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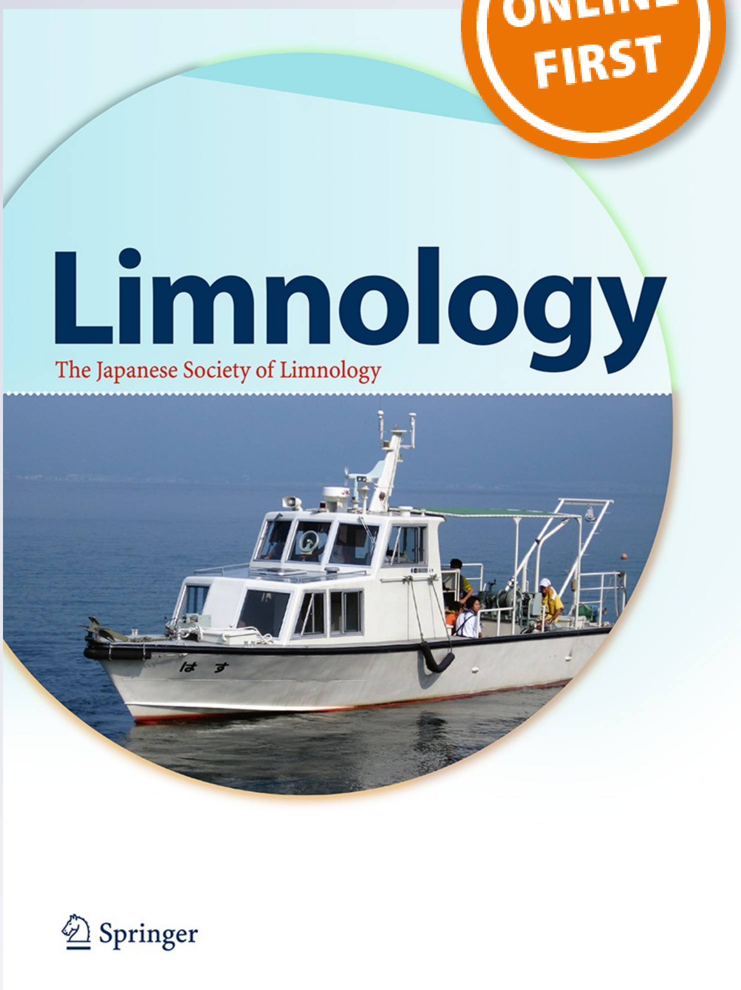

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RESEARCH PAPER

Aquatic microinvertebrate abundance and species diversity in peat bogs of Tierra del Fuego (Argentina)

Patricia E. García[1] · R. Daniel García[1] · M. Cristina Marinone[2] · Valeria Casa[3,4] · Gabriela González Garraza[3,4] · Gabriela Mataloni[3,4]

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Abstract Peat bogs are regarded as extreme environments due to their low pH and low nutrient concentration, and thus hold a unique biota adapted to these particular conditions. The island of Tierra del Fuego encompasses the southernmost extensive peat bog area in the world, and is therefore particularly interesting from a biogeographical viewpoint. Within the same peat bog, different environment types can be identified: clear ponds, vegetated ponds and *Sphagnum* patches. In this study we compare the abundance, richness and species diversity of microinvertebrates (Copepoda, Cladocera and Rotifera) in these three types of environments from two peat bogs (Andorra and Rancho Hambre). Out of the 29 taxa recorded, 19 were common to both peat bogs, including four cladocerans endemic to Southern Patagonia and three rotifers endemic to Fuegian peat bogs. The rotifers were the dominant group in all environment types from Rancho Hambre, while in Andorra the *Sphagnum* moss was dominated by copepods, particularly harpacticoids. The results revealed that the environment type rather than peat bog was the key factor at explaining differences in species richness and diversity among microinvertebrate communities. This study highlights the importance of *Sphagnum* moss as a low diversity extreme environment which supports highly endemic species.

Keywords Microinvertebrates · Peat bogs · Diversity · Tierra del Fuego

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Introduction

Peatlands are globally relevant environments for both researchers and environmental policy makers, since they represent 3 % of total merged land surface on Earth and have high holding capacity of soil carbon and freshwater, acting as carbon and water reservoirs (Joosten and Clarke 2002). Their peculiar characteristics arise from the accumulation of slowly decomposing organic matter, mostly derived from *Sphagnum* mosses, under low temperatures and abundant evenly distributed precipitation (Roig and Roig 2004; González Garraza et al. 2012). The accumulation of this decomposing organic matter (peat) decreases the pH, conductivity and nutrient concentrations of water retained among moss shoots (Clymo 1964; Mataloni 1999).

Within peatlands, the areas in which peat is actively formed are called mires or bogs. Tierra del Fuego Island encompasses the southernmost area of extensive peat bog development (Lindsay et al. 1988). As much as 95 % of the

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Argentinean peatlands are hosted by Tierra del Fuego (Rabassa et al. 1996). A typical ombrotrophic peat bog landscape consists of a matrix of terrestrial vegetation dominated by *Sphagnum* mosses encompassing patches of shallow, acid and humic water bodies (Mataloni et al. 2015). These ponds can show distinct physico-chemical features, even when located only a few meters apart (Mataloni and Tell 1996; González Garraza et al. 2012). According to Mataloni (1999) such distinct environmental characterizations accounted for differences among the phytoplankton compositions of ponds rather than the geographical distance between them.

Among aquatic microinvertebrates, Rotifera, Cladocera and Copepoda, play a key role in the functioning of food webs in freshwater systems from Patagonia (Modenutti et al. 1998, 2003; Quiroga et al. 2013). Microinvertebrate communities have been intensely surveyed in several peat bogs around the world (Sharma and Bhattarai 2005; Klimaszyk and Kuczyńska-Kippen 2006; Kuczyńska-Kippen 2008, 2009). In peat bogs of Tierra del Fuego, this community has been studied by Mariazzi et al. (1987) who found 3 copepod taxa and 3 cladoceran taxa in Laguna Luz, a shallow lake located in the extensive peat bog of Mitre Peninsula. De los Ríos et al. (2011) found cladocerans (*Ceriodaphnia dubia*, *Neobosmina chilensis*, *Chydorus sphaericus*) and cyclopoid copepodites in *Sphagnum* mosses from the Cape Horn Biosphere Reserve (54° S, Chile). Burroni et al. (2011) found a much higher biodiversity of crustaceans in seven peatland ponds of the Argentinean province of Tierra del Fuego, with 9 cladoceran and 2 copepod taxa. In turn, Quiroga et al. (2013) sampled all plankton communities in five ponds from Rancho Hambre peat bog over two consecutive open water periods (October–April). These authors found total abundances as well as dominant groups to be strongly influenced by pool size. Also, abundance and composition of ad hoc defined taxonomic-trophic groups (micro-filter feeding rotifers, micro-filter feeding nauplii, filter feeding cladocerans, omnivorous copepods, and predators) varied over time, shifting the control of heterotrophic flagellates abundance from bottom-up regulation in spring to top-down in late summer (Quiroga et al. 2013). As this microinvertebrate characterization was mainly functional, there is still little detailed information about the taxonomic composition, diversity and habitat influence at different scales (from pond or *Sphagnum* patch to peat bog) on these features.

The aim of this study was to analyze the microinvertebrate composition and abundance in three different environment types (clear water, vegetated water and *Sphagnum* moss) from two pristine peat bogs located in Tierra del Fuego, by addressing the following questions: what is the microinvertebrate species composition, richness and diversity in Andorra and Rancho Hambre peat bogs? Which (environment type or bog identity) are the main factors driving local microinvertebrate structure patterns? Do microinvertebrate communities from disparate environments differ and how? And finally, how different are both peat bogs in this respect?

Materials and methods

Study site

The peat bogs are located in the south of Tierra del Fuego Province (Argentina). The climate of this island is described as cold-temperate in the south and temperate-oceanic in the north, with an annual mean temperature of 5 °C and rainfall decreasing from the SW (600 mm year^{-1}) to the NE (less than 300 mm year^{-1}) (Rabassa et al. 2006). Local weather conditions in the studied area recorded an annual average temperature of 3.4 °C (from −0.7 to 8.5 °C). Monthly average precipitation for the area is 60 mm, with higher values in late summer (González Garraza et al. 2012). At this time of the year, zooplankter reach their adult stage, as described in Quiroga et al. (2013). Andorra peat bog is located about 20 km away from Ushuaia city in the Andorra Valley (54°44′ S; 68°20′ W); whereas Rancho Hambre peat bog is located nearly 50 km from Ushuaia, in Tierra Mayor Valley (55°44′ S; 67°49′ W) (Fig. 1a; Table 1). Both peat bogs are ombrotrophic (only fed by precipitation) with low nutrient concentration (Roig and Roig 2004). These peat bogs can be characterized by a low pH, similar DOC, NH_4–N, TP and PO_4P concentrations (Table 1). Andorra peat bog had a higher mean conductivity (59.03 µS cm^{-1}) than Rancho Hambre (45.93 µS cm^{-1}), whereas TN concentration was higher in Andorra (4523.23 µg l^{-1}) than in Rancho Hambre (2615.38 µg l^{-1}) (Table 1).

The bottom of the studied ponds was either covered with a continuous moss layer including *Sphagnum magellanicum*, *S.* cf. *fimbriatum* and *Drepanocladus uncinatus*, which in some cases reached the surface (vegetated ponds), or they were denuded of vegetation and covered with a layer of fine debris (clear ponds). A total of 13 sites were sampled in each peat bog during February 2014 (Table 1), including the following environment types: (1) 5 clear ponds (Fig. 1b), (2) 4 vegetated ponds (Fig. 1c), and (3) 4 *Sphagnum* moss sites in which interstitial water was sampled (Fig. 1d). Most ponds studied were shallow (less than 1.5 m deep), and small (3.6–193 m^2 in Andorra, 48–16,121 m^2 in Rancho Hambre). In both peat bogs, the *Sphagnum* moss sites showed the highest conductivity and DOC concentrations as compared with the clear and vegetated ponds (Table 1). Morphometric features (pond area), were measured using Google Earth Pro software.

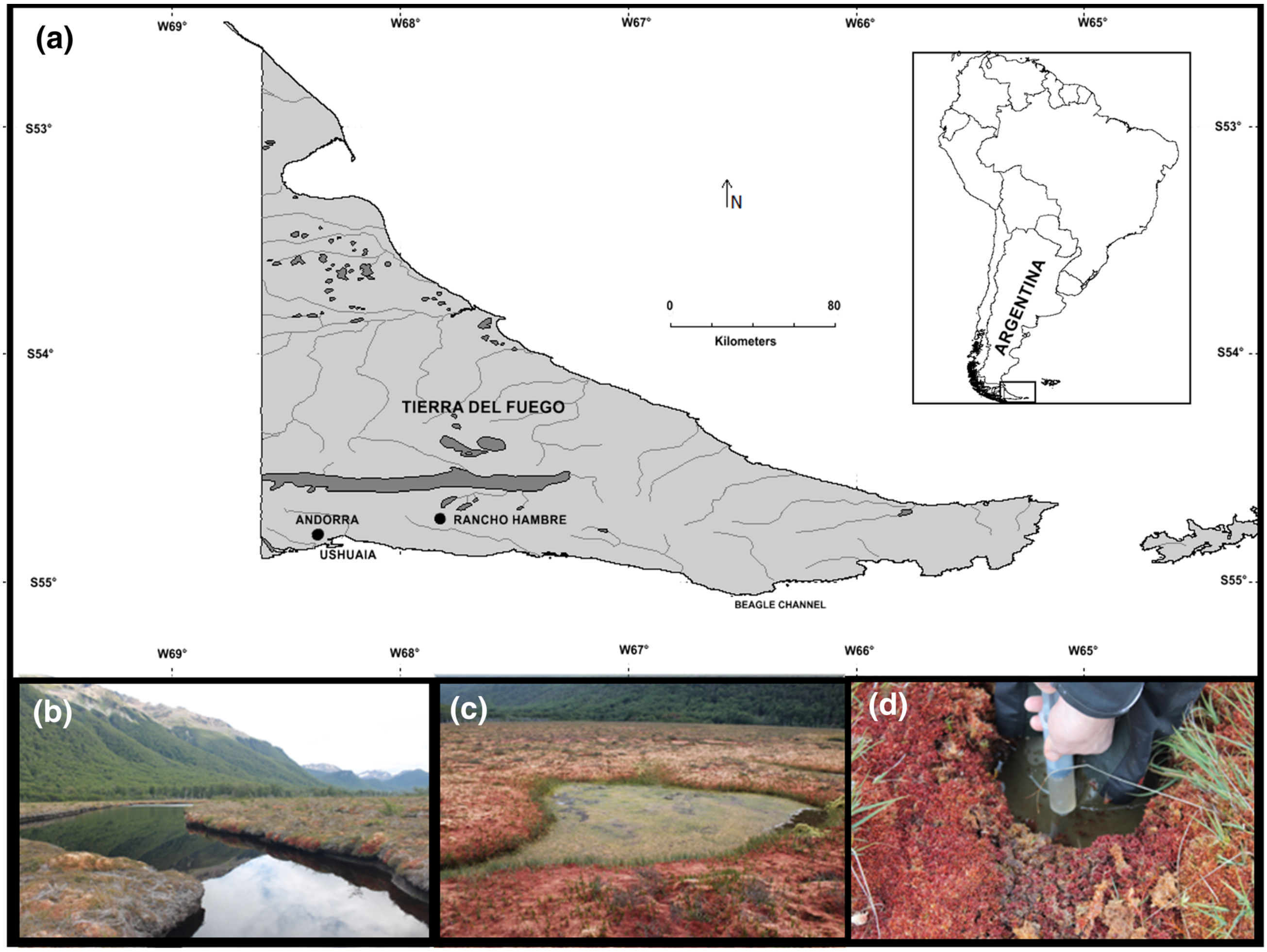

Fig. 1 Map and view of the type of ponds. **a** Location of Andorra and Rancho Hambre peat bogs (Tierra del Fuego Province, Argentina), **b** clear pond from Rancho Hambre, **c** a vegetated pond from Andorra and, **d** *Sphagnum* moss sampling procedure in Rancho Hambre

Water physical and chemical features

Temperature, conductivity and pH were measured in situ using a multiparametric probe (Hach Sension 156, Hach Co., USA) (Table 1). Water samples for measurement of dissolved nutrient concentrations were filtered through Millipore APFF filters (0.7 µm pore size). Ammonium (NH_4–N) and phosphate (PO_4-P) samples were analyzed following the salicylate and ascorbic acid methods, respectively (APHA 2005). Total nitrogen (TN) and total phosphorus (TP) were determined in unfiltered samples as described in González Garraza et al. (2012). Measurements were carried out with a Hach spectrophotometer (Hach DR2800; Hach Co., USA) using the appropriate reagents. Dissolved organic carbon (DOC) was determined from filtered water with the high temperature Pt catalyst oxidation method (TOC-L, Shimadzu, Co., Japan) following the recommendations of Sharp et al. (1993). Samples for chlorophyll *a* (CHL A) were collected in plastic bottles and preserved in dark and cold conditions until filtration in the laboratory through fiberglass filters (pore size 0.7 µm) that were preserved at −20 °C. Photosynthetic pigments were extracted with hot methanol (60 °C). Chlorophyll *a* concentrations corrected for phaeopigments were measured with a spectrophotometer and calculated following Marker et al. (1980).

Microinvertebrate sampling and analysis

The survey included 13 sites (9 ponds and 4 *Sphagnum* moss sites) from each peat bog (total = 26). Two replicates were taken at each sampling site. Sampling procedure consisted in collecting 20 l of water from clear ponds and 10 l from vegetated ponds with a limnological bottle, and filtering it through a 40-µm mesh size net. For *Sphagnum* mosses, 1 l of interstitial water was collected by squeezing handfuls of mosses and then filtering the obtained water though the same net. All samples were preserved

Table 1 Geographical location, morphometric and physicochemical features of the studied environments

Peat bog	Environ. type	Name	Long	Lat	Depth (m)	Area (m^2)	Temp. (°C)	Cond. (µS/cm)	pH	DOC (mg l^{-1})	TN (µg l^{-1})	NH_4–N (µg l^{-1})	PO_4–P (µg l^{-1})	TP (µg l^{-1})	CHL A (µg l^{-1})
Andorra	Clear pond	ANCP1	−68°20′16.0′’	−54°45′22′’	0.08	142	13.3	34	4.6	15.12	7900	50	90	220	3.95
		ANCP2	−68°20′15.9′’	−54°45′21.9′’	0.2	11.8	11.7	39.7	4.4	11.91	10,800	30	90	110	1.39
		ANCP3	−68°20′18.0′’	−54°45′19.5′’	0.34	3.66	13.8	38.9	3.6	14.49	4100	10	130	520	6.14
		ANCP4	−68°20′18.2′’	−54°45′18.5′’	0.17	36.2	13.6	36.7	3.3	12.17	4400	20	180	600	1.89
		ANCP5	−68°20′16.0′’	−54°45′12.6′’	0.1	5.38	12.8	9.7	4	12.23	8500	40	180	200	5.89
	Vegetated pond	ANVP1	−68°20′23.1′’	−54°45′11.8′’	0.25	42.2	13	46.8	4.3	11.61	2700	20	160	550	4.42
		ANVP2	−68°20′17.1′’	−54°45′19.4′’	1.4	83.4	13.8	31.1	4.3	8.421	2900	10	130	410	3.47
		ANVP3	−68°20′16.8′’	−54°45′14.6′’	0.6	193	14.8	23.2	4.6	6.285	2900	20	140	420	1.26
		ANVP4	−68°20′20.2′’	−54°45′14.6′’	0.64	46	12.6	33.2	4.1	9.363	4900	30	210	260	7.11
	Sphagnum moss	ANSM1	−68°20′23.1′’	−54°45′11.8′’	–	–	13.4	122.1	3.9	23.04	100	150	190	1070	10.11
		ANSM2	−68°20′15.1′’	−54°45′21.0′’	–	–	14	144.4	3.9	22.83	6400	70	80	620	29.49
		ANSM3	−68°20′18.5′’	−54°45′16.5′’	–	–	–	67.6	3.8	16.12	2300	10	190	520	28.89
		ANSM4	−68°20′20.9′’	−54°45′13.2′’	–	–	10.3	140.1	3.3	20.35	900	30	160	1150	25.28
Rancho Hambre	Clear pond	RHCP1	−67°49′29.2′’	−54°44′52.6′’	1.2	1904	16.4	21.7	4.3	7.993	3800	40	120	910	2.52
		RHCP2	−67°49′29.2′’	−54°44′52.6′’	0.85	5744	14	25.8	4.7	6.783	1900	10	180	160	0.25
		RHCP3	−67°49′31.9′’	−54°44′48.8′’	0.3	307	8.9	31.3	4.3	13.67	2300	80	130	200	4.79
		RHCP4	−67°49′33.7′’	−54°44′46.3′’	0.4	16,121	10.6	22	6.2	5.077	2500	0	140	210	8.16
		RHCP5	−67°49′28.2′’	−54°44′42.4′’	0.2	566	10.2	30.2	4.3	12.85	1900	20	170	270	10.11
	Vegetated pond	RHVP1	−67°49′27.12′’	−54°44′39.5′’	0.63	48	11	41.4	4.4	16.89	2000	0	80	220	1.78
		RHVP2	−67°49′31.51′’	−54°44′56.9′’	0.18	85.6	13.2	37.1	4.4	15.87	1800	20	130	300	1.55
		RHVP3	−67°49′27.98′’	−54°44′53.1′’	0.1	48.6	11.3	47.9	3.9	21.23	1400	10	90	470	1.55
		RHVP4	−67°49′28.70′’	−54°44′40.7′’	0.15	159	12.6	48.6	4.4	18.12	1500	0	160	320	3.79
	Sphagnum moss	RHSM1	−67°49′28.13′’	−54°44′38.1′’	–	–	11.3	74.7	3.6	24.1	1800	150	170	750	15.23
		RHSM2	−67°49′29.78′’	−54°44′37.9′’	–	–	12.3	61.6	4.4	19.37	6400	80	20	1920	15.51
		RHSM3	−67°49′29.64′’	−54°44′52.0′’	–	–	8.6	85.4	3.9	28.78	3400	120	140	850	11.89
		RHSM4	−67°49′32.98′’	−54°44′46.5′’	–	–	9.2	69.4	3.9	24.59	3300	20	220	510	2.63

immediately with 4 % formaldehyde. Microinvertebrates were identified to species level whenever possible. Taxonomic identifications basically followed Reid (1985) and Bayly (1992) for copepods; Paggi (1979, 1995), Smirnov (1992, 1996), Benzie (2005) for cladocerans; and Boltovskoy and Urrejola (1977), Voigt and Koste (1978) and Nogrady and Segers (2002) for rotifers. Rotifers and copepod nauplii were counted and analyzed in 1-ml Sedgwick-Rafter counting cells with an Olympus SZ30 binocular microscope. Adult copepods and cladocerans were examined in 5-ml Bogorov chambers using an Olympus SZ61 stereomicroscope. From each replicate, 3 aliquots were counted and average values were used in order to keep the estimation error <10 % (Cassie 1971). Abundances of the two replicates taken at each sampling point were averaged and expressed as individuals per liter (Ind l^{-1}). Species richness (S) was the number of different taxa recorded from each environment type: species accumulation curves were calculated and plotted using EstimateS 7.5 (Colwell 2005). The rarefaction curve was calculated using the Mao Tau estimator (Supplementary Fig. 1_S). The Shannon-Wiener diversity index (H) was calculated according to Spellerberg and Fedor (2003) as:

$$H = -\sum_{i=0}^{S} P_i \ln(P_i),$$

in which P_i is the proportion the ith species. The evenness (J) varies from 0 to 1, and was calculated as the Shannon-Wiener diversity divided by the species richness as follows:

$$J = -\sum_{i=0}^{S} \frac{P_i \ \ln(P_i)}{\ln(S)}$$

Data analysis

A cluster analysis was performed on all 26 sampling sites in order to compare the microinvertebrate composition. For this purpose, a similarity matrix was obtained on the basis of the presence/absence of each taxon using the Dice similarity coefficient and weighted pair-group method using arithmetic averages (WPGMA) (Jackson et al. 1989; Finch 2005) using NTSYSpc 2.2 software.

In a preliminary multivariate analysis, a unimodal response to the environmental gradient length was detected by means of a detrended correspondence analysis (DCA) (ter Braak and Smilauer 1998). Therefore, a canonical correspondence analysis (CCA) based on raw data was used to elucidate the relationship between microinvertebrate abundance, biotic factors (chlorophyll *a*) and abiotic variables. A forward selection of variables was done to extract synthetic gradients, which revealed pH, conductivity, dissolved organic carbon, and ammonium (NH_4–N) as significant variables. Significance of the canonical axes was tested by Monte Carlo permutation tests (Leps and Smilauer 2003). For these analyses the CANOCO 4.5 software was used (ter Braak and Smilauer 1998).

In order to study the relationship between the pond area and diversity-related parameters (richness, Shannon-Wiener diversity, and evenness) correlation analyses were performed using the Pearson correlation index. Lastly, differences in total abundance, richness, Shannon-Wiener diversity, and evenness among all sampling sites were analyzed by means of two-way ANOVA, with the factors *peat bog* (2 levels: Andorra and Rancho Hambre) and *environment type* (3 levels: clear pond, vegetated pond and *Sphagnum* moss), followed by Tukey's post hoc test (Zar 1999). All data were previously analyzed for distribution and homoscedasticity using normality and equal variance tests. In all the cases, the significance level used was 0.05. All data analyses were performed using Sigma Plot 9.0 with the Sigma Stat 3.5 package.

Results and discussion

Microinvertebrate composition

A total of 29 taxa and 2 immature stages of copepods (nauplii and copepodites) were found in Andorra and Rancho Hambre peat bogs, among which 5 Copepoda, 8 Cladocera and 16 Rotifera were identified (Table 2). Both peat bogs share a large proportion of taxa (Fig. 2a). Among the 25 species recorded from Rancho Hambre, 16 were previously found by Quiroga et al. (2013) in a 2-year analysis of the five clear ponds (Fig. 2b). While the finding of 8 new taxa in this study reflects the larger environmental heterogeneity which includes vegetated ponds and the interstitial water from the *Sphagnum* moss, the missing of 4 previously recorded taxa is likely due to our single sampling in time.

Interestingly, harpacticoid copepods and the rotifer *Elosa worrallii* Lord were only found in *Sphagnum* moss samples from both peat bogs. Harpaticoid copepods are known to be mostly benthic but also interstitial (groundwater) and limnoterrestrial (they are important bryophyte dwellers): typically they are crawlers, walkers, and burrowers (Huys and Boxshall 1991; Dole-Olivier et al. 2000). *E. worrallii* has been designated as "sphagnophile", with a preference for low pH waters (Pejler and Berzins 1993). On the other hand, the rotifers *Cephalodella gibba* Ehrenberg, *Lecane lunaris* Ehrenberg, *Lepadella imbricata* Harring and *Trichocerca collaris* Rousselet, typical dwellers of littoral habitats also reported from peat bogs (Jersabek and Leitner 2013; Glime 2013), revealed a more plastic character through their distribution over all habitat types from both peat bogs.

Table 2 List of the taxa recorded from each environment type at Andorra and Rancho Hambre peat bogs and adult body length range (mm)

	Andorra peat bog			Rancho Hambre peat bog			Body length (mm)
	Clear pond	Vegetated pond	*Sphagnum* moss	Clear pond	Vegetated pond	*Sphagnum* moss	
Copepoda							
Boeckella poppei Mrázek				x			1.4–2.6
Diacyclops sp.	x	x					0.4–0.8
Eucyclops sp.	x					x	0.1–0.5
Tropocyclops prasinus meridionalis Kiefer	x						0.5–0.6
Harpacticoida			x			x	0.2–0.3
Nauplii	x	x	x	x	x	x	
Copepodites Calanoida	x	x		x			
Copepodites Cyclopoida				x	x		
Cladocera							
Alona spp.	x	x		x	x	x	0.2–0.4
Alonella excisa Fischer		x					0.2–0.5
Bosmina (Liederobosmina) chilensis Daday	x	x		x	x		0.2–0.6
Cactus cactus Vavra				x	x		0.3–0.6
Ceriodaphnia cf. *dubia* Richard				x	x		0.5–0.8
Chydorus patagonicus Ekman	x	x		x	x	x	0.2–0.3
Daphnia commutata Ekman		x					0.2–0.5
Streblocerus serricaudatus Fischer	x	x		x			0.2–0.4
Rotifera							
Ascomorpha ecaudis Perty	x	x		x	x	x	0.1–0.3
Asplanchna girodi de Guerne				x	x		0.2–0.8
Cephalodella gibba Ehrenberg	x	x	x	x	x	x	0.1
Conochilus unicornis Rousselet					x		0.1
Elosa worrallii Lord			x			x	0.06
Keratella ona Boltovskoy and Urrejola	x	x	x	x	x		0.1–0.16
Keratella valdiviensis Thomasson		x	x	x	x	x	0.1–0.2
Keratella yamana Boltovskoy and Urrejola			x	x		x	0.1–0.14
Lecane lunaris Ehrenberg	x	x	x	x	x	x	0.1–0.14
Lepadella imbricata Harring	x	x	x		x	x	0.06–0.1
Monommata sp	x			x			0.1–0.17
Ploesoma truncatum Levander	x	x		x	x		0.1–0.14
Polyarthra dolichoptera Idelson	x	x			x		0.1–0.2
Synchaeta pectinata Ehrenberg					x		0.1–0.3
Trichocerca collaris Rousselet	x	x		x	x	x	0.06–0.3
Bdelloidea	x		x	x	x	x	0.1–0.2

The cluster analysis based on the presence/absence matrix of microinvertebrates showed that *Sphagnum* moss samples (SM) have a remarkably different taxonomical composition to that of ponds (Fig. 3). Second to this, consistent differences were also found between *Sphagnum* moss samples from Andorra (AN) and Rancho Hambre (RH).

The clear ponds from Rancho Hambre (RHCP) clustered together forming a homogeneous group. Notably, the five ponds within this group clustered into subgroups

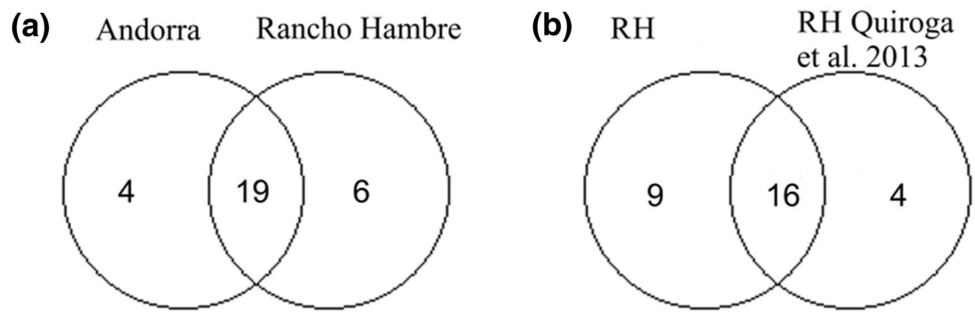

Fig. 2 *Venn diagrams* showing the number of common taxa among: **a** Andorra and Rancho Hambre and, **b** Rancho Hambre according to this study and Quiroga et al. (2013)

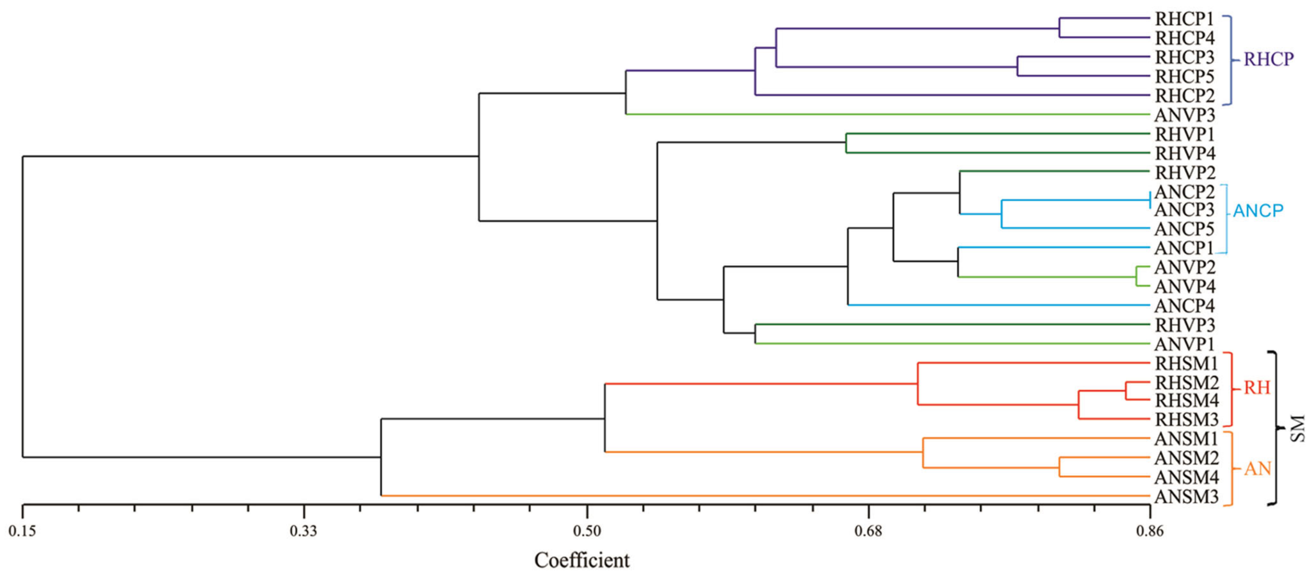

Fig. 3 Cluster analysis of sampling sites based on microinvertebrate composition (presence/absence) using Dice similarity coefficient

in the same way as previously reported by Mataloni et al. (2015), who described RHCP1 and RHCP4 as minerotrophic (slightly acid, harder water partially delivered by ground water), RHCP3 and RHCP5 as ombrotrophic (acidic waters, only fed by precipitation), whereas RHCP2 represented a mixture of features. Three clear ponds (ANCP2, ANCP3 and ANCP5) from Andorra formed another small group to which vegetated ponds from both peat bogs clustered in, forming a larger cluster with little discriminating power among pond types and peat bogs (Fig. 3).

The first two axes of the canonical correspondence analysis (CCA) explained 79.9 % of the taxa-environment relationships with a significance of $p < 0.002$. Chlorophyll *a* (0.81), DOC (0.72), conductivity (0.72), and pH (−0.47) were the variables with the strongest influence on the distribution of the samples over axis 1, while NH–N (−0.6) had the strongest influence over axis 2 (Fig. 4). The resulting plot of axis 1 vs axis 2 shows a clear separation between *Sphagnum* moss and ponds; harpacticoids were associated with the most acidic *Sphagnum* moss sites from Andorra (ANSM 2, 3 and 4), in accordance with previous reports from Italy (Minelli 2004; Bottazzi et al. 2011). In turn, *Sphagnum* moss sites from Rancho Hambre and a single site from Andorra (ANSM1) were characterized by high abundances of the rotifers *Keratella yamana*, *Keratella valdiviensis*, *Lepadella imbricata*, and the copepod *Eucyclops* sp. (Fig. 4).

In contrast, vegetated ponds from Rancho Hambre (RHVP) and Andorra (ANVP) were characterized by the presence of a mixture of littoral and planktonic cladocerans. *Alonella excisa* Fischer, *Daphnia commutata* Ekman, *Bosmina chilensis* Daday and *Alona* spp. were present in Andorra; whereas *Cactus cactus* Vavra, *Chydorus patagonicus* Ekman, *Ceriodaphnia* cf. *dubia* Richard and *Streblocerus serricaudatus* Fischer were associated with Rancho Hambre. However, the cladoceran species found in Andorra were formerly reported from Rancho Hambre (Quiroga et al. 2013). Clear ponds were linked to the presence of copepods, since RHCP1 and RHCP2 were characterized by high abundances of *Boeckella poppei* Mrázek copepodites and ANCP2 and ANCP5 were

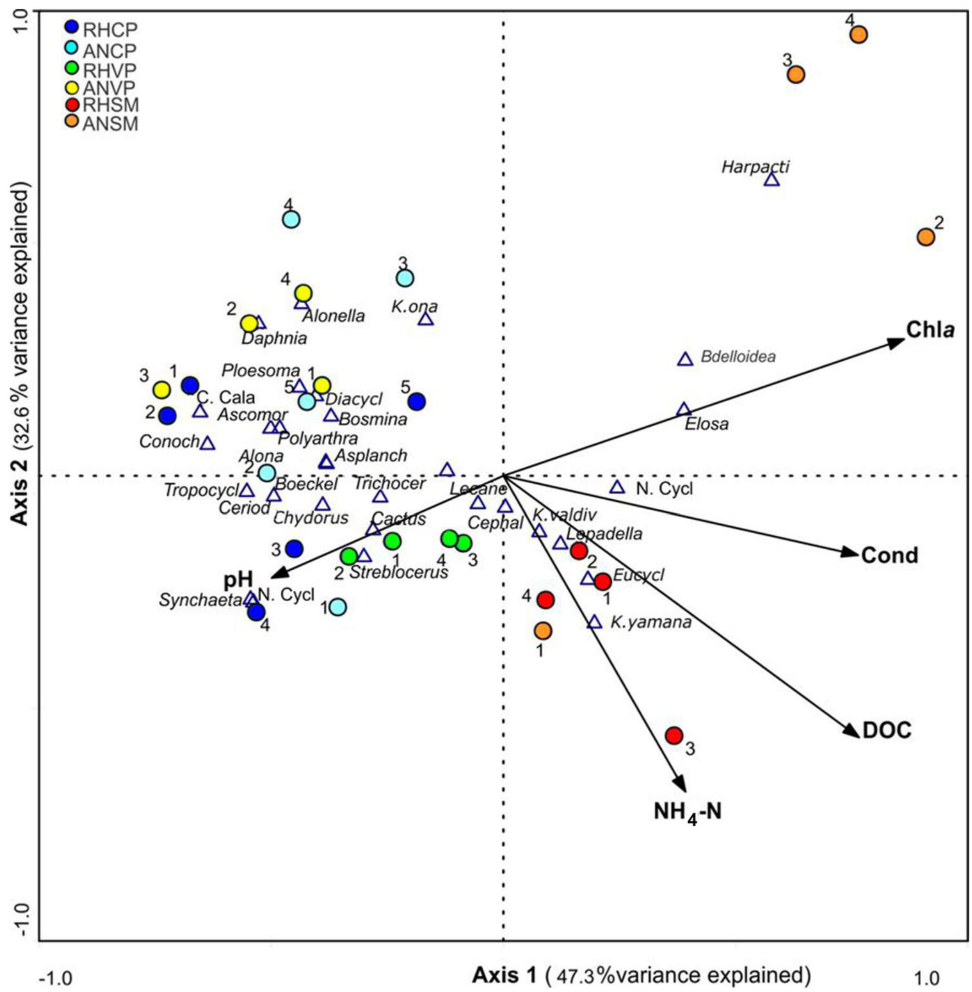

Fig. 4 Ordination of the microinvertebrate abundance on the first two axes of a canonical correspondence analysis (CCA), mainly representing pH, conductivity (Cond) and chlorophyll *a* (Chla) (axis 1) and DOC, and NH_4-N (axis 2). The *circles* represent different types of environments, while the *triangles* are microinvertebrate taxa

associated *Diacyclops* sp. Rotifers were highly abundant in all environments, particularly the genus *Keratella*, represented by *K. yamana*, *K. ona* and *K. valdiviensis*, three endemic species from Tierra del Fuego peat bogs (Boltovskoy and Urrejola 1977; Segers and De Smet 2008; Marinone 2009). In particular, *K. yamana* showed extraordinary high abundances ($\sim$500 Ind l^{-1}) in the *Sphagnum* moss from Andorra (ANSM1) (Fig. 4).

Among the cladocerans found in both peat bogs, there was a remarkable degree of endemism that included the southern Patagonian species *D. commutata*, *B. chilensis*, *C. cactus,* and *C. patagonicus* (Paggi 1993, 1998). On the other hand, *S. serricaudatus* is a cryophilic species distributed along the Andes (Paggi 1993, 1998), also inhabiting peatland pools in other continents (Glime 2014). Another remarkable feature of the studied peat bogs is the presence of a single representative of calanoid copepods, *Boeckella poppei*, which is a widely distributed Andean-Patagonian cryophilic species, also extant in Antarctica (Marinone and Menu Marque 2011). Among cyclopoid copepods, the identity at species level of the taxa herein reported is not yet solved, but they may also be endemic (Menu Marque, pers. comm.).

Microinvertebrate community analysis

Total abundance

In general, the environments from Andorra peat bog showed higher abundances than their Rancho Hambre counterparts (Fig. 5), the highest being recorded for one Andorra clear pond, followed by *Sphagnum* moss and the vegetated ponds. In contrast, Rancho Hambre peat bog recorded the highest total abundance in *Sphagnum* moss. The microinvertebrate total abundances thus showed an interactive effect of peat bog and environment type ($F = 5.756$, $p = 0.006$) (Table 3). Notably, vegetated ponds showed the lowest abundances in both systems.

The microinvertebrate composition within each peat bog showed differences among environment types (Fig. 5). In Andorra, clear and vegetated ponds were strongly

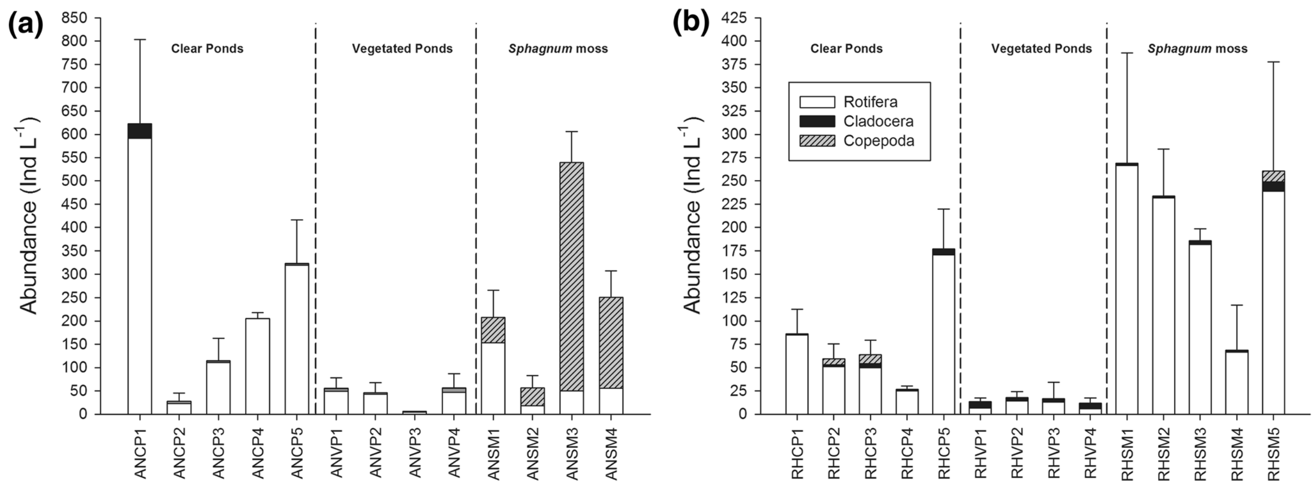

Fig. 5 Microinvertebrate group (Rotifera, Cladocera and Copepoda) abundance (mean ± SD) in the different environment types in: **a** Andorra and, **b** Rancho Hambre peat bogs

Table 3 Result of the two-way ANOVA comparing total abundance and community descriptors (Shannon-Wiener diversity, evenness and species richness) of both peat bogs (2 levels: Andorra and Rancho Hambre) and pool types (3 levels: clear, vegetated and *Sphagnum* moss) and their interactions

Parameter	Factor	*F*	*P*
Total abundance	Peat bog	0.53	0.47
	Environment	1.05	0.35
	Peat bog × environment	5.75	**0.006**
Species richness	Peat bog	2.82	0.1
	Environment	54.34	**<0.001**
	Peat bog × environment	3.1	0.054
Diversity (H)	Peat bog	1.57	0.215
	Environment	28.59	**<0.001**
	Peat bog × environment	0.76	0.471
Evenness	Peat bog	0.002	0.96
	Environment	33.454	**<0.001**
	Peat bog × environment	4.962	**0.011**

Bold value indicates significant *p*-value

dominated by rotifers, whilst the *Sphagnum* moss showed a high abundance of copepods, particularly harpacticoids (Fig. 5a). On the other hand, in Rancho Hambre, rotifers dominated all environment types (Fig. 5b). Regarding the high microinvertebrate abundance in *Sphagnum* moss, similar results were reported from a Polish peat bog, where the *Sphagnum* mats presented higher abundance values than the littoral zone and the open water of pools in the same system, thus suggesting that *Sphagnum* could act as refuge from predators (Kuczyńska-Kippen 2008). In the peat bog ponds of Tierra del Fuego, the reported predators included Dytiscidae larvae (*Lancetes* spp.), Chironomidae larvae (predatory Tanypodinae) and *Hydra* spp. (Mercado 2004; Burroni et al. 2011), though the role of *Sphagnum* shoots as foraging sites (Henrikson 1993; Kuczyńska-Kippen 2008) should not be disregarded.

Species richness and diversity

Considering all ponds ($n = 18$), none of the diversity indicators (species richness, Shannon-Wiener diversity and evenness) showed a significant correlation with the area ($r = 0.22$, $p = 0.37$; $r = -0.04$, $p = 0.87$; $r = -0.07$, $p = 0.77$; respectively), suggesting that although this feature influenced community structure in a study involving the same five clear ponds from Rancho Hambre over 2 years (Quiroga et al. 2013) other factors seems to dictate differences in diversity-related features across different environment types and peat bogs. Although both peat bogs shared similar overall characteristics regarding the structure of microinvertebrate communities, these features (richness, diversity and evenness) did differ locally among environment types. For instance, species richness showed a significant environment type-dependent variation ($F = 54.34$, $p < 0.001$) (Table 3; Fig. 6a). In both peat bogs, *Sphagnum* mosses had low species richness in comparison with ponds. Although it is widely known that the *Sphagnum* moss can act as shelter and also as foraging site for crustaceans and rotifers (Kuczyńska-Kippen 2008), there is also evidence supporting the idea that the more extreme conditions in the *Sphagnum* moss may act as environmental filters, selecting for a restricted number of well-adapted species (Mataloni 1999). This fact would account for the low diversity coupled with high abundances characterizing this environment.

The Shannon-Wiener diversity index (H) was also affected by the environment type ($F = 28.59$, $p < 0.001$)

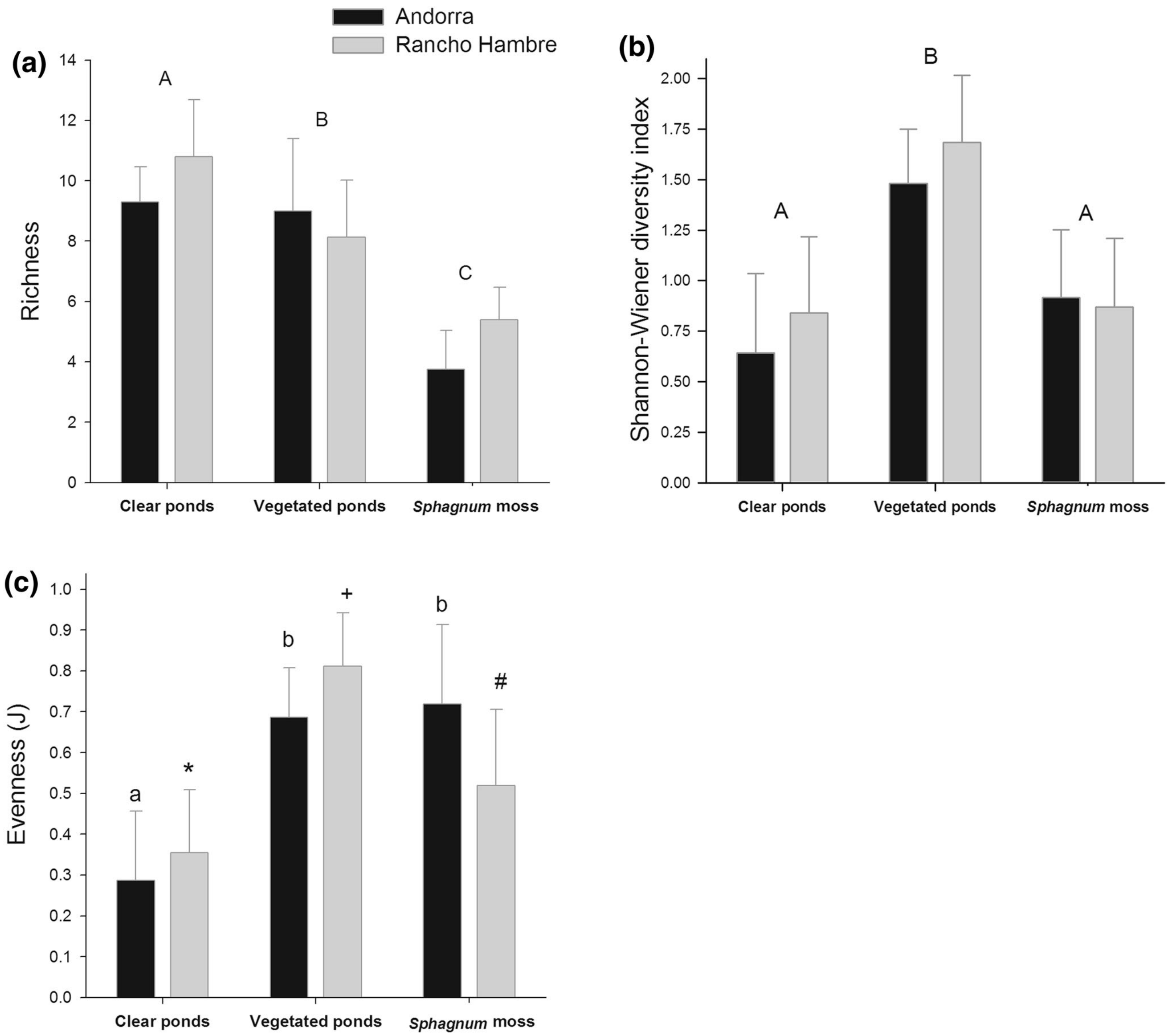

Fig. 6 Microinvertebrate community features (mean ± SD) in the different pond types from Andorra (*black bar*) and Rancho Hambre (*gray bar*) peat bogs: **a** richness, **b** Shannon-Wiener diversity index, and **c** evenness (J). *Upper case, lower case letters* and *symbols* represent post hoc homogenous groups (Tukey)

(Table 3). Moreover, both peat bogs showed high mean values of Shannon-Wiener index (mean ± SD) in the vegetated ponds (Andorra: $H = 1.68 \pm 0.33$; Rancho Hambre: $H = 1.48 \pm 0.27$) as compared with the other environment types (Fig. 6b). The evenness (J) showed a significant interactive effect of peat bog and environment type ($F = 4.962$, $p = 0.011$) (Table 3). In both peat bogs, clear ponds showed significantly lower values ($J = 0.28 \pm 0.16$ for Andorra; $J = 0.35 \pm 0.15$ for Rancho Hambre) (Table 3; Fig. 6c). The dominance of a few species in clear ponds brings evidence that vegetation-related environmental heterogeneity could be one key factor accounting for the overall diversity of ombrotrophic peat bogs such as the ones studied here.

Conclusions

During the first survey of aquatic microinvertebrates comparing different environment types from two ombrotrophic Fuegian peat bogs, we expanded to 29 the list of taxa previously reported for this area only from Rancho Hambre. Furthermore, 19 taxa were found in both peat bogs, including four cladocerans endemic to Southern Patagonia and three rotifers exclusive to Fuegian peat bogs.

Overall, this study highlights the importance of comprehensive conservation of peat bogs in Tierra del Fuego, as their high microinvertebrate diversity largely complies with the high environmental diversity within each system. Furthermore, environment type (clear pond, vegetated pond and *Sphagnum* moss) was the key feature explaining differences in species richness, diversity and evenness. Although all of the studied environments are part of such a particular and well-defined ecosystem as ombrotrophic peat bogs are, the distinct taxonomic composition in each environment highlights the contribution of habitat heterogeneity to the overall diversity within each peat bog. In particular, we emphasize the relevance of the *Sphagnum* matrix environment, which allows high abundance of rotifers and copepods, many of them endemic; while vegetated ponds showed the lowest abundances but the highest diversity. This study provides a base line for the assessment of the importance of microfauna in peat bogs of Tierra del Fuego, and for future investigations at a higher spatial resolution. In view of this, conservation of peat bogs from Tierra del Fuego is important in biogeographical terms, since slight environmental changes in these systems could lead to a decrease in endemic species adapted to these extreme habitats.

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