to increasing our knowledge on this topic. If searched for the right indicators in archaeological records, research on ecosystem changes in the past could give insight in the characteristics of ecosystem resilience. Regarding zoological and botanical research it is essential to focus on wild species. In general, archaeological research is most focused on human-related material, and thus on domesticated animal and plant species. Though such material can give information on indirect effects of climate change, for the research on direct climate influences on ecosystems one should look at wild species.

Possible contributions from archaeology are:

- Zoological data: significant, long term changes in the faunal composition in an area, the morphology of existing species, or dominance of certain species, could indicate an ecosystem change (Tchernov 1982).
- Botanical data: similar to zoological data, significant, long term changes in the botanical composition in an area, the morphology of existing species, or dominance of certain species, could point at an ecosystem shift.
- Anthropogenic data: Changes in culture or subsistence strategies could be an indirect indicator for a changing natural environment.
- Genetic data: changes in the genetic variability within species (even if no phenotype changes are observed), e.g. the occurrence of a genetic bottleneck in a species, could indicate a changing ecosystem, and could be a sign of deterioration of ecosystem resilience.
- Data on soil characteristics: A comparison of nutrient and water availability in different soil types at crucial moments in history can give more insight in the factors behind changes in ecosystem resilience.

These types of archaeological data should be searched from time periods where climate or ecosystem shifts have taken place, and in places where effects can possibly be detected. Examples are the 8.2 event in Tell Sabi Abyad and other areas in the world, or the sudden desertification process that took place in the Sahel. By combining the archaeological results found in such research, a dataset can be made with information on the characteristics of ecosystems with different levels of resilience and different levels of environmental impact. Such a dataset could then be used as a model to compare new data with, and at the same time would become larger and more fine-tuned as more and more data is incorporated. Furthermore, this data could be used for assessing current changes in ecosystems and give more insight in the level of resilience of current ecosystems, and thus their vulnerability for external impacts.

Furthermore, there should be a focus on zoological and botanical changes in the long term. This is necessary in order to separate short term anomalies from long-term ecosystem change and actual ecosystem shifts.

By coupling information from for example ice core and speleothem data to changes found in archaeology, it becomes possible to find out how ecosystems are influenced by external factors. Climate models could then be used to predict how external factors would most likely affect an ecosystem. Coupling this back to archaeology one could look for consistencies or for missing information and thus possibilities for further research.

Important for such research is to have sufficient amounts of material for research, as well as the ability to find material of sufficient quality. Furthermore, it should be possible to get reliable dates on the material found. To find such material is difficult and in many places impossible. Nevertheless, if archaeological research is targeted specifically on ecosystem resilience, most likely more valuable data would be found than what is available in records now.

10. Conclusion

Research on ecosystem resilience and climate-ecosystem interactions is extremely complex due to the large variety of factors that play a role. Climate characteristics are mainly determined by meteorological factors, which affect temperature, moisture, and carbon availability. Additionally, internal factors can play a decisive role in the response of an ecosystem to external perturbations.

This research aimed at determining which factors are involved in ecosystem resilience, which methods are needed to research this, and how archaeology can contribute to such research. The influence of the 8.2 ka climate event on the natural environment of Tell Sabi Abyad served as a case study for larger-scale research on ecosystem resilience.

Archaeological research in Tell Sabi Abyad has revealed that many changes took place during and after the timing of the North Atlantic fresh water perturbation 8.2 thousand years ago. Changes were found in culture and subsistence strategies, and even a temporary migration of human communities has been observed. These developments seem to correspond with results of climate models, and direct influences of the 8.2 event have been suggested in many publications on Tell Sabi Abyad and the Near East.

However, this study has presented some critical notes to these assumptions. First, the reliability of certain dating methods is debatable. One should beware of so-called 'anomaly hunting', where an observed vegetation change is placed within the time frame of a climate perturbation merely because the two seem to overlap.

Second, the suggested climatic influences of the 8.2 event have not been found all over the world, or even all over the Near East. In the case of Sabi Abyad, the botanical records do not indicate a climate deterioration around 8.2 ka BP. In addition, most changes in Sabi Abyad took place between 6300 and 6200 BC, which is earlier than the expected onset of the 8.2 event (around 6200 BC) or the assumed moment of highest impact (dated 50 years after the fresh water pulse).

As no direct influences of the 8.2 event have been observed, it is likely that the natural environment of Tell Sabi Abyad had at the time of the 8.2 event a level of resilience that was high enough to cope with the sudden effects of the climate perturbation. Hence, ecosystem resilience in Tell Sabi Abyad was clearly above minimum, contrary to the assumption of Tchernov (1982) that the ecosystems in the Near East were close to their limit of resilience during the Neolithic. Possibly other factors, like anthropogenic influences or cultural development, account for the changes observed in the archaeological material of Tell Sabi Abyad.

This research on Tell Sabi Abyad has shown that climate models are useful for research on ecosystem resilience, but are currently too general for research on a local level. Therefore, further research is needed in order to create detailed climate models.

In addition, this study stresses the importance of archaeology for research on ecosystem resilience. Information on for instance changes in species diversity or dominance of certain species during a climate event can be used for assessing the characteristics of ecosystems and their resilience. Unfortunately, current information on botanical and zoological records is not sufficient for such research, as there is too strong a focus on domesticated species. Future archaeological research should therefore focus on wild species. In this way the direct effects of climate change can be detected and possible bias from anthropogenic influences is reduced. Furthermore, future research should aim at identifying long term zoological and botanical changes in order to detect ecosystem shifts.

By combining the archaeological results found in this research, a dataset can be made with information on the characteristics of ecosystems with different levels of resilience and different levels of environmental impact. Such a dataset can then be used as a model to compare new data with, and possibly for the development of more precise climate models. In addition, the results can serve as reference material for current changes in ecosystems and give insight in the level of resilience of current ecosystems, and thus their vulnerability for external impacts.

Thus, by focusing research on specific ecosystem characteristics, archaeology can provide a valuable contribution to research on ecosystem resilience, and on the effects of climate change in the past and in the future.

Abstract

Research on ecosystem resilience and climate-ecosystem interactions is extremely complex due to the large variety of factors that play a role. This research aimed at determining which factors are involved in ecosystem resilience, which methods are needed to research this, and how archaeology can contribute to such research. The influence of the 8.2 ka climate event on the natural environment of Tell Sabi Abyad served as a case study for larger-scale research on ecosystem resilience.

This study presents critical notes to the assumption that the changes which took place in Tell Sabi Abyad at the timing of the 8.2 event were a consequence of climate change. First, the timing of the changes in Tell Sabi Abyad is earlier than the timing of the expected impact of the 8.2 event. In addition, the botanical records of Tell Sabi Abyad do not indicate a climate deterioration. As no direct influences of the 8.2 event have been observed, it is likely that the natural environment of Tell Sabi Abyad had a level of resilience that was high enough to cope with the sudden effects of the 8.2 climate perturbation. Possibly other factors, like anthropogenic influences or cultural development, account for the changes observed in the archaeological material of Tell Sabi Abyad.

Furthermore, this study shows that archaeology can form a valuable contribution to research on ecosystem resilience if future research would focus on wild plant and animal species and long term ecosystem changes. This would enable research on the direct effects of climate change. By combining the archaeological results found in such research, a dataset can be made with information on the characteristics of ecosystems with different levels of resilience and different levels of environmental impact.

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