

Late Quaternary vegetation and climate dynamics in southeastern Amazonia inferred from Lagoa da Confusão in Tocantins State, northern Brazil*

by

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Abstract

Late Quaternary vegetation and climate dynamics have been reconstructed by pollen analysis of a lacustrine sediment core from Lagoa da Confusão. The lake lies about 160 km southwest of Palmas, capital of Tocantins State. The study area is located in the cerrado (savanna) and cerrado/Amazon rain forest transition region of southeastern Amazonia. The record, dated by 4 AMS radiocarbon dates, provide insight into vegetation and climate dynamics of late Pleistocene and Holocene age. Pollen data indicate that the study region was dominated by cerrado (savanna), first of the campo limpo type (grassland savanna) between 60,300-51,700 (chronology A) or 29,000-27,400 ^{14}C yr B.P. (chronology B) and than of the campo sujo type between 51,700-24,670 (chronology A) or 27,400-14,000 ^{14}C yr B.P. (chronology B). Existing small areas of gallery forests increased slightly during the second period. Amazon forest taxa occurred sparsely in the study region. The palaeovegetation infer a markedly drier climate (low precipitation and long annual dry season) during the glacial periods compared to the modern climate. A sedimentary gap probably occurred during the full glacial and/or Lateglacial period, suggesting drier climatic conditions than during the two earlier periods. During the early and mid Holocene the campo cerrado type (savanna woodland) was dominant and the landscape was more forested by the stronger presence of gallery forest and Amazon forest trees. Precipitation was higher, and the length of the annual dry season was shorter than during the late Pleistocene periods. After 5460 ^{14}C yr B.P. campo cerrado was still dominant, but forest cover increased markedly by the expansion Amazon forest populations and palm trees, reflecting the wettest climate period recorded. The results from Lagoa da Confusão support the general trend of dry glacial conditions, as reported from other tropical South American lowland regions. The expansion of the Amazon rain forest since the mid Holocene in northwestern and southwestern Amazonia is now also confirmed for the southeastern Amazon region.

Keywords: Late Quaternary, Amazon rain forest, savanna-cerrado, vegetation dynamics, climate dynamics, Brazil.

Resumo

A vegetação do Quaternário Superior e a dinâmica climática tem sido reconstruídas através da análise de polens de sedimentos lacustrinos amostrados da Lagoa da Confusão. O lago encontra-se a 160 km do

*Dedicated to Prof. Dr. Harald Sioli on the occasion of his 90th anniversary.

sudeste de Palmas, a capital do estado do Tocantins. A área de estudo está localizada no cerrado (savana) e em uma região de transição cerrado/floresta tropical no sudeste da Amazônia. Os registros, com 4 datações por radiocarbono (AMS), esclarecem a dinâmica climática e a vegetação do Pleistoceno Superior e do Holoceno. Dados de pólen indicam que a região de estudo foi dominada pelo cerrado do tipo campo limpo (savana de gramas) entre 60.300-51.700 (cronologia A) ou 29.000-27.400 ^{14}C anos A.P. (cronologia B) e do tipo campo sujo entre 51.700-24.670 (cronologia A) ou 27.400-14.000 ^{14}C anos A.P. (cronologia B). A existência de pequenas áreas de florestas de galerias aumentaram durante o segundo período. A floresta amazônica ocorreu em diferentes pontos na região de estudo. A paleovegetação infere um clima seco (baixa precipitação e uma longa estação seca anual) durante o período glacial comparado ao clima moderno. Um “gap” sedimentar provavelmente ocorreu durante a totalidade do período glacial e/ou no período glacial superior, sugerindo condições climáticas mais secas do que durante os dois períodos antecessores. Durante o Holoceno médio e inferior o campo cerrado foi dominante e a paisagem foi mais florestada por uma mais forte presença de floresta de galeria e árvores da floresta amazônica. A precipitação foi maior, e a extensão da estação seca anual foi mais curta do que durante o período Pleistocênico. Depois de 5460 ^{14}C anos A.P. o campo cerrado foi ainda dominante, mas a cobertura de floresta aumentou marcadamente pela expansão da população da floresta amazônica e árvores de palmeiras, refletindo um período climático mais úmido. Os resultados da Lagoa da Confusão apóiam uma tendência geral de condições glaciais secas, como revelado em outras regiões tropicais baixas da América do Sul. A expansão da floresta tropical Amazônica desde o Holoceno médio no noroeste e sudoeste da Amazônia é agora também confirmado para o sudeste da região Amazônica.

Introduction

The late Quaternary environmental history of tropical South American lowland ecosystems is poorly known despite the importance to understand the natural amplitude of the dynamics of tropical ecosystems. Improved understanding would help to verify global climate models and estimation on late Quaternary carbon storage by forest ecosystems. Further, studies on past ecosystem dynamics are important to understand modern ecosystem and climate dynamics.

Only a few pollen records are available from southeastern Amazonia and the cerrado region of the northern part of central Brazil (Fig. 1). There is the record from the Carajas mountain (Serra Sul, CSS2) in southeastern Pará State (ABSY et al. 1991). Further there are two records available from central Brazil: Agua Emendadas (BARBERI 1994; SALGADO-LABOURIAU et al. 1997) and the record from Cromínia (FERRAZ-VICENTINI & SALGADO-LABOURIAU 1996).

A review of pollen records from tropical South American savanna and forest/savanna transition zones show that sites in transitional zones between savanna and forest, were most sensitive to past environmental change (BEHLING & HOOGHMISTRA 2001). Pollen analytical records from Amazon rain forest/savanna transition regions north and south of the equator illustrate that during the full-glacial period savannas expanded due to markedly drier conditions. The Amazon rain forest area must have been reduced. During the early Holocene the climate was drier in most of the South American savannas than during the Lateglacial and late Holocene periods. Early Holocene distribution of savanna was much larger than during late Holocene periods. In western South America in the savanna/Amazon rain forest transitional zone north and south of the equator an expansion of the Amazon rain forest since mid and/or late Holocene has been documented by BEHLING & HOOGHMISTRA (2000) and MAYLE et al. (2000), respectively.

The aim of this study is to investigate the environmental history of the southeastern Amazonia between the region of the Amazon rain forest and the central Brazilian

cerrado. Special focus will be on savanna/Amazon rain forest dynamics to explore if the Amazon rain forest also expanded in the southeastern Amazonia. Late Quaternary climate dynamics will be inferred from the reconstructed palaeovegetation.

Modern environmental setting

Lagoa da Confusão (10°38'S, 49°43'W) is found in a soft rolling landscape at 180 m elevation, about 160 km southeast of the city Palmas in Tocantins State (Fig. 1). To the east of the study region begins in 30 km distance the Araguaia National Park. The park belongs to the Bananal Island, a river island of the Rio Araguaia drainage system. The study site lies in about 90 km distance to Rio Araguaia. The circular shaped lake is about 5 km in diameter and is with 2 m water depth relatively shallow. The lake has apparently no connections to major rivers.

The modern vegetation of the Lagoa da Confusão region is cerrado and transition vegetation types from cerrado to Amazon rain forest. The distance to the Amazon rain forest is about 100 km, located on the western side of Rio Araguaia. Cerrado can be classified into five physiognomic vegetation forms (EITEN 1972, 1982). These are: (1) grasslands (campo limpo), (2) grasslands with small shrubs and occasionally small trees (campo sujo), (3) open or closed low tree and/or scrub woodlands (campo cerrado), (4) tree and scrub woodland with 2 to 5 m tall trees and an open tree canopy (cerrado, in the strict sense), and (5) arboreal woodlands with 5 to 15 m tall trees with a semiclosed or closed tree canopy (cerradão). The composition and distribution is the result of several environmental constraints, including pedological, physical, biotic, and climatic factors. The floristic composition of the extensive cerrado area is not homogeneous and has contact zones with other vegetation types such as the Amazon rain forest, deciduous and semideciduous forest, and caatinga. Floristic analysis of 98 cerrado sites, including Amazon savannas, showed that cerrado vegetation is very heterogeneous (RATTER et al. 1996).

The modern climate of the Lagoa da Confusão region is characterised by a tropical seasonal climate. A dry period of 5 months occurs between June and November. The climate station of Conceição do Araguaia and Paraná (WALTER & LIETH 1967), 450 km north and 300 km southeast of Lagoa da Confusão, respectively, documents a mean annual precipitation of 1580 mm for both stations. The average annual temperature is 25.9 °C for Conceição do Araguaia and 22.8 °C for Paraná. Measured maximum and minimum temperatures for Paraná are 40.6 °C and 8.9 °C, respectively.

The general atmospheric circulation of the study region is controlled by the position of the intertropical convergence zone (ITCZ), which shifts from 7°-9°N in July to 10°-20°S in January (SNOW 1976; WEISCHET 1996). Consequently, two different main climate types are represented: a climate without a dry season in the equatorial latitudes, and climates with marked dry seasons north of south of the equatorial latitudes, which determine the distribution of savanna vegetation north and south of the Amazon rain forest.

Material and methods

The sediments were cored in the central-eastern part of the lake from a wooden platform fixed on two inflatable rubber boats, using a modified Livingstone piston sampler. The recovered core is 5 cm in diameter and 68 cm long. Sediments were kept in the original aluminium tube and transported to the laboratory. Core material was stored in a dark cold room at 4°C.

Four small 1 cm thick bulk sediment samples were dated by Accelerator Mass Spectrometry (AMS)

at the University of Utrecht.

Subsamples of 1 cm³, at 2 cm intervals along the 68-cm-long core, were processed with standard pollen analytical methods, including sodium pyrophosphate, acetolysis, and heavy liquid separation by bromoform (FAEGRI & IVERSON 1989). To determine the pollen concentration, one tablet of exotic *Lycopodium clavatum* spores were added to each sample. Pollen and spores were well preserved and sufficient for analysis, starting at 52 cm core depth. Samples below 53 cm contained no or poorly preserved pollen. A minimum of 300 pollen grains was counted for each sample. The pollen sum includes herbs, shrubs and trees, but not aquatic pollen, fern spores, and the algae *Botryococcus*. Pollen identification relied on morphological descriptions published by BEHLING (1993), HERRERA & URREGO (1996), ROUBIK & MORENO (1991), SALGADO-LABOURIAU (1973) and on the author's own reference collection containing about 2000 Brazilian species.

For illustration of the pollen and spore data, calculations and cluster analysis, the software TILIA, TILIAGRAPH and CONISS were used (GRIMM 1987). The pollen percentage diagram include individual records of the most abundant pollen and spore taxa. The percentage summary pollen diagram show records of the groups: (1) cerrado herbs, (2) cerrado shrubs and trees, (3) Amazon and gallery forest shrubs and trees, (4) aquatics, (5) ferns without *Isoetes*, (6) fungal spores, and (7) *Botryococcus*, followed by the pollen concentration, and a cluster analysis dendrogram (Fig. 3). The zonation of the pollen record is based on changes in the pollen assemblages illustrated by cluster analysis.

Results

Stratigraphy

The 68-cm-long sediment core from Lagoa da Confusão consist at the base of yellow sand with very little clay, followed by fine sand with clay (68-58 cm), clay with fine sand (58-23 cm), sandy fine detritus mud (23-0 cm) (Table 1).

Radiocarbon data and chronological control

Four AMS radiocarbon dates (Table 2) provide chronological control for the pollen record and indicate lacustrine deposits of late Pleistocene and Holocene age. The obtained radiocarbon dates of the sediment samples at 44 cm and at 24 cm core depth are nearly of the same age with $24,880 \pm 200$ ¹⁴C yr B.P. and $25,900 \pm 220$ ¹⁴C yr B.P., respectively. The pollen concentration between 44 and 24 cm core depth (see Fig. 3 and following chapter) is about 4 times higher than in the Holocene samples. This indicates that the deposits between 44 cm and 24 cm contain a relatively long time interval, suggesting that the radiocarbon date at 44 cm is to young or the date at 24 cm is to old. The calculated radiocarbon age for the beginning of the pollen record at 52 cm is 60,300 ¹⁴C yr B.P. (excluding the date at 44 cm) - chronology A - or 29,000 ¹⁴C yr B.P. (excluding the date at 24 cm) - chronology B -. Anyway, both dates are of Pleistocene age.

Changes between 24 cm and 22 cm core depth in stratigraphy and abrupt changes in pollen concentration, frequency of *Botryococcus* and several other pollen taxa such as the Unknown type 1 (Figs. 2, 3), suggest a sedimentary gap for the full glacial and/or Lateglacial period. The radiocarbon date at 8 cm core depth is 6250 ± 49 ¹⁴C yr B.P., indicating deposits of Holocene age. Due to the similar pollen concentration and composition of the pollen assemblages (Fig. 3) in the core above 23 cm, the sediments between 23 and 0 cm all are probably of Holocene age. The radiocarbon date at 0 cm core depth is -30 ± 38 ¹⁴C yr B.P, indicating that the top of the core is of modern age. The extrapolated and interpolated radiocarbon ages for each pollen zone are given below.

Description of the pollen diagram Lagoa da Confusão

The pollen diagram of the sediment core from Lagoa da Confusão (Figs. 2 and 3) shows the most abundant pollen and spore taxa out of the 157 identified types, including 36 unknown types. Based on changes in pollen assemblages, illustrated by cluster analysis CONISS, four pollen zones (LDC I-IV) are recognized. Pollen concentration is about 15,000 grains/cm³ in zone LDC-I, about 40,000 grains/cm³ in zone LDC-II and about 10,000 grains/cm³ in zone LDC-III and IV.

Zone LDC-I (52-45 cm, 60,300-51,700 according to chronology A or 29,000-27,400 ¹⁴C yr B.P. according to chronology B., 4 samples):

Zone LDC-I is marked by a high representation of cerrado herb pollen (70-80 %), primarily Poaceae (50-60 %), Cyperaceae (10-15 %) and *Borreria* (1-2 %). Taxa of the cerrado trees and shrubs (1-2 %) are poorly represented by single pollen grains of *Curatella*, *Byrsonima*, the *Copaifera*-type, the *Stryphnodendron*-type and *Didymopanax*. Representation of Amazon and gallery forest trees and shrubs is low (10-25 %), primarily represented by taxa such as Melastomataceae/Combretaceae (5-10 %) and a few pollen grains of Moraceae/Urticaceae, Myrtaceae and *Alchornea*. Representation of the aquatic taxa are low (1-5 %) and mainly represented by *Eichhornia* and *Sagittaria*. The representation of fern spores is low (2-4 %); also in the following zones. Spores of *Isoetes* are rare. Fungal spores are rare or absent. Colonies of the algae *Botryococcus* are found in moderate amounts.

Zone LDC-II (45-23 cm, 51,70- 24,670 according to chronology A or 27,400-14,000 ¹⁴C yr B.P. according to chronology B, 11 samples):

Zone LDC-II is characterized by a markedly lower representation of cerrado herbs (about 50 %), primarily by the decrease of Poaceae. The representation of cerrado trees and shrubs is slightly higher as in the previous zone (1-4 %), primarily by *Byrsonima*. Representation of Amazon and gallery forest trees and shrubs (20-30 %) is higher, specially by Melastomataceae/Combretaceae (10-15 %), Moraceae/Urticaceae, Myrtaceae and *Alchornea*. Representation of aquatic taxa is slightly higher. An unidentified pollen type is quite frequent in this zone (5-25 %). Fern spores remain low. Spores of *Isoetes* become frequent at the end of this zone. Colonies of the algae *Botryococcus* are still moderate.

Zone LDC-III (23-7 cm, early Holocene - 5460 ¹⁴C yr B.P., 8 samples):

Zone LDC-III shows still similar high percentages of cerrado herbs (about 50 %) compared to the previous zone. The percentages of cerrado trees and shrubs increase (4-8 %), primarily by *Curatella* and a few grains of the *Copaifera*-type and the *Stryphnodendron*-type. The representation of the Amazon and gallery forest trees and shrubs is markedly higher than in the previous zone (28-38 %), due to the higher values of Moraceae/Urticaceae, *Alchornea* and several other taxa such as Malpighiaceae and *Lithraea*/*Schinus*-type. In the upper section of this zone, there is one sample with a high value of *Alchornea* pollen grains. Representation of aquatic pollen is higher compared to the previous zone. Spores of *Isoetes* are lower represented, except for the uppermost sample of this zone. *Botryococcus* is abundant.

Zone LDC-IV (7-0 cm, 5460 ^{14}C yr B.P. - modern, 4 samples):

In Zone LDC-IV savanna herbs (about 40 %) are slightly lower than in the previous zone. Percentages of cerrado trees and shrubs are higher (5-10 %), *Byrsonima* in particular. Representation of Amazon and gallery forest trees and shrubs (40-50 %) are higher. Within this group values of Melastomataceae/Combretaceae and Myrtaceae decrease, while percentages of Moraceae/Urticaceae and *Alchornea* in particular, but also other representatives of this category increase. Pollen grains of the palms *Mauritiella* and the *Euterpe/Geonoma*-type are well presented in this zone. Aquatic show in this zone the highest values of this record, primarily by *Sagittaria* and *Eichhornea*. *Isoetes* and *Botryococcus* are frequent in this zone.

Interpretation and discussion

Reconstruction of late Quaternary vegetation and climatic dynamics

The large and shallow lake Lagoa da Confusão can be seen as a huge pollen trap, which archived the environmental history of a relatively large area surrounding the lake. Absence of pollen grains or poorly preserved pollen below 53 cm core depth may indicate that the lake was not permanent. Due to the uncertainties of the radiocarbon dating in the lower core section, the beginning of the pollen record is not clearly determined. It is possible that the lake was shallower and smaller during the last glacial period, as indicated by the presence of only a few pollen grains of *Sagittaria* (shallow water indicator).

During the period dated between 60,300 and 51,700 ^{14}C yr B.P. according to chronology A, or 29,000 and 27,400 ^{14}C yr B.P. according to chronology B (zone LDC-I), the pollen spectra indicate a landscape dominated by cerrado of the campo limpo type, a grass savanna with rare woody savanna shrubs and trees such as *Curatella*, *Byrsonima*, *Stryphonodendron* or *Copaifera*. Abundant Poaceae pollen also indicate that the cerrado was much more extended to the north and east. Low presence of other trees and shrubs indicate that along the drainage system little gallery forests was present. The annual precipitation must have been significantly lower, and the length of the dry season longer than today.

Between 51,700-24,670 (chronology A) or 27,400-14,000 ^{14}C yr B.P. (chronology B) (zone LDC-II) the presence of cerrado herbs decrease, and cerrado shrubs and trees increase. The cerrado apparently changed from campo limpo to campo sujo. Higher presence of Amazon and gallery forest shrubs and trees indicate that gallery forest expanded along the drainage system. Amazon rain forest was still limited.

Marked and abrupt change between 24 cm and 22 cm core depth in pollen concentration, frequency of *Botryococcus* and many records of pollen taxa, might be indicative of a sedimentary gap. This hiatus would cover the full glacial and Lateglacial period according to chronology A, or the Lateglacial period when applying chronology B. This gap suggests drier climatic conditions for that time.

During the early Holocene until 5460 ^{14}C yr B.P. (zone LDC-III), cerrado herbs were less frequent whereas cerrado shrubs and trees were more abundant than during the glacial part of this record. The cerrado apparently changed from campo sujo to campo cerrado in which *Curatella* was well presented. More abundant Amazon and gallery forest shrubs and trees indicate that gallery forest had expanded, and trees of the Amazon forest, Moraceae/Urticaceae and *Alchornea* in particular, were more frequent in the study region. The high amount of *Alchornea* pollen in just on sample (10 cm core

depth), suggest that this tree grew in the surroundings of the lake. The expanding forest replaced the grass savanna and led to a new balance between forest and savanna during this period. The annual precipitation must have been higher and the length of the annual dry season shorter, than during glacial times. Also aquatic taxa increased and may suggest an expansion of the lake.

Since 5460 ^{14}C yr B.P., wooded cerrado and the Amazon and gallery forest were more abundant than during the early Holocene period. Cerrado herbs stay relatively frequent suggesting that campo cerrado continued its presence in the study area up to today. Palm tress (*Mauritiella*, *Euterpe/Geonoma*) became now common in the landscape. These vegetational changes reflect the wettest recorded period since mid Holocene times.

Comparison of the Lagoa da Confusão record with pollen records from southeastern Amazon region and central Brazil

In the region of southeastern Amazonia and in the cerrado region of the northern part of central Brazil there are three pollen records available (Fig. 1). The studied swamp on the Carajas mountain (Serra Sul, CSS2), at 700–800 m elevation in southeastern Pará State (southeastern Amazonia), lies about 480 km north of Lagoa da Confusão. The pollen record is about 60,000 ^{14}C yr B.P. and shows several alternating periods dominated by arboreal and herbaceous savanna taxa. This has been interpreted as alternations between forest and edaphic savanna in the surrounding region (ABSY et al. 1991). Savanna extension, reflecting dry episodes, occurred at ca. 60,000 and ca. 40,000 ^{14}C yr B.P., and between ca. 7500 and 3000 ^{14}C yr B.P. A sedimentary gap probably occurs between ca. 22,900 and 12,500 ^{14}C yr B.P.

Two pollen records from palm swamps are available from central Brazil (Fig. 1). The record from Agua Emendadas, 550 km southeast of Lagoa da Confusão, represents the period of 35,000 to 3500 ^{14}C yr B.P. (BARBERI 1994; SALGADO-LABOURIAU et al. 1998). The period from 26,000 to 21,500 ^{14}C yr B.P. is marked by abundant grassy vegetation and the presence of marsh, cerrado, and gallery forest taxa. Pollen grains of the palm *Mauritia* were not found. This period has been interpreted as moist and cold. The period from 21,500 to 7200 ^{14}C yr B.P. contains a thin sand layer without pollen, suggesting that a climate with a long dry season prevailed. This period is followed by a transitional phase until ca. 5000 ^{14}C yr B.P., characterised by the development of a *Mauritia* palm swamp, suggesting an increase in moisture. During the late Holocene, vegetation and climate were similar to present-day conditions.

The Crominia swamp is located about 320 km southwest of Agua Emendadas and 750 km south of Lagoa da Confusão. The record reaches back to 32,000 ^{14}C yr B.P. (FERRAZ-VICENTINI & SALGADO-LABOURIAU 1996). In the lower part of the core, three samples from the interval of 281 to 154 cm depth have a radiocarbon age of about 32,000 ^{14}C yr B.P. Vegetational and climatic conditions inferred from this core interval are similar to modern conditions; i.e., the presence of cerrado, gallery forest, and *Mauritia* palm swamp under semihumid seasonal climatic conditions. From 32,000 to ca. 20,000 ^{14}C yr B.P., the vegetation was grassland with gallery forest, without the presence of a palm swamp. This period is interpreted as having wetter climatic conditions and lower temperatures than today. The period from ca. 18,500 to ca. 10,500 ^{14}C yr B.P. apparently had a landscape with reduced vegetation cover under very dry climatic conditions. During the following period, until ca. 6500 ^{14}C yr B.P., conditions

were dry, and since ca. 5000 ^{14}C yr B.P. the modern vegetational composition is found in this region.

The Lagoa da Confusão record confirms the predominance of savanna with dry climatic conditions during the pre-full glacial and probably also full glacial period as it has been reported also from other eastern tropical South American lowland regions, such as from the Laguna El Pinal record of the Llanos Orientales in northwestern South America (BEHLING & HOOGHIEMSTRA 1999), from the Laguna Bella Vista and Chaplin record in southwestern Amazonia (MAYLE et al. 2000) and from the Catas Altas record in southeastern Brazil (BEHLING & LICHTHE 1997).

Periods of wetter climatic conditions than today in the Agua Emendadas region from 26,000 to 21,500 ^{14}C yr B.P. and in Cromínia from 32,000 to ca. 20,000 ^{14}C yr B.P., were not observed in the Lagoa da Confusão record. The slightly wetter conditions in pollen zone LDC-II (between 51,700-24,670 or 27,400-14,000 ^{14}C yr B.P.) perhaps may reflect this period, but climatic conditions at the site Lagoa da Confusão were still drier than today.

The possible sedimentary gap for the full glacial and/or Lateglacial period in the Lagoa da Confusão core has also been observed in the Carajas record (CSS2) between ca. 22,900 and 12,500 ^{14}C yr B.P. Poor pollen preservation was also found in the Agua Emendadas core between 21,500 to 7200 ^{14}C yr B.P.; all this evidence points to dry conditions. Sedimentary gaps for the full glacial period, apparently are common in the tropical South American lowland cores (LEDRU et al. 1998) and point to widespread dry climatic conditions.

Higher representation of Amazon rain forest trees in the Lagoa da Confusão record after 5460 ^{14}C yr B.P. (interpolated age), indicates an expansion of Amazon forest tree population into the gallery forest and cerrado vegetation, and reflects a markedly wetter climate. The wettest Holocene climatic conditions has been registered in the Carajas record (Serra Sul, CSS2) somewhat later, i.e. since about 3000 ^{14}C yr B.P., and to the South in central Brazil (Agua Emendadas and Cromínia) since about 5000 ^{14}C yr B.P. Differences in age estimations may be caused by the relative low resolution radiocarbon time control of these four records.

Pollen analytical studies in other tropical South American lowland regions document similar vegetational dynamics between forest and savanna (Fig. 1). Records from the Llanos Orientales document an expansion of gallery forests since mid Holocene, reflecting a change to a wetter climate (BEHLING & HOOGHIEMSTRA 1998, 1999). The well dated pollen record Laguna Loma Linda, which is located in the transition zone between savanna and Amazon rain forest, shows an expansion of gallery and Amazon rain forest since 6000 ^{14}C yr B.P., and specially since 3600 ^{14}C yr B.P. (BEHLING & HOOGHIEMSTRA 2001). South of the equator there is evidence of Amazon rain forest expansion (Laguna Bella Vista and Chaplin, Bolivia) during the late Holocene at least since 3000 ^{14}C yr B.P. (MAYLE et al. 2000).

The Lago do Pires record from southeastern Brazil shows expansions of semideciduous forest replacing cerrado vegetation, since 5530 ^{14}C B.P. and since 2780 ^{14}C B.P. indicating increased annual precipitation and shorter annual dry season than during early Holocene periods (BEHLING 1995).

Conclusions

The pollen analytical results from the Lagoa da Confusão deposits document vegetational and climate dynamics of the cerrado and transition zone from cerrado to Amazon rain forest during late Pleistocene and Holocene times.

The pollen record shows that the study region, located in the southeastern Amazon rain forest border, was dominated by cerrado, first of the campo limpo type (between 60,300-51,700 ^{14}C yr B.P. according to chronology A, or 29,000-27,400 ^{14}C yr B.P. according to chronology B) and later of the campo sujo type (between 51,700-24,670 ^{14}C yr B.P. according to chronology A, or 27,400-14,000 ^{14}C yr B.P. according to chronology B). Little gallery forest occurred during the first period, and increased during the second period mentioned. Amazon forest taxa occurred sparsely in the study region during the second period. Vegetational reconstructions point to a markedly drier climate with less precipitation and longer dry season at that time, compared to modern conditions.

In the lacustrine deposits of Lagoa da Confusão is apparently a sedimentary gap spanning the full glacial and/or Lateglacial period. Also a number of other records from the tropical South American lowland show gaps in the sediment records and suggest dry climatic conditions during the last glacial maximum.

Between the early Holocene and 5460 ^{14}C yr B.P., cerrado shrub and trees were more frequent than during the two recorded late Pleistocene periods, suggesting a stronger presence of the campo cerrado type. Gallery forest shrubs and trees expanded along the drainage system and Amazon trees became more frequent in the study area. Annual precipitation must have increased, and the length of the annual dry season longer. After 5460 ^{14}C yr B.P. campo cerrado was still the dominant vegetation, but forest cover increased markedly and palm trees became frequent, documenting the wettest period of the record. Modern environmental conditions is inferred since mid Holocene.

The results from Lagoa da Confusão follow the general trend of dry glacial conditions, which have been reported from southeastern Amazonia (Carajas, CSS2) and from central Brazil. Periods of wetter climatic conditions than today, such as shown in the Crominia record of central Brazil from 32,000 to ca. 20,000 ^{14}C yr B.P., were not found. The expansion of the Amazon rain forest since the mid Holocene in northwestern and southwestern Amazonia is also confirmed in the southeastern Amazon region and in the Lagoa da Confusão record registered at about 5460 ^{14}C yr B.P.

The general trend of Amazon rain forest expansion north and south of the equator may be driven by the latitudinal migration of the ITCZ. The annual shift of the ITCZ apparently increased synchronously north and south of the central South American equator.

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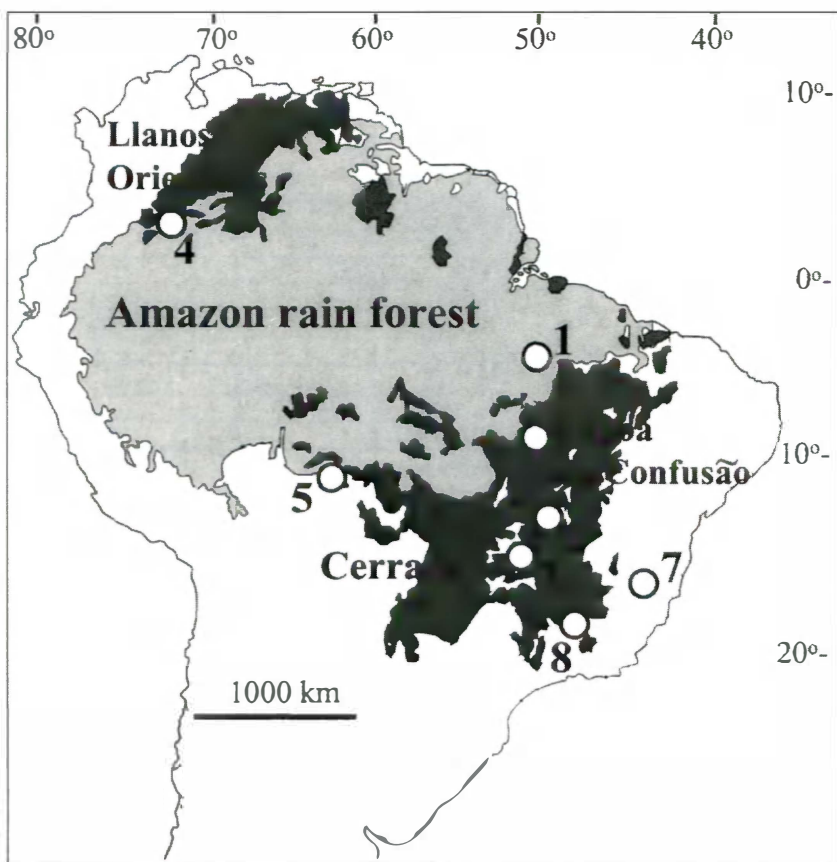


Fig. 1:

Map showing the geographical location of the studied site Lagoa da Confusão and other sites mentioned in the text: (1) = Carajas, Serra Sul. (2) = Agua Emendadas, (3) = Crominia, (4) = Laguna Loma Linda, (5) = Laguna Bella Vista and Chaplin, (7) = Lago do Pires and (8) = Catas Altas.

Fig. 2:

Pollen percentage diagram showing the most important taxa of core Lagoa da Confusão, located at 180 m elevation in the southeastern Amazon region in Tocantins State, northern Brazil.

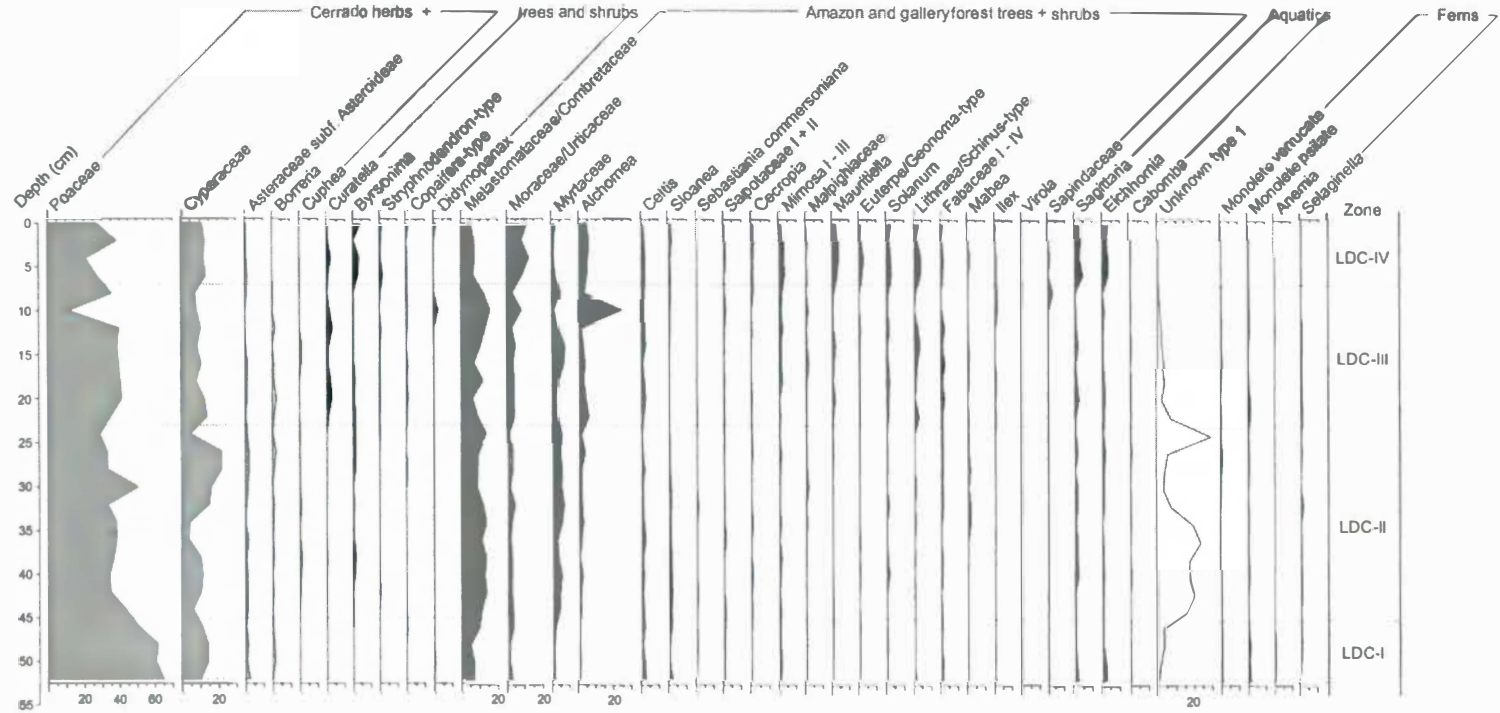


Fig. 3:

Pollen percentage diagram of core **Lagoa da Confusão** showing radiocarbon dates, stratigraphy, the sums of ecological groups, records of the pollen concentration, pollen zones and the cluster analysis dendrogram.

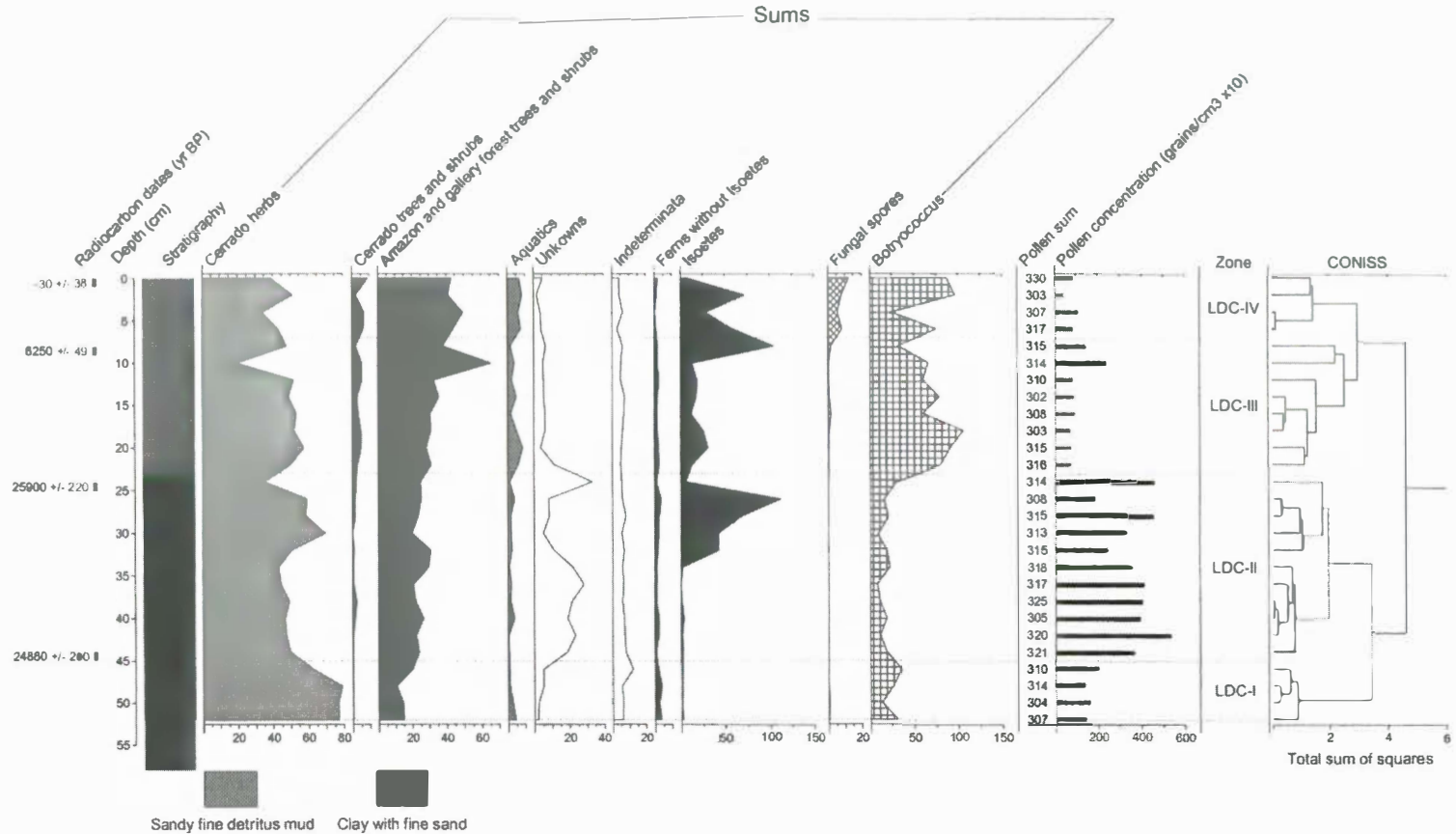


Table 1: Stratigraphy of core Lagoa da Confusão.

Depth	Description
0- 9 cm	light gray-brown sandy fine detritus mud
9-30 cm	gray compact sandy fine detritus mud
13-23 cm	relatively soft, more sandy
30-58 cm	gray clay with fine sand
58-68 cm	fine sand with gray clay
68-	yellow sand with very little clay

Table 2: Radiocarbon dates for the core Lagoa da Confusão.

Lab. number	Depth (cm)	¹⁴ C yr B.P.	13C/12C r.	Calendar Age (cal BC)
UtC-7686	0	-30 ± 38	-25.8	Modern
UtC-7687	8	6250 ± 49	-25.5	7205-7154, 7120-7087, 7061-7035
UtC-7688	24	25900 ± 220	-27.1	Not available
UtC-7689	44	24880 ± 200	-25.0	Not available