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Article

Aquatic Oligochaeta (Annelida: Clitellata) in wetlands and irrigated rice fields in the state of Rio Grande do Sul (Southern Brazil)

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ABSTRACT. The knowledge of the diversity and distribution of aquatic Oligochaeta (Annelida: Clitellata) species is scarce in southern Brazil. This study presents a list of the species of aquatic Oligochaeta in wetlands and irrigated rice fields in the state of Rio Grande do Sul. Collections were carried out in two large wetland remnants and seven irrigated rice fields distributed in three regions across the state. We recorded eight species from two families (Alluroididae and Naididae). We expanded the distribution ranges of two species (*Brinkhurstia americana* and *Stylaria lacustris*), which represent new records for the state of Rio Grande do Sul and registered their occurrence in non-documented environments. In specific, the present study increases to 24 species the aquatic Oligochaeta diversity for the state of Rio Grande do Sul. In addition, the spatial distribution of the species recorded suggests that rice fields support a subset of the wetland fauna of aquatic Oligochaeta. The results provide important information on the ecology and distribution of limnic Oligochaeta and are useful to inform on the diversity of this fauna in agroecosystems.

KEYWORDS. Agroecosystems, freshwater biodiversity, oligochaetes, paddies, wetlands.

RESUMO. Oligochaeta aquáticos (Annelida: Clitellata) em áreas úmidas e arrozais irrigados no estado do Rio Grande do Sul (Sul do Brasil). O conhecimento sobre a diversidade e distribuição das espécies aquáticas de Oligochaeta (Annelida: Clitellata) é escasso no sul do Brasil. Este estudo apresenta uma lista das espécies de Oligochaeta aquáticas em áreas úmidas e arrozais irrigados no estado do Rio Grande do Sul. As coletas foram realizadas em dois grandes remanescentes de banhados e sete arrozais irrigados distribuídos em três regiões do estado. Nós registramos oito espécies de duas famílias (Alluroididae e Naididae). Nós expandimos as áreas de distribuição de duas espécies (*Brinkhurstia americana* e *Stylaria lacustris*), que representam novos registros para o estado do Rio Grande do Sul e documentamos sua ocorrência em diferentes ambientes. Especificamente, o presente estudo aumenta para 24 a diversidade de espécies de Oligochaeta aquáticas para o estado do Rio Grande do Sul. Além disso, a distribuição espacial das espécies registradas sugere que os arrozais sustentam um subconjunto da fauna de Oligochaeta aquática. Os resultados fornecem informações importantes sobre a ecologia e distribuição de Oligochaeta límnicos e são úteis para informar sobre a diversidade desta fauna em agroecossistemas.

PALAVRAS-CHAVE. Agroecossistemas, biodiversidade aquática, lavouras de arroz, oligoquetos, banhados.

Agricultural expansion promoted the conversion and degradation of freshwater ecosystems and represents a special threat to aquatic biodiversity (Dudgeon, 2019). For instance, conversion to irrigated rice fields is one the major drivers of the loss of the world's wetland ecosystems, which is estimated to have reached approximately 70% of their original extent in the twentieth century (Davidson, 2014). However, the diversity of many wetland-dependent organisms remains undocumented in many regions of the world. Taking into account that wetlands are biodiversity hotspots and that they provide a range of ecosystem services (Davidson *et al.*, 2019), the lack of knowledge on wetland species diversity hampers the adoption of adequate biodiversity conservation policies in these ecosystems. Nevertheless, given that agricultural land use has increasingly replaced natural ecosystems worldwide (Winkler *et al.*, 2021), one of the main targets of Conservation Biology is therefore the study of biodiversity in agroecosystems (Altieri, 1999). On this matter, rice fields have received great attention, since earlier studies found that they can harbor an expressive fraction of the biodiversity of wetland species, leading some authors to consider them alternative sites for the wetland biota (Lawler, 2001; Bambaradeniya *et al.*, 2004). This is because irrigated rice fields can emulate many of the environmental conditions of a typical wetland, such as low water depth, temporary hydroperiod, presence of vegetation, etc. (Lawler, 2001).

Macroinvertebrates are fundamental to many ecological processes in freshwater ecosystems and are important components of the fauna of irrigated rice fields

(Roger, 1996; Bambaradeniya *et al.*, 2004). In southern Brazil (state of Rio Grande do Sul), the largest rice-producing region in the country, rice is an annual culture taking place between early spring (sowing) and late summer (harvest); almost the entirety of the rice production in Rio Grande do Sul is under the irrigated system (Ana & Conab, 2020). Some authors found that irrigated rice fields support a wide range of macroinvertebrate taxa (Maltchik *et al.*, 2010, 2011, 2017; Stenert *et al.*, 2012; Sousa *et al.*, 2021). However, authors that simultaneously compared macroinvertebrate communities in paddies and wetlands showed that certain aspects of their structures diverge (Pires *et al.*, 2016). In this context, species inventories are of great importance to support the formulation of management plans because they provide information on the diversity and distribution of various taxa (Christoffersen, 2010; Souza *et al.*, 2021). In particular, inventory data from natural ecosystems act as a reference for decision making on biodiversity management and conservation policies in sites under anthropogenic impact such as agroecosystems. This is especially important taking into account that approximately 90% of the original wetlands in southern Brazil were lost, mostly due to drainage for rice plantations (Stenert & Maltchik, 2007).

Aquatic Oligochaeta are one of the main components of the macroinvertebrate fauna in wetlands (Batzer & Boix, 2016). Oligochaeta are important consumers (*e.g.*, algal feeders), and thus play an important role in nutrient cycling and energy flow in these ecosystems; in addition, some aquatic Oligochaeta species are indicators of polluted waters and can be important tools for ecosystem health assessment (Govedich *et al.*, 2010). Christoffersen (2007) compiled a list of 171 nominal species of aquatic Oligochaeta (except Enchytraeidae) for South America, 86 species of which occur in Brazil. However, most available inventories of Oligochaeta in Brazil focus land-dwelling species. In light of the Brazilian territory, the aquatic oligochaete fauna catalogued so far, *i.e.*, the states of São Paulo, Minas Gerais and Mato Grosso do Sul (Rodrigues *et al.*, 2013; Takeda *et al.*, 2017; Girolli *et al.*, 2021) reflects a small fraction of the diversity in the country. Therefore, more inventories are necessary to improve the knowledge of this fauna in the country (Christoffersen, 2010; Rodrigues & Alves, 2018).

Four species of aquatic Oligochaeta had been originally recorded in the state of Rio Grande do Sul (Christoffersen, 2007). Subsequent studies reported 16 species of Oligochaeta in irrigated rice fields (Maltchik *et al.*, 2011; Stenert *et al.*, 2012), and four species in large wetland remnants in the state (Pires *et al.*, 2016). However, the available data for rice fields stem from small-range studies, while the knowledge of the diversity of Oligochaeta species in the largest rice-growing areas of Rio Grande do Sul remains unknown. This study presents a list of the species of aquatic Oligochaeta occurring in wetlands and irrigated rice fields in three rice-growing areas in the state of Rio Grande do Sul (southern Brazil). We aimed at updating the knowledge about the distribution of this group in the state and also at providing considerations on the diversity in such agroecosystems.

MATERIAL AND METHODS

Study area. Collections took place in three study regions covering important rice-growing areas and large wetland remnants across the state of Rio Grande do Sul (Fig. 1). In the western region of Rio Grande do Sul, the study region covered the São Donato Biological Reserve (SD; area: 4,300 ha), which consists the largest extant wetland in the region (Carvalho & Ozório, 2007). This region covers the largest rice-growing areas of Rio Grande do Sul, with over 100,000 ha of crop area and production of ~1 mi tons/year (IRGA, 2012). In the central region of Rio Grande do Sul, the study region covered a large wetland represented by a river confluence zone (Foz do Vacacaí wetlands (FV); area of ~4,600 ha; Carvalho & Ozório, 2007). The crop areas in the region cover ~35,000 ha, with production of ~250,000 tons/year (IRGA, 2012). In the southwestern region of Rio Grande do Sul (SG region), the crop areas cover ~30,000 ha, with production of ~220,000 tons/year (IRGA, 2012). Across the study regions, the climate is Cfa of Köppen (humid subtropical with hot summer), with mean annual temperature of ~18 °C and annual rainfall ranging from 1,600 and 2,200 mm (Alvares *et al.*, 2013).

Site characterization and sampling period. Collections were carried out in nine study sites: one wetland and two rice fields were sampled in the FV study region; three rice fields in the SG study region; one wetland and two rice fields in the SD study region (Fig. 1; Tab. I). Rice fields had a water depth of ~10 cm, variable cultivation systems and irrigation sources. Wetlands were characterized by macrophyte stands dominated by different families. For environmental characterization purposes, we took measurements of the following water physicochemical variables: dissolved oxygen (DO), electrical conductivity (EC), water turbidity (NTU) and pH (Tab. I). Physicochemical data were taken with a multiparameter probe (HORIBA® U-50). Collections took place in the summer of 2012 (January; austral season), during the vegetative growth phase of the rice cultivation cycle.

Sampling methods and laboratory procedures. In each study region, collections occurred simultaneously in each environment. In each study site, three samples were taken with a D-net (0.3-m diameter; 0.5-mm mesh size). Each sample consisted of three 1-m sweeps that were at least 1 m from one another. In the wetlands, samples were taken in emergent macrophyte stands, while in rice fields, samples were taken in the secondary irrigation channels (*i.e.*, rice-growing area). The collected material was preserved *in situ* in 70% ethanol. Specimens were identified in the laboratory to species level whenever possible, according to specialized keys (Brinkhurst & Jamieson, 1971; Righi, 1984; Brinkhurst & Marchese, 1989). Specimens were deposited in the Zoological Collection of the Biology Laboratory of the University of Araraquara (UNIARA; Araraquara, SP, Brazil), under registration number 00265.

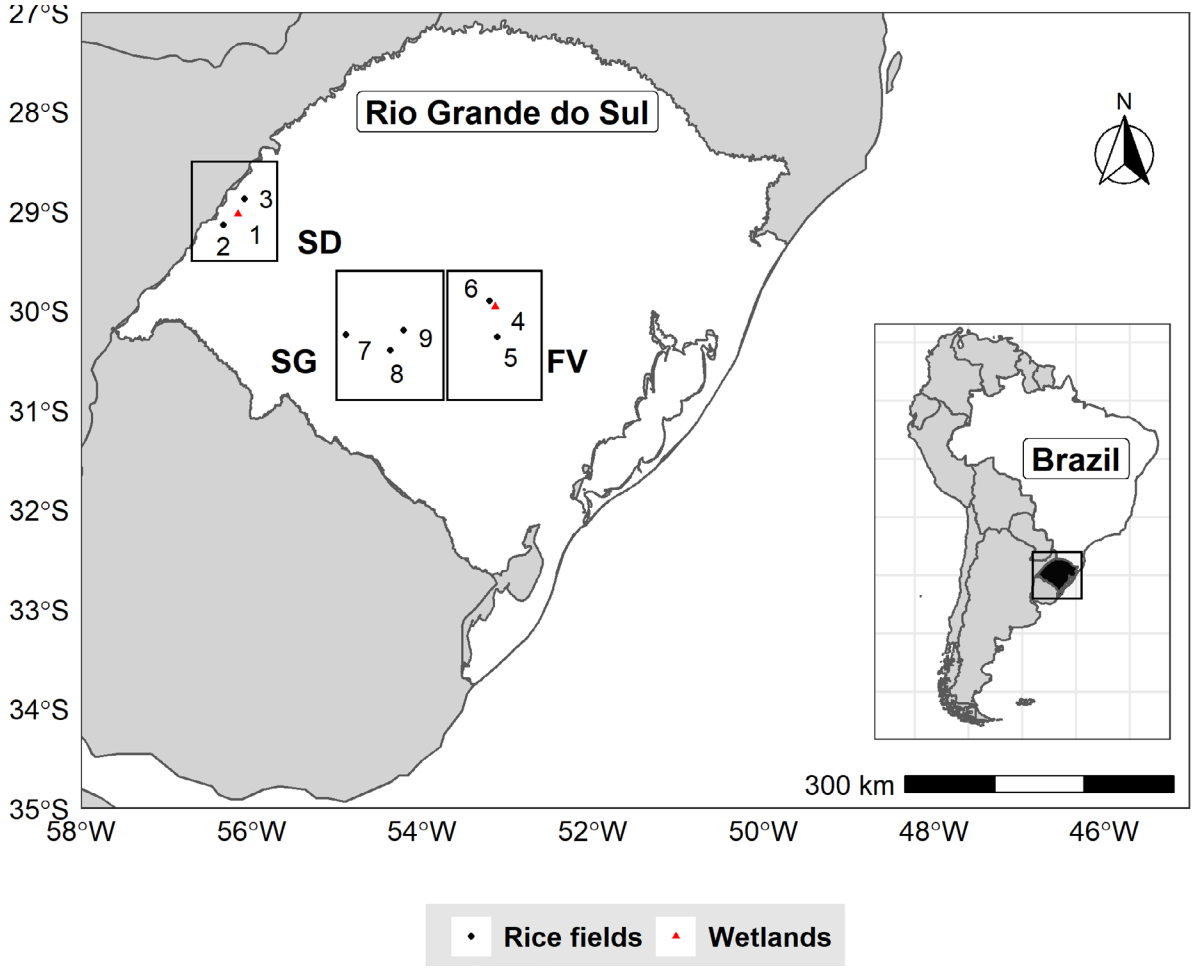


Fig. 1. Location of the study regions and study sites in Rio Grande do Sul state, Brazil. Abbreviations of the study regions: FV = 'Foz do Vacacaí' study region; SD = 'São Donato' study region; SG = 'southwestern' study region. Numbers indicate the study sites and follow Table I.

Tab. I. Location and environmental description of the study sites [DO, dissolved oxygen (mg/L); EC, electrical conductivity (µS/cm); NTU, water turbidity; IS, irrigation source; CS, cultivation system)]. Site code numbers follow the codes in Fig. 1.

Region	Site code	Environment	Longitude	Latitude	pH	EC	DO	NTU	IS	CS
SD	1	Wetland	53°05'56"	29°56'22"	6.11	331	0.01	8.15		
SD	2	Rice field	56°19'37"	29°08'09"	7.18	55	7.90	3.10	Reservoir	Conventional
SD	3	Rice field	56°05'05"	28°52'23"	7.92	87	10.29	7.70	River	Conventional
FV	4	Wetland	56°11'0.3"	29°00'29"	6.45	124	0.01	8.67		
FV	5	Rice field	54°22'13"	30°23'53"	7.23	71	6.98	6.60	Reservoir	Conventional
FV	6	Rice field	53°12'23"	29°54'08"	6.16	10	8.33	107.00	Reservoir	Pre-germinated
SG	7	Rice field	54°53'28"	30°14'25"	6.56	130	6.45	26.8	Reservoir	Conventional
SG	8	Rice field	53°07'03"	30°15'51"	5.92	175	7.90	10.7	Reservoir	Conventional
SG	9	Rice field	54°13'11"	30°11'45"	6.35	62	3.48	7.40	River	Conventional

Compilation. Finally, we compiled the occurrence records of species of aquatic Oligochaeta in Rio Grande do Sul. For this purpose, we conducted an online literature search for primary records (*e.g.*, published inventories of Oligochaeta species, specialist homepages, etc.) and secondary records of species of Oligochaeta (*e.g.*, online databases and public online repositories).

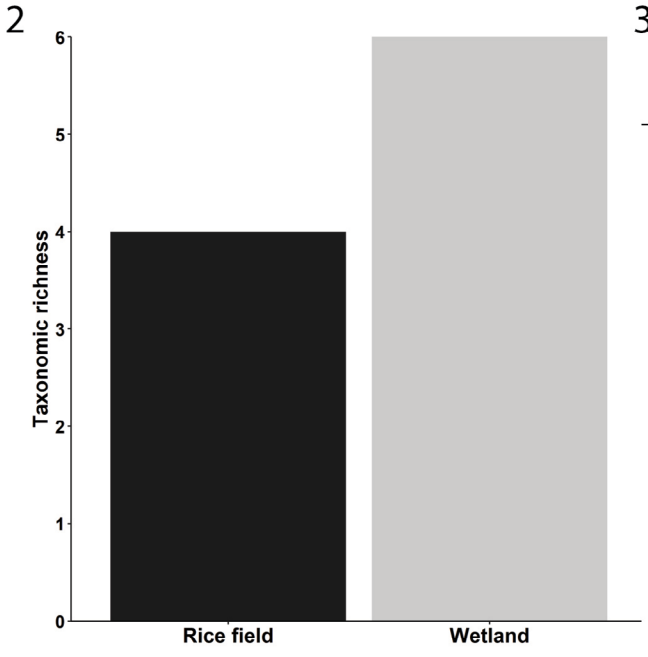
RESULTS

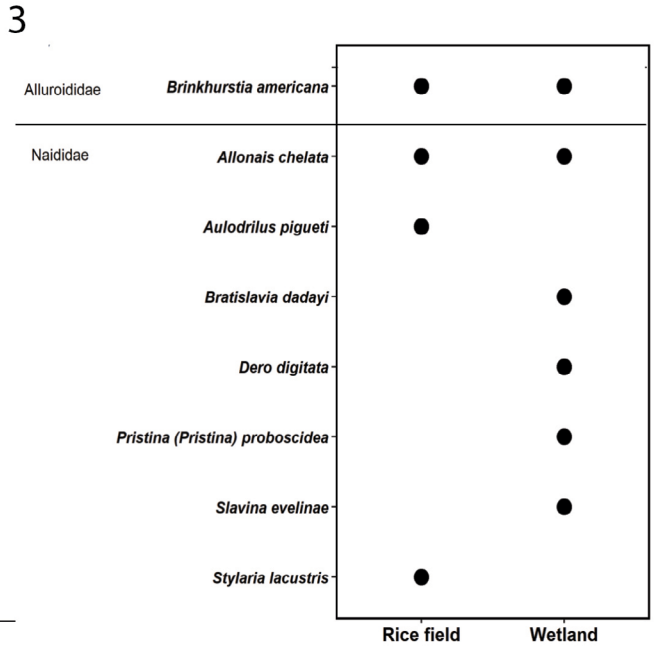
In the study sites, we recorded 70 specimens from eight species of aquatic Oligochaeta and two families (Alluroididae and Naididae) (Tab. II). Alluroididae was represented by a single species [*Brinkhurstia americana* (Brinkhurst, 1964)], while Naididae was the richest family, with seven species from three subfamilies (Naidinae, Pristininae and Tubificinae). *Brinkhurstia americana* was the most frequent species in the study area (recorded in four out of nine study sites), followed by *Allonais chelata* (Marcus, 1944) (two out of nine study sites); all the other species were recorded in a single study site (Tab. II).

Four species were recorded in the wetland of the SD region, and two species in the wetland of the FV region, while rice fields harbored one species each (Tab. II). Overall, four species were recorded in rice fields of the SG region, while six species were recorded in wetlands (Fig. 2). *Brinkhurstia americana* and *A. chelata* occurred in both environments; two species were exclusive of rice fields (*Aulodrilus pigueti* Kowalewski, 1914 and *Stylaria lacustris* Linnaeus, 1758), while four species were exclusive of wetlands (*Bratislavia dadayi* Michaelsen, 1905, *Dero digitata* Müller, 1774, *Slavina evelinae* Marcus, 1942 and *Pristina proboscidea* Beddard, 1896) (Fig. 3).

Tab. II. Species composition and number of individuals (N) of aquatic Oligochaeta recorded in wetlands and irrigated rice fields in the state of Rio Grande do Sul, Brazil. (-) = No specimen detected.

Region (according Fig. 1)				SD			FV				SG	
Environment				Wetland	Rice field	Rice field	Wetland	Rice field	Rice field	Rice field	Rice field	Rice field
Site code				1	2	3	4	5	6	7	8	9
Order	Family	Subfamily	Species									
Haplotaxida	Alluroididae		*Brinkhurstia americana* (Brinkhurst, 1964)	19	2	2	–	9	–	2	–	–
	Naididae	Naidinae	*Allonais chelata* (Marcus, 1944)	1	–	–	–	–	2	–	–	–
			Bratislavia dadayi (Michaelsen, 1905)	2	–	–	–	–	–	–	–	–
			Dero digitata (Müller, 1774)	–	–	–	2	–	–	–	–	–
			Slavina evelinae (Marcus, 1942)	4	–	–	–	–	–	–	–	–
			Stylaria lacustris (Linnaeus, 1758)	–	–	–	–	–	–	–	–	13
		Pristininae	*Pristina proboscidea* Beddard, 1896	–	–	–	1	–	–	–	–	–
		Tubificinae	*Aulodrilus pigueti* Kowalewski, 1914	–	–	–	–	–	–	–	11	–





Figs 2, 3. Aquatic Oligochaeta in wetlands and irrigated rice fields in the state of Rio Grande do Sul, Brazil: 2, taxonomic richness; 3, species composition.

The compilation of occurrence records showed that 24 species (from three families) of aquatic Oligochaeta occur in the state of Rio Grande do Sul, including the species recorded in this study. Furthermore, a comparison of the species composition between environments showed that 19 species occur in irrigated rice fields, while five species occur in wetlands. Five species were recorded in other freshwater ecosystems (*e.g.*, lakes, lagoons) (Tab. III).

Tab. III. Species of aquatic Oligochaeta recorded in freshwater ecosystems in the state of Rio Grande do Sul, Brazil. Codes for the 'Reference source' column: 1: Christoffersen, 2007; 2: Maltchik *et al.*, 2011; 3: Stenert *et al.*, 2012; 4: Pires *et al.*, 2016; 5: GBIF, 2019. Grey-colored lines indicate the new records of Oligochaeta for the state.

		Reference source						Habitat		
Family	Species	1	2	3	4	5	This study	Rice fields	Wetlands	Other
Alluroididae	*Brinkhurstia americana* (Brinkhurst, 1964)						X	X	X	
Naididae	*Allonais chelata* (Marcus, 1944)		X	X	X			X		
	Aulodrilus pigueti Kowalewski, 1914		X				X	X		
	Aulodrilus limnobius Bretscher, 1899			X				X		
	Aulophorus furcatus (Müller, 1774)		X					X		
	Aulophorus vagus Leidy, 1880			X				X		
	Bratislavia dadayi (Michaelsen, 1905)				X		X		X	
	Branchiura sowerbyi Beddard, 1892					X				
	Dero botrytis Marcus, 1943	X						X		X
	Dero digitata (Müller, 1774)		X	X	X			X	X	
	Dero evelinae Marcus, 1943	X	X	X				X		X
	Dero multibranchiata Stieren, 1892			X				X		
	Dero nivea Aiyer 1930		X	X				X		
	Dero obtusa d'Udekem, 1855		X	X				X		
	Dero sawayai Marcus, 1943		X	X				X		
	Limnodrilus hoffmeisteri Claparède, 1862	X								X
	Pristina americana Černosvitov, 1937		X	X				X		
	Pristina leidyi Smith, 1896		X	X				X		
	Pristina proboscidea Beddard, 1869				X				X	
	Slavina sawayai Marcus, 1944			X				X		
	Slavina evelinae (Marcus, 1942)		X	X	X			X	X	
	Amerigodrilus kleerekoperi (Marcus, 1944)	X								X
	Stylaria lacustris (Linnaeus, 1758)						X	X		
Opistocystidae	*Opistocysta funiculus* Cordero, 1948		X	X				X		

DISCUSSION

To date, little is known about the diversity and distribution of aquatic oligochaetes in South America, especially in Brazil (Rodrigues & Alves, 2018). The few regional inventories of oligochaetes in this country (*e.g.*, states of Amazonas, Rondônia, Mato Grosso, São Paulo, Paraná and Rio Grande do Sul) mostly refer to land species (Christoffersen, 2010). Although the compilation of Christoffersen (2007) assigned 86 species of aquatic Oligochaeta to Brazil, there have been no published inventories of limnic species, for many states, including Rio Grande do Sul (southern Brazil). According to our compilation of previous studies of aquatic Oligochaeta in Rio Grande do Sul, 22 species of aquatic oligochaetes occurred across the state (Tab. III). Our results thus updated the information on the diversity and distribution of known aquatic Oligochaeta species in the state, as they increase to 24 the number of species occurring in Rio Grande do Sul. In specific, *B. americana* and *S. lacustris* represent new records for this state.

Our study indicates that Rio Grande Sul harbors approximately one fourth (27%) of the known aquatic Oligochaeta species in Brazil. In comparison with recent inventories in other states of Brazil, the diversity of Oligochaeta recorded so far in Rio Grande do Sul is lower than other states in subtropical regions of the country. In specific, 77 species are recorded for the state of São Paulo (Gorni *et al.*, 2015; Girolli *et al.*, 2019; 2021), and 41 species for the state of Mato Grosso do Sul (Takeda *et al.*, 2017). In contrast, the observed diversity of Oligochaeta in Rio Grande do Sul is higher than the states of Minas Gerais (Rodrigues *et al.*, 2013; 19 species), Mato Grosso (Gorni *et al.*, 2018; 22 species) and Rondônia (Gomes *et al.*, 2017;

nine species). Such contrasting pattern is a contingency associated with the fact that the latter inventories focused a single ecosystem type (lotic), while the records in Rio Grande do Sul cover different habitats (Tab. III). Thus, the diversity of Oligochaeta likely represents a subset of the known diversity in those states.

The earlier species inventories of Oligochaeta indicated the occurrence of 17 species in rice fields in Rio Grande do Sul (Maltchik *et al.*, 2011; Stenert *et al.*, 2012). In this study, we increased the number of species occurring in these agroecosystems to 19, since *B. americana* and *S. lacustris* had not been reported in rice fields. *Brinkhurstia americana* is common in other states in Brazil (Christoffersen, 2007) and was recorded in a wide array of freshwater ecosystems (from lakes and large dams to streams and high-order rivers) (Pamplin *et al.*, 2005; Alves *et al.*, 2006; Gorni *et al.*, 2015; Sanches *et al.*, 2016). *Stylaria lacustris* is reported as an opportunistic species with broad ranges (Timm & Erséus, 2021). This suggests a generalist habit of those species in relation to habitat type and possibly explain their establishment in a harsh environment such as rice fields.

Interestingly, a higher number of Oligochaeta species is recorded in rice fields than in wetlands in Rio Grande do Sul. This is likely the result of a combination between methodological contingencies of earlier studies and the lack of studies in other ecosystems. With respect to the former, the previous data for rice fields refer to studies that solely focused rice fields (Maltchik *et al.*, 2011; Stenert *et al.*, 2012); in addition, the authors in these studies covered the full cultivation cycle of the rice crop and sampled different microenvironments (*i.e.*, primary and secondary channels). It is known that macroinvertebrate composition temporally varies over the growth phase of the rice crop and spatially across the plantation (Roger, 1996). This artifact likely contributed to increase the diversity of the Oligochaeta fauna in this agroecosystem. Conversely, species-level inventories of macroinvertebrates are rare in Rio Grande do Sul (Talhaferro *et al.*, 2021). The study of Pires *et al.* (2016) recorded four species of Oligochaeta; here, we elevate to five species the known diversity of the group in wetlands in the state, as *B. americana* was not reported in wetlands so far.

Finally, it is important to notice in this study that the majority of the species found in wetlands were not found in rice fields. In addition, 50% of the species recorded in rice fields occurred in wetlands (Fig. 3) and the species so far recorded in wetlands in the state are not yet recorded in rice fields (Tab. III). These results reinforce the hypothesis that rice fields represent an alternative habitat for the wetland biota (Lawler, 2001; Maltchik *et al.*, 2017); however, only part of the species of Oligochaeta in wetlands were capable of occupying rice fields, namely habitat generalist species such as *B. americana*, *S. lacustris* and *A. chelata*. Earlier studies of the spatial distribution of Oligochaeta species have shown that these invertebrates respond to variation in the local environmental conditions of a given site, *e.g.*, water quality and habitat structure (Alves *et al.*, 2006). Our study thus suggests that rice fields are suitable habitats only for a subset of the wetland fauna of Oligochaeta, in accordance with findings of previous studies with macroinvertebrates (Pires *et al.*, 2016; Maltchik *et al.*, 2017).

Our study provided the first inventory of aquatic Oligochaeta species in the state of Rio Grande do Sul. Our results include two new species records for the state and show that 24 species occur in Rio Grande do Sul, suggesting that approximately one fourth (27%) of the known aquatic Oligochaeta species in Brazil is found in the state. This study also contributed to increase the knowledge of the diversity and distribution of aquatic Oligochaeta in wetlands and irrigated rice fields. In specific, we documented the occurrence of additional species in each environment and indicated that rice fields tend to harbor generalist species. In this context, species inventories in natural and man-made ecosystems are of great importance to support the formulation of policies on biodiversity management in threatened ecosystems, such as wetlands and conservation policies in sites under anthropogenic impact such as rice crops. This is particularly important taking into account that approximately 90% of the wetlands in Rio Grande do Sul were mostly lost to rice plantations and that agricultural expansion is concentrated in South American countries.

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