# The history of European hemp cultivation

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**Department of Geology**
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# Contents



**Cover Picture:** Hemp fibres (https://www.wikileaf.com )

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MIMMI SCHROEDER

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**Abstract:** Humans and hemp (*Cannabis sativa*) have an ancient relationship, dating back to the beginning of recorded history. Nevertheless, controversy surrounds the antiquity of the plant. Today *Cannabis* is probably most famous for its psychoactive properties and illicit status in numerous countries, however hemp has primarily been cultivated as a fibre crop in the past. This study examines the European history of hemp cultivation, based on already published data collected from the European Pollen Database and other relevant studies. The oldest indicators of hemp cultivation from the European pollen record is from the Lake Varna-region in Bulgaria, dated to 4280 BCE. However, this find is the only of its kind from this time. Much later, by 500-600 BCE, there are clear indications that hemp cultivation was initiated in southeast Europe. By 700 CE cultivation had spread all the way to the northern and western parts of Europe, including Scandinavia. The earliest evidence of hemp cultivation from Sweden are dated to 20 CE. The most intensive period of cultivation took place between 800-1400 CE. During this time hemp retting was common all over Europe, which explains the extraordinarily large amounts (>80%) of *C. sativa* pollen recorded in some of the datasets. In the late 17$^{th}$ century the cultivation of hemp almost ceased completely as the cotton industry expanded in Europe. Today hemp fibres only represent a tiny fraction (0.15%) of the European textile market.

**Keywords:** hemp, *Cannabis sativa*, pollen, cultivation, Europe.

**Supervisor(s):** Karl Ljung

**Subject:** Quaternary Geology

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# Historisk hampaodling i Europa

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**Sammanfattning:** Människan och hampan (*Cannabis sativa*) har en gemensam historia som går långt bak i tiden, denna historia är dock omgiven av kontroverser. Idag är *Cannabis* mest känt för sina psykoaktiva egenskaper och narkotika klassificering i många länder, men hampa har historiskt sett främst odlats för fiberproduktion. Denna studie undersöker historisk hampaodling i Europa och är baserad på redan publicerade data från European Pollen Database och andra relevanta studier. Den äldsta tecknet på hampodling från europeiska polleninsamlingar kommer från Varna-regionen i Bulgarien och är daterat till 4280 f.v.t. Detta fynd är dock den enda i sitt slag från den här tiden. Först långt senare, omkring 500-600 f.v.t., finns det tydliga tecken på att hampodling initierats i sydöstra Europa. På 700-talet e.v.t. hade hampa odling spridit sig hela vägen till nord- och Västeuropa, inklusive Skandinavien. De tidigaste bevisen på hampodling från Sverige är daterade till 20 e.v.t. Den mest intensiva odlingsperioden ägde rum mellan 800-1400 e.v.t. Under denna tid var hampa rötning vanligt, vilket förklarar fynd av extraordinärt stora mängder (> 80%) av hampa pollen vid vissa lokaler. I slutet av 1700-talet upphörde odlingen av hampa nästan helt och hållet samtidigt som bomullsindustrin expanderade i Europa. Idag utgör hampafibrer bara en liten del (0.15%) av den europeiska textilmarknaden.

**Nyckelord:** hampa, *Cannabis sativa*, pollen, hampaodling, Europa.

**Handledare**: Karl Ljung

**Ämnesinriktning**: Kvartärgeologi

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# 1 Introduction

Hemp, *Cannabis sativa* L., is undoubtedly one of the most important cultivated plants throughout history. The controversial plant is today perhaps most famous for its psychoactive properties and illicit status in numerous countries, but hemp has in fact primarily been cultivated for fibres in the past.

The bast fibres, which can be extracted from the phloem in the stem, are extraordinarily strong and durable which makes them suitable for production of materials like ropes and textiles. Although fibre production seems to have been the focus historically, hemp is a versatile plant and there is no wonder it became such an important part of human culture. The seeds have traditionally been used for food and seed oils and the cannabinoid-containing flowers have been utilized for medicinal, spiritual/religious and recreational purposes (Russo 2007; Long et al. 2016).

Although hemp is well-known and has been extensively cultivated in large parts of the world for thousands of years, the most basic questions regarding the plant's origin, taxonomy and domestication history remain under debate.

*Cannabis* is primarily a dioecious annual herb, belonging to the family Cannabaceae together with her sister genus *Humulus.* Eight other genera; *Aphananthe, Celtis, Chaetachme, Gironniera, Lozanella, Parasponia*, *Pteroceltis* and *Trema* are today also considered part of the Cannabaceae family. Earlier taxonomic placements of *Cannabis* include the nettle family (Urticaceae) and the mulberry family (Moraceae) (McPartland 2018). While scientists now have reached common ground regarding the members of the Cannabaceae family, the number of species belonging to the genus *Cannabis* is still disputed.

Although initially described in Europe by Fusch 1542, Linneaus gave name to *Cannabis sativa* L., as a singular species. Since then some scientist have recognized up to three morphological species: *Cannabis sativa* L.*, Cannabis indica* Lam. and *Cannabis ruderalis*. *C. sativa* are tall, branched plants which traditionally have been cultivated for fibre production. They contain the highest amount of tetrahydrocannabinol (THC), up to 16%, which is the main psychoactive cannabinoid. On the other hand, *C. indica* is generally shorter with broader leaves and contain about equal parts of the cannabinoid's THC and CBD (Cannabidol). Finally*, C. ruderalis* is a short, unbranched variation with a notably lower cannabinoid content. *C. ruderalis* is sometimes called industrial hemp as this variation today often is legally cultivated for industrial purposes, and slightly less regulated due to the low cannabinoid content (Russo 2007). Although the three are different enough to be separate species according to some scientists, others argue they should be classified as subspecies*: C. sativa* ssp. *sativa*, *C. sativa* ssp. *indica* and *C. sativa* ssp. *ruderalis,* since there are no reproductive barriers between the three (Zhang et al. 2018).

There is still no consensus on where hemp originated. Most of the literature suggests the center of origin to be somewhere in Central Asia, however Russia, East Asia, China and the foot of the Himalayas have all been proposed by various scientists as possible centers of origin (Bouquet 1950; Vavilov & Dorofeev 1992; Long et al. 2016). The domestication history is equally uncertain as the previous view of a single domestication event now is being challenged by new genetic studies indicating that *Cannabis* in fact has been domesticated several times in different locations (De Candolle 1883; Zhang et al. 2018).

Hemp is a wind-pollinated plant which produces remarkably large amounts of pollen. One single anther can produce 70,000 pollen grains (ca. 350,000 pollen grains per flower). Dispersed by the wind over large areas, some fall into rivers and lakes and are preserved in sediment. The pollen grains have tough outer cell walls, which prevent them from decomposing (Subba Reddi & Reddi 1986; Small & Antle 2003). Thus, pollen make up an indispensable archive for geologists and paleoecologists interested in reconstructing past environments.

Some lake sediments have been found to contain unproportionally large amounts of *Cannabis* pollen. This relates to a traditional practice of fibre processing, called "retting". Retting is a bacterial process which separates the fibres from the rest of the plant material. It is done by submerging the mature stems in water, usually lakes, for extended amounts of time. This practice may have greatly impacted these aquatic environments as it is known that retting causes over-fertilization and anoxia (Edwards & Whittington 1990; Paridah et al. 2011).

Pollen from hemp make up a majority of the plant's (sub)fossil record. Other finds include macrofossils (parts of plants and flowers), achenes (seeds), imprints of seeds and plant parts on pottery and materials like textiles and ropes made from hemp fibres (Fleming & Clarke 1998).

By mapping subfossils and pollen data many scientists have tried to explain the cultivation history of hemp. The purpose of this project is to further explore the European cultivation history based on already published pollen data and literature. What does pollen data from localities in Europe reveal about the cultivation history? When was *Cannabis sativa* introduced to Europe and where was it introduced first? To what extent was hemp cultivated in Europe during different times? How did hemp cultivation and water-retting impact local environments? When did cultivation begin in Scandinavia and Sweden? At what time did hemp cultivation start declining in Europe and what is a possible reason for the decline?

# 2 Methods

This study is based on already published data from the European Pollen Database (EPD) and literature. The study of published pollen data aims to reveal trends in the pollen record regarding where and when *Cannabis sativa* was introduced and cultivated in Europe. The purpose of this study is also to include and discuss relevant material which has not been published on the EPD.

The taxa I have searched for in the European database, and included in my study are: *Cannabis sativa, Cannabaceae/Urticaceae and Humulus/Cannabis,* whereof most of the results are recorded as *Humulus/ Cannabis.* The various classifications reflect the difficulties to accurately separate *Cannabis* pollen from the pollen of her sister genus *Humulus*. In this study I will refer to pollen recorded as *Cannabaceae/Urticaceae* and *Humulus/Cannabis,* i.e. pollen which has not been decided to genus, as “cannabis-type” pollen.

I chose to include all the taxa mentioned above, despite the risk of including *Humulus*-data in my study. It is generally accepted that values around 1% of cannabis-type pollen likely reflects wild growing native hops, i.e. *Humulus lupus*. Cannabis-type pollen exceeding 5% of the total pollen sum is generally considered a strong indication of cultivation of *Cannabis sativa* in the area. Values approaching 10%, together with macrofossils such as achenes and other plant material are strongly suggestive of retting (Whittington & Edwards 1989; Larsson & Lagerås 2014).

I searched the EDP in April and May 2019. The searches resulted in hundreds of datasets which had recorded cannabis-type pollen. However, most of these only displayed very small quantities of the taxa (<2%) and many datasets were not dated or only displayed uncalibrated dates. I chose to only include dated and calibrated datasets with ages displayed in BCE/CE (Before the Common Era/Common Era), which have recorded levels of cannabis-type pollen >2% of the total pollen sum (total pollen sum = all determinable pollen grains and fern spores, unless otherwise stated).

My results were delimited to a total of 13 data sets from the EPD including pollen data from: Czech Republic, France, Poland, Switzerland, Germany, Bulgaria and Finland. An additional 22 literature studies with relevant pollen data from the Netherlands, Italy, England, Scotland, Finland, Denmark, and Sweden were also included. Some of these references were given to me by my supervisor and the rest I found in the literature lists of these articles as well as by searching LUB search and google scholar. Some of the words I used for searching the databases were: “hemp”, *“Cannabis”,* “pollen”, “Europe” and “retting”.

Unpublished data from two study sites in Sweden: Lyngsjön and Skärpingsgölen were given to me directly from the authors. Between 1-4 sites (average: 2.3) were included from each country, except from Sweden. I deliberately included more studies (a total of 12) from Sweden since little focus has been on this region in earlier publications regarding the cultivation history of hemp in Europe.

The relevant datasets were downloaded from the EPD and compiled in Microsoft excel. The program C2 was used for plotting the data and visually presenting the results in figure 1. Figure 2 and 3, which give a geographical overview of the study sites, was created using mapchart.net and gimp.

# 3 Results

All the study sites included in this project are summarised in table 1.

## 3.1 Switzerland

Lobsigensee (47°03’19”44 N, 7°29’91”67 E) is a partly overgrown kettle-hole lake in northern Switzerland. Several cores were collected with a Livingstone borer from the center of the lake.

Pollen of *Cannabis sativa* from this location peaks with 6.6% at 199 CE in sediment core LOBHOLO. However, substantially higher pollen percentages of cannabis-type pollen (>70%) have been found and described in two other sediment cores (LQ-170 and LL -2) from the same locality, but which are not available from EPD. Most of the abundant pollen were identified as *C. sativa* on a morphological basis.

Due to hardwater-errors, the $^{14}$C dates were found to be unreliable. Thus the chronology of the cores was established by studying and correlating pollen assemblages. The author tentatively dated the *Cannabis*-rich sediments to 1100-1200 CE based on similar finds from the Swiss Plateau. Pollen data from Lobsigensee are presented in figure 1 (Ammann 1989).

## 3.2 France

Lake Lauzon is a small lake located 1980 meter above sea level in south east France (44°40'31" N, 5°47'36" E). A sediment core was taken from 40 – 450 cm depth in the lake. The core was sampled for palynological analysis and a chronology was established using $^{14}$C dates.

Cannabis-type pollen first occur at 429 cm depth, which was dated to 5583 BCE. However, only a very small quantity was present (0.143%) at this depth. Therefore, it is likely that these data reflect wild growing *Humulus* rather than cultivated *Cannabis*.

However, in samples dated to 215 BCE the content of cannabis-type pollen had increased to 1.88%. Cannabis-type pollen keeps increasing upwards in the stratigraphy and reaches a peak of 7,2% in samples dated to 36 BCE. Thereafter cannabis-type pollen decreases to values ranging between 0.4%–1.8% between 23-757 CE. Pollen data from Lake Lauzon are presented in figure 1 (Argant & Argant 2000).

Tourbière de Nay is a peat bog located by the river Erdre in western France. A sediment core was collected from the bog on a depth of 95 – 970 cm. The first

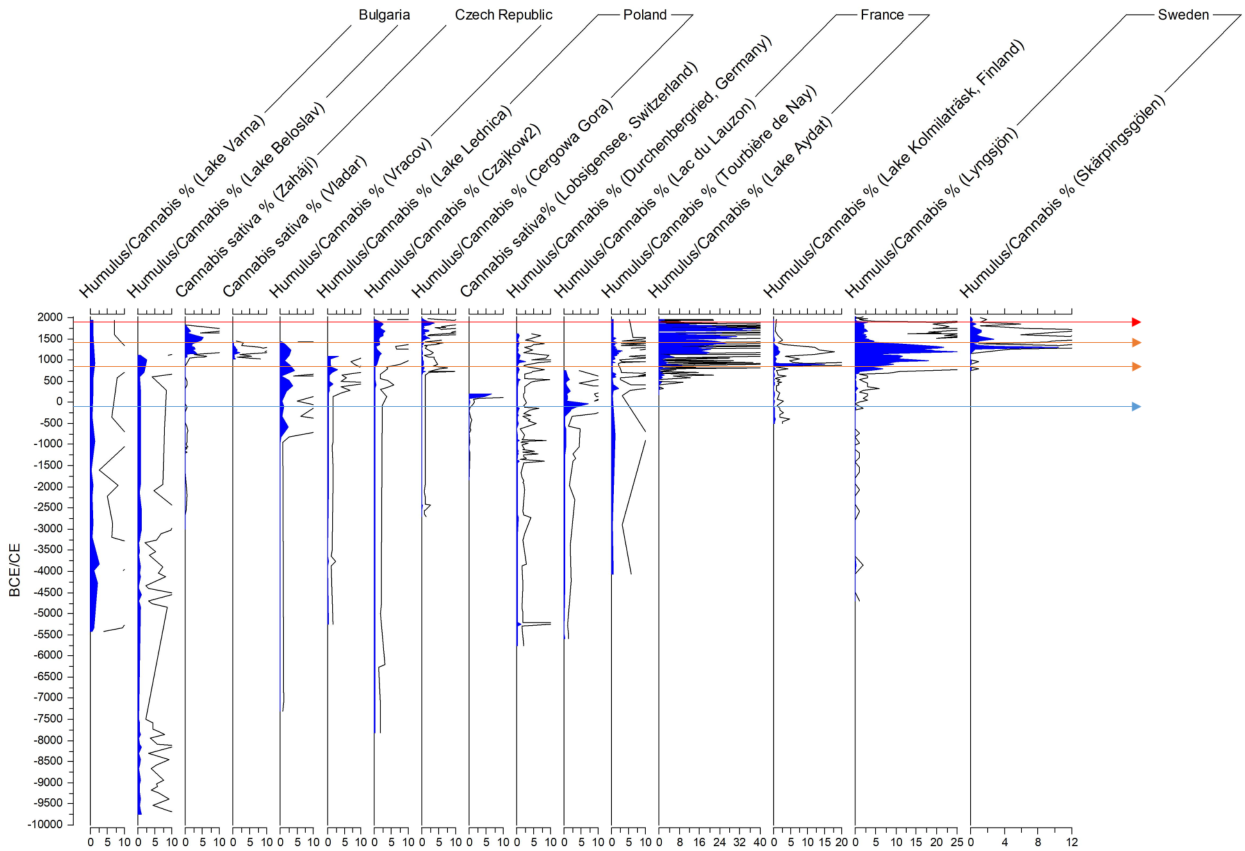


*Fig 1.* This figure illustrates the results of the pollen data study, based on data from the European Pollen Database and unpublished data from study sites Lyngsjön and Skärpingsgölen. The x-axis display the percentage (%) of cannabis-type pollen (or *C. sativa*) from the different sites. The ages of the samples are displayed on the y-axis in BCE/CE. Cultivation of hemp was initiated ca. 557 BCE in Vracov (Czech Republic), but no other sites included in the figure show signs of cultivation at this time (except for Lake Varna that display high values already ca. 4000 BCE). The blue arrow marks the beginning of cultivation in western Europe. The period of most intense cultivation (800-1400 CE) is marked with two orange arrows. The red arrow marks the decline of cultivation (ca. 1850-1880 CE).

occurrence of cannabis-type pollen is on 810 cm depth, which was dated to 4066 BCE. However, at this sample level cannabis-type pollen occur in very small quantities: 0.58%, and are therefore likely from *Humulus*. The cannabis-type pollen reaches 2% at 384 cm depth, which was dated to 332 CE. Thereafter there is a decrease to values below 2% until 195 cm depth, where cannabis-type pollen reaches 2.11%. This sample level was dated to 1142 CE. Cannabis-type pollen peaks with 3,116% at 175 cm depth, which was dated to 1224 CE. In the overlying sample, dated to 1245 CE, the value decreases to 0.847%. Thereafter cannabis-type pollen remains lower than 2% (mostly lower than 1%) until the top of the core. Pollen data from Tourbière de Nay are presented in figure 1 (Ouguerram 2002).

Lake Praver (45°04'25"N, 5°21'23"E) is situated 1170 meters above sea level in the Romanche river valley, south east of Grenole in France. A sediment core was retrieved from the middle of the lake and >500 terrestrial pollen were counted for each sample, which were taken with an interval of 5 cm to 10 cm. A chronology was established using AMS $^{14}$C dating on macrofossils.

The pollen analysis revealed two peaks of cannabis -type pollen: >80% at 237.5 cm, dated to 540 CE and >40% at 197.5 cm, dated to 1230 CE. Shortly after the initial peak, at ca. 200 cm depth, there is a rapid decline of cannabis-type pollen to values approaching 0, before the quick increase leading to the second peak. At 240 cm depth cannabis-type pollen has declined to values <10% and continues to decline until the top of the profile where no cannabis-type pollen were recorded (Nakagawa et al. 2000).

Lake Aydat (45°39.809′N, 2°59.106′E) is located in central France. A high-resolution sediment core was collected from 14.5 meters water depth. The core was radiocarbon dated and a total of 50 samples were collected for pollen analysis. In each sample a minimum 500 dry land pollen was counted. The resulting percentages are of total land pollen, hence excluding hygrophytes, aquatic plants and fern spores. The core was dated using AMS radiocarbon dates and $^{137}$Cs measurements.

Cannabis-type pollen occur from 717 cm depth, which was dated to 470 CE. Because of the small

Table 1. Summary and characteristics of study sites. The numbers correspond to the numbers on the maps (fig. 2 and fig. 3).

| Number | Country | Site name | Site type | Peak cultivation |
|---|---|---|---|---|
| 1 | Switzerland | Lobsigensee | kettle-hole lake | 1100-1200 CE |
| 2 | France | Lac du Lauzon | small lake | 36 BCE |
| 3 | France | Tourbière de Nay | peat bog | 1224 CE |
| 4 | France | Lake Praver | lake | 540 CE |
| 5 | France | Lake Aydat | lake | 1746 CE |
| 6 | Czech Republic | Záhají | spring mire | 1531 CE |
| 7 | Czech Republic | Vracov | former lake | 746 CE |
| 8 | Czech Republic | Vladar | cistern | 1165 CE |
| 9 | Bulgaria | Lake Varna | lake | 3823 BCE |
| 10 | Bulgaria | Lake Beloslav | small lake | 1010 CE |
| 11 | Italy | Lake Albano | lake | 190 CE |
| 12 | Italy | Lake di Nemi | lake | 50 CE |
| 13 | Poland | Czajkow | karst sink-hole | 1684 CE |
| 14 | Poland | Cergowa | landslide depression | 1900 CE |
| 15 | Poland | Wolin Island | kettle-hole lake | 1320 BC |
| 16 | Poland | Lake Lednica | lake | 1095 CE |
| 17 | England | Thorpe Bulmer | potential kettle-hole | 220 CE |
| 18 | England | Crose Mere | shallow lake | 340-895 CE |
| 19 | England | Muddymore pit | natural pit | 1020-1210 CE |
| 20 | Scotland | Kilconquhar Loch | shallow lake | 330 BC |
| 21 | Scotland | Black Loch | lake | 985-1160 CE |
| 22 | Germany | Durchenbergried | kettle-hole mire | 964 CE |
| 23 | Germany | Mindelsee | glacial finger lake | 540- 1750 CE |
| 24 | Netherlands | Lake Uddelemeer | lake | 1500 CE |
| 25 | Finland | Lake Kolmilaträsk | lake | 829 CE |
| 26 | Finland | Likolampi | kettle-hole lake | 1590 CE |
| 27 | Denmark | Dallund sø | lake | 1200 CE |
| 28 | Denmark | Gundsømagle Sø | shallow lake | 1150-1800 CE |
| 29 | Sweden | Östra Ringarp | former lake | 1000 CE |
| 30 | Sweden | Bussjösjön | small lake | 650-1200 CE |
| 31 | Sweden | Krageholmssjön | lake | |
| 32 | Sweden | Bjäresjön | lake | 600-900 CE |
| 33 | Sweden | Skärpingsgölen | lake | 1300 CE |
| 34 | Sweden | Femtingagölen | lake | 1300 CE |
| 35 | Sweden | Ödetjärnen | lake | 1200-1400 CE |
| 36 | Sweden | Ösbysjö | lake | 800-900 CE |
| 37 | Sweden | Kroppsjön | lake | 300-400 CE |
| 38 | Sweden | Sänkemosse | peat bog | 1300-1500 CE |
| 39 | Sweden | Lindängelund | waterlogged pit | 20-220 CE |
| 40 | Sweden | Lyngsjön | lake | 1184 CE |

quantity, 0.18%, it is probably pollen from wild growing *Humulus* and not *Cannabis*. The first occurrence >2% (2.16%) was dated to 646 CE. By 874 CE cannabis-type pollen reaches 9.03% and later 18.59% at a level dated to 1159 CE. The percentage of cannabis-type pollen keeps increasing upwards in the stratigraphy and peaks with 30.73% by 1564 CE, 36.47% by 1697 CE and finally with 38.16% by 1746 CE. Thereafter there is a decrease and by 1915 CE cannabis-type pollen only make up 0.84% of the total pollen sum. However, in samples dated to 1945 and 1958 there was a slight increase again to 2.17% and 2.14%. Pollen data from Lake Aydat are presented in figure 1 (Lavrieux et al. 2013).

### 3.3 Czech Republic

The Záhají study site is a medium sized spring mire located on a large loess plateau in central Bohemia, Czech Republic. The landscape surrounding the location is sculptured by parallel valleys.

A sediment core was retrieved with a piston corer and sampled for pollen analysis. In every subsample at least 700 pollen grains were counted. The resulting percentages are expressed in total arboreal and non-arboreal pollen (AP+NAP), including monolete spores but excluding all pollen from aquatic species. A chronology was established using radiocarbon dates on macrofossils found in the core.

The first recorded occurrence of *Cannabis sativa* pollen is on 530 cm depth, dated to 2552 BCE. However, it is a negligible amount, only 0.025%. At 155 cm, dated to 1142 CE, pollen of *C. sativa* make up 1.5% of the total pollen sum. Thereafter there is a further increase to values around 2-3% until the curve peaks with slightly higher 5.4% at 60 cm depth, dated to 1531 CE. Thereafter follows a decrease of *C. sativa* pollen and at the top of the core, dated to 1838 CE, there are no recorded pollen of *C. sativa.* Pollen data from Záhají are presented in figure 1 (Pokorný 2005).

The next site from Czech Republic is a former lake located in a broad valley next to the town Vracov in south east Moravia. Documents from early 20$^{th}$ century describes the 0.22 km$^2$ area as a landscape mainly consisting of wet meadows. However, the area was drained in in the 1920s.

Pollen samples from Vracov were collected during an excavation of the top 200 cm of the former lake, consisting mainly of organic material. The profile was radiocarbon dated using macrofossils.

Cannabis-type pollen occurs first on 195 cm depth, dated to 7310 BCE, but only in very small amounts: 0.09%. The first substantial find: 2.4%, was on 105 cm depth, dated to 577 BCE. Thereafter the curve decreases to values ranging from 0.6-1.8% until it reaches a small peak with 3.9% by 385 CE, followed by a decrease. There is a second peak with 4.2% at sample a level dated to 746 CE, followed by a decrease. Thereafter pollen values increase again to 3.2% in a sample dated to 1228 CE. By 1420 CE the cannabis-type pollen had decreased again to only represent 0.5% of the total pollen sum. Pollendata from Vracov are presented in figure 1 (Rybíček 1983).

Vladar (50°05' N, 13°13' E) is located on a hilltop in northwest Bohemia, Czech Republic. The study location is an archaeological site with a fortification from the Bronze age. In the centre of the citadel a cistern (50 x 30 m) has been constructed to serve as a water reservoir for the settlement. Today the basin is almost completely dried out and is filled with approximately 3 meters of peat sediment.

Sediment cores were retrieved from two transects in the cistern and a 275 cm deep trench was dug in the middle of the basin. The cores were subsampled for pollen analysis and 900 pollen grains were counted from each sample. The result of the pollen analysis shows the total sum of terrestrial pollen (AP+NAP). A chronology was established using six AMS radiocarbon dates and the cores were correlated based on stratigraphy.

Pollen of *Cannabis sativa* first occur on 85 cm depth, but only in small amounts: 0.825% (There is no *Humulus* curve and the author does not mention any methods for separation of the two *Cannabaceae* genus, so it is possible that the author has not made any separation between the two. It is therefore hard to say for sure that this is *Cannabis* and not *Humulus*, or a mix between the two). The sample level in which cannabis-type pollen first occur was dated to 1027 CE. At 73 cm depth, dated to 1165 CE, *C. sativa* pollen make up about 2% of the total terrestrial pollen. It is present alongside pollen from *Secale cereale.* In the overlying sample (70 cm depth, dated to 1199 CE) there is a decrease in C. *sativa* pollen to 0.951%. Upwards in the core *C. sativa* pollen remains under 1%, with only one exception: at 67 cm depth, dated to 1234 CE, where *C. sativa* makes up 1,349% of total land pollen. Pollen data from Vladar are presented in figure 1 (Pokorný et al. 2006).

### 3.4 Bulgaria

Lake Varna is approximately 13 km long and 1.2 wide, and located right by the Bulgarian coast of the Black sea. The lake is situated at sea level and was previously a closed lagoon. The max depth of Lake Varna is 19 meters and the average depth is 9.5 meters.

Several cores have been collected from different sites in the area. The core ARS1 (43°10'N, 27°48 ' E) was retrieved by divers from the middle of the lake. Additionally, the two cores POV1 and POV2 (43° 12'N, 27°40'E and 43°11'N, 27°39'E) were taken from the northern shore of the much smaller Lake Beloslav, which is located to the west of Lake Varna. Pollen data from ARS1 and POV2 are presented in figure 1. A chronology was established using radiocarbon dates.

First occurrence of cannabis-type pollen in core ARS1 is dated to 5428 BCE, however it is only about 0.4%, and therefore probably reflects wild *Humulus*. At 500 cm depth, dated to 4280 BCE, cannabis-type pollen makes up 2.192% and by 3823 BCE the curve peaks with 2.755%. Thereafter cannabis-type pollen decreases and never exceed values of 1.5% again. In the POV2 core cannabis-type pollen first occur at 730 cm depth, dated to 9743 BCE. At this depth the cannabis-type pollen makes up 1.157%. In this core cannabis-type pollen is generally lower than 1% (with a few exceptions) until it peaks with 2.727% by 1010 CE.

However, by 1114 CE cannabis-type pollen has decreased to 0.884%. Pollen data from Lake Varna and Lake Beloslav are presented in figure 1 (Bozilova & Beug 1994).

### 3.5 Italy

Lago Albano (41°45'N, 12°40'E) and Lago di Nemi (41°43'N, 12°42'E) are two lakes located in a volcanic complex about 25 km southeast of Rome, Italy. Both lakes are hydrologically closed basins and are situated approximately 300 meters above sea level. Lake Albano is larger, covering 6 $km^2$, compared to lake di Nemi which is about 1.8 $km^2$.

Two sediment cores were collected from the two lakes respectively, the 14-meter-long Albano core was collected from 70 meters water depth and the 9.15-meter-long Nemi core from about 30 meters depth. A total of 161 samples were selected for pollen analysis, collected with 10 cm interval. Approximately 600 pollen grains were counted from each sample and the results are expressed in total land pollen, excluding *Pinus* (Pine).

The cores were not suitable for AMS radiocarbon dating due to the lack of macrofossils. However, a chronology was established based on correlations with an earlier radiocarbon dated core from the area as well as paleomagnetic analysis, stratigraphy and tephra chronology.

Generous amounts of *Cannabaceae* pollen occur in both cores and these were separated into three categories*: Cannabis, Humulus* and *Cannabis/Humulus*, based on the morphology of the exine, pore protrusion and grain size. The first occurrence of cannabis-type pollen (*Cannabis/Humulus*) in the Albano core are from the late-glacial time period, about 11750 BCE. The first identified *Cannabis sativa* pollen follows shortly at 11450 BCE. *C. sativa* occur continuously in all the samples from approximately 6750 BCE and onwards, and peaks with 20% of total land pollen by 190 CE. There is a second peak of 18.5% by 780 CE and finally a third peak of 18.5%, dated to 1220 CE. After 1290 CE *C. sativa* decreased to insignificant values.

In the core from Lake Nemi cannabis-type pollen occur from about 9250 BCE, that is early Holocene. *C. sativa* is present from about 7000 BCE, but does not reach any high percentages until much later. *C. sativa* pollen peaks with 21% by 50 CE and later with 5% at 160 CE and 4% in a sample dated to 950 CE (Mercuri et al. 2002).

### 3.6 Poland

Czajkow study site (50°47'0" N, 21°17'0" E) is located in the north-eastern part of the Nida Basin in southern Poland. The landscape in the 8200 $km^2$ depression is characterised by numerous karst sink-holes.

Organic sediments were collected from 9 of the holes. The bottom of profile Czajkow 2 (500-510 cm) was radiocarbon dated to 9980 (±400) BCE. Subsamples for pollen analysis were collected with 5 cm interval. The results reflect the total terrestrial pollen sum and percentages are expressed in non-arboreal pollen + arboreal pollen (NAP + AP), where NAP reflects the sum of all sporomorphs excluding *Sphagnum.*

Profiles Czajkow 2 and Czajkow 4 are available as full data sets on EPD, however only Czajkow 2 is properly dated and calibrated. Cannabis-type pollen occur in small amounts (0.19%) from 490 cm depth in profile Czajkow 2, dated 7810 BCE. It is unclear if these finds are *Cannabis* or *Humulus* as the authors unsuccessfully attempted to separate the two by measuring grain diameters. Much higher up in the stratigraphy (85 cm), by 1099 CE, cannabis-type pollen reaches a value over 1% (1.57%) for the first time. Thereafter the curve hits values >2% a couple of times: 2.16% at 80 cm depth dated 1152 CE, 2.66% at 40 cm depth dated 1578 CE and 2.56% at 35 cm depth dated 1631 CE, before peaking with 3.08% at 30 cm depth, dated to 1631 CE. Between 1737-1837 CE the values vary between 1.79-2.57% and at 5 cm, dated 1950 CE, the value has decreased to 0.39%.

Profile Czajkow 4 shows similar percentages at the same depths but has a slightly higher peak (5.3%) at 30 cm. At sampling sites Czajkow 3 and Czajkow 5 exceptionally high percentages of cannabis-type pollen were found, 91.3% and 81.5%, together with fruits of *Cannabis sativa.* This event is synchronized with peaks in other cultivated plants. Pollen data from Czajkow 2 are presented in figure 1 (Szczepanek 1971).

Study site Cergowa Gora is located at the north-western slope of Mt. Cergowa (49°32′ N, 21°42′ E), in the Dukla Pass region of the Carpathian Mountains. In 1994, organic sediments were retrieved with a borer from a landslide depression, 495 meters above sea level. A total of 121 samples, 5 cm apart, were collected for palynological studies. In every sample a minimum of 500 pollen grains of: tree, shrub, herb and spores from *Sphagnum* and *Filicales* were counted.

Eleven samples were radiocarbon dated using $^{14}C$ dates to create a chronology. Cannabis-type pollen are first present in the stratigraphy with 0.12% on a depth of 525 cm, dated to 2699 BCE. At 125 cm depth, dated 1481 CE, the curve exceeds 1% for the first time. At 115 cm depth, dated 1521 CE, the content of cannabis-type pollen increased to 2.4%. Thereafter follows a decrease before the cannabis-type pollen reaches 2% again at 70 cm, dated 1701 CE. Another period follows with values <1%, until 40 cm depth, dated 1820 CE, where cannabis-type pollen make up 2.2%. From 40-20 cm all samples contain >2% cannabis-type pollen. At 25 cm depth, dated to 1880 CE, the curve peaks with 3.8%. Thereafter cannabis-type pollen decrease to 0.2% at the very top of the profile. Pollen data from Cergowa Gora are presented in figure 1 (Szczepanek 2001).

Wolin Island is the most north-western point of Poland. The 254 $km^2$ island was formed during the Littorina transgressions in the Holocene. Three sites;


*Fig 2.* The map shows the geographical positions of all the study sites included in this study (marked with red circles).

Kolczewo (mire), Wolin II (mire) and Lake Racze (kettle-hole lake) were selected and sampled with a Russian corer. The Lake Racze core were collected 80 meters off the southern shore.
From each site two profiles were retrieved and subsampled every 1, 2 or 5 cm and at least 1000 arboreal pollen grains were counted for each sample. The results are expressed in relative values where arboreal pollen, non-arboreal pollen and charcoal particles together make up 100%. A chronology was established using 26 $C^{14}$ dates.

Pollen grains of *Cannabis sativa* and *Humulus lupus* were separated based on morphological features of the porus and grain size. Small amounts of *C. sativa* pollen were found in Kolczewo samples dated to pre-Roman Iron age (approximately 1-500 BCE). A few grains of *C. sativa* were also found in the top of the Wolin II profiles. However, in the Lake Racze profile exceptionally large amounts of *C. sativa* pollen were found. In one sample, which was dated to 1320 (±80) BCE, pollen from *C. sativa* made up 40% of the total pollen sum (Latałowa 1992a; Latałowa 1992b).

Lake Lednica (52°33′N, 17°22′E) is a 3.48 $km^2$ large lake about 40 km northeast of Poznan, Poland. A 828 cm long core was collected from 990 cm water depth. Cannabis-type pollen occur from 660 cm depth but only in very low amounts: 0.165%. The presence of cannabis-type pollen is continuously low until 100 cm depth where it increases to 1.573%, and thereby exceeds 1% for the first time. This level was dated to 429 CE. Between 90-60 cm depth cannabis-type pollen are <1% again. At 50 cm depth the curve reaches a peak with 2.956%, dated to 775 CE, followed by another decrease. A second peak follows, in the very top layer of the core, dated to 1095 CE, where cannabis-type pollen reaches a value of 3.153% of the total pollen sum. Pollen data from Lake Lednica are presented in figure 1 (Makohonienko 1991).

## 3.7 England

Thorpe Bulmer is a farm situated about 10 kilometers north of York. The study site is a 100 meter wide depression, potentially a kettle-hole, located about a kilometer from the farm. Boring was done in the southern part of the basin. Pollen analysis revealed occurrence of cannabis-type and other cereals from 114 BCE.

Large amounts of cannabis-type pollen (19% of the total pollen sum) were found on 364-368 cm depth, which was radiocarbon dated to 220 CE. Thereafter followed a strong decline of cannabis-type pollen, with only small amounts present in the overlaying layers up until 1098 CE (Bartley et al. 1976).

Crose Mere is a shallow lake situated in glacial deposits six kilometer south of Ellesmere. A sediment core of 612 cm was collected from the deepest part of the lake, as well as a 120 cm core from the mud/water boundary. The cores were sampled for pollen analysis and 11 radiocarbon dates. A minimum of 500 pollen were counted for each pollen sample and the results are expressed in total land pollen + spores.

There were occasional finds of cannabis-type pollen from 400 cm depth, it is not clear whether these are finds of *Humulus* or *Cannabis*. Between 146 -11 cm depth the content of cannabis-type pollen exceeds 15% of total pollen sum. The cannabis-rich level was dated to 340(±75) CE – 895 (±72) CE (Beales 1980).

Muddymore pit (50°54'N, 0°56'E) is a natural pit located on the gravel beach of Dungeness foreland in south-east England. Overlapping sediment cores were obtained from the 50 x 75-meter basin and sampled for pollen analysis and radiocarbon dates. In every pollen sample a total of 300 terrestrial pollen grains were counted.

On 353 – 332 cm depth, in sediment consisting of organic mud, 80-90% of all land pollen counted were found to be *Cannabis sativa*. The pollen grains were identified as *C. sativa* and not *H. lupus* on the morphology of the pore structure and grain size. The cannabis-rich level was dated to 1020-1210 CE. At a depth of 332-283 cm the content of *C. sativa* decreased to 20%, dated to 1160-1250 CE. From 283–260 cm there is a further decline and above 266 cm *C. sativa* make up <2% of total land pollen. The decline of *C. sativa* coincides with the expansion of aquatic vegetation.

Muddymore pit has most likely been a place of hemp retting. Although the exceptional percentages of *C. sativa*, not a single achene was found. This could be explained by the use of male plants rather than female plants, since their fibres are more elastic and hence better for production of materials. Hemp retting likely took place here between 1000 – 1400 CE (Schofield & Waller 2005).

## 3.8 Scotland

Kilconquhar Loch is a shallow lake situated on the coastal plain north of Elie, Scotland. Black Loch is another lake situated in volcanic bedrock north of Fife. A 200 cm core and a 300 cm core were collected from the central parts of Kilconquhar Loch and Black Loch respectively and sampled for pollen analysis. 500 pollen grains were counted in each sample, and the results are expressed as total terrestrial pollen. Pollen grains of *C. sativa* were separated from *H. lupus* by the morphology of the pore protrusion. Due to the calcareous nature of the sediment cores, the radiocarbon dates established may be inaccurate.

Pollen of *C. sativa* first appears at 164 cm depth in the core from Kilconquhar Loch. The sample level at 154 – 159 cm was dated to 6910± 100 BP (4960±100 BCE). Pollen of *C. sativa* are thereafter continuously present in all samples until approximately 34 cm depth. The highest percentage measured for *C. sativa* in the core from Kilconquhar Loch was 8.6% of total terrestrial pollen. This sample level was dated to 2280±80 BP (330±80 BCE).

The base of the core from Black Loch was dated to 810 -1000 CE. Pollen from *C. sativa* occur with 3-4 % (peak 6.2%) in layers dated to 985-1160 CE. The taxa disappear completely after 1430-1520 CE (Edwards & Whittington 1990).

## 3.9 Germany

The study site Durchenbergried is a small kettle-hole mire located in the western part of the Lake Constance region. The study site is surrounded by wetlands and meadows. The pollen data comes from an 840 cm long peat profile which was obtained from the center of the mire. A chronology was established with radiocarbon dates.

Cannabis-type pollen is present in the stratigraphy from 552 cm depth, which was dated to 5767 BCE. However, cannabis-type pollen is only present in small quantities, generally around 0,2%, at this depth. The highest values measured was 2,55% at 50 cm depth, dated to 964 CE. At 47 cm depth, dated to 994, the amount of cannabis-type pollen has declined to 0.446%. Pollen data from Durchenbergried are presented in figure 1 (Rösch 1986).

Mindelsee (47°45′16″N, 9°01′20″E) is a glacial finger lake located on the Bodanrück peninsula which forms divides Lake Constance in two parts. The lake is small: 2.2 km long and approximately 570 meter wide, with a medium depth of 8.5 meter. The area surrounding Mindelsee is partly covered by forest and partly by wetlands and mires.

A sediment core was retrieved from the deepest part of the lake (13.5 meter) and the core was subsampled with 2-4 cm intervals. In total 220 samples were analysed and approximately 1500 terrestrial pollen grains were counted in each sample.

Cannabis-type pollen was present throughout the core (in 217 samples), but only in small quantities prior 675 CE. However, around 540 CE cannabis-type pollen begin to increase to reach values around 20% between 925-1050 CE. Following 1245 CE there is an even stronger increase and until 1750 CE cannabis-type pollen are present with values up to 40% of the total pollen sum. After 1750 CE there is a rapid decrease to insignificant values (Rösch 2013).

## 3.10 The Netherlands

Lake Uddelemeer (52°14'48"N, 5°45'40"E), in the centre of the Netherlands, is the only site in the country which constitutes a full record of the whole climate development and history since late glacial time. The sediment, which thickness exceed 15 meters, have been accumulating for approximately 14000 years.

Several cores were collected from the lake, where of one all the way down to the bottom (1500 cm depth) and one from the top of the substrate down to 67 cm. The cores were sampled every 20 or 10 cm and dated with radiocarbon dates and $^{210}$Pb. A total of 78 samples were selected from 0-1300 cm for palynological analysis and the results is a combination of pollen from trees, shrubs, Ericaceae and herbs.

Cannabis-type pollen is present in large quantities (almost 40%) from 1500 CE, however the increase started already around 900 CE. At present time (1950 CE), the cannabis-type pollen is present with approximately 10% (Engels et al. 2018).

### 3.11 Finland

Lake Kolmilaträsk (60°17'0" N, 20°9'0" E) is surrounded by swamps and fens on Åland island. The lake is about 320 x 160 meters and at most 3.7 meter deep. A sediment core was collected from the lake and sampled for palynological analysis every 5 cm. A total of 1000 arboreal pollen grains were counted for each sample. And the number of non-arboreal pollen + spores were counted for every 1000 arboreal pollen. *Juniperus* was excluded from the total pollen sum due to the large fluctuation of the taxa.

Cannabis-type pollen is present in low concentrations from the base of the core at 208 cm, dated 503 BCE. At 95 cm cannabis-type pollen suddenly increases to a maximum of 14-18% (the pollen data from EPD says 14%, article states 18%). This exceptionally rich horizon was dated to 829 CE. It was not established if these pollen grains belonged to *C. sativa* or *H. lupus*, however they were notably small (c. 17 µm).

On 90 cm depth, directly overlying the cannabis-rich level, cannabis-type pollen rapidly drops to 0.946%. The sample level representing the fast decrease was dated to 919 CE. Upwards in the core cannabis-type pollen is only present in values <1%, except for samples between 65-50 cm, where it reaches a small peak of 1.781%. This minor peak at 50 cm was dated to 1192 CE. Pollen data from Lake Kolmilaträsk are presented in figure 1 (Sarmaja—Korjonen et al. 1991).

Likolampi (62 °44' N, 31° 00' E) is a small kettle-hole lake in Illomantsi, eastern Finland. The deepest part of the basin has a water depth of 11 meter. The lake sediment was sampled for palynological studies down to a depth of 200 cm using a freeze corer and a peat sampler. A minimum of 500 pollen grains were counted for each sample.

The first occurrence of cannabis-type pollen was wound on 74 cm depth. At 50 cm depth cannabis-type pollen reaches a peak of nearly 30% of the total pollen sum. This sampling level, which also represents a notable change of environment as the earlier moss dominated debris is being replaced with an algal gyttja, was dated to 1590 CE. After the peak a gradual decline of the taxa follows in to the 1900s CE. Noteworthy is that Likolampi means “retting pond” in Finnish (Grönlund et al. 1986).

### 3.12 Denmark

Dallund Sø in north Funen in Denmark is a 15-ha lake with a maximum depth of 2.6 meter. The lake has a small catchment area which means the pollen data obtained from the study site reflects the local vegetation. Study methods included sediment coring, AMS $^{14}$C dating and subsampling for pollen and diatom analysis.

Cannabis-type pollen are present from levels dated to 380 CE. However, by 1100 CE the percentage of cannabis-type pollen starts increasing to reach three peaks: 10% by 1200 CE, 15% by 1500 CE and once again 10% by 1700 CE. By the beginning of the 1900s CE the cannabis-type pollen has decreased to insignificant values. Although cannabis-type pollen from 380-530 CE are relatively scarce, the scientists propose that the site might have been used for retting at this time. The presence of cannabis-type pollen in these horizons, together with results from diatom data indicating an increase in nutrient loading in the lake at this time suggests retting might have taken place (Bradshaw et al. 2005a; Bradshaw et al. 2005b).

Gundsømagle Sø is a shallow lake located on Zealand, about 25 km west of Copenhagen. Two sediment cores were collected from the lake and dated and correlated using $^{210}$Pb and $^{137}$Cs for recent sediment and pollen stratigraphy for older sediment, as $^{14}$C dating proved unsuitable. The cores were subsampled from 67 levels and a total of 1000 land pollen + spores were counted in each sample. The authors tried to separate *C. sativa* and *H. lupus,* hence cannabis-type pollen in this study only includes cannabis-type pollen with raised pores.

Samples dated to 400 CE – 600 CE as well as 1150 CE – 1800 CE were found to contain the highest percentages of cannabis-type pollen (about 5% of total land pollen + spores). In samples dated to 1900 CE, the cannabis-type pollen has declined to insignificant values (Rasmussen & Anderson 2005).

### 3.13 Sweden

Östra Ringarp (56° 16’N, 13°19E) is located 56 km northeast of Helsingborg, southern Sweden. The sampling location is a former lake located one kilometer southeast of Lake Hjälmsjön. Before being covered in dense vegetation in the last 200 years, the lake had an approximate diameter of 150 meter. The landscape around the study site is characterized by a gently hummocky terrain consisting of glaciofluvial deposits.

The former lake was sampled with a russian corer and revealed sediments dominated by gyttja (>6 meters), except for the uppermost 57 cm which consisted of peat. The border between the different deposits was dated to 1800 CE. The core was subsampled for pollen analysis and between 400-500 pollen grains were counted for each sample-level.

Cannabis-type pollen first occur in small amounts at 140 cm depth, dated to 500 CE. From 1000 CE there is an increase of cannabis-type pollen with values reaching around 5% of the total pollen sum, followed by a decline around 1800 CE. Cannabis-type pollen occur together with pollen of grass, cereal-type, *Secale*, *Hordeum*, *Triticum* and *Linum*, which reflect an agricultural landscape in the area during this time (Lagerås 2007).

Lake Bussjösjön (55°28’ N, 13°49 E) and Lake Krageholmssjön (55°30’ N, 13°45 E) are both located in the Ystad area in southern Sweden. The landscape surrounding the lakes is hummocky. Lake Krageholmssjön has an area of about 220 ha and a maximum water depth of 8 meter. Lake Bussjösjön had an area of 2 ha in early Holocene but is today only about 0.3 ha due to drainage of the whole catchment area that begun in the $19^{th}$ century.

In 1982 several cores were retrieved from Lake Krageholmssjön at 735 cm water-depth. Cores were collected from Lake Bussjösjön in 1984-85. Due to the hardwater effect the sediment from Krageholmssjön was not suitable for $^{14}$C-dating. Measurements of $^{210}$Pb and $^{137}$Cs were done in order to establish a time line for the past 150 years and the cores were correlated with earlier $^{14}$C dated profiles from the region based on pollen stratigraphy. The cores from Lake Krageholmssjön and Lake Bussjösjön were subsampled for pollen analysis and 1000 pollen were counted from each sampling-level.

Very high values of cannabis-type pollen are present on 550 – 300 cm depth in the profile from Lake Bussjösjön, which corresponds to approximately 650 CE – 1200 CE. The highest value measured is 65% of total pollen sum. The large amount of cannabis-type pollen was deposited in sediments consisting of a black sulphide gyttja. Cannabis-type pollen was also present in the cores from Lake Krageholmssjön, although in much smaller quantities (Regnéll 1989).

Lake Bjäresjön is just like Lake Bussjösjön and Lake Krageholmssjön located in a hummocky landscape in the Ystad region in southern Sweden. Pollen analysis of sediment samples collected from the lake revealed exceptionally large quantities of cannabis-type pollen in layers dated to 700 CE and 1000 CE. Between 600-900 CE cannabis-type pollen exceeds values of 40% of the total pollen sum. After 1000 CE the amount of cannabis-type pollen decreases, however it is still present in quantities around 10% of total pollen sum until 1500 CE (Gaillard et al. 1991).

Study site Skärpingsgölen is a small lake surrounded by coniferous forest, located 30 km north of Växjö. Around the lake several archaeological remnants from small homesteads and a farm have been found. In 2010 a core was collected from 760 cm water-depth in the lake. The 75 cm sediment profile was subsampled for pollen analysis (every 1-5.5 cm) and a chronology was established using radiocarbon dating on four macro fossils. Cannabis-type pollen occur almost throughout the whole core, although not in particularly high quantities until approximately 1200 CE. There is a peak of

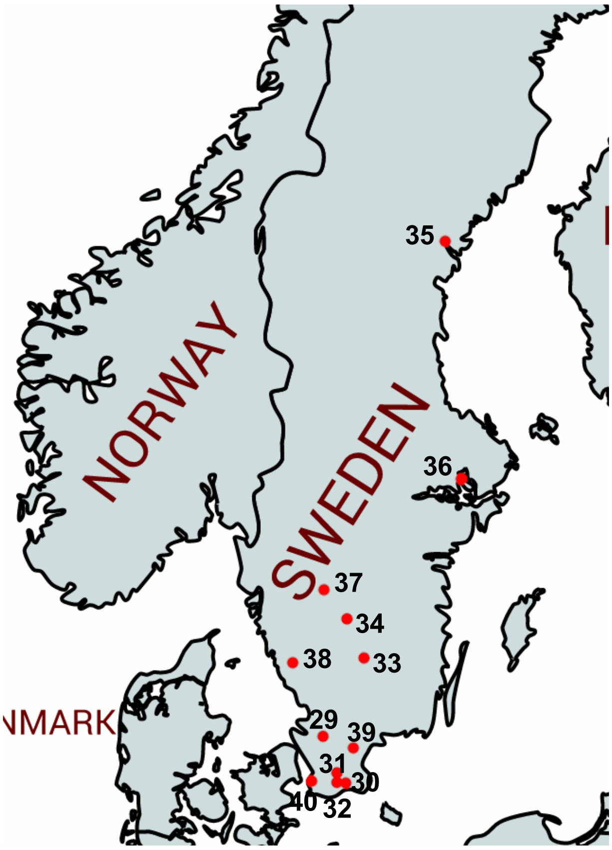


*Fig 3.* The map shows the geographical positions of all the study sites from Sweden (marked with red circles).

Cannabis-type pollen around 1300 CE, with values reaching 10% of the total pollen sum. Unpublished data from Skärpingsgölen are presented in figure 1 (Fredh et al. 2019).

The small lake Femtingagölen is situated in a valley in Småland, about 12 km southeast of Jönköping. The landscape and sediments surrounding the site are of glaciofluvial origin. From the deepest part of the lake, at 273 cm water depth, a 930 cm long sediment core was obtained, in parts of 100 cm with 20 cm overlap. The sediment was found to be dominated by gyttja, which was sampled for radiocarbon dating. The core was also subsampled for pollen analysis with 10 cm interval in the top 589 cm of the core, 20 cm between 589 – 660 cm and with 40 cm interval from 660 cm down to the very bottom of the core. At least 700 pollen grains were counted for each sampling level.

Cannabis-type pollen is present in the profile at levels dated to 1300-1400 CE to 1900 CE and reaches a maximum of 2% around 1300 CE (Lagerås 1996).

Close to the Ångermanälven river valley in northern Sweden four lakes were sampled for pollen analysis. In one of them, lake Ödetjärnen (62° 58’N, 17° 55’ E), Cannabis-type pollen makes up 2-3% of the total pollen sum in samples dated to 1200 – 1400 CE.

The chronology was established by counting the varves of the lake sediment and the pollen analysis was based on 63 subsamples. There was no attempt to separate *Cannabis sativa* and *Humulus lupus*. In the other three lakes in that was part of the study, Cannabis-type pollen occur in very small amounts only and was therefore interpreted as wild growing *Humulus*.

The author concludes that the pollen data from Ödetjärnen reflects cultivation of either *Cannabis* or *Humulus* (Wallin 1996).

The Ösbysjö lake (59° 24'N, 18° 4'E) is situated in a basin 400-meter-long and 180-meter-wide, north of Stockholm. A 500 cm long core was collected from the centre of the lake, from a water depth of 230 cm. The core was subsampled at levels 5-10 cm apart, except for the uppermost 15 cm where the samples were collected with only 2.5 cm spacing. A chronology was created using radio carbon dates.

The results of the pollen analysis are presented as percentages of the total arboreal pollen sum. In one core, cannabis-type pollen are present continuously from 200 cm depth to the very top. There is a notable increase at 120 cm and a peak at 85 cm where the amount of cannabis-type pollen exceeds 20%. The cannabis-type rich horizons are interpreted to be from the Viking age, ca. 800-900 CE (Fries 1962).

Klämmesjön, Spånsjön and Kroppsjön are three lakes located in the hilly landscape of Varnhem, in the region of Västergötaland. The area is exceptionally rich in archaeological remnants from Neolithic times. The study site is situated 120-135 meters above sea level and has not been covered by the ocean since late glacial time.

From Lake Klämmesjön a 600 cm long core, consisting of gyttja and peat, was obtained. From Lake Spånsjön a 1050 cm long profile consisting of rapidly deposited gyttja (10 m/5000 years) was collected, together with another core of 760 cm from a point 10 meter away.

Two cores, one of 750 cm and one of 865 cm were retrieved from Lake Kroppsjön. These also consisted mainly of gyttja, which likely have been deposited a little slower than the Kroppsjö-sediments (about 5m/5000 years).

The profiles were subsampled for pollen analysis and arboreal pollen, non-arboreal pollen and spores were counted. Pollen of cannabis-type are present throughout the profiles, but rarely exceeds 1% of arboreal pollen, except from certain layers in profiles from Lake Spånsjön and Lake Kroppsjön where exceptionally high values (up to 80%) of cannabis-type were discovered. These samples were directly overlying layers marked by expansion of *Picea,* which has been dated to 300-400 CE (Fries 1962).

Sänkemosse is a peat bog located in Yttra Berg, a nature reserve in southwest Sweden. The study site is situated in close vicinity to historical agricultural remnants. Stone piles in the surrounding forest and grassland are indicating that these lands once were cultivated, as the stones were moved to clear the fields.

A 292 cm peat core was retrieved from the middle of the 5,200 $m^2$ bog. A total of 39 samples were collected for pollen analysis, with 5 – 10 cm interval. For each sample at least 1000 pollen were counted, sometimes more in order to better reflect the non-arboreal pollen in layers where arboreal pollen was abundant. A chronology was established using radiocarbon dates on bulk samples of peat.

Cannabis-type pollen is present throughout the profile, mostly in low quantities. However, between 43 -23 cm depth there is a strong increase culminating in a peak of 40% of total pollen sum and an equally rapid decrease. This event has been dated to 1300 – 1500 CE (Sköld et al. 2010).

Lake Lyngsjön is located in the municipality of Kristianstad, in southern Sweden. The lake is approximately 2.7 meter deep (maximum depth is 6 meter) and is located 18 meters above sea level (Regnéll 1980). A sediment core of 690 cm was retrieved from the lake (501-1191 cm depth). Cannabis-type pollen occurs in a small fraction (<1%) from the bottom of the profile up to 781 cm depth. At 776 cm there is an increase of cannabis-type pollen to 5.3%, this sample level was dated to 761 CE. This marks the beginning of a rapid increase, which culminates in a peak of 24% at 706 cm depth. This peak was dated to 1184 CE. Thereafter, cannabis-type pollen slowly decreases to values around 10% by 1387 CE, and between 1504-1903 CE the values are even lower: between 3-2%. After 1903 CE the content of cannabis-type pollen are continuously lower than 0.5% in the stratigraphy. These are unpublished data, which are represented in figure 1.

Lindängelund is an excavation site in Malmö, southern Sweden. Archaeological remnants of early farming provide evidence that the site has been settled during two periods: 1-200 CE and 900-1100 CE. Soil samples were retrieved from two water filled pits and analysed for macro fossils and 5 samples were collected for pollen analysis. Fruits and stem fragments of *C. sativa* were found, and the fruit was radiocarbon dated to 20-220 CE. Two of the pollen samples revealed large amounts of cannabis-type pollen: 31.5% and 7.3%. It is likely that these reflects *C. sativa* rather than *H. lupus* due to the finds of plant material from *C. sativa.* These finds represent the earliest evidence for hemp-retting in Sweden (Larsson & Lagerås 2014).

# 4 Discussion

## 4.1 First ocurrence

The problematics regarding the separation of pollen from *H. lupus* and *C. sativa,* and the fact that few people even try to differentiate between the two, is making it difficult to say exactly when *C. sativa* was introduced to Europe. In only 9 out of the 13 datasets from EDP and 23 articles (+2 datasets obtained directly from the authors) the authors made attempts to separate the two taxa. This is not surprising as the pollen of the two taxa are incredibly hard to distinguish between, see figure 4. Even when authors have made the effort to distinguish between pollen of *C. sativa* and *H. lupus*, it is hard to know how accurately this separation has been done.

In cases where large quantities of cannabis-type pollen are recorded, especially together with macrofossils of *C. sativa*, we can be fairly certain that it is cultivated *C. sativa* we are looking at. However, the first occurrence of cannabis-type pollen from locations around Europe is generally in very small quantities, <1%, likely background values from a wild growing plant. These finds dates back to late Pleistocene (11750 BCE – Lake Albano, Italy), hence establishing a lower boundary for the introduction, with the inconvenient detail that these data may very well reflect wild growing *H. lupus* (Mercuri et al. 2002).

However, Mercuri et al. (2002) did attempt to separate the two taxa by carefully examined the morphological features of all recorded cannabis-type pollen at 1000x magnification. They report finds of pollen from *C. sativa* in samples from 11450 BCE. However, noteworthy is that they based the separation between *C. sativa* and *H. lupus* on the assumption that pollen of *C. sativa* generally display unraised pores, referring to a study by French& Moore (1986).

French& Moore (1986) compared pollen from modern populations of *C. sativa* and *H. lupus*, which were treated the same ways as fossil pollen. They found that *C. sativa* generally have raised pores and *H. lupus* in a higher grade have unraised pores. However, one of the populations of *C. sativa* pollen contradicted this result. This was explained by being due to swelling that occurs in the area between the pores, causing them to appear unraised, when pollen samples been subject to prolonged storage in glycerol jelly.

Hence, Mercuri et al. (2002) assumes this "swelling effect" as a standard when they separate the two taxa, which is potentially problematic. However, the separation was not entirely based on the morphology of the pores – but also on grain size, a method which also has proved problematic as there is a big overlap of sizes even though pollen of *C. sativa* generally are slightly larger (Whittington & Edwards 1989).

Nevertheless, Mercuri et al. (2002) are not the only ones willing to place the lower boundary of the introduction already back in the Pleistocene/Early Holocene. Long et al. (2016) argue that *Cannabis* has been a part of the native vegetation in Europe since early Holocene, based on results from a systematic review of palynological and archaeological records of *C. sativa* and cannabis-type pollen.

However, McPartland & Hegman (2017) address the problematics regarding misinterpretations of the archaeological record in a comprehensive study of 136 articles reporting cannabis-related finds (mainly achenes, seed impressions on pottery and fibres) from Europe. While evaluating the robustness of evidence from these studies, McPartland & Hegman (2017) concludes that many of the reports of archaeological finds are in fact most likely misinterpretations.

After analyzing evidence from the Neolithic (10,000-4500 BCE), mainly consisting of seed impressions on pottery, they reach the conclusion that Neolithic Europeans did neither cultivate nor domesticate *C. sativa.* This is coherent with the datasets included in my study, as they do not provide any evidence of cannabis cultivation from this time period.

The earliest archaeological evidence that was found trustworthy by McPartland & Hegman (2017) are hemp fibres from the Varna-region in Bulgaria. These finds were dated to 4200 BCE, which is consistent with the pollen data from Lake Varna: >2% cannabis-type pollen in a sample dated to 4280 BCE, which represent an increase in cannabis-type pollen with more than 100% from previous sample (Bozilova & Beug 1994). The fibres together with the increase in cannabis-type pollen is suggesting that people living in the region were cultivating cannabis.

## 4.2 Domestication

One of the main questions regarding the introduction of hemp to the European continent is the one concerning domestication. Earlier scholars favor the view of a single domestication event taking place somewhere in central Asia and a later expansion from the center of domestication to Europe by human agency (De Candolle 1883; Fleming & Clarke 1998).

But is it possible that *C. sativa,* like her sister *H. lupus,* spontaneously spread to Europe and started off as a wild growing component of the natural fauna, and later was domesticated a second time? McPartland et al. (2018) argue for a multiregional domestication theory in a recent study of pollen data from 479 already existing datasets dating back to Holocene/Late Pleistocene (+36 from samples predating Late Pleistocene time).

In order to get around the problem regarding the infrequent and often questionable separation of *C. sativa* and *H. lupus*, and in retrospect dissect the two taxa, they created an algorithm based on ecological proxies (fig 5.). The algorithm divides cannabis-type pollen into four groups: wild *Humulus*, wild *Cannabis*, cultivated *Cannabis* and undeterminable cannabis-type pollen, based on the pollen assemblages they occur alongside with.

Cannabis-type pollen which appears in the stratigraphy for the first time together with pollen from other crops like *Avena, Hordeum, Triticum, Secale*, Cerealia-type, or rapidly increase to quantities at least twice the amount of earlier counts, were identified as cultivated *Cannabis*.

Cannabis-type pollen occurring together with steppe species like Poaceae, *Artemisia* and Chenopodiaceae, and where arboreal pollen only made up 1/3 of the pollen sum (indicating an open, tree-less steppe landscape), were identified as wild-type *Cannabis*.

*Humulus* on the other hand, need trees to climb, and often occur in modern assemblages together with *Alnus, Salix* and *Populus*. Hence, cannabis-type pollen present in assemblages together with pollen from these taxa, and where arboreal pollen exceeds non arboreal pollen with 2:1 ratio, were identified as wild *Humulus lupus*.

Since the interpretation of the cannabis-type pollen in the algorithm is (partially) based on the AP/NAP ratio (arboreal pollen/non-arboreal pollen), the oscillation of species between the stadials and interstadials of the Pleistocene are replicated in the result. This means that the cannabis-type pollen present with the typical steppe vegetation of stadials are interpreted as wild *Cannabis* and the cannabis-type pollen present alongside the tree-dominated vegetation of interstadials are interpreted as *Humulus*. Hence, these interpretations are highly biased.

According to the algorithm *Cannabis* has been present in Europe since the Last Glacial Maximum. This might seem both assumptious and unlikely, however this hypothesis gets support from a recent genetic study by Zhang et al. (2018). In this study 645 individuals of Cannabis from both wild and domesticated populations from around the world were genetically analyzed. The results revealed that *C. sativa* diverged into three separate genetic lineages at 2.24 Mya, interestingly synchronized with the Pleistocene glaciation.

These lineages represent different genotypes: Low-latitude *C. sativa*, Mid-latitude *C. sativa* and High-latitude *C. sativa*, which perfectly matches the division of *Cannabis* into the three subspecies: ssp. *indica*, ssp. *sativa* and ssp. *ruderalis*. The L-latitude group, i.e. *C. sativa* ssp. *indica* was found to be the basal group, which places the center of origin south of 30° N, possibly on the Indian sub-continent or in southeast Asia.

However, the cultivated populations of *Cannabis* were not limited to one of the three groups, which provides strong evidence that *C. sativa* has been domesticated several times. The fact that *Cannabis* split into three groups at the time of the Pleistocene glaciation, might not be a coincidence. Maybe the glaciation in fact was a driving factor, causing allopatric separation resulting in the three subspecies (Zhang et al. 2018). The oldest fossil pollen from Europe interpreted as *Cannabis* by the algorithm created by McPartland et al. (2018) is from 1.8 Mya.

Assuming the multiregional domestication approach supported by McPartland et al. (2018), Long et al. (2016) and Zhang et al. (2018) is true, and *Cannabis* is in fact indigenous to Europe and was domesticated there as well as in Asia, the question remains: by whom and where?

As mentioned earlier, the oldest robust evidence of

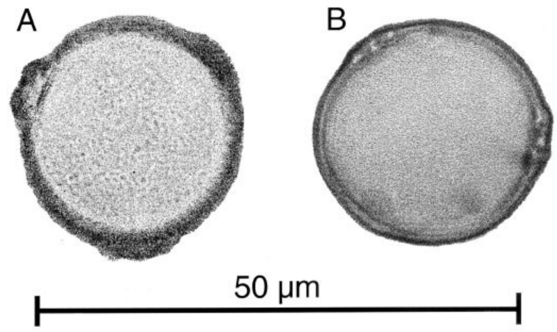


*Fig 4.* A: Pollen grain of *Cannabis sativa* (hemp), B: pollen grain of *Humulus lupus* (hops). Distinguishing between pollen of the two taxa is very problematic as they look very similar (Fleming & Clarke 1998).

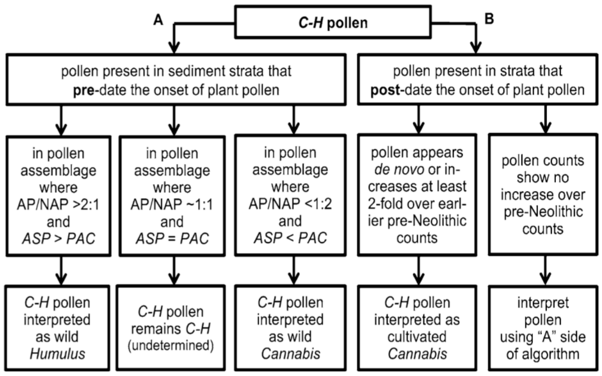


*Fig 5.* McPartland et al. (2018) created this algorithm for retrospective separation between pollen of cultivated *C. sativa,* wild *C. sativa* and *H. lupus.* The algorithm is based on the modern pollen assemblages typical for *C. sativa* and *H. lupus (*PAC: Poaceae, *Artemisia* and Chenopodiaceae; ASP: *Alnus, Salix, Populus )* as well as the arboreal/non-arboreal ratio (AP/NAP). The AP/NAP ratio is relevant as *C. sativa* prefer open steppe vegetation while *H. lupus* on the contrary need trees to climb.

cultivated hemp from Europe appears to be the cannabis-type pollen (dated to 4280 BCE) and hemp fibres (dated to 4200 BCE) from the Varna region in Bulgaria (Bozilova & Beug 1994; McPartland & Hegman 2017). Except for the Varna-site there are no signs of cultivation from the 45 study sites included in my research until 577 BCE. However, McPartland& Hegman (2017) reports reliable remnants from the Yamnaya culture in Urkaine from 3500-2300 BCE as well as cystolithic trichomes from a grave from the Catacomb culture in southern Russia from 2800-2200 BCE.

Most likely cultivation was initiated in south eastern Europe and then expanded from there, alternatively domestication of wild growing hemp occurred several times in different locations. McPartland & Hegman (2017) credits the Scynthians, who migrated from Asia to the Pontic steppe, for the expansion of hemp to Celtic, Slavic and Finno-Ugric cultures. Herodotus (ca. 450 BCE) confirms Scynthian cultivation of *Cannabis* and also provides a description of the Scynthian practice of inhaling the smoke of burned *Cannabis,* which caused an altered state of consciousness (Long et al. 2016).

By 557 BCE cultivation had begun at study site Vracov in the Czech Republic. No other locations from my study show signs of cultivation (i.e. cannabis-type pollen >2%) from this time. However, McPartland et al. (2018) reports trustworthy macrofossils (mainly fabric and seeds) from Austria, Germany, Switzerland, France, Hungary, Czech Republic, Slovakia and Romania from 800-50 BCE.

There are also early finds of fibres from Scotland, which after measuring the diameters appeared to be more like hemp than flax. These finds were dated to 800 BCE, which makes it one of the earliest finds from Northern Europe together with hemp fibres from southwest Germany dated to 500 BCE (Körber-Grohne 1988; Ryder 1999). Macrofossils in the form of textiles and fibres are evidence for use of hemp, but they do not provide evidence for cultivation in the area (Larsson & Lagerås 2014).

From around 100 BCE the pollen data shows how hemp cultivation had expanded to western Europe (figure 1). Cultivation had now begun in France and Switzerland. The earliest finds from Sweden (achene, stem material and pollen) are those from study site Lindängelund in southern Sweden. These finds were dated to 20-220 CE (Larsson & Lagerås 2014). Thus, hemp cultivation had expanded all the way to northern Europe and Scandinavia at this time.
From ca. 700 CE there is a notable increase of cultivation in almost all regions displayed in the diagram. Hemp cultivation was also initiated in the Lake Constance region in Germany around this time. In the time period between 800-1400 CE there seem to have been a synchronized intensification of cultivation all over Europe. This is the time period where cultivation peaks in almost all study sites from the EPD, as well as from the literature. However, France and Italy might have experienced an earlier peak and decline, in the first couple of centuries CE. This might very well reflect the expansion and decline of the Roman Empire. However, this is hard to determine from this study alone, as the early peak only is obvious in data from a few sites.

Most of the studies from Sweden indicate that the most extensive hemp cultivation took place between 800-1400 CE there as well. However, data from two of the sites peak much earlier; at 20-300 CE, which suggests hemp was continuously cultivated in the region for at least 1400 years. According to Skoglund et al. (2013) we need to reconsider the role hemp has played in Scandinavian cultural history. After analysing several Swedish ornamental textiles from the Viking and Middle ages, which previously were believed to be made of flax fibres, they found these fabrics in fact were made of hemp. This contradicts the belief that hemp mainly was used to make coarser materials like ropes and sail cloths and indicates that hemp fibres were used for production of fine household textiles as well (Skoglund et al. 2013).

### 4.3 Retting

During the time of intensive hemp farming in Europe, many of the study sites display extraordinarily high levels of cannabis-type pollen (up to 80% of the total pollen sum). Pollen percentages this high cannot solely be explained by wind deposition, -but are strong evidence that hemp retting has taken place at these locations.

Retting is a traditional practice of fibre extraction which involves submerging bundles of stems in water, preferably small ponds of standing water. Boulders or logs would then be placed on top of the stems to keep them below surface (Bradshaw et al. 1981). The plants would be submerged for several weeks at a time, which resulted in microbial processes breaking down the cellular tissues so the residual fibres could easily be extracted from the core of the stems.

In absence of standing water, retting could take place in rivers or by spreading the stems on fields where the dew would initiate the retting process (Larsson & Lagerås 2014). Male plants were favoured for fibre production, which both explains the incredible abundance of pollen and the absence of achenes from many of the study sites (Mercuri et al. 2002).

The practice of retting has been reported to have a considerable impact on the surrounding environment by polluting the water in which the plants were submerged, as well as creating a revolting odour (French & Moore 1986; Edwards & Whittington 1990). Perhaps because of this, hemp retting was moved away from the settlements to the shores of larger lakes. However, this would have slowed down the retting process because of the colder water temperature in larger lakes (Larsson & Lagerås 2014).

The unnaturally large accumulation of plant material in the lakes used for retting resulted in eutrophication, which in many cases drastically changed the ecosystems (Bradshaw et al. 2005b). Oxygen deficiency and an increased sedimentation rate of poorly decomposed organic material are examples of environmental change due to nutrient loading into the small water bodies (Grönlund et al. 1986).

### 4.4 Modern cultivation

Between 1850-1880 CE hemp cultivation ceased simultaneously around Europe (see figure 1). This abrupt decline coincides with the rapid global expansion of the cotton industry, a result of new inventions of the industrial revolution which made production cheaper and more efficient (Lavrieux et al. 2013). Hemp suddenly went from being one of the main European fibre crops, used in large scale for textiles, rope and canvas, -to being mainly (>95%) used for bible paper, bank notes and cigarette pulps.

Although industrial hemp was somewhat rediscovered in the 1990s, pulps and paper are still the main market for hemp fibres in Europe (Carus 2017). Cotton on the other hand, represent 30-40% of world textile production today, while hemp only represent 0.15%.

From a sustainability perspective it would be preferable if the roles reversed as hemp use less than half the amount of water and land to produce the same amount of fibre, and does not require the extensive use of pesticides that cotton does (Cherrett et al. 2005).

Hemp could also be a good alternative for production of renewable energy according to a Swedish study from 2011, which analysed the benefits of cultivating hemp for biofuel production. The study showed that the methane yield from anaerobic digestion of hemp was higher than that of both ethanol made from wheat and bio diesel made from rapeseed (Kreuger et al. 2011) Except for being environmentally friendly, hemp is a very versatile plant and the demand for the highly nutritious hemp seeds are on the rise as this superfood is gaining more popularity in Europe. Currently the European demand is larger than the supply and 10,000 tonnes of hemp seeds were imported in 2015, mainly from China. The market for hemp seed has huge potential in Europe, but legislation is delaying the progress. The same is true for Cannabidol-products (CBD), a non psycho-tropic cannabinoid which has been proved to have great health effects (Carus 2017). However, Bulgaria recently became the first country in the EU to allow free sales of CBD products (Hasse 2019).

# 5 Conclusions

The large amount of pollen data from Europe provides a decent record for the cultivation history of hemp albeit the problematics regarding the separation of *C. sativa* and *H. lupus*.

The earlier belief that hemp was domesticated in a single event in Asia and later brought to Europe by human agency is today challenged. A new multi-regional domestication approach is emerging and gains support from both pollen studies and genetic studies. This theory favors the view that hemp spontaneously expanded to Europe and thus should be regarded as a natural part of the flora. It is possible that domestication of hemp arose independently in several places in Europe.

Study sites from the Varna-region in Bulgaria display both a substantial increase in cannabis-type pollen and remnants of hemp fibres from ca. 4200 BCE, representing some of the earliest finds from Europe indicative of cultivation. However, trustworthy finds from this time period are rare. Clear signs of European cultivation appear in the pollen record from 500-600 BCE from southeast Europe. A prominent increase began around 700 CE, at this time cultivation had spread all over Europe. The earliest evidence of hemp cultivation from Sweden are from 20 CE. The most intensive period of cultivation took place between 800-1400 CE. During this time hemp retting was common all over Europe, which is signposted by high abundance (>80%) of *C. sativa* pollen in the stratigraphies.

In the late 1800s the cultivation of hemp experienced a strong decline as cotton production expanded, fueled by new inventions of the industrial revolution. Today hemp fibres only account for a tiny fraction of the European textile production, while cotton still holds a strong position on the market. However, it looks like hemp might come back in fashion soon, as its diverse range of benefits as a sustainable fibre crop, food source, medicinal plant and potential biofuel are getting more attention in both media and in the scientific community.

The European history of hemp cultivation might be longer than we earlier thought. However, it is problematic that we must rely on imprecise practices for separation of *C. sativa* and *H. lupus,* as well as biased algorithms because of the absence of separation altogether. Further macrofossil studies as well as DNA-studies of pollen would be to prefer, in order to once and for all determine how long hemp has been a part of the European flora and culture.

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