



## Vegetation and hydrology changes in Eastern Amazonia inferred from a pollen record

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### ABSTRACT

Pollen, charcoal, and C14 analyses were performed on a sediment core obtained from Lake Tapera (Amapá) to provide the palaeoenvironmental history of this part of Amazonia. A multivariate analysis technique, Detrended Correspondence Analysis, was applied to the pollen data to improve visualization of sample distribution and similarity. A sedimentary hiatus lasting 5,500 years was identified in the Lake Tapera. Because the timing of the hiatus overlapped with the highest Holocene sea-level, which would have increased the local water table preventing the lake from drying out, it is clear that sea-level was not important in maintaining the lake level. Lake Tapera probably depended on riverine floodwaters, and the sedimentary gap was caused by reduced Amazon River discharge, due to an extremely dry period in the Andes (8,000-5,000 years BP), when precipitation levels markedly decreased. The lack of Andean pollen (river transported) in the record after this event supports this interpretation. The pollen analysis shows that when sedimentation resumed in 1,620 cal. years BP, the vegetation around the lake was changed from forest into savanna. This record demonstrates the need to improve our understanding of climate changes and their associated impacts on vegetation dynamics.

**Key words:** vegetation change, hydrology change, Amazonia, pollen record, climate change.

### INTRODUCTION

It is undisputed the large growing body of evidence for climate changes, such as oscillations on mean temperature and precipitation in the geological time. Records of climate and environmental changes obtained from proxies such as ice cores from polar and tropical regions (Grootes et al. 1994, Thompson et al. 1995, 1998, Petit et al. 1999), tree rings (Rodríguez et al. 2005, Sano et al. 2005, Therrell 2005), coral reefs (Dunbar et al. 1996, Gagan et al. 2000), diatoms (Steinitz-Kannan et al. 1993, Jenny et al. 2002, Fritz et al. 2004) and fossil pollen (Absy 1979, Absy et al. 1991, Behling 1995, Van der Knaap and Van Leeuwen 1997, De Oliveira et

al. 1999, Haberle and Maslin 1999, Behling et al. 2004, 2005, Garcia et al. 2004), indicate that these changes took place within decadal to century time scales, and affected both relatively small geographic scales (e.g. the Little Ice Age in Europe) and entire hemispheres (e.g. the last glacial period).

Holocene climatic changes have been invoked to account for vegetation changes worldwide, and the variation in the range of Amazonian savannas is not an exception. A paleoecological study conducted on a mosaic landscape of forest-savanna ecotone in Bolivia revealed a forest expansion of c. 100 km in the last 3000 years (Mayle et al. 2000). Similarly, palaeoecological records from Colombian savannas also suggest a forest expansion in the last 4000 years (Behling and Hooghiemstra 1998, 1999, Berrio et al. 2002).

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Even though climate change may be one of the most powerful drivers of modifications in the environment and vegetation, the anthropogenic impacts of occupation in the Amazonian region cannot be dismissed. Archaeological studies provided evidence that humans have lived in Amazonian lowlands for at least 11,000 years (Roosevelt et al. 1991, 1996). Further evidence that these Neotropical landscapes have been intensely used and modified by pre-Columbian human populations comes from savannas in the Bolivian Amazonia (Erickson 2000, 2001) and Upper Xingu (Heckenberger et al. 2003), in Southern Brazilian Amazonia. However, the full extent of the Pre-European manipulation of Amazonian habitats remains unclear (Meggers 2003).

The main goal of this study was to investigate how the vegetation of this portion of Amazonia responded to climate changes and human impacts during the Holocene. For this purpose, a sediment core was systematically analyzed for its pollen contents and micro-charcoal fragments in order to provide a record of vegetation dynamics and palaeo-fires (natural or anthropogenic in origin).

#### STUDY SITE

Lake Tapera (N 0°07'40.9" / W 51°04'47.8") is a small (1 km long and 700 m wide) shallow lake (1.5-2.5 m deep), located at north of Macapá, about 10 km from the Amazon River, and lying at less than 10 m above sea level (Fig. 1). This lake drains into a larger system, known as Curiaú, therefore being part of its watershed, but presumably a little higher and consequently more isolated. Lake Curiaú is an L-shaped basin 6.5 km long in the vertical axis (N-S), 3.5 km long in the horizontal axis (E-W), and 1.2 km wide; its watershed area is estimated to be at least 150 km<sup>2</sup>. Even though Curiaú dries out seasonally, Lake Tapera is known to be a permanent water body.

The modern vegetation of the study site is a mosaic of dry and flooded savannas and patches of secondary and dry forests. Gallery forests and palm swamps are also present along the water drainages (locally called "igara-pés"). Lake Tapera is surrounded by semi-deciduous and gallery forests, with *Mauritia* palms and *Montrichardia* growing on the margins as well. In a phytosociological study in this savanna region, Thomaz et al. (2004) identified 44 families, 83 genera and 119 species. The

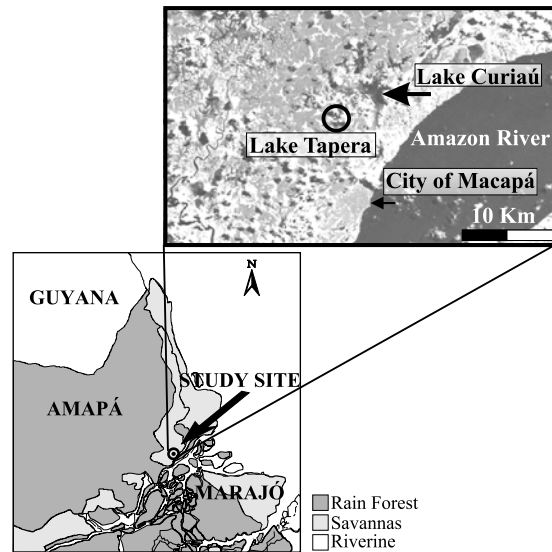


Fig. 1 – Map of the study area, showing the location of Lakes Curiaú and Tapera (the studied lake), the city of Macapá, and the Amazon River.

most important families were Cyperaceae (18 species), Poaceae (15 species), Fabaceae (7 species), Rubiaceae (3 species), Lentibulariaceae and Onagraceae (5 species each). It is noteworthy to mention that among the dominant species were *Sagittaria rhombifolia*, *Montrichardia arborescens* and *Mauritia flexuosa*, and the latter ones are found in isolated populations throughout the Curiaú watershed.

The climate in this region is tropical humid, with mean annual temperatures of 25-27°C and 2500 mm of precipitation, falling mainly between December-August with a dry season from September to November (IBGE 2002).

#### MATERIALS AND METHODS

A sediment core (200 cm long) was obtained in 2002 using a Colinvaux-Vohnout corer (Colinvaux et al. 1999) from a platform supported by inflatable boats. The platform was anchored in the middle of the lake. The sealed core tubes were transported unopened to the laboratory and stored in a dark cold room until opened and the sediments described. A total of 79 samples (0.5 cm<sup>3</sup>), 39 for pollen and 40 for charcoal, were collected from the sediment core. Samples for C<sup>14</sup> AMS dating were sent to the INSTAAR – AMS Radiocarbon Laboratory

at the University of Colorado at Boulder, and the resulting dates were calibrated to calendar years using the software CALIB 4.0 (Stuiver and Reimer 1993).

Standard pollen preparation procedures with HCl, KOH, HF, and acetolysis followed Faegri and Iversen (1989). Tablets of *Lycopodium* spores were added to the samples prior to processing, in order to calculate pollen concentrations (Stockmarr 1971). The pollen residues were mounted in glycerol and counts of at least 300 grains were conducted at 400 $\times$  and 1000 $\times$  magnification on a Zeiss Axioskop. Pollen grains were identified using the Florida Institute of Technology reference collection of modern pollen and published catalogs with photographs and morphological descriptions of pollen types (Hooghiemstra 1984, Roubik and Moreno 1991, Colinvaux et al. 1999).

The pollen sum, which included only the terrestrial taxa, pollen percentage and concentration were all calculated in TILIA (Grimm 1992). Afterwards, all the data were plotted in C<sup>2</sup> 1.3 (Juggins 2003).

Samples for charcoal analysis were disaggregated in KOH (10%), and the resulting slurry washed through a 170  $\mu$ m sieve (particles > 170  $\mu$ m were retained). The charcoal analysis was performed under an Olympus dissection microscope (20 $\times$  magnification) equipped with a video camera (Clark and Patterson 1997). Digital measurements were made via the video system and image recognition (NIH-IMAGE) software. This software provides the area of charcoal particles according to the number of pixels occupied by the fragment on the screen.

In order to investigate the complex relationships among the samples, Detrended Correspondence Analysis – DCA (Hill and Gauch 1980) was performed using PC-ORD 4.0 (McCune and Mefford 1999). The main goal of DCA is to reduce the number of dimensions, with a minimum loss of information, of a multidimensional space that describes the variables relationship (McCune and Grace 2002). Through the use of these more advanced numerical techniques, we are able to observe the most relevant of a possibly infinite number of patterns in the ecological data, identifying the similarity, association, and correlation among all the variables (Behling et al. 2005).

This technique was chosen basically because it is not subject to the infamous arch effect. Additionally, as

very complex data sets with many rare taxa can hinder DCA, the data set was reduced to include only pollen taxa with percentage values equal to or higher than 1% and that were present in at least 3 samples throughout the sediment core. The percentage values were then standardized by square root transformation (McCune and Grace 2002). Because the eigenvalues provided by DCA cannot be used to demonstrate the proportion of variation explained by the axes, as in Principal Component Analysis (PCA), we used an after-the-fact coefficient of determination between relative Euclidian distance in the unreduced species space and Euclidian distance in the ordination space (McCune and Grace 2002) in order to evaluate the effectiveness of the ordination. The resulting sample scores from axis 1 were plotted against sample depths.

## RESULTS

### LITHOLOGY

The 200 cm-long sediment core from Lake Tapera (Fig. 2) is mostly composed of blue-grey clay rich in plant fragments in the bottom (200–65 cm) and black silt with no plant remains on the top 65 cm. In the bottom of the core (197–200 cm) there is a layer of dark-blue clay rich in black organic fragments, and between 69–76 cm depth the clay is very sandy (Table I).

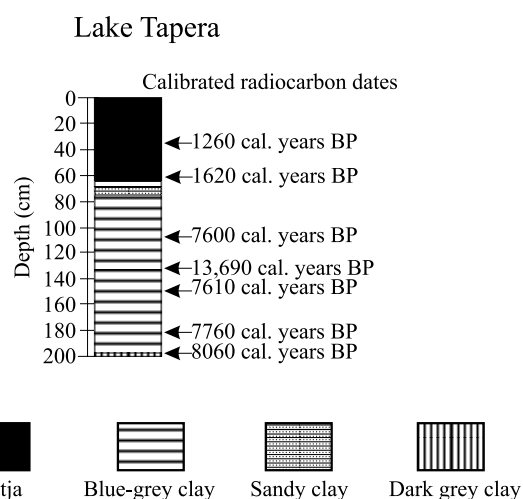


Fig. 2 – Lithology of sediment core from Lake Tapera (Amapá). Also showing location of dated samples on the sediment core (cal. years BP).

**TABLE I**  
**Sediment description of core from Lake Tapera**  
**(Amapá – Brazil).**

Depth (cm)	Sediment description
0–65	Black organic silt, no plant remains present
65–69	Blue-gray clay rich in plant remains
69–76	Very sandy blue-gray clay
76–197	Blue-gray clay with some plant remains
197–200	Dark clay rich in charcoal fragments

#### RADIOCARBON DATES

The sedimentary chronology for Lake Tapera was derived from 7 AMS radiocarbon dates (Table II). In order to account for variations in carbon isotopic fractionation throughout time, the resulting ages were calibrated to calendar years using the software CALIB 4.0 (Stuiver and Reimer 1993). For each calibrated age a maximum probability solution (type 2 solution) was adopted. All ages used henceforth will be interpolated (rounded up) calibrated years (cal. yrs) before present (BP), unless specifically noted otherwise. The basal age of 8,060 cal. yrs BP for Lake Tapera indicates that the sediments are Holocene in age. The age vs. depth relationship (Fig. 3) shows that sedimentation rates were not constant through time. As the age of 13,480–13,890 cal. yrs BP, obtained from sample OS-38390 at 132 cm depth (Table II), was probably originated from erosion of much older sediments from elsewhere, it was rejected because it does not represent the true time of deposition of the sedimentary layers.

#### PALAEOECOLOGICAL RECORD

The pollen and charcoal records from Lake Tapera (Fig. 4) allow the distinction of 2 main zones: zone T1, which lasts from c. 8,060 until before 1,620 cal. yrs BP; and zone T2 lasting from ~ 1620 cal. yrs BP until the present. The diagram zonation was based both on DCA scores and visual inspection.

##### *T1A (200 cm–65 cm; 8,060–1,620 cal. yrs BP)*

Sediments are composed of dark clay rich in fragments of charred wood on the bottom, and blue grey clay with plant fragments. Pollen concentration displays strong fluctuations, peaking at 190 cm (c. 32,500 grains  $\text{cm}^{-3}$  of

sediment), 165 cm and 150 cm (around 15,000 grains  $\text{cm}^{-3}$  of sediment), and decreasing to almost nothing upwards (Fig. 4). This zone lasts from 8,060 cal. yrs BP until c. 1,620 cal. yrs BP, and is characterized by low percentages of Asteraceae, Bignoniaceae, *Cassia*, *Cecropia*, Dilleniaceae, *Euterpe*, Mimosaceae, *Macrolobium*, *Mauritia*, Combretaceae type (Mel/Comb), Moraceae/Urticaceae 2-porate and 3-porate types (Mor/Urt2, Mor/Urt3), Poaceae, *Polygonum*, *Spondias*, and Cyperaceae. These pollen types show higher values upwards. On the other hand, pollen of *Coccoloba*, *Desmodium*, *Didymopanax*, Lecythidaceae, Caesalpinaceae, Papilionaceae, *Machaerium*, Malpighiaceae, *Protium*, *Symphonia*, *Virola*, and *Rhizophora* display higher percentage values in this zone (Fig. 4). Even though the fern spores display relatively small and constant percent values throughout the core, there is one distinct peak at 75 cm (128%). Pollen commonly found in mountain regions (e.g. in the Andes), such as *Alnus*, *Hedyosmum*, and *Podocarpus* are recorded with low percentage values in this zone. No charcoal particles were found in this zone.

##### *T2 (65 cm–0 cm; c. 1,620 to present)*

Sediments are composed of a layer of sandy blue-grey clay on the bottom, a transition from blue-grey clay rich in plant fragments to black organic silt with no plant fragments. Pollen concentration increases sharply and the values fluctuate around 10,000–20,000 grains  $\text{cm}^{-3}$  of sediment (Fig. 4). Pollen spectra are characterized by decreased percentage values of Asteraceae, Bignoniaceae, *Cassia*, *Coccoloba*, *Desmodium*, *Didymopanax*, Lecythidaceae, Caesalpinaceae, *Machaerium*, Malpighiaceae, *Protium*, Rubiaceae, *Symphonia*, and *Virola*. Other taxa display increased percentages, such as *Euterpe*, *Macrolobium*, *Mauritia*, Mel/Comb, *Polygonum*, *Spondias*, *Sagittaria*, *Typha*, and *Utricularia*. The percentage of Poaceae pollen exhibits a 5-fold increase in this zone, and despite some fluctuation remains abundant. *Cecropia* pollen reaches its highest values at 55 cm (c. 17%), but does not increase above 10% anywhere else, displaying only small variation throughout this zone (Fig. 4). Pollen from *Alnus* is completely absent from this zone, and *Hedyosmum* and *Podocarpus* are recorded in only one sample at insignificant values.

**TABLE II**  
**Radiocarbon dates from Lake Tapera.**

Sample	Depth (cm)	<sup>14</sup> C yr BP	<sup>13</sup> C/ <sup>12</sup> C ratio	Age (cal. years BP)
OS-38388	35	1320 ± 30	-27.93	1230–1300
OS-38389	65	1710 ± 35	-27.37	1540–1700
OS-40060	108	6720 ± 30	-26.72	7570–7630
OS-38390	132	11,750 ± 55	-25.37	*13,480–13,890
OS-40061	150	6730 ± 35	-27.86	7570–7630
OS-38391	182	6930 ± 45	-27.03	7670–7850
OS-38392	197	7260 ± 35	-23.39	8000–8120

\*Date rejected as an outlier.

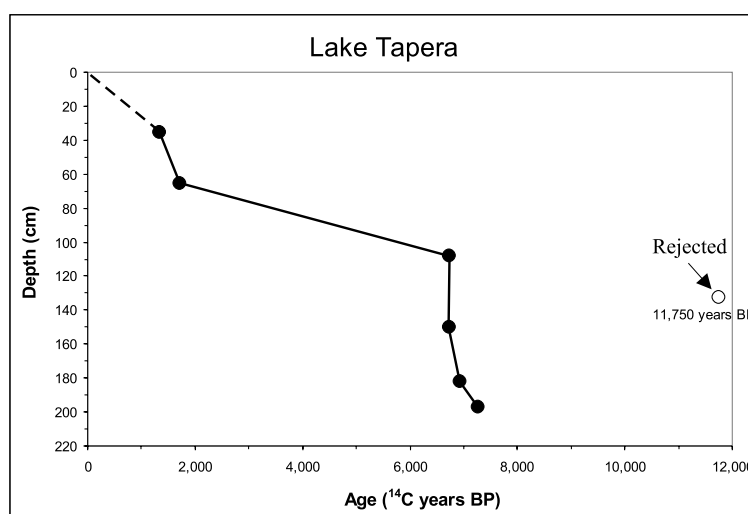


Fig. 3 – Radiocarbon ages from Lake Tapera plotted against depth (cm). The radiocarbon age that is represented by an open circle (11,750 years BP) was considered to be a contamination, and therefore rejected as an outlier. The dashed lines represent the extrapolated ages towards the present.

The accumulation of charcoal particles, measured here as  $\text{mm}^2 \text{cm}^{-3}$  of sediment, starts at 65 cm (1,620 cal. yrs BP), and displays a peak of c.  $15 \text{ mm}^2$  at 60 cm. At the depth of 35 cm (1,258 cal. yrs BP) charcoal area is greatly decreased, and values remain small until the end of the zone.

MULTIVARIATE ANALYSIS

The resulting DCA scores from Lake Tapera were also plotted in two different ways. First, axis 1 vs. axis 2, then the sample scores from axis 1 were plotted with the corresponding depths (Fig. 5). The proportion of

variance explained by the first two axes, as given by the after-the-fact coefficient of determination, was 80%.

Axis 1 vs. Axis 2

The DCA polarized samples on axes 1 and 2 so that the bottom samples of the core are on the positive side of axis 1, representing zone T1, and the top samples of the core on the left side representing zone T2.

The highest scores for axis 1 were yielded by *Pachira*, *Bignoniaceae*, *Malpighiaceae*, *Symphonia*, and *Euphorbiaceae*. The species that scored lowest in this axis, and therefore were responsible for samples being placed

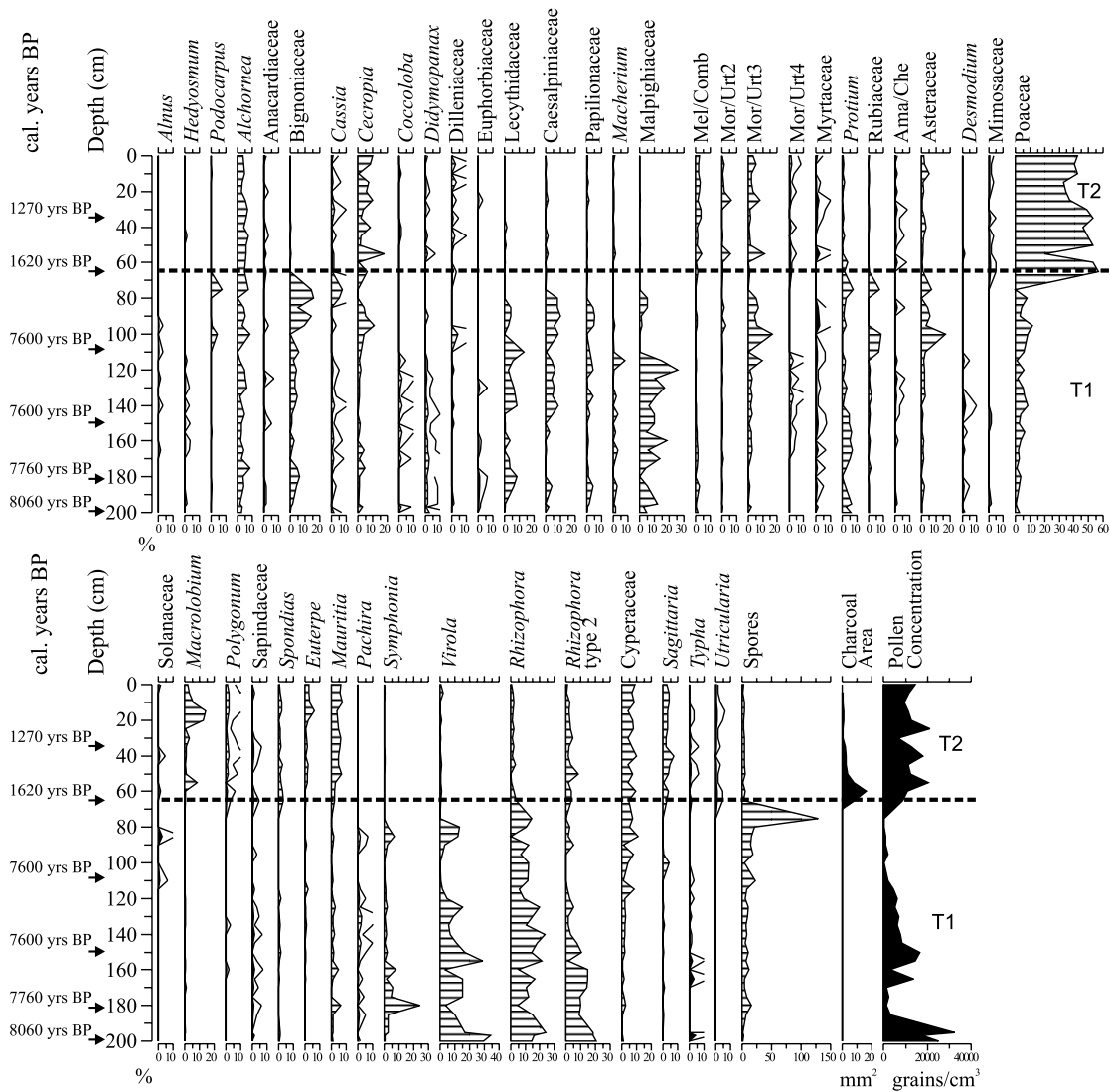


Fig. 4 – Pollen percentage diagram of Lake Tapera, Amapá (Brazil), showing the most representative taxa, including Andean taxa, area of charcoal particles ( $\text{mm}^2/\text{cm}^3$  of sediment), pollen concentration ( $\text{grains}/\text{cm}^3$  of sediment), and radiocarbon dates (cal. years BP). The hollow curves are exaggerated 5 times.

on the more negative side of axis 1 on zone T2, were *Utricularia*, *Polygonum*, *Sagittaria*, *Mimosaceae*, and *Macrolobium*.

On axis 2 samples from zone T1 (bottom of the core) were subdivided into two groups. The species that scored highest in this axis were *Coccoloba*, *Typha*, *Desmodium*, *Didymopanax*, and *Virola*. The lowest species scores were yielded by *Solanaceae*, *Bignoniaceae*, *Rubiaceae*, *Lecythidaceae*, *Papilionaceae*, *Asteraceae*, *Cyperaceae*, *Caesalpinaceae*, *Myrtaceae*, and *Symphonia*.

*Axis 1 vs. Depth*

Plotting axis 1 DCA sample scores against sample depth revealed a striking pattern, in which a transition between zones T1 and T2 occurred at 70 cm (between c. 7,600 cal. yrs BP and 1,618 cal. yrs BP). In zone T1, samples were placed on positive side of axis 1 and showed small oscillation upwards, with the exception of sample T-100 (100 cm) that scored much lower values. In zone T2, from 70 cm until 0 cm (before 1,620 cal. yrs BP until the present), samples present a smaller range of variation

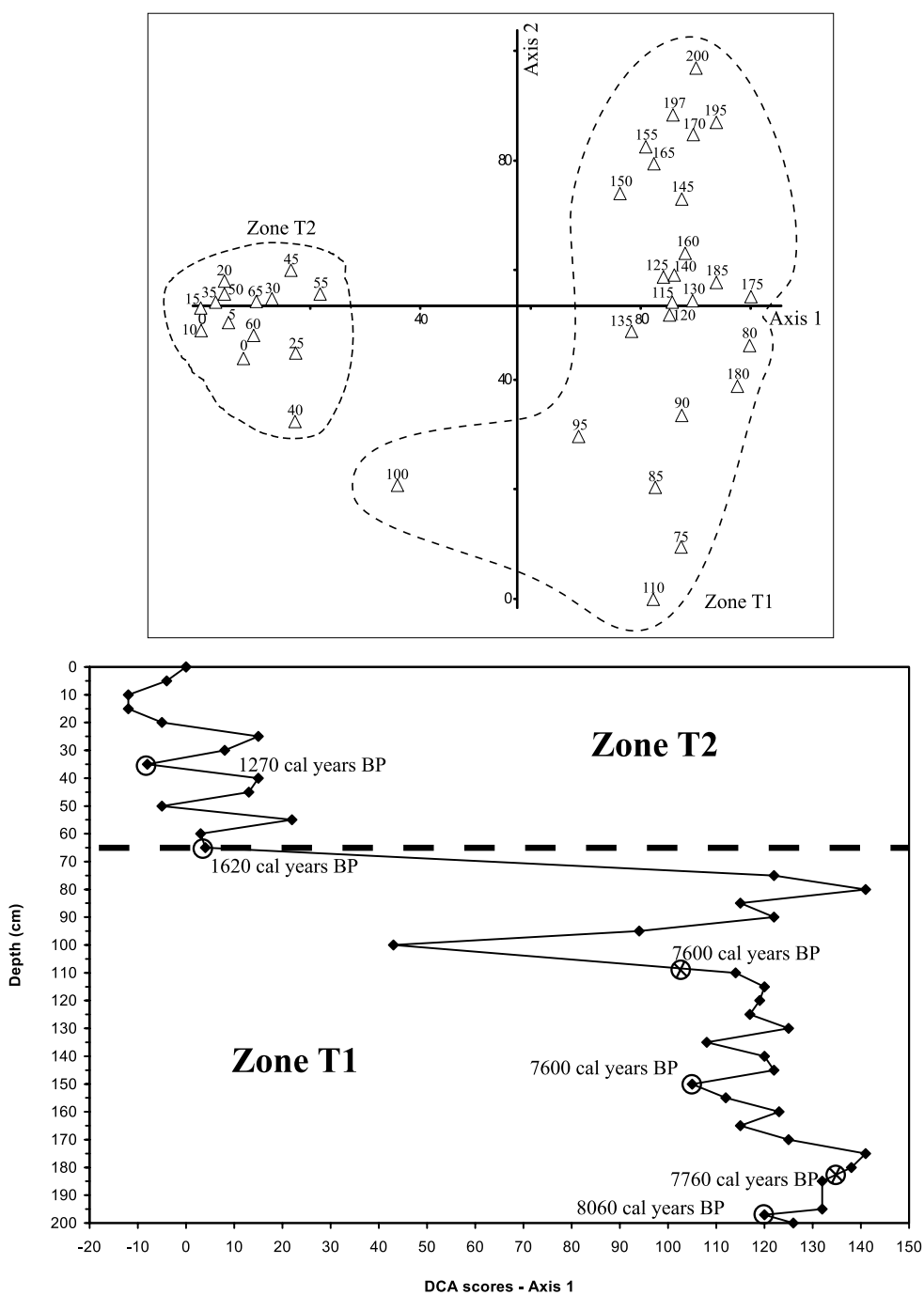


Fig. 5 – DCA scores from Lake Tapera. Top graph shows axis 1 vs. axis 2. Samples are encircled to display zones as interpreted from pollen diagrams. Bottom graph represents resulting DCA scores of axis 1 plotted vs. depth (cm) showing a strong polarization of samples into two main groups representing zones T1 and T2. Ages obtained from C<sup>14</sup> AMS are also shown.

than in the bottom of the core, and were placed on the negative side of the axis.

## DISCUSSION

### SEDIMENTARY EVIDENCE

Stratigraphy alone indicates that the core from Lake Tapera provides a record of an environmental change, as it shows blue-grey clay in the bottom being replaced by black-organic sediments upwards (Fig. 2). The sharp shift of the sediments implied that this change was at least locally (basin scale) significant and may have been even abrupt. The blue-grey clay that constitutes the bottom of the sediment core was full of plant remains, wood and fragments of charred wood, indicating a shallow and unstable depositional environment. The coring location may have supported a gallery forest subjected to periodic river flooding, which may explain the presence of wood and plant fragments. The sandy layer at 69-76 cm in the core was another indication of environmental instability, suggesting drought and maybe associated erosion of nearby sediments.

Sedimentation rate was the fastest in the basal portion of the core, slowing down upwards (Fig. 3). Slowing of sedimentation in the middle of the core was so extreme that it almost certainly represents a long gap, or a series of depositional hiatuses that resulted in little net sedimentary accumulation between c. 7,610 and 1,620 cal. yrs BP.

The sharp change in sediment type, combined with a rapid change in community composition, and different sediment depositional rates below and above the boundary (65 cm) suggest the occurrence of a sedimentary hiatus in the lake. Such breaks in sedimentation are common in shallow tropical lakes (C. Listopad, unpublished data, Bush et al. 2007a) and are generally taken to indicate conditions in which lake water level fell.

Duration of the sedimentary hiatus at Tapera, given by the difference between interpolated ages estimated through sedimentation rates from the bottom upwards and from the top downwards is  $\sim 5,500$  years. From this observation, it is possible to infer that lake level fell during this time interval and was reestablished as a permanent water body only at c. 1,620 cal. yrs BP. With the flooding of Tapera, deposition of organic-rich mud initiated.

### PALEOECOLOGICAL EVIDENCE

The pollen and charcoal records from Lake Tapera revealed two main contrasting zones. The most obvious biological distinction between them was the increase in Poaceae pollen, rising from  $< 10\%$  in T1 to almost  $60\%$  (40-55%) in T2. Interestingly, these percentage values are comparable with proportions of Poaceae pollen (50-90%) found in the pollen rain of cerrados (Salgado-Labouriau 1973), suggesting the establishment of savanna vegetation.

A further indication of a significant vegetation change was the loss of *Rhizophora* pollen in zone 2. The declining proportion of *Rhizophora* pollen suggests a weakening of the fluvial-marine influence. Possibly, as the lake became more isolated from the Amazon, and fresher. Replacement of forest taxa, e.g. Bignoniaceae, Caesalpiniaceae, *Cassia*, Lecythidaceae, *Machaerium*, Malpighiaceae, *Protium*, *Symphonia*, and *Virola* (Marchant et al. 2002) in T2 with those from flooded savanna and swamp vegetation, such as *Amaranthus*/Chenopodiaceae, Asteraceae, *Ludwigia*, *Macrolobium*, *Euterpe*, *Mauritia*, *Polygonum*, Cyperaceae, *Typha*, and *Utricularia*, is consistent with a shift towards less dense forest. Additionally, the higher percentage values of *Cecropia* upwards suggest increased disturbance on the vegetation, as this tree is a well-known pioneer that occupies forest gaps (Marchant et al. 2002).

The sample scores derived from DCA when plotted against core depths provided an illustrative way to demonstrate the impact of environmental changes that took place in this system. Axis 1 was interpreted to show a hydrology gradient, changing from an environment subjected to seasonal river flooding, to a more permanently flooded one, accompanied by a landscape change from gallery forest to swamp forest, with strong influence of savanna. The timing of the environmental change was coincident with on set of fire near the lake. The replacement of *Symphonia* and *Pachira* in T1 by *Macrolobium*, *Polygonum*, *Mauritia* and Cyperaceae in T2 suggested changes within the community of wetland plants.

To sum up, the pollen and charcoal data showed a general environmental trend from gallery forest to savanna with swamp elements. Anthropogenic impacts on the environment were suggested by large quantities of charcoal particles after c. 1,600 cal. yrs BP in Lake



Tapera. Impacts on the vegetation were corroborated by the increasing abundance of *Cecropia* pollen in the upper part of the core.

#### INFLUENCE OF SEA-LEVEL VARIATION

In the early Holocene, relative sea level started to rise and reached its modern level at approximately 7,000 cal. yrs BP along the northern coast of Brazil (Suguio et al. 1985, Martin et al. 1986, Bezerra et al. 2003). The impacts of rising sea level on the water table changed the dynamics of rivers and also formed lakes in the Amazonian lowlands (Behling 1996, 2002 Behling and Da Costa 2000, 2001, Behling et al. 2001). The initial ponding of Tapera at ~8,060 cal. years BP was probably induced by rapid sea level rise in the Pleistocene-Holocene boundary.

At c. 5,000 cal. yrs BP, even though relative sea level was at least 2 meters higher than modern levels (Suguio et al. 1985, Bezerra et al. 2003), Lake Tapera was dry at this time, which suggests that sea level was not the primary control of lake level. Therefore, it is probable that the lake relied on river floodwater to keep a high stand. It is important to note that Lake Tapera is slightly higher than Lake Curiaú, which makes it more isolated from river floodwaters. A further possibility is that the Tapera lake basin was not completely closed yet, so that the lake could be losing water through seepage.

#### ANDEAN DRY SPELL AND AMAZON RIVER FLOW

A drought or series of droughts influenced both Andean and Amazonian systems in the Mid-Holocene. Lake Titicaca (Peru-Bolivia) presented its lowest lake level in the Holocene at c. 5,500 cal. yrs BP (Baker et al. 2001). Though this drought probably began as early as 9,000 cal. yrs BP, and terminated as late as 3,400 yrs BP (Abbott et al. 1997), with 5,500 cal. yrs BP being the peak of the dry spell. Indeed, analyses of western Amazonian lakes suggest the last 1,000 years as being the wettest period of the Holocene (Bush et al. 2007b). A pollen record from Serra dos Carajás suggests that the interval 8,000-5,000 yrs BP was the driest period of the Holocene (Absy et al. 1991). High dust concentrations in the Sajama (Bolivia) ice core also reflect a period of Andean drought at this time (Thompson et al. 1998). As the climate of the southern tropical Andes, an impor-

tant hydrological influence on Amazon River discharge was dry between 8,000 and 5,000 years BP, it is probable that the flow of the river was reduced. One of the impacts of this process would have been diminished river flooding, probably both spatially and temporally, during the wet season. That Tapera received floodwater is evident in the input of Andean pollen taxa, such as *Podocarpus*, *Hedyosmum* and *Alnus*. Therefore, as the lake probably relied on floodwaters from the Amazon River, it dried out, even though relative sea level was high at 5,000 yrs BP. This hypothesis is supported by the pollen record of Tapera that shows a relatively greater abundance of Andean pollen before the sedimentary hiatus than after, when sedimentation resumed. Even though some of these pollen types may be found in modern Amazonian forests (e.g. *Hedyosmum* and *Podocarpus*), their absence after the interpreted environmental change supports the assumption that they were river transported instead of airborne.

Although the climate change at the Andes was probably the main factor influencing the isolation of Lake Tapera, local sedimentary processes, such as the drowning of the Curiaú paleo-drainage system, probably played an important role. As relative sea level was high, and the Amazon flow was reduced, it is possible that a build up of sediments at the mouth of the Amazon and within the estuary induced a "coastal progradation" cutting the Curiaú hydrologic system, intensifying the effects of isolation from riverine floodwater, already experienced by the lake. A similar process was described for a mangrove in French Guiana, in which a coastal progradation at ca. 5,000 years BP was proposed to explain the decline in mangrove vegetation in the pollen record of a coastal lake during the peak of the Holocene sea-level highstand (Tissot et al. 1987).

Although the volume of the Amazon River may have increased rapidly, it is improbable that floodwaters were reaching the lake in the same way as before the dry event, especially because of the lowering sea level. The replacement of blue-grey clay by black-organic sediments, indicative of autochthonous sedimentation, and the lack of Andean pollen from the lake record support this interpretation.

Another Mid-Holocene event that may have exerted an influence on this record is the oscillating intensity of

the El Niño/Southern oscillation (ENSO). An increase in ENSO frequency, especially La Niña events, after 5,000 cal. yrs BP (Moy et al. 2002, Riedinger et al. 2002) might have caused drought in eastern Amazonia, and could have augmented the inferred pattern. It is probable that long-term shifts in ENSO intensity influenced both the Andes and Amazonia during the Holocene. However, as is not possible to parse out the ENSO signal from that of other factors in this study, we consider the reduction on river discharge and the resulting coastal progradation to be both more proximate and parsimonious explanations of the observed changes at Tapera.

#### CONCLUSIONS

The fossil pollen and charcoal records from a lake in eastern Amazonia revealed an environmental change that was initiated by a reduction in river flooding, consistent with a well-documented climate change in the central Andes. As the lake was dependent on flooding to maintain its hydrological balance, the reduced input resulted in a sedimentary hiatus lasting ~5, 500 years at Lake Tapera.

The resume of sedimentation, indicative of local wet conditions, did not bring about a return to pre-drought conditions as a combination of factors, such as changed hydrology due to coastal progradation, human occupation and palaeo-fires may all have played a role in deflecting the system onto a new path.

Despite resumption of wet conditions, flooding of the system was never reestablished, consistent with the long-term change in hydrology induced by falling sea levels in the late Holocene. The rise of lake level within the last 2,000 years, even without significant white-water flooding, is consistent with the observation that the late Holocene has been an unusually wet period.

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#### RESUMO

Análises de pólen, carvões e datações  $C^{14}$  foram conduzidas em um testemunho coletado no lago Tapera (Amapá) com o objetivo de interpretar a história paleoambiental desta parte da Amazônia. Uma das técnicas de análises multivariadas, Análise de Correspondência Destendenciada (DCA), foi utilizada a fim de melhor visualizar a distribuição e similaridade das amostras. Foi identificado um hiato sedimentar com duração de 5.500 anos no lago Tapera. Como o hiato ocorreu simultaneamente ao nível do mar mais alto do Holoceno, o que deveria ter aumentado o lençol freático, impedindo assim o lago de secar, é evidente que variações do nível do mar não foram importantes na manutenção do nível do lago. O lago Tapera provavelmente dependia de água das cheias fluviais, e o hiato sedimentar foi causado por uma redução da descarga do Amazonas, devido a um período extremamente seco nos Andes (8.000-5.000 anos cal. AP), quando os níveis de precipitação diminuíram drasticamente. A ausência de pólen transportado dos Andes pelo rio Amazonas no registro sedimentar, após este evento, apóia esta interpretação. A análise palinológica demonstra que quando a sedimentação reiniciou, em 1.620 anos cal. AP, a vegetação em torno do lago havia mudado de floresta para savana. Este registro demonstra a necessidade de melhorar nosso entendimento sobre a extensão e os impactos das mudanças climáticas sobre a evolução da vegetação.

**Palavras-chave:** mudança na vegetação, mudança na hidrologia, Amazônia, registro palinológico, mudança climática.

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