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Characteristics of Soils in Highland Wetlands as a Subsidy to Identifying and Setting their Limits

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ABSTRACT: Palustrine areas and wetlands in particular are fragile ecosystems, with high biodiversity and high ecological productivity, and they provide benefits to society. The aim of this study was to describe and classify the main soils occurring in the wetlands of the Southern Plateau of Santa Catarina, and propose criteria for identification of hydromorphic environments as an aid in demarcation of their boundaries. Soils of four wetlands, in the municipalities of Bom Jardim da Serra, Bom Retiro, Lages, and Painel were described, collected, and taxonomically classified. A transection was demarcated in each one in which soils were analyzed in sites with different degrees of hydromorphism, corresponding to the inner, transition, and outer areas. In hydromorphic areas, the content of organic matter in the soil is higher than in non-hydromorphic areas, which influences the color and classification of the soils. In these soils, Aquents, Aquepts, and Histosols predominate, and Udepts predominate in the outer area. The drainage class and the higher chroma in the subsurface horizons of the Udepts indicate that they are outside the boundaries of the wetlands. The dark color in the surface horizons, along with the greyish colors, associated or not with the presence of mottling in the subsurface horizons, were the most obvious characteristics of a hydromorphic condition, indicating that the soil is located in the transitional and inner areas of the wetlands.

Keywords: chemical attributes, hydromorphic soils, soil classification.

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INTRODUCTION

Wetlands are ecosystems located in areas constantly or temporarily flooded and are usually characterized by the presence of hydromorphic soils, resulting in a peculiar physicochemical environment, morphologically and physiologically adapted to the hydroperiod of the system, which depends on water balance, topography, and subsurface conditions (Carvalho et al., 2007). They result from the combination of two factors favorable to their formation: geomorphology and hydrology (Steinek, 2007). The flat relief forming a basin allows water accumulation, which controls the dynamics of plant and animal life in these spaces. As a result, morphological and physical properties develop in the soils, along with specific chemical properties, related to permanent or temporary hydromorphism (Buol et al., 1997). They are constituted by semiterrestrial environments in which the influence of water is not absolute, as in lakes, but is relevant, and some areas are classified as transition sites between terrestrial and aquatic ecosystems, uniting specific biological components of each environment, which make them a priority for protection of biodiversity (Maltchik, 2003).

Wetlands are among the most productive natural environments in the world, with high rates of biological diversity, since they are an environment that is at the same time a source and storage area of water and the primary production area and shelter for numerous plant and animal species. Furthermore, they are important reservoirs of genetic material, whilst excelling especially in regulation of water resources (Meller, 2011). Despite their importance, studies related to wetlands are scarce and their diversity is still largely unknown. Recently there has been an advance in the development of research in Brazil (Alves et al., 2011), mainly because of the creation in 1996 of the National Institute of Science and Technology in Wetlands (Instituto Nacional de Ciência e Tecnologia em Áreas Úmidas - INAU) to study their conservation.

Inventory strategies, zoning, and conservation for these ecosystems were proposed by Maltchik (2003) and Maltchik and Callisto (2004). Maltchik (2003), with data from the World Conservation Monitoring Center, estimated that the global area of wetlands is approximately 5.7 million km^2, whereas about 20 % of the surface of the tropical portion of South America is covered by wetlands (Junk et al., 2016), which are home to different palustrine systems. In areas of the Southern Plateau of Santa Catarina, Magalhães (2013), found that wetlands represent 15 to 20 % of the total area under study. Although they are a limiting factor for expansion of agricultural activities, preservation of these environments should be a priority as they represent important water reservoirs forming the springs of the major rivers of the basin of the Pelotas and Uruguay rivers (Almeida et al., 2007).

In the Brazilian environmental legislation, wetlands are recognized as Permanent Preservation Areas (PPA), although there are some conflicts of interpretation because the term “wetlands” is not objectively stated in the legislation, which indicates the term “veredas” (swampy plains). The Forest Code, established by law 4,771 (Brasil, 1965) and the amendments introduced by law 12,727 (Brasil, 2012), provide protection to areas with the occurrence of springs or “water holes”, even if intermittent, in any topographical situation; however, they do not make specific reference to the wetland ecosystem. There is regulation of wetland protection even at the federal level through interpretation of the concepts and definitions of Conama Resolution 303 (Brasil, 2002), which establishes the parameters, definitions, and limits of the Permanent Preservation Areas. This resolution states that the PPA around wetlands (which we understand under the conceptualization of veredas given by the Conama resolution) should have a minimum width of 50 m in horizontal projection from the boundary of the wetland and waterlogged space, as well as around springs and water holes.

According to the State Environmental Code of Santa Catarina under Law 14,675 of April 13, 2009 (Santa Catarina, 2009), “highland wetlands” are considered Permanent Preservation Areas, consisting of areas that: “*occur above 850 (eight hundred and* *fifty) meters above sea level, consisting of wetlands in an open or closed system, with the occurrence of soils with permanent hydromorphism and the presence of at least 25 % (twenty five percent) of plants that are typical of waterlogged soil, according to specific technical study.*" In addition, a border of at least 10 m from the wet area should be respected, as required by Article 114, item II of the law.

For implementation of the legislation, one of the main problems for environmental enforcement agencies, agroforestry companies, and farmers is to correctly identify the boundaries of a given wetland and, from that limit, demarcate the Permanent Preservation Area. In the absence of this identification, the cultivation of agricultural and forest species in places that should be permanent preservation areas is common. Studies indicate that this demarcation can be made by evaluating geomorphology (Steinek, 2007), vegetation (Bertuzzi, 2013; Magalhães et al., 2013), and soil properties (Almeida et al., 2007).

Generally, the limits of a wetland are established through visual interpretation of satellite images, using humidity, elevation, and vegetation as auxiliary criteria. As this definition may contain errors, it is necessary to include additional criteria. Thus, the hypothesis of this study is that for identification of the hydromorphic environment, the chemical, physical and morphological attributes of soils should be considered, especially the color and content of organic matter.

To contribute to resolving this problem, the aim of this study was to describe and classify the main soils occurring in the wetlands of the Southern Plateau of Santa Catarina, and propose criteria for identification of hydromorphic environments as an aid in demarcation of their boundaries.

MATERIALS AND METHODS

In a more comprehensive study, eight areas of the Southern Plateau of the state of Santa Catarina were studied (Warmling, 2013). They are located in seven different municipalities, namely: Bom Retiro, Bom Jardim da Serra, Campos Novos, Capão Alto, Lages (Morrinhos and Coxilha Rica), São José do Cerrito, and Painel. In this study, the results of four of these areas are shown (Figure 1): Bom Jardim da Serra (BJS - 28° 19' 54" S; 49° 40' 46" W), Bom Retiro (BR - 27° 47' 52" S, 49° 31' 31" W), Lages (LGS - 28° 17' 11" S, 50° 32' 37" W), and Painel (PA - 27° 57' 35" S, 50° 06' 09" W). The pictures of the areas studied were generated through photographs of the Aerophotogrammetric Survey of the state of Santa Catarina, obtained in 2010.

The climate of the mesoregion is of the Cfb type, according to Köppen classification system. According to Braga and Ghellre (1999), it is of the mild mesothermal class, with an average temperature in the coldest month between 10 and 11.5 °C and annual average ranging from 13.8 to 15.8 °C. The average maximum varies from 19.4 to 22.3 °C, and the minimum from 9.2 to 10.8 °C. Total annual rainfall may range from 1,400 to 2,300 mm. Three areas (LGS, BJS, and PA) are in the domain of the igneous rocks that come from the lava flows of the Serra Geral Formation and the other (BR) is in the domain of Permian Sedimentary rocks.

In each area, the soils were studied along a transect perpendicular to their drainage lines, at a distance ranging from 30 to 90 m. The soil sampling units were described and collected in the inner area, in the transition area, and in the outer area of the wetland, trying to evaluate and identify soil change based on changes in internal drainage. In these sites, from four to seven soil profiles were observed, but the results of four representative profiles will be presented.

As some areas evaluated were flooded, identification and collection of horizons and layers were carried out in an open profile with a straight shovel up to 0.30 m deep and in a monolith collected with a Dutch auger from 0.30 to 1.30 m or, in shallow soils, until there

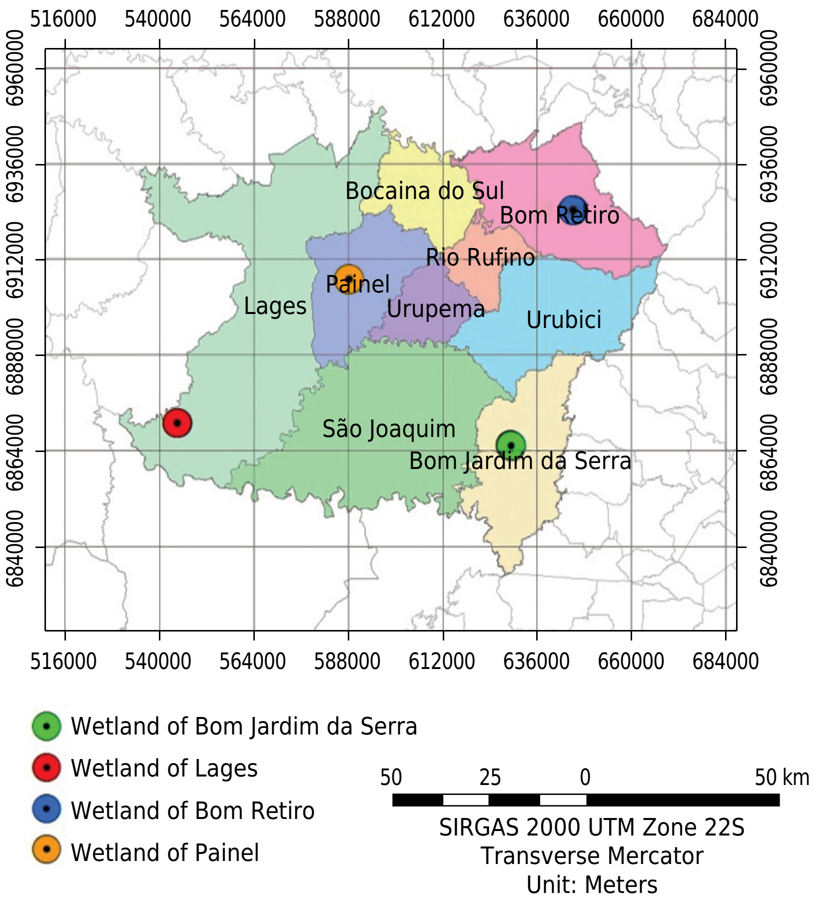

Figure 1. Location of the wetlands studied in the state of Santa Catarina. BJS: Bom Jardim da Serra; BR: Bom Retiro; LGS: Lages; PA: Painel. Figure of the Aerophotogrammetric Survey of the state of Santa Catarina, Brazil, 2010.

was contact with rock. Based on soil volumes collected with a straight shovel and auger, the samples were carefully arranged on a board according to the natural sequence of horizons and layers, rebuilding soil monoliths, in which the thickness and the moist color of horizons and layers was determined. After that, the monoliths were photographed and samples were collected for physical and chemical analysis. The degree of decomposition of the organic material was described according to the Von Post method (Stanek and Silc, 1977). The samples were dried in a laboratory oven at 35 °C for 120 h; the clods were crushed and sieved to obtain the fraction of air-dried fine soil.

The clay fraction was determined by the pipette method (Gee and Bauder, 1986) modified by Corá et al. (2009) and Suzuki et al. (2015), the sand by sieving, and the silt by the difference. In some horizons, due to the difficulty of dispersing the clay, the fraction that was retained in the 53 µm sieve was processed in the manner described above for only the sand fraction to remain in the sieve. This was necessary because wetland soils have high organic matter content that hinders dispersion.

The chemical analyses were: pH in 1 mol L^{-1} KCl solution, pH in water, and potential acidity (Claessen, 1997); contents of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Al^{3+}, and P (Tedesco et al., 1995); and organic carbon (OC) determined by the Walkley-Black method modified by Tedesco et al. (1995). By quantifying these elements, the following parameters were obtained: sum of bases (SB), effective CEC, CEC at pH 7, base saturation (V), and aluminum saturation (m) (Claessen, 1997). The profiles were classified according to the Brazilian Soil Classification System (Santos et al., 2013) and, after that, also according to Soil Taxonomy (Soil Survey Staff, 2014).

RESULTS

In Bom Jardim da Serra (BJS), Painel (PA), and Lages (LGS), the soils are located over rhyodacites of the Serra Geral Formation (outer part), or on a colluvium of sediments previously weathered from these materials, whereas the wetlands of Bom Retiro (BR) have, in their outer area, soils developed from shale of the Terezina Formation and, in the inner area, Holocene sediments of alluvial or colluvial origins that resulted from alteration of the above rocks (DNPM, 1986) (Table 1). Regarding internal drainage, the BJS wetland is a closed system, it is not interconnected with any surface drainage network (Figure 2), while the others are open systems because downstream from them there is water flow that drains the surface that continues from them (Figures 3, 4, and 5). In PA, an open system, one of the springs of the Pelotinhas River, a tributary of the Pelotas River, is formed.

In the outer areas of BJS and PA, there is the presence of *Araucaria angustifolia* woods in the middle of native pasture (Figures 2 and 3); in LGS, there is an extensive area surrounding the wetland composed of native pasture (Figure 4); and in BR, at one end there is a *Pinus elliotti* plantation and, at the other end, predominance of native pasture and a strip of riparian forest near the Matador river, tributary of the Canoas river (Figure 5).

Table 1. Identification and characteristics of the wetland areas evaluated in the field

Area	Municipality	Height	System	Relief		Parent material	
				Inner area	Outer area	Inner area	Outer area
		m					
1	Bom Jardim da Serra	1221	Closed	Flat	Gently rolliing	Holocene, sediments of alluvial or colluvial origins	Rhyodacites of the Serra Geral Formation
2	Painel	1272	Open	Flat	Gently rolling		
3	Lages	985	Open	Gently rolling	Rolling		
4	Bom Retiro	871	Open	Flat	Gently rolling		Shale of the Terezina Formation

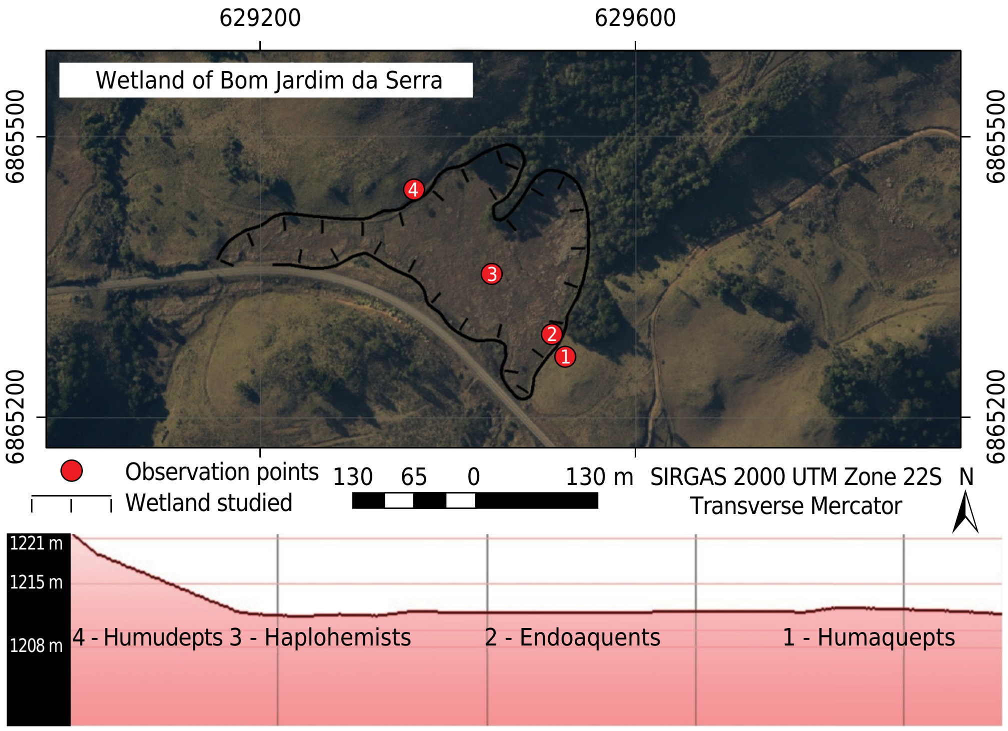

Figure 2. Location of the wetland in the municipality of Bom Jardim da Serra (BJS), SC, and elevation profile. Distance between points 1 and 2: 10 m; 2 and 3: 37 m; 3 and 4: 40 m. Figure of the Aerophotogrammetric Survey of the State of Santa Catarina, Brazil, 2010.

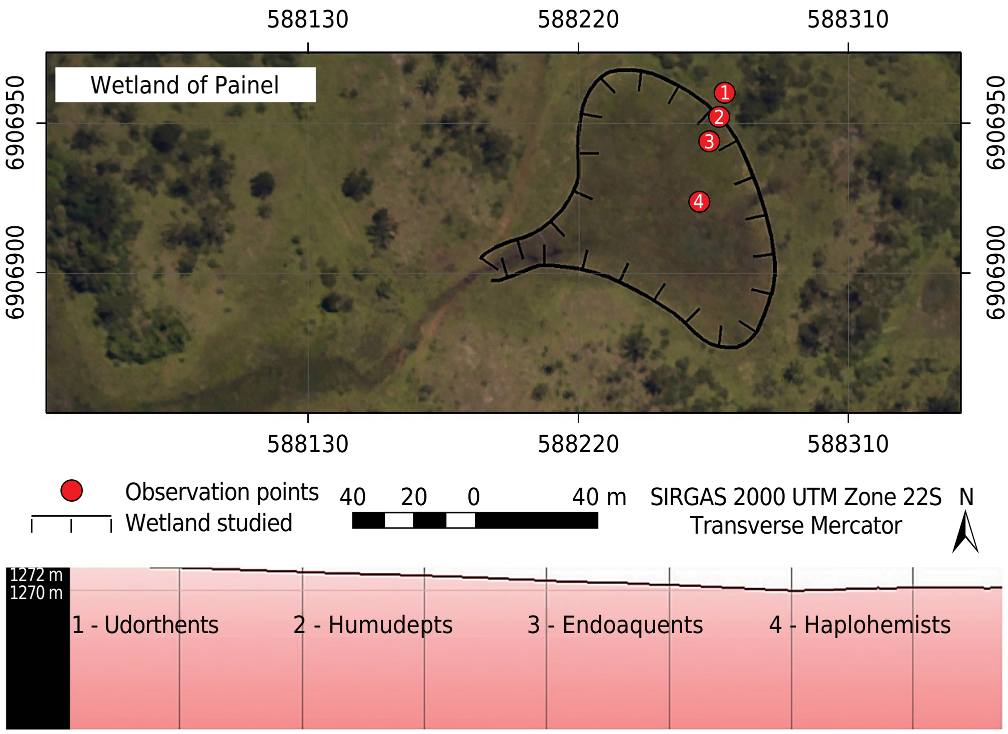

Figure 3. Location of the wetland in the municipality of Painel (PA), SC, and elevation profile. Distance between points 1 and 2: 16 m; 2 and 3: 8 m; 3 and 4: 10 m. Figure of the Aerophotogrammetric Survey of the State of Santa Catarina, Brazil, 2010.

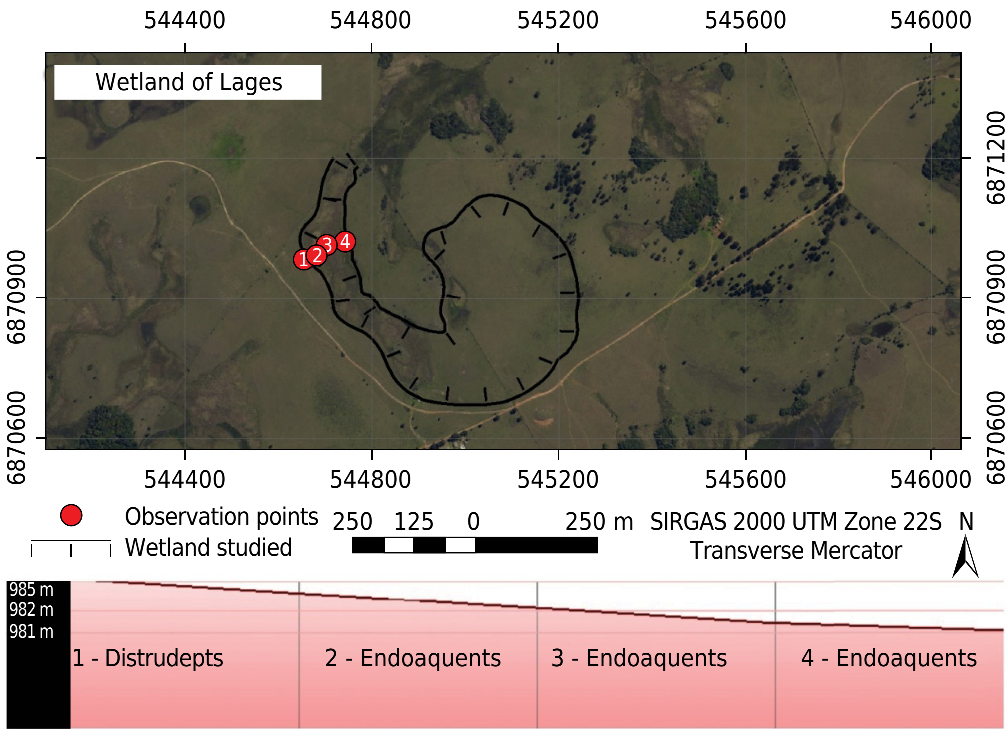

Figure 4. Location of the wetland in the municipality of Lages (LGS), SC, and elevation profile. Distance between points 1 and 2: 7 m; 2 and 3: 25 m; 3 and 4: 25 m. Figure of the Aerophotogrammetric Survey of the State of Santa Catarina, Brazil, 2010.

In area 1, located in the municipality of Bom Jardim da Serra (BJS), the BJS1 soil (Figure 2) is located outside the area of the drenched environment in flat relief (2 % slope) and was evaluated up to a depth of 0.95 m (Table 2). It has A1 + A2 horizons of 0.27 m thickness, with a very dark gray color (7.5YR 3/1) in A1, and very dark brown color (10YR 2/2) in A2. The Bg horizons have 0.25 m thickness and black color (2.5Y 2.5/1) with gleying characteristics, and the Bi horizon has a 0.43 m thickness and dark brown color (10YR 3/3) with common mottling that is small and distinctive of dark yellowish brown color (10YR 4/6). The C horizon occurs as of a depth of 0.95 m. It is therefore a soil with more superficial hydromorphic characteristics since the features of gleying manifest themselves only at the top of the B (Bg) horizon. Based on the carbon and clay content and on horizon thickness, the A horizon was classified as humic. Overall, the pH in the soil ranged from 4.5 to 5.5, indicating an acidic reaction, high clay activity (Ta), and base

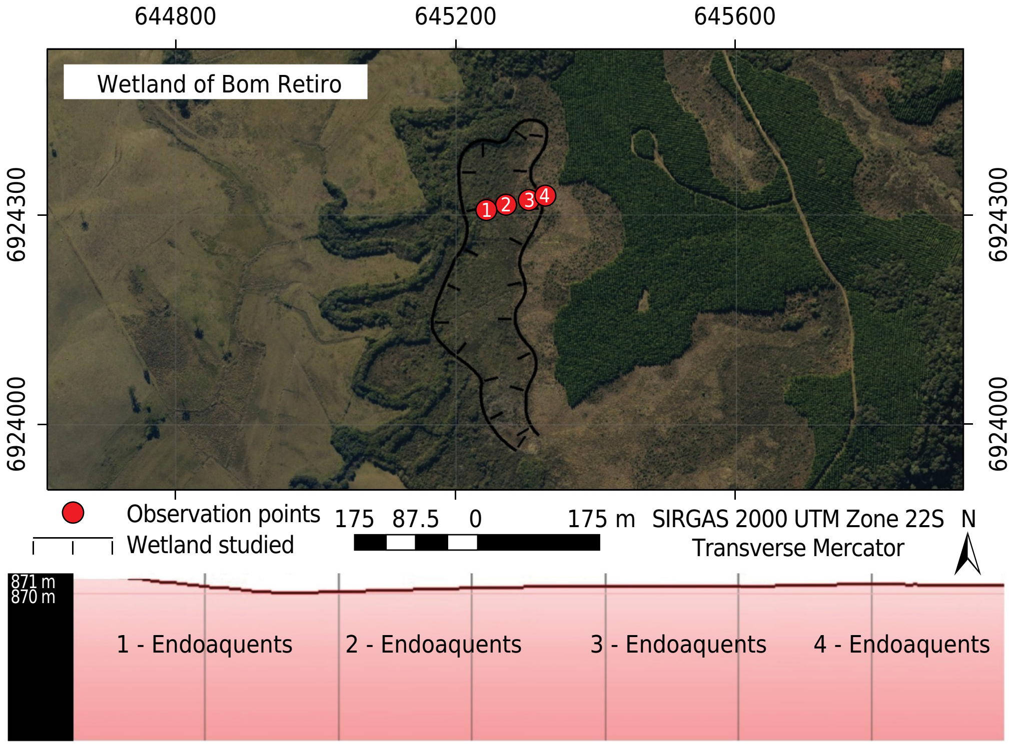

Figure 5. Location of the wetland in the municipality of Bom Retiro (BR), SC, and elevation profile. Distance between points 1 and 2: 12 m; 2 and 3: 25 m; 3 and 4: 17 m. Figure of the Aerophotogrammetric Survey of the State of Santa Catarina, Brazil, 2010.

Table 2. Morphological, physical, and chemical properties of the soils collected in the wetland of Bom Jardim da Serra (BJS), SC, Brazil

BJS1 - *Gleissolo Melânico Ta Distrófico cambissólico* (Humaquepts)												
Hor.	Depth	Color		Sand	Silt	Clay	Silt/clay	pH		OC	PD	
		Wet	Dry					H_2O	KCl			
	m			g kg^{-1}						g kg^{-1}	Mg m^{-3}	
A1	0.00-0.16	7.5YR 3/1	7.5YR 3/2	160	480	360	1.31	5.5	4.6	69	2.15	
A2	0.16-0.27	10YR 2/2	10YR 3/1	90	400	510	0.78	4.6	3.9	73	2.39	
Bg	0.27-0.52	2.5Y 2.5/1	2.5Y 3/1	90	280	630	0.44	4.5	3.8	32	2.56	
Bi2	0.52-0.95	10YR 3/3	10YR 4/4	190	250	560	0.44	4.8	4.1	18	2.77	
	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	H+Al	SB	CEC_{pH7}	CEC_{ef}	P	V	m
	cmol$_c$ kg^{-1}									mg kg^{-1}	%	
A1	13.0	2.9	0.59	0.09		11.1	16.6	27.7	16.6	18	60	0
A2	10.4	2.0	0.23	0.06	3.0	20.1	12.6	32.7	15.6	21	39	19
Bg	8.0	2.0	0.23	0.06	3.9	15.7	10.3	26.0	14.2	19	40	28
Bi2	6.3	1.8	0.25	0.03	0.6	10.2	8.4	18.5	9.0	29	45	7

Continue

Continuation

BJS2 - *Gleissolo Melânico Ta Distrófico organossólico* (Endoaquents)												
Hor.	Depth	Color		Sand	Silt	Clay	Silt/clay	pH		OC	PD	
		Wet	Dry					H_2O	KCl			
	m				$g\ kg^{-1}$					$g\ kg^{-1}$	$Mg\ m^{-3}$	
H1	0.00-0.05	7.5YR 2.5/2	7.5YR 3/3	400	420	180	2.38	5.8	4.9	113		
H2	0.05-0.24	7.5YR 2.5/1	7.5YR 3/1					5.0	4.1	256		
H3	0.24-0.36	10YR 2/1	2.5Y 3/1					4.5	3.8	141		
Cg1	0.36-0.63	10YR 2/1	10YR 2/1	100	160	740	0.21	4.1	3.3	63	2.23	
Cg2	0.63-1.02	10YR 3/1	2.5Y 3/1	120	150	730	0.20	4.3	3.6	30	2.36	
Cg3	1.02-1.28	2.5Y 4/1	5Y 3/1	80	200	720	0.28	4.3	3.5	20	2.58	
	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	H+Al	SB	CEC_{pH7}	CEC_{ef}	P	V	m
				$cmol_c\ kg^{-1}$						$mg\ kg^{-1}$	%	
H1	7.8	3.0	1.38	0.43	0.6	12.1	12.6	24.7	13.2	9	51	4
H2	3.4	1.1	1.59	0.31	0.0	18.2	6.4	24.6	6.4	13	26	0
H3	9.6	1.1	0.83	0.19	0.0	30.7	11.7	42.5	11.7	12	28	0
Cg1	8.5	2.8	0.50	0.11	9.0	26.6	11.9	38.5	20.9	21	31	43
Cg2	15.0	3.3	0.46	0.11	2.8	17.0	18.9	35.9	21.7	23	53	13
Cg3	15.1	5.1	0.61	0.13	5.2	9.0	20.9	30.0	26.2	29	70	20
BJS3 - *Organossolo Háplico Hêmico típico* (Haplohemists)												
Hor.	Depth	Color		Sand	Silt	Clay	Silt/clay	pH		OC	PD	
		Wet	Dry					H_2O	KCl			
	m				$g\ kg^{-1}$					$g\ kg^{-1}$	$Mg\ m^{-3}$	
H1	0.00-0.28	10YR 2/2	10YR 3/1	240	230	530	0.43	4.7	4.0	99	1.47	
H2	0.28-0.52	2.5Y 3/1	2.5Y 3/1	90	240	670	0.36	4.3	3.5	85	2.06	
Cg1	0.52-0.80	10YR 2/1	2.5Y 3/1	130	90	780	0.11	4.2	3.4	33	2.34	
Cg2	0.80-0.96	7.5YR 2.5/1	10YR 3/1	150	140	710	0.20	4.4	3.7	29	2.63	
Cg3	0.96-1.20	10YR 3/1	2.5Y 3/1	80	160	760	0.22	4.3	3.5	10	2.63	
	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	H+Al	SB	CEC_{pH7}	CEC_{ef}	P	V	m
				$cmol_c\ kg^{-1}$						$mg\ kg^{-1}$	%	
H1	6.7	1.3	2.30	0.30	4.6	30.9	10.7	41.5	15.2	9	26	30
H2	6.0	2.6	0.29	0.10	7.3	23.7	9.0	32.7	16.2	9	27	45
Cg1	6.9	3.4	0.30	0.11	6.1	20.4	10.6	31.0	16.7	18	34	36
Cg2	8.5	4.4	0.26	0.10	1.9	16.5	13.3	29.8	15.3	26	45	13
Cg3	14.7	8.1	0.46	0.10	4.8	10.4	23.4	33.8	28.2	29	69	17
BJS4 - *Cambissolo Húmico Distrófico léptico* (Humudepts)												
Hor.	Depth	Color		Sand	Silt	Clay	Silt/clay	pH		OC	PD	Fe
		Wet	Dry					H_2O	KCl			
	m				$g\ kg^{-1}$					$g\ kg^{-1}$	$Mg\ m^{-3}$	$g\ dm^{-3}$
A	0.00-0.30	7.5YR 3/3	10YR 3/3	310	290	400	0.73	4.7	3.9	35	2.39	
Bi	0.30-0.48	7.5YR 2.5/3	7.5YR 3/4	270	280	450	0.60	4.7	3.9	15	2.83	0.79
BC	0.48-0.62	7.5YR 3/3	10YR 3/4	290	290	420	0.71	4.8	4.0	7	2.66	
Cr	0.62-0.75	10YR 3/4	10YR 4/4	430	290	280	1.09	4.8	3.8	9	2.69	
	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	H+Al	SB	CEC_{pH7}	CEC_{ef}	P	V	m
				$cmol_c\ kg^{-1}$						$mg\ kg^{-1}$	%	
A	2.1	1.2	0.46	0.03	4.9	12.0	3.8	15.8	8.7	18	24	56
Bi	1.5	0.6	0.17	0.01	5.1	9.5	2.3	11.8	7.4	21	20	69
BC	1.5	0.6	0.18	0.01	5.8	9.0	2.3	11.3	8.1	14	20	72
Cr	3.9	2.1	0.29	0.04	17.6	18.4	6.3	24.7	24.0	16	26	74

Hor: horizon. Sand, silt, and clay (Gee and Bauder, 1986); Silt/clay: silt/clay ratio (Santos et al., 2013); pH(H_2O): pH in water; pH(KCl): pH in 1 mol L^{-1} KCL solution; PD: particle density, H+Al: potential acidity, SB: sum of bases, CEC: cation exchange capacity, V: base saturation; m: aluminum saturation (Claessen, 1997); OC: total organic carbon (Tedesco et al., 1995).

saturation lower than 50 % (dystrophic) in most of the B horizon within one meter from the surface (Table 2). The soil has a cambic B horizon immediately below the gley horizon, which characterizes it at the fourth level as *cambissólico* in the Brazilian Soil Classification System. Because the gley horizon occurs within the first 0.5 m of the surface, just below the A horizon, the soil was classified as a *Gleissolo Melânico Ta Distrófico cambissólico* (Santos et al., 2013) or Humaquepts (Soil Survey Staff, 2014) (Table 2).

The BJS2 soil (Figure 2) is located in the transition between the inner and the outer areas, on flat relief (2 % slope), at a distance of 10 m from BJS1. The profile was evaluated up to a 1.28 m depth. The soil has a surface horizon with an organic constitution (H1, H2, and H3) formed by stagnant water, due to the presence of groundwater near the surface. However, the added H sub-horizons totaled only 0.36 m thickness, not enough to characterize a Haplohemists. The H1 has a very dark brown color (7.5YR 2.5/2), whereas H2 and H3 are black (7.5YR 2.5/1 and 10YR 2/1, respectively). Below these horizons, from 0.36 to 1.28 m, there is a gley horizon, which was subdivided into Cg1, Cg2, and Cg3, with black color (10YR 2/1), followed by a very dark gray color (2.5Y 4/1), with common mottling that is small and distinct of dark yellowish brown color (10YR 4/4) (Table 2). This is, therefore, a soil characteristic of a hydromorphic environment. The soil has an acidic reaction in most horizons, with pH in water slightly higher in the H1 horizon (5.8), with high clay activity and base saturation lower than 50 % in most of the first meter of the soil. It was classified as *Gleissolo Melânico Ta Distrófico organossólico* (Santos et al., 2013) or Endoaquents (Soil Survey Staff, 2014) (Table 2).

The BJS3 soil (Figure 2) is located in the center of the wetland at a distance of 37 m from the BJS2, and was described up to a 1.20 m depth. The soil has a 0.52 m thick organic horizon, characterized by the symbols H1, of very dark brown color (10YR 2/2), followed by the H2 horizon of very dark gray color (2.5Y 3/1), and Cg with strong gleying characteristics, subdivided into Cg1 and Cg2, which occur from a 0.52 to 0.96 m depth, with black color (10YR 2/1 and 7,5YR 2.5/1 respectively), and Cg3 of very dark gray color (10YR 3/1) with common mottling that is medium and distinct of a yellowish brown color (7.5YR 5/8), which occurs from 0.96 to 1.20 m. The water table, in this case, occurred at the soil surface. This is, therefore, a soil characteristic of a hydromorphic environment. It has an acidic reaction in all horizons, with pH ranging from 4.2 to 4.7. The organic material was classified as hemic in the horizons studied. It was classified as an *Organossolo Háplico Hêmico típico* (Santos et al., 2013) or Haplohemists (Soil Survey Staff, 2014) (Table 3).

The BJS4 soil is located in the outer area, 40 m away from the BJS3, with an altimetric level higher than the wetland itself (Figure 2), but a few meters away from its edge. The slope is 17 % with slightly concave relief. Soil is shallow with a Cr horizon occurring at 0.62 m from the soil surface, represented by the saprolite of the rhyodacite. The A horizon has 0.30 m thickness and dark brown color (7.5YR 3/3), followed by the Bi horizon of very dark brown color (7.5YR 2.5/3) with 0.18 m thickness and a BC horizon of dark brown color (7.5YR 3/3) with 0.14 m thickness. Up to the level analyzed, ground water was not detected. This is, therefore, a non-hydromorphic soil. Because of the C and clay content and its thickness, the A horizon was classified as humic (Table 2). The soil has an acidic reaction in all horizons, with pH ranging from 4.7 to 4.8 and base saturation lower than 50 % in most of the soil at 1 m from the B horizon. Lithic contact occurs below 0.75 m, which characterizes it as leptic in the fourth category level, and it is classified as a *Cambissolo Húmico Distrófico léptico* (Santos et al., 2013) or Humudepts (Soil Survey Staff, 2014) (Table 2).

In area 2, in the municipality of Painel (PA), the PA1 soil (Figure 3) was described in the outer part of the wetland in a gently rolling landscape (4 % slope) with slightly concave relief and was evaluated up to a 0.22 m depth. The soil has a humic A horizon (0.22 m) of dark brown color (7.5YR 3/2) that runs in direct contact with the rhyodacite. Drainage was described as moderate due to the gently rolling landscape and clayey characteristic,

Table 3. Morphological, physical, and chemical properties of the soils collected in the wetland of Painel (PA), SC, Brazil

PA1 - *Neossolo Litólico Húmico típico* (Udorthents)												
Hor.	**Depth**	**Color**		**Sand**	**Silt**	**Clay**	**Silt/clay**	**pH**		**OC**	**PD**	
		Wet	**Dry**					**H_2O**	**KCl**			
	m				g kg^{-1}					g kg^{-1}	Mg m^{-3}	
A	0.00-0.22	7.5YR 3/2	10YR 3/3	190	370	440	0.85	4.4	3.9	79	2.26	
	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	H+Al	SB	CEC_{pH7}	CEC_{ef}	P	V	m
					$cmol_c\ kg^{-1}$					mg kg^{-1}	%	
A	0.2	0.3	0.81	0.08	11.2	22.5	1.4	23.9	12.6	6	6	89
PA2 - *Cambissolo Húmico Alítico léptico* (Humudepts)												
Hor.	Depth	Color		Sand	Silt	Clay	Silt/clay	pH		OC	PD	
		Wet	Dry					H_2O	KCl			
	m				g kg^{-1}					g kg^{-1}	Mg m^{-3}	
H	0.00-0.15	2.5Y 2.5/1	10YR 3/3	40	490	470	1.06	5.0	4.1	95	2.20	
Bi	0.33-0.62	10YR 3/2	10YR 3/3	60	290	650	0.44	4.8	4.0	37	2.61	
	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	H+Al	SB	CEC_{pH7}	CEC_{ef}	P	V	m
					$cmol_c\ kg^{-1}$					mg kg^{-1}	%	
H	1.9	0.7	0.93	0.07	4.5	20.2	3.6	23.9	8.1	10	15	55
Bi	0.3	0.2	0.24	0.02	8.4	14.4	0.7	15.2	9.1	14	5	92
PA3 - *Gleissolo Melânico Alítico organossólico* (Endoaquents)												
Hor.	Depth	Color		Sand	Silt	Clay	Silt/clay	pH		OC	PD	
		Wet	Dry					H_2O	KCl			
	m				g kg^{-1}					g kg^{-1}	Mg m^{-3}	
H2	0.09-0.25	10YR 2/1	2.5Y 3/1	110	430	460	0.93	4.7	4.0	105	2.16	
Cg2	0.37-0.70	7.5YR 3/1	10YR 3/1	80	260	660	0.40	4.6	3.9	27	3.21	
	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	H+Al	SB	CEC_{pH7}	CEC_{ef}	P	V	m
					$cmol_c\ kg^{-1}$					mg kg^{-1}	%	
H	0.7	0.3	0.88	0.06	8.5	28.5	2.0	30.5	10.4	8	6	81
Cg	0.5	0.3	0.23	0.03	11.7	17.7	1.1	18.8	12.8	29	6	92
PA4 - *Organossolo Háplico Hêmico típico* (Haplohemists)												
Hor.	Depth	Color		Sand	Silt	Clay	Silt/clay	pH		OC	PD	
		Wet	Dry					H_2O	KCl			
	m				g kg^{-1}					g kg^{-1}	Mg m^{-3}	
H1	0-0.18	10YR 2/1	10YR 2/1	150	510	340	1.51	4.7	4.0	179	1.51	
H2	0.18-0.32	10YR 2/1	10YR 3/1	70	400	530	0.75	5.1	4.1	158	1.73	
H3	0.32-0.43	10YR 2/1	10YR 3/1	120	460	420	1.09	4.7	4.1	102	2.01	
Cg1	0.43-0.67	7.5YR 3/1	10YR 3/1	90	240	670	0.36	4.7	4.1	61	2.30	
	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	H+Al	SB	CEC_{pH7}	CEC_{ef}	P	V	m
					$cmol_c\ kg^{-1}$					mg kg^{-1}	%	
H1	1.7	0.6	1.11	0.1	6.7	34.9	3.5	38.4	10.1	6	9	66
H2	0.5	0.1	0.24	0.1	10.4	43.7	0.9	44.6	11.3	2	2	92
H3	0.3	0.1	0.10	0.0	10.5	34.3	0.5	34.8	11.0	6	1	95
Cg1	0.2	0.1	0.14	0.0	9.4	24.7	0.5	25.1	9.8	8	2	95

Hor: horizon; sand, silt, and clay (Gee and Bauder, 1986); Silt/clay: silt/clay ratio (Santos et al., 2013); pH(H_2O): pH in water; pH(KCl): pH in 1 mol L^{-1} KCL solution; PD: particle density, H+Al: potential acidity, SB: sum of bases, CEC: cation exchange capacity, V: base saturation; m: aluminum saturation (Claessen, 1997); OC: total organic carbon (Tedesco et al., 1995).

but gleying or the presence of groundwater, characteristics of a soil in a hydromorphic environment, were not identified, which characterizes a soil from a non-hydromorphic environment. The A horizon shows an acidic reaction at pH 4.4 (Table 3). It was classified as a *Neossolo Litólico Húmico típico* (Santos et al., 2013) or Udorthents (Soil Survey Staff, 2014) (Table 3).

The PA2 soil (Figure 3) is located in the outer part of the wetland, very close to it, 16 m away from the PA1, still with a gently rolling landscape (4 % slope), and it was evaluated up to 0.62 m, where the contact with rock occurs. The soil has H, A, AB, and Bi horizons, but only the H and Bi horizons were collected for chemical and physical analysis. The H Horizon is approximately 0.15 m thick of black color (2.5Y 2.5/1); the A horizon is 0.12 m thick, followed by the transitional AB horizon, which is 0.11 m thick, and the Bi (cambic) horizon with 0.29 m thickness of very dark grayish brown color (10YR 3/2) and some mottling that is medium and distinct of dark yellowish brown color (10YR 4/4). The soil is imperfectly drained, maintaining characteristics of temporary hydromorphism. The H horizon does not have enough thickness to be considered histic (0.15 m thick). The soil has an acidic reaction in the horizons, with pH ranging from 4.8 to 5.0 and high Al content (alic) in most of the first meter above the ground. It was classified as a *Cambissolo Húmico Alítico léptico* (Santos et al., 2013) or Humudepts (Soil Survey Staff, 2014) (Table 3).

The PA3 (Figure 3) soil is in the transition between the inner and outer parts of the wetland on flat relief, 8 m away from PA2, and was evaluated up to a 0.70 m depth. The soil has H1, H2, and Cg1 and Cg2 horizons, but only the H2 and Cg2 horizons were collected for physical and chemical analysis. The soil has horizons of organic constitution (H1 and H2) formed by stagnant water, with a black color (10YR 2/1) and 0.25 m thickness, therefore insufficient to characterize it as a Histosol. Below the histic horizons there is a gley horizon (Cg1 and Cg2) from 0.25 to 0.70 m depth, with very dark gray color (7.5YR 3/1) and common mottling that is small and diffuse of a dark yellowish brown color (10YR 3/4). The water table is found at 0.29 m below the ground surface. This is a typical soil of a hydromorphic environment, although invaded by vegetation of a terrestrial habit, due to lowering of the water level in the drier seasons. It has an acidic reaction, with pH ranging from 4.6 to 4.7 and high Al content (alic) in most of the first meter above the ground. It was classified as a *Gleissolo Melânico Alítico organossólico* (Santos et al., 2013) or Endoaquents (Soil Survey Staff, 2014) (Table 3).

The PA4 soil (Figure 3) is located close to the center of the wetland in flat relief, 10 m away from PA3, and was evaluated up to a 0.67 m depth. This soil features horizons of an organic constitution up to 0.43 m depth, characterized as H1, H2, and H3, all of them black (10YR 2/1). From the H3 on, there is a strongly gleying horizon (Cg1) of very dark gray color (7.5YR 3/1). Considered a poorly drained soil, the water table is found at 0.11 m below the soil surface. It is therefore a soil characteristic of a hydromorphic environment. It has an acidic reaction in all horizons, with pH ranging from 4.7 to 5.1. The organic material was classified as hemic in the horizons studied. It was classified as an *Organossolo Háplico Hêmico típico* (Santos et al., 2013) or Haplohemists (Soil Survey Staff, 2014) (Table 3).

In area 3, in Lages (LGS), the LGS1 soil (Figure 4) is located at the outer part of the wetland; the slope is 12 %, with slightly concave relief, and it was evaluated up to a 1.10 m thickness. The A horizon has 0.19 m thickness, followed by the AB horizon with 0.19 m thickness, BA horizon with 0.14 thickness, B horizon with 0.34 m thickness, and BC horizon from 0.86 to 1.10 m, all of dark brown color (10YR 3/3), but with no evidence of gleying or mottling. It is, therefore, a soil without hydromorphic characteristics. The soil has an acidic reaction in all horizons, with pH ranging from 4.4 to 4.5 and high Al content (alic) in most of the first meter of soil evaluated. It was classified as a *Cambissolo Háplico Alítico típico* (Santos et al., 2013) or Distrudepts (Soil Survey Staff, 2014) (Table 4).

Table 4. Morphological, physical, and chemical properties of the soils collected in the wetland of Lages (LGS), SC, Brazil

LGS1 - *Cambissolo Háplico Alítico típico* (Distrudepts)												
Hor.	**Depth**	**Color**		**Sand**	**Silt**	**Clay**	**Silt/clay**	**pH**		**OC**	**PD**	
		Wet	**Dry**					**H_2O**	**KCl**			
	m				g kg^{-1}					g kg^{-1}	Mg m^{-3}	
A	0.00-0.19	10YR 3/3	10YR 4/3	130	310	560	0.55	4.4	3.7	29	2.48	
AB	0.19-0.38	10YR 3/3	10YR 3/4	100	280	620	0.46	4.4	3.7	14	2.60	
BA	0.38-0.52	10YR 3/3	10YR 3/4	100	230	670	0.34	4.4	3.7	9	2.45	
B	0.52-0.86	10YR 3/3	10YR 3/4	130	190	680	0.28	4.5	3.7	6	2.68	
BC	0.86-1.10	10YR 3/3	10YR 3/4	110	190	700	0.27	4.5	3.7	7	2.65	
	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	H+Al	SB	CEC_{pH7}	CEC_{ef}	P	V	m
				cmol$_c$ kg^{-1}						mg kg^{-1}	%	
A	1.0	0.4	0.73	0.04	11.2	17.9	2.2	20.1	13.4	7	11	84
AB	0.3	0.0	0.21	0.01	12.8	16.2	0.5	16.7	13.3	8	3	96
BA	0.2	0.0	0.18	0.03	13.1	15.7	0.4	16.1	13.5	9	3	97
B	0.1	0.0	0.13	0.01	12.4	14.3	0.3	14.6	12.7	8	2	98
BC	0.4	0.2	0.54	0.02	12.1	12.5	1.1	13.7	13.2	17	8	91
LGS2 - *Gleissolo Melânico Alítico típico* (Endoaquents)												
Hor.	Depth	Color		Sand	Silt	Clay	Silt/clay	pH		OC	PD	
		Wet	Dry					H_2O	KCl			
	m				g kg^{-1}					g kg^{-1}	Mg m^{-3}	
A	0.00-0.21	10YR 3/1	10YR 4/1	120	400	480	0.82	3.8	3.7	34	2.34	
AC	0.21-0.32	10YR 3/2	10YR 4/2	90	390	520	0.74	4.2	3.5	9	2.50	
Cg1	0.32-0.44	10YR 3/2	10YR 4/2	110	400	490	0.80	4.3	3.6	3	2.59	
Cg2	0.44-0.72	10YR 4/2	10YR 5/3	100	410	490	0.83	4.4	3.7	2	2.60	
Cg3	0.72-0.87	10YR 4/2	10YR 5/3	190	320	490	0.64	4.5	3.8	2	2.71	
Cg4	0.87-1.12	10YR 6/3		120	260	620	0.41	4.6	3.7	1	2.65	
	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	H+Al	SB	CEC_{pH7}	CEC_{ef}	P	V	m
				cmol$_c$ kg^{-1}						mg kg^{-1}	%	
A	0.3	0.2	0.46	0.07	10.4	22.0	1.1	23.1	11.5	23	5	91
AC	0.8	0.4	0.94	0.04	9.8	17.5	2.2	19.7	11.9	21	11	82
Cg1	1.2	0.4	0.71	0.04	7.7	12.7	2.4	15.1	10.1	14	16	76
Cg2	0.8	0.4	0.63	0.03	6.4	8.8	1.9	10.7	8.3	8	18	77
Cg3	1.0	0.5	0.70	0.03	5.7	7.9	2.3	10.2	7.9	10	22	71
Cg4	1.3	0.7	0.87	0.03	7.4	8.1	2.9	11.0	10.2	6	26	72
LGS3 - *Gleissolo Melânico Alítico organossólico* (Endoaquents)												
Hor.	Depth	Color		Sand	Silt	Clay	Silt/clay	pH		OC	PD	
		Wet	Dry					H_2O	KCl			
	m				g kg^{-1}					g kg^{-1}	Mg m^{-3}	
H1	0.00-0.22							4.6	4.0	226		
H2	0.22-0.38	10YR 2/1	2.5Y 2.5/1					4.3	3.6	169		
Cg 1	0.38-0.73	2.5Y 2.5/1	2.5Y 2.5/1	100	150	750	0.20	4.0	3.2	58	2.22	
Cg2	0.73-1.00	Glei12.5/N	Glei12.5/N	90	190	720	0.27	4.2	3.4	58	2.20	
Cg3	1.00-1.20	Glei12.5/N	Glei12.5/N	60	280	660	0.43	4.4	3.5	98	2.21	
Cg4	1.20-1.30	Glei12.5/N	Glei12.5/N	120	330	550	0.60	4.4	3.6	43	2.41	

Continue

Continuation

	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	H+Al	SB	CEC_{pH7}	CEC_{ef}	P	V	m
					$cmol_c\ kg^{-1}$					$mg\ kg^{-1}$	%	
H1	4.3	1.5	1.99	0.12	6.8	34.9	8.0	42.9	14.8	5	19	46
H2	2.7	0.7	1.96	0.15	10.4	30.8	5.5	36.3	15.8	9	15	65
Cg 1	5.4	1.5	0.40	0.08	10.8	28.2	7.5	35.7	18.2	18	21	59
Cg2	7.9	2.6	0.55	0.06	10.5	27.1	11.1	38.1	21.5	13	29	49
Cg3	10.7	2.5	0.59	0.06	8.6	35.8	13.9	49.7	22.5	11	28	38
Cg4	6.4	2.3	0.60	0.05	6.1	18.1	9.4	27.5	15.5	7	34	40
LGS4 - *Gleissolo Melânico Alítico típico* (Endoaquents)												
Hor.	Depth	Color		Sand	Silt	Clay	Silt/clay	pH		OC	PD	
		Wet	Dry					H_2O	KCl			
	m				$g\ kg^{-1}$					$g\ kg^{-1}$	$Mg\ m^{-3}$	
A	0.00-0.15	10YR 2/2	10YR 3/2	230	390	380	1.07	4.7	3.9	45	2.32	
AC	0.15-0.32	10YR 3/2	10YR 3/4	200	370	430	0.85	4.7	4.0	32	2.42	
CA	0.32-0.49	10YR 3/2	10YR 3/2	290	320	390	0.82	4.5	3.9	24	2.47	
Cg1	0.49-0.75	10YR 4/3	10YR 5/4	250	310	440	0.71	4.5	3.7	14	2.94	
Cg2	0.75-1.00	Glei1 7/N		190	300	510	0.59	3.9	3.3	10	2.41	
	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	H+Al	SB	CEC_{pH7}	CEC_{ef}	P	V	m
					$cmol_c\ kg^{-1}$					$mg\ kg^{-1}$	%	
A	0.8	0.2	0.37	0.06	6.2	13.6	1.3	14.9	7.5	9	9	82
AC	0.6	0.2	0.28	0.03	6.5	13.6	1.1	14.8	7.6	10	8	85
CA	0.4	0.1	0.18	0.02	7.8	11.7	0.7	12.4	8.5	9	6	92
Cg1	0.6	0.2	0.21	0.02	6.7	8.0	1.1	9.0	7.8	12	12	86
Cg2	2.2	1.1	0.51	0.03	15.8	16.7	3.9	20.6	19.7	9	19	80

Hor: horizon; sand, silt, and clay (Gee and Bauder, 1986); Silt/clay: silt/clay ratio (Santos et al., 2013); pH(H_2O): pH in water; pH(KCl): pH in 1 mol L^{-1} KCL solution; PD: particle density, H+Al: potential acidity, SB: sum of bases, CEC: cation exchange capacity, V: base saturation; m: aluminum saturation (Claessen, 1997); OC: total organic carbon (Tedesco et al., 1995).

The LGS2 soil (Figure 4) is in the transition between the inner and outer area of the wetland, 7 meters away from LGS1, the slope is 8 % with slightly concave relief, and it was evaluated up to a 1.12 m depth. The soil has an A horizon of very dark gray color (10YR 3/1) that is 0.21 m thick, followed by a transitional AC horizon of 0.11 m thickness and very dark grayish brown color (10YR 3/2), and then a Cg horizon, subdivided into Cg1, Cg2, Cg3, and Cg4, which goes from 0.32 to 1.12 m. The Cg1 has a thickness of 0.12 m and a very dark grayish brown color (10YR 3/2); the Cg2 and Cg3 have a dark greyish brown color (10YR 4/2), and the Cg4 has a thickness of 0.25 m and a pale brown color (10YR 6/3), with the presence of abundant mottling that is medium and prominent of a strong brown color (10YR 5/6). Due to the strong gleying characteristics observed, it is a soil typical of a hydromorphic environment, despite the prevalence of vegetation of terrestrial habit. Because the carbon and clay content and the thickness met requirements, the A horizon was classified as humic. It has an acidic reaction in all horizons, with pH ranging from 3.8 to 4.6 and high Al content (alic) in most of the first meter of soil evaluated. It was classified as a *Gleissolo Melânico Alítico organossólico* (Santos et al., 2013) or Endoaquents (Soil Survey Staff, 2014) (Table 4).

The LGS3 soil (Figure 4) is located in the center of the inner area of the wetland, 25 m away from the LGS2; its slope is 4 % and it was evaluated up to a 1.30 m depth. The soil features horizons of an organic constitution that are 0.38 m thick, characterized as H1 and H2, of black color (10YR 2/1) and constituted by plant residues in decomposition. As of 0.38 m from the surface, there is a strongly gleyed horizon (Cg) of black color (2.5Y 2.5/1 and Gley 1 2.5/N), which extends up to 1.3 m thickness. Mottling does not occur, which is indicative of a permanently wet and strongly reducing environment. Considered a poorly drained soil, its water table was at the soil surface. It is, therefore, a soil typical of a hydromorphic environment. The soil has a histic horizon with 0.38 m thickness (therefore insufficient to characterize it as a Histosol) and has an acidic reaction in all horizons, with pH ranging from 4.0 to 4.6 and high Al content (alic) in most of the first meter of soil evaluated. It was classified as a *Gleissolo Melânico Alítico organossólico* (Santos et al., 2013) or Endoaquents (Soil Survey Staff, 2014) (Table 4).

The LGS4 soil (Figure 4) is located in the transition between the inner and outer area of the wetland, at the opposite side of the LGS1 soil, 25 m away from the LGS3; the slope is 4 % with slightly concave relief and was evaluated up to the first meter depth. The soil has an A horizon of a very dark brown color (10YR 2/2) with 0.15 m thickness, followed by a transitional AC horizon extending from 0.15 to 0.32 m, and a CA horizon with 0.17 m thickness, both of very dark grayish brown color (10 YR 3/2). The Cg1 horizon, 0.26 m thick, has a brown color (10YR 4/3). In the Cg2 horizon, from a 0.75 to 1 m depth, gleying is evident, of light gray color (Gley1 7/N). It is thus a soil with characteristics of hydromorphism. Due to the C and clay content and its thickness, the horizon was classified as humic. The reaction is acidic in all horizons, with pH ranging from 3.9 to 4.7 and high Al content (alic) in most of the first meter of the soil. It was classified as a *Gleissolo Melânico Alítico típico* (Santos et al., 2013) or Endoaquents (Soil Survey Staff, 2014) (Table 4).

In area 4, in Bom Retiro (BR), the BR1 soil (Figure 5) is located in the inner area of the wetland, the slope is 3 %. It has an A1 horizon with 0.06 m thickness (horizon not collected for physical and chemical analysis) and an A2g horizon with 0.16 m thickness and a very dark brown color (10YR 2/2). Below that horizon, there is a transitional gleyed horizon (ACg) with 0.09 m thickness and a very dark gray color (2.5Y 3/1). The Cg horizon is divided into Cg1, of a very dark gray color (2.5Y 3/1), and Cg2 and Cg3 of a dark gray color (10YR 4/1 and Gley1 4/N), all with common mottling that is medium, distinct, and a dark yellowish brown color (10YR 3/6), extending from 0.31 to 0.95 m, apparently continuing from that point on (Table 5). Since this is a poorly drained soil, the groundwater was at 0.45 m below the soil surface. Thus, it is a soil typical of a hydromorphic environment. The morphological characteristics reveal frequent fluctuation of the water table throughout the year, as evidenced by the mottling formation in the Cg horizons. Due to the carbon

Table 5. Morphological, physical, and chemical properties of the soils collected in the wetland of Bom Retiro (BR), SC, Brazil

BR1 - *Gleissolo Melânico Alítico típico* (Endoaquents)												
Hor.	Depth	Color		Sand	Silt	Clay	Silt/clay	pH		OC	PD	
		Wet	Dry					H_2O	KCl			
	m			g kg^{-1}						g kg^{-1}	Mg m^{-3}	
A2g	0.06-0.22	10YR 2/2	10YR 4/1	210	290	500	0.56	4.4	3.8	65	2.18	
ACg	0.22-0.31	2.5Y 3/1	2.5Y 5/1	70	280	650	0.44	4.5	3.7	58	2.31	
Cg1	0.31-0.46	2.5Y 3/1	2.5Y 5/1	110	240	650	0.38	4.6	3.6	32	2.49	
Cg2	0.46-0.67	10YR 4/1	10YR 6/1	100	240	660	0.36	4.6	3.5	18	2.59	
Cg3	0.67-0.95	Glei1 4/N	Glei1 6/N	40	320	640	0.49	4.9	3.9	24	2.72	
	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	H+Al	SB	CEC_{pH7}	CEC_{ef}	P	V	m
	cmol$_c$ kg^{-1}									mg kg^{-1}	%	
A2g	8.1	2.5	0.74	0.13	6.8	14.1	11.5	25.6	18.3	10	45	37
ACg	8.1	3.1	0.75	0.13	7.6	18.9	12.0	31.0	19.6	13	39	39
Cg1	8.2	3.3	0.51	0.19	7.6	13.1	12.2	25.3	19.7	11	48	38
Cg2	4.6	3.2	0.57	0.12	9.8	10.2	8.5	18.7	18.3	17	46	53
Cg3	7.1	5.8	1.43	0.21	3.1	6.7	14.5	21.2	17.6	24	68	18

Continue

Continuation

BR2 - *Gleissolo Melânico Alítico típico* (Endoaquents)												
Hor.	Depth	Color		Sand	Silt	Clay	Silt/clay	pH		OC	PD	
		Wet	Dry					H_2O	KCl			
	m			g kg^{-1}						g kg^{-1}	Mg m^{-3}	
A	0.00-0.19	7.5YR 3/1	10YR 5/2	90	560	350	1.59	4.4	3.7	68	2.38	
ACg	0.19-0.30	7.5YR 3/1	10YR 5/1	30	730	240	3.01	4.4	3.7	66	2.37	
Cg1	0.30-0.46	2.5Y 3/1	2.5Y 4/1	70	270	660	0.41	4.6	3.7	15	2.71	
Cg2	0.46-0.68	10YR 3/2	10YR 3/2	20	350	630	0.56	5.3	3.9	21	2.57	
Cg3	0.68-1.10	2.5Y 4/1	2.5Y 6/1	40	420	540	0.77	4.3	3.5	13	2.74	
	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	H+Al	SB	CEC_{pH7}	CEC_{ef}	P	V	m
	cmol$_c$ kg^{-1}									mg kg^{-1}	%	
A	1.4	1.1	1.20	0.06	7.7	19.7	3.8	23.4	11.5	4	16	67
ACg	3.5	2.4	0.74	0.09	5.0	18.6	6.8	25.4	11.8	8	27	42
Cg1	2.0	3.7	1.72	0.10	6.7	7.4	7.5	14.9	14.2	14	50	47
Cg2	6.2	5.6	0.78	0.16	2.5	3.1	12.7	15.8	15.2	19	80	16
Cg3	7.8	3.5	0.78	0.13	7.8	8.3	12.2	20.5	20.0	18	59	39
BR3 - *Gleissolo Melânico Alítico típico* (Endoaquents)												
Hor.	Depth	Color		Sand	Silt	Clay	Silt/clay	pH		OC	PD	
		Wet	Dry					H_2O	KCl			
	m			g kg^{-1}						g kg^{-1}	Mg m^{-3}	
A1	0.00-0.12	10YR 2/1	10YR 4/1	80	440	480	0.93	4.2	3.6	73	2.21	
A2	0.12-0.33	10YR 3/1	10YR 4/1	50	490	460	1.06	4.5	3.7	48	2.44	
AC	0.33-0.52	10YR 3/1	10YR 5/1	40	360	600	0.61	4.4	3.7	40	2.44	
Cg	0.52-0.60	2.5Y 5/1	2.5Y 6/2	30	370	600	0.61	4.5	3.7	21	2.40	
Cr	0.60-0.70	Glei1 4/N	Glei1 5/N	130	260	610	0.43	4.4	3.7	15	2.53	
	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	H+Al	SB	CEC_{pH7}	CEC_{ef}	P	V	m
	cmol$_c$ kg^{-1}									mg kg^{-1}	%	
A1	2.0	1.2	1.04	0.07	22.0	24.4	4.2	28.6	26.2	7	15	84
A2	1.1	0.8	0.76	0.05	21.4	21.9	2.7	24.6	24.1	6	11	89
AC	0.7	0.8	0.92	0.06	19.8	21.5	2.6	24.0	22.3	8	11	89
Cg	0.9	1.5	1.42	0.07	13.6	15.6	3.8	19.4	17.4	10	20	78
Cr	1.7	3.3	1.48	0.08	8.8	10.2	6.5	16.7	15.3	10	39	57
BR4 - *Gleissolo Melânico Alítico típico* (Endoaquents)												
Hor.	Depth	Color		Sand	Silt	Clay	Silt/clay	pH		OC	PD	
		Wet	Dry					H_2O	KCl			
	m			g kg^{-1}						g kg^{-1}	Mg m^{-3}	
A	0.00-0.20	10YR 2/1	10YR 4/1	70	380	550	0.69	4.4	3.7	67	2.32	
Cg1	0.20-0.47	10YR 3/2	2.5Y 5/1	50	370	580	0.65	4.6	3.7	24	2.54	
Cg2	0.47-0.90	2.5Y 5/1	2.5Y 7/1	120	190	690	0.27	4.7	3.7	37	2.36	
	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	H+Al	SB	CEC_{pH7}	CEC_{ef}	P	V	m
	cmol$_c$ kg^{-1}									mg kg^{-1}	%	
A	3.6	1.7	1.35	0.07	12.7	21.1	6.7	27.8	19.4	9	24	66
Cg1	0.8	1.0	1.12	0.09	14.0	14.4	2.9	17.3	16.9	6	17	83
Cg2	3.1	3.1	0.54	0.12	9.8	14.5	6.9	21.3	16.7	11	32	59

Hor: horizon; sand, silt, and clay (Gee and Bauder, 1986); Silt/clay: silt/clay ratio (Santos et al., 2013); pH(H_2O): pH in water; pH(KCl): pH in 1 mol L^{-1} KCL solution; PD: particle density, H+Al: potential acidity, SB: sum of bases, CEC: cation exchange capacity, V: base saturation; m: aluminum saturation (Claessen, 1997); OC: total organic carbon (Tedesco et al., 1995).

and clay content and its thickness, the A horizon was classified as humic. The horizons have an acidic reaction, with pH ranging from 4.4 to 4.9, and the soil has high Al content (alic) in most of the first meter of the soil. It was classified as a *Gleissolo Melânico Alítico típico* (Santos et al., 2013) or Endoaquents (Soil Survey Staff, 2014) (Table 5).

The BR2 soil (Figure 5) is located in the inner area of the wetland, 12 m away from the BR1; the slope is 3 %, and it was evaluated up to a 1.10 m depth. It has an A horizon, 0.19 m thick, and an ACg horizon from 0.19 to 0.30 m, both of very dark gray color (7.5YR 3/1). After that, there is a Cg1 horizon of very dark gray color (2.5Y 3/1), followed by a Cg2 horizon of very dark grayish brown color (10YR 3/2) and a Cg3 of dark gray color (2.5Y 4/1), extending from a 0.30 to 1.10 m depth. The Cg3 horizon has common mottling that is large, distinct, and of brownish yellow color (10YR 6/6), which are indicative of oscillation in the water table, which was 0.90 m below the soil surface. This is a soil typical of a hydromorphic environment. The A horizon has been reported as humic. An acidic reaction occurs in all horizons, with pH ranging from 4.3 to 5.3 and high Al content (alic) in most of the first meter of the soil. It was classified as a *Gleissolo Melânico Alítico típico* (Santos et al., 2013) or Endoaquents (Soil Survey Staff, 2014) (Table 5).

The BR3 soil (Figure 5) is in the transition between the inner and outer area of the wetland, at a distance of 25 m from the BR2; the slope is 3 %, with predominance of vegetation of terrestrial habit, and it was evaluated up to a 0.70 m depth. The soil has an A1 horizon that is 0.12 m thick and of black color (10YR 2/1), and A2 and AC horizons of very dark gray color (10YR 3/1), with thickness ranging from 0.12 to 0.52 m. The Cg horizons of gray color (2.5Y 5/1) and the Cr horizon of dark gray color (Gley 1 4/N) occur from 0.52 m, extending up to contact with rock. In this case, more permanent conditions of hydromorphism are maintained since gleying processes have been favored in this soil. The A horizon has been reported as humic, and an acidic reaction occurs in all horizons, with pH ranging from 4.2 to 4.5 and high Al content (alic) in most of the first meter of the soil. It was classified as a *Gleissolo Melânico Alítico típico* (Santos et al., 2013) or Endoaquents (Soil Survey Staff, 2014) (Table 5).

The BR4 soil (Figure 5) is located in the outer area of the wetland, at 17 m from the BR3, in a headwater drainage area under a gently rolling landscape (slope 5 %), and it was evaluated up to 0.90 m. The soil has an A horizon of black color (10YR 2/1) with 0.20 m thickness. Under that is a gleyed horizon (Cg1) of very dark grayish brown color (10YR 3/2), with 0.27 m thickness and the presence of common mottling that is medium, distinct and a dark yellowish brown color (10YR 3/4), followed by another gleyed horizon (Cg2) of gray color (2.5Y 5/1), extending from a 0.47 to 0.90 m depth, with common mottling that is medium, distinct and a brownish yellow color (10YR 6/6), which are indicative of oscillation in the water table, causing partial oxidizing conditions in certain drier periods of the year. Although this soil is located at a topographical level about 1 m higher than the wetland itself, the water table was 0.85 m below the soil surface. The location of this soil in an area marginal to headwater drainage, associated with the fact that the soil is shallow and on shales, favored intense lateral subsurface flow in the Cr horizon, which forms one of the springs. Because of the strongly gleyed characteristics, it is a soil of a permanent hydromorphic environment. The A horizon was classified as humic. An acidic reaction occurs in the horizons, with pH ranging from 4.4 to 4.7, and high Al content (alic) in most of the first meter of the soil. It was classified as a *Gleissolo Melânico Alítico típico* (Santos et al., 2013) or Endoaquents (Soil Survey Staff, 2014) (Table 5).

DISCUSSION

The wetlands with soils developed in the igneous rock domain, or from colluvium of materials previously weathered from these rocks in most of the Southern Plateau of Santa Catarina, occur in small depressions surrounded by areas of a gently rolling landscape, where the condition of landscape relief, steeper at the outskirts, favors better individualization and delimitation. In these cases, the soil characteristics change more abruptly, i.e., at a shorter distance. In many cases, as already examined in previous studies (Almeida et al., 2007), such wetlands are confined in closed systems, like an amphitheater, as in area 1 (BJS). In most cases, however, as in the situations of areas 2 (PA) and 3 (LGS), they occur interconnected to other wetland systems, forming a heterogeneous whole (open systems), which, at some point downstream, will constitute sources of small watercourses, creeks, or streams that connect to the main water network.

In other cases, particularly when they occupy a larger single area over wider areas with lower declivity, their delimitation is more difficult, either by remote sensing or in field work that is necessary for their delimitation. This was the case in area 4 (BR), with a flatter surface surrounded by a gently rolling landscape, where the soil characteristics change gradually (Figure 5).

In the four wetlands studied, there was little variation in the soil types identified, at least at the suborder level. In the inner areas, there were mainly Aquents, Aquepts, and Histosols, three classes that are relatively easy to identify because of their inherent characteristics from the processes of gleying (Aquents and Aquepts) and waterlogging (Histosols).

In the inner areas of the wetlands, the Aquents and Aquepts usually occupy slightly higher topographic elevations than the Histosols. In these places, the water table is above or at ground surface level during certain times of the year. However, during the driest period, in the area of Aquents and Aquepts, the thickness of the groundwater was observed a few centimeters below the surface, while in the area of Histosols, that level was observed on the surface, or above it, configuring a condition of a more permanent hydromorphism. These differences explain the lower content of organic matter observed in the Aquents and Aquepts.

It should be noted that the soils were observed at points along a transect perpendicular to the drainage lines, and therefore, the methodology does not allow determination of the wetland as a whole; the surface area occupied by each of the identified classes of soil, only indicates their occurrence.

Therefore, Histosols can occupy both the central position and the areas closest to the margin of it, depending mainly on the internal drainage condition, but these soils often accompany the flow lines that concentrate more water and keep the water table near or above the surface.

Histosols are soils formed in hydromorphic environments saturated with water most of the year, whose surface horizons, of predominantly organic constitution and represented by the symbol H (H1, H2, H3...), should have contents equal to or larger than 80 g kg^{-1} of C and a minimum thickness of 0.40 m extending in a single section starting from the soil surface or cumulatively within 1 m of the soil surface. These horizons are classified as histic, although they are not exclusive of Histosols (Santos et al., 2013). All the soils studied had this continuous accumulation starting from the surface, as shown in Figure 6a. Below the histic horizon, the Histosols had a gley horizon of a predominantly dark gray color, due to loss of most Fe compounds in an anaerobic environment.

The Aquents and Aquepts are hydromorphic soils with a gley horizon starting within 0.50 m of the soil surface, immediately below the A horizon (Figure 6b). The melanic epipedon is a thick, dark-colored (commonly black) horizon at or near the soil surface. It has high concentrations of organic carbon, generally associated with short-range-order minerals or aluminum-humus complexes (Soil Survey Staff, 2014). In the soils studied, the Aquents and Aquepts usually had a histic or humic A horizon.

The gleying processes that lead to the formation of the gley horizon in hydromorphic environments may occur in varying intensities and may lead to an almost complete decolorization of the horizon, forming a uniformly gray matrix (light or dark), or form a dominantly gray matrix with the presence of mottling in red, yellow, and yellowish red. When hydromorphism is permanent and the environment is strongly anaerobic, the tendency is for reduction processes to lead to more intense removal of solubilized Fe, generating a predominantly gray matrix (Figure 6c). When the water table fluctuates during certain times of the year, part of the Fe compounds not yet removed can undergo re-oxidation, forming Fe oxides such as hematite or goethite that form mottling and partially add color to the gray matrix (Figure 6d). If their presence is common or abundant, however, this feature may hinder identification of the environment as hydromorphic.

Considering their location in small flat depressions, surrounded by areas of steep slope, the subsurface water flows in the inner area are faster in areas with an open system than in the ones with a closed system, keeping the level of the water table generally slightly below or at the surface throughout most of the year, forming a surface water layer only during episodes of increased rainfall. Thus, vegetation, especially in transition to the outside area, is usually composed of hygrophilous and terrestrial plants, with a frequent invasion of the latter during episodes of more prolonged drought. This is one situation that usually hinders identification of the boundaries of wetlands by inspection agents linked to environmental agencies.

In characterizing the vegetation of highland wetlands in Santa Catarina, Magalhães et al. (2013) reported that families with the highest richness of species were Poaceae (26 spp.), Asteraceae (23), Cyperaceae (23), Iridaceae (six), Lamiaceae (five), Juncaceae (four), Rubiaceae (four), and Verbenaceae (four). Also in highland wetlands of Santa Catarina, Almeida et al. (2007) reported that families with the highest richness of species were Poaceae (31 spp.), Cyperaceae (24), and Asteraceae (27).

Therefore, the following general criteria for soil properties should be taken into account, either alone or in combination, in identifying the hydromorphic environment: a) a permanent water table within a thickness of 0.50 m from the surface; b) a histic horizon at the surface, regardless of soil class; c) identification of the soil as Histosols (at least 0.40 m of organic layers accumulated under anaerobic conditions); d) identification of the soil as Aquents and Aquepts (i.e., a gley horizon within 0.50 m from the surface occurring immediately below the A horizon); and e) in cases of doubt regarding identification of

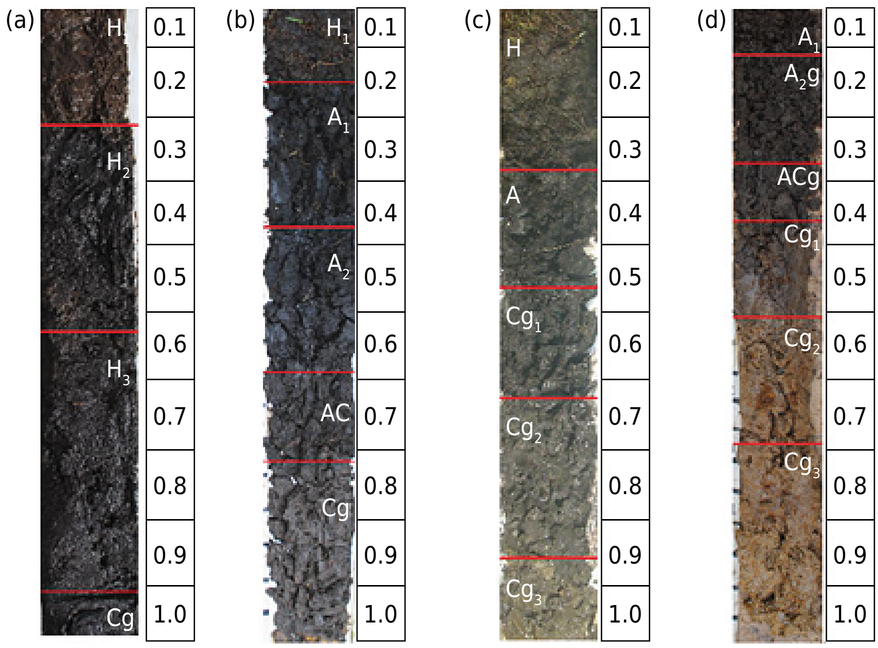

Figure 6. Digital photography of the soil monoliths classified as (a) Haplohemists - *Organossolo Háplico Hêmico típico*; (b) Endoaquents - *Gleissolo Melânico Alítico organossólico*; (c) Endoaquents - *Gleissolo Melânico Alítico organossólico*; and (d) Endoaquents - *Gleissolo Melânico Alítico típico*.

a gley horizon, due to a great deal of mottling disseminated in the matrix, the decisive criterion for identifying the environment as hydromorphic should be the predominance of gray in the soil matrix.

Based on these criteria, it is believed that environmental agencies may receive assistance in more reliably identifying the limits of highland wetlands, thus being able to more clearly demarcate the area of protection in their surrounding areas. The aim of this study was not to propose environment protection limits, because this is still a controversial topic, with different approaches among professionals linked to environmental issues.

Although wetlands constitute important environments for conservation and sustainability of terrestrial and aquatic ecosystems, their preservation is not ensured by defining a border of only 10 m in their surrounding areas, as is stipulated in Art. 114, item II of Law no. 14,675/April 13, 2009 of the Environmental Code of Santa Catarina, because for extremely small wetlands, this may represent a area larger than currently occupied. However, in larger wetlands, the defined area of protection in the surrounding areas seems insufficient to ensure their preservation. Agricultural expansion in areas close to wetlands may have negative impacts on those wetlands, mainly due to the high load of chemical inputs used in modern agricultural systems. Thus, based on field observations made during this study, the legislation should be revised to increase the area of protection in surrounding areas.

It should be noted, however, that soil attributes are only one of the parameters that must be taken into account in delimitation of wetlands, and other marsh areas. Vegetation attributes of these environments, combined with the soil attributes, may be more appropriate tools for the purpose of identification and protection of these environments, as shown in the study of Magalhães (2013).

CONCLUSIONS

In highland wetlands of the Southern Plateau of Santa Catarina, there are Udepts in the outer areas, with a predominance of non-hydromorphic conditions, and Aquents, Aquepts, and Histosols in the transition and inner areas, with a predominance of hydromorphism. The occurrence of these soils depends on the occurrence of better drainage or the occurrence of groundwater at the soil surface or slightly below it.

For identification of a hydromorphic environment, the following general criteria, alone or in combination, must be considered: a) a permanent water table within a thickness of 0.50 m from the surface; b) a histic horizon at the surface, regardless of soil class; c) identification of the soil as Histosols (at least 0.40 m of organic layers accumulated under anaerobic conditions); d) identification of the soil as Aquents and Aquepts; and e) in cases of doubt regarding identification of a gley horizon, due to a great deal of mottling disseminated in the matrix, the decisive criterion for identifying the environment as hydromorphic should be the predominance of gray in the soil matrix.

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