Richness and distribution of aquatic pteridophytes in wetlands of the State of Rio Grande do Sul (Brazil).

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ABSTRACT: Richness and distribution of aquatic pteridophytes in wetlands of the State of Rio Grande do Sul (Brazil). **Wetlands are among the most important ecosystems on Earth. These systems must be considered as biological reserves because of the extensive food chain and rich biodiversity they support. In this sense, wetlands are important sites for conservation. Studies of biodiversity and distribution of aquatic pteridophytes are scarce in the world. The goal of this study was to analyze the richness and distribution of aquatic pteridophytes in wetlands in the State of Rio Grande do Sul using the Rapid Assessment Programme for Biodiversity as tool. Six pteridophyte species belonging to 4 families were observed: *Azolla filiculoides* Lam., *Equisetum giganteum* L., *Marsilea ancylopoda* A. Braun, *Regnellidium diphyllum* Lindm., *Salvinia herzogii* De la Sota and *Salvinia minima* Bak.. The pteridophyte richness varied over the Rio Grande do Sul and was not related to altitude (R^2= 0.004; P= 0.698) and wetland area (R^2= 0.004; P= 0.699). The highest richness was found on the Coastal Plain (6 species), and most of the analyzed wetlands (68.3%) presented only one pteridophyte species**.

Key-words: **aquatic macrophytes, aquatic ferns, biodiversity, conservation, Aqua-rap.**

RESUMO: Riqueza e distribuição de pteridófitas aquáticas em áreas úmidas do Estado do Rio Grande do Sul (Brasil). **As áreas úmidas estão entre os ecossistemas mais importantes da Terra. Esses sistemas devem ser considerados como reservas biológicas devido à extensa cadeia trófica e à rica biodiversidade que suportam. Nesse sentido, as áreas úmidas são locais importantes para a conservação. Estudos de biodiversidade e distribuição de pteridófitas aquáticas são escassos no mundo. O objetivo desse estudo foi analisar a riqueza e distribuição de pteridófitas aquáticas em áreas úmidas do sul do Brasil utilizando como ferramenta o Programa de Avaliação Rápida para Biodiversidade. Foram observadas seis espécies de pteridófitas aquáticas pertencentes a quatro famílias: *Azolla filiculoides* Lam., *Equisetum giganteum* L., *Marsilea ancylopoda* A. Braun, *Regnellidium diphyllum* Lindm., *Salvinia herzogii* De la Sota e *Salvinia minima* Bak.. A riqueza de pteridófitas variou ao longo do Rio Grande do Sul e não esteve relacionada à altitude (R^2= 0,004; P= 0,698) e ao tamanho de área úmida (R^2= 0,004; P= 0,699). A maior riqueza foi encontrada na Planície Costeira (6 espécies), e a maioria das áreas úmidas analisadas (68.3%) apresentava apenas uma espécie de pteridófita.**

Palavras-chave: **macrófitas aquáticas, samambaias aquáticas, biodiversidade, conservação, Aqua-rap.**

Introduction

One of the central theoretical tasks of conservation biology is to prioritize environments on the basis of their diversity value (Sarkar et al., 2002). The "Rapid Assessment Programme" (RAP) constitutes a powerful tool used to select important areas for the conservation of biodiversity, concentrating effort of specialists aiming to sample the highest possible number of sites in the shortest possible time (Mittermeier & Forsyth, 1992). An extension of the RAP approach for aquatic ecosystems is the Aqua-Rap (Chernoff et al., 1996).

Wetlands are among the most important ecosystems on Earth, since some wetland classes produced and preserved many of the fossil fuels on which human population

now depend (Mitsch & Gosselink, 2000). These systems are often located between dry terrestrial systems and permanently inundated deepwater aquatic ecosystems such as rivers, lakes, estuaries, or oceans (Mitsch & Gosselink, 2000). Wetlands must be considered as biological reserves because of the extensive food chain and rich biodiversity that they support. In this sense, wetlands are important sites for conservation, and were the first major ecosystems to be protected by an international treaty (Ramsar, 1996).

One of the main hydrological characteristics of South America is the existence of large wetlands (Neiff, 2001). Neiff (2001) considered that diversity in natural systems in South America is a parameter positively related to the specific area under consideration, despite the fact that many studies do not state the area of which the measurements were taken. Maltchik et al. (2002), Matsubara et al. (2002) and Stenert et al. (2002) found wetlands of small area with high biological diversity in southern Brazil and they suggested that these ecosystems should be included in conservation programs.

Wetlands are ecological islands surrounded by terrestrial habitats. Area and habitat relationships have been investigated by biologists and numerous studies and experiments have developed general theories about habitat to construct species-specific regression models (MacArthur & MacArthur, 1961; Petit & Petit, 1999). However, much of this research has been conducted in terrestrial landscapes (Harris, 1984; Fernandez, 1997), information about area and habitat relationships of wetland biota remains scarce (Tyser, 1983, Brown & Dinsmore, 1986, Maltchik et al., 2002, Matsubara et al*.,* 2002, Stenert et al*.,* 2002).

Despite the isolation of wetland habitats, aquatic plants tend to have broader distributions than their counterparts due to biotic and abiotic connections all around. The dispersal potential of aquatic plants, either through water movement or biota movements, influences the composition and functioning of their ecosystems (Santamaria, 2002). Uniformity of the aquatic environment, clonal reproduction, high dispersal rates, and plasticity are some arguments that could explain the broad distribution of aquatic plants (Santamaria, 2002).

Published studies on biodiversity and distribution of aquatic pteridophytes are scarce (Caudales et al., 1999; Hernandez & Caudales, 2000). Most of these worldwide studies are related with the physiologic aspects (Keeley, 1998; Ridge et al., 1998; Eyini et al., 2000; Kim et al., 2000), economic use (Carrapico et al., 2000; Shiomi & Kitoh, 2001; Cohen et al., 2002), excessive growth control (Sahoo & Datta, 1999; Barreto et al., 2000; Wijeyaratne & Perera, 2000; Nelson et al., 2001) and fossil studies (Bajzath, 1998; Archangelsky et al., 1999; Rich et al., 2001).

In southern Brazil, published studies of biodiversity and distribution of aquatic pteridophytes carried out at wider spatial scale are scarce (Sehnem, 1979a; 1979b; Irgang & Gastal, 1996). Oliveira et al. (1988), Gastal & Irgang (1997), Rosa & Irgang (1998), Maltchik et al. (2002) studied the macrophyte composition in the State of Rio Grande do Sul (southern Brazil), however, most of these studies were carried out at a hydrographic basin scale, lacking information on diversity and distribution of aquatic plants at a wider scale.

The goals of this study were 1. to analyze the richness of aquatic pteridophytes in 146 wetlands of the State of Rio Grande do Sul using the Rapid Assessment Programme for Biodiversity as a tool; 2. to analyze the relationships between the richness of aquatic pteridophytes and wetland area and 3. to improve the knowledge on the distribution of aquatic pteridophytes in southern Brazil. In this study the term aquatic pteridophytes refers to floating species and species rooted in saturated soil which are associated with other wetland plants.

Study Area

The State of Rio Grande do Sul has an area of 282,184 Km^2. The Moist Subtropical Mid-Latitude Climate prevails in this region. The annual precipitation varies between 1200-1800 mm, and is relatively well distributed throughout the year, without dry period (Cf - Koeppen's climate classification). The mean temperature varies between 15 and 18 °C. The minimum temperature is below 10 °C in Winter and the maximum, above 32 °C in Summer (RADAMBRASIL, 1986).

The vegetation is represented by small fragments of forest and temperate and tropical grassland areas. The forest is represented by different major types: Temperate summergreen deciduous forest, mixed evergreen-deciduous forest, and Temperate Mountainous Coniferous Forest. The grasslands are represented by Savanna, Steppe, and pioneering formations. The main rivers of the state are the rivers Uruguai, Jacuí, Taquarí, Ibicuí, Ijuí, Pelotas and Camaquã distributed along the three hydrological watersheds (Guaíba, Uruguai and Coastal). The State presents four geomorphologic formations: Highlands, Central Depression, Cristaline Shield and Coastal Plain.

The Highlands are located in the northern region of Rio Grande do Sul with altitudes between 1200 (E) and 50 (W) meters. The Central Depression is located in the central area of the State with altitudes between 250 and 300 meters. Jacuí and Ibicuí are the largest rivers of the Central Depression. The Cristaline Shield is located in southeastern Rio Grande do Sul with altitude below 600 meters. The Coastal Plain extends for 600 km of Atlantic Ocean shore, and its main hydrologic characteristic is the lack of large rivers and the presence of several lagoons spread all over (Rambo, 2000).

The main wetland types in the State of Rio Grande do Sul are palustrine formations, shallow lakes, lagoons, floodplain systems (lacustrine and riverine) and rice fields. Wetland distribution is quite heterogeneous with higher density in the Central Depression, Coastal Plain and in the west of Highlands (Maltchik et al., 2003).

Material and methods

This study was carried out using as tool the Aqua-Rap (Chernoff et al., 1996), an extension of Rapid Assessment Programme for Biodiversity (Mittermeier & Forsyth, 1992) for aquatic ecosystems. This approach provides, in the shortest time, basic information about the diversity and distribution of aquatic organisms.

A total of 146 wetlands were sampled in the State of Rio Grande do Sul distributed within the four geomorphologic provinces (36 in Coastal Plain, 19 in Central Depression, 15 in Cristaline Shield, 76 in Highlands) (Fig. 1). The collection sites were selected by the following criteria: access, macrophyte occurrence, wetland type and area, altitude and distribution along the geomorphologic characteristics. The wetland types selected were: palustrine wetlands (75), shallow lakes (51), floodplain systems (13) and rice fields (7). Palustrine wetlands include marshes, bogs, fens, wet meadows, swamps and seasonally wetted woods. The hydrology of the majority of palustrine wetlands is affected by precipitation, runoff, and groundwater discharge in different combinations. They constitute great percentage of wetlands in southern Brazil, and they may be flooded permanently, periodically, or never flooded, but saturated for extended periods during the annual cycle (Tiner, 1999). The main difference of palustrine wetlands and shallow lakes is related to the limnological analysis of the degree of interaction between the mass of water and the drainage area. The influence of the terrestrial ecosystem is maximum in the palustrine wetlands and declines as the relationship between inundation area/water volume decreases (Bernaldez & Montes, 1989). Floodplains are areas that are periodically inundated by the overflow of river or lakes, and by direct precipitation and groundwater.

Pteridophyte collections were carried out from March to October 2002. The time spent for collections varied between 20 and 70 min depending on the wetland area. The wetland areas, which were up to 3 ha, were measured with a tape measure of 50 m. The wetland areas, which were between 3 and 10 ha, were estimated based on the size of the fragment of the 3 ha system (measured with a tape measure). Sampling was performed along the wetland and distributed throughout the various habitats (water depth and distance from the margins). The sampling effort carried out among the different wetlands areas was sufficient to search through the edges and the majority of the different habitats and to confirm the difference among the richness of the species.

The collected samples were put into the oven (60 ºC), for approximately 72 h and identified to species level following taxonomic keys specific to southern Brazil (Sehnem, 1979a; Sehnem, 1979b; Irgang & Gastal, 1996; Alonso, 1997). Some samples were preserved with alcohol (70%) and identified in the laboratory.

Figure 1: Wetlands sampled and distribution of aquatic pteridophytes in wetlands of the State of Rio Grande do Sul. ● sampled areas ○ presence of aquatic pteridophytes.

The diversity of aquatic pteridophytes corresponds to the number of collected species in each sampled area. Samples which were deposited in herbaria and previously published studies were not taken into consideration in the analysis of the diversity and distribution of the species. Wetland localization was determined using Global Position System (Personal Navigator, model GPS III Plus). The frequency of species occurrence was classified as constant (100%), frequent (99-50%), sporadic (49-10%) and occasional (9-1%) (Ávila, 2002). Linear regression was used to analyze the correlation between pteridophytes richness and wetland area, and altitude.

Results

Six pteridophyte species belonging to 4 families were found in the State of Rio Grande do Sul: ***Azolla filiculoides*** **Lam.,** ***Equisetum giganteum*** **L.,** ***Marsilea ancylopoda*** **A. Braun,** ***Regnellidium diphyllum*** **Lindm.,** ***Salvinia herzogii*** **De la Sota and** ***S. minima*** **Bak.** These species were observed only in 28% of the total sampled areas (Fig. I).

The pteridophyte richness varied along the Rio Grande do Sul (Tab. I). The highest pteridophyte richness was found on the Coastal Plain (6 species). Only 3 pteridophyte species were found in the other geomorphologic units (Central Depression, Cristaline Shield, and Highlands). While ***A. filiculoides*** (10.9%) was the single sporadic species, the other species were characterized as occasional. ***R. diphyllum*** (8.2%) and ***S. herzogii***

Table 1: Locality, geographic localization, wetland types, geomorphologic provinces, area, altitude and pteridophyte richness in wetlands of the State of Rio Grande do Sul.

cont. Table I.

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(7.5%) were the most frequent (Tab. II). The highest pteridophyte richness was found at the locality of Caçapava do Sul (3 species), however most of the analyzed wetlands (68.3%) presented only one pteridophyte species. The pteridophyte richness was not related to altitude (R^2= 0.004; P= 0.698) and wetland area (R^2= 0.004; P= 0.699).

Table II: Diversity, distribution and frequency of aquatic pteridophytes in wetlands of the State of Rio Grande do Sul.

Families	Species	Locality	Frequency (%)
AZOLLACEAE	*Azolla filiculoides* Lam.	1, 2, 5, 11, 12, 14, 15, 16, 17, 23, 24, 27, 28, 30, 31, 40	10.9
EQUISETACEAE	*Equisetum giganteum* L.	20	0.7
MARSILEACEAE	*Marsilea ancylopoda* A. Braun	17, 31, 35, 36, 37, 38, 39, 41	5.5
	Regnellidium diphyllum Lindm.	1, 9, 14, 15, 18, 19, 24, 29, 30, 31, 32, 33	8.2
SALVINIACEAE	*Salvinia herzogii* De la Sota	2, 3, 5, 6, 7, 22, 23, 25, 26, 34, 37	7.5
	Salvinia minima Bak.	4, 8, 10, 13, 16, 21, 22	4.8

The highest pteridophyte frequency was found on the Coastal Plain (63.8%). The species were found in all wetland classes, with larger prevalence in the palustrine formation (50%). The most frequent species on the Coastal Plain were *A. filiculoides* (43%), *S. herzogii* (30%), *S. minima* (30%) and *R. diphyllum* (26%). The pteridophyte distribution reached all extensions of Coastal Plain, with different areas (0.1 to 10 ha) and altitudes (from 13 to 89 m) not presenting relationship between richness and wetland area (R^2= 0.0001; P= 0.957), and altitude (R^2= 0.091; P= 0.173).

The lowest frequency of pteridophytes was found in the Highlands (10.5%). *A. filiculoides, S. herzogii* and *M. ancylopoda* were found in different wetland classes with prevalence in shallow lakes (50%). *M. ancylopoda* (75%) was the most frequent species. The pteridophyte distribution in the Highlands was concentrated in the west (62.5%), but they were observed in different altitudes (from 93 to 235 m) and areas (from 0.1 to 10 ha), not existing relationship between richness and wetland area (R^2= 0.060; P= 0.558) and altitude (R^2= 0.001; P= 0.935).

The pteridophytes frequency in the Cristaline Shield was 40%. *A. filiculoides* (50%), *R. diphyllum* (83%) and *M. ancylopoda* (17%) were found only in two wetland classes (palustrine formation and shallow lake), and in different wetland areas (0.15 to 2 ha) and altitudes (118 to 396 m). In this province the pteridophyte richness was correlated with wetland area (R^2= 0.811; P= 0.014) but not with altitude (R^2= 0.003; P= 0.916).

The pteridophyte frequency in the Central Depression was smaller than average of the state (21.1%). *A. filiculoides* (50%), *S. herzogii* (50%) and *R. diphyllum* (25%) were found in different wetlands classes, areas (1.5 to 10 ha) and altitudes (44 to 105 m). While the pteridophyte richness was correlated with the wetland area (R^2= 0.975; P= 0.012), it was not correlated with altitude (R^2= 0.570; P= 0.245).

A. filiculoides was distributed along the four geomorphological provinces and in all wetland classes, being most frequent in the palustrine formations (68.7%). This species was found in different wetland areas (0.2 to 10 ha) and altitudes (13 to 396 m). *E. giganteum* was only observed in one wetland of the Rio Grande do Sul (Osório, Coastal Plain).

S. herzogii was found in three geomorphological provinces (except in the Cristaline Shield) and in different wetland classes, being most frequent in the palustrine formations (64%). This species was found in different wetland areas (0.4 to 10 ha) and altitudes (13 to 235 meters). *S. minima* was restricted to the Coastal Plain, however, this species was found in different wetland classes, areas (0.25 to 10 ha) and altitudes (14 to 73 m).

M. ancylopoda was observed in three geomorphologic provinces (except Central Depression), and in different wetlands classes. This species was found in different wetland areas (1.1 to 10 ha) and altitudes (36 to 177 m). *R. diphyllum* was found in three geomorphologic provinces (except Highlands) and in different wetland classes, areas (0.1 to 10 ha) and altitudes (33 to 396 m).

Discussion

The pteridophyte richness in the world is estimated in about 12,000 species (Wilson, 1997). There are about 3,250 species in America, with 3,000 of them in the tropics. The southeastern Brazil (from Minas Gerais to Rio Grande do Sul) contains about 600 species (Tryon & Tryon, 1982). Cook et al. (1974) identified six families of aquatic pteridophytes (Azollaceae, Equisetaceae, Isoëtaceae, Marsileacea, Parkeriaceae and Salviniaceae).

A series of lists of macrophytes species is known for Rio Grande do Sul, not existing specific research on the richness of aquatic pteridophytes in Brazil. The majority of published work on diversity and distribution of aquatic pteridophytes in Rio Grande do Sul (Sehnem, 1979a; Sehnem, 1979b; Sehnem, 1979c; Sehnem, 1984; Fuchs-Eckert, 1986) is out of date. Many wetlands disappeared in the last twenty years in Rio Grande do Sul, due to the update of biodiversity surveys is an important tool for the conservation strategies.

Isoëtes brasiliensis Fuchs, *I. fusco-marginata* Fuchs, *I. ramboi* Herter, *I. sehnemii* Fuchs, *I. smithii* Fuchs (Isoëtaceae); *Ceratopteris thalictroides* (L.) Brongn (Parkeriaceae); *Pilularia americana* A. Br. (Marsileaceae); *Azolla caroliniana* Willd. (Azollaceae) and *Salvinia auriculata* Aubl. (Salviniaceae) were not found in this study, but they were previously recorded in the state (Sehnem, 1979a; Sehnem, 1979b; Sehnem, 1979c; Fuchs-Eckert, 1986). The aquatic pteridophytes tolerant of flooding (e.g. some species of Blechnaceae, Pteridaceae and Thelypteridaceae) and species associated with brackish environment (e.g. *Acrostichum danaeifolium* Langsd. & Fisch) were not considered in this work.

Ecological factors and climate are known to constrain the distribution of plant species (Walter, 1973). While some families have higher species diversity in tropical latitudes, others present higher diversity in temperate latitudes (Crow, 1993). The U.S. Army Corps of Engineers uses size as the primary consideration in wetland regulations (Snodgrass et al., 2000). In wetlands, the relationship between species richness and ecosystems area was observed for waterbirds, mammals, reptiles and plants (Findlay & Houlahan, 1997), such studies being nonexistent for pteridophytes. The lack of relationship between pteridophyte richness and wetland area in Rio Grande do Sul can be due to the low number of pteridophyte species recorded in the studied ecosystems (in general, 1 species in each wetland). The pteridophyte frequency was low in Rio Grande do Sul, occurring mainly in areas of low altitude, besides the Highlands. This result indicates that altitude can be a limiting element to pteridophyte establishment in southern Brazil. However, physico-chemical parameters of surface water should also be considered.

Many aquatic plants have broad worldwide or continental ranges (Hutchinson, 1975) and local endemism is rare, although their abundance seems to increase in the tropics (Cook, 1983; 1985). Camenish & Cook (1996) regarded that even rare and endemic species tend to have large geographic ranges, e.g. *Wiesneria triandra* (Dalzell) Micheli which occupies a geographic range of approximately 900 km. *Regnellidium diphyllum* Lindm. is considered endemic to the southern Brazil and surrounding countries (Argentina and Uruguay) (Viana, 1974; Tryon & Tryon, 1982). In spite of the low occurrence of aquatic pteridophyte species in the studied area, some species had a wide distribution in southern Brazil, occurring in different wetland classes, areas, and altitudes. *Azolla filiculoides*, *Regnellidium diphyllum, Salvinia herzogii,* and *Marsilea ancylopoda* were found in different wetland classes, areas, altitude and geomorphologic units. In this sense, these species have a wide distribution at State level, including *Regnellidium diphyllum,* characterized as endemic to southern Brazil, Uruguay and Argentina. *Equisetum giganteum* and *Salvinia minima* have a low distribution in Rio Grande do Sul, and they are restricted to the Coastal Plain. Nevertheless, both species have a broad continental range (Tryon & Tryon, 1982).

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