Vegetation stability in the Southeastern Brazilian coastal area from 5500 to 1400 $^{14}$C yr BP deduced from charcoal analysis

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Abstract

Charcoal analysis of six shell mounds showed that no major changes of the mainland vegetation ecosystem have taken place along the southeastern Brazilian coast (22°53′–22°57′S, 42°03′–42°33′W) from 5500 to 1400 $^{14}$C yr BP. These shell mounds have been occupied by sedentary fisher-gatherer-hunters. Charcoal fragments retrieved from vertical profiles in the archaeological sites were examined; taxonomic determinations were based on a reference collection of charred woods and a program for computer-aided identification. Charcoal assemblages of all the studied sites present taxa from various restinga vegetation types, mangroves, xeromorphic coastal forest, and inland Atlantic Forest. The restinga ecosystem, characteristic of the Brazilian coast, is associated with sandy beach ridges; the restinga forest was much more abundant during the studied period than nowadays. The charcoal assemblages represent mainly the local vegetation; a regional reconstruction depends on the study of numerous sites. In the Cabo Frio region, open restinga taxa are more abundant in the Sambaqui do Forte, while forest elements are more important in the Sambaquis Salinas Peruano and Boca da Barra. The sites studied in the Arraial do Cabo (Sambaqui da Ponta da Cabaça) and in the Saquarema regions (Sambaquis da Pontinha and da Beirada) show that restinga formations were locally predominant. A comparison of multivariate analysis applied to both charcoal assemblages and to phytosociological data of the extant vegetation showed a good correspondence between the charcoal spectra and the present vegetation. The high taxonomic diversity of archaeological charcoal samples and numerous fragments showing traces of decay before charring suggests that aleatory gathering of dead wood constituted the main source of firewood for fisher-gatherer-hunters populations. Condalia sp. was probably selected for cultural reasons.

The only significant fluctuations on the charcoal spectra relate to the mangrove vegetation. Two relatively humid episodes (recorded from ca. 5500 to 4900 $^{14}$C yr BP, intercalated by two episodes of increased dryness with increased lagoon salinity (from ca. 4900/4500 to 2300 and from ca. 2000 to 1400 $^{14}$C yr BP) were recorded in the Cabo Frio region. The changes in mangrove vegetation cannot be attributed to sea-level variations, for the three regressive and the two transgressive episodes identified for the Brazilian coast during this period are not in phase with the development of mangroves. The stability of the mainland vegetation ecosystem is probably due to the edaphic character of the coastal environments, which makes coastal formations much more resistant to climatic variations and less sensitive to climatic change. We propose that this environmental stability was a decisive factor in the maintenance of the fisher-gatherer-hunter sociocultural system. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: archaeological site; Brazil; charcoal analysis; Holocene; palaeoclimate; palaeoenvironment

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1. Introduction

The palaeoenvironmental history of Brazil is still poorly known, but various studies have demonstrated that significant climatic changes affected this country during previous millennia (e.g. Soubie, 1980; Servant et al., 1989; Absy et al., 1991; Ledru et al., 1995; Ferraz-Vicentini and Salgado-Labouriau, 1996; Behling, 1997; Ybert et al., in press). Climatic changes led to vegetational modifications in all studied regions.

The Brazilian coast of the southeastern portion of the Rio de Janeiro state is presently characterized by geological, climatic and ecological features that allow it to be considered as an important area for palaeoenvironmental study (Martin et al., 1988; Tasayco-Ortega, 1996). Modifications on the lagoon sedimentation in several lagoon cores suggest regional climatic variations during the Holocene (Tasayco-Ortega, 1996). This author proposes five dry episodes, attributed to a reinforcement of semi-arid conditions (3600–3500, 3100–3000, 1200–1100 and 600–500 14C yr BP), and two rainy episodes (2300–2100 and 700–600 14C yr BP). The main objective of the present study was to reconstruct the palaeoenvironmental evolution of the plant cover in this region during the last 6000 years.

Charcoal analysis of six archaeological sites and of a modern surface sample of another site from this region are presented. This discipline allows a good reconstruction of the local woody vegetation, and comparison with phytosociological data is quite direct. We will refer to it from this point on as anthracology (from the Greek word for charcoal, anthrakos). Many anthracological studies, mostly in temperate and Mediterranean climates, have already demonstrated the value of these analyses for palaeoenological reconstruction (e.g. Vernet and Thiebault, 1987; Vernet, 1992; Hopkins et al., 1993; Badal et al., 1994; Figueiral, 1995; Heinz and Thiebault, 1998), but these studies are still very rare in the tropics, where floristic diversity is far greater than in temperate regions.

2. Regional setting

Four of the seven studied sites are situated in the Cabo Frio region (22°53′S, 42°03′W) (Fig. 1).
Fig. 1. Geographical location of the studied sites. (1) Sambaqui do Forte; (2) Sambaqui Boca da Barra; (3) Sambaqui do Meio; (4) Sambaqui Salinas Peruano; (5) Sambaqui da Ponta da Cabeça; (6) Sambaqui da Beirada; (7) Sambaqui da Pontinha.

rain water streaming, for there are no important rivers in the region (Barroso, 1987). The very shallow Saquarema Lagoon is connected to the sea by a transient passage. It is strongly influenced by the alternation of continental and marine waters, and its salinity may vary from 0 to 35‰ (Moreira and Carmouze, 1991).

The palaeogeographical development of these lagoons is closely related to Quaternary sea-level fluctuations (Turcq et al., in press). During the Holocene, the sea level rose progressively to the present mean level, which was reached by 7000 \(^{14}C\) yr BP (Fig. 2) (Martin et al., 1979/80, 1997; Turcq et al., in press). Subsequently, three main transgressive episodes occurred (7000-5100, 3900-3600 and 2700-2500 \(^{14}C\) yr BP), intercalated by three regressive episodes (5100-3900, 3600-2700 and after 2500 \(^{14}C\) yr BP). It was not possible to reconstruct a record of the relative sea-level curve for the sector between Sepetiba bay and Cabo Frio, but it is assumed to be comparable to other studied sectors (Turcq et al., in press).

2.1. Vegetation

Plant associations in this region vary according to physiographic conditions and distance from the ocean. The land–sea interface, especially along the edges of rivers and lagoons, is covered by floristically poor mangrove forests and saltwater marshes. \textit{Avicennia schaueriana} and \textit{Laguncularia racemosa} are common species. \textit{Rhizophora mangle}, less tolerant to high salinity, is rare.

The \textit{restinga} ecosystem, characteristic of the

Fig. 2. Curve of relative sea level variation on the Rio Doce coastal plain, Espírito Santo (after Martin et al., 1997).
Brazilian coast, is associated with sandy beach ridges. This complex ecosystem includes different vegetation types, from sparse open plant communities, herbaceous and scrub formations ('open restinga') to dense evergreen forest ('restinga forest'). Each of these vegetation types occupies a well-defined relief configuration, producing zonation of the ecosystem. Low areas between the beach ridges and dune slacks support marshy vegetation. Scrub communities usually grow inland on the external sand barrier, on dunes or in low areas. The remnant restinga forests, growing on the innermost sand barrier, are ca. 8 m high with emergent trees that reach 15–25 m, a dense understory and many epiphytes (Araujo and Henriques, 1984; Araujo, 1997).

Xeromorphic formations on hillsides near the ocean from Cabo Frio Island to Búzios Peninsula are unique along the coast and present many endemic species (Araujo, 1997). Columnar cacti give a characteristic appearance to the low thickets on the steep slopes facing the sea. Xeromorphic forest, up to ca. 8 m high, has a well-developed understory (FEEMA, 1988). Farther from the ocean, low mountains support forests similar in composition to those of the Atlantic rain forest (Rizzini, 1979).

2.2. Prehistoric occupation

The most ancient vestiges of human occupation of the Brazilian coast are the sambaquis, shell mounds constructed by fisher-gatherer-hunter populations who have inhabited the coast from at least 7100 to 500 14C yr BP (Gaspar, 1996). Archaeological deposits are constituted by mollusk shells and fish bones, frequently alternating with sandy layers. Most archaeological layers contain artifacts, burials and hearths. Habitation structures are occasionally found. The composition of sedimentary layers varies from one site to another, but the manufactured artifacts found in these horizons are similar in all of them (Gaspar, 1992). The sites usually stand out distinctly on the landscape. They are generally established on the margins of large water bodies, presenting a set of various ecological habitats in the surroundings (the ocean, lagoons, rivers, restingas, mangroves, forests…). These populations were probably sedentary (Gaspar, 1992) and have occupied the same sites for a very long time. In the studied sites, the period of occupation varies from about 500 to over 3000 years (Table 1).

3. Material and methods

Charcoal fragments were retrieved from vertical profiles along the entire sambaqui height. Each sample consists of a sediment layer of 2 m width, 50 cm depth and 10 cm thick. Sediment was dry-sieved in the field using 4 mm meshes. The charcoal from the residues was recovered in the laboratory with a flotation device (Ybert et al., 1997). One exception is the Sambaqui da Ponta da Cabeça, for which charcoal fragments were collected during the archaeological excavation, and plant remains were hand-sorted.

Charcoal fragments were examined under a reflected light brightfield/darkfield microscope on transversal, tangential longitudinal and tangential radial sections along fresh hand-made fractures. Systematic determination was made by comparing the anatomical structure with that of known wood samples and with descriptions and photographs from the literature (Record and Hess, 1943; Metcalfe and Chalk, 1950; Déienne and Jacquet, 1983; Mainieri and Chimelo, 1989 and papers on wood anatomy). As the wood anatomy of tropical plants is poorly known, especially in our study region, assembling a reference collection of charred wood was indispensable. We have assembled 1840 identified samples (920 species, 410 genera, 101 families), obtained from wood collections and field sampling. Charcoal identification was facilitated by the development of a program for computer-aided identification, coupled to a databank of anatomical features from extant and fossil charcoal (Scheel-Ybert et al., 1998).

All charcoal fragments measuring over 4 mm were analysed. Smaller fragments are normally impossible to identify. Conventionally, results are presented either by weight or by number of charcoal pieces. In this paper, count is the only unit.
Table 1

Radiocarbon dates from the studied sites: conventional ages and calendar ages with 2σ of confidence interval (95%)

<table>
<thead>
<tr>
<th>Site</th>
<th>Level</th>
<th>Conventional age</th>
<th>Calibrated age</th>
<th>Material</th>
<th>Laboratory number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forte</td>
<td>Level IVa</td>
<td>5520 ± 120 BP</td>
<td>6180–5630 cal BP</td>
<td>Shells</td>
<td>Bah</td>
</tr>
<tr>
<td></td>
<td>270–320 cm³</td>
<td>3270 ± 80 BP</td>
<td>3710–3280 cal BP</td>
<td>Charcoal</td>
<td>Gif-A-95340</td>
</tr>
<tr>
<td></td>
<td>240–250 cm³</td>
<td>4910 ± 55 BP</td>
<td>5400–4890 cal BP</td>
<td>Charcoal</td>
<td>Ly-8467</td>
</tr>
<tr>
<td></td>
<td>150–160 cm³</td>
<td>3815 ± 50 BP</td>
<td>4340–3980 cal BP</td>
<td>Charcoal</td>
<td>Ly-8466</td>
</tr>
<tr>
<td></td>
<td>Level IIIa</td>
<td>4320 ± 140 BP</td>
<td>4620–4070 cal BP</td>
<td>Shells</td>
<td>Bah</td>
</tr>
<tr>
<td></td>
<td>Level IIa</td>
<td>3940 ± 140 BP</td>
<td>4280–3740 cal BP</td>
<td>Shells</td>
<td>Bah</td>
</tr>
<tr>
<td></td>
<td>40–50 cm³</td>
<td>2320 ± 55 BP</td>
<td>2660–2410 cal BP</td>
<td>Charcoal</td>
<td>Gif-A-11038</td>
</tr>
<tr>
<td></td>
<td>Level Ib</td>
<td>2240 ± 70 BP</td>
<td>1990–1870 cal BP</td>
<td>Shells</td>
<td>Bah</td>
</tr>
<tr>
<td>Moio</td>
<td>0.70 m³</td>
<td>5180 ± 80 BP</td>
<td>5700–5320 cal BP</td>
<td>Shells</td>
<td>Beta-44809</td>
</tr>
<tr>
<td>Salinas Peroano</td>
<td>130–140 cm³</td>
<td>4540 ± 70 BP</td>
<td>5040–4650 cal BP</td>
<td>Charcoal</td>
<td>Gif-A-1034</td>
</tr>
<tr>
<td></td>
<td>100–110 cm³</td>
<td>4400 ± 40 BP</td>
<td>5000–4670 cal BP</td>
<td>Charcoal</td>
<td>Gif-A-11042</td>
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<tr>
<td></td>
<td>20–30 cm³</td>
<td>1330 ± 45 BP</td>
<td>1520–1370 cal BP</td>
<td>Charcoal</td>
<td>Gif-A-11041</td>
</tr>
<tr>
<td>Boca da Barra</td>
<td>70–80 cm³</td>
<td>3700 ± 150 BP</td>
<td>4340–3580 cal BP</td>
<td>Charcoal</td>
<td>Beta-43827</td>
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<tr>
<td></td>
<td>20–30 cm³</td>
<td>1430 ± 55 BP</td>
<td>1580–1380 cal BP</td>
<td>Shells</td>
<td>Gif-A-11043</td>
</tr>
<tr>
<td>Ponta da Cabeça</td>
<td>160–170 cm³</td>
<td>3270 ± 70 BP</td>
<td>3630–3270 cal BP</td>
<td>Charcoal</td>
<td>Beta-43332</td>
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<tr>
<td>Beirada</td>
<td>Level IVb</td>
<td>4520 ± 190 BP</td>
<td>5240–4190 cal BP</td>
<td>Shells</td>
<td>Bah-1651</td>
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<tr>
<td></td>
<td>Level IIIb</td>
<td>4580 ± 190 BP</td>
<td>5380–4370 cal BP</td>
<td>Shells</td>
<td>Bah-1647</td>
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<td></td>
<td>Level IIb</td>
<td>4160 ± 180 BP</td>
<td>4720–3710 cal BP</td>
<td>Shells</td>
<td>Bah-1636</td>
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<tr>
<td></td>
<td>Level Ia</td>
<td>3800 ± 190 BP</td>
<td>4250–3290 cal BP</td>
<td>Shells</td>
<td>Bah-1765</td>
</tr>
<tr>
<td>Pontinha</td>
<td>Level IVe</td>
<td>2270 ± 190 BP</td>
<td>2750–1750 cal BP</td>
<td>Charcoal</td>
<td>Bah-1634</td>
</tr>
<tr>
<td></td>
<td>Level IIIe</td>
<td>1810 ± 50 BP</td>
<td>2020–1540 cal BP</td>
<td>Charcoal</td>
<td>Gif-A-0863</td>
</tr>
<tr>
<td></td>
<td>Level IIe</td>
<td>1790 ± 40 BP</td>
<td>1790–1540 cal BP</td>
<td>Charcoal</td>
<td>Gif-A-0862</td>
</tr>
</tbody>
</table>

a Kneip (1980).
c Teno´rio (1996).
e Teno´rio (unpublished).

presented, for two reasons: (1) tropical woods present a very wide range of density values [from 0.1 to 1.3 in dry wood (Briane and Doat, 1985)] that may greatly distort biomass estimations based on weight; (2) frequently, shell-mound charcoal fragments are impregnated with carbonates that randomly increase the sample weight.

Our interpretations are based on multivariate analyses applied to both charcoal assemblages and the results of phytosociological analyses of the extant vegetation. The sample validity was tested by the analysis of saturation and Gini-Lorenz curves (Scheel-Ybert, 1998). In some samples, the number of available charcoal fragments was too low to afford consistent palaeoenvironmental interpretations. These levels are represented by light bars in the charcoal diagrams.

4. Chronology

Many levels of the studied sites had already been dated by archaeologists, and we have obtained additional dates from analysed charcoal samples. After calibration, all the chronological sequences obtained are coherent (Table 1). This argument favours the utilization of archaeological deposits for the study of palaeoenvironmental events.

We have calibrated dates obtained from mollusk shells using a 'global' world ocean reservoir age correction (Stuiver and Reimer, 1993). However, dating of mollusk shells should be avoided, especially in this region, where the reservoir effect can be significant due to local upwelling. Appropriate sampling methodology, like
flotation, usually allows the recovery of enough charcoal for dating.

5. Anthracological results

5.1. Cabo Frio region

The Sambaqui do Forte’s charcoal diagram shows a great floristic diversity (Fig. 3), with a strong predominance of Myrtaceae species. This family is present in different communities of Brazilian vegetation, but high percentages are typical for restinga formations. Most of the 102 taxa identified correspond to the different plant associations presently existing in the region. The most typical for the restinga forest are Annonaceae aff. Duguetia, Actinostemon sp., Alibertia sp., Guettarda aff. viburnoides, Rubiaceae type Randia/Coutarea, Budrea sp. and Ensbeckia sp. These taxa can also occur in the xeromorphic forest. Aspidosperma sp., Melastomataceae, Condalia sp. and Pouteria sp. are typical for the restinga forest as well as the open restinga. Maytenus sp., Rheedia sp., Byrsonima sp., Rapanea sp. and Sideroxylon aff. obtusifolium are characteristic of the open restinga. Gochnatia sp., Pachystroma sp. and Lonchocarpus sp. are typical for the xeromorphic forest. Caesalpinia echinata and Cupania sp. occur both in the xeromorphic forest and in the restinga forest, but are considered as typical for the xeromorphic forest Securinega sp. and Sloanea sp. are known only in the Atlantic forest, but they can also occur in the xeromorphic forest. Laguncularia racemosa and Avicennia aff. schaueriana are characteristic of the mangrove forest.

In the Sambaqui Salinas Peroano (Fig. 4), the most important taxa are: Gochnatia sp., Pachystroma sp., Securinega sp., cf. Caesalpinia echinata (xeromorphic forest), Annonaceae aff. Duguetia, Rubiaceae type Randia/Coutarea, Rutaceae aff. Metrodorea (restinga forest and xeromorphic forest), Condalia sp. (restinga forest and open restinga), Sideroxylon aff. obtusifolium (open restinga), Laguncularia racemosa and Avicennia aff. schaueriana (mangrove), and in the Sambaqui Boca da Barra (Fig. 5): Gochnatia sp., Pachystroma sp., Lonchocarpus sp., Machaerium sp., Cupania sp. (xeromorphic forest), Annonaceae aff. Duguetia, Actinostemon sp., Lauraceae, cf. Pitardenia, Guettarda aff. viburnoides, Rubiaceae type Randia/Coutarea, Budrea sp. (restinga forest and xeromorphic forest), Condalia sp. (restinga forest and open restinga), Maytenus sp., Rapanea sp., Sideroxylon aff. obtusifolium (open restinga), Laguncularia racemosa and Avicennia aff. schaueriana (mangrove). Species of Myrtaceae are frequent all along the diagrams, but they are less important than in the Sambaqui do Forte.

Mangrove taxa are responsible for most of the significant variations in these charcoal diagrams. In the Sambaqui do Forte, mangrove elements are abundant from the base of the sequence until ca. 4900 $^{14}$C yr BP. After 4900 $^{14}$C yr BP, they are rare until ca. 2300 $^{14}$C yr BP and increase again thereafter. In the Sambaqui Salinas Peroano, they are abundant at the base of the diagram (between 100 and 210 cm, ca. 4300/4500 $^{14}$C yr BP), while in the upper 100 cm, there is a reduction in the percentages and an irregular presence. Higher percentages of Avicennia aff. schaueriana between 50 and 90 cm are probably not significant because of the small number of charcoal fragments analysed. In the Sambaqui Boca da Barra, mangrove elements are recorded in small percentages between 3700 and 1400 $^{14}$C yr BP.

Mangrove evolution is different on both sides of the channel. On its western side (Sambaqui do Forte), mangrove vegetation reduces abruptly just after 4900 $^{14}$C yr BP; it remains rare from 4900 to 2300 $^{14}$C yr BP, and an important re-establishment is evidenced thereafter. On the eastern side of the channel (Sambaquis Salinas Peroano and Boca da Barra), mangrove is abundant until 4300/4500 $^{14}$C yr BP and reduced thereafter. These chrono logical differences may be due to geomorphological and/or sedimentological features of the channel related to: different bathymetry; different contours (which can lead to a stronger erosion at one side than another); differences in the sedimentary nature of the subsurface (sandy or clayey); differences in shore nature, which are sandy on the west side and rocky on the east side (favouring rainfall flow on its east side). It is likely that a precipitation reduction would affect the west side.
Fig. 3. Charcoal percentage diagram of the Sambaqui do Forte. Light bars represent samples with less than 100 fragments analysed. Nop: number of taxa; Ni: number of determinable fragments; Nt: total number of fragments analysed; Vs: sediment volume (in litres).

Fig. 4. Charcoal percentage diagram of the Sambaqui Salinas Perono (see legend to Fig. 3). The sediment volume retrieved in each level is 100 l.
Fig. 5. Charcoal percentage diagram of the Sambaqui Boca da Barra (see legend to Fig. 3). The sediment volume retrieved in each level is 100 l.
of the channel more intensely, due to the more effective drainage associated with sandy soils.

The changes in mangrove vegetation cannot be attributed to sea-level variations. The three regressive and two transgressive episodes identified for the Brazilian coast during this period are not in phase with the mangrove evolution (see Fig. 2). Probably, precipitation reduction provoked a higher salinity in the Araruama Lagoon which, consequently, resulted in a reduction in mangrove vegetation. This hypothesis agrees with the existence of climatic oscillations in the southeastern Rio de Janeiro State, proposed by Tasayco-Ortega (1996) based on sediment analysis. Our results have been compared to his curve of changes in the isotopic composition of carbonates in sediments of the Araruama Lagoon (Fig. 6). Low values of δ18O are interpreted to reflect a major influence of rainwater, while high values signify increased salinity. The curve shows that salinity in the lagoon was low until ca. 5000 14C yr BP. This can be correlated to the high percentages of mangrove elements in the base of the charcoal diagrams. After this point, salinity is high until ca. 2300 14C yr BP. During this period, mangrove is rare on both sides of the Itajuru Channel. A net reduction of salinity is recorded between 2300 and 2000 14C yr BP. It can be correlated to the re-establishment of mangrove elements in the Sambaqui do Forte after 2300 14C yr BP. This re-establishment is certainly related to a humid episode. We cannot estimate its duration, but the fact that it is not recorded in the east side of the channel suggests it was brief.

5.2. Arraial do Cabo region

Sorting of plant remains from the Sambaqui da Ponta da Cabeça is not finished, so we cannot yet present charcoal and palm-fruit samples for all levels. However, analysis of the charcoal diagram is very interesting and shows an important contribution of mangrove taxa in the upper levels. The charcoal assemblage has a high floristic diversity, most of the taxa presenting low percentages, with exception of Myrtaceae species and, in the upper 30 cm of the analysed profile, Laguncularia racemosa (Fig. 7). Amongst the more significant elements are Gochnatia sp., Pachystroma sp., Lonchocarpus sp. and Cupania sp. (xeromor-
Fig. 7. Charcoal percentage diagram of the Sambaqui da Ponta da Cabeca (see legend to Fig. 3).
5.4. Comparison of palaeoenvironment and present vegetation

Anthracological results were compared to phytosociological data of comparable plant associations from diverse Brazilian localities using factor correspondence analyses (FCA).

We also compared these results to the surface charcoal sample retrieved from Sambaqui do Meio, which is probably associated with a local charcoal production not older than a few decades. The taxonomic assemblage of this modern sample is very similar to that found in the archaeological samples (Fig. 9). The taxa represented are typical for restinga formations (Zollernia sp., cf. Piptadenia, Jacaranda sp., Capparis sp., Rapanea sp., Sideroxylon all. obtusifolium, cf. Maytenus sp., Erythroxylum sp., Byrsonima sp., Rheedia sp.,...). The diversity of Myrtaceae and their overall proportions are lower than in archaeological samples. Mangrove elements are rare. Hibiscus cf. tiliacus and Seshania sp. show high percentages. These pioneer taxa, presently very frequent in the region, are particularly abundant in areas where mangrove existed previously and in marshy zones at the margins of the lagoons. Most of the predominant taxa are typical for degraded or secondary vegetation (Schinus, Hibiscus, Seshania, Aegiphila), thus corresponding to what is presently found locally. Araucaria angustifolia represents an imported taxon (wooden furniture, crates?).

The first FCA represents only the present-day vegetation data. All analyses were made at the generic level, to allow a comparison with charcoal assemblages. The following phytosociological data were used:

(1) Eleven studies in restinga forest: two areas from the Jacarepia Ecological Reserve, near Saquarema, one presenting a well-preserved vegetation (Sa and Araujo, unpublished data), and the other concerning a zone cleared 6 years earlier (Sa, 1993); one area from Espírito Santo State (Fabris, 1995); two distinct areas from Cananéia, São Paulo State (Sugiyama, 1993); four different areas from Ilha do Mel, Paraná State, and the global data of this author (Silva, 1990); one area from...
Fig. 8. Charcoal percentage diagram of the Saquarema region. Lower part, Sambaqui da Beirada; upper part, Sambaqui da Pontinha (see legend to Fig. 3). The sediment volume retrieved in each level is 100 l.
Fig. 9. Charcoal percentage diagram of the Sambaqui do Meio surface sample (see legend to Fig. 3).

(2) Four studies in Atlantic Forest: two areas from Rio de Janeiro State (Guedes, 1988; Kurtz, 1994); two areas from São Paulo State (Silva and Leitão Filho, 1982; Negreiros et al., 1995).

Despite the floristic similarities between restinga and Atlantic forests (Rizzini, 1979; Araujo and Lacerda, 1987), FCA produces a clear separation of these formations, even at the generic level. Three groups are clearly recognized (Fig. 10): (1) Atlantic Forest, (2) restinga forest from tropical areas (Rio de Janeiro, Espírito Santo, Rio Grande do Norte) and (3) restinga forest from subtropical areas (São Paulo, Paraná). The dataset from the secondary restinga forest is supplementary, that is to say, the dataset relative position is represented in the graphical results, but its numerical contributions are not considered for the FCA calculations. Otherwise, it is very isolated from the other elements, because this floristic assemblage presents high percentages of pioneer taxa and is therefore very different from the others.

Archaeological charcoal samples resemble each other more than they resemble the present vegetation types, but their resemblance to modern tropical vegetation types corroborates the robustness of the phytosociological data of the present-day vegetation. Extant taxa absent from the fossil assemblages are supplementary, and we have grouped together at the family level all taxa for which the wood anatomy does not allow a better identification, e.g. Myrtaceae and Nyctaginaceae. In this analysis, axis 2 identifies a group associating the Sambaqui do Meio with the secondary restinga forest and, to a lesser extent, a group associating subtropical Atlantic Forest datasets. Axis 1 identifies one group associating all fossil samples with the tropical Atlantic and restinga forests datasets, and another associating subtropical restinga forest datasets (Fig. 11).

Archaeological charcoal samples resemble each other more than they resemble the present vegetation types, but their resemblance to modern tropical vegetation types corroborates the robustness of the phytosociological data of the present-day vegetation. Extant taxa absent from the fossil assemblages are supplementary, and we have grouped together at the family level all taxa for which the wood anatomy does not allow a better identification, e.g. Myrtaceae and Nyctaginaceae. In this analysis, axis 2 identifies a group associating the Sambaqui do Meio with the secondary restinga forest and, to a lesser extent, a group associating subtropical Atlantic Forest datasets. Axis 1 identifies one group associating all fossil samples with the tropical Atlantic and restinga forests datasets, and another associating subtropical restinga forest datasets (Fig. 11).
of the anthracological method. The Sambaqui do Meio modern sample is associated with the secondary restinga forest sample. Both are characterized by pioneer taxa (especially *Aegiphilla* sp.), typical for disturbed plant associations and early stages of secondary succession.

A FCA with these two samples as supplementary confirms the high similarity between archaeological samples (Fig. 12). However, for axis 1 opposes most of the extant vegetation datasets. The predominant of restinga forest elements in the Sambaqui do Forte makes these samples more similar to the Rio Grande do Norte restinga, while the levels of Sambaqui Boca da Barra are less similar. Those of Sambaqui Salinas Perto, all of them situated in the Saquarema region. The dataset from the Rio Grande do Norte restinga forest is associated with the Sambaquis da Beirada et da Pontinha, described as a ‘composite habitat’ (Trindade, 1991), which is exactly the case for archaeological samples. The predominance of restinga forest elements in the Sambaqui do Forte makes these samples more similar to the Rio Grande do Norte restinga, while the levels of Sambaqui Boca da Barra are less similar. Those of Sambaqui Salinas Perto, with a strong predominance of xeromorphic forest elements, form an isolated group.

The mixing of taxa from different plant associations in the archaeological samples explains why they resemble each other more than they resemble the present samples. Nevertheless, in spite of all the processes that affect the charcoal sample from the moment of wood gathering until its analysis (physical transformations of charred wood, post-depositional processes, charcoal frag-
Fig. 12. Factor correspondence analysis. Correlation between archaeological samples and phytosociological studies. Sambaqui do Meio and R2R supplementary (see legend to Fig. 11).

mentation, etc.), and in spite of the limited number of charcoal fragments analysed, our results show that the anthracological taxonomic assemblage resembles the present-day plant associations reasonably well.

We compared the palaeoenvironmental results of each studied site in a FCA considering all taxa identified. It shows a strong opposition between archaeological samples and the Sambaqui do Meio, with a weak discrimination of sites on axis 2. A factor analysis with the Sambaqui do Meio dataset as supplementary leads to a good separation of the different sites (Fig. 13). Axis 1 opposes the sites from Saquarema and Araraí do Cabo regions to those from Cabo Frio region. Axis 2 opposes the upper part of Sambaqui Salinas Peroano to the lower part of this site and to the other samples. Five groups can be identified:

1. All levels of Sambaquis da Beirada and da Pontinha, where open restinga elements are predominant; mangrove elements are rare.
2. All levels of Sambaqui da Ponta da Cabeça, with predominance of restinga elements, but also presenting some forest elements; mangrove taxa are frequent, especially in the upper levels.
3. The Sambaqui Salinas Peroano, where xeromorphic forest is predominant, is separated in two groups: the upper levels…
4. and the lower levels, where mangrove elements are more abundant.
5. On a central position, all levels of Sambaquis do Forte and Boca da Barra, which present elements of the various plant associations in rather equitable proportions. Levels where the mangrove elements are more important have values that are more negative on axis 2. Sambaqui Boca da Barra, where forest elements are predominant on open restinga elements, shows values that are slightly more positives on axis 1 than those of the Sambaqui do Forte.

In conclusion, axis 1 opposes open restinga elements to xeromorphic forest elements, while...
axis 2 separates samples with a strong contribution of mangrove taxa from samples with a weak contribution.

6. Discussion

6.1. Palaeoenvironmental interpretation

Our results show that various plant associations existed in the Cabo Frio region during the Late Holocene (from ca. 5500 to 1400 $^{14}$C yr BP, or 6190 to 1180 cal yr BP). Restinga forest, open restinga, xeromorphic forest and mangrove taxa are present in the three studied sites in variable proportions. Open restinga is better represented in the Sambaqui do Forte, while closed forest formations are more important in Sambaquis Salinas Peroano and Boca da Barra. This is a consequence of the local site characteristics: the former sambaqui is situated near the beach, in the phytosociological domain of open restinga, while the latter are situated on the margin of the channel, on crystalline hills dominated by forest formations.

The only significant variations in the charcoal diagrams concern mangrove vegetation (Fig. 14). We attribute these to climatic oscillations provoking changes in lagoon salinity. This interpretation is corroborated by changes in isotopic composition of sediment carbonates in the Araruama Lagoon (Tasayco-Ortega, 1996), which confirms the existence of at least two dry episodes in the Cabo Frio region, intercalated with brief humid episodes. In spite of these climatic oscillations affecting mangrove vegetation, no other significant evidence of vegetation change is evidenced.

It is expected that climatic changes produce vegetation changes. We show that this is not the case with regard to the coastal mainland vegetation. The restinga ecosystem is related to sandy soils and to the geomorphologic nature of sandy beach ridges. This implies that it is essentially an edaphic formation, with a marked resilience to climatic change. This is also the case of the xeromorphic forest characteristic of rocky outcrops in the Cabo Frio region. In spite of the fact that this forest is also related to climate parameters, edaphic factors may certainly explain why it has not been greatly affected by climatic oscillations.

Bisa (1998) presented a palynological study of a peat core from a flooded forest area in the coastal zone of São Paulo State between ca. 4300 and 1000 $^{14}$C yr BP. He found no variations in the vegetation that could be attributed to climatic changes. This seems to confirm that coastal formations, strongly depending on edaphic conditioning, are much more resistant to climatic variations and less sensitive to climatic change.

The charcoal assemblage in the Arraial do Cabo region shows that during the period of human occupation of the Sambaqui da Ponta da Cabeça (from ca. 3300 until after 2000 $^{14}$C yr BP, or 3630–1880 cal yr BP), open restinga formations were locally predominant. This is also a consequence of the site location. In spite of the fact that this site is situated upon a crystalline hill, it is located very near the beach and characterized by an especially dry climate due to upwelling centred in its vicinity.
Mangrove vegetation, which is currently absent from this region, was probably established on the margins of the Araruama Lagoon during this period.

At the Saquarema region, sandy beach ridges were already occupied by the restinga vegetation between 4300 and 3800 $^{14}$C yr BP (4860–3290 cal yr BP) and from ca. 2300 until after 1800 $^{14}$C yr BP (at least 2750–1540 cal yr BP). Open restinga formations were predominant. The slight increase of Atlantic Forest elements at the Sambaqui da Pontinha’s level 100–120 cm, i.e. around 2300 $^{14}$C yr BP (2750–1750 cal yr BP), is too small to be interpreted as significant for an environmental change. The oscillations in the relative percentages of the vegetation types in the Sambaqui da Beirada, as well as in some levels of the Sambaquis da Pontinha and Salinas Persano, are not significant because of the exceptionally small number of charcoal fragments analysed.

6.2. Cultural selection

Aleatory gathering of dead wood certainly constituted the main source of firewood for fisher-gatherer-hunters populations. This is suggested by the great diversity of the charcoal assemblage and the numerous fragments that show traces of decay or signs of insect larvae attack before charring.

However, the high frequencies of Condalia sp. in most of the samples (Figs. 3–8) are difficult to explain by environmental criteria. Condalia buxi-
folia, the only species that occurs in the Brazilian coastal vegetation nowadays, is a very rare taxon (Silva and Oliveira, 1989). Two hypotheses may explain its high frequencies: (1) the species was abundant in the environment, implying that the vegetation was somewhat different from the present vegetation; (2) the species was not particularly frequent but was selected for cultural reasons. Both hypotheses imply that this taxon was at least more frequent than it is nowadays, but the first must be discarded because the floristic assemblage of the archaeological charcoal is otherwise very similar to the present vegetation. Frequencies of Condalia fragments in our samples could be explained by a cultural selection due to wood features. It is considered as an excellent combustible and is reported to produce a blue pigment; the root bark of some species is utilized as soap or medicine; the plant bears edible fruits (Record and Hess, 1943). The hypothesis of a ritual or mystical utilization of this taxon is also possible. This would explain why all Condalia fragments are vitrified, suggesting that its wood was always charred green (Scheel-Ybert, 1998).

Species selection is apparently contradictory to a good representation of the surrounding vegetation in the charcoal fragments. However, we think that most of the species present in the environment can be represented in archaeological charcoal, especially if fuel wood is obtained from dead wood gathering. We assume that this argument justifies that anthracological analyses are representative to reconstruct palaeoenvironments, in spite of the cultural selection that may cause over-representation of a few taxa. The high taxonomic diversity of archaeological charcoal samples and the good correspondence between the anthracological spectra and the present vegetation corroborate this argument.

7. Conclusions

Our results show that the analysis of tropical archaeological charcoal provides reliable information on past environments and confirm the validity of anthracology for tropical palaeoenvironmental reconstruction. The charcoal samples’ great taxonomic diversity, the similarity of the anthracological results in neighbouring sites and the good correspondence between the charcoal assemblages and the present-day vegetation indicate that wood gathering by prehistorical populations, most likely for domestic fires, was not selective.

However, charcoal assemblages represent mainly the local vegetation. The analysis of isolated sites provides only site information, and a regional reconstruction depends on the study of numerous sites distributed over a relatively large area.

The six archaeological sites studied have been occupied for a long time, from ca. 5500 to 1400 \(^{14}C\) yr BP (6190–1180 cal yr BP). Analysis of over 15 500 charcoal fragments demonstrates that during the Late Holocene, the southeastern coast of Brazil presented different restinga vegetation types, forest formations like the xeromorphic forest from the rocky shore of Cabo Frio region and, inland, the Atlantic Forest, and mangrove vegetation, especially on lagoons margins of Cabo Frio and Arraial do Cabo regions. Restinga forest was very frequent in this region during this period, and open restinga formations were probably restricted to the external beach ridges, to lower zones between beach ridges and to lagoons edges.

The mainland coastal vegetation was not perturbed during this period, but changes in mangrove elements were recorded. These changes are associated with two humid episodes in the Cabo Frio region (recorded from ca. 5500 to 4900/4500 and from ca. 2300 to 2000 \(^{14}C\) yr BP) intercalated by two episodes of increased dryness with increased lagoon salinity (from ca. 4900/4500 to 2300 and from ca. 2000 to 1400 \(^{14}C\) yr BP). We propose that the stability of the coastal mainland vegetation is a consequence of its edaphic character, which makes coastal formations much more resistant to climatic variations and less sensitive to climatic change.

Environmental stability has important consequences on prehistorical populations. We propose that this has been a main factor in the maintenance of the sociocultural system of the fisher–gatherer–hunters that have lived on the Brazilian coast for more than 6000 years (Gaspar, 1996).
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