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GEOCIENCES

Modern pollen rain analysis from Itapuã State Park (*Parque Estadual Itapuã*), RS, Brazil

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Abstract: Itapuã State Park is located in the municipality of Viamão, between the 30º 20 'and 30º 27' S and between 50º 50' and 51º 05' W, in the state of Rio Grande do Sul, southern Brazil. The Park is one of the state conservation units, maintaining remnants of the Atlantic forest, rocky fields vegetation, coastal forest, "vassoural," mixed grassland, moist, bathed and juncal plains. Artificial pollen traps were installed inside the park, between forest and human-modified field. The study presents a morphological description of 34 plant families, represented by 47 different pollen grains and monilophyte spores (including exotic taxa), unpublished data for the park's palinoflora. Quantitative data revealed the presence of 77% of non-arboreal pollen grains, 20% of arboreal pollen grains, 2% of monilophyte spores and 1% of other that can be both arboreal and non-arboreal pollen grains. Non-arboreal pollen grains, especially Poaceae, dominated in all the traps, even those located in forest areas. The dominance of the human-modified fields around collectors and winds from the northeast influenced the dispersion of these grains. Exotic pollen grains of the Betulaceae family, of Andean origin, also occurred in the pollen rain, resulting from dispersion by atmospheric currents of long distances.

Key words: Atlantic forest, pollen fall, Itapuã Park, Rio Grande do Sul.

INTRODUCTION

Pollen analysis is an excellent tool for studying reconstitutions of paleoenvironments and paleoclimates, especially when associated with isotopic dating methods. To do this, descriptions and illustrations of modern palynomorphs and their ecological correlations are fundamental resources capable of providing comparisons with elements in the environmental and paleoenvironmental register. It also enables us to evaluate the composition of modern and fossil assemblages and their responses to changes that have occurred over time (Ferrazo et al. 2008).

Modern pollen rain analysis is important because as well as providing parameters for environmental and/or paleoenvironmental studies, it also generates data about the current pollen diversity of an area, and may also support studies related to allergic diseases (hay fever), paleoecological, paleogeographic and paleoclimatic data and to the dynamics of plant communities in a region.

In Brazil, there is still little data on modern pollen rain analysis, highlighting studies by, Silva (2002) for the mangroves in the Northeast, Behling & Negrelle (2006) for the Atlantic forest in Paraná, Chaves (2013) for the National Park Serra da Capivara (Piauí), Guimarães et al. (2017) for the Amazon rain forest and Silva et al. (2017) for the State Park Itutinga-Pilões (São Paulo).

Most studies are based on surface sediments or on samples, such as Colinvaux

et al. (1999) for the Amazon, Neves & Cancelli (2006), Melhem & Abreu (1981) and Carreira & Barth (1986) for aquatic environments. Another part comes from studies on palinotaxonomy, for example Salgado-Labouriau (1973) for the cerrado, Carreira (1976) for woody plants from the Amazonian plains, Melhem et al. (1984) for the Reserve at the Parque das Fontes do Ipiranga-São Paulo, Carreira & Barth (1986) for the vegetation in the Canga da Serra de Carajás-Pará, Melhem et al. (2003) for the plants in Campos do Jordão, among others. Modern pollen rain data for the State of Rio Grande do Sul are rare, highlighting works regarding medical conditions (hay fever) such as Lorscheitter et al. (1986) and Avila & Bauermann (2001). Most of the studies come from surface sediment analyses or from samples such as those from Neves & Lorscheitter (1992), Leal & Lorscheitter (2006), Leonhardt & Lorscheitter (2007), Neves & Bauermann (2003, 2004), Roth & Lorscheitter (2008) and Macedo et al. (2009), among others.

This study presents the results of modern pollen rain analysis in the Itapuã State Park, in the municipality of Viamão, in the State of Rio Grande do Sul aiming to provide new data for palinoflora and pollen diversity in an area that involves different physiognomies and types of vegetation. The study followed the morphological description of pollen grains and spores of 34 plant families, comprising 4 monilophytes, 1 gymnosperm and 29 angiosperms. Quantitative data are also presented regarding the occurrence and grain distribution along the sampling points, between forest and human-modified field.

MATERIALS AND METHODS

Study area

The Itapuã State Park is located in the municipality of Viamão in the State of Rio Grande do Sul, it has a total area of 5,566.50ha and it is located about 57km from the centre of Porto Alegre. It is a Nature Conservation Unit (Federal Law 9.985/2000), covering a range of phytophysiognomies, maintaining remnants of the Atlantic forest, rocky fields, coastal forest, "vassoural" (grassland with tall herbaceous layer and shrubland), mixed grassland, moist, bathed and juncal plains (Antonio 1996), (Fig. 1).

In the Park there are rocks from the *Escudo Sul-rio-grandense* and sedimentary formations of the Coastal Plain. The first one is represented by hilly grassland and hills with altitudes generally between 50 and 200 meters. The second one presents horizontal and flat or slightly undulating reliefs related to areas of marshes, in the clogging phase, and lacustrine sandy beaches of Quaternary origin on the Patos Lagoon banks (Antonio 1996). The climate is humid subtropical, with an annual average rainfall of 1,300 mm and an average annual temperature of 17.5°C. The prevailing winds in the area are from the northeast, coming from the ocean, the Minuano, continental west wind of winter and the carpenter of the coast, southeast wind, beach, oceanic (Antonio 1996).

The park has a wide range of plant families, as indicated by botanical surveys from Antonio (1996), Scherer et al. (2005, 2007) and Buss et al. (2009) which are summarized in Table I.

Collection, processing and material analysis

The collection was carried out by artificial pollen traps (particle gravimetric collectors) as described by Bush (1992). The trap consists of two parts: one is a funnel with fiberglass able to retain all particles. The other is formed by a reservoir (pet bottle) with an efficient drainage system that prevents the return of water to the collector. The water collected in the reservoir evaporates during dry periods and this helps to keep the trap moist, increasing its ability to retain palynomorphs. About 20 collection points were

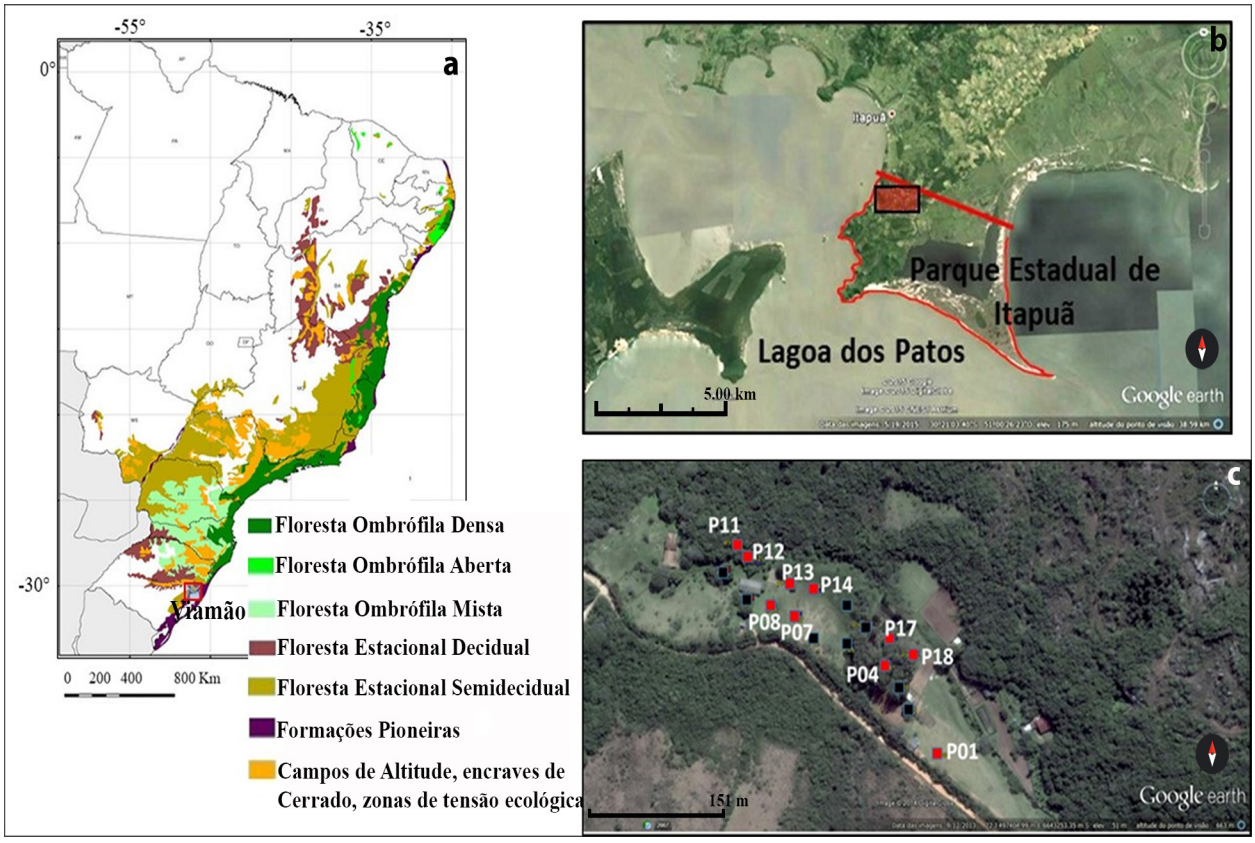

Figure 1. (a) Location of the study area: territorial insertion and vegetal physiognomies of Brazil (Source FIBGE 1993); (b) Collection area in the Itapuã State Park and (c) Inserted traps with GPS coordinates, taken during the field work. Points analyzed highlighted in red. Source of images: Google Earth (2015).

placed in an area between the forest and the human-modified fields, in the northwest sector of the park, distanced every 30 meters, during one year (from January 2002 to January 2003). Only 10 points that remained in the sites until the end of the one year period were analyzed, because the other points were disturbed by animals. The pollen rain corresponds to a one-year rainfall for each collector.

The project has IBAMA (0223.003731/00-57) and the Secretariat of Environment and Sustainable Development - Conservation Unit Division of Rio Grande do Sul (SEMA-DUC: 005120-05/00-1) licenses for research.

After the material was collected, it was stored and frozen until it was time to process it at the Laboratory of Paleoecology and Landscape Ecology at the Institute of Environmental, Chemical and Pharmaceutical Sciences at the Federal University of São Paulo (UNIFESP). The material was initially treated with floridric acid (HF) to remove glass fibre from the trap, followed by the traditional method of acetolysis (Erdtman 1952).

The final contents were adhered by small portions of Kisser glycerine gelatine to the bottom of the test tube to assemble the slides, with coverslips fixed by colourless varnish. Five permanent slides were made for each sampling point, and the remainder was stored in glycerol vials. All material is deposited in the Palynotheca at the Laboratory of Paleoecology and Landscape Ecology at UNIFESP.

Table I. Botanical list of the Itapuã State Park, based on Antonio (1996), Scherer et al. (2005, 2007).

	Botanical Survey Data
Lycophytes	Lycopodiaceae, Selaginellaceae
Monilophytes	Dryopteridaceae, Marsileaceae, Polypodiaceae, Pteridaceae, Salviniaceae, Schizaeaceae.
Gymnosperms	Ephedraceae
Angiosperms	Acanthaceae, Alismataceae, Amaranthaceae, Amaryllidaceae, Anacardiaceae, Annonaceae, Apiaceae, Apocynaceae, Aquifoliaceae, Araceae, Araliaceae, Arecaceae, Aristolochiaceae, Asteraceae, Basellaceae, Begoniaceae, Bignoniaceae, Boraginaceae, Bromeliaceae, Cactaceae, Calyceraceae, Campanulaceae, Caryophyllaceae, Celastraceae, Chrysobalanaceae, Cistaceae, Clusiaceae, Commelinaceae, Convolvulaceae, Cucurbitaceae, Cyperaceae, Dioscoreaceae, Droseraceae, Ebenaceae, Ericaceae, Eriocaulaceae, Euphorbiaceae, Erythroxylaceae, Fabaceae-Caesalpinoideae, Fabaceae-Mimosoideae, Gentianaceae, Gesneriaceae, Haloragaceae, Hypoxidaceae, Icacinaceae, Iridaceae, Juncaceae, Juncaginaceae, Lamiaceae, Lauraceae, Lentibulariaceae, Linaceae, Loranthaceae, Lythraceae, Malpighiaceae, Malvaceae, Mayacaceae, Melastomataceae, Meliaceae, Molluginaceae, Monimiaceae, Moraceae, Myrsinaceae, Myrtaceae, Nyctaginaceae, Onagraceae, Opiliaceae, Orchidaceae, Passifloraceae, Pedaliaceae, Piperaceae, Plantaginaceae, Poaceae, Polygalaceae, Polygonaceae, Pontederiaceae, Portulacaceae, Potamogetonaceae, Primulaceae, Proteaceae, Ranunculaceae, Rhamnaceae, Rosaceae, Rubiaceae, Rutaceae, Salicaceae, Sapindaceae, Sapotaceae, Scrophulariaceae, Smilacaceae, Solanaceae, Styracaceae, Symplocaceae, Thymelaeaceae, Tropaeolaceae, Typhaceae, Ulmaceae, Urticaceae, Valerianaceae, Verbenaceae, Violaceae, Viscaceae, Vitaceae, Vivianiaceae, Xyridacea.

The palynomorphs were identified by morphological criteria, according to Erdtman (1952), Barth & Melhem (1988) and Punt et al. (2007). The palynological descriptions were carried out based on the main morphological characters,of pollen and spore: unit, polarity, shape, number of apertures or lesion, exine or exospore ornamentation, and dimension (one measure for each morphometric parameter): polar axis (P), equatorial axis (E), for elliptical grains and spores; major axis (MA) and minor axis (Ma) for monocotyledons; diameter for spherical grains (D), for polar view equatorial diameter (EVP), ecological data, occurrence and reference of the material examined.

The botanical classification for angiosperms adopted in this work is in accordance with APG II (2009) and Smith et al. (2006) for monilophytes, as well as specialised literature such as neotropical pollen catalogues and atlases such as Colinvaux et al. (1999), Leonhardt & Lorscheitter (2007), Roth & Lorscheitter (2008), Roubik & Moreno (1991) and various other works from the Pollen Flora of the Reserve at the Fontes do Ipiranga State Park.

The word "Type" was used for those where morphological similarities were found, preceded by the names established in the literature, e.g. "Type *Baccharis* L.", according to Erdtman (1952) and Salgado-Labouriau (1973). The pollen and

spore were analysed using an optical microscope (Nikon-Eclipse E200 microscope), under 1000 x magnification. All the images were generated using a Motic Images Plus 2.0 camera.

Quantitative data were obtained by counting at least 300 arboreal pollens grains, according to Mosimann (1965), considering in parallel all the other grains of pollens and spores for each sampling point. Pollen percentage graph was generated by program R (R Development Core Team 2018) using Rioja package (Juggins 2017) and arboreal (AP) and non-arboreal (NAP) percentage graph by Excel.

RESULTS

Thirty-four families were identified from the material of the pollen rain in the Itapuã State Park. Among them, four are Monilophytes: Blechnaceae, Cyatheaceae, Dryopteridaceae and Polypodiaceae, corresponding to 2% of the accounted material. Gymnosperm (Pinaceae), corresponding to 5%, and twenty-nine Angiosperms, where ten families were non-arboreal: Cyperaceae, Poaceae, Amaranthaceae (type *Gomphrena*), Portulacaceae, Fabaceae (type *Desmodium*), Euphorbiaceae (type *Chamaesyce*), Passifloraceae, Rubiaceae (types *Borreria* and *Diodia*), Apiaceae (type *Eryngium*) and Asteraceae (type *Baccharis*) making a total of 77% of the accounted material. Thirteen families are arboreal: Arecaceae, Melastomataceae, Myrtaceae, Ochnaceae (type *Ouratea*), Betulaceae, Euphorbiaceae (type *Actinostemon*), Moraceae (type *Brosimun*), Ulmaceae (type *Celtis*), Anacardiaceae (type *Lithraea*), Meliaceae, Rutaceae (type *Zanthoxylum*), Sapotaceae (type *Chrysophyllum* and type *Pouteria*) and Myrsinaceae (type *Myrsine*), corresponding to 20% of the accounted material. Finally, six other families: Nyctaginaceae, Ochnaceae, Malpighiaceae, Apocynaceae, Scrophulariaceae and Solanaceae, corresponding to 1% of the accounted pollen grains (Fig. 2).

Morphological Descriptions

Monilophytes
Polypodiopsida
Polypodiales
Family Polypodiaceae

Microgramma C.Presl. (Fig. 3a).

Monolete spore, heteropolar, plano-convex, verrucate exosporium, with high verrucae, distributed irregularly throughout the whole surface.

Sizes: E: 80µm; P: 55µm; irregular exosporium: 2µm.

References: (Leonhardt & Lorscheitter 2007).

Ecological data: Epiphyte or rock species, with wide distribution in the American tropics, in rainforests, marshes and in secondary forests (Tryon & Tryon 1982). Lorscheitter et al. (2005) cite M. *squamulosa* (Kaulfuss) Sota and M. *vacciniifolia* as the only representatives of the genus in the State of Rio Grande do Sul. In the park area, it was found in traps located in the human-modified field and the forest.

Material examined: LPE 00167, England Finder coordinate O32/2.

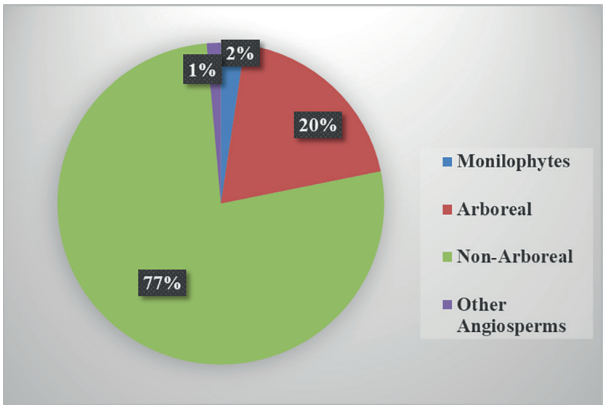

Figure 2. Percentage of palynomorphs recorded in the pollen rain in Itapuã State Park.

Type *Serpocaulon* A.R. Sm. (Fig. 3b).

Monolete spore, heteropolar, plano-convex, verrucate exosporium, irregular verrucae, low and uniformly distributed on the surface.

Sizes: E: 45µm; P: 30µm; exosporium: 1µm.

Reference: Leonhardt & Lorscheitter (2007).

Ecological data: In tropical America, species of the genus grow in low areas of tropical forests, mountain forests or nebular forests. In Rio Grande do Sul, they generally occur as epiphytes, in forests. (Tryon and Tryon 1982, Lorscheitter et al. 2005). In the park area, it was found in traps located in human-modified field and the forest.

Material examined: LPE00146, England Finder coordinate V33.

Family Dryopteridaceae

Type *Dryopteris* Adans. (Fig. 3c).

Monolete spore, heteropolar, plano-convex, winged exosporum with numerous short and irregular folds and psilate surface.

Sizes: E: 60µm; P: 40µm; exosporium: 1.5µm.

Reference: Leonhardt & Lorscheitter (2007).

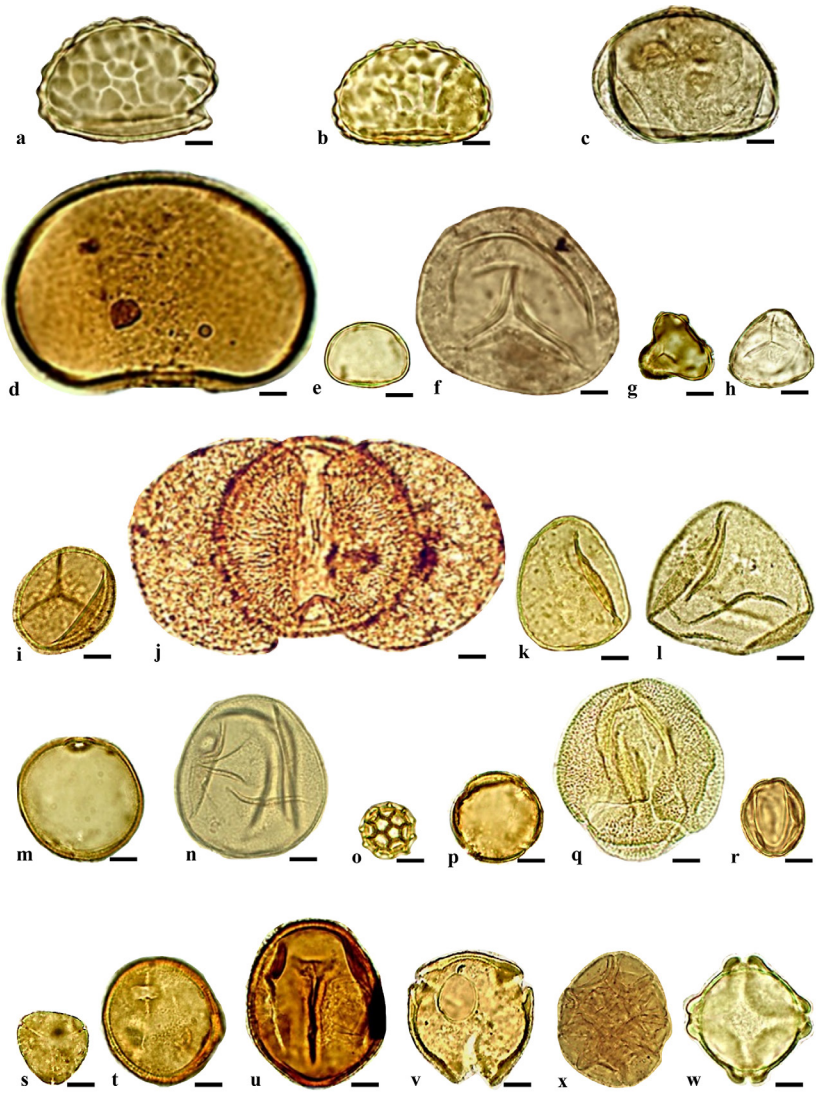

Figure 3. Monilophytes: Type *Microgramma* **(a);** Type *Serpocaulon* **(b);** Type *Dryopteris* **(c);** *Blechnum* Type 1 **(d);** *Blechnum* Type 2 **(e);** Cyatheaceae **(f);** Spore Type 1 **(g);** Spore Type 2 **(h)** Spore Type 3 **(i). Gymnosperms:** *Pinus.* **(j). Angiosperms-Monocotyledons:** Arecaceae **(k);** Cyperaceae **(l);** Poaceae Type 1 **(m);** Poaceae Type 2 **(n). Angiosperms-Eudicots:** Type *Gomphrena* **(o);** Type *Guapira* **(p);** Type *Talinum* **(q). Angiosperms-Rosids:** Type *Miconia* **(r);** Myrtaceae **(s). Angiosperms-Eurosids I:** Type *Ouratea* **(t);** Type *Desmodium* **(u);** Type *Machaerium* **(v);** Type *Acacia* **(x);** Type *Alnus* **(w). Scale bar: 10µm.**

Ecological data: Plants terrestrial, rupicolous and rarely epiphytic (Flora do Brasil 2020). In the park area, it was found in traps located in forest areas.

Material examined: LPE 00264, England Finder coordinate Q52/04.

Family Blechnaceae

Blechnum L. Type 1 (Fig. 3d).

Monolete spore, heteropolar, plano-convex psilate exosporium.

Sizes: E: 27µm; P: 23µm; exosporium: 2µm.

Reference: Leal & Lorscheitter (2006).

Ecological data: Terrestrial or rupestrian plants, more rarely epiphytes. Widely distributed in the American tropics, found in marshes, interior of tropical forests, forest edges and anthropic sites (Tryon & Tryon 1982). In the park area, it was found at points in human-modified field and in the forest.

Material examined: LPE00146, England Finder coordinate N51/03.

Blechnum L. Type 2 (Fig. 3e).

Monolete spore, heteropolar, plano-convex, psilate exosporium.

Sizes: E: 120µm; P: 85µm; exosporium: 1µm. Type 2 is larger than type 1.

Reference: Leal & Lorscheitter (2006).

Ecological data: Same as Type 1. In the park area, it was equally found at points in human-modified field and in the forest.

Material examined: LPE00199, England Finder Coordinate P38/02.

Cyatheales

Family Cyatheaceae (Fig. 3f).

Trilete spore, heteropolar, circular, psilate exosporium.

Sizes: D: 58µm; exosporium 2µm.

Reference: Leal & Lorscheitter (2006).

Ecological data: Arborescent plants, widely distributed in the American tropics, in rain forests, marshy forests, ravines, mountain slopes, rocky sites, along streams (Tryon & Tryon 1982). In the park area, it wasfound at points in the human-modified field.

Material examined: LPE00203, England Finder coordinate H40.

Indeterminated spores

Type 1 (Fig. 3g).

Trilete spore, heteropolar, triangular, verrucate exosporium.

Sizes: D: 28µm; exosporium: 1µm.

Ecological data: Found in the human-modified field.

Material examined: LPE00146, England Finder coordinate M34/03.

Type 2 (Fig. 3h).

Trilete spore, heteropolar, triangular, psilate exosporium.

Sizes: D: 40 µm; exosporium: 1µm.

Ecological data: In the park area, it was found at points in the forest.

Material examined: LPE00156, England Finder coordinate Q42.

Type 3 (Fig. 3i).

Trilete spore, heteropolar, circular, psilate exosporium.

Sizes: D: 40µm; exosporium: 1.5 µm.

Ecological data: In the park area, it was found in closed forest points.

Material examined: LPE00291, England Finder coordinate C51.

Gimnospermae

Pinalles

Family Pinaceae

Pinus L. (Fig. 3j).

Monads, saccate, heteropolar, spheroidal central body, reticulate aerial sacs with irregular mesh.

Sizes: Larger Diameter: central body: 35µm; aerial sacs: diameter 31µm.

References: Colinvaux et al. (1999), Macedo et al. (2009).

Ecological data: Trees. Exotic species extensively used in Rio Grande do Sul for reforestation and resin production (Lorenzi 2003, Backes & Irgang 2004). Appeared at all collection points.

Material examined: LPE 00167, England Finder coordinate K38/02.

Angiosperms
Monocotiledoneae
Arecales

Family Arecaceae (Fig. 3k).

Monads, heteropolar, elliptic, monosulcate, scabrate exine.

Sizes: MA= 45µm; Ma= 40µm, exine: 1.5µm.

Reference: Leal & Lorscheitter (2006).

Ecological data: Shrubs or trees, better known as palm trees. Their fruit can range from cherries to coconuts. It is found all over the world and has great economic importance given the wide range of products used by man (Miguel et al. 2007). In the park area, it appeared mostly at points in the human-modified field.

Material examined: LPE00146, England Finder coordinate Y/40.

Poales

Family Cyperaceae (Fig. 3l).

Monads, heteropolar, bell-shaped, 5-poroid, pores coated with granular membrane, granular-perforated exine.

Sizes: MA: 56µm, exine: 1.6µm.

References: Roubik & Moreno (1991), Leal & Lorscheitter (2006).

Ecological data: Herbaceous plants, most of them inhabiting marshes and swamps. Most species prefer humid sites (Joly 2002). In the park area, it was found in the forest.

Material examined: LPE00265, England Finder coordinate M31.

Family Poaceae

Poaceae Type 1 (Fig. 3m).

Monads, heteropolar, spheroidal, 1-porate annullus pore, scabrate exine.

Sizes: D: 40µm, exine: 1µm.

References: Leal & Lorscheitter (2006).

Ecological data: Predominantly herbaceous plants, in characteristic associations of field. Cosmopolitan family, found in all climates, terrains and altitudes (Joly 2002). In the park area, it was widely found at all collection points.

Material examined: LPE00203, England Finder coordinate K40.

Poaceae Type 2 (Fig. 3n).

Monads, heteropolar, spheroidal, 1-(2)-porate, (two non-equidistant pores), pore with annulus thickness, microreticulate exine.

Sizes: D: 50µm, exine: 2µm.

References: Roubik & Moreno (1991).

Ecological data: Same as Type 1. In the park area, it was found at point (P12) in the forest. The count was not differentiated. Material examined: LPE00198, England Finder coordinate T29/4.

Eudicotiledonae
Caryophyllalles
Family Amaranthaceae

Type *Gomphrena* L. (Fig. 3o).

Monads, apolar, spherical, pantoporate (one pore on each lumen), exine lophate with

hexagonal mesh and pila at each apex of the mesh, muri high and straight.

Sizes: D: 15µm, exine: 2µm.

References: Leal & Lorscheitter (2006).

Ecological data: A genus consisting of herbs or sub-shrubs, concentrated in hot and temperate zones. In Rio Grande do Sul about 6 native species were found (Vasconcellos 1973). In the park area, it mostly appeared at points in the human-modified field.

Material examined: LPE00146, England Finder coordinate G39/01.

Family Nyctaginaceae

Type *Guapira* Aubl. (Fig. 3p).

Monads, isopolar, circular, 4-colporate, spiculate exine.

Sizes: D: 22µm, exine: 3µm.

References: Souza et al. (2010).

Ecological data: The family presents trees, shrubs, lianas or herbs. Some genera are considered economically important, such as *Mirabilis* L. and *Bougainvillea* Spach, whose species are used as ornamental plants (Reitz 1970, Barroso et al. 1986). In the park area, it appeared at a point in the forest.

Material examined: LPE00156, England Finder coordinate R43.

Family Portulacaceae

Type *Talinum* Adans. (Fig. 3q).

Monad, apolar; spherical, pantocolpate, short colpi, narrow with irregular outline, espiculate-perfurate exine.

Sizes: D: 58µm, exine: 1.5µm.

Reference: Silvestre-Capelato & Corrêa (1995).

Ecological data: Herbs. Portulacaceae includes about 30 genera and 500 species, which are distributed mainly in Western North America, South America and Africa, with a few representatives in Europe and Asia. In Brazil there are ten species in two genera: *Talinum* Adans. and *Portulaca* L., the latter with eight species (Coelho & Giulietti 2010). In the park area, it appeared at a point in the human-modified field.

Material examined: LPE00250, England Finder coordinate X54/3.

Rosids
Myrtales
Family Melastomataceae

Type *Miconia* Ruiz & Pav. (Fig. 3r).

Monads, isopolar, subprolate, heteroaperturate, 6-aperture (3 colporus interleaved by 3 colpi), psilate-perfurate exine.

Sizes: P = 23µm, E = 20µm, exine: 1µm.

Reference: Cruz-Barros et al. (2006).

Ecological data: Herbs, shrubs or trees, inhabiting fields, swamps, borders or forests. More present in the tropical region of the world, abundant in the Brazilian flora (Joly 2002). In the park area, it also appeared at points in the human-modified field and forest.

Material examined: LPE00203, England Finder coordinate P31/02.

Family Myrtaceae (Fig. 3s).

Monads, isopolar, triangular, 3-colporate, parassincolporate, scabrate exine.

Sizes: EVP: 22µm, exine: 1.0µm.

Reference: Leal & Lorscheitter (2006).

Ecological data: Trees and shrubs, tropical and subtropical, found in various types of environments (humid or dry), and large number of forest-forming species. It is one of the main families found in the forests of the State of Rio Grande do Sul (Reitz et al. 1983, Sobral 2003). It appeared at all the collection points.

Material examined: LPE00146, England Finder coordinate P37/03.

Eurosids I
Malpighiales
Family Ochnaceae

Ouratea Aubl. (Fig. 3t).

Monads, isopolar, prolate-spheroidal, 3-colporate, lalongate endoaperture, short and narrow colpi, rugulate-perfurate exine.

Sizes: P: 35µm; E: 34µm; exine: 2.0µm.

Reference: Macedo et al. (2009).

Ecological data: Native trees, shrubs and subshrubs. Rupicolous and terricolous substrate. In Brazil, they are found in the phytogeographical domains of the Amazon, *Caatinga*, *Cerrado,* Atlantic Forest (Reflora 2017). In the park area, they appeared at all the collection points.

Material examined: LPE00198, England Finder coordinate X29.

Fabales
Family Fabaceae

Type *Desmodium* Desv. (Fig. 3u).

Monads, isopolar, subprolate, 3-colporate, colporus with thick margin, regulate exine.

Sizes: P = 51, E = 42µm, exine: 2µm.

Reference: Moreti et al. (2007).

Ecological data: The genus is widely distributed in the tropics and subtropics of the world, and are also found in temperate regions. Some species can be considered pioneers for reforestation and others have high forage value. The genus is widely distributed in Brazil, presenting greater specific richness in the southern region of the country (Freitas 2012). In the park area, it mostly appeared at points in the human-modified field.

Material examined: LPE 00167, England Finder coordinate K39/01.

Type *Machaerium* Pers. (Fig. 3v).

Monads, isopolar, subcircular, 3-colporate, microreticulate exine.

Sizes: EVP: 35µm, exine: 2µm.

Reference: Barreto et al. (2013).

Ecological data: In Brazil, the largest number of species was found, ranging from trees to plant spinescence, inerm or scandent. The scandate forms predominate in the Amazon hileia (equatorial forest that runs from the eastern slopes of the Andes, throughout the Amazon valley to the Guianas), while trees predominate in southern Brazil (Sartori & Tozzi 1998). In the park area, it was found at points in the human-modified field.

Material examined: LPE 00167, England Finder coordinates J35 and G32/04.

Family Fabaceae

Type *Acacia* Mill. (Fig. 3x).

Circular polyad, acalymmate probably with 16 grains, symmetrically arranged, 8 in the centre and 8 in the periphery, psilate exine to scabrate.

Sizes: D: 41µm, exine: 1µm

Reference: Silvestre-Capelato & Melhem (1997).

Ecological data: Trees, shrubs or woody vines. They are found in tropical and subtropical regions, they are abundant in savannas and forests, as well as in xerophytic forests, in tropical America, Africa, Asia and Australia (Burkart 1979). In the park area, they were found at points in the human-modified field.

Material examined: LPE00199, England Finder coordinate H47.

Family Betulaceae

Type *Alnus* Mill (Fig. 3w).

Monads, isopolar, quadrangular amb, 4 to 5-colporate, annular pores and connected by arcs formed from a differential thickening of the scabrate and psilate exine.

Sizes: D: 36µm, exine: 1.5µm.

Reference: Leal & Lorscheitter (2006).

Ecological data: This genus is typically found in tropical and subtropical Andes forests, and the presence of pollen in sediments in southern Brazil may be related to long-distance anemophilic dispersion, which is found recurrently in this genus (Lorscheitter 1988, Joly 2002). In the park area, they were found at points in the human-modified field and forest.

Material examined: LPE00288, England Finder coordinate K52/03.

Malpighiales
Family Euphorbiaceae

Type 1 (Fig. 4a).

Monads, isopolar, subprolate, 3-colporate, reticulate exine.

Sizes: P = 30µm; E = 22µm, exine: 1µm.

Ecological data: The family can be presented as trees, shrubs, sub-shrubs and herbs (Flora do Brasil 2020). In the park area, it was found in the human-modified field.

Material examined: LPE00170, England Finder coordinate L42/01.

Type *Actinostemon* Mart.ex Klotzsch (Fig. 4b).

Monads, isopolar, prolate-spheroidal, 3-colporate, long colpi, lalongate endoaperture, reticulate exine.

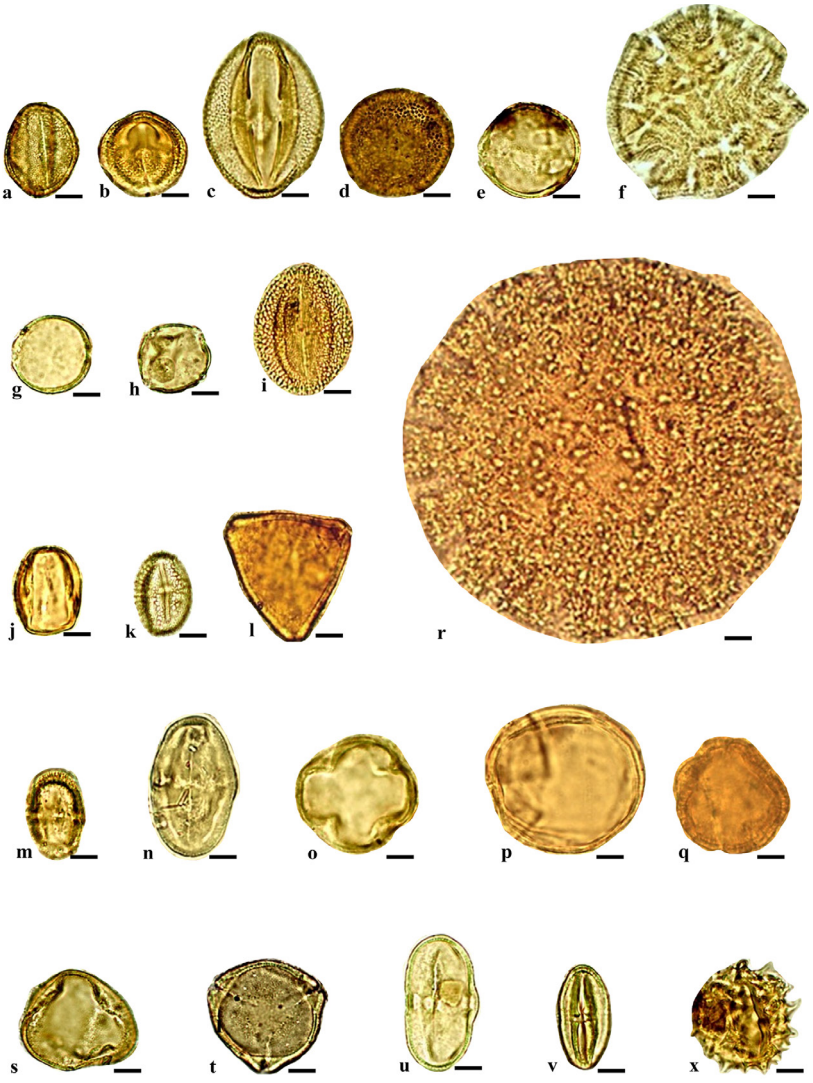

Figure 4. Euphorbiaceae Type 1 (a); Type *Actinostemon* (b); Type *Chamaesyce* (c); Type *Croton* (d); Malpighiaceae (e); Passifloraceae (f). Angiosperms-Eurosids I: Type *Brosimun* (g); Type *Celtis* (h). Angiosperms-Eurosids II: Type *Lithraea* (i); Type *Trichilia* (j); Type *Zanthoxylum* (k); Sapindaceae (l). Angiosperms-Asterids: Type *Chrysophyllum* (m); Type *Pouteria* (n); Type *Myrsine* (o); Apocynaceae (p); Type *Borreria* (q); Type *Diodia* (r); Scrophulariaceae (s); Solanaceae (t); Apiaceae *Eryngium* Type 1 (u); *Eryngium* Type 2 (v); Type *Baccharis* (x). Scale bar: 10µm.

Sizes: P = 26µm; E = 26µm, exine: 2µm.

Reference: Sales et al. (2011).

Ecological data: Trees or shrubs. The genus *Actinostemon* contains 30 species, most of them found in Brazil (Eymael 2012). In the park area, they were mostly found at points in the human-modified field.

Material examined: LPE00250, England Finder coordinate R47/01.

Type *Chamaesyce* Gray (Fig. 4c).

Monads, isopolar, subprolate, 3-colporate, colporus with margin, reticulate exine

Sizes: P = 40µm; E = 35µm, exine: 1µm.

Reference: Corrêa (2010).

Ecological data: Typically herbs. The genus *Chamaesyce* contains about 250 species, most belonging to the deserts and coastal regions of tropical America and the Polynesian Islands (Pahlevani & Riina 2011). In the park area, it appeared mostly at points in the human-modified field.

Material examined: LPE00146, England Finder coordinate V34.

Type *Croton* L. (Fig. 4d).

Monads, apolar, spheroidal, inaperturate, exine with type *Croton* pattern, exine formed by a regular arrangement with 5-8 subunits of reticulate ornamentation.

Sizes: D: 33µm, exine: 3µm

Reference: Corrêa (2010).

Ecological data: Trees, herbs or shrubs. The genus *Croton* L. is the second largest and most diverse of the family Euphorbiaceae, it has about 1,200 species, grouped into 40 sections, with pantropical distribution, of which the majority is found in the Americas. In South America, Brazil congregates the largest number of species, approximately 356 (Lima & Pirani 2008). In the park area, it appeared at points in the forest.

Material examined: LPE00156, England Finder coordinate N39.

Family Malpighiaceae (Fig. 4e).

Monads, apolar, pantoporate, psilate to rugulate exine.

Sizes: D: 29µm, exine: 2µm.

Reference: Leal & Lorscheitter (2006).

Ecological data: herbaceous plants, shrubs, arboreal and, more often, climbing plants with wide distribution in tropical regions (Joly 2002). In the park area, it appeared at points in the human-modified field.

Material examined: LPE00250, England Finder coordinate K35.

Family Passifloraceae (Fig. 4f).

Monads, isopolar, circular, 6 to 12-colporate, operculate reticulate exine.

Sizes: D: 58µm; exine: 2µm

Reference: Dettke & Santos (2009).

Ecological data: The Passifloraceae family is widely distributed from regions with a tropical climate to warm temperate, climbing plants or lianas with auxiliary tendrils or less frequently shrubs and trees without tendrils (Zamberlan 2007). In the park area, it appeared at points in the human-modified field.

Material examined: LPE00199, England Finder coordinate L42.

Rosales

Family Moraceae

Type Brosimum Sw. (Fig. 4g).

Monads, isopolar, spherical, 2-porate, scabrate exine.

Sizes: D: 20µm, exine: 1µm.

Reference: Roubik Moreno (1991).

Ecological data: The family Moraceae includes trees, shrubs or herbs, with predominantly tropical and subtropical distribution and is

represented in Brazil by 27 genera with about 250 species, among them *Brosimum gaudichaudii* Trécul, arboreal species popularly known as *mama-cadela*, it is very common in the cerrado (Jacomassi et al. 2007). In the park area, it mostly appeared at points in the forest.

Material examined: LPE00265, England Finder coordinate N31/02.

Family Ulmaceae

Type *Celtis* L. (Fig. 4h).

Monads, isopolar, quadrangular, 4-porate, scabrate exine.

Sizes: D: 23µm, exine: 0.5µm

Reference: Leal & Lorscheitter (2006).

Ecological data: A genus consisting of trees or shrubs, they are components of low forest, on the edge of Serra Geral from Rio Grande do Sul (Schultz 1984, Rambo 2000, Joly 2002). In the park area, it appeared at points in the human-modified field.

Material examined: LPE 00167, England Finder coordinate T35/04.

Eurosids II
Sapindales
Family Anacardiaceae

Type *Lithraea* Miers ex Hook. & Arn. (Fig. 4i).

Monads, isopolar, prolate, 3-colporate, long colpi and with a margin, reticulate-striate

Sizes: P = 35µm; E = 25µm; exine: 2µm

Reference: Leal & Lorscheitter (2006).

Ecological data: Trees, shrubs or sub-shrubs of very varied habitat, such as interior or margin of not very dense forest, margin of streams and altered fields (Fleig 1987). In the park area, it also appeared at points in the human-modified field and forest.

Material examined: LPE00200, England Finder coordinate Q36/02.

Family Meliaceae

Type *Trichilia* P. Browne (Fig. 4j).

Monads, isopolar, subprolate, 4-colporate, psilate exine.

Sizes: P = 25µm; E = 20µm, exine: 0.5µm.

Reference: Leal & Lorscheitter (2006).

Ecological data: The family comprises forest plants, usually large trees. They are found in most of the forests in Rio Grande do Sul (Girardi-Deiro 1975). In the park area it was found at points in the human-modified field.

Material examined: LPE 00167, England Finder coordinate P34/3.

Family Rutaceae

Type Zanthoxylum L. (Fig. 4k).

Monads, isopolar, prolate, 3-colporate, long colpi with a margin, lalongate endoaperture, reticulate-striate.

Sizes: P = 23µm; E = 17µm; exine: 2µm

Reference: Barth (1982).

Ecological data: The genus *Zanthoxylum* comprises approximately 200 woody, bushy or arboreal, pantropical species with few species extending in the temperate zones of North America and East Asia (Melo & Zickel 2004). In the park area, it appeared at points in the forest.

Material examined: LPE00154, England Finder coordinate J34.

Family Sapindaceae (Fig. 4l).

Monads, isopolar, triangular, prolate, 3-colporate, syncolporate, microreticulate exine.

Sizes: D: 36µm; exine: 2µm

Reference: Macedo et al. (2009).

Ecological data: In Rio Grande do Sul, the family is represented by the genera *Paullinia* L., *Serjania* Vell., *Thinouia* Planch. & Triana and *Urvillea* K. found as vines and, *Allophylus* L., *Cardiospermum* L.,*Cupania* L., *Diatenopteryx* Radlk., *Dodonaea* Adans. and *Matayba* Aubl.,

found with arboreal and/or herbaceous habit (Backes & Nardino 1998). In the park area, it appeared at points in the human-modified field.

Material examined: LPE 00167, England Finder coordinate P37/02.

Asterids
Ericales
Family Sapotaceae

Type *Chrysophyllum* L. (Fig. 4m).

Monads, isopolar, prolate, 3-colporate, microreticulate exine in the equatorial region and rugulate-striate at the poles, thicker at the poles.

Sizes: P = 25µm, E = 15µm; exine: 4µm (polar region) and 2µm (equatorial region)

Reference: Macedo et al. (2009).

Ecological data: Trees. Four species of the genus were found in Rio Grande do Sul: C. *inornatum* Mart., *C. viride* Mart. & Eichler ex Miq, C. *gonocarpum* (Mart. & Eichler ex Miq.) Engl., and *C. marginatum* (Hook. & Arn.) Radlk., distributed in all forest formations of the State (Sobral et al. 2006). In the park area, it appeared at points in the forest.

Material examined: LPE00154, England Finder coordinate K35

Type *Pouteria* Aubl. (Fig. 4n).

Monads, isopolar, prolate, 3-colporate, lalongate endoaperture, psilate-rugulate exine.

Sizes: P = 39µm, E = 26µm; exine: 2µm.

Reference: Barreto et al. (2013).

Ecological data: Hypophyte and hygrophyte species that grow on the slopes and river banks. The genus is characteristic of Brazil and with endemic forms of the Atlantic Forest, with great richness of forms especially in Rio de Janeiro (Lorenzi 1998, Monteiro et al. 2007). In the park area, it appeared at points in the human-modified field.

Material examined: LPE00298, England Finder coordinate R46/03.

Family Myrsinaceae

Type *Myrsine* L. (Fig. 4o).

Monads, isopolar, quadrangular amb, 4-colporate, psilate exine.

Sizes: D: 33µm exine 2µm.

Ecological data: The Myrsinaceae family has a pantropical distribution and about 1,500 species. In Brazil, the following genus are found: *Ardisia* Sw., *Cybianthus* Mart. (including *Conomorpha* A.DC.), *Myrsine* L. (including *Rapanea* Aubl.) and *Stylogyne* A.DC., totaling about 100 species. The Myrsinaceae species are trees, most frequently shrubs (Freitas & Carrijo 2008). In Rio Grande do Sul, the genus is represented by species of arboreal and shrubs habit (Sobral et al. 2006). In the park area, it appeared at points in the human-modified field and points in the forest.

Material examined: LPE 00167, England Finder coordinate Q35.

Euasterids I
Gentianales

Family Apocynaceae (Fig. 4p).

Monads, isopolar, circular, 4-porate, psilate exine.

Sizes: D: 45µm; exine: 2µm

Reference: Macedo et al. (2009).

Ecological data: Lianas, mostly, also trees and shrubs are found. In Rio Grande do Sul, eight genera were found: *Aspidosperma* Mart. & Zucc., *Condylocarpon* Desf., *Forsteronia* G. Mey., *Mandevilla* Lindl., *Tabernaemontana* L., *Prestonia* R. Br., *Rauwolfia* Ruiz & Pav., *Temnadenia* Miers & Woodson (Backes & Nardino 1998). In the park area, it appeared at points in the human-modified field.

Material examined: LPE00203, England Finder coordinate O38/01.

Family Rubiaceae

Type *Borreria* G. Mey. (Fig. 4q).

Monads, isopolar, circular, zonocolporate, with short colporus, microreticulate exine.

Sizes: D: 48µm, exine: 3µm

Reference: Cassino & Meyer (2011).

Ecological data: The Rubiaceae family has wide diversity and occurs in the most diverse types of environment. In Brazil, it is more commonly found in rainforests such as the Amazon Forest and the Atlantic Forest. It is represented by large and medium-sized trees, shrubs, sub-shrubs, perennial or annual herbs, but about 80% of the genera are composed of exclusively woody plants, constituting one of the most important components of arboreal and shrub vegetation in tropical forests (Melo and Barbosa 2007, Pereira and Kinoshita-Gouvêa 2013). In the park area, it appeared mostly at points in the human-modified field.

Material examined: LPE00156, *England Finder* coordinate Q42.

Type *Diodia* Gronov. (Fig. 4r).

Monads, isopolar, circular, zonocolporate (18-colporate), echinate-granulate exine, with large base coniform spines and sharp apex, with heterogeneous sizes, evenly distributed over the pollen grain, small granules and evenly distributed.

Sizes: D: 126µm, exine: 2µm

Reference: Silveira Júnior et al. (2012).

Ecological data: Same as Type *Borreria*.

Material examined: LPE 00167, England Finder coordinate N41/01.

Lamiales

Family Scrophulariaceae (Fig. 4s).

Monads, isopolar, oblate-spheroidal, 3-colporate, microreticulate exine.

Sizes: P: 32 µm; E: 35µm, exine: 1µm.

Reference: Costa (2014).

Ecological data: It comprises about 4000 species in 190 genera of cosmopolitan distribution, but more abundant in temperate regions and tropical mountains. Herbs or sub-shrubs, rarely shrubs or small trees (Souza & Giulietti 1990, 2003). In the park area, it appeared at points in the human-modified field.

Material examined: LPE00250, England Finder coordinate S46/02.

Solanales

Family Solanaceae (Fig. 4t).

Monads, isopolar, triangular amb, convex sides, 3-colporate, parasyncolpate, psilate-perforate exine.

Sizes: Diameter Evp: 35µm, exine: 2µm

Reference: Cassino & Meyer (2011).

Ecological data: Solanaceae is a family of about 94 genera and 2950 species, with subcosmopolitan distribution, especially in tropical America. Plants are herbs, trees and shrubs (Perveen & Qaiser 2007). In the park area, it appeared at points in the human-modified field.

Material examined: LPE 00201, England Finder coordinate N39/02.

Eurasterids II
Apiales
Family Apiaceae
Eryngium L.

Type 1 (Fig. 4u).

Monads, isopolar, prolate, 3-colporate, long colpi, psilate to scabrate exine.

Sizes: P = 42µm; E = 22µm; exine: 2µm.

Reference: Macedo et al. (2009).

Ecological data: Herbs. The Apiaceae family presents a cosmopolitan distribution constituting one of the largest families of angiosperms. In Rio Grande do Sul, they are

widely represented by the genus *Eryngium* L., which includes 29 species, ranging from dry to moist areas common in "capoeira" (growth of secondary forest), marshes, lagoons and peat bogs (Irgang 1974, Souza & Lorenzi 2005). In the park area, it appeared mostly at points in the human-modified field.

Material examined: LPE 00250, England Finder coordinate Y53/02.

Type 2 (Fig. 4v).

Monads, isopolar, perprolate, 3-colporate, lalongate endoaperture, scabrate exine.

Sizes: P = 32µm, E = 15µm; exine: 2µm

Reference: Macedo et al. (2009).

Ecological data: Same as *Eryngium* Type 1.

Material examined: LPE00289, England Finder coordinate P49/04

Asterales
Family Asteraceae

Type *Baccharis* L. (Fig. 4x).

Monads, isopolar, oblate-spheroidal, 3-colporate, equinate exine, with robust spines.

Sizes: P = 25µm; E = 25µm; exine: 2µm

Reference: Leal & Lorscheitter (2006).

Ecological data: The genus includes more than 500 species, distributed from the United States to Argentina, with 90% occurring in South America. These are usually shrubs. In the southwestern region of Brazil, there are approximately 120 species. The great concentration of species in Brazil and the Andes indicates that this whole area is the probable center of origin of the taxon (Duarte et al. 2005). In the park area, it mostly appeared at points in the human-modified field

Material examined: LPE00146, England Finder coordinate T39/04.

Occurrence and distribution of pollen fall from sample records

For the arboreal pollen (AP) ratio, the following tree families were considered, according to ecological data: Pinaceae, Arecaceae, Melastomataceae, Myrtaceae, Ochnaceae type *Ouratea,* Fabaceae type *Machaerium*, Betulaceae, Euphorbiaceae type *Actinostemon* Moraceae type *Brosimun*, Ulmaceae type *Celtis*, Anacardiaceae type *Lithraea*, Meliaceae, Rutaceae type *Zanthoxylum*, Sapotaceae type *Chrysophyllum,* Sapotaceae type *Pouteria*, and Myrsinaceae type *Myrsine*. The non-arboreal pollen (NAP) were: Cyperaceae, Poaceae, Amaranthaceae type *Gomphrena*, Portulacaceae, Fabaceae type 1, Fabaceae type *Desmodium*, Euphorbiaceae type *Chamaesyce*, Passifloraceae, Rubiaceae type *Borreria*, Rubiaceae type *Diodia*, Apiaceae type *Eryngium* and Asteraceae type *Baccharis*. Due to the impossibility of approaching genera, the other families were allocated as "other" as they can gather plants from different habits.

The occurrence and distribution of pollen fall is illustrated in Fig. 5. The collectors located in the human-modified field (P1, P7, P8, P13, P14), registered the occurrence of Poaceae, with more than 50%, followed by *Ouratea* type (Ochnaceae) and *Baccharis* type (Asteraceae), between 5 to 15%. In this domain, arboreal pollen of Arecaceae and Mytaceae registered less than 10% and *Pinus* (Pinaceae) around 10%. Ferns spores occurred, predominantly *Blechnum* (Blechnaceae), *Microgramma* and *Serpocaulon* (Polypodiaceae), with less than 5%, and *Dryopteris* (Dryopteridaceae) only on P8, with less than 5%.

The collectors located in the forest domain (P4, P11, P12, P17, P18) also showed a significant predominance of Poaceae, with more than 50%, followed by *Ouratea* type and *Baccharis* type with values between 5 and 10%. The main records of arboreal pollen are marked by Myrtaceae,

with emphasis on P17, with a value around 40%, and *Pinus* between 2 to 10%. Ferns spores also occur in this domain, with *Microgramma* (P17 and P18), around 2%; *Blechnum, Dryopteris* and *Serpocaulon* in almost all points, with less than 5%. Other pollen and spores occurred with lower percentages and varied distribution.

In general, the distribution of non-arboreal pollen (NAP) and arboreal pollen (AP) did not reflect the predominance of the vegetation surrounding the collector. There was an expressive predominance of Poaceae pollen grains, above 50% for both areas, while arboreal pollen registration was below 25% in forest area collectors, only P17 showed a higher percentage (Fig. 6).

DISCUSSION AND CONCLUSIONS

The data of the pollen rain presented comprise unpublished contributions to the pollen diversity of the Itapuã State Park. Regarding angiosperms, 26 of the 165 families listed in the botanical surveys occurred in pollen rain, highlighting the following: Amaranthaceae, Anacardiaceae, Apiaceae, Apocynaceae, Arecaceae, Asteraceae, Cyperaceae, Euphorbiaceae, Fabaceae/Mimosoideae, Malpighiaceae, Melastomataceae, Meliaceae, Moraceae, Myrsinaceae, Myrtaceae, Nyctaginaceae, Passifloraceae, Poaceae, Portulacaceae, Rubiaceae, Rutaceae, Sapindaceae, Sapotaceae, Scrophulariaceae, Solanaceae, Ulmaceae. On the other hand, Betulaceae is registered in the pollen rain, but is not native and does not occur in the area, besides Pinaceae (*Pinus*), which is exotic in the

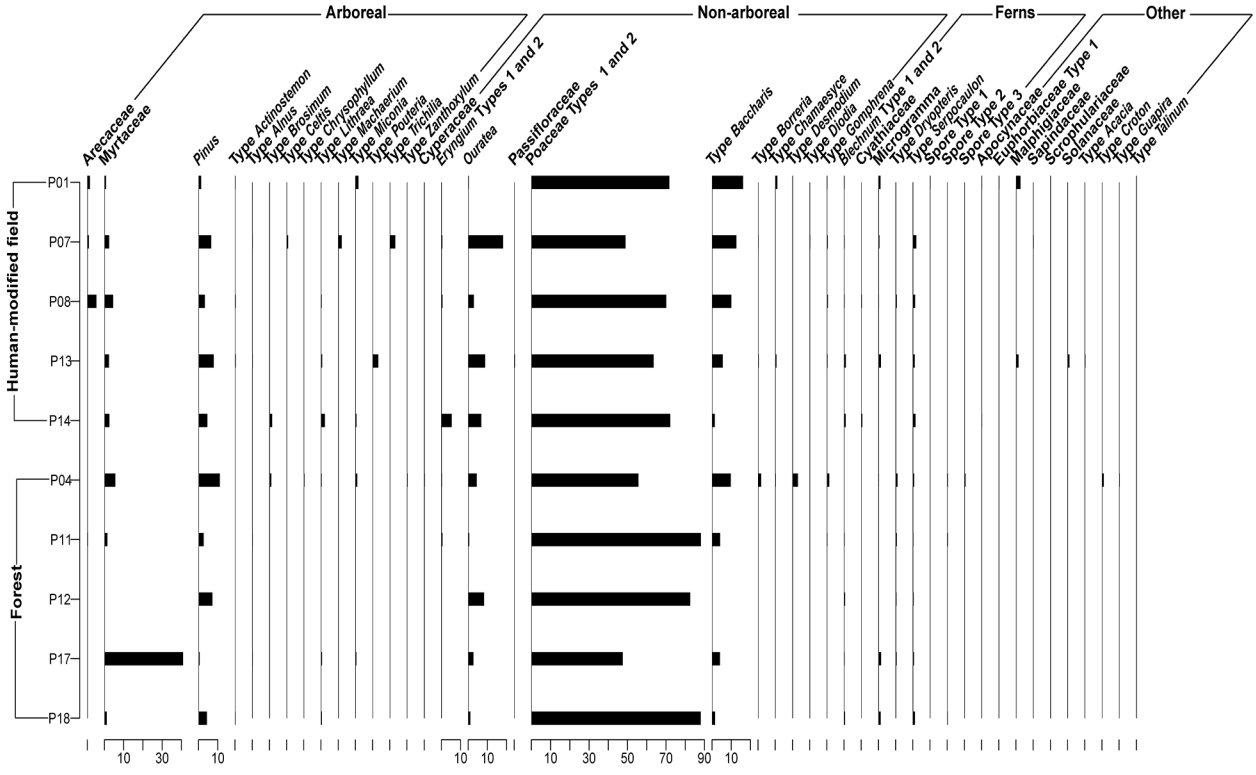

Figure 5. Pollen percentage spectra from surface samples from Itapuã State Park.

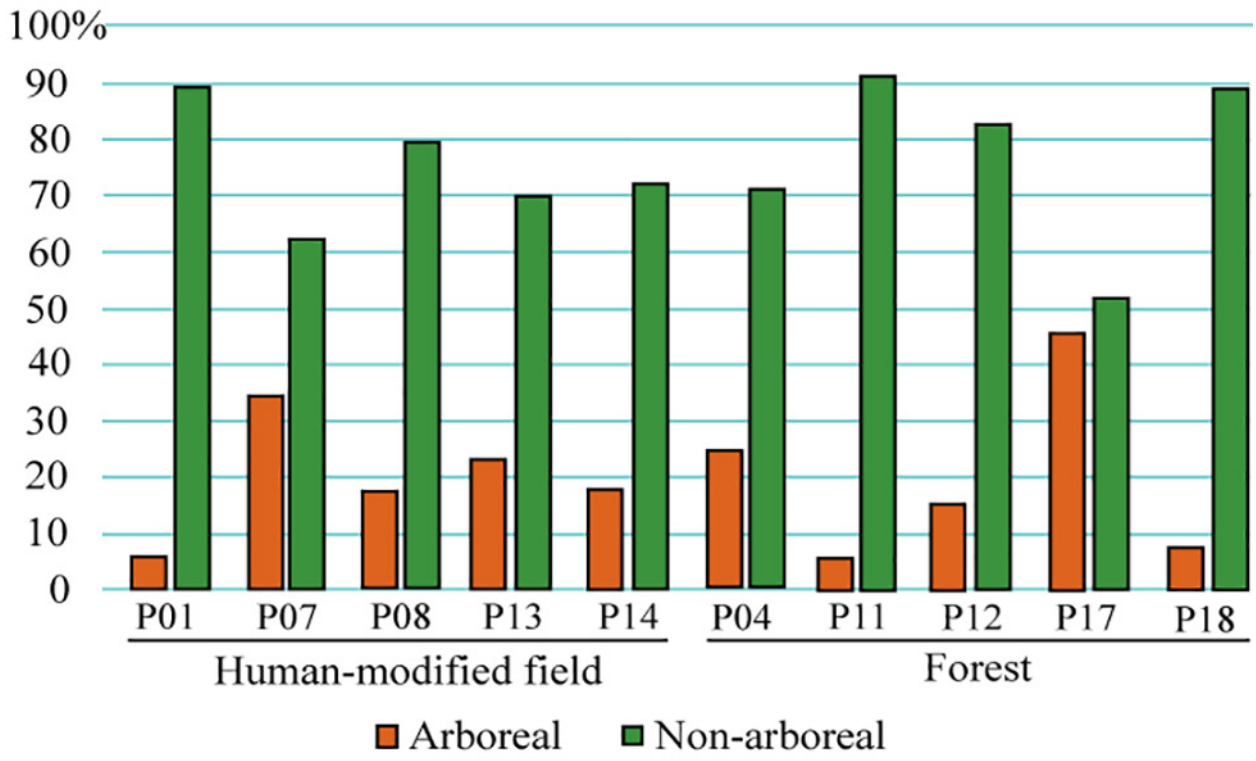

Figure 6. Percentage of arboreal and non-arboreal pollen grains for each point studied.

landscape and used extensively for reforestation and resin production in Rio Grande do Sul. Its observed a high percentage of Myrtaceae pollen in one point (P17) that could be due the influence of *Eucalyptus*, a exotic Myrtaceae genus that is used for reforestation and other economic purposes. There were also spores of monilophytes (Blechnaceae and Cyatheaceae) not listed in the park's botanical surveys.

The differences observed between the botanical list and the modern pollen rain diversity may be due to the different sampling areas, where botanical surveys derive mainly from the park's coastal forest (Antonio 1996, Scherer et al. 2005, 2007). The pollen rain survey was carried out inside the park a little distant from the coastal forest, near the headquarters (as shown in Materials and Methods), aimed at assessing the ratio between the occurrence of pollen in traps located in forest areas and human-modified field.

The quantitative analysis revealed the dominant presence of non-arboreal pollen grains, especially Poaceae, at all points. The result did not reflect a direct relationship between the occurrence of pollen grains and the dominant vegetation around the trap, being, in this case, mainly influenced by human-modified field. On the other hand the incidence of the northeast, southeast and east directions winds probably influenced the dispersion of non-pollen grains from human-modified field towards the forest areas. Behling & Negrelle (2006) analyzed the relationship between vegetation and pollen rain from pollen traps under tropical forests comment that the data are very variable and often show a very local assemblage. A similar study carried out by Silva et al. (2017), observed the correspondence between arboreal and non-arboreal pollens with the dominant vegetation around the traps from the Itutinga-Pilões Unit in the Serra do Mar State Park, São Paulo.

The pollen grains from the Betulaceae family, typically from the tropical and subtropical Andes forests, shows a continuous occurrence throughout the Quaternary. This pollen grain is common in the Quaternary sediments in the south of Brazil. The presence of this pollen is interpreted as coming from anemophilous dispersion at long distances (Lorscheitter 1988). In the pollen rain material studied by Silva et al. (2017), this pollen grains were also registered, indicating the contribution of these grains until nowadays in the South and Southeast regions of Brazil.

Finally, the data presented is pioneering in terms of contributions of the park´s palinoflora, including relevant information on the transport mechanism of grains and pollen, influenced by the domain of the human-modified field, local and long distance atmospheric currents.

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BTG performed pollen analyses and drafted the manuscript. AMSC aided pollen morphological descriptions and writing. ESB helped with writing and pollen descriptions. ALVB conceived the research, performed field surveys, sample processing and writing. All authors contributed equally to revisions.