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Thematic Review

The Origin and Development of the Central European Man-made Landscape, Habitat and Species Diversity as Affected by Climate and its Changes – a Review

Peter Poschlod^a

^a*Chair of Ecology and Conservation Biology, Institute of Plant Sciences, University of Regensburg, 93040 Regensburg, Germany*

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ABSTRACT

Climate optima, but also climate pessima, are shown to have strongly affected the origin of settlement in central Europe and the development of the man-made landscape and its habitat and species diversity. Driving forces for climate changes, until recently, were fluctuations of solar activity and radiation, but also comet impacts and volcano eruptions. It could be shown that climate optima increased landscape, habitat and species diversity as well as the expansion of open man-made habitats.

Four climate optima were identified to have had a strong impact. In the Neolithic Age the climate optimum favoured the settlement of people which created the first man made habitats, arable fields, pastures and heathlands. High precipitations resulted in the expansion of wetlands and the origin of raised bogs. In a short climate optimum period in the Bronze Age Alp farming started creating new habitats through *e.g.* grazing practices. The climate optimum which started at the end of the Iron Age resulted in the first diversity revolution in the landscape during the following Roman Empire Period. Meadows, orchards and vineyards were established. Archaeobotanical remains have shown that during the Roman period most new species/100 years have established in arable fields and grasslands. The medieval climate optimum finally resulted in the largest expansion of open man-made habitats but also new habitats such as fish ponds.

In contrast, during climate pessima abandonment of man-made habitats occurred. During the Migration Period and the Little Ice Age starting at the end of the Medieval Period forests increased. During the climate pessima in the Bronze Age we had the lowest number of new species/100 years.

Actually, through recent laws concerning renewable resources as a reply to the recent climate warming, landscape is changing again.

1. Introduction

Sedentism and the development of the first man-made landscape started about 12,000 years ago in the Fertile Crescent. First, starting with the collection of wild cereals, plants were domesticated while at the same time hunting still continued. Only after the dramatic falls in game populations (dorcids and Cuvier's gazelles) about 11,000 years ago did the domestication of animals start (Hillman 1996; Bar-Yosef 1998; Hillman *et al.* 2001; Zeder 2005; 2008). The causes for these processes were probably of multiple origins (Zeder 2006). They may have been a lack of resources due to an increasing population density (Cohen 1977; Binford

2001; Winterhalder, Kennett 2006; Watkins 2007), the change of social organization and ideology of the people (Cauvin 2000; Hodder 2001) or simply the discovery of the process of fermentation and the need of the drug alcohol (Reichholf 2008; Dietrich *et al.* 2012). However, the climate amelioration 11,500 years ago, from a postglacial to a Mediterranean climate with drier summers and wet winters and springs might have played the most important role (McCorrison, Hole 1991; Hillman 1996; Richerson *et al.* 2001; Gupta 2004). Richerson *et al.* (2001) claim that only stable Holocene climates allowed the evolution of agriculture.

Climate change, in that case a drought in western Asia between 8500 and 8000 BP, probably around 8200 BP and therefore also known as 8200 BP event (Alley *et al.* 1997; see also Figure 1), was also responsible for the migration of farmers from the centre of Fertile Crescent to the west

*Corresponding author. E-mail: peter.poschlod@ur.de

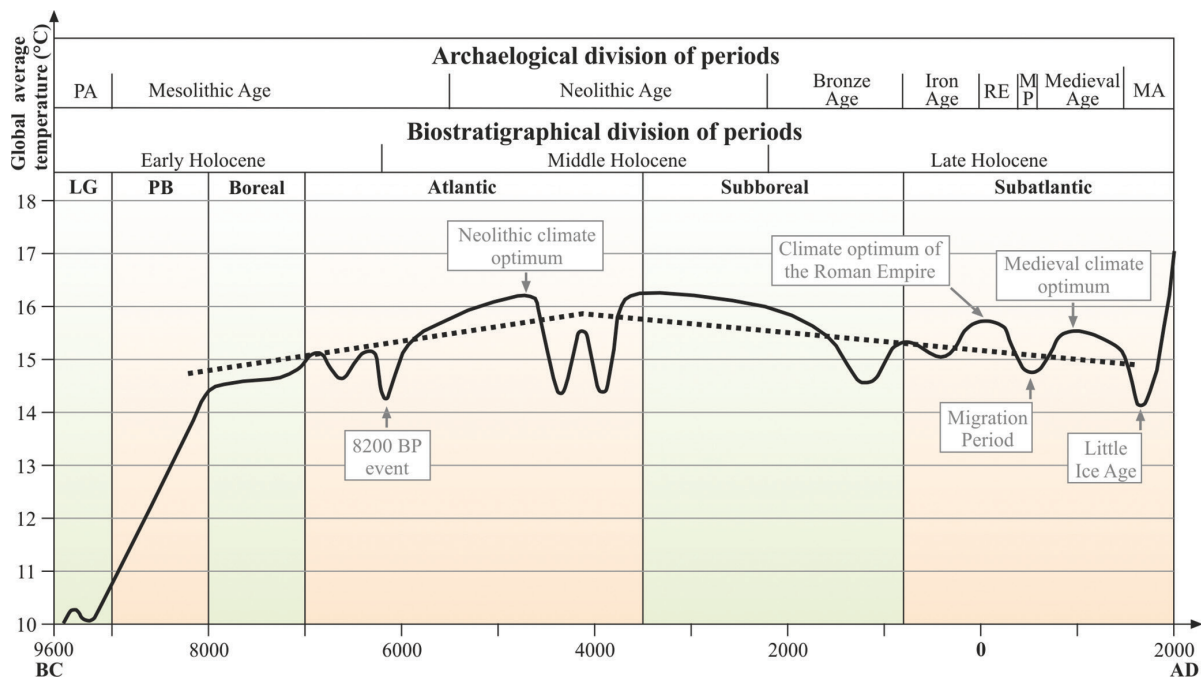


Figure 1. Global average annual mean temperature trend during the Holocene after Schönwiese (1995) and Eitel (2007). Dotted line: Trend reversal in the temperature pattern during the Atlantic Period. PA – Palaeolithic, RE – Roman Empire period, MP – Migration period, MA – Modern Age, LG – Last glacial, PB – Preboreal.

(Weninger *et al.* 2006; Berger, Guilaine 2008; Clare *et al.* 2010). The movement started at many places at the same time (Özdoğan 2002; 2011). Özdoğan (2002) described this process as following: “Almost of a sudden we start seeing more habitation, (...) not only in Central Anatolia, but also in the Western Aegean regions, to be accompanied quickly by the Balkans. (...) the number of Pottery Neolithic sites increases dramatically, and almost all of a sudden. In the East, however, there is a decrease in the number of settlements, or the existing ones become smaller (...)... there must have been an endemic movement which started (...) towards the end of the Pre-Pottery Neolithic B. There must have been some kind of beginning stage of this westward movement. There is clearly a kind of a momentum to migrate in masses before the end of the thing. (...) All of a sudden you see that people are moving.”

The flooding of the Black Sea through the Bosphorus by the rising level of the Mediterranean Sea, often synonymous with Noah’s flood (Ryan, Pitman III 1998; Haarmann 2003; 2011; different dating of the start of flooding, earliest moment around 8500 BC, latest 5600 BC, see Poschlod 2015), might have caused another movement (Milisauskas 2011). However, the date, height and rate of the flooding are still under debate (Ryan *et al.* 1997; 2003; Bahr *et al.* 2006; Yanko-Hombach *et al.* 2007; Giosan *et al.* 2009; Lericolais *et al.* 2009; Thom 2010).

Also, the origin of the man-made landscape in central Europe around 5500 BC started during a climate amelioration (Schönwiese 1995; Gronenborn, Sirocko 2010; see also Birks 2003 *etc.*) caused partially by an increased sun activity which started already in the Mesolithic Age (Steinhilber *et al.* 2009). The first farmers belonging to the LBK culture spread

quite fast from the southeastern edge of central Europe and even Anatolia during this climate optimum which was shown through recent molecular studies of early LBK populations (Haak *et al.* 2010). Genetic discontinuity to the Mesolithic hunters supports the hypothesis that the first farmers were immigrants (Bramanti *et al.* 2009; Malmström *et al.* 2009).

Since then the climate has changed in central Europe (see also Figure 1). Several climate optima and pessima have been described by several authors which, have had clear and distinct impacts on the history of mankind and its cultures (Lamb 1995; Le Roy Ladurie 2004; 2006; 2009a; 2009b; 2009c; Blümel 2006; Behringer 2007; Sirocko 2010). However, climate also affected land use and land use intensity (Bork *et al.* 1998; Bork 2006) and therefore the man-made landscape, the origin and development of habitats as well as their species diversity (Poschlod 2015). The latter were only reviewed on a local or regional level for certain periods (*e.g.* Zolitschka *et al.* 2003) but not for the whole time span since settlement started. This is therefore the aim of this review. Furthermore, the most recent knowledge on the causes of each particular climate change was included.

2. Climate and the origin of sedentism in central Europe

The first climate optimum after the last ice age started around 6000 BC and lasted until 3250 BC (Figure 1; Table 1). Causes were an increased solar activity at the beginning and an increased solar radiation during this period (Steinhilber *et al.* 2009; Nussbaumer *et al.* 2011).

Warmer temperatures permitted a much higher treeline than today. In the central Austrian Alps the treeline laid at

Table 1. Characterization of the climate and its chronological classification into zones and respective archaeological and historical epochs. Historical and climate data after Poschod (2015), mainly according to Schönwiese (1995) and Nelle (2002); biostratigraphical zones after Mangerud *et al.* (1974)¹ and Walker *et al.* (2012)².

Biostratigraph. zone ¹	Biostratigraph. zone ²	Archaeological/historical epochs		Year BC/AD	Characterisation of the climate
Subatlantic	Late Holocene	M.T.	Modern Times (“Anthropocene”)	Today	“ Modern climate optimum ”: the warm epoch since the mid-20 th century, relatively dry.
			Early Modern Times (M.T.)	1750	Climate pessimum “Little Ice Age” (1300 to 1850 AD): starting with extreme weather events in the 14th century, cooling; especially harsh winters, fluctuating precipitation.
		Medieval Age	Late Medieval Age	1500	Climate optimum (1000 to 1300 AD): warming, first with low precipitation, later with high precipitation; expansion of the man-made landscape into the mountains and of viniculture to northern Europe.
			Medieval Age	1300	
			Early Medieval Age	1000	Climate pessimum (350/450 to 750 AD): cooling, high precipitation; glacial advances.
			Migration Period	500	
		Roman Empire	Roman Empire period	350	Climate optimum (300 BC to 350 AD): warming, mostly high precipitation; some Alpine crossings also in winter without snow; at the end of the period drier; expansion of viniculture to northern Europe.
		Iron Age	La Tène period	0	Climate pessimum (1200 to 600 BC):
			Hallstatt period	500	
		Subboreal		Bronze Age	Urnfield period
Late Bronze Age	1200				Mainly warm epoch but distinct fluctuations, less precipitation than in the following climate pessimum.
Bronze Age	1300				
Early Bronze Age	1800				
Atlantic	Middle Holocene	Chalcolithic period	Late chalcolithic period	2200–2300	End of climate optimum from 3400 BC onwards: cold epoch with glacial advances (Piora oscillation); in the beginning with low precipitation, later increasing; “Ötzi” as indicator of the glacial advance.
			Chalcolithic period	2500	
		Neolithic Age	Neolithic	4400 (NCE)	Start of the Neolithic Age in southern central Europe (SCE) from 5500 BC onwards, in northern central Europe (NCE) only from 4000 BC. Climate optimum (ca. 6000 to 3400 BC): warmest epoch since the last glacial period, very mild winters, high precipitation; start of human settlement (“ Neolithic revolution ”).
				(SCE) 5500	
			Late Mesolithic	6000	
			Mesolithic Age	Early Mesolithic	7000
8000	Summers warm, winters very cold.				
Late glacial	Pleistocene	Palaeolithic	Epipalaeolithic	9600	Cold epoch.
					Transition of the last cold epoch to the warm interval.
			Upper Palaeolithic		End of the last cold epoch.

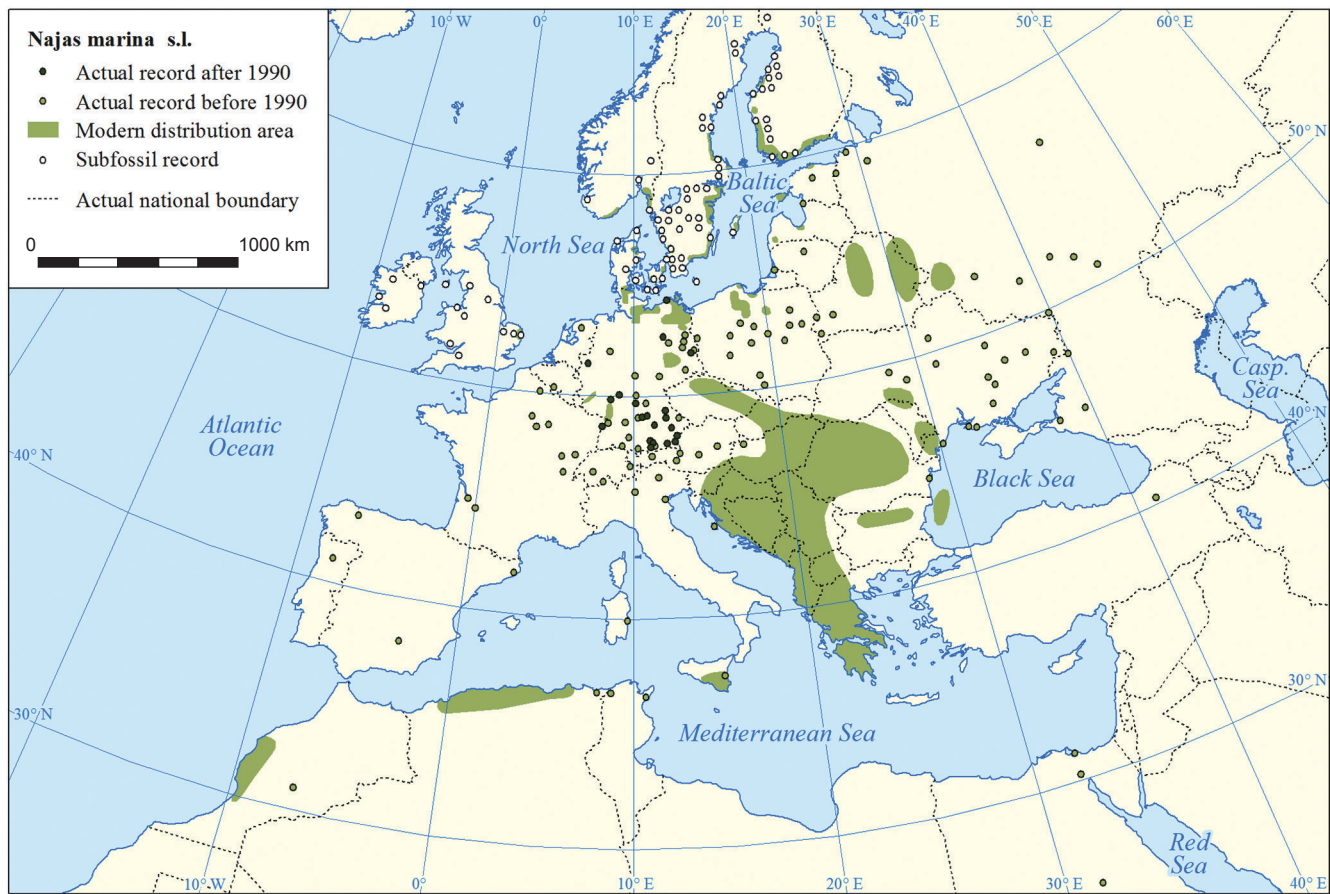


Figure 2. Historical and recent (before 1990 and after 1990) distribution of *Najas marina* s.l. (historical data and actual data until 1990 after Lang 1994, actual data after 1990 after Poschod 2015).

2,400 m a. s. l. compared to 2,250 m a. s. l. in 1980 (Nicolussi *et al.* 2005). Subfossil remains from thermophilic aquatic plants, such as *Trapa natans* (von Post 1946; Hultén, Fries 1986; Lang 1994) as well as *Najas marina* agg. (Figure 2) and *N. flexilis* (Godwin 1975; Lang 1994), but also from animals such as the European pond turtle (*Emys orbicularis*; Degerbøl, Krog 1951; Sommer *et al.* 2007; 2009), reveal that they reached their most northern distribution since then.

High precipitation initiated the start of the development of ombrotrophic from minerotrophic- or groundwater-fed mires; the origin of most raised bogs in central Europe date from this period (Paul, Ruoff 1932; Overbeck 1975; Couwenberg *et al.* 2001). The increased discharge of calcareous springs in combination with high temperatures led to the formation of large meteorogenic travertine or tufa deposits (Pentecost 1995; Ford, Pedley 1996) *e.g.* in the Bohemian Karst (Ložek 1961; 1963; 1964; Starkel 1966) or in the Jurassic mountains of the Swabian Alb (Groschopf *et al.* 1952) and its respective habitats. At the end of the Neolithic age precipitations increased again (often called pluvial period; Schönwiese 1995) which caused an increase in ground water level evident through the increase of paludification and spread of alder carr, for example, in northwest-Germany (Overbeck 1975). For Lake Constance, a strong water level rise has been dendrochronologically dated to 3370 BC (Magny *et al.*

2006). High precipitation also caused a retreat in pine (*Pinus sylvestris*) and an increase in common hazelnut (*Corylus avellana*) in that region. In the south German Federsee, the highest water level was reported at the end of the Neolithic Age. An earlier rise of water level in the Federsee occurred between 4800 and 4500 BC (Wall 1961), in the Lake of Constance between 4600 to 4700 BC (Magny *et al.* 2006). During both periods, pollen of *Cyperaceae*, most of their species belonging to wetland plants in central Europe, increased at the Lake Constance (Magny *et al.* 2006). Water level rises between 6000 and 4000 BC have also been reported from southern Sweden (Harrison, Digerfeldt 1993). Therefore, the first half of the Neolithic period may be also called the wetland expansion period.

At the same time, the favourable climate supported the start of sedentism – resulting in the origin of the first man-made habitats, arable fields and pastures (grasslands, heathlands).

To understand the origin of open habitats and grasslands, respectively, we first have to ask the question: how did the landscape and forests look like around 5500 BC? Until recently, most studies on central Europe claimed that there was already a closed forest cover everywhere below the timberline (Firbas 1949; 1952; Lang 1994; maps of the natural landscape: Schwickerath 1954; Hueck, Behrmann 1962), except in certain specific habitats such as: gravel

islands in river beds (Osborne 1972; 1997; Ellenberg 1996; Gao *et al.* 2000); rock formations (Meusel 1935; 1939; Gradmann 1950; Müller 1980); “beaver meadows” (Wells *et al.* 2000; Schneider 1996; Harthun 1998; 1999); open stages during autogenous cyclic succession in alder carrs (Pokorný *et al.* 2000; Sádlo 2000); and mires (particularly percolation mires; Succow, Jeschke 1986). In contrast to this hypothesis, Vera (2000) claimed that the forests were partly open. His hypothesis is based on the assumptions that the first megaherbivores, which today are partly extinct, such as the aurochs or the European bison, contributed to more open forests (but see Stuart *et al.* 2004 and Mitchell 2005). However, besides the megaherbivore hypothesis, there are many other aspects and new results which support the hypothesis of a more open landscape, and more open forests, when the first farmers settled (see also Kreuz 2008):

1. The forests consisted of oak (*Quercus* spp.), elm (*Ulmus* spp.), common hazel (*Corylus avellana*), lime tree (*Tilia* spp.) and ash (*Fraxinus excelsior*; Clark *et al.* 1989). All these species are not so shade-tolerant. Oak, for example, is not able to regenerate by seed under a closed canopy and common hazel would not even flower (Vera 2000). However, the shade-tolerant and most dominant species in the actual potential natural vegetation would be beech (*Fagus sylvatica*) and fir (*Abies alba*). Although beech might have already occurred locally in northern Germany before the Neolithic Age (Robin *et al.* 2016) it has only spread after the first farmers have settled. It may have even immigrated with the first farmers – being an important crop and fodder plant (Bonn, Poschlod 1998) since beech came from the southeast (Slovenia; Magri *et al.* 2006; Magri 2008) and started to establish only around 5000 BC in southeast Germany (Huntley, Birks 1983; Lang 1994). Fir having come from the south (Konnert, Bergmann 1995; Hewitt 1999) arrived

around 4500 BC in southwest Germany (Black Forest; Lang 1994). According to Küster (1997), beech is a synanthropic species, an idea that has recently been confirmed for Bohemia, through its asynchronous immigration (Pokorný 2005), and the northern part of central Europe (Tinner, Lotter 2006), but declined for Switzerland and southern Germany (Tinner, Lotter 2006).

2. Fire might have played a further role by maintaining open landscapes/forests. The high proportions of common hazel pollen may have been caused through natural fires (Clark *et al.* 1989). Alternatively, fire might have been used by Mesolithic people to increase common hazel as an important fodder plant (Bos, Urz 2003). For North America, natural or man-made fires have also been discussed as having maintained oak forests (Abrams 1992).

3. Recently, studies from the Czech Republic have shown that forests had not reached their maximum expansion during the beginnings of settlement (Hájková *et al.* 2011) and that there were continuous grassland habitats (forest steppe) represented today by semi-natural grasslands (Kuneš *et al.* 2015; Pokorný *et al.* 2015).

4. Phylogeographic studies on grassland plants, despite having their main distribution in a Mediterranean climate, such as *Eryngium campestre*, have shown that they may have survived in central Europe in (micro)refugia (Bylebyl *et al.* 2008; see also Poschlod 2015).

Evidence of arable fields has come from pollen analysis and seed remains in Neolithic settlements, and of grasslands from pollen and pediaanthracological analyses. One exception has been the findings of plant macroremains (vascular plants, bryophytes) in the sods of a Celtic grave mound (Fritz 1977; 1979; Fritz, Wilmanns 1982).

Arable fields mainly developed from slash and burn, but also through clearing, and only rarely after wood pasturing

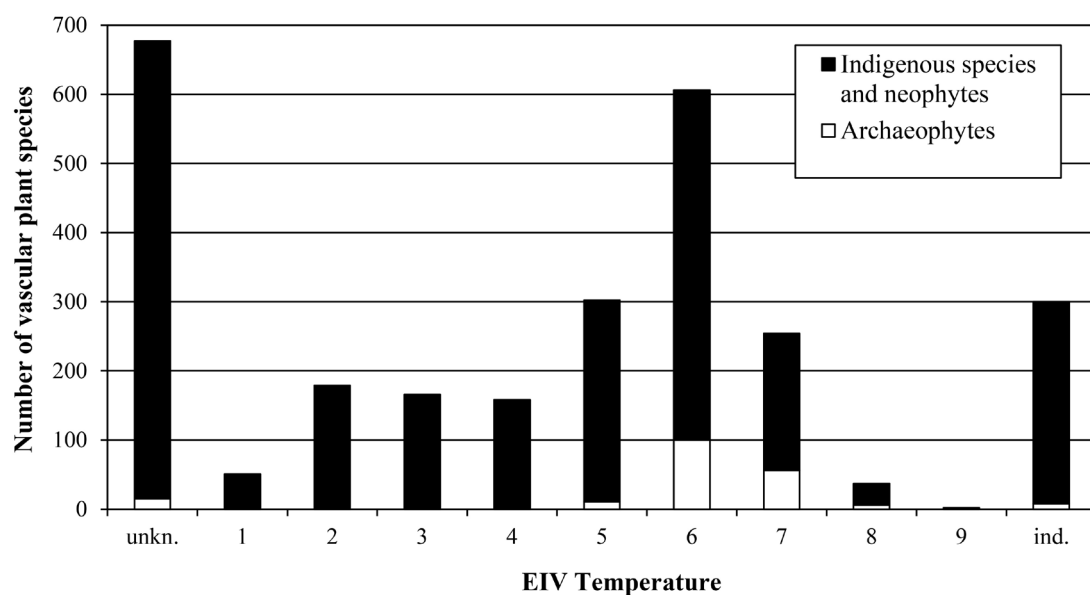


Figure 3. Proportion of archaeophytes, indigenous species and neophytes (in Bavaria) at each temperature indicator value category according to Ellenberg (Ellenberg *et al.* 1991). Ellenberg indicator values define a species’ niche along an environmental gradient, in this case temperature (or altitude): 1 – alpine, nival to 9 – very warm, colline; Ind – indifferent species (not indicating a specific niche along a temperature/altitudinal gradient).

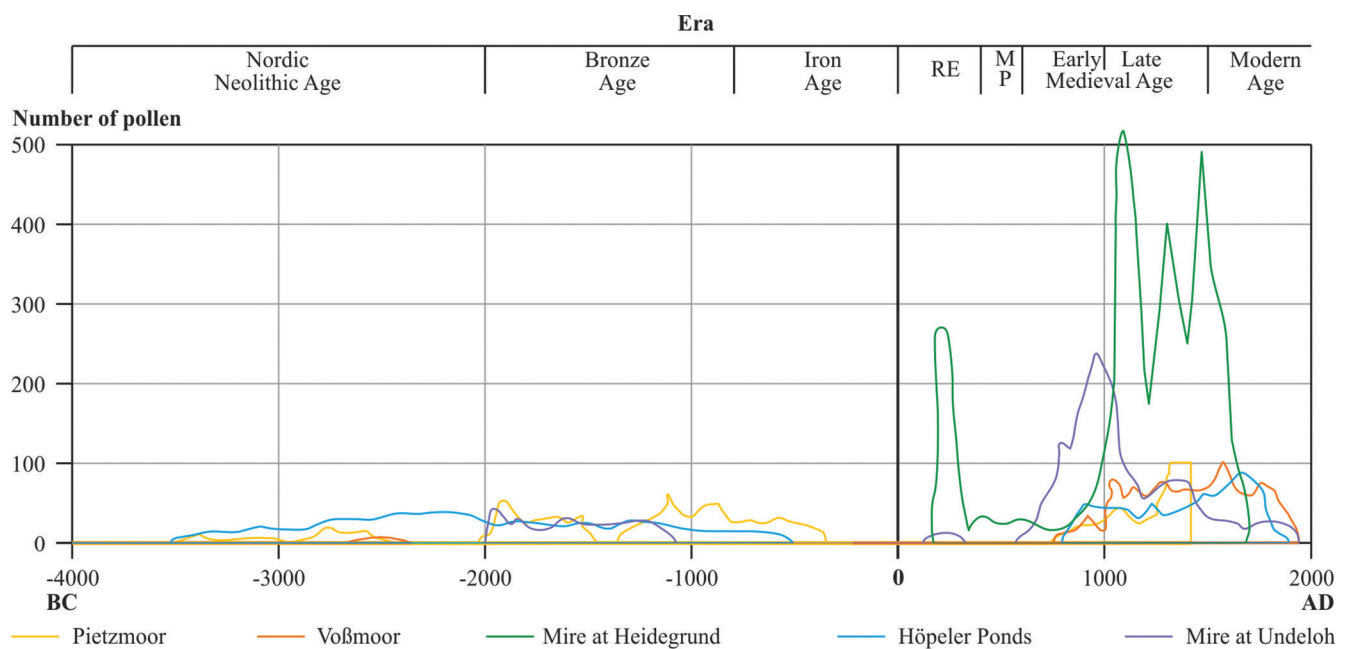


Figure 4. Chronological development of heathland and its expansion in the Luneburg heath (northwest Germany) based on pollen data of *Calluna vulgaris* from different peatland localities in this region (after Pott 1999). RE – Roman Empire period; MP – Migration period.

(Roberts 1998; Behre 2008). The first crops were einkorn, emmer, barley, pea, lentil, flax and poppy, crops which evolved in a Mediterranean climate. In central Europe they were grown as summer crops, meaning that they were sown in spring and harvested during summer (Willerdig 2003a). This allowed the arable fields to be grazed after harvesting until the next spring. Thus the fields were fertilized and could be managed over longer periods (Kreuz, Schäfer 2011). Arable fields were often managed on a long-term basis without alternating grassland use (Knörzer 1986), since the first settlements of LBK people were established in regions with fertile loess deposits (Jankuhn 1969). This hypothesis of naturally fertile soils is supported through the records of nutrient-demanding or nitrogen-indicating species in the cereal remains of the earliest LBK settlements, such as: *Bromus secalinus*, *Chenopodium album*, *Galium aparine*, *G. spurium*, *Lapsana communis*, *Phleum pratense*, *Fallopia convolvulus*, *Setaria* spp., *Solanum nigrum* (Bogaard 2002; 2004; Kreuz, Schäfer 2011). Nevertheless, depending on the region and soils, either agroforestry, or alternate arable field-grassland and arable field-forest use, or shifting cultivation, have also occurred (Rösch 1990; 1991; Schier 2009). The vegetation of this plant community was composed of indigenous species, but also archaeophytes that came from regions with a Mediterranean climate either from the Near East, Asia Minor or southeast Europe. At least 27 archaeophytes arrived during the Neolithic Age via uncleaned crop seeds, although some might also have been used as fodder plants (Poschlod 2015). Still today, arable weed communities contain the highest proportion of archaeophytes (Willerdig 1986). Archeophytes are a reflection of warm climatic conditions through their temperature indicator value which is above average compared to that of the whole central European flora (Figure 3).

Grazing either in forest steppe grasslands, or in more-or-less open forests, and in arable fields after their abandonment, resulted in the first “man-made” grasslands. Few palynological studies have shown a continuous existence of calcareous grasslands in northern or northwest Europe since the Neolithic Age (Königsson 1968; Bush 1993; Preece, Bridgland 1999). Applying pedomorphological analyses, Dutoit *et al.* (2009) supposed the establishment of calcareous grasslands for western Europe, in the Seine valley (Upper Normandy, France), through forest clearing by fire around 4800 to 4600 BC. For eastern central Europe, Hájková *et al.* (2011) have shown that actual, extremely species-rich grasslands, or those with a high number of so-called relict species, were always situated in the vicinity of Neolithic settlements and concluded from this fact that the continuous management since then has maintained this high species-richness (Kuneš *et al.* 2015; Pokorný *et al.* 2015). In Germany, the existence of man-made grasslands has been proved from at least the Bronze Age (Poschlod, Baumann 2010), or the Iron Age (Fritz, 1977; 1979; Fritz, Wilmanns 1982).

Heathlands were first verified in north Germany (Behre 2008) for the period of the Funnel Beaker culture (4100 to 2800 BC; Müller 2011). The first evidence for heathlands in the famous Luneburg heath dates back to around 3500 BC (Pott 1999; Figure 4).

3. The first climate pessimum period from the end of the Neolithic Age to the start of the Iron Age

At the end of the Neolithic period, around 3400 BC, the climate optimum ended and temperatures cooled down. The

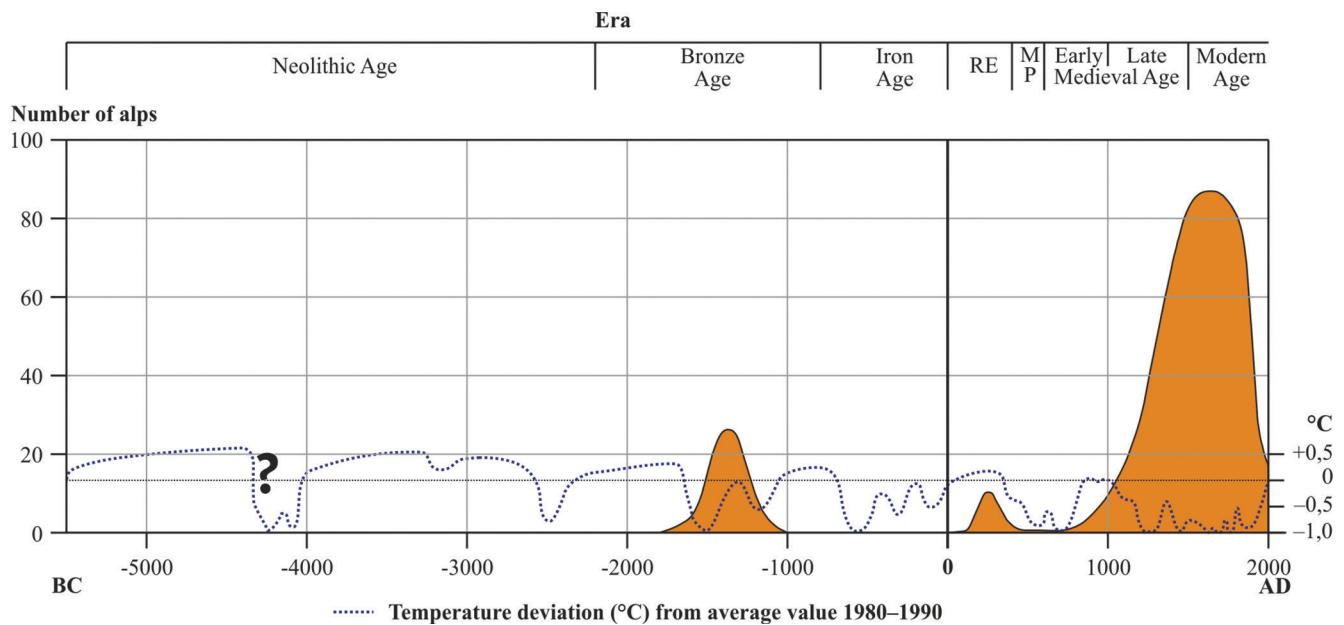


Figure 5. Temperature trend (blue dotted line) and origin of alpine farming/number of alps in the Dachstein mountains (Austria; after Mandl 2009). RE – Roman Empire period; MP – Migration period.

following cold period, called Piora Oscillation (around 3400 BC to 3000 BC; Zoller 1960), caused a decline of the tree line (Frenzel 1966; Wick, Tinner 1997; Nicolussi *et al.* 2005) and an expansion of the glaciers in the Alps (Joerin *et al.* 2006), as well as a decrease in the dominant tree species *Tilia* and *Ulmus* (Lang 1994). Temperatures in central Europe were around 1 to 2°C lower (Amesbury *et al.* 2008; Bleicher, Sirocko 2010). The causes for the cooling are not clear and may have been influences from orbital change of the earth around the sun, a decrease of solar activity, or the expansion of polar sea currents (Magny *et al.* 2006). Ötzi, the “iceman”, who was found at 3210 m a. s. l, is the most famous indicator of this cool period (Baroni, Orombelli 1996; Fleckinger 2011; Magny, Haas 2004).

Probably he was a migrating herder (Hollemeyer 2008), the hypothesis being supported through isotope analyses of his teeth and bones (Müller *et al.* 2003). This would also indicate transhumant herding in the central Alps, a finding which was already proven for the Neolithic Age and Bronze Age in the Mediterranean region, the Pyrenees and the central Alps through archaeological findings (Mandl 2007a; 2007b; Reitmaier 2009), soil layers indicating slash and burn (Reitmaier, Walser Bakk 2008), pedoanthracological findings (Wick, Tinner 1997; Talon *et al.* 1998), dung deposits (Akeret, Jacomet 1997; Akeret *et al.* 1999) and pollen analysis (Drescher-Schneider 2009).

In contrast to transhumant herding, alpine farming only appeared for first time during the Bronze Age. The oldest proven incidence is from the Dachstein mountains where it started around 1700 BC (Mandl 2009) at the beginning of a short climate optimum (Figure 5). Transhumant herding, as well as alpine farming, during that period have strongly contributed to the decline of forests of *Larix decidua* and *Pinus cembra* and, as a consequence, to the lowering of

the tree line. New habitats developed – such as the “*Larix* pastures”. Pasture weeds such as *Rhododendron* spp. and *Alnus viridis* increased (Zoller 1960; Tinner *et al.* 1999, 2003; Gobet *et al.* 2004). Today, the *Rhododendron* belts above the tree line often represent ancient abandoned pastures (Ellenberg 1996; Anthelme *et al.* 2003). *Alnus viridis* was also favoured through the application of fire (Gobet *et al.* 2003). Transhumant and alpine farming may have strongly contributed to the enrichment of lowland grassland biodiversity through the transport of seeds from higher to lower altitudes by domestic livestock, but it also probably occurred in the opposite direction (Poschlod, Bonn 1998; Poschlod 2015).

After the first cold epoch and the short optimum which lasted until 1200 BC, another climate pessimum started which was probably the coldest since the last ice age (Table 1). One cause might have been the outbreak of the Hekla volcano in Iceland (Baker *et al.* 1995; Yurco 1999; Eiríksson *et al.* 2000). Glaciers expanded again (Holzhauser *et al.* 2005) and alpine farming was abandoned (Mandl 2009). Crop failures and food supply problems may have been the stimulus for novelties and technological progress. Robust crop plants such as spelt (*Triticum spelta*; from Asia Minor), foxtail millet (*Setaria italica*) and common millet (*Panicum miliaceum*; both from East Asia) (Crawford 2005; Nasu *et al.* 2007; Zohary *et al.* 2012), as well as the fava bean (*Vicia faba*, from Asia Minor; Tanno, Willcox 2006), were increasingly cultivated. However, according to Rösch and Heumüller (2008), the cultivation of these plants might have been as a consequence of the nutrient-impoverished soils, due to the permanent application of fire during shifting cultivation (slash and burn agriculture). Speier (1994) assumed that the increase of pollen of wet grassland plants around 1000 BC indicates the start of hay making.

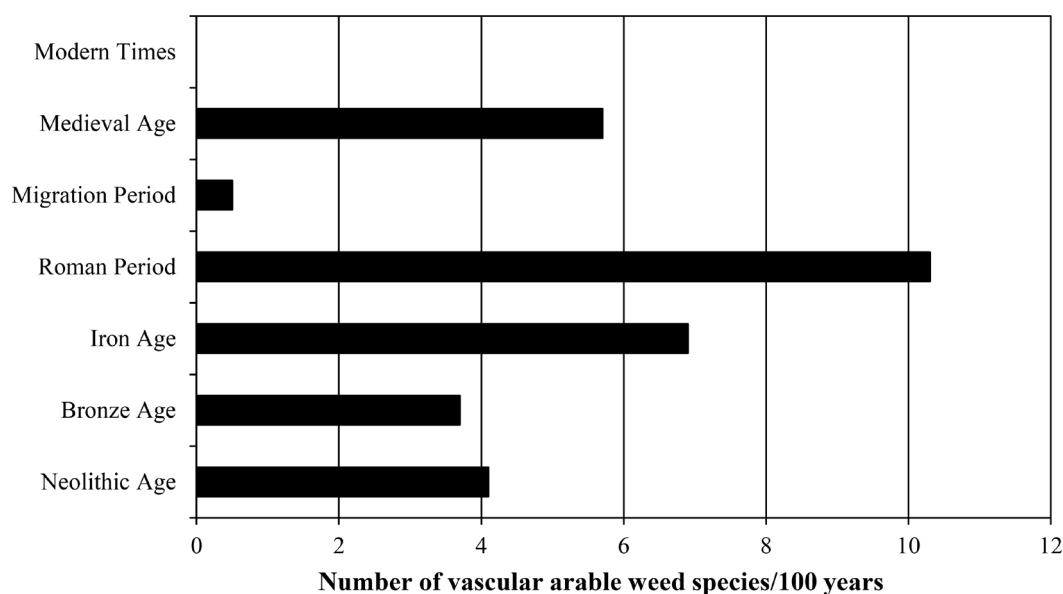


Figure 6. Number of new arable weed species (per 100 years) in archaeobotanical findings of central Europe for each archaeological/historical period (after Willerding 1986).

However, his indicator species – such as sedges, marsh-marigold (*Caltha palustris*), lesser spearwort (*Ranunculus flammula*), bistort (*Bistorta officinalis*), Devil's bit (*Succisa pratensis*) and thistles (*Cirsium* spp.) – also occur on wet pastures. Grazing was still the main land use within wetland areas until the 18th century. According to Hodgson *et al.* (1999), who used a functional approach, the earliest meadow use was in the Iron Age where the first scythes were found (Leube 2003). In southern Germany, grassland species only increased in the Iron Age, which was interpreted as a signal of

permanent open land or grassland (Rösch, Heumüller 2008). In the eastern part of Europe which was settled by Slavic people, meadow use only started as late as the Medieval Age (earliest 11th/12th century, latest 14th century; Hempel 2008). The Slavs, who immigrated during the Migration Period to the eastern part of central Europe (Brather 2008), did not know the scythe (Hempel 2008).

Taking into account the number of new archaeophytes, the Bronze Age had the lowest increase per 100-year period, not only in arable weeds but also grassland species (Figures 6 to 8).

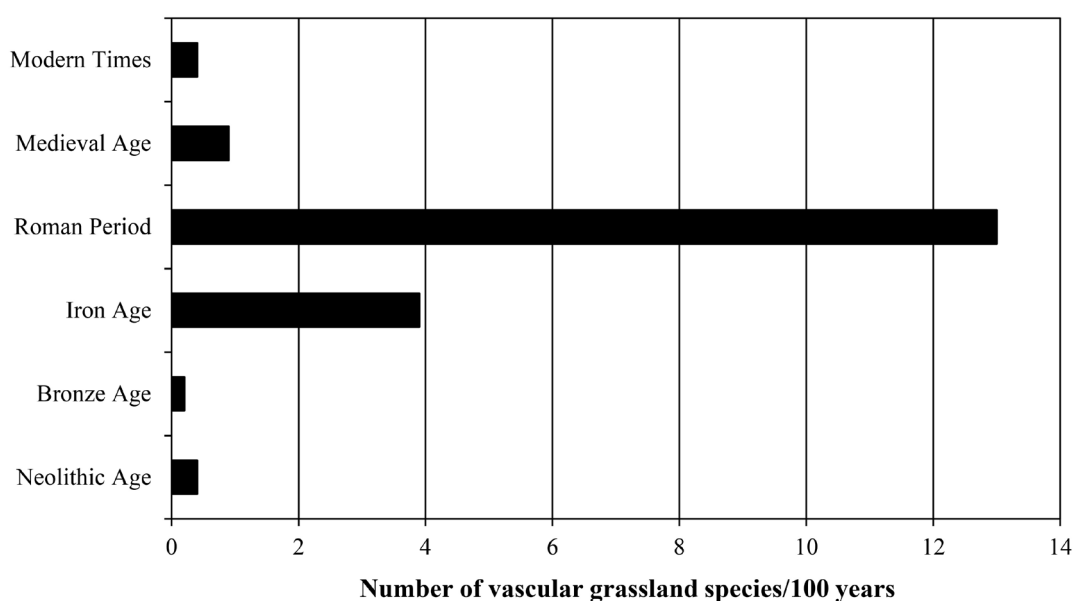


Figure 7. Number of new grassland species (per 100 years) in archaeobotanical findings of the Lower Rhine region for each archaeological/historical period (after Knörzer 1996).

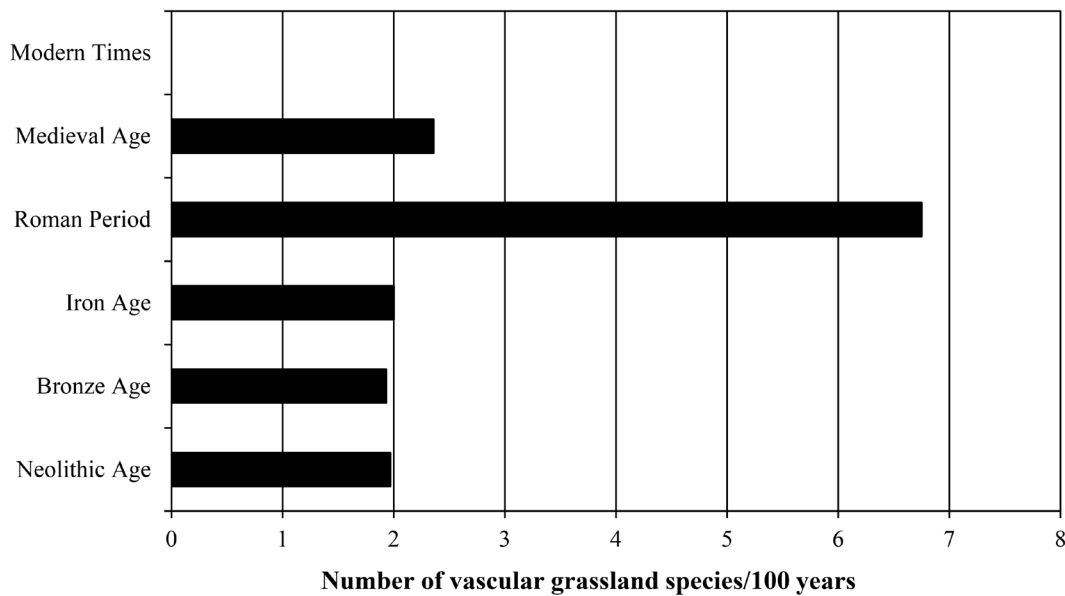


Figure 8. Number of new grassland species (per 100 years) in archaeobotanical findings of northern Switzerland (region around Basel) for each archaeological/historical period (after Jacomet, Brombacher 2009).

4. The second climate optimum during the Roman Empire period – the first diversity revolution in the man-made landscape

A new climate optimum followed from around 300 BC to 350 AD (Figure 9; Ljungqvist 2010). Its main cause was increased sun activity, which at the beginning and end of this period was probably the highest during the Holocene (Steinilber *et al.* 2008). According to Crumley (1994), there was an extreme shift of three climatic regions colliding with each other in

central Europe – the Mediterranean, oceanic and continental climates. Whereas from 1200 BC to 300 BC the border of the Mediterranean climate was situated to the south of European Mediterranean countries, it moved considerably further north during the following 600 years. At this time, central Europe was mainly covered by forests, as described by Tacitus in his “Germania” in the 1st century: “*The land may vary a certain amount in its appearance, but in general it either bristles with forests or festers with marshes. It is wetter on the side facing the Gauls, windier opposite Noricum and Pannonia*” (Birley 1999).

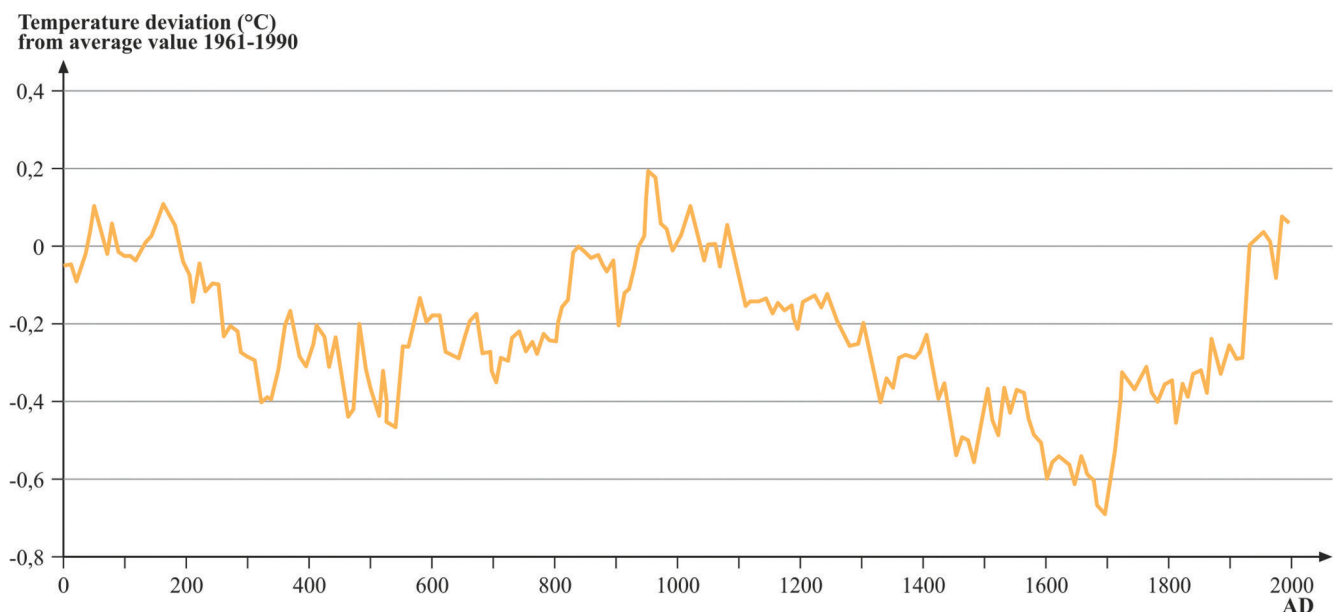


Figure 9. Decade average temperature trend in the non-tropical northern hemisphere (90 to 30°N) between 1 AD and 1999 AD in comparison to the average mean annual temperature between 1961 and 1990 (after Ljungqvist 2010).

This climate optimum or change was the first to have been documented in written sources and for which hypotheses as to its causes were set up. Columella wrote in his first book on “Agriculture”: “*For I have found that many authorities now worthy of remembrance were convinced that with the long wasting of the ages, weather and climate undergo a change;... For in that book on agriculture which he (Saserna, a pre-Christian Roman writer; note of the author) has left behind he concludes that the position of the heavens has changed from this evidence: that regions which formerly, because of the unremitting severity of winter, could not safeguard any shoot of the vine or the olive planted in them, now that the earlier coldness has abated and the weather is becoming more clement, produce olive harvests and the vintages of Bacchus in the greatest abundance*” (Ash 1941).

Lamb (1977) mentioned a shift in the distribution of beech (*Fagus sylvatica*) in book XVI of Plinius. However, from the original source there is no evidence.

The climate optimum allowed for a more efficient agriculture in central Europe. It resulted in the first foundation of towns and in the expansion of the Roman Empire. Famous towns founded at the end of the Iron Age were some celtic oppida (Iron Age fortified settlements) such as Manching (3rd century BC; Bavaria, Germany) or Bibracte/Mont Beuvray (2nd century BC; Rieckhoff, Fichtl 2011; France), and at the beginning of the Roman times, such as Treves/Trier (Augusta Treverorum; Rhineland-Palatinate), Augsburg (Augusta Vindelicorum), Kempten in the Allgäu (Cambodunum; Bavaria), Xanten (Vetera; North Rhine-Westphalia) and many more (Thiel 2008).

With the expansion of the Roman Empire the central European man-made landscape within the limites (the empire’s frontier limits) became more diverse. Crop rotation was practiced, mainly as a two-field rotation system (Drexhage *et al.* 2002), but already probably also as three-field rotation system (Küster 1994).

The two-field rotation system consisted of two parts, the arable fields and the fallow which alternated every year (Schröder-Lembke 1978). Locally, the two-field rotation system existed in the Rhine region, especially in Alsace, Palatinate, at the Moselle and at Jülich, until the beginning of the 19th century (Schwerz 1816a; 1816b).

Livestock breeding was so intensely practiced that some authors call it the first agricultural bloom or even “revolution” (Peters 1994). The Romans also brought new animals to central Europe. They domesticated the carp (*Cyprinus carpio*) which originally occurred in southeast European and Asian rivers running to the Black and Caspian Seas, as well as to the Aral Sea (Balon 1995). Rabbit (*Oryctolagus cuniculus*; originally distributed in North Africa and Spain) and pheasant (*Phasianus colchicus*; originally distributed in central Asia) were introduced. Rabbit was probably introduced merely to France and only came to central Europe during the Medieval Ages (Niethammer 1963; Kroll 1973). The edible snail (*Helix pomatia*) was farmed in so-called “snail gardens”. These were a source of food for the Romans,

who probably brought it for that purpose to England where it is still called “Roman snail” (Mansfield 2011).

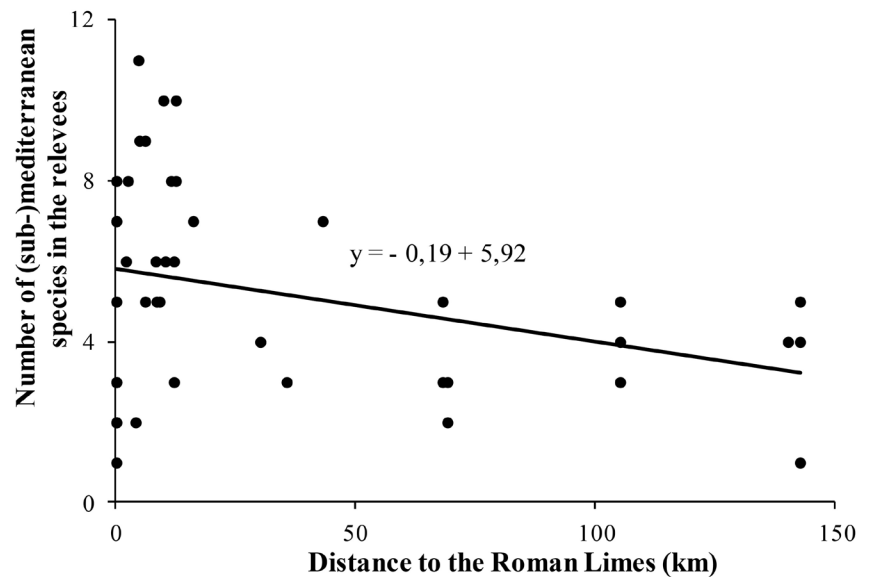
In the vicinity of Roman villas (*Villae Rusticae*) new habitats developed, such as vineyards and orchards through the import of new crop plants such as fruit trees and vines (Willerding 1992; 2003b). Such fruit included sweet cherry, pear, prune, walnut, apple, plum, peach, apricot and quince (Willerding 2003b; Poschlod 2015). However, the introduction of other new crop plants such as vegetables (lettuce, onion, leek, garlic, chard, common purslane, *etc.*; Körber-Grohne 1994) and spices (dill, coriander *etc.*; Knörzer 2004) may have also contributed to an increasing habitat and species diversity. In the regions outside the empire’s limits (limites) there has been no evidence of these crop plants (Willerding 2003b).

Tacitus wrote in his Germania in the 1st century AD, that the country “*is fertile for sown crops but will not grow fruit trees*” and there were neither orchards nor meadows (Birley 1999): “*In fact, however, for all that their land is fertile and extensive, they make no effort at planting orchards, fencing off pasturing, or irrigating gardens. Their only demand on the soil is for corn*”. The taste of the fruit from the wild apple trees was described by Pliny the Elder in his “Naturalis Historia” (Rackham 1945): “*There are also wild apples with little attraction of flavour and an even sharper scent; their special fault is that of horrible sourness, and it is so powerful that it will blunt the edge of a sword*”.

Many German terms in pomiculture and viniculture have therefore Latin roots. In viniculture, these are, for example, “Wein” (wine; from latin *vinum*), “Winzer” (wine grower; from latin *vinitor*), “Lämpel”, “Lämbel” or “Limbel” (border of the vineyard; from latin *limbulus/limbus*), “keltern” (wine pressing; from latin *calcare*), “Keller” (cellar; from latin *cellarium*), “Legel” (little barrel; from latin *lagella*). In pomiculture, these are “propfen” (grafting; from latin *propagare*), “emden”, “impten” or “impfen” (inoscultation; from latin *inserere*), “pelzen” (grafting a branch behind the bark; from latin *pellis*), “Most” (must, newly-pressed juice from grapes/fruit; from latin *mustum*), “Torkel” (wine press; from latin *torcular*), “Kufe” (vat; from latin *cupa*), “Kübel” (bucket; from latin *cupella*) and, of course, the names of the fruits or fruit trees such as “Kirsche” (cherry; from latin *cerasus*), “Birne” (pear; from latin *pirus*) and “Nuss” (nut; from latin *nux*; Grimm, Grimm 1854–1960; Kleiber *et al.* 1993; Zehnder, Weller 2006).

The agricultural diversity resulted in the highest increase in “new” (archaeophytic) arable weed as well as grassland species per 100 year period ever since then (Figures 6 to 8). For the arable weeds, the main reason was certainly the cultivation of new crop plants (Willerding 1986; Lang 1994; Knörzer 2004; Jacomet, Brombacher 2009). For the grassland plants, the beginning of the application of mowing might have been one reason (Knörzer 1979; Körber-Grohne 1983; 1990; but see Hodgson *et al.* 1999), but also the introduction of hay (for example, for the horses of the cavalry) at least at the beginning of the Roman conquering expedition. According to Kronfeld (1919), the

Figure 10. Number of (sub)mediterranean species in historical relevés from Gauckler (1938) of calcareous grasslands in southeast Germany in relation to the distance of the Roman *limes* (significant decrease with increasing distance to the *limes*; $p < 0,05$; from Baumann 2006).



plentiful occurrence of the pellitory-of-the-wall (*Parietaria officinalis*) in the floodplains of the Danube at Vienna is a relict of the Roman troops. If grassland species were intentionally introduced, we do not know. The pattern of a declining number of (sub-)Mediterranean species in calcareous grasslands of the Jurassic mountains within reasonable distance of the empire's *limites*, let us at least assume some impact (Figure 10; Baumann 2006; Poschlod, Baumann 2010).

Finally, for the supply of the Roman troops but also the increasing civil population, large forest areas were also cut (Figure 11; Küster 1994; Junkelmann 2006). The increasing demand for firewood in combination with coppicing led to the transformation of the beech forests to oak-hornbeam forests, the latter species being able to resprout after coppicing (Ellenberg 1996).

5. The Migration period – a climate pessimum as catalyst

Another climate pessimum with lower mean annual temperatures, less precipitation and changeful weather (extreme weather events with flood disasters along the coast of the North Sea) started around 350 AD and lasted until 600 AD (Migration Period, early Medieval Age; Lamb 1995; Büntgen *et al.* 2011). The cause of this climate pessimum was probably low sun activity (Schreg 2010; Schreg, Sirocko 2010; Wirth *et al.* 2013). Reinforcing acted a dust veil in the upper atmosphere which reflected the sunlight and caused a global cooling down of the mean annual temperature of up to 3°C, the strongest during the last 2000 years (Stothers 1984a; Larsen *et al.* 2008). The effects are particularly obvious for the period between 536 to 545 AD, manifested in the northern hemisphere through the increased

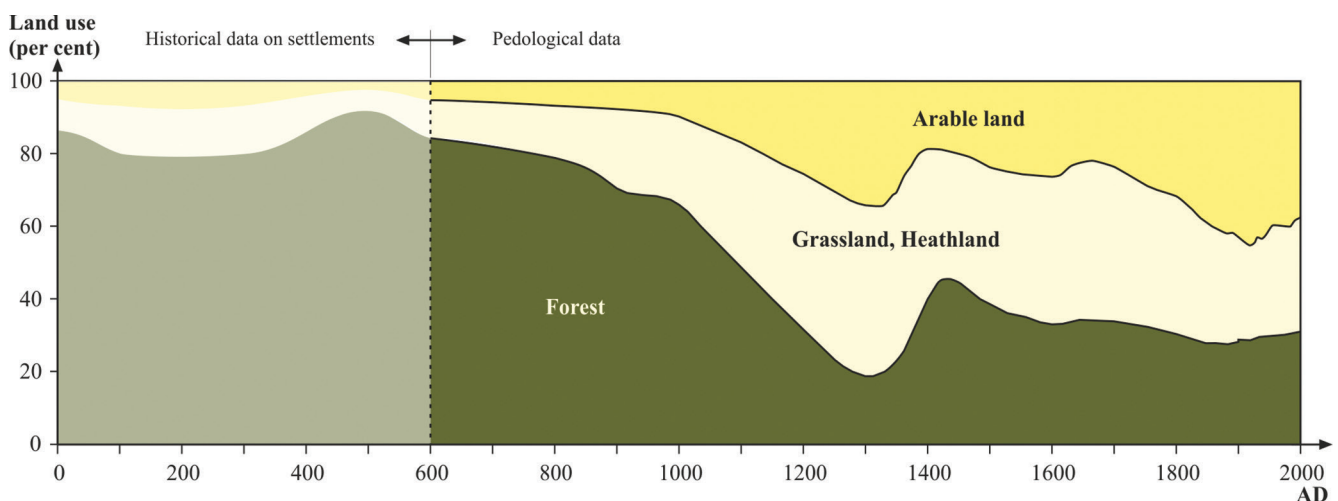


Figure 11. Chronological development of open man-made habitats and forests in the landscape of Germany since the beginning of the common era (after Bork 2006 and Poschlod 2015).

sulphate depositions in Arctic ice cores (Larsen *et al.* 2008) and in the extremely narrow annual rings and frost rings in trees (Baillie 1994; D'Arrigo *et al.* 2001a; 2001b). Volcanic eruptions in the tropics have been suggested as the origin of the dust veil (Larsen *et al.* 2008; Ferris *et al.* 2011; *if* Ilopango, El Salvador: age dating 430 AD, Dull 2004; *if* Krakatau in southeast Asia: Keys 1999; *if* Rabau in Papua New Guinea: Stothers, Rampino 1983). However, much more likely is a comet impact (Baillie 2001; 2007; Rigby *et al.* 2004). Historical chronicles confirm a dust veil and subsequent famines and plague epidemics (Stothers and Rampino 1983; Rampino *et al.* 1988) for the 6th century. The Byzantine historian Prokopius noted for 536/537 AD (Dewing 1916): “*And it came about during this year that a most dread portent took place. For the sun gave forth its light without brightness, like the moon, during this whole year; and it seemed exceedingly like the sun in eclipse, for the beams it shed were not clear nor such as it is accustomed to shed. And from the time when this thing happened men were free neither from war nor pestilence nor any other thing leading to death. And it was the time when Justinian was in the tenth year of his reign.*” At the same time, other historical authors from Constantinople described the phenomenon, for example, Zachariah of Mytilene (“... and the sun began to be darkened by day and the moon by night ...” and “... as the winter was a severe one, so much so that from the large and unwonted quantity of snow the birds perished ...”; Hamilton, Brooks 1899) and Johannes Lydus (“... if the sun becomes dim because the air is dense from rising moisture-as happened in the course of the recently passed fourteenth indiction (535/36) for nearly a whole year; ..., so that the produce was destroyed because of the bad time – it predicts heavy trouble in Europe. And this we have seen from the events themselves, when many wars broke out in the west”; Arjava 2005). Michael the Syrian probably quoting John of Ephesos wrote in the 12th century of this period: “... there was a sign in the sun the like of which had never been seen and reported before in the world. If we had not found it recorded in the majority of proved and credible writings and confirmed by trustworthy people, we would not have recorded it; for it is difficult to conceive. So it is said that the sun became dark and its darkness lasted for one and a half years, that is, eighteen months. Each day it shone for about four hours, and still this light was only a feeble shadow. (...) The fruits did not ripen, and the wine tasted like sour grapes”; Arjava 2005).

And in Italy the Roman praetorian prefect Flavius Magnus Aurelius Cassiodorus wrote around 538 AD to the delegate Ambrosius: “*The Sun, first of stars, seems to have lost his wonted light, and appears of a bluish colour. We marvel to see no shadows of our bodies at noon, to feel the mighty vigour of his heat wasted into feebleness, and the phenomena which accompany a transitory eclipse prolonged through a whole year. The Moon too, even when her orb is full, is empty of her natural splendour. Strange has been the course of the year thus far. We have had a winter without storms, a spring without mildness, and a summer without heat. Whence can*

we look for harvest, since the months which should have been maturing the corn have been chilled by Boreas?” (Hodgkin 1886).

In central Europe glaciers expanded (Holzhauser *et al.* 2005; Joerin *et al.* 2006). Whole tribes started to migrate from north to south and east to (south)west due to famine and restricted food supply. Drought periods in central Asia caused the movement of the Huns to central Europe (Blümel 2002). The vehemence of the migrations was one of the reasons of the breakdown of the Roman Empire (Heather 2005). Not only within but also outside the limites, this period is characterized through its increase of tree pollen and decrease of pollen from cereals and settlement indicators (Donat, Lange 1983; Küster 1988; Müller-Wille *et al.* 1988; Dörfler 1992; Dreßler *et al.* 2006; Hempel 2009; Schreg, Sirocko 2010).

Such changes in pollen indicate the abandonment of many settlements as well as their arable fields and grasslands (Figures 11) in which nearly no new species appeared during that period (Figures 6 to 8). At the beginning of the Medieval Age central Europe was therefore still strongly dominated by forests, which is also indicated in that aurochs and European bison were still present (Poschlod 2015).

6. The medieval climate optimum – the expansion of man-made habitats and man-made landscapes

From 850 AD to around 1250 AD there was another warming (medieval warm period or medieval climate anomaly; Figure 9; Lamb 1965; Le Roy Ladurie 1967; 2009b; 2009c; Hughes, Diaz 1994; Glaser 2008; Mann *et al.* 2008; Guiot *et al.* 2010; Ljungqvist 2010; Goosse *et al.* 2012a). Most publications and the changes in the man-made landscape give a clear picture of a warm period with temperatures compared to today or even higher for central Europe. Depending on the proxies used (annual rings, pollen, diatom, foraminifer analyses, *etc.*) temperatures have been reconstructed as being somewhat lower to around 2°C higher compared to mean annual temperatures between 1961 to 1990 (Mann *et al.* 1999; Blümel 2002; 2006; Moberg *et al.* 2005; Loehle 2007; Glaser 2008). Dendroecological data allows us to assume that there was a temperature decrease between 1050 and 1150 (Büntgen *et al.* 2006; Corona *et al.* 2010), and some authors even state that there were only three short warmer periods (1010–1040, 1070–1105, 1155–1190; Crowley, Lowery 2000). The latest meta-analysis confirmed up to more than 2°C higher temperatures for Europe in the 10th century, as well as at the end of the 12th and beginning of the 13th century (PAGES 2k Consortium 2013). However, a global warming probably did not take place (Bradley *et al.* 2003; Mann *et al.* 2009; PAGES 2k Consortium 2013).

Causes for the warming were an increased solar activity and radiation (Bard *et al.* 2000; Shindell *et al.* 2001; Muscheler *et al.* 2007; Guiot *et al.* 2010) that resulted in the dislocation of the Gulf Stream to the north (Goosse *et al.* 2012b). The solar activity probably fostered a positive North

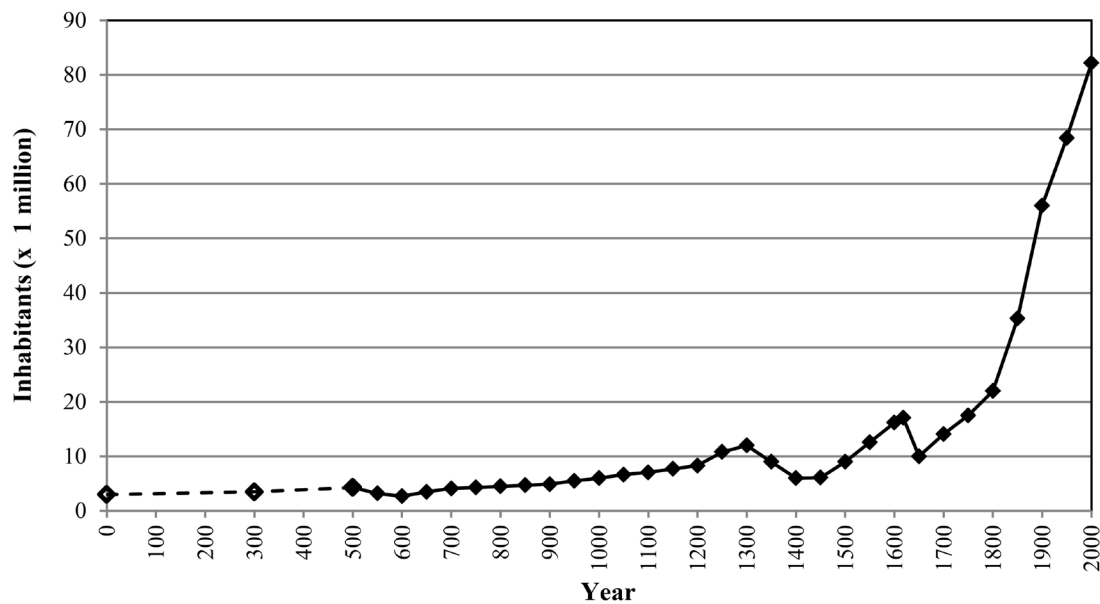


Figure 12. Chronological population development in Germany since the beginning of the common era (from Poschlod 2015).

Atlantic Oscillation (fluctuation of atmospheric pressure differences between the Iceland depression to the north and the Azores anticyclone to the south in the North Atlantic) which brought mild and moist air to central Europe (Trouet *et al.* 2009; van Loon *et al.* 2012).

The climate optimum allowed an increase in the human population which reached its highest density up until then (Figure 12; Grupe 1986). It resulted in the largest ever expansion of man-made landscape in central Europe (Figure 11; Bork *et al.* 1998; Bork 2006). This development

is also reflected in the number of towns founded around then (Figure 13), reaching its peak in the 12th and 13th century (Stoob 1956). Accordingly, the number of villages also increased, mainly through the clearing of forests (“great age of clearing”; Smith 1978), especially in less favourable regions such as mountains (Fehn 1966, Smith 1978). Villages still existing in Germany from this period have names whose ending correspond to the kind of forest clearing (*e.g.* -reute, -scheid, -schlag, -rod from clearing through felling; and -brand, -schwend from clearing through burning), or

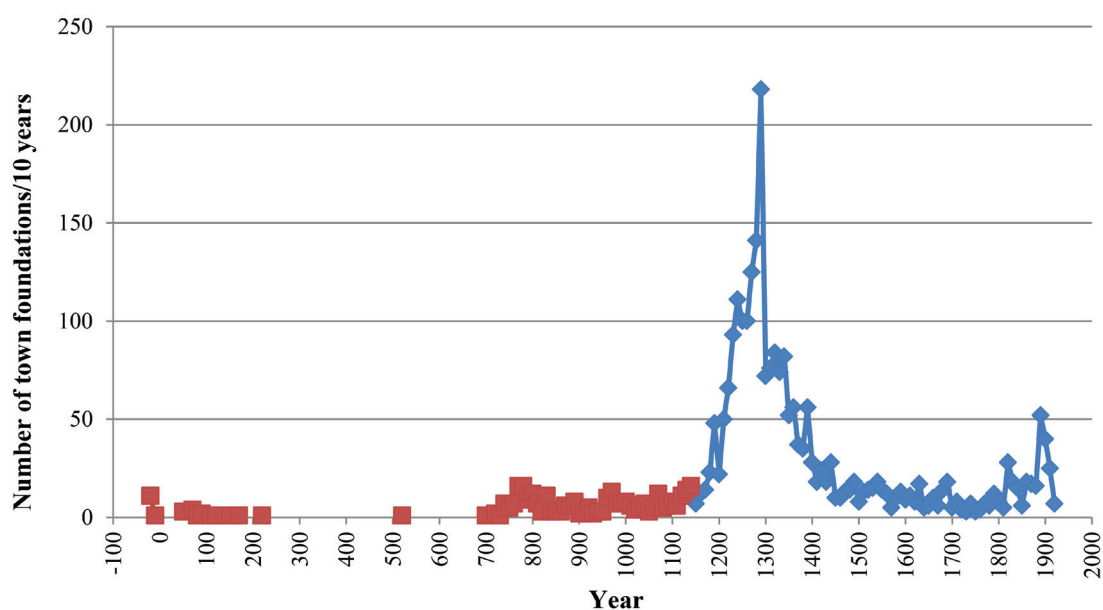


Figure 13. Chronological development of town foundations in Germany from 100 BC to 1100 AD (red squares) and in central Europe since 1100 AD (blue squares; from Poschlod 2015). Data before 1150 from different sources; data (n=ca. 2000) after 1150 from Stoob (1956). Definitions of towns according to different criteria such as privilege, fortification, economy, society and magisterial infrastructure (Haase 1958).

according to their topography (-bach – brook; -tal – valley; -berg – mountain; Bach 1954). The Gothic architecture and style are considered the expression of a powerful, surplus-generating society (Blümel 2002).

A perfect indicator for the medieval warming is viniculture (David-Sirocko, Sirocko 2010), which expanded during this period to England and the Baltic states (Weber 1980; Lamb 1995), even to regions where there was no viniculture possible in the 20th century.

Many thermophilous horticultural and medical plants were introduced, mainly from the Mediterranean and West Asia, which included: wallflower (*Erysimum cheiri*), hyssop (*Hyssopus officinalis*), and catnip (*Nepeta cataria*; Lohmeyer, Sukopp 1992). Today they are naturalized in warm and dry habitats and act as a reminder of this warm period. From England, data on certain animals show how they had their most northern distribution during this period. One example is the Nettle Ground Bug (*Heterogaster urticae*), which occurred in the 20th century only in southern England. It has been found in Roman and medieval deposits in York, in the north of England (Buckland 1986; Hall, Kenward 2004).

The population growth resulted not only in an expansion of arable fields and grasslands, particularly in the mountains, but also in an improvement of agricultural practices. Peatland cultivation started in northwest Germany (Berger 1950; Rabenstein 1982; Göttlich, Kuntze 1990; Behre 2008). Marshlands on the North Sea coast were colonised (Behre 2008).

In south and west Germany, as well as in Switzerland, France and Belgium, the three-field rotation system was already established by the early Medieval Age, whereas in the eastern part of central Europe the alternate arable-field-grassland use was still practiced (Smetánka 2009). The three-field rotation system resulted in a final differentiation of the arable field and grassland vegetation. In contrast, in northwest Germany and the Netherlands the one-field-system with its permanent rye cultivation was practiced (Gringmuth-Dallmer 2003), which contributed to the strong expansion of heathlands due to the necessary regular fertilization through the “Plaggen” economy (Figure 4; Behre 2008).

Compared to the Roman Empire period, only a relatively few new crop plants were introduced: buckwheat (*Fagopyrum esculentum*), cowpea (*Vigna unguiculata*), common sorrel (*Rumex acetosa*), common salsify (*Tragopogon porrifolius*), parsnip (*Pastinaca sativa*), (wild) cabbage (*Brassica oleracea*), carrot (*Daucus carota* ssp. *sativus*), spinach (*Spinacia oleracea*) and endive (*Cichorium endivia*), which were respectively used either as root or leafy vegetables, and tuber or salad plants (Poschlod 2015). The “agricultural heritage” of the Romans has determined the agriculture and habitats that have evolved from the respective practices in central Europe up until Modern Times (Poschlod 2015).

From original documents we know about the grassland use of peatlands, which date back to the 11th and 12th century (e.g. “Pfrunger Ried” in Upper Swabia; Göttlich, Kuntze 1990). Peatlands were grazed and used for fodder and dung production. The latter was used to fertilize the arable fields

that were created during peatland amelioration; from that time on until the 20th century, in German, the word existed “*the meadow is the mother of the arable field*” (Brüne 1946; Göttlich, Kuntze 1990). With the fodder production the first wet meadows in peatlands may have developed.

In northwest Germany, the first settlements at the edge of the geest (sandy heathland) were founded to cultivate the minerogenous mires. They stemmed from the foundation of Cistercian monasteries (e.g. Loccum 1163, Osterholz 1185, Wienhausen around 1225, Hude 1232, Lilienthal 1232, and Scharnebeck at Lüneburg 1243, etc.; Wegener 1985; Eberl 2002). In 1300 AD, the complete connected network of dykes of Friesland was finished (Behre 2008). Since that time freshwater and saltwater habitats have been separated and the ecologically diverse transition zone (brackish water) has been lost (Behre 2008).

The food shortage due to the bulging population caused the re-introduction, or increase, of archaic land-use types such as the alternate arable-field-grassland-coppice use which was particularly practiced in mountain areas such as the Bavarian Forest, the Black Forest, the Eifel, the Siegerland and the Spessart (Poschlod 2015; see also Rösch 1990; Lünig 2000). Since the different land use practices were applied at one locality at the same time but on different parcels of land, an extremely high biodiversity began to develop in these regions. The open structure of the coppices allowed the strong expansion of certain species, such as ground-living birds like the hazel grouse (*Tetrastes bonasia*; Poschlod 2015). Another land-use practice, ridge and furrow, dates from this period of man-made landscape expansion (Schenk 2000).

Due to the increased livestock, extensive hay production was practiced, resulting in the first expansion of meadows. That meadow-use was only practiced on a larger scale in the Medieval Age, is also supported through the fact that the German word for meadow, “Wiese”, does not stem from the Latin “*pratium*” like e.g. the French word “*pré*” but first appears at the end of the 8th century. The etymological origin is found in the old nordic word “*veisa*” (mud) or the Anglo-Saxon terms “*wās*” (moisture) and “*wase*” (swamp) (Grimm, Grimm 1854–1960; Boesch 1981). In the German dictionary, Grimm, Grimm (1854–1960) wrote that the term moisture seems to be strongly attached to the word “Wiese” and that the original meaning “swampy grassland” has been lost today. Konold (1994) even assumes that the prototype of the meadow was an irrigated meadow. It can thus be concluded that the first meadows were mainly established in river floodplains, which is confirmed through the frequent archaeobotanical findings of wet meadow plants, such as Ragged Robin (*Lychnis flos-cuculi*), meadowsweet (*Filipendula ulmaria*), common spike-rush (*Eleocharis palustris*) and wood club-rush (*Scirpus sylvaticus*; Willerding 1996). However, the practice of meadow irrigation was already described by Columella in the 1st century AD (Richter 1981).

In central Europe, especially in the foothills of the Alps and in southern Scandinavia, hay was produced in wooded meadows (Swiss “*Studmatten*”, Burger 1927; swedish “*(löv) ängar*”; Hægström 1995; Emanuelsson 2005), which is

another ancient meadow type. The wooded meadows were a multi-functional habitat: trees were used for lumber (oak), firewood (birch, *etc.*), fertilizer (ash of the leaves of the common hazelnut), fruit (hazelnut, rowan berries) or leaf hay production (ash, lime tree, *etc.*), with the grassland underneath mown and later grazed (Kukk, Kull 1997; Hæggström 1998; Emanuelsson 2009). The oaks were also maintained to provide acorns (mast) for pig fattening in autumn (Backmund 1941).

Finally, the first artificial ponds were constructed – another new man-made habitat which has developed its own species assembly due to its specific management practices (Poschlod 2015).

According to Bork *et al.* (1998; see also Bork 2006), the proportion of forest decreased to less than 20% whereas the proportion of arable fields increased to over 30% and that of meadows, pastures and heathlands to around 50% (Figure 11). At the end of the 13th century there was the largest expansion of habitat from man-made landscape ever (until today). Relicts of that period, such as clearance cairns which were piled up at the edge of arable fields during that period, can still be found in forests in mountain areas today, often covered by shrubs and trees (Poschlod 2015).

7. The Little Ice Age – extreme weather events initiate a climate pessimism at the end of the Medieval period and the beginning of Modern Times

At the beginning of the 14th century the last climate pessimism began; it started with a period of extreme weather events. At the beginning of Modern Times, from the mid-16th century until the beginning of the 19th, a period of lower mean annual temperatures and fluctuating precipitation ensued (Le Roy Ladurie 2004; 2009a; 2009b; Glaser 2008). Due to the cooler temperatures this period has been called the “Little Ice Age” (Le Roy Ladurie 2004; Glaser 2008).

Its causes might have been fluctuations in solar activity, which decreased at the end of the 14th century and reached other minima in the 16th and 17th century (Lean 2002; Shindell *et al.* 2003; Solanki *et al.* 2004; Steinhilber *et al.* 2008; see also Vonmoos *et al.* 2006). The period, however, was also characterized by some strong volcanic eruptions on Vanuatu in the 13th and 15th century and Papua New Guinea in the 16th and 17th century (Cowie 2007; Miller *et al.* 2012; see also Shindell *et al.* 2003).

As examples of the extreme weather events of the 14th century, the period from 1311 to 1319 AD, as well as the year of the millenium floods, 1342 AD, should be mentioned. Between 1311 and 1319, heavy precipitation flooded large parts of the central European landscape, severely damaging crop harvests. In the chronicle of Bad Windsheim (Bavaria) it was written for 1315 that the wet summer had caused a big famine which forced people to eat dogs, horses – and even thieves who had been hanged (Glaser 2008)!

The following Latin poem from this year describes the situation: “*Ut lateat nullum tempus Famis, ecce CVCVLLVM*

Albani festa de narvant tristia gesta, Terxam portentis tetigit manus Omnipotentis, Imbribus in numeris, merguntur senina qua vis, Brutaque cum stabulis pereunt, atque oppida villis.” CVCVLLVM on the one hand, relates to the year 1315, and, on the other hand, to the cuckoo which was in Germany a synonym for the devil (“*geh zum Kuckuck*”, “*der Kuckuck soll dich holen*”) which means “go to hell”). In the vicinity of settlements the cuckoo was a bringer of woe (Bächtold-Stäubli, Hoffmann-Krayer 1927–1942). Translated the poem means: “*That the hunger is not hidden at any time, look at the cuckoo, it tells about sad incidents at the feast of Saint Alban, the hand of the Almighty has touched the earth with awful auguries, the sowings cease to exist through countless rainfalls, the livestock perish together with the stables and the towns and the villages*”.

Continuous tallies of the medieval grain harvest (from 1211 to 1491) in England showed indeed only half of the usual yield for 1315 (Grove 2002; Campbell, Ó Gráda 2011).

The year 1342 was that of the thousand-year flood (Glaser 2008). Many reports can be found in chronicles throughout central Europe, for example, from Erfurt (Thuringia; according to Weikinn 1958 from Tetzlaff *et al.* 2002; Glaser 2008): “*This summer there was a such large flood which did not develop from rainfalls but it seemed if the water spluttered from everywhere, even from the peaks of the mountains ... and over the walls of Cologne one could run over with barges ... Danube, Rhine and Main ... carried towers, solid walls and houses away ... as well as the ramparts of towns ... and the watergates of the sky were open, and rain fell on the earth like in the 600th year of Noahs life, ... it happened in Würzburg that the Main destroyed the bridge with strong force and forced many people to leave their housings ...*”. Flood events also occurred in the northwestern and northern parts of central Europe, such as the Rhine-Meuse-Scheldt delta where the dykes broke, and the valleys of Elbe, Eider and Weser (Arends 1833).

The effects on the man-made landscape were tremendous. Due to the low proportion of forest and large expansion in arable field area, more than 50% of the soil eroded during the last 2000 years was washed away, in just the year 1342 alone at least 20% (Bork *et al.* 1998; Bork 2006). Alluvial clay deposits up to several metres in height reshaped floodplains during this period (Mensching 1951; Händel 1967; Bork *et al.* 1998; Dotterweich 2008; Stolz, Grunert 2008; Hempel 2009).

Whole new habitats developed. Since proportions of forest cover were low, potential rainfall interception was greatly reduced, with the result that most of the precipitation seeped into the soil, increasing percolation and spring water emersions. As a consequence, many swampy hillsides underwent paludification and sloping mires started to be formed. In fact, the origin of many sloping mires started during the Medieval Age (Lange *et al.* 1978; Jeschke 1990; see also Succow, Jeschke 1986; Kapfer, Poschlod 1997). Also the development of many “Missen” mires in the higher reaches of the Black Forest started during this period (Radke 1973). Many plants and animals characteristic for wetlands

or mires might have therefore expanded their distribution within this century.

Extreme weather events also reshaped the coast of the North Sea. The second Marcellus flood in 1362, also called the “Grote Mandrenke” (great drowning of men), was able to give the German and Dutch coast its present-day shape (Petersen, Rohde 1977; Behre 2008).

Heavy damages through pathogens and harmful insects followed the periods of extreme weather events. During 1338, 1339 and 1340, plagues of migrating locusts occurred over a vast region from Bohemia and Austria to Bavaria, Thuringia and Hesse (Glaser 2008).

The landscape, however, was not only reshaped by floods and soil erosion, but also through a large increase in forest area (Figure 11). Due to the many failures of crops, people suffering from famines were more prone to illness. The subsequent epidemics, such as the Black Death, caused a catastrophic decrease in population – from around 12 to 6 million people in Germany for instance (Figure 12) – and thus the abandonment of settlements and man-made habitats such as arable fields and grasslands. According to Abel (1978), the number of settlements in Germany decreased from 170,000 to 130,000. In certain regions, such as Hesse, the proportion of abandoned settlements was around 50%. In mountain areas, such as the Rhön or Solling, it could have even reached 70% (Born, Haarberg 1963; Abel 1976; 1978; Born 1984). This period is also called the medieval period of deserted settlements (Abel 1978). Relicts from this period include the “ridge and furrow” of abandoned field systems, which are found today under the forests of mountain areas where settlements had been founded just 100 to 200 years before. These relatively new settlements were the first to be abandoned.

The effect on species diversity has not yet been verified, but the process of abandonment contributed to the expansion of sheep husbandry by the local nobility. They wanted to maintain the landscape open – and thus added to the expansion of dry calcareous and sandy grasslands, as well as heathlands, in the landscape (Hornberger 1959; Poschlod, WallisDeVries 2002). During this period large-scale transhumance developed in south Germany (Poschlod, WallisDeVries 2002).

Furthermore, the following period of cooler temperatures at the end of the Medieval Age and the beginning of Modern Times may have accelerated various agricultural innovations. In the 16th and 17th centuries, when the famous winter paintings by Dutch and Flemish masters were produced, the improved three-field-rotation system and crop rotation with row crops were introduced to central Europe (Poschlod 2015). The improved field-rotation system meant that the fallow of the former traditional field-rotation system was given up and forage plants cultivated. These were red clover (*Trifolium pratense*), lucerne (*Medicago sativa*), common sainfoin (*Onobrychis viciifolia*) and crown vetch (*Securigera varia*). Many of these arable fields were later transformed into grasslands by natural succession and grazing, or hayseed application, where the three latter species often still occur today – as indicators of the former arable field use (Poschlod *et al.* 2008; Karlik, Poschlod 2009).

Row crops such as fodder beet and potato became an inherent part of crop rotation and resulted in the origin of new arable weed communities (phytosociological class of *Chenopodietea*; Ellenberg 1996; Hempel 2009). Through the introduction of false oat-grass (*Arrhenatherum elatius* var. *elatius*) at the end of the 17th, and start of the 18th century from France, thus also called in German French rye grass, the so-called *Arrhenatherum elatius* meadows (*Arrhenatheretum*; Poschlod *et al.* 2009a, 2009b) developed. They were the dominant farm-meadow types up until the second half of the 20th century (Ellenberg 1996).

The Little Ice Age lasted until the 19th century. The coldest period was between 1805 and 1820. 1815 and the following years were probably the second coldest period after the event of 536 AD. Three large volcano eruptions were the cause for the dramatic cooling – the Soufrière on Saint Vincent in the Caribbean erupted in 1812, the Mayon on the Philippines followed in 1814, and finally in 1815 the Tambora in Indonesia (Fagan 2000). The eruption of the Tambora, which started in April 1815, resulted in the most extreme cooling which lasted for at least three years (Stommel, Stommel 1983; Harington 1992; de Boer, Sanders 2004). The eruption is presumed to be the second largest (after the one in 1259 which has not yet been localised) of the more than 5500 until-now dated volcano eruptions (Stommel, Stommel 1983; Zielinski *et al.* 1994; Zielinski 2000). The year 1816 was in Europe (but also in North America) the “year without summer” (Stommel, Stommel 1983; Stothers 1984b). In Germany, the year got the name “eighteenthundred and frozen to death” (Hamm 1956). Mean annual temperatures decreased by more than 2°C (Luterbacher *et al.* 2004). The consequences were crop failures and famines, especially in the south German and alpine regions (Fischer 1999; Specker 1993; 1995). During these years, anything eatable was eaten: hay was cooked, snails and slugs and even cats eaten (Scheitlin 1820). In a painting of 1817, people are pictured even grazing (Specker 1993; 1995)! The botanist and physician Heinrich Rudolf Schinz wrote a pamphlet on behalf of the agricultural commission of the Society for Natural History in Zurich, in which he described the usefulness and risk of alternative nutrition: “... for the benefit and protection of harm ... because the hunger does not select the best ...” (Specker 1995). In doing so, Schinz, when describing edible roots, particularly indicated the bulbs of marsh-orchids and gave advice to only eat them boiled: “If you would add some salt, pepper, caraway, sage, thyme, marjoram, mint, garlic, onions or chive, the simple dish would be more healthy and pleasant” (Specker 1995). Among the fleshy-fruity species, he recommended amongst others the berries of common whitebeam (*Sorbus aria* agg.) and rowan (*Sorbus aucuparia* agg.), as well as rose hips. Other herbs which were strongly collected during those years were common nettle (*Urtica dioica*) and common sorrel (*Rumex acetosa*). Even lower plants such as lichens were eaten (e.g. Iceland moss, *Cetraria islandica*; Fagan 2000). However, despite this heavy pressure on habitats and biodiversity, no detailed

natural history data from that period exist. After this period, the Little Ice Age ended. However, already since the end of the 18th, beginning of the 19th century, climate was no longer the main driving force affecting landscape, habitat and species diversity but human spirit, technical innovations, economic changes and political directives (Poschlod 2015). Only since very recently has the man-made climate change started to affect our landscape, habitat and species diversity again to such an extent.

8. The recent climate change and the effects of climate regulating laws such as the EEG

In contrast to former climate changes the most recent one is man-made, but just as before this one is also causing changes in the landscape, habitat and species diversity. One fact is that certain aquatic species, which we know through the analysis of macrorests in sediment deposits were more northerly distributed during the climate optimum of the Atlantic period or Neolithic Age, have started to spread again; this is known, for example, for *Najas marina* s.l. (Figure 2; Poschlod 2015). Continuous distribution mapping of other organisms since the 20th century has shown the expansion in distribution of another plant, *Ilex aquifolium*, to the north, but more especially in many mobile organisms such as birds, locusts, beetles, dragonflies, butterflies and wild bees (Poschlod 2015).

Political efforts as a reaction to this climate warming, such as the implementation of directives or laws to decrease the consumption of fossil resources, have a much stronger effect on landscape and habitat diversity changes. In Germany this is especially true for the law of renewable resources (EEG – Erneuerbare Energien-Gesetz), which was implemented in the year 2000. It has resulted in an increase of area under cultivation for corn (*Zea mays*) from 15,000 to 25,000 km² to produce biogas. Additionally, rape (*Brassica napus* subsp. *napus*) is cultivated on another 9130 km² to produce biodiesel, and sugar beet and wheat on another 2,500 km² for bioethanol. In total, more than 20,000 km² of arable land in Germany are under cultivation for the production of biofuels: this is nearly 20% of the total arable land! The high input of fertilizers and pesticides has strongly decreased biodiversity and, via atmospheric deposition, is even changing other habitats such as the last remaining natural peatlands – and thus similarly decreasing species diversity (Poschlod 2015). The EEG also supports the establishment of solar panel parks and wind farms; the numbers are continuously increasing. Presently there are around 25,000 inland wind turbines. Detailed data on the numbers and sizes of solar panel parks in the open landscape are not even available (Poschlod 2015)! The future dimension of the actual climate change and its effect on landscape, habitat and species diversity is not yet clear. However, the EEG as a reaction to the actual climate change has resulted in a dramatic decline of species-rich grasslands, one of our most diverse habitats and diverse cultural heritage (Poschlod 2014).

9. Conclusion

It has been shown that climate and climate change have been, and still are, important drivers of our man-made landscape, its habitats and species diversity. Climate optima were shown to have been important for an increase in both habitat and species diversity. Therefore, actual climate change may be also a chance – if we take the past into account. Migrations during climate optima (but also pessima) may have had another strong effect on our biodiversity. However, we have to take into account that only very specific land-use practices have created and maintained our biodiversity. To save and to maintain biodiversity we have to understand the historical and actual context (Poschlod 2014; 2015). This challenge can only be handled in the context of broader interdisciplinary and transdisciplinary cooperation of the respective disciplines than that existing until now.

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