Holocene Vegetation and Land Use History in the Northern Vosges (France)

Dirk Sudhaus, Arne Friedmann

Abstract: A radiocarbon-dated peat profile from Rond Pertuis supérieure mire in the uplands of the Northern Vosges is studied using palynological methods. The profile dates from the middle Atlantic period (4500–3100 B.C.) to recent times.

During the middle of the Atlantic period an oak forest rich in pine covered the Northern Vosges. Fir and beech immigrated at the end of the Atlantic leading to the decline of oak and pine in the forest. This also marked the onset of decisive human influence on the development of the terrestrial vegetation.

Five land use phases were detected, the first one at the end of the Neolithic period (~4000–2200 B.C.). Subsequently, continuous land use is evident from the Bronze Age (2200–800 B.C.) up to now. In the late Middle Ages (A.D. 900–1500) and the early Modern Era (since A.D. 1500), the woodlands were completely altered by human activities. During the 19th century modern forestry introduced spruce into the investigated area in the Northern Vosges. Spruce afforestation then accelerated in the middle of the 20th century.

Holozäne Vegetation und Landnutzungsgeschichte in den Nordvogesen (Frankreich)

Kurzfassung: Für das in den Nordvogesen liegende Moor Rond Pertuis supérieure wurde ein mit der ¹⁴C-Methode datiertes Pollenprofil erstellt. Das Profil umfasst einen Zeitraum vom mittleren Atlantikum (4500–3100 Jahre v. Chr.) bis heute.

Während der Mitte des Atlantikums bedeckte ein kiefernreicher Eichenmischwald die Nordvogesen. Tanne und Buche wanderten am Ende des Atlantikums ein und führten zu einem Rückgang des Eichen- und Kiefernwaldes. Zu dieser Zeit begann auch der maßgebliche menschliche Einfluss in die Vegetationsentwicklung.

Fünf Landnutzungsphasen konnten differenziert werden, die Erste am Ende des Neolithikums (~4000–2200 v. Chr.). Von der Bronzezeit an (2200–800 v. Chr.) bis in heutige Zeit ist eine kontinuierliche Landnutzung nachweisbar.

Im Spätmittelalter (900–1500 n. Chr.) und der Neuzeit (1500 n. Chr. bis heute) haben sich die Wälder durch die Nutzung vollständig verändert. Im 19. Jahrhundert ist die Fichte in das Untersuchungsgebiet in den Nordvogesen eingeführt worden. In der Mitte des 20. Jahrhunderts wurde die Fichtenaufforstung forciert.

Keywords: *Pollen analysis, Holocene, Human Impact, Northern Vosges, France*

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1 Introduction

The vegetation history of the Northern Vosges is known through some older pollen studies, which lack chronostratigraphic control. Radiocarbon-dated studies have been limited to the Southern High Vosges (e.g. Janssen et al. 1972, 1975, de Valk 1981, Edelman 1985, Kalis 1985, Kalis et al. 2006).

The following studies are available from the Northern Vosges: The Col de Prayé site was examined by Hatt in 1937 and covers the periods from the Boreal to the Sub-Atlantic, but the sample and taxonomic resolution is low, incorporating only six samples over 175cm, and with only six tree species identified. Hatt (1937) also analysed the Soutte bog, the Champ du Feu and the Maxe bog. The Champ du Feu bog was also analysed by Bunnik (1978) as well as the Col

de Prayé. The investigations of Firbas et al. (1948) at the Maxe bog cover the period from the Pre-Boreal to the Sub-Atlantic; Gevelaar's (1982) investigation covers only the Late Glacial period, as does the study of Walter-Simonnet et al. (2008), who also studied the tephra in this bog. Firbas et al. (1948) published two undated pollen diagrams from the Northern Vosges: Hochfeld (Champ du Feu) and Schneeberg. The first results of the Rond Pertuis supérieure analysis presented in this study were published by Sudhaus (2005).

The main features of the Holocene vegetation history are available from these older investigations, particularly the Maxe bog analysis. The younger part of the Holocene period, however, is not represented in this record, because of a hiatus in the profile. Hence, land use history is difficult to reconstruct in detail due to sparse data without independent chronologies.
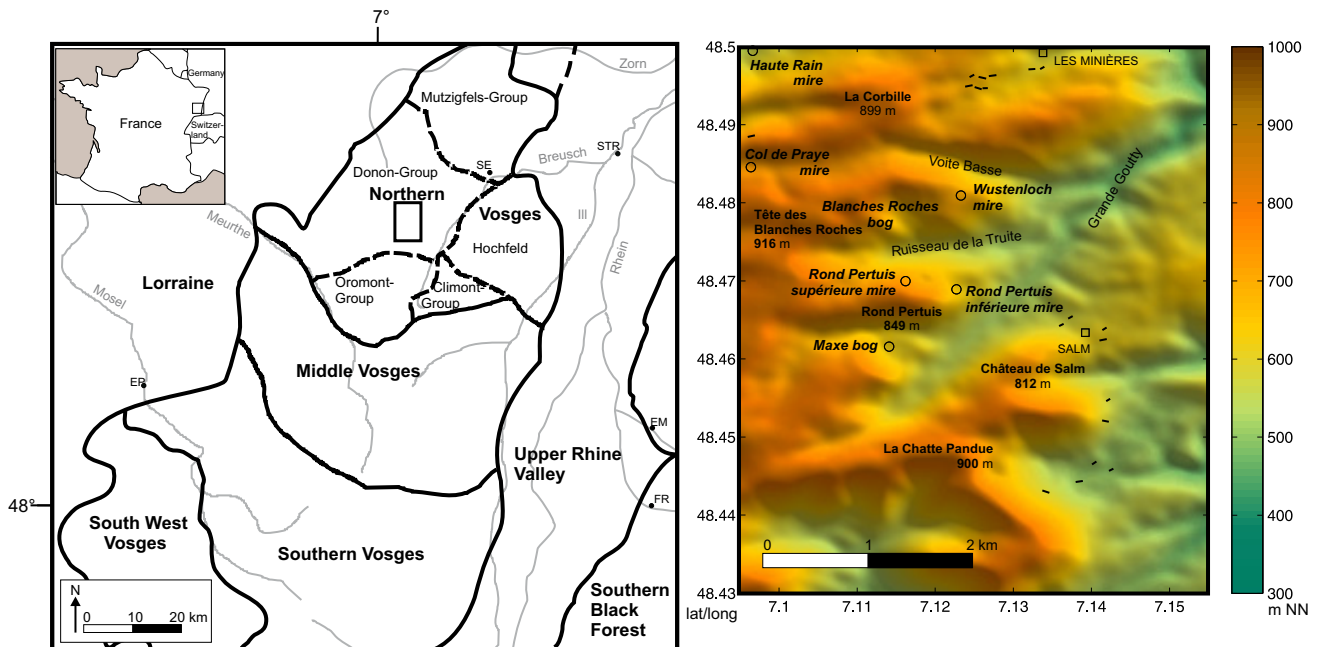
Fig. 1: Natural units of the investigation area and locations of the investigated bog (modified after FREY 1965, BREUNING 1998 and SELL et al. 1998, altidues: JARVIS et al. 2008), STR = Strasbourg, SE = Schirmeck, EP = Epinal, Em = Emmendingen, FR = Freiburg.

Abb. 1: Naturräumliche Einheiten des Untersuchungsgebiets und Standorte der untersuchten Moore (nach FREY 1965, BREUNING 1998 und SELL et al. 1998, Höhendaten: JARVIS et al. 2008), STR = Straßburg, SE = Schirmeck, EP = Epinal, Em = Emmendingen, FR = Freiburg.

In order to better understand the natural vegetation development and the impact of anthropogenic activity, more detailed regional palaeoenvironmental records with sufficient dating precision are needed. Here we aim to reconstruct the vegetation history based on a palynological analysis of the bog Rond Pertuis supérieure (Donon Mountain Range), southwest of Strasbourg near Schirmeck (Fig. 1), with an emphasis on reconstructing past human impact on the environment. Little is known about ancient settlements in this upland. Palaeoecological studies can provide insight into the settlement history in this area, identifying and timing agricultural activities and land cover changes. Furthermore a comparison of the later Holocene vegetation development in the Northern Vosges with the Southern Vosges and the Black Forest is given.

2 Study area

Mount Rond Pertuis is located at the head of the river Breusch catchment, which is situated within the Donon-Group (Northern Vosges, Fig. 1). The bedrock is formed by lower-Triassic reddish sandstones (Buntsandstein) and the common soils in that area are Cambisols and Podzols. The annual precipitation equals 1600mm and the mean annual temperature is around 7°C (REKLIP 1995). The actual vegetation is dominated by spruce stands that replace the natural beech-fir forests. In the Breusch Valley the forest is dominated by *Quercus petraea* (sessile oak) (TIMBAL 1985).

Generally the Northern Vosges have a low mire density, but in the study area several small bogs are located (Fig. 1). The best known is the Marais de la Maxe (Maxe bog), first palynologically examined by FIRBAS et al. (1948). The majority of bogs are shallow and developed in glacial cirques. Besides the Maxe bog the deepest bog is the Rond Pertuis supérieure with a depth of more than 3 m. All bogs are par-

tially drained and/or afforested with *Picea abies* (Norway spruce).

The bog developed in a northward-oriented glacial cirque. The actual surface vegetation of the Rond Pertuis supérieure bog (690 m a.s.l., 48.46487 N, 7.12626 E) consists of *Sphagnum* spp. (peat moss), *Eriophorum* spp. (cotton grass) and other Cyperaceae (sedges). Some parts of the bog are dominated by *Drosera rotundifolia* (common sundew), and *Picea abies* and *Betula pubescens* (white birch) are advancing in the southern part of the bog. In the 1970s the bog was dominated by *Sphagnum*/*Polytrichum* (haircap moss). The *Sphagnum spp.* mosses are in decline on all of the described bogs (SELL et al. 1998). This decline is probably caused by reduced water supply and enhanced shading as a consequence of the expansion of trees on the bog surfaces. Currently the bog is surrounded by a *Picea abies*-dominated forest.

A Neolithic settlement has been identified by archeologists at the Donon hilltop, about 5 km to the north of the investigation area. There were also findings from the Iron Age and Roman period, when the site was used as a place of worship (CZARNOWSKY 1947, LINCKENHELD 1947). This shows that the mountain area was visited or settled during these times, but evidence, however, is scarce.

Several tumuli in the Breusch Valley were built during the Metal Ages (LASSERE 2007). A permanent settlement was supported by monasteries in the Breusch Valley from the 6th century onwards, and further settlers arrived in the 10th century. From the 13th to the 19th centuries iron mining was an important regional factor in the upper Breusch Valley nearby, but because of long-lasting wars in Alsace, mining was interrupted in the 17th century (MÜLLER 1905). Mining was most intensive in the 16th century (GARNIER 2000). In the 18th century textile industries were the driving force for settlement in the Vosges.

3 Material and methods

From the Rond Pertuis supérieure bog a 300 cm peat profile was taken with a Russian peat corer at the deepest part of the bog. The profile is situated towards the wall of the cirque. The lowest 60 cms at the bottom showed bad pollen preservation and were not analysed further. The description of the lithostratigraphy follows Sponagel (2005).

Pollen analysis was performed with a sub-sampling interval of 4 cm. The samples were processed using standard techniques (adjusted according to Fægri and Iversen 1989), with HCl, KOH, acetolysis, HF and ultrasonic sieving. Pollen grains were identified with the aid of keys (e.g. Fægri & Iversen 1989, Moore et al. 1991, Beug 2004), photographs (Reille 1992), a modern reference pollen collection from Central Europe, and using a microscope with 400−1000 times magnification and phase contrast. Pollen percentages in the diagrams are calculated on a total pollen sum of terrestrial pollen excluding all local types from bog, aquatic and wetland species, *Betula,* and all ecologically indifferent pollen types like Cyperaceae and *Calluna vulgaris* (heather). Regional pollen assemblage zones (RPAZ) were defined with the aid of CONISS (Grimm 1987) and based on the terrestrial pollen percentages, excluding the pollen types mentioned above. The additionally shown land use phases (LUP) are based on visual inspection.

Pollen and charcoal concentrations were determined by adding a known amount of *Lycopodium* spores (Stockmarr 1971). Only charcoal pieces larger than 38 µm have been counted, because these can be correlated with local fires (Clark et al. 1989). A time control for the sequence was established using six radiocarbon age determinations on bulk samples. The radiocarbon ages were calibrated against the IntCal09 northern hemisphere calibration curve (Reimer et al. 2009) with the OxCal online system (http://c14.arch. ox.ac.uk/) (Table 1). Pollen accumulation rates were calculated with psimpol 4.27 (Bennett 2009), using a linear interpolation between the available ^{14}C-dates.

4 Results
4.1 Lithostratigraphy and pollen accumulation rates

The Rond Pertuis supérieure peat profile is underlain by sand (Fig. 2). The lowest layer of the peaty sapropel indicates a limnic origin of the bog. Therefore the Rond Pertuis supérieure is a terrestrialisation bog. Peat growth started with swamp peat in the Atlantic period, as indicated by the deepest radiocarbon date of 245 cm depth (6205−5925 B.C., Table 1).

From the Sub-Boreal period (3100−800 B.C.) onwards, at 210−10cm coring depth, sedge peat and dwarf-shrub peat alternate. During most of the Sub-Atlantic period (800 B.C.−today) dwarf-shrub peat was formed. The uppermost section of the bog is made up of a thin layer of *Sphagnum* peat, indicating recent acidification and the transition to ombrotrophic bog conditions.

The linear model between the ^{14}C ages, as shown in Fig. 2, suggests a very high peat growth during the Sub-Bo-
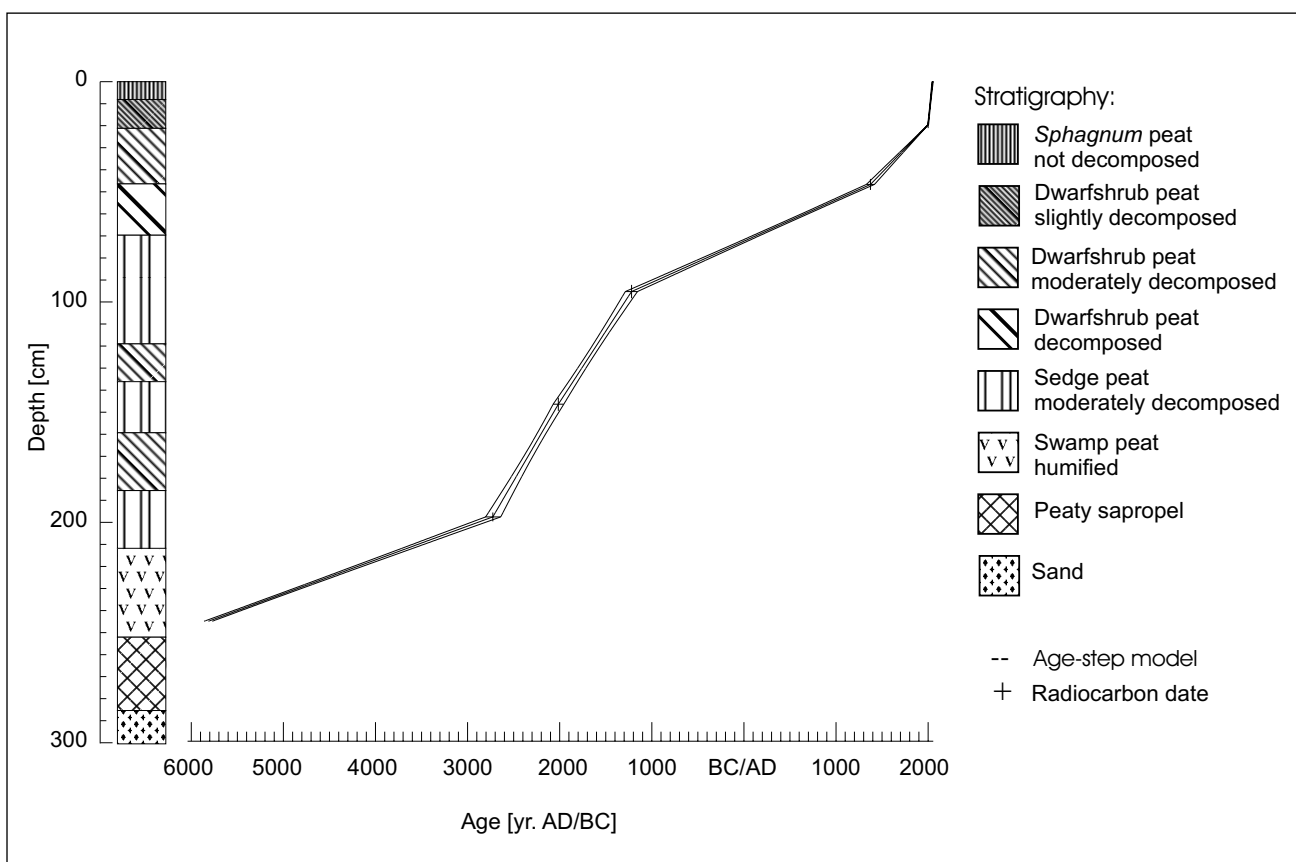

Fig. 2: Stratigraphy and age depth model for the Rond Pertuis supérieure profile. Stratigraphy legend also applies to the presented pollen diagrams (Fig. 3).

Abb. 2: Stratigrafie und Alter-Tiefe-Modell für das Bohrprofil aus dem Rond Pertuis supérieure. Gleichzeitig Legende der Stratigrafie im Pollen-Diagramm (Abb. 3).

Depth [cm surface]	Laboratory sample No.	¹⁴C-date BP	2 σ date AD/BC	Sample substratum
18–21	Hd-23583	modern	modern	dwarfshrub peat
44–49	Hd-23581	677±53	AD 1255–1405	dwarfshrub peat
92–98	Hd-23564	3016±35	1390–1130 BC	sedge peat
143–149	Hd-23565	3679±36	2195–1950 BC	sedge peat
195–199	Hd-23582	4197±58	2910–2620 BC	sedge peat
245–249	Hd-23586	7173±45	6205–5925 BC	swamp peat

real period (Sudhaus 2005). This results in relatively high pollen accumulation rates during this time (Fig. 4). Lower pollen accumulation rates for the Sub-Atlantic period are given by a general line-fitting, but with regard to the whole diagram, the linear model used results in the most plausible pollen accumulation rates. Overall, the pollen accumulation rates do not vary greatly.

4.2 Pollen stratigraphy

The pollen stratigraphy within the profile of Rond Pertuis supérieure stretches from the middle of the Atlantic period to the present time (Fig. 3a and b). Four regional pollen assemblage zones (RPAZ, Table 2) were distinguished.

RPAZ 1 (240–218cm): *Quercetum mixtum – Corylus – Pinus*, middle Atlantic period.

A mixed oak forest also rich in *Pinus* (pine) and *Corylus* (hazel) covered the area during RPAZ 1. *Abies* (fir) and *Fagus* (beech) pollen appear simultaneously at the end of RPAZ 1.

RPAZ 2 (218–134cm): *Abies – Fagus*, late Atlantic to middle Sub-Boreal period.

The pollen values of *Quercus*, *Pinus* and *Corylus* decrease after the appearance of *Fagus* and *Abies*. This decrease is also visible in the pollen accumulation rates diagram and is accompanied by a decrease of the total influx sum (Fig. 4). The pollen abundance of *Fagus* rises slowly and more continuously compared to *Abies*, and accumulates slowly and constantly. *Abies* values decline immediately after the initial rise, and this is also reflected in the accumulation rates, and in the varying abundance, including two further

maxima around 45%. The increase of the *Fagus* values continues until the middle of the Sub-Boreal period, where *Fagus* becomes the dominant pollen type. At the beginning of RPAZ 2 the abundance of Poaceae (grasses) and some herbs increases. In the middle of RPAZ 2 the first Cerealia (cereals) pollen type, *Hordeum* type (inter alia barley), was found, accompanied with rising values for non-arboreal pollen (NAP).

At the end of RPAZ 2 the *Abies* percentages show a sharp decline, while the *Fagus*, *Corylus* and *Pinus* abundances increase.

RPAZ 3 (134–42cm): *Fagus – Abies – Pinus*, middle Sub-Boreal to middle Sub-Atlantic period.

The *Pinus* values remain elevated, while *Abies* remains at a level around 20%. *Plantago lanceolata* (ribwort plantain) is almost continuously evident during this RPAZ. *Carpinus* (hornbeam) pollen was detected from the middle of RPAZ 3 onwards. From then on *Artemisia* (mugwort etc.) pollen were found almost continuously and the *Plantago lanceolata* curve increases. At the end of RPAZ 3 *Pinus* abundance decreases to a very low level, while the *Corylus* pollen influx increases (Fig. 4).

RPAZ 4 (42–0cm): (*Picea –*) *Pinus* – NAP (non-arboreal pollen), late Sub-Atlantic period.

At the beginning of RPAZ 4 *Quercus* values are higher than before. *Pinus* pollen at first has a low representation but then rises right up until recent times. In the middle of RPAZ 4, when *Quercus* levels fall, *Abies* increases first but decreases afterwards, while the pollen percentages of *Fagus* remain at a low level. *Betula* and *Corylus* frequencies rise. In the second part of RPAZ 4 *Picea* shows increasing values.

PAZ	Dominant pollen types	Depth in cm	Boundary	
			Rise	Decline
4	[*Picea –*] *Pinus* – NAP	42–0	*Corylus*, NAP and *Quercus* *Pinus* *Abies* and *Fagus*	*Pinus* and *Abies*
3	*Fagus – Abies – Pinus*	134–42		
2	*Abies – Fagus*	218–144		QM
1	Quercetum mixtum – *Corylus – Pinus*	240–218		
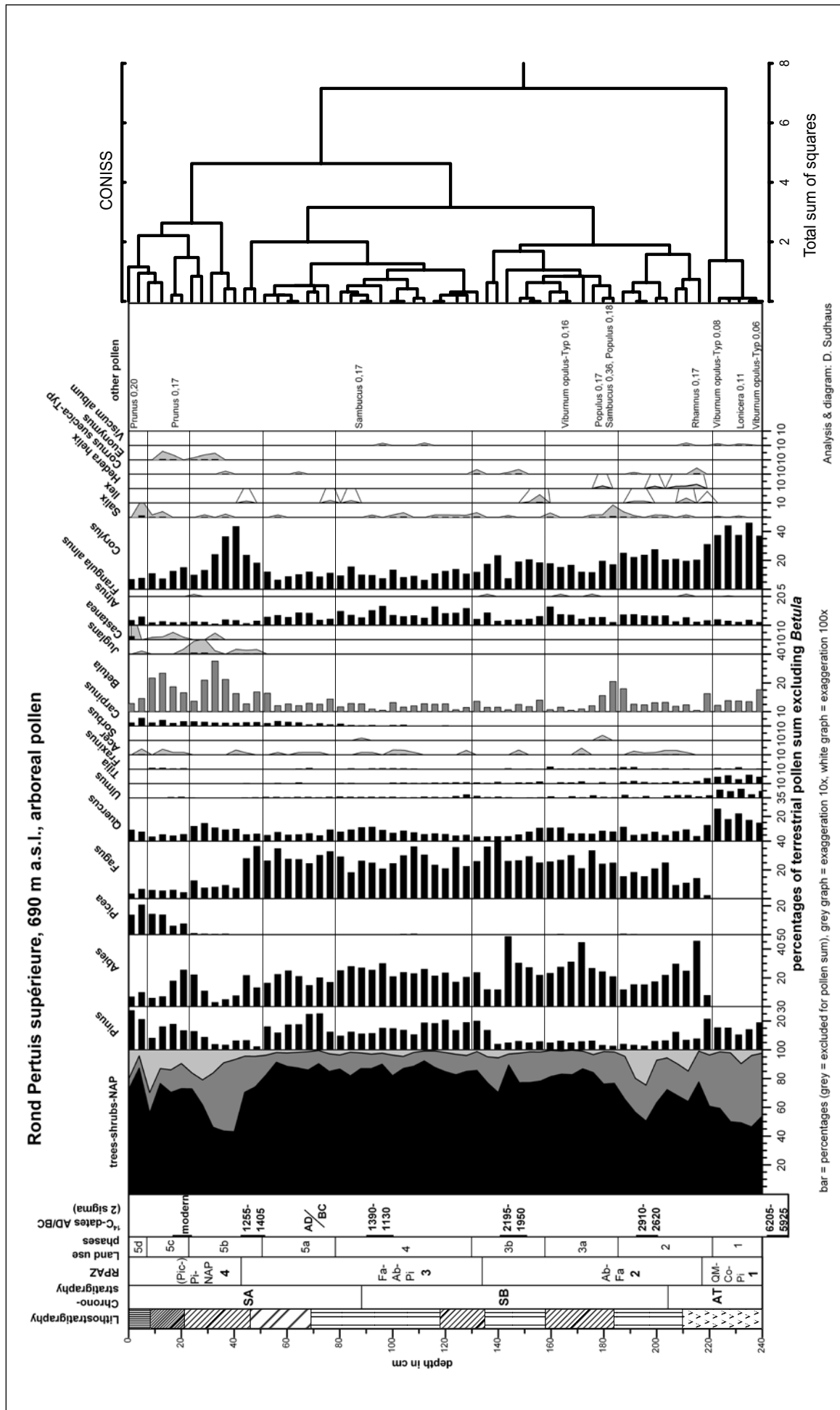
Fig. 3a: Arboreal pollen diagram from the Rond Pertuis supérieure bog, Northern Vosges, France, 690 m a.s.l. SA = Sub-Atlantic period, SB = Sub-Boreal period, AT = Atlantic period, Pic = Picea, Pi = Pinus, NAP = non-arboreal Pollen, Fa = Fagus, Ab = Abies, QM = Quercetum mixtum, Co = Corylus.

Abb. 3a: Baumpollendiagramm vom Rond Pertuis supérieure, Nordvogesen, Frankreich, 690 m ü. NN, SA = Subatlantikum, SB = Subboreal, AT = Atlantikum, Pic = Picea, Pi = Pinus, NAP = Nichbaumpollen, Fa = Fagus, Ab = Abies, QM = Eichenmischwald, Co = Corylus.
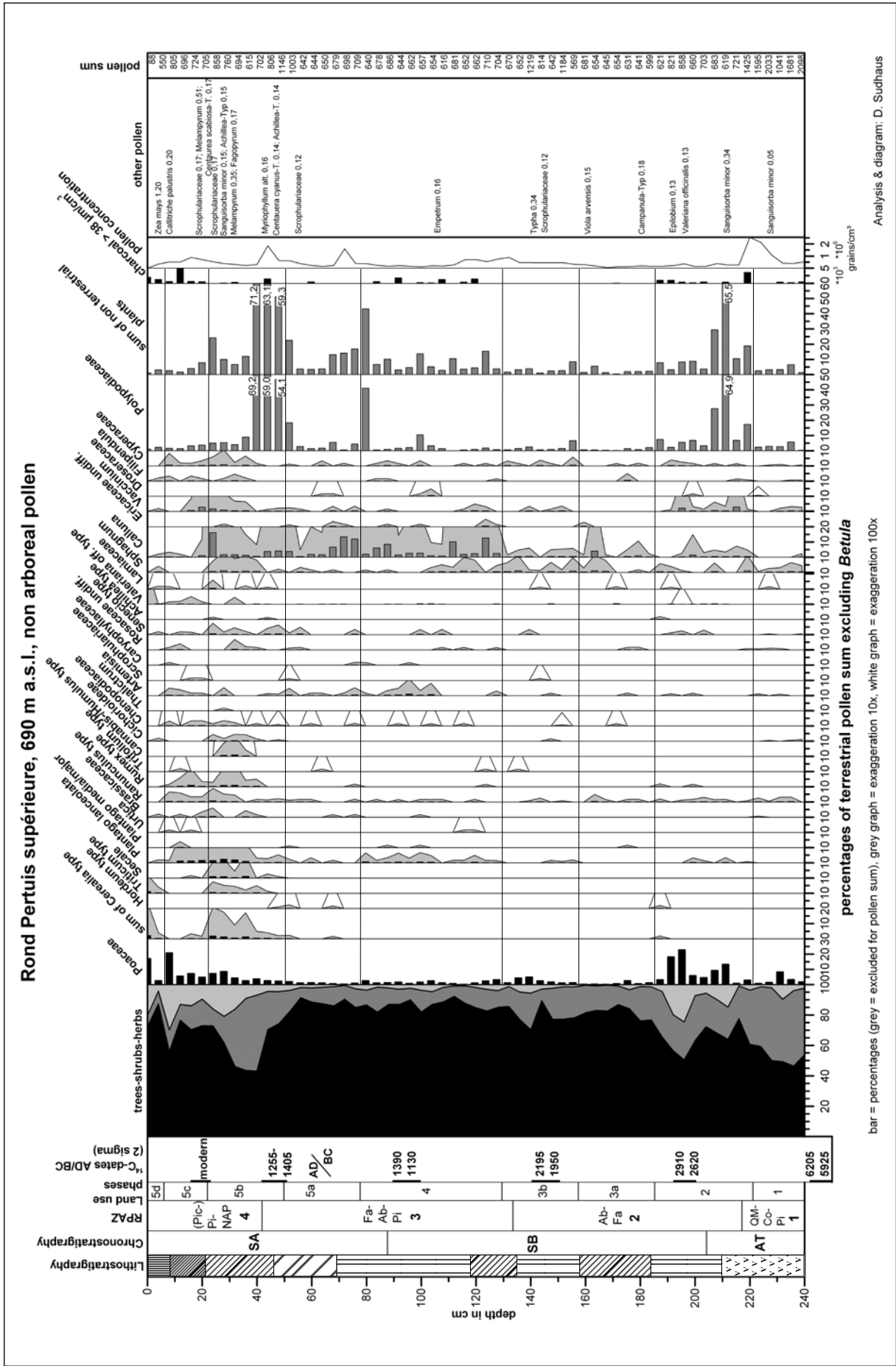
Fig. 3b: Non-arboreal pollen diagram from the Rond Pertuis supérieure bog, Northern Vosges, France, 690 m a.s.l, abbr. see Fig. 3a.

Abb. 3b: Nichtbaumpollen-Diagramm vom Rond Pertuis supérieure, Nordvogesen, Frankreich, 690 m ü. NN, Abkürzungen siehe Abb. 3a.
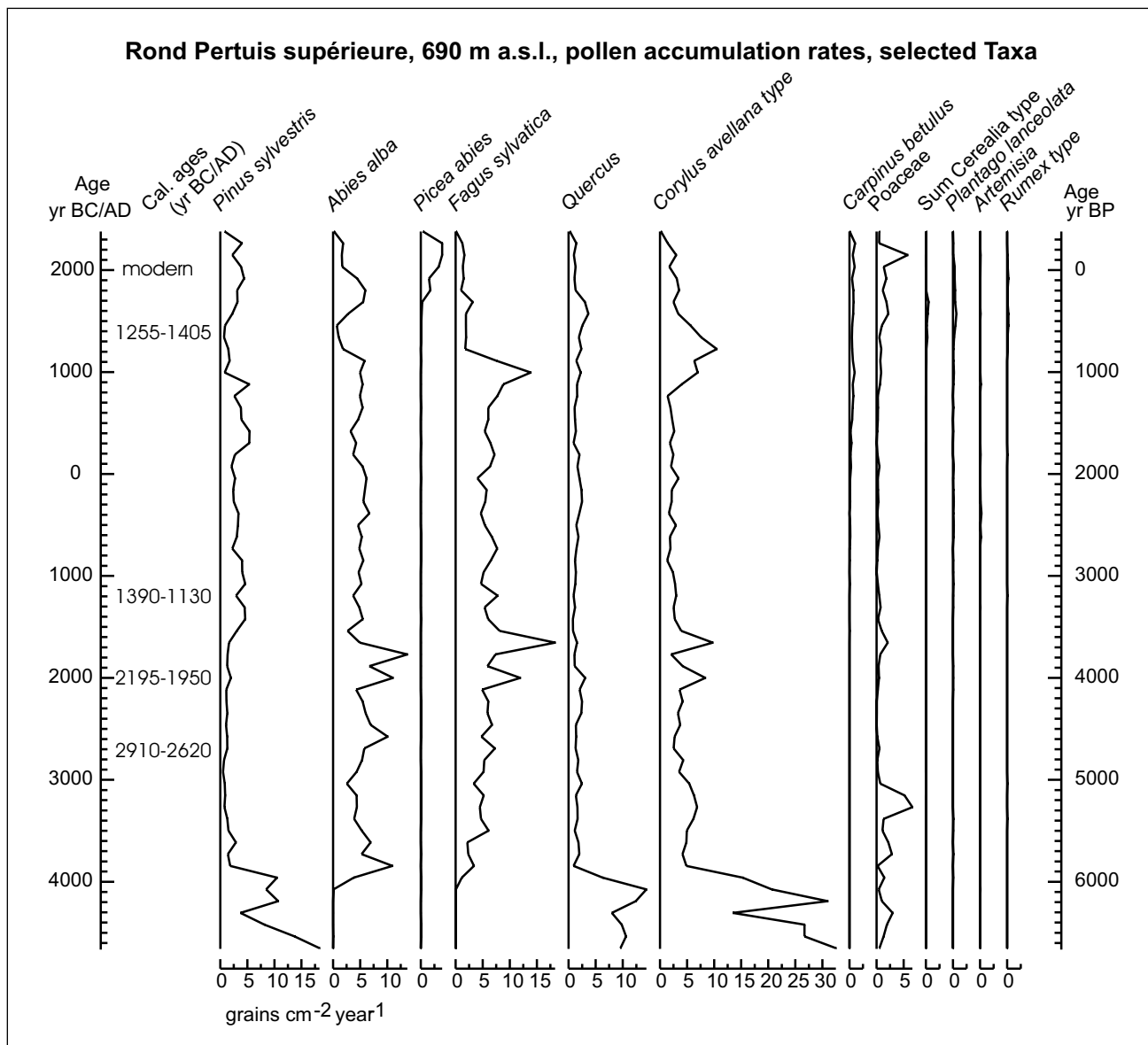
Fig. 4: Pollen accumulation rates from the Rond Pertuis supérieure bog, Northern Vosges, France, 690 m a.s.l with selected Taxa.

Abb. 4: Raten des Pollenniederschlags für ausgewählte Taxa des Rond Pertuis supérieure, Nordvogesen, Frankreich, 690 m ü. NN.

5 Discussion
5.1 Pollen source area

Following Sugita (1994), the pollen source area for a lake with the dimensions of the Rond Pertuis supérieure bog is less than 800 m from the lake-shore. The pollen assemblage from a bog differs from a lake of similar radius (Sugita 1993). According to Huntley and Webb (1988), in a site of this size most of the pollen arises from a 500 m radius. We suppose that the pollen source area in this mountain area with a distinctive relief, may be even larger. Maximum pollen emission for a lot of plants takes place at noon (Zwander 1997). During this time the quasi-periodic valley wind regime may transport pollen from lower altitudes to the higher ones. Most of the deposited pollen must be transported by air, only during the lake period of the Rond Pertuis supérieure transportation by water from the small catchment area in the south / southwest is possible.

According to this interpretation we examined the radius of 1 km around the bog more closely, which most likely represents the possible pollen source area. Fig. 5 is showing aspect, elevation and slope for a radius of 1 km around the coring point in the Rond Pertuis supérieure bog based on the 90 m digital SRTM elevation model (Jarvis et al. 2008). As shown in Fig. 1 the Rond Pertuis supérieure is situated at the Ruisseau de la Truide valley, which is east-west orientated. Most of this valley is in a 1 km circle around the bog, which implies that the expected pollen source of the area has an eastern aspect. High southern aspect rates are found on the north side of the valley. The elevation of the assumed pollen source area ranges from 440 to 810 m a.s.l. Most parts of the area have slopes between 10 and 25 degrees. Agriculture may be possible only up to a slope of 15 degrees. So about 40% of the estimated pollen source area may be suitable for agriculture, but this is an overestimation, because most of the levelled area is found on the bog itself. Additional steep slopes are under-represented in the figure, because the resolution of the SRTM data causes an inadequate representation of the steep slope of the cirque.
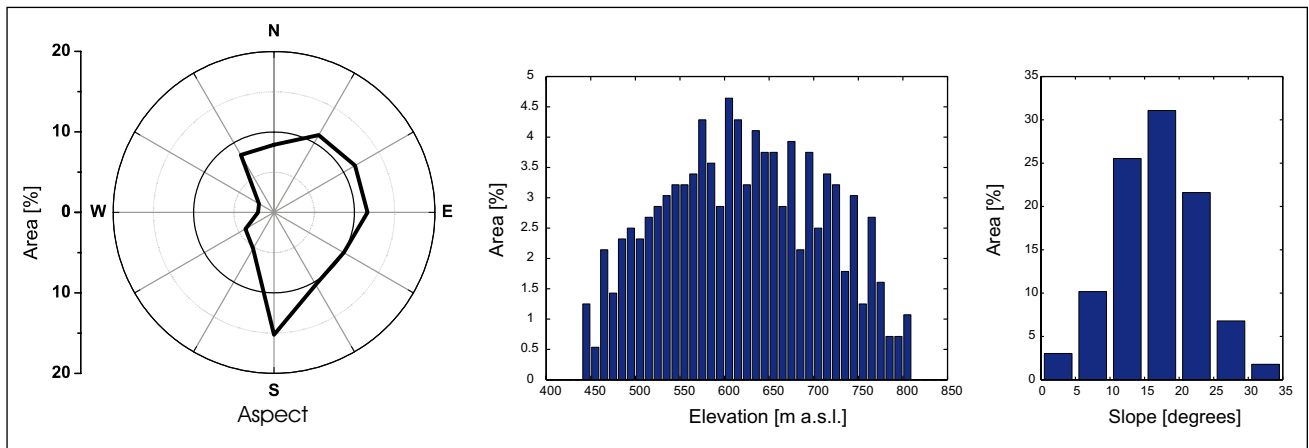
Fig. 5: Aspect, elevation and slope in a 1 km radius around the coring point in the Rond Pertuis supérieure bog.

Abb. 5: Verteilung von Exposition, Höhe und Neigung im Umkreis von 1 km um den Bohrpunkt im Rond Pertuis supérieure.

5.2 Natural Vegetation

The pre-Atlantic vegetation history, despite being absent in the presented pollen diagrams, can be reconstructed from the Maxe bog analysis (FIRBAS et al. 1948). In the Pre-Boreal and Boreal periods *Pinus*, *Corylus* and *Betula* were the dominant species. The decline of *Corylus* pollen in the Maxe bog indicates the expansion of a mixed oak forest from the Boreal to the late Atlantic period.

From the middle Atlantic period (approx. 5000 B.C.) onwards the vegetation history is represented in the Rond Pertuis supérieure diagram (Figs. 3a and 3b).

The high representation of *Pinus* and *Corylus* pollen in the oak forest during the Atlantic period indicates an occurrence of these species. Either the oak-dominated forests were open enough for these heliophilous tree species, or perhaps *Pinus* and *Corylus* grew in different areas to the mixed oak forest species, e.g. on the steep slopes of the cirque. The low number on heliophilous herbs does not indicate an open oak forest. *Pinus* might have grown on the well drained sites, whereas *Colyus* needs moister conditions (THEUERKAUF et al. 2014) and therefore could have grown around the lake.

As the profile of the Maxe bog is showing high values of *Pinus* and *Corylus* and a very slow decline of both species from the Boreal period onwards, this may represent a natural phenomenon in the northern sandstone Vosges (FIRBAS et al. 1948, FRIEDMANN 2000), and not a local effect at the Rond Pértuis site. In the Maxe profile *Pinus* is also detected in macrofossils, so a local occurrence is likely (FIRBAS et al. 1948). The long persistence of *Pinus* could hence be attributed to the more acidic soils on the sandstone bedrock. The harsher environmental conditions of the cirques (shadier, cooler and moister) may give ecological advantage to the establishment of pine-dominated ecosystems, thus hampering the immigration of other tree species. Human influence on the vegetation is not detectable during this time (LUP 1).

Abies and *Fagus* immigrated simultaneously at the end of the Atlantic period and increased rapidly. They lead to a decrease of the oak forest, *Pinus* and *Corylus* shortly after immigration. First *Abies* expanded more rapidly and dominated the early fir-beech forests. The later domi-nance of *Fagus* from the middle of the Subboreal period onwards is more the result of a decrease in the other pollen types (Fig. 3a, 4), maybe caused by a more stable population of *Fagus* in contrast to other tree species.

From the beginning of the Sub-Boreal period onwards, at 210 cm depth (Fig. 2), sedge peat and dwarf-shrub peat alternate. This points to alternating wetness levels in the bog. Sedge peat was a result of wetter phases, Ericaceae indicate a drier bog surface. Immigration of *Carpinus betulus* at the end of the Sub-Boreal period (Fig. 3a) was incomplete and the representation of *Carpinus* in the diagram is very low. The following vegetation history of the study area was strongly influenced by human impact.

5.3 Human impact

In the pollen diagrams (Figs. 3a and b), signs of influence from human activities can be detected in the vegetation record. Five different land use phases (LUP, Table 3, Figs. 3a and b) can be distinguished, with different levels of human impact characterised by pollen types indicative of agricultural and settlement activities (BEHRE 1981, 1988 and LANG 1994).

The land use phase 2 (LUP 2, 4000–2500 BC) covers the time from the Younger to the Late Neolithic period, at the transition from the Atlantic to the Subboreal period (approx. 3100 B.C.). The first phase of human impact is characterised by the increase of Poaceae and heliophilous herbs and the appearance of *Plantago lanceolata*, as well as the immediate decline of *Abies*. A high number of charcoal particles indicate local fires. Only charcoal pieces larger than 38 μm have been counted, because these can be correlated with local fires (CLARK et al. 1989). Nevertheless, very extensive fires can transport larger charcoal particles for longer distances (TINNER et al. 2006). Natural fires are possible in coniferous forests, but here charcoal particles occur contemporaneously with secondary anthropogenic indicators (Fig. 3a, Table 3). Therefore this may be better explained by human settlement and woodland pasture in the valleys during the Younger Neolithic period. At the end of this land use phase, agriculture may have occurred, as a single grain of *Hordeum* type was ascertained. Barley (*Hordeum vulgare*) cultivation is known for the Younger

Neolithic onwards (Körber-Grohne 1995) and LUP 2 is representing the Late Neolithic. This should be a local evidence for agriculture, because the pollen from seeds do not fly long distances (Behre 1988). The following increase in *Betula* could be the result of a succession on the abandoned farmland. The land use phase 2 covers the time from the Younger to the Late Neolithic period, at the transition from the Atlantic to the Sub-Boreal periods (approx. 3100 B.C.).

The pollen diagram from the Maxe bog (Firbas et al. 1948) shows a similar decrease of *Abies* and an increase of *Betula* values, therefore supporting the notion of a regional land use pattern. This phase is contemporaneous to a known settlement in the Donon Range (see chapter 2). Human impact has been recognised in the Southern Black Forest at the same time (Steerenmoos, Human Impact Phase 4 of Rösch 2000). This leads to the conclusion that the climatic condi-

Tab. 3: Land use phases in the area of Rond Pertuis as differentiated in the pollen diagram (Fig. 3). Definition of primary and secondary anthropogenic indicators following Behre (1981, 1988) and Lang (1994).

Tab. 3: Aus dem Pollendiagramm (Abb. 3) hergeleitete Landnutzungsphasen für das Gebiet des Rond Pertuis. Primäre und sekundäre Indikatoren anthropogener Aktivität nach Behre (1981, 1988) und Lang (1994).

LUP	Depth in cm / Age in BC/AD	Primary anthropogenic indicators	Secondary anthropogenic indicators	Changes in forest composition	Era / Possible land use
5d	8–0	*Triticum*	*Plantago lanceolata*, Brassicaceae and Cichorioideae in low quantities	Abundant *Pinus* and *Picea*; decrease of *Abies*, *Fagus* and *Betula*; more *Castanea sativa*	Youngest Modern Era
5d	1950 AD–today	*Triticum*	*Plantago lanceolata*, Brassicaceae and Cichorioideae in low quantities	Abundant *Pinus* and *Picea*; decrease of *Abies*, *Fagus* and *Betula*; more *Castanea sativa*	Silviculture, grassland farming
5c	24–8	Several *Secale* grains	*Plantago lanceolata*, *Artemisia* and Ranunculaceae continuous; high Poaceae values; sporadic Brassicaceae, *Urtica* and *Plantago media*; charcoal levels elevated	*Abies* decline; *Pinus* elevated; *Betula* increase; earliest *Picea* cultivation; *Fagus*, *Quercus* and *Corylus* reduced	Modern Era
5c	1700–1950 AD	Several *Secale* grains	*Plantago lanceolata*, *Artemisia* and Ranunculaceae continuous; high Poaceae values; sporadic Brassicaceae, *Urtica* and *Plantago media*; charcoal levels elevated	*Abies* decline; *Pinus* elevated; *Betula* increase; earliest *Picea* cultivation; *Fagus*, *Quercus* and *Corylus* reduced	Silviculture, pasture farming
5b	52–24	At first some *Hordeum* grains, later *Secale* and *Triticum*, as well as *Cannabis*; a single grain of *Fagopyrum*	Continuous high frequencies of *Plantago lanceolata*; Chenopodiaceae, Brassicaceae and Cichorioideae abundant; Poaceae increase; charcoal common	*Pinus*, *Abies* and *Fagus* decline; *Corylus* and *Betula* spread; *Juglans* from the beginning; *Castanea* from the middle of the phase onwards	Central Medieval Ages to early Modern Era
5b	1150–1700 AD	At first some *Hordeum* grains, later *Secale* and *Triticum*, as well as *Cannabis*; a single grain of *Fagopyrum*	Continuous high frequencies of *Plantago lanceolata*; Chenopodiaceae, Brassicaceae and Cichorioideae abundant; Poaceae increase; charcoal common	*Pinus*, *Abies* and *Fagus* decline; *Corylus* and *Betula* spread; *Juglans* from the beginning; *Castanea* from the middle of the phase onwards	Charcoal burning, mining, agriculture and pasture farming
5a	80–52	Several *Hordeum* grains	*Plantago lanceolata* reduced; *Trifolium*, Chenopodiaceae and *Plantago* in low quantities	*Pinus* increase	Roman Ages to central Medieval Ages
5a	400 BC– 1150 AD	Several *Hordeum* grains	*Plantago lanceolata* reduced; *Trifolium*, Chenopodiaceae and *Plantago* in low quantities	*Pinus* increase	Pasture farming, limited agriculture
4	132–80	None	*Plantago lanceolata* continuous; *Artemisia* distinct; Chenopodiaceae, *Urtica* and *Plantago major* with low values; charcoal elevated	*Pinus* elevated; higher representation of *Fagus* than *Abies*	Middle Bonze Age to younger Iron Age
4	1800–400 BC	None	*Plantago lanceolata* continuous; *Artemisia* distinct; Chenopodiaceae, *Urtica* and *Plantago major* with low values; charcoal elevated	*Pinus* elevated; higher representation of *Fagus* than *Abies*	Pasture farming
3b	160–132	None	*Plantago lanceolata*, *Trifolium*, *Artemisia*, Chenopodiaceae, Cichorioideae present; Poaceae increase	*Abies* values increase towards the middle of the period, than decrease. *Fagus* becoming dominant; at the end *Pinus* frequencies rise	Early Bonze Age
3b	2200–1800 BC	None	*Plantago lanceolata*, *Trifolium*, *Artemisia*, Chenopodiaceae, Cichorioideae present; Poaceae increase	*Abies* values increase towards the middle of the period, than decrease. *Fagus* becoming dominant; at the end *Pinus* frequencies rise	Temporary woodland pasture
3a	188–160	None	*Plantago major*, presence of Chenopodiaceae and Ranunculaceae	At the beginning high levels of *Betula*; *Abies* is spreading	Late Neolithic
3a	2500–2200 BC	None	*Plantago major*, presence of Chenopodiaceae and Ranunculaceae	At the beginning high levels of *Betula*; *Abies* is spreading	No land use detectable
2	224–188	*Hordeum* grain at the end of the phase	*Plantago lanceolata* distinct; Poaceae and charcoal elevated; low values of *Artemisia*, Ranunculaceae and *Plantago lanceolata*	*Abies* and *Fagus* immigration and spreading; *Abies* decline; *Betula* percentages increase at the end	Younger to late Neolithic
2	4000–2500 BC	*Hordeum* grain at the end of the phase	*Plantago lanceolata* distinct; Poaceae and charcoal elevated; low values of *Artemisia*, Ranunculaceae and *Plantago lanceolata*	*Abies* and *Fagus* immigration and spreading; *Abies* decline; *Betula* percentages increase at the end	Woodland pasture, first agriculture
1	240–224	None	*Artemisia*, Ranunculaceae and Cichorioideae in low quantities	Mixed oakwood with *Corylus*	Younger Neolithic
1	5000–4000 BC	None	*Artemisia*, Ranunculaceae and Cichorioideae in low quantities	Mixed oakwood with *Corylus*	No land use detectable

tions during this time must have permitted agriculture in the montane zone.

According to Firbas et al. (1948) the proportions of *Fagus* and *Abies* in the forest depend on the altitude. The dominance of *Fagus* increases with altitude. In the Northern Vosges (Maxe bog and Rond Pertuis supérieure area) the dominance of *Fagus* may have been caused by human impact as indicated in RPAZ 2 (Fig. 3a). A decline of the dominant forest tree *Abies* corresponds to an increase of secondary cultural indicators. Afterwards *Fagus* expands slowly. Hence the development of altitudinal vegetation zones, especially in the upper montane *Fagus* zone (600–1000m) (Firbas et al. 1948), may have been triggered by human activity. This may also have led to the slow increase in *Fagus* values, as discussed by van der Knaap et al. (2005) for sites in the Alps.

In the following period (LUP 3a, 2500–2200 B.C.) anthropogenic influences are not detectable in the Northern Vosges. The area was covered by an *Abies* and *Fagus* dominated forest (Fig. 3a, RPAZ 3). This period up until the Roman Ages is not represented in the analysis of the Maxe bog (Firbas et al. 1948), shown by the sharp lithostratigraphic change.

In the Early Bronze Age temporal land use is recognised by the slightly enhanced values of heliophilous herbs and Poaceae towards the end of this phase (LUP 3b, 2200–1800 B.C.). In the middle of the Sub-Boreal period *Fagus* becomes the dominant tree species with pollen frequencies higher than 25%. The distinctive decline of the *Abies* values, while those of *Fagus* and *Corylus* increase, may indicate a selective cutting of fir trees by humans. Subsequently the *Pinus* values also increase while the curve of *Abies* does not show a rise to the same high level as before. Slightly elevated amounts of charcoal particles are also found, pointing to the occurrence of local forest fires, probably associated with the cutting of *Abies* trees. *Abies* was used as construction timber, a connection with the first mining activities is possible.

From the Middle Bronze Age and Younger Iron Age (LUP 4, 1800–400 B.C.) up to now, continuous human impact is detectable. Secondary cultural indicators indicate pasture and animal husbandry with forest grazing in the surrounding areas of the mire until the Younger Iron Age (Fig. 3a, b, Tab. 3). In the pollen diagram (Fig. 3a,b) *Pinus*, *Alnus* (alder), *Salix* (willow) and *Calluna* increase in LUP 4, which may be due to local drying of the bog surface leading to the local expansion of these species.

Thereafter Younger Iron Age farming is indicated by the occurrence of *Hordeum* type pollen grains (LUP 5a, 400 B.C.–A.D. 1150). During Roman times elevated levels of *Calluna* point to drier conditions or even a hiatus. Peat accumulation rates were very low and this time period is not well documented in the record.

The Vosgean valleys have been cleared and developed since the Middle Ages, as well as the 'chaumes' in the subalpine zone on the top of the mountains (Garnier 2000). In the late Middle Ages and the early Modern Era, the forests around Rond Pertuis were partly cleared and severely altered by humans (LUP 5b, A.D. 1150–1900) as documented in Fig. 3a. The woodland was very likely intensively used for charcoal production. Near the investigated cirque sev-

eral historical charcoal kilns were found. This is also the time when a forest edict of King Louis XIV in 1669 changed forest use in the Vosges from the cutting of individual trees to more intense forest exploitation (Garnier 2000). A succession in the exploited forests is shown by the increase of *Corylus* and *Betula* (RPAZ 5).

The nearby settlements were related to iron-ore mining in the valley of the Breusch from the 13th to the 19th century (Geyer 1995). Agriculture is likely to have been very diverse during this period since a broad range of primary anthropogenic indicators, including *Secale* (rye), *Triticum* type (wheat) and *Fagopyrum* (buckwheat), were observed (Fig. 3b). A high number of *Cannabis/Humulus* type grains is recorded for the Late Middle Ages. During this time the textile industry developed, based on locally produced wool, hemp and flax, which was a common home industry in the Vosges (Michna 1977). This may be indicated in the pollen diagram. During the 19th century, agriculture decreased and textile manufacturing was the driving force of settlement development in the Vosges (Stadelbauer 1992). The textile industry changed during this time through mechanization and the raw material now most commonly used was cotton (Michna 1977). This change may have led to the collapse of hemp farming.

The spreading of *Quercus* during the Late Middle Ages may be a result of its use for coppicing practice and the use of oak bark in tanneries, and may furthermore be attributed to the general use of oak stands during the Medieval Ages and the early Modern Era for pig fodder (acorns). Mining was intense during this time (Granier 2000) leading to a distinct decrease of *Abies*. The interrupted mining activities in the 17th century could have led to a recovery of the *Abies* population (Friedmann 2000, Mäckel et al. 2009). However also in the Modern Era the woodlands were afforested by *Abies* and *Pinus*. Most recently *Abies* declined due to the introduction of *Picea*. The appearance of *Picea abies* in the Central Vosges may date to 50 B.C.–A.D. 80 (Kalis et al. 2006). Afterwards *Picea* may have grown in isolated localities, e.g. deep cool canyons, in the central Vosges (Kalis 1984). As a result of the degradation of the forest by overexploitation during the 17th and 18th centuries (Dion 1970), it is likely that spruce spread from the isolated stands. The plantation of *Picea* forests began in the 1850s (Closset-Kopp et al. 2006). The decreasing population density after the First World War (Frey 1964) may also have helped the spreading of *Picea* (Dion 1970).

For the study area in the Northern Vosges, Firbas et al. (1948) describe a fir forest around the Maxe bog. The younger radiocarbon date for the sample at the depth of 18–21cm (Table 1), representing the time of spruce spreading, may be the result of dating a bulk sample containing rootlets. Today's forest is a spruce monoculture; *Abies* and *Fagus* are only growing in higher areas of the Northern Vosges Mountains from 700 m a.s.l. upwards, but not within the cirques.

Land use phase 5c (A.D. 1900–recent time) is characterised by silviculture and pasture farming. The detected *Secale* pollen (Fig. 3b) may originate from rye fields at greater distances, because of its high pollen production and excellent dispersal capacity (Burga & Perret 1998). The increasing number of charcoal particles could be a possible

sign of slash-and-burn agriculture, which was practised for a long time in the Northern Vosges (HERRMANN 1914).

Apart from silviculture, grassland farming characterizes the youngest Modern Era (LUP 5d, A.D. 1950–today). Also *Cerealia* pollen are detected in higher numbers. Additionally, wheat, potato and cattle fodder are cultivated in the Breusch Valley (TIMBAL 1985, SICK 1991). In most recent times the forests suffered from strong storms (named e.g. Vivian and Wiebke in 1990, and Lothar in 1999), and large forest areas have been blown over. Future succession and modern silviculture will likely lead to more diverse and species-rich forests.

5.4 Regional Context

The vegetation history of the Northern Vosges shows certain similarities to the development in the Southern Vosges (JANSSEN et al. 1972, 1975, de VALK 1981, EDELMAN 1985, KALIS 1985), but also distinct differences (FRIEDMANN 2000). During the Preboreal a pine-birch forest covered the whole Vosges Mountains. Then regional differences in the vegetation development become apparent. In the Boreal the immigration of hazel, elm, oak and other thermophilous trees occur. The hazel expansion in the Southern Vosges was very strong, but much reduced in the Northern Vosges (FIRBAS et al. 1948, BUNNIK 1978). The hazel-rich oak forests largely replace during the Atlantic the pine-birch forests in the Southern Vosges, but in the Northern Vosges pine and to a lesser extent birch still constitute an important part of the forests. Beech and fir spread in the Southern Vosges from the middle Atlantic times onward and reach the Northern Vosges in the late Atlantic (Fig. 3a). In the Subboreal period the expansion of beech and fir lead to a decline of the mixed oakwood and also to a reduction of the pine in the Northern Vosges. The long dominance of pine might be a result of the permeable sandstone rock and more acid soil conditions in the Northern Vosges, which gave pine an ecological advantage over other trees. During the Subatlantic the forests are severely changed by human impact in the whole Vosges Mountains. Spruce was able to establish itself in a few areas of the Southern Vosges with particularly harsh climatic conditions (KALIS et al. 2006), but not in the Northern Vosges. The modern forest cover rich in spruce is a result of plantations.

The main differences of the vegetation history of the Vosges to the Black Forest concern the role of the spruce (FRIEDMANN 2000, RÖSCH 2000). The spruce naturally immigrated and spread slowly into the Black Forest from the east during the early Atlantic. Mass expansion of the spruce into the high, middle and northern Black Forest occured during the Subatlantic.

6 Conclusion

The presented pollen diagram fills an important gap in knowledge of the Holocene vegetation development and land use history of the Northern Vosges and the Central European Uplands. There is a high persistency of *Pinus* in the Northern Vosges until the middle Holocene period. These high frequencies of *Pinus* in the northern sandstone Vosges are probably a natural phenomenon, resulting from the special local site conditions (more acidic soils on the permeable sandstone bedrock) and the relatively late immigration and spread of *Abies* and *Fagus*. This immigration led to a decrease of *Pinus*. *Abies* spread earlier than *Fagus*, but soon diminished, most likely because of early human use. Human activity has certainly influenced the development of the high-montane *Fagus* zone in this area, probably driven by the selective use of *Abies*. Human impact on the vegetation of the Northern Vosges started in the late Atlantic period and increased until the Late Medieval Ages. Land use in association with mining led to cutting of the forest at the Rond Pertuis supérieure in the early Modern Age. Also the changing raw materials used by the textile industry in the Vosges may be recognized in the vegetation development. *Picea* pollen is detected during the time of silviculture for the first time and therefore a natural immigration in the Northern Vosges is undiscernible.

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