



**HAL**  
open science

# Sahel environmental variability during the last millennium: Insight from a pollen, charcoal and algae record from the Niayes area, Senegal

Anne-Marie Lézine, Kévin Lemonnier, Cheikh Abdoul Kader Fofana

## ► To cite this version:

Anne-Marie Lézine, Kévin Lemonnier, Cheikh Abdoul Kader Fofana. Sahel environmental variability during the last millennium: Insight from a pollen, charcoal and algae record from the Niayes area, Senegal. *Review of Palaeobotany and Palynology*, 2019, 271, pp.104103. 10.1016/j.revpalbo.2019.104103 . hal-02370143

**HAL Id: hal-02370143**

**<https://hal.science/hal-02370143>**

Submitted on 20 Dec 2021

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

1 **Sahel environmental variability during the last millennium: insight from a pollen, charcoal**  
2 **and algae record from the Niayes area, Senegal**

3

4 A.M. Lézine<sup>1</sup>, K. Lemonnier<sup>1</sup>, C.A.K. Fofana<sup>2</sup>

5

6 <sup>1</sup> Laboratoire d'Océanographie et du Climat, Expérimentation et Approche numérique/IPSL,  
7 Sorbonne Université, CNRS-IRD-MNHN, 4 Place Jussieu, 75005, Paris, France. Anne-  
8 marie.lezine@locean-ipsl.upmc.fr

9 [orcid.org/0000-0002-3555-5124](https://orcid.org/0000-0002-3555-5124)

10 <sup>2</sup> Département de Géologie, Faculté des Sciences et Techniques, Université Cheikh Anta  
11 Diop, Dakar, Sénégal

12

13 **Abstract :**

14 The pollen, algae and charcoal record from the “Baobab” depression near Mboro in the  
15 Niayes area of Senegal shows that the last millennium was characterized by a gradual  
16 aridification which started 1340 CE and culminated 1845 CE. The sub-Guinean gallery forests,  
17 which survived the previous environmental crisis dated from the end of the Holocene Humid  
18 Period, suddenly collapsed and the Niayes region suffered a dramatic loss of biodiversity. We  
19 show that the tipping point between a forested and non-forested state occurred ca 400  
20 centuries after the onset of aridity recorded by the lowering of the water level and the  
21 progressive salinization of the aquatic environment.

22

23 **Key words :** Pollen, Algae, Charcoal, last millennium, Sahel, Senegal

24

## 25 **1. Introduction**

26

27 Was the last major Sahelian drought in the 1970s unusual? By studying records of  
28 environmental changes and associated forcing mechanisms in the recent past, it is possible  
29 to situate this major climate crisis in the context of the natural variability of the west African  
30 monsoon climate system. Natural archives such as lake sediments can fill gaps in  
31 understanding climate variability by providing access to a long-term perspective  
32 encompassing periods out of any anthropogenic influence. In western Africa, such long-term  
33 records are rare (e.g., Nash et al., 2016 and references therein) and somewhat contradictory.  
34 In particular, the well-known interval of the Little Ice Age (LIA - 1400-1850 CE) when  
35 exceptionally cool temperatures were reached in the Northern hemisphere, was described  
36 as a dry period in the Lake Bosumtwi area (Ghana) (Shanahan et al., 2009) and a humid  
37 period in the Saloum delta (Senegal) (Carré et al., 2018).

38 The littoral depressions of the Niayes area, along the northern coast of Senegal have  
39 provided major information on the Holocene history of the West African environments  
40 (Lézine et al., 2011; Hély and Lézine, 2014). Local environmental conditions linked to the  
41 proximity of the coast have favored accumulation of organic matter and expansion of gallery  
42 forests in the bottom of the depressions during the Holocene (Lézine, 1989) which have  
43 persisted up to recently thanks to the high level of the water table (Trochain, 1940; Pézeril et  
44 al., 1986). It has been shown that these gallery forests were highly sensitive to variations of  
45 the level of the water table whatever the temporal resolution considered, from decades  
46 (Aguiar, 2010) to centuries (Lézine and Chateauneuf, 1991). Here we present a study  
47 combining pollen and diatom analyses on a sedimentary series recovered NW of Mboro in  
48 the center of the Niaye area. The aim of our study is to examine the hydrological variations

49 during the last millennium and to discuss their impact on the local vegetation. We also aim  
50 at characterizing the signature of human activities on the natural environment.

51

## 52 **2. Regional setting**

53 The Niaye area consists of depressions formed between linear fixed and partially fixed  
54 coastal dune ridges, located between 15° and 16° N, at roughly 17°W along the Atlantic coast  
55 of Senegal. These depressions belong to an extensive river system which took place during  
56 the Holocene Humid Period ca 12 ka yr BP. (Lézine, 1989). Edification of coastal dunes  
57 (Michel, 1973) gradually closed access to the sea of water courses and promoted the  
58 development of thick, continuous peat accumulations. The presence of fresh, shallow  
59 ground-water near the surface in the bottom of the interdune depressions (Lézine and  
60 Chateauneuf, 1991) supports the preservation (though deeply degraded today by intensive  
61 agriculture activity) of gallery forests of Guinean phytogeographical affinity, which are the  
62 last traces of the northern extension of tropical humid forests during the Holocene (Watrin  
63 et al., 2009; Hély and Lézine, 2014). This is the "sub-Guinean domain" of Trochain (1940)  
64 consisting of enclaves of aquatic vegetation in open water areas (*Nymphaea*, *Potamogeton*,  
65 *Pistia*) and reed-swamp populations (*Typha*, *Phragmites*) associated with *Syzygium*  
66 *guineense* in the flooded zone, surrounded by Guinean forest relicts at the foot of the dunes  
67 (*Elaeis guineensis*, *Ficus*, *Treculia*, *Phoenix*) followed by *Dodonaea*, *Alchornea*, *Zanthoxylum*,  
68 *Combretum* toward the upper limit of the gallery forests, whereas typically Sahelian trees  
69 grow at the top of the dunes (*Acacia*, *Balanites*) (Adam, 1953, 1958; Jaeger, 1949; Villiers,  
70 1957; Michel et al., 1969; Raynal, 1963) (Figure 1A).

71 Hydrological studies in the Niayes area have shown that the water level varies greatly in  
72 phase with local rainfall. Accentuated dryness associated with intensive water pumping in

73 recent decades has led to the lowering of the fresh water table and the penetration of salt  
74 waters from the adjacent sea into the depressions closest to the coast (e.g., Faye, 1995;  
75 Aguiar, 2008; Maugis et al., 2009).

76

### 77 **3. Material and methods**

78 A 4 m long sediment core was collected in the center of the so-called "Baobab" depression in  
79 2016 (15.149132N; 16.909275W) under few tens cm of water using a "Russian" manual  
80 corer (Jowsey, 1966). Baobab lies SW of the main paleoriver channel of M'Boro at the NW  
81 extremity of a depression separated from the sea shore by a ridge of ca 2 km wide dunes of  
82 recent Holocene age (Michel, 1973) (Figure 1B). The sediment consists of homogeneous  
83 organic clay. Samples were taken at 5 cm intervals for pollen and algae analyses.

84 For pollen and non-pollen palynomorph (NPP) analyses samples were processed using the  
85 standard HF method described by Faegri and Iversen (1977). After sieving in a 5 µm mesh,  
86 the residue was stained with safranin and mounted in glycerine. Pollen identification was  
87 based on the reference slide and photo collections of the LOCEAN laboratory and the  
88 Museum national d'Histoire naturelle in Paris as well as on pollen atlases of tropical African  
89 flora from e.g., Maley (1970), APLF (1974), Ybert (1979) and Bonnefille and Riollet (1980).  
90 Pollen nomenclature, which follows the standard defined by the African Pollen Database  
91 (Vincens et al., 2007), was based on Lebrun and Stork (1991-2015). The pollen microflora  
92 was composed of 86 taxa (Table 1): 44 trees, shrubs, palms and lianas, 17 herbs and 14  
93 undifferentiated taxa mainly because of the low level of determination of the grains or when  
94 the family or genus level corresponded to several life-forms. In addition, 4 aquatic pollen  
95 taxa and 4 ferns were encountered. Pollen taxa were grouped according to the  
96 phytogeographical affinity of the parent species following Lézine et al. (2009) in four entities

97 according a decreasing rainfall gradient: Guineo-congolian, Sudanian, Sahelian and Saharan.  
98 In addition, some taxa have been selected as indicators of water-table fluctuations according  
99 to their distance from the open water area (Raynal, 1963; Michel et al., 1969; Lézine, 1987)  
100 (Fig. 2).

101 Pollen percentages were calculated against a sum excluding aquatics and ferns, the  
102 percentages of which were calculated separately against a sum including all the pollen grains  
103 and fern spores counted.

104 Undifferentiated fungi and 4 green algae (*Botryococcus*, *Coelastrum*, *Pediastrum*, *Tetraedron*)  
105 represent the NPP group. NPP are presented as percentages (Fig. 3B) and micro-charcoal as  
106 influxes (nbr of particles/cm<sup>2</sup>/year) (Fig.4).

107 For diatom analyses samples were processed using a standard method (Battarbee, 1986).

108 The residu was diluted in 20 ml of water and 2 ml was taken, then dried and fixed with  
109 Naphrax. Diatom identification was based on e.g., Guerneur (1954), Servant-Vildary (1978),  
110 Foged (1986), Gasse (1986), Compère (1991), Cocquyt et al. (1993), Bellinger and Sigee  
111 (2015). In addition, Ouattara et al. (2000), Sow and Diène (2002), Sow (2001; 2004), Sow et  
112 al. (2005) were used to precise the ecological requirement of taxa, particularly in Senegal.

113 Twenty-two diatoms were determined (Table 2). They correspond to three main hydrological  
114 conditions: freshwater, freshwater/salt tolerant, brackish/marine waters and  
115 undifferentiated. Diatoms are presented as percentages calculated against the sum of all the  
116 diatoms counted (Fig. 3A).

117 Both pollen and diatom data are presented under the form of diagrams using Tilia and  
118 CONISS (Grimm, 1991). Diversity indices were derived from PAST 3.23 software (Hammer et  
119 al., 2001).

120

#### 121 **4. Age control**

122 Age control was established by 3 accelerator mass spectrometry (AMS) radiocarbon dating  
123 of total organic matter on the whole Baobab sequence, conducted at UMS-ARTEMIS AMS  
124 Facilities (France). An additional control point was given by the first occurrence of *Casuarina*  
125 *equisetifolia* pollen grains in our samples the parent trees of which were planted in 1948 in  
126 the Niaye area (Ndiaye et al., 1993) (Table 3). According to this, the last millennium is  
127 represented by the 121 uppermost centimeters of the 4m-long Baobab sedimentary section.  
128 Our analysis has a temporal resolution varying between 70 and 12 years.

129

#### 130 **5. Results**

131 The pollen (Fig. 2), diatom (Fig. 3A) and NPP (Fig. 3B) records display several phases of  
132 environmental change over the last millennium with a remarkable coherency. They are  
133 described from the base to the top of the sequence.

134

#### 135 **5.1 Pollen**

136 The pollen spectra are characterized by the dominance of Poaceae and the continuous  
137 occurrence of Chenopodiaceae/Amaranthaceae and Asteraceae. This, together with the high  
138 number of other taxa, mainly herbaceous, from steppes, grasslands and wooded grasslands  
139 point to an open and fairly dry regional landscape. Except Poaceae, all the other taxa are  
140 poorly represented. This is particularly true for tropical trees which are characterized by a  
141 low pollen productivity and an entomophilous way of pollen dispersal (e.g., Watrin et al.,  
142 2007). As a consequence, their percentages are rarely higher than 10% (e.g., *Alchornea*).

143 **Zone 1, base-1340 CE:** Zone 1 is typified by tropical tree taxa, e.g., *Alchornea*, *Macaranga*,  
144 *Allophylus*, *Detarium* and *Mitragyna inermis* which reach their highest values (%). Aquatics

145 (*Potamogeton*, *Nymphaea*) are also present. All this depict an open water surface  
146 surrounded by a relatively developed gallery forest. By the end of this zone, in sub-zone 1b  
147 (1235-1340 CE) tropical trees start to decline whereas *Typha* starts to increase showing the  
148 onset of lake level lowering under drier conditions. Zone 1b marks the onset of *Elaeis*  
149 *guineensis* development.

150 **Zone 2, 1340-1810 CE:** Some tropical tree taxa disappear (*Allophylus*, *Mitragyna inermis*) or  
151 decline (*Alchornea*, *Macaranga*). In contrast, *Syzygium guineense* increases, as well as taxa  
152 from reed-swamp populations (*Typha*, ferns) both recording low water stands and marsh  
153 encroachment.

154 **Zone 3, 1810-1945 CE:** This zone shows a dramatic environmental change with the  
155 disappearance of most of the plant taxa replaced almost exclusively by Poaceae (91%). As a  
156 consequence, biodiversity falls sharply and Simpson diversity index values, which fluctuated  
157 only slightly around 0.6 in the lowermost zones, fall to 0.177 at level dated 1845 CE. The  
158 peak of Fungi at this level (Fig. 3B) testify for the at least partial or seasonal desiccation of  
159 the Baobab depression.

160 **Zone 4, 1945-2016 CE:** This zone is characterized by the increase in markers of  
161 anthropogenic activity with the appearance of pollen from the planted tree *Casuarina*  
162 *equisetifolia*. Charcoal remains, which steadily increased since 1370 CE, peaked at 1989 CE,  
163 suggesting the dramatic increase in fire occurrence. Increase in diversity compared to zone 3  
164 as well as significant percentages of tropical tree taxa suggests a certain recovery of the  
165 gallery forest. However, these taxa never reach values as high as in zones 1 and 2. *Typha* and  
166 *Syzygium* show that the level of the water table remained low during this zone. The increase  
167 of *Suaeda* in the uppermost levels (post 1980 CE: zone 1b) points to the setting of saline  
168 conditions.



169

## 170 **5.2 Algae**

### 171 **5.2.1 Diatoms**

172 *Aulacoseira granulata* and *Nitzschia* (*N. acicularis* and *N. scalaris*) are the most dominant  
173 species and account for up to 95, 49 and 23% respectively (Fig. 3A).

174 **Zone 1, base-1340 CE:** the diatom assemblage is almost exclusively represented by *A.*  
175 *granulata*, a planktonic species characteristic of well mixed fresh waters. This taxon is  
176 associated with *N. acicularis*, which confirms the presence of enriched turbid waters (zone  
177 1a). Towards the top of Zone 1 at levels dated 1235 CE and above, Zone 1b shows an  
178 increase in diversity with *N. scalaris*, *Eunotia pectinalis* and *Thalassiosira decipiens* showing  
179 the appearance of more brackish/saline conditions.

180 **Zone 2, 1340-1925 CE:** This zone is characterized by the gradual decline of *A. granulata*,  
181 which reached its lowest values in year 1906 EC. Three main taxa successively increase: *N.*  
182 *scalaris* (Zone 2a), *T. decipiens* (Zone 2b), then *N. acicularis* (Zone 2c) suggesting the gradual  
183 increase of dry conditions initiated in Zone 1b.

184 - **Zone 2a** (1340-1600 CE) is characterized by a noticeable increase in diversity and  
185 the appearance of periphytic (e.g., *Fragilaria construens*) or bentic (e.g., *F.*  
186 *pinnata*, *Pinnularia neomajor*) species. That together with the presence of species  
187 either cosmopolite or salt tolerant point to the lowering of the water level and  
188 the setting of dry conditions.

189 - **Zone 2b** (1600-1800 CE): *N. scalaris* decrease and is replaced by *T. decipiens* and  
190 *C. stelligera* showing that salt waters increased in the aquatic environment.

191 - **Zone 2c** (1800-1925 CE): *N. acicularis* dominate the diatom assemblage is  
192 association with *T. descipiens*. Meanwhile *A. granulata* reaches its lowest values.

193 All this suggests that the water level reached its lowest position.

194 **Zone 3, 1925-2001 CE:** The increase of *A. granulata* in the upper levels of the core suggests a  
195 certain recovery of the fresh water environment. This remained however highly variable and  
196 salty conditions are suggested in the upper level (Zone 3b) by the reappearance of *T.*  
197 *decipiens* and *S. Tenera* which were absent from Zone 3a.

198

### 199 **5.2.2 Green algae**

200 The green algae record (Fig. 3B), shows the opposite trend between *Tetraedron*, *Pediatrum*,  
201 *Coelastrum* which gradually decrease from the base to the top of the sequence, though  
202 fluctuating, and *Botryococcus*. This pattern illustrates the gradual depletion of nutrient and  
203 lowering of the water level. The absence of any other green algae except *Botryococcus* at  
204 levels post-1954 CE indicates the emergence of clearly oligotrophic conditions. This nutrient  
205 poor environment immediately followed the phase of lake level lowering indicated by the  
206 increase of fungi peaking at 1845 CE.

207

## 208 **6. Discussion**

209 Three main features emerge from our study:

### 210 **6.1 The dramatic collapse of the Guineo-Congolian gallery forest at 1640 CE.**

211 The end of the HHP, from 4500 cal yrs BP onward (Lézine et al., 2011), was marked the  
212 decline of tropical plants that previously widely expanded throughout the Sahel and the  
213 Sahara (Watrin et al., 2009; Hély et al. 2014). The abruptness of the forest collapse in the  
214 Niayes area (Lézine, 1989) was interpreted as the result of crossing a hydrological threshold,

215 after a long period of increased seasonality in rainfall since the mid-Holocene. The tipping  
216 point between a forest environment and an open and degraded environment occurred ca.  
217 2500 cal yrs BP (Lézine, 1989), i.e. approximately 2000 years after the end of the HHP in  
218 Western Africa. The specific hydrological conditions due to the proximity of the ocean led to  
219 maintain a high level of the groundwater at the bottom of the depressions. They  
220 compensated for a possible precipitation deficit by maintaining moisture conditions allowing  
221 the forest to maintain at the foot of the dunes for an additional two millennia after the end  
222 of the HHP.

223 Over the past millennium, tropical plant types stabilized at 30%, reflecting that sub-Guinean  
224 gallery forests remained only moderately developed in the Niayes area as compared to the  
225 HHP during which these values were at least 80% (Lézine, 1989). These % dramatically fall at  
226 1640 CE to a minimum at 1845 CE pointing to the setting of a severe environmental crisis:  
227 the biodiversity dramatically declined and the Baobab depression dried up, at least partially.  
228 The disappearance of green algae and their replacement by fungi in the lake sediments as  
229 well as the high values of salt-tolerant diatoms clearly show that hydrological conditions  
230 were more evaporated including pronounced seasonal drying of the depression (Fig. 4). This  
231 drought event in the Niayes area of Senegal is contemporaneous with the repeated dry years  
232 in the inner delta of the Niger River as recorded by documentary sources since 1639  
233 (Coquery-Vidrovitch, 1997) and continuing into the 19<sup>th</sup> century, particularly between years  
234 1800 and 1850 CE (Nicholson et al., 2012 *in* Nash et al., 2016). Similarly, the level of Lake  
235 Chad underwent multiple lowering phases (Maley, 1976) and drought conditions developed  
236 at Lake Bal, Nigeria (Holmes et al., 1999) during the 17<sup>th</sup> century.

## 237 **6.2 The drying trend from 1375 CE to 1900 CE**

238 The forest collapse 1640 CE occurred after several centuries of increasing drought starting  
239 from 1340 CE, as revealed by the development of marshy plant populations and of saline  
240 conditions in the Baobab depression.

241 The most prominent feature of the hydrological evolution of the Baobab depression during  
242 the last millennium is the development of *Syzygium* and *Typha* populations both resulting  
243 from the lowering of the water table responsible for a marsh development. As the water  
244 level dropped, *Syzygium* trees were able to expand towards the center of the depression.  
245 This situation also occurred in the Niayes area during the dry phases of the Holocene as  
246 shown by the well preserved woods of *Syzygium* trees north of Baobab, around Diogo  
247 (Figure 5).

248 The *Syzygium* development at Baobab occurred during the time interval 1340-1810 CE with a  
249 peak at 1490 CE. As the level dropped further, these trees progressively declined and were  
250 replaced by reed-swamp (*Typha*) populations that reached their maximum at 1688 CE. The  
251 *Typha*:Aquatic Pollen ratio used to illustrate the hydrological evolution of the Baobab  
252 depression (Figure 4B) confirms the gradual lowering of the water level. This evolution is also  
253 confirmed by the emergence of benthic and periphytic diatom taxa reflecting the lowering of  
254 the water level during the time-interval 1600-1925 CE (Diatom Zone 2b and 2c), i.e., during  
255 the drought event revealed by the pollen and fungi record. In the meantime, diatom taxa of  
256 cosmopolite or saline ecological tolerance reached their maximum testifying for increased  
257 evaporation. The development of the freshwater taxon *Typha* at the lake margin during this  
258 period is not incompatible with the increase in water salinity revealed by the diatomaceous  
259 flora since *Typha* can tolerate brackish water for long periods of time and even develop on  
260 dry soils affected by seawater infiltration (Adam, 1964).

261 Our Baobab record does not show the humid event described in the Sahel by Maley (1977)  
262 at lake Chad around 1600 CE and Carré et al (2018) in the Saloum area of Senegal, 1500-  
263 1800 CE as well as in Eastern Africa by e.g., Verschuren et al., 2000 and Stager et al., 2005.  
264 However, it closely matches the Lake Bosumtwi record (Shanahan et al., 2009) which  
265 identifies a drought event between 1400 and 1750 CE, “*similar in timing to the Little Ice Age*  
266 *(LIA, ~1400 to 1850 CE)*”. From our record, the LIA was a period of increased dryness in the  
267 Niaye area of Senegal with a particularly severe drought event peaking at 1845 CE.

### 268 **6.3 The anthropogenic impact**

269 Micro-charcoal fragments are insignificant in number at levels prior to 1600 CE. Then, during  
270 the LIA, they increase slightly, reflecting repeated fires during marked and probably longer  
271 dry seasons. In contrast, their unprecedented increase over the past two decades suggests a  
272 radical change in regional economic activities, probably in relation to the intensification of  
273 charcoal production around the cities of Thiès and St-Louis (Gueye, 2000).

274

### 275 **7. Conclusion**

276 Our pollen, charcoal and algae record of the Baobab sedimentary sequence near Mboro  
277 shows that, during the last millennium, the Niayes area of Senegal underwent a gradual  
278 aridification which culminated 1845 CE. This drying trend occurred during the Little Ice Age  
279 during which the Northern Hemisphere experienced cool climate conditions. In the Niayes  
280 area, the sub-Guinean gallery forests, which survived the previous environmental crisis  
281 dated from the end of the Holocene Humid Period 2500 years ago, suddenly collapsed and  
282 the region suffered a dramatic loss of biodiversity. We show that the tipping point between  
283 a forested and a non-forested state occurred ca 400 centuries after the onset of aridity  
284 recorded by the lowering of the water level and the progressive salinization of the aquatic

285 environment. This response time of tropical ecosystems to climate change can have critical  
286 implications for biodiversity and forest management strategies.

287

## 288 **Acknowledgements**

289 This work was initiated in the frame of a CNRS INSU LEFE research project headed by M.  
290 Carré and an IRD scientific network coordinated by A. Sifeddine (CLIMACTE). It is an  
291 "ACCEDE" Belmont Forum contribution (18 BELM 0001 05). Thanks are due to the Institut de  
292 Recherche pour le Développement (IRD) in Senegal and the UCAD Geological Department for  
293 logistic support in the field and authorizations and to the ECLAIRS international laboratory,  
294 Dakar and the LOCEAN laboratory for fundings. AML and KL are funded by CNRS, CAKF by  
295 UCAD. Raw data will be stored at NEOTOMA and are also available on request from the first  
296 author.

297

## 298 **References**

- 299 Adam, J.G. 1953. Note sur la végétation des Niayes de la presqu'île du Cap Vert (Dakar, AOF).  
300 Bulletin de la Société Botanique de France 100, 153-158.
- 301 Adam, J.G. 1958. Flore et végétation de la réserve botanique de Noflaye (environs de Dakar,  
302 Sénégal). Bulletin de l'Institut Fondamental d'Afrique Noire (A), 20/3, 809-868.
- 303 Adam, J.G. 1964. Contribution à l'étude de la végétation du lac de Guiers (Sénégal). Bulletin  
304 de l'Institut Fondamental d'Afrique Noire (A) 26/1, 1-72.
- 305 Aguiar, L.A., Garneau, M., Lézine, A.M., Maugis, P., 2010. Évolution de la nappe des sables  
306 quaternaires dans la région des Niayes du Sénégal (1958-1994): relation avec le climat  
307 et les impacts anthropiques. Sécheresse 21(2), 97-104.

308 Association des Palynologues de Langue Française (APLF) 1974. Pollen et spores d'Afrique  
309 tropicale. Talence, CEGET. Travaux et Documents de Géographie Tropicale 16.

310 Battarbee, R.W., 1986. Diatom analysis. In Berglund, B.E. and Ralska-Jasiewiczowa, M. (eds)  
311 Handbook of Holocene palaeoecology and palaeohydrology, pp. 527-570. Chichester,  
312 John Wiley and Sons Ltd.

313 Bellinger, E.G., Sigeo, D.C. 2015. Freshwater algae, identification, enumeration and use as  
314 bioindicators. 2nd edition, Wiley Blackwell.

315 Bonnefille, R., Riollet, G. 1980. Pollens des savanes d'Afrique tropicale. Paris, CNRS.

316 Carré, M., Azzoug, M., Zaharias, P., Camara, A., Cheddadi, R., Chevalier, M., Fiorillo, D., Gaye,  
317 A.T., Janicot, S., Khodri, M., Lazar, A., 2019. Modern drought conditions in western  
318 Sahel unprecedented in the past 1600 years. *Climate Dynamics* 52(3-4), 1949-1964.

319 Cocquyt, C., Vyverman, W., Compère P. 1993. A check-list of the algal flora of the East  
320 African Great Lakes (Malawi, Tanganyika and Victoria). National Botanic Garden of  
321 Belgium.

322 Compère, P. 1991. Contribution à l'étude des algues du Sénégal. Algues du lac de Guiers et  
323 du Bas Sénégal. *Bulletin du Jardin Botanique National de Belgique* 61, 171–267.

324 Coquery-Vidrovitch, C. 1997. Écologie et histoire en Afrique noire. In: Histoire, économie et  
325 société, 16<sup>e</sup> année, n°3. Environnement et développement économique. pp. 483-504

326 Faegri, K., Iversen, J. 1977. Textbook of pollen analysis. Oxford, Blackwell.

327 Faye, S. 1995. Modélisation hydrodynamique des nappes du littoral Nord entre Cayar et St.  
328 Louis. Impact des futurs prélèvements envisagés dans le cadre de l'approvisionnement  
329 en eau de Dakar et de ses environs. PhD Thesis, Université Cheick Anta Diop, Dakar.

330 Foged, N. 1986. Diatoms in Gambia. *Bibliotheka diatomologica* 12, 1–124.

331 Gasse, F. 1986. East African diatoms. Taxonomy, ecological distribution. *Bibliotheca*  
332 *Diatomologica* 11, 1–202.

333 Grimm, E. 1991. *Tilia and Tiliagrah*, Illinois State Museum, Springfield.

334 Guerneur, P. 1954. Diatomées de l'AOF (première liste, Sénégal). Institut français d'Afrique  
335 noire

336 Guèye, S., 2000. Etude sur les ressources forestières et les plantations forestières du  
337 Sénégal: période 1992-99. Projet GCP/INT/679/EC. CE, FAO.

338 Hammer, Ø., Harper, D.A.T., Ryan, P.D. 2001. PAST: Paleontological Statistics Software  
339 Package for Education and Data Analysis. *Palaeontologia Electronica* 4(1).

340 Hély C., Lézine A.-M., APD members 2014. Holocene changes in African vegetation: tradeoff  
341 between climate and water availability. *Climate of the Past* 10(2), 681-686.

342 Holmes, J.A., Allen, M.J., Street-Perrott F.A., Ivanovich, M., Perrott, R.A., Waller, M.P. 1999.  
343 Late Holocene palaeolimnology of Bal Lake, Northern Nigeria, a multidisciplinary study  
344 *Paleogeography, Paleoclimatology, Palaeoecology* 148, 169-185.

345 Jaeger, P. 1949. La végétation. *Etudes sénégalaises I “la presqu’île du Cap Vert”*, pp. 93-157,  
346 Dakar, Institut Fondamental d’Afrique Noire.

347 Jowsey, P. C. 1966. An approved peat sampler. *New Phytologist* 65, 245-248.

348 Lebrun, J.-P., Stork, A.L. 1991-2015. *Enumération des plantes à fleurs d'Afrique tropicale*  
349 *et Tropical African Flowering Plants: Ecology and Distribution*, vol. 1-7. Conservatoire  
350 et Jardin botaniques de la Ville de Genève.

351 Lézine, A.-M. 1987. Paléoenvironnements végétaux d'Afrique nord-tropicale occidentale  
352 depuis 12 000 B.P: analyse pollinique de séries sédimentaires continentales (Sénégal-  
353 Mauritanie). PhD Thesis, Univ. Aix-Marseille.



354 Lézine, A.-M. 1989. Late Quaternary vegetation and climate of the Sahel. Quaternary  
355 Research 32, 317-334.

356 Lézine, A.-M., Chateauneuf, J.-J. 1991. Peat in the "Niayes" of Senegal: depositional  
357 environment and Holocene evolution. Journal of African Earth Sciences 12, 171-179.

358 Lézine, A.-M., Hély, C., Grenier, C., Braconnot, P., Krinner, G. 2011. Sahara and Sahel  
359 vulnerability to climate changes, lessons from paleohydrological data. Quaternary  
360 Science Reviews 30, 21-22, 3001-3012.

361 Lézine, A.-M., Watrin, J., Vincens, A., Hély, C. and contributors. 2009. Are modern pollen  
362 data representative of west African vegetation? Review of Palaeobotany and  
363 Palynology 156, 3-4, 265-276

364 Maley, J., 1976. Mécanisme des changements climatiques aux basses latitudes.  
365 Paleogeography, Paleoclimatology, Palaeoecology 14, 193-227.

366 Maley, J. 1970. Contribution à l'étude du bassin tchadien : atlas des pollens du Tchad.  
367 Bulletin du Hardin Botanique national de Belgique 40, 29-48.

368 Maugis, P., Aguiar, L., Grenier, C., 2009. Hydrogeological modeling as a tool supporting the  
369 interpretation of pollen proxies for palaeoclimate reconstitution: The Senegalese  
370 "niayes" case-study. Comptes Rendus Geoscience 341(8-9), 783-793.

371 Michel, P., 1973. Les bassins des fleuves Sénégal et Gambie: étude géomorphologique.  
372 ORSTOM, Paris.

373 Michel, P., Naegelé, A., Toupet, C. 1969. Contribution à l'étude biologique du Sénégal  
374 septentrional. I : le milieu naturel. Bulletin de l'Institut Fondamental d'Afrique Noire  
375 (A) 31, 757-839.

376 Nash D. J., De Cort G., Chase B. M., Verschuren D., Nicholson S. E., Shanahan T. M., Asrat A.,  
377 Lézine A.-M., Grab S. W. 2016. African hydroclimatic variability during the last 2000  
378 years. *Quaternary Science Reviews* 154, 1-22.

379 Ndiaye, P., Mailly, D., Pineau, M., Margolis, H.A. 1993. Growth and yield of *Casuarina*  
380 *equisetifolia* plantations on the coastal sand dunes of Senegal as a function of  
381 microtopography. *Forest ecology and management* 56(1-4), 13-28.

382 Nicholson, S.E., Klotter, D., Dezfuli, A.K., 2012. Spatial reconstruction of semi-quantitative  
383 precipitation fields over Africa during the nineteenth century from documentary  
384 evidence and gauge data. *Quaternary Research* 78, 13-23.

385 ORSTOM, 1962. Carte pédologique 1:10000, M'Boro. Paris/Dakar, ORSTOM

386 Pezeril, G., Chateauneuf, J. J., Diop, C. E. W. 1986. La tourbe des Niayes au Sénégal : genèse  
387 et géologie. Symp. intern. INQUA-ASEQUA "Changements globaux en Afrique durant le  
388 Quaternaire. Passe, Present, Futur", 385-391. Paris, ORSTOM. Travaux et docs 197.

389 Raynal, A. 1963. Flore et végétation des environs de Kayar (Sénégal). (de la côte au lac  
390 Tanma). *Annales de la Faculté des Sciences de Dakar* 9, 121-231.

391 Servant-Vildary, S. 1978. Etude des diatomées et paléolimnologie du bassin Tchadien au  
392 Cénozoïque supérieur. *Travaux et Documents ORSTOM-Paris* 84, 1-346.

393 Shanahan, T.M., Overpeck, J.T., Anchukaitis, K.J., Beck, J.W., Cole, J.E., Dettman, D.L., Peck,  
394 J.A., Scholz, C.A., King, J.W., 2009. Atlantic forcing of persistent drought in West Africa.  
395 *science* 324(5925), 377-380.

396 Sow, E. 2001. Le Quaternaire récent du Sénégal occidental (Lacs Retba et Tanma; Estuaire de  
397 la Casamance). PhD Thesis, Université de Dakar, Sénégal.

398 Sow, E. 2004. Les diatomées subfossiles de la mare de Thiaroye (Dakar-Sénégal): inventaire  
399 floristique et paléoenvironnement. *Vie et Milieu* 54, 171-180.

400 Sow, E., Diene, M., 2002. Résultats préliminaires sur les diatomées de la Casamance  
401 (Sénégal): mise en évidence de deux périodes pluviales le long du sondage de Sédhiou.  
402 *Diatom Research* 17(1), 219-234.

403 Sow, E., Sarr, R., Diop-Ngom, F. 2005. Les diatomées du Quaternaire récent de Diana Malari  
404 (Casamance, Sénégal): implications paléoclimatiques. *Sécheresse* 16, 137–142.

405 Stager, J.C., Ryves, D., Cumming, B.F., Meeker, L.D., Beer, J., 2005. Solar variability and the  
406 levels of Lake Victoria, East Africa, during the last millenium. *Journal of Paleolimnology*  
407 33(2), 243-251.

408 Trochain, J. 1940. Contribution à l'étude de la végétation du Sénégal. Paris, Larose.

409 Verschuren, D., Laird, K.R., Cumming, B.F. 2000. Rainfall and drought in equatorial east Africa  
410 during the past 1,100 years. *Nature* 403, 410.

411 Villiers, A. 1957. Aperçu sommaire sur le peuplement des Niayes de la presqu'île du Cap Vert  
412 (Sénégal). *Bulletin de l'Institut Fondamental d'Afrique Noire (A)*19/1, 333-345.

413 Vincens, A., Lézine, A.-M., Buchet, G., Lewden, D., Le Thomas, A. and contributors. 2007.  
414 African Pollen Database inventory of tree and shrub pollen types. Review of  
415 *Palaeobotany and Palynology* 145, 1-2, 135-141

416 Watrin, J., Lézine, A.-M., Gajewski, K., Vincens, A. 2007. Pollen-Plant-Climate relation in sub-  
417 Saharan Africa. *Journal of Biogeography* 34, 3, 489-499

418 Watrin, J., Lézine, A.-M., Hély, C. 2009. Plant migration and ecosystems at the time of the  
419 "green Sahara". *Comptes Rendus Geoscience* 341, 656-670.

420 Ybert, J.P. 1979. Atlas des pollens de Côte d'Ivoire. Paris, ORSTOM.

421

422 **Table and Figure captions:**

423 Table 1: List of pollen taxa recovered in the Baobab last millennium sequence. Nomenclature  
424 follows Vincens et al., 2007.

425 Table 2: List of Diatom taxa recovered in the Baobab last millennium sequence.

426 Table 3: Radiocarbon measurements (UMS-ARTEMIS AMS Facilities, France) and additional  
427 control points: 1948 CE: first appearance of *Casuarina equisetifolia* pollen grains in the  
428 sediments; 2016 CE: date of the core recovery).

429

430 Figure 1: The Niaye gallery forest. A: Schematic distribution of plants on dune slopes from  
431 the Sahelian steppes at the top of the dunes to the open-water surface at the bottom  
432 of the depressions (Raynal, 1963; Michel et al., 1969); B: The Mboro complex of  
433 paleodrainages and interdunal depressions filled by organic matter and the location of  
434 the study site (black dot) (ORSTOM, 1962).

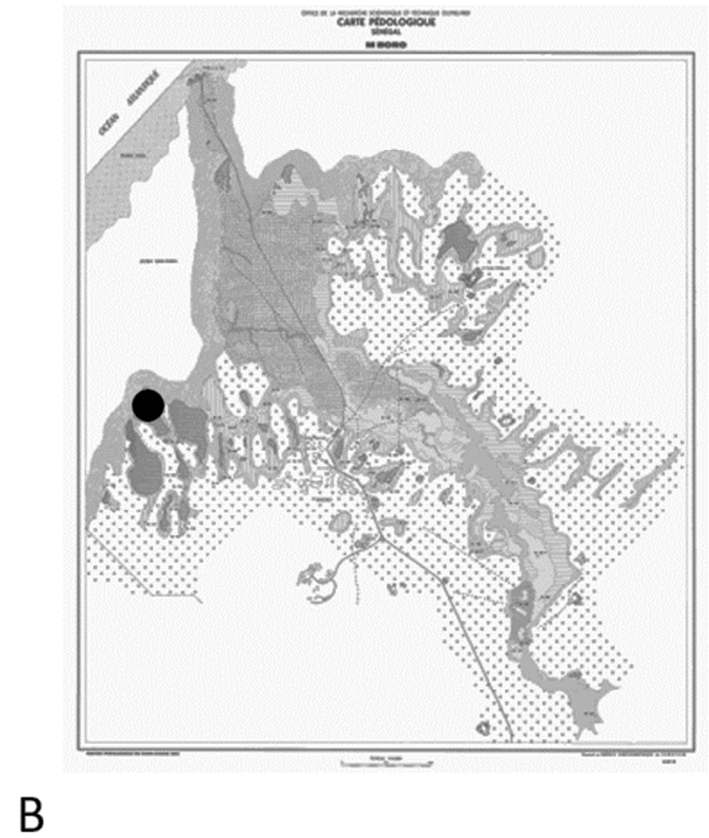
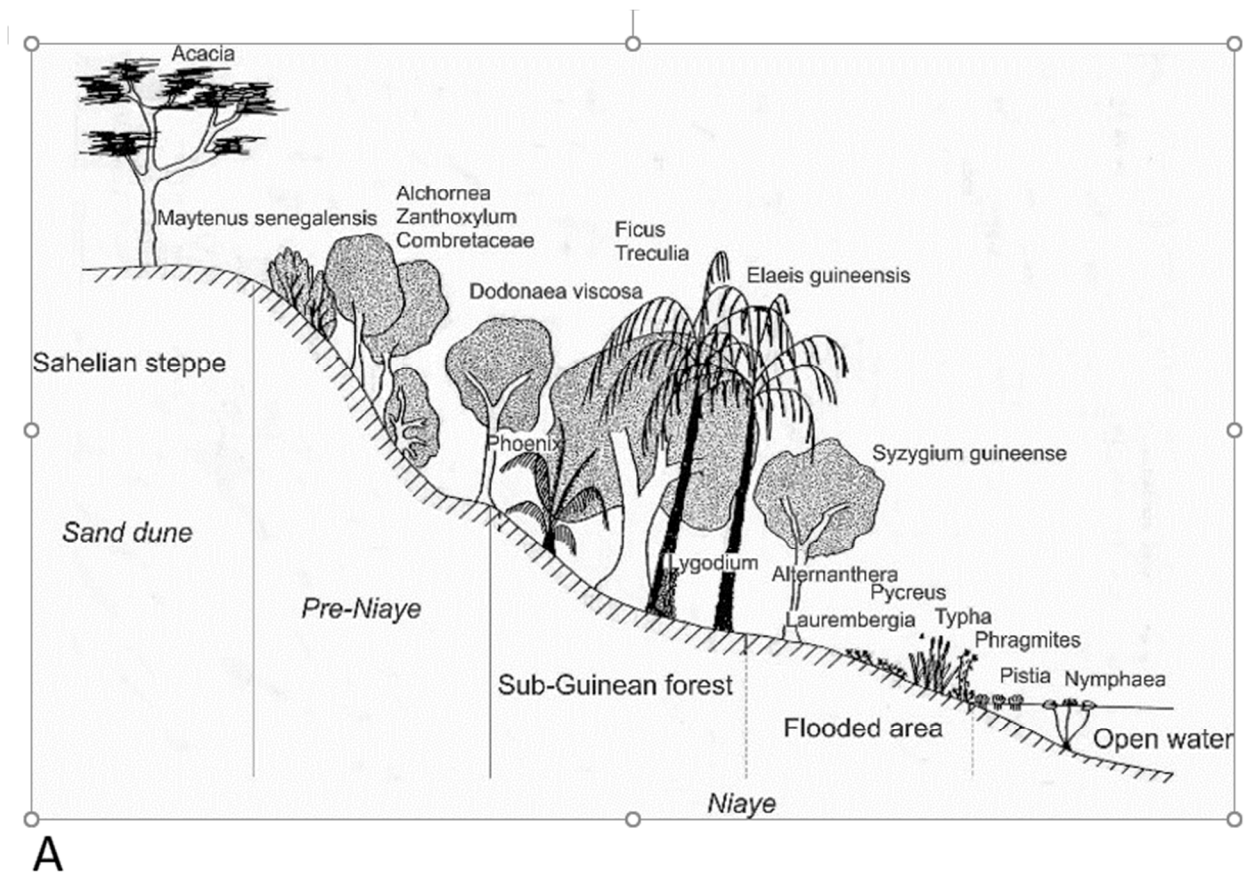
435 Figure 2: Synthetic pollen diagram of the Baobab (last millennium) showing from left to right  
436 versus time (in chronology CE) selected plant taxa. On the right, the Simpson D-1 index  
437 of diversity.

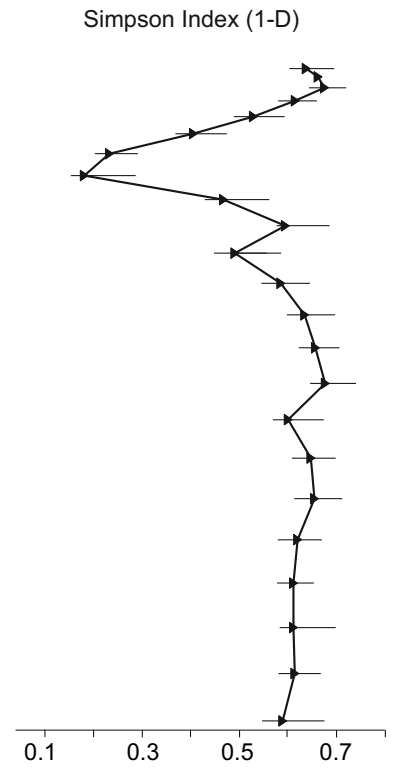
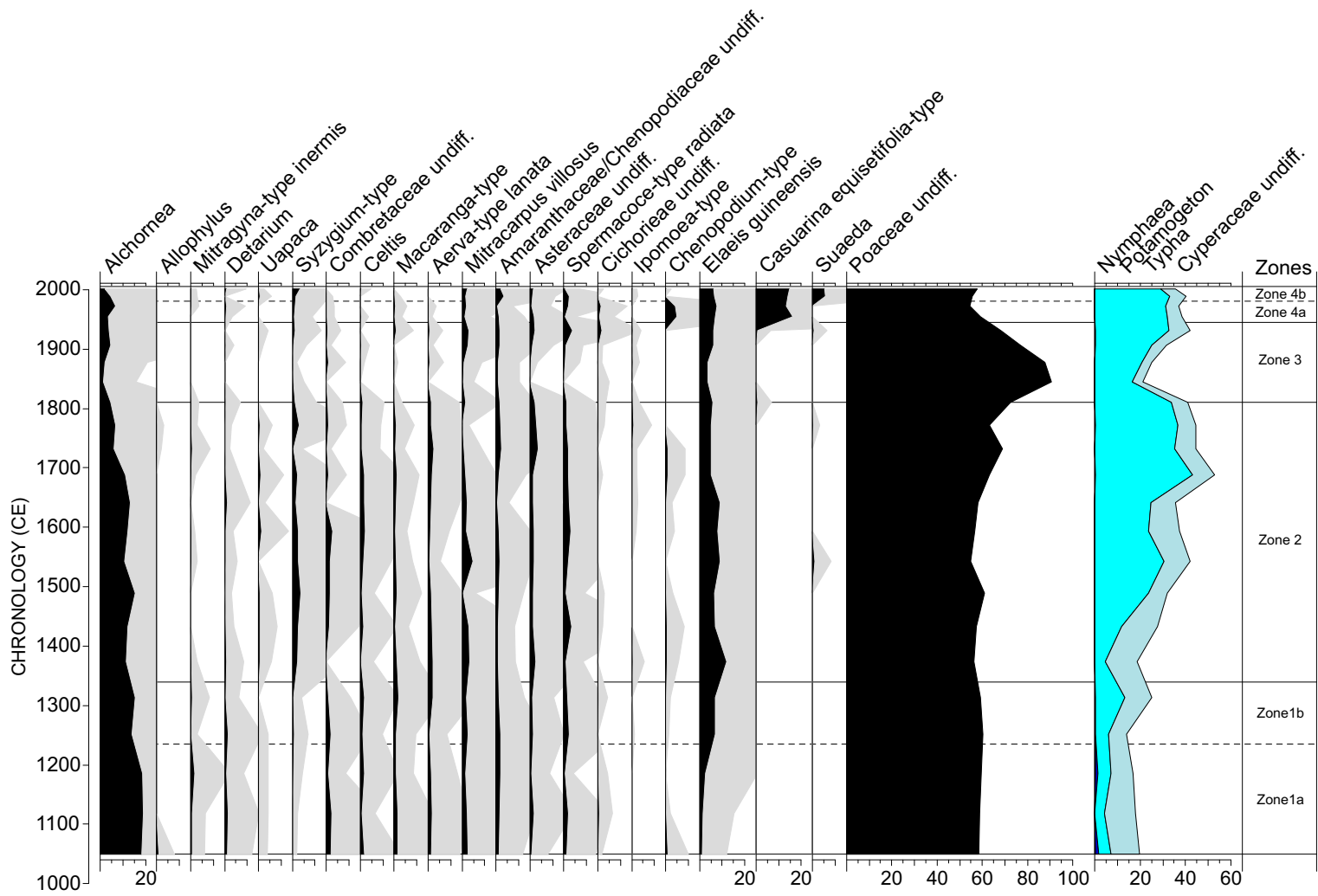
438 Figure 3: Synthetic diagram of the Baobab (last millennium) diatom and NPP record showing  
439 from left to right versus time (in chronology CE) A: selected diatom taxa, main groups  
440 of diatoms according to their ecological significance, the Simpson D-1 index of diatom  
441 diversity and B: the NPP (Fungi and Green Algae) record.

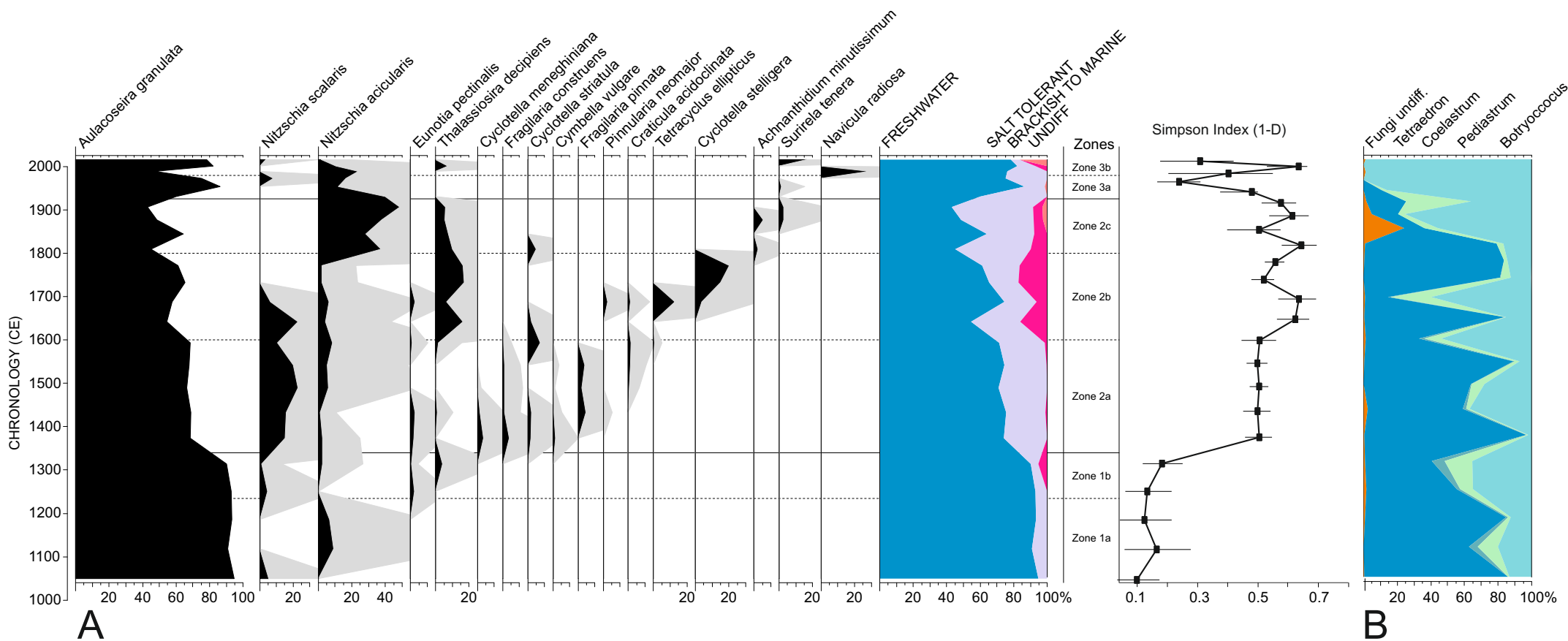
442 Figure 4: Main paleoenvironmental features at Baobab, (Mboro sector of the Niaye area,  
443 Senegal) during the last millennium. A: Pollen and Fungi% and Charcoal influxes  
444 illustrating the drying trend which led to the main environmental crisis peaking at 1845  
445 CE in the Niayes area of Senegal and the increase of the anthropogenic activity during

446 the last centuries; B: pollen markers of lake level lowering; C: diatom markers of  
447 increased salinity.

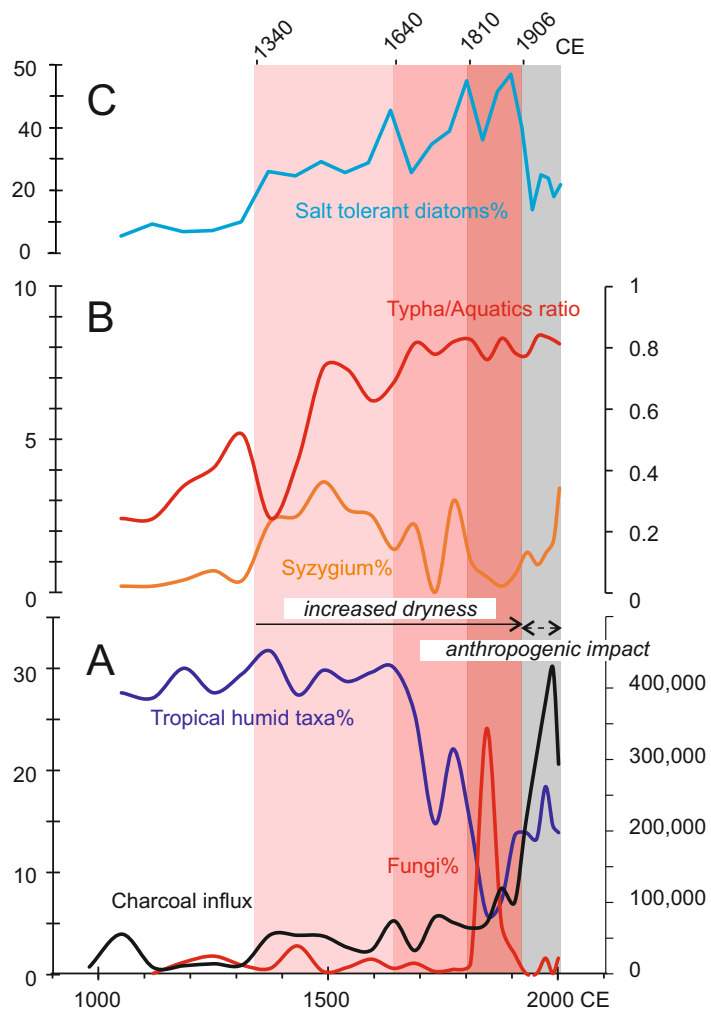
448 Figure 5: Fossil woods of *Syzygium guineense* of late Holocene age preserved in the organic  
449 levels of the Niaye sediments (Mandeng-Yogo, work in progress). A: the trunks emerge  
450 thanks to the digging of a well; B: the red arrows show the traces of the base of the  
451 *Syzygium* trees that formed a dense forest at the bottom of the interdunal  
452 depressions.

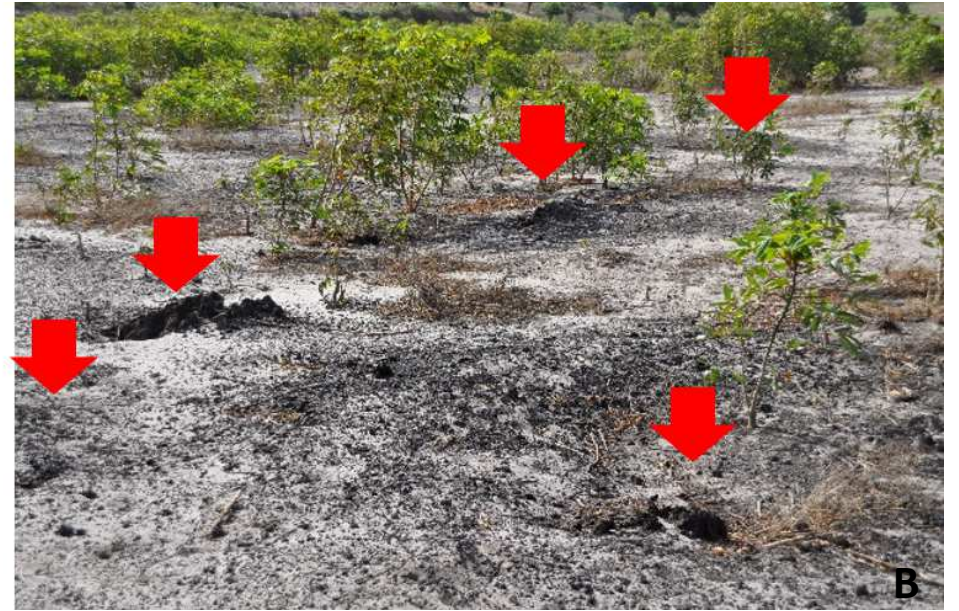












**TREES and SHRUBS**

Acacia  
Adansonia digitata  
Alchornea cordifolia  
Allophylus  
Anacardiaceae undiff.  
Anogeissus-type leiocarpus  
Anthostema-type  
Bridelia-type  
Capparis fascicularis-type  
Casuarina equisetifolia-type  
Celastraceae undiff.  
Celtis  
Chrysobalanus icaco/Parinari  
Cissampelos-type  
Cocculus pendulus-type  
Combretaceae undiff.  
Combretum-type aculeatum  
Combretum-type molle  
Commiphora africana-type  
Detarium senegalense  
Dictyandra  
Diospyros  
Elaeis guineensis  
Ficus  
Hymenocardia  
Khaya-type senegalensis  
Lannea-type  
Macaranga-type  
Mallotus-type  
Mitragyna-type inermis  
Morelia senegalensis  
Myrianthus-type  
Paullinia pinnata  
Phoenix reclinata-type  
Prosopis-type africana  
Salacia  
Sapotaceae undiff.  
Syzygium-type  
Tabernaemontana  
Tamarix  
Tapinanthus-type  
Tetracera  
Tinospora bakis  
Uapaca  
Zanthoxylum-type zanthoxyloides

**UNDIFFERENTIATED**

Acalypha  
Aeschynomene  
Amaranthaceae/Chenopodiaceae undiff.  
Asteraceae undiff.  
Cichorieae undiff.  
Hibiscus  
Ipomoea-type  
Justicia-type  
Polygala-type  
Rubiaceae undiff.  
Solanum-type  
Suaeda  
Triumfetta-type  
Undetermined

**HERBS**

Achyranthes-type aspera  
Aerva-type lanata  
Alternanthera  
Centaurea-type perrottetii  
Cerastium-type  
Chenopodium-type  
Cleome-type gynandra  
Commelina-type benghalensis  
Commelina-type forskalaei  
Gomphrena  
Justicia-type flava  
Mitracarpus villosus  
Poaceae undiff.  
Polycarpaea-type  
Polycarpon-type  
Spermacoce-type radiata  
Tribulus

**AQUATICS**

Cyperaceae undiff.  
Laurembergia tetrandra  
Ludwigia-type stolonifera  
Nymphaea lotus-type  
Polygonum senegalense-type  
Potamogeton  
Typha

**FERNS**

Lygodium microphyllum  
Monolètes à épines et non lisses autres  
Monoletes undiff.  
Triletes undiff.

FRESHWATER

*Aulacoseira granulata*

*Craticula acidoclinata*

*Cymbella vulgare*

*Fragilaria construens*

*Fragilaria pinnata*

*Navicula densa*

*Navicula radiosa*

*Pinnularia divergens*

*Pinnularia neomajor*

*Tetracyclus ellipticus*

SALT TOLERANT

*Achnanthydium minutissimum*

*Cyclotella meneghiniana*

*Cyclotella stelligera*

*Cyclotella striatula*

*Eunotia pectinalis*

*Nitzschia acicularis*

*Nitzschia scalaris*

*Rhopalodia gibba*

BRACKISH TO MARINE

*Navicula groveoides*

*Surirela fastuosa*

*Thalassiosira decipiens*

UNDIFF

*Surirela tenera*

Lab number SacA	Sample (cm)	Nature	Median Age CE	Range 1 $\sigma$
49827	BAOBAB 2016 (99-100)	MO	1346	1317-1407
49828	BAOBAB 2016 (299-300)	MO	-1547	1607-1503
49829	BAOBAB 2016 (399-400)	MO	-2349	2454-2289

Additional control points (Age CE)				
	BAOBAB 2016 (0.5)	surface	2016	
	BAOBAB 2016 (30.5)	First record of Casuarina pollen grains	1948	