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PALYNOLOGY: A FORENSIC TRACE TOOL TO IDENTIFY A TEMPORAL COASTAL VEGETATION CHANGES

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Abstract: The purpose of this paper was to identify the temporal vegetation changes at the mouth of the Jucu River (ES), southeastern Brazil using palynology as a forensic trace tool. Thus, a sedimentary core was collected with a depth of 190 cm, and was used to perform pollen, sedimentary and C-14 dating analyses. The results showed the formation of four zones to describe the vegetation evolution and the environmental changes, according to cluster analysis of pollen taxa. The first zone started more than two thousand years before present (BP), with sandy sediments, which is indicative of high energy flow. The analysis of the palynological profile indicated the presence of herbaceous vegetation. For the second and third zones, there were a predominance of silt-sandy sediment, with the installation of the mangrove since at least ±2212 cal years BP. Finally, the fourth zone considers the period of half-century until the present, marked by the presence of silt-clay sediment and the predominance of herbaceous vegetation. Therefore, those results demonstrate a high application of the pollen analysis to describe the vegetation succession.

Keywords: Brazilian Coastal Region; Holocene; Mangrove; Pollen; Sedimentology.

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1 INTRODUCTION

The coastal zone is largely controlled by complex interactions involving gradients of tidal oscillation, river discharge, littoral currents, sediment, and nutrient supply (SCHAEFFER-NOVELLI et al., 2000; DOMINGUEZ, 2006), and human influence.

Previous studies of pollen and sedimentary records along the Brazilian coast have presented valuable information about coastal vegetation history (GRINDROD et al., 2002; AMARAL et al., 2006; COHEN et al., 2009; SMITH et al., 2011; FRANÇA et al., 2012; GUIMARÃES et al., 2012; FRANÇA et al., 2013; SILVA et al., 2022).

The coastal zone would seem to be an excellent location for using pollen data in forensic applications, for instance. The vegetation within the region is highly diverse ranging from areas such as *restinga* and mangroves. The diversity, often characterized in most locations by unique combinations of pollen types, makes the use of forensic pollen a reliable technique that can often be used to associate individuals with a unique geographical region. Nevertheless, forensic pollen studies are currently one of the most highly underutilized techniques available (BRYAN and JONES, 2006).

In this context, palynological studies have been applied to deltas and estuaries which are great locations for understanding the coastal dynamics, where also a great range of human activities (DEPARTMENT FOR ENVIRONMENT FOOD AND RURAL AFFAIRS, 2011), including ports, fishing, recreation, tourism, and inhabitation.

The largest cities in the world are located in coastal areas, which highlights the important relation that exists between these zones and humankind. In fact, around 60% of the world's population lives along the coast (UNITED NATIONS, 2016).

Among depositional environments, coastal systems can elucidate continental and marine influences that have occurred in the past, as well as human environmental impacts. Thus, assessing sedimentological records associated with vegetation pollen data can reveal environmental changes that have occurred (LAMB et al., 2006), and help us better understand these environments' (MCCARTHY et al., 2012; WARTENBERG and FREUND, 2012; MILLER et al., 2013; SOBRINHO et al., 2014).

Therefore, the purpose of this work is present a millennial pollen record to study the environmental history in a southern part of Espírito Santo State. We focus on vegetation development to describe the environmental evolution.

2 BACKGROUND OF STUDY AREA

The study area is located at the mouth of the Jucu River that flows over Quaternary fluvio-marine and Quaternary paludal deposit into the coastal plain of the southeastern Brazilian littoral (Figure 1), State of Espírito Santo. The coastal plain of the Jucu River has a maximum width of about 7 km and a length of about 5 km. This region is characterized by stretches with rocky embayments, forming a very indented coastline (KLEIN and SHORT, 2016), where small Quaternary coastal plains and small rivers are present (SUGUIO, MARTIN and DOMINGUEZ, 1982; MAHIQUES and SOUZA, 1999). This coastal region is influenced by the

Atlantic Ocean with semidiurnal micro-tides (tidal range < 2 m), and water salinity between 9 and 34‰. The Jucu River has a maximum and minimum outflow of 42 and 15 m3 s-1 (DEINA, BASTOS and QUARESMA et al., 2011).

Figure 1: Study site - a) Brazil; b) Tidal creek, mangrove vegetation, and core location; c) Sampling and Peat Sampler; d) sediment core; e) State of Espírito Santo and core location (Vila Velha).

VEGETATION

The coastal plain is characterized by forest pioneering freshwater species such as *Hypolytrum* sp., *Panicum* sp., and also brackish/marine water species such as *Polygala cyparissias*, *Remiria maritima*, *Typha* sp., *Cyperus* sp., *Montrichardia* sp., *Tapirira guianensis* and *Symphonia globulifera* (SILVA et al., 2022). Tropical rainforest-type vegetation is also present in this region, where the most representative plant families are Annonaceae, Fabaceae, Myrtaceae, Sapotaceae, Bignoniaceae, Lauraceae, Hippocrateaceae, Euphorbiaceae, and Apocynaceae (PEIXOTO and GENTRY, 1990). The mangrove ecosystem is characterized by *Rhizophora* sp., *Laguncularia* sp. and *Avicennia* sp., which are currently restricted to the mouth of the Jucu River.

3 MATERIALS AND METHODS

For this study one sediment core, 190 cm depth, was analyzed from the area occupied by a mangrove and herbaceous vegetation. The core was X-rayed in order to identify sedimentary structures, and also provided radiocarbon dating (three samples), sedimentary, and pollen analysis (20 samples). Palynological samples of 1.0 cm^3 were taken at 10 cm intervals along the studied core.

RADIOCARBON DATING

Bulk samples of organic matter were checked and physically cleaned under the stereo-microscope, removing shell fragments, roots, and seeds. Samples were selected based on stratigraphic discontinuities that suggest changes in the tidal inundation regime. The residual material for each sample was then extracted with 2% HCl at 60°C for 4 hours, washed with distilled water until neutral pH was reached, and dried at 50°C (PESSENDA et al., 2010, 2012). The organic matter from the sediment was analyzed by Accelerator Mass Spectrometry (AMS) at the Center for Applied Isotope Studies (CAIS), University of Georgia (UGA), USA. Radiocarbon ages are reported in years before AD 1950 (years BP) normalized to δ13C of -25‰ VPDB and in cal years BP, 2σ (REIMER et al., 2013).

SEDIMENTS

The sediment grain size distributions were determined following the methods of Wentworth (1922), for sand (2-0.0625 mm), silt (62.5-3.9 µm), and clay fractions (3.9-0.12 µm). Facies analysis included descriptions of color (MUNSELLCOLOR, 2009), lithology, texture, and structure (HARPER 1984; WALKER, 1992). The sedimentary facies were codified according to Miall (1978).

PALYNOLOGICAL ANALYSIS

All samples were prepared using standard analytical techniques for pollen including acetolysis (FAEGRI and IVERSEN, 1989). Sample residues were placed in Eppendorf microtubes and kept in a glycerol gelatin medium. Morphological descriptions (ROUBIK and MORENO, 1991; BEHLING, 1993; HERRERA and URREGO, 1996; COLINVAUX, OLIVEIRA and PATIÑO, 1999) were consulted for identification of pollen grains and spores. Software packages TILIA and TILIAGRAPH were used to calculate and plot pollen diagrams (GRIMM, 1990). CONISS was used for cluster analysis of pollen taxa, permitting the zonation of the pollen diagram (GRIMM, 1987).

4 PALEOENVIRONMENTAL HISTORY

The results consist of radiocarbon data, pollen diagrams and sedimentary features since at least ±2210 cal years BP from a current estuary area of the Jucu River mouth, southeastern Brazil. Basically, the sediment core presents light brown muddy and sandy silt. This deposit presents massive, cross-laminated, parallel laminated, and heterolithic bedded.

Radiocarbon dates ranged from at least 2210 cal years BP to 460 cal years BP and revealed the following sedimentation rates: 0.42 mm/year (165-163 cm), 44 mm/year (92-90), and 0.23 mm/year (12-10), according to Figure 2. This core presents an alternation for the sedimentation rates. Although the rates are non-linear between the dated points, they are within the vertical accretion range of mangrove forests from southeastern Brazil (FRANÇA et al., 2016; SILVA et al., 2022). The results showed the formation of four zones to describe the vegetation evolution and the environmental changes, according to cluster analysis of pollen taxa.

ZONE I

This deposit consists of sandy sediments with massive sand (Sm), coarse sand, and cross-laminated fine-grained sand (facies Sc) until at least around 2210 cal years BP (Figure 2). This deposit corresponds to the bottom section of the core. The pollen assemblage of this zone is characterized by the predominance of herbaceous pollen (34-72%), mainly represented by Cyperaceae (24-30%), Poaceae (10-20%), Asteraceae (±10%), and Cannabaceae (±10%). Pollen of trees and shrubs are also registered (±48%), represented by Euphorbiaceae (±24%), Fabaceae (±19%), Myrtaceae (±10%), and Rubiaceae (±5%). Palm pollen was also counted, represented by Arecaceae (9-20%). Samples from this zone contain marine microfossils, such as foraminifera (±15%).

ZONE II

This deposit consists basically of sand and silt sediments, coarse sand (facies Sm), and a low concentration of clay, between around 2210 and 480 cal years BP (Figure 2). The pollen assemblage of this zone is mainly characterized by mangroves beginning with the presence of *Laguncularia* (9%), *Rhizophora* (2%), and *Avicennia* (2%). The herbaceous pollen (45-70%) is mainly characterized by Poaceae (18-37%), Cyperaceae (9-25%), Asteraceae (±10%), Moraceae (±5%), Alismataceae (±8%), Malvaceae (±8%), Polygonaceae (±8%), Eriocaulaceae (±4%), Cannabaceae (±4%), Amaranthaceae (±2%), Convolvulaceae (±2%), and Marcgraviaceae (±2%). The most common shrub taxa are (20-27%): Euphorbiaceae (±12%), Rubiaceae (±11%), Fabaceae (4-10%), Cactaceae (±9%), Aquifoliaceae (±4%), Myristicaceae (±4%), Araliaceae (±2%), Loranthaceae (±2%), and Myrsinaceae (±2%). Some palms were counted in this zone (7-23%), as well as trees (6-19%), represented by Combretaceae (2-8%), Myrtaceae (2-7%), Apocynaceae (±7%), Ulmaceae (±4%), and Bignoniaceae (±4%). Ferns also were counted (±65%), such as Pteridaceae (8-64%) and Polypodiaceae (8-52%), as well as fungi (±36%) and foramnifera (±10%).

ZONE III

This zone occurs between around 480 and 470 cal years BP, between 115 and 45 cm in depth (Figure 2). It mainly consists of silt-sandy sediments.

A mangrove occurs in this zone (3-7%), mainly represented by *Laguncularia* (6%), and *Rhizophora* (1%), respectively (Figure 2). The pollen assemblage of this zone is characterized by the predominance of herbaceous pollen (46-55%), mainly represented by Poaceae (12-37%), Cyperaceae (4-17%), Moraceae (±10%), Alismataceae (±8%), Malvaceae (±8%), Asteraceae (±7%), Curcubitaceae (±4%), Solanaceae (±4%), and Amaranthaceae (±2%). Pollen of shrubs are also registered (10-42%), represented by Fabaceae (5-15%), Euphorbiaceae (3-8%), Rubiaceae (±8%), Smilaceae (±5%), Capparaceae (±4%), Connaraceae (±4%), Loranthaceae (±4%), Anacardiaceae (±2%), Meliaceae (±2%), Anacardiaceae (±2%), Aquifoliaceae (±1%), Araliaceae (±1%), Cactaceae (±1%), and Symplocaceae (±1%). Palms pollen also counted, basically represented by Arecaceae (8-30%). Trees (3-18%) were represented by Combretaceae (±5%), Myrtaceae (±5%), Bignoniaceae (±5%), Annonaceae (±4%), Asparagaceae (±4%), Apocynaceae (±3%), Ulmaceae (±3%), Bombacaceae (±2%), and Violaceae (±1%).

ZONE IV

This deposit consists of silt-clay sediments since at least around 460 cal years BP (Figure 2). The bottom of this zone was marked by silt, clay, and sand sediments. The pollen assemblage is characterized by mangrove pollen presence as well around 2-7%, mainly represented by *Laguncularia* (2-8%) and *Rhizophora* (±2%). The herbaceous pollen (42-53%) was mainly represented by Poaceae (20-27%), Cannabaceae (2-18%), Asteraceae (±10%), Moraceae (5-9%), Amaranthaceae (±6%), and Cyperaceae (±4%). Pollen of shrubs (14-34%), and trees (20-36%) are also registered, represented by Fabaceae (3-10%), Anacardiaceae (±9%), Euphorbiaceae (3-8%), Rubiaceae (±2%), Apocynaceae (5-15%), Ericaceae (9-12%), Combretaceae (±11%), Myrtaceae (5-7%), and Ilex (±2%); furthermore, Arecaceae is found around 15%. Samples from this zone contain marine microfossils such as foraminifera (±2%), as well as fungi (±33%) and ferns (±30%).

REVISTA Ifes Ciência

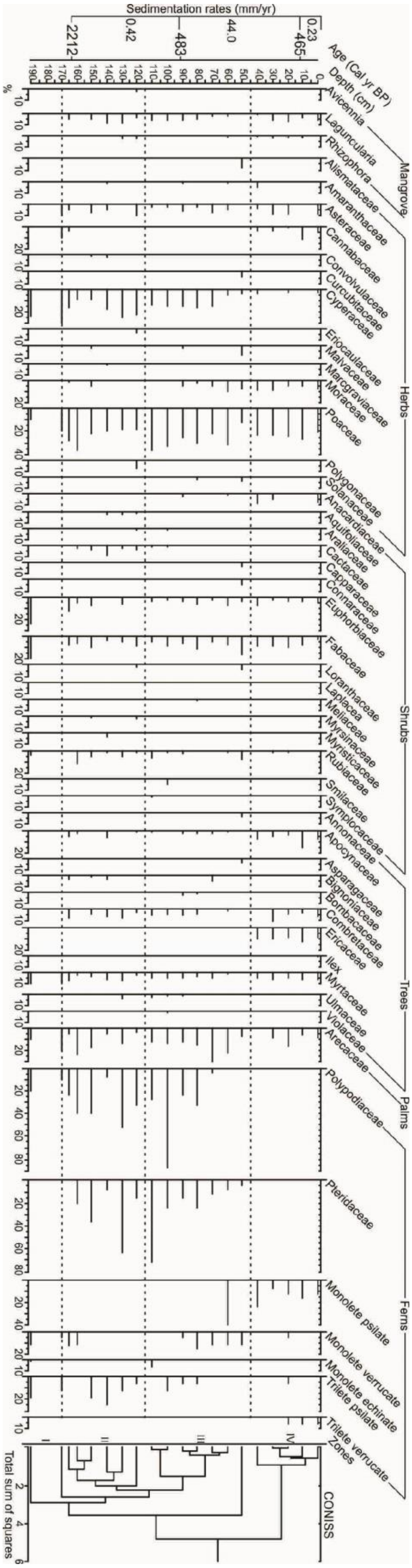

Figure 2: Pollen diagram.

COASTAL VEGETATION DYNAMICS

Climate change and Atlantic sea-level oscillation have produced an impact on sedimentary dynamics and displacements of coastal ecosystems along the Brazilian littoral during the Holocene, especially along the coastal zone of Espírito Santo State (BUSO JUNIOR et al., 2013; FRANÇA et al., 2013, 2016; COHEN et al., 2014; ROSSETTI et al., 2015; BOZI et al., 2021; SILVA et al., 2022).

Regarding the mangrove ecosystems and vegetations, they occur broadly on the coast (SCHAEFFER-NOVELLI et al., 2000), especially on Tropical and Subtropical coastal zones, and they have reacted clearly to climate change and sea-level fluctuations, as they respond to environmental factors such as water salinity, nutrients and input of sediment and freshwater (KRAUSS et al., 2008; STEVENS, FOX and MONTAGUE, 2006; STUART et al., 2007). The evolutionary development of these ecosystems is controlled by land-ocean interaction, and their expansion is determined by topography, and sediments geochemistry (ALONGI, 2002), as well as current energy conditions (WOODROFFE, 1982). This ecosystem is highly adaptive, with plants tolerant of extreme environmental conditions such as high salinity, anoxia and constant water inundation (VANNUCCI, 2001). This adaptability has allowed mangroves to withstand environmental change throughout the Holocene (MONACCI et al., 2009), and become a marker of great importance for scientific analysis of coastal change (BLASCO. SAENGER and JANODET, 1996).

The mangroves in the northern Espírito Santo State littoral were present along the current coastline since the late Holocene, since at least ±2700 years BP (SILVA et al., 2022). On the other hand, considering the central littoral, the mangroves began at least ±2212 cal years BP, according to our data, close to the mouth of Jucu River. On the southern littoral, close to Guarapari, the mangroves were registered between 6300 and 2700 cal years BP, and close to the mouth of Benevente River the first mangroves were registered around ±515 cal years BP (BOZI et al., 2021).

5 CONCLUSIONS

Palynological, sedimentary, and C-14 dating data obtained from a sedimentary core collected at the mouth of the Jucu River, State of Espírito Santo, southeastern Brazil (ES), were used to identify millennial vegetation changes. Since at least around 2210 until 460 cal years BP the presence of sandy-silt sediment was predominant. During this period, the first pollen of mangrove vegetation appeared, which was initially colonized by *Laguncularia* and has occurred continuously until the present. Later there was the installation of *Rhizophora* and *Avicennia*, occurring in a non-expressive way. After ±460 cal years BP to the present there was a predominance of herbaceous vegetation and the number of spores decreased. During this period, *Laguncularia* and *Rhizophora* pollen grains occurred almost continuously, which can be explained by the predominance of silt-clay sediment. Therefore, the palynological results demonstrated a high precision such as a forensic trace tool for a coastal vegetation change, considering natural evolution and/or caused by human actions.

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