The limnological character of bog pools in relation to meteorological and hydrological features

G. González Garraza[1,4], G. Mataloni [1,4], R. Iturraspe[3], R. Lombardo[2,4], S. Camargo[3] and M.V. Quiroga[1,4]

[1]Universidad Nacional de San Martín and [2]Universidad de Buenos Aires, Buenos Aires, Argentina
[3]Universidad Nacional de Tierra del Fuego, Antártida e Islas del Atlántico Sur, Ushuaia, Argentina
[4]Consejo Nacional de Investigaciones Científicas y Tecnológicas (CONICET), Argentina

SUMMARY

As part of a major limnological characterisation of Rancho Hambre mire complex (Tierra del Fuego), five water bodies (bog pools) were sampled between October 2008 and April 2010 and their physico-chemical features studied in relation to meteorological, hydrological and morphometric variables. The meteorological data recorded mostly fitted within the ranges of historical records. The influence of water body size was evidenced by the higher thermic stability of the largest pool as compared to the smallest, which reflected changes in air temperature. Water levels in the pools varied according to their superficial connectivity: deep water bodies with surface inflow and/or outflow channels had the most stable water levels; but the deepest water body, which was hydrologically isolated, had the most variable water level. In an ordination of samples resulting from a Principal Component Analysis of limnological data, the first axis reflected the minero/ombrotrophic status of water bodies, while the second represented a temporal gradient separating spring (post-thawing) samples from summer samples. Inter-annual variations in weather also influenced the limnological properties of the water bodies. Our results enable us to propose an interpretative model for the limnological characterisation of the pools, which will be a valuable tool for understanding the structure and fluctuations of the planktonic communities inhabiting these systems.

KEY WORDS: hydrology; limnology; ombrotrophic mire; pond; Tierra del Fuego; water chemistry

INTRODUCTION

Water bodies in peat bogs are subjected to low temperatures, high humidity and high precipitation (Mataloni 1999). The majority (95 %) of the peatlands present in Argentina are located in Tierra del Fuego, which is the country's southernmost and only island province (Rabassa *et al.* 1996). The peatlands of the Fuegian Archipelago have been studied since the early 20th century. Bonarelli (1917) first classified them in terms of topographic position and dominating plant communities; and Auer (1965) identified five peatland zones on the basis of stratigraphy, vegetation type and precipitation. Most of the general information about Tierra del Fuego's peatlands was summarised by Rabassa *et al.* (1996). Subsequently, Iturraspe & Urciuolo (2000) identified four types of hydrological basins in Tierra del Fuego. The southern (Range) type occurs within the area delimited by the Fuegian Andes to the north and the Beagle Channel to the south, and includes the Lasifashaj River Basin where the work reported here was carried out. This basin type is characterised by a dense drainage network and a variety of natural regulation systems including glaciers, seasonal snowpack, lakes, and peatlands hosting small standing water bodies (pools).

In 2005, the International Mire Conservation Group (IMCG) emphasised the need to record the biodiversity and survey the functioning of Tierra del Fuego's mires, and thus to develop a baseline data bank to enable monitoring of their behaviour and change in the future (IMCG 2005). In this context, a recent multidisciplinary project aiming to characterise the limnological systems of the Rancho Hambre Mire Complex (Figure 1) included a survey of phyto- and zooplankton diversity as well as a study of interactions between abiotic features and the structure and dynamics of all planktonic communities (bacterio-, phyto- and zooplankton).

The first study of phytoplankton communities in the pools at Rancho Hambre showed that variations in floristic composition could be related to water body morphometry and electrical conductivity (EC), and the abundances of certain taxonomic groups were correlated with pH (Mataloni & Tell 1996). This analysis was based on a single sampling occasion and raised many further questions about the influence of environmental factors on the communities. Subsequently, Mataloni (1999) studied microalgal communities along gradients

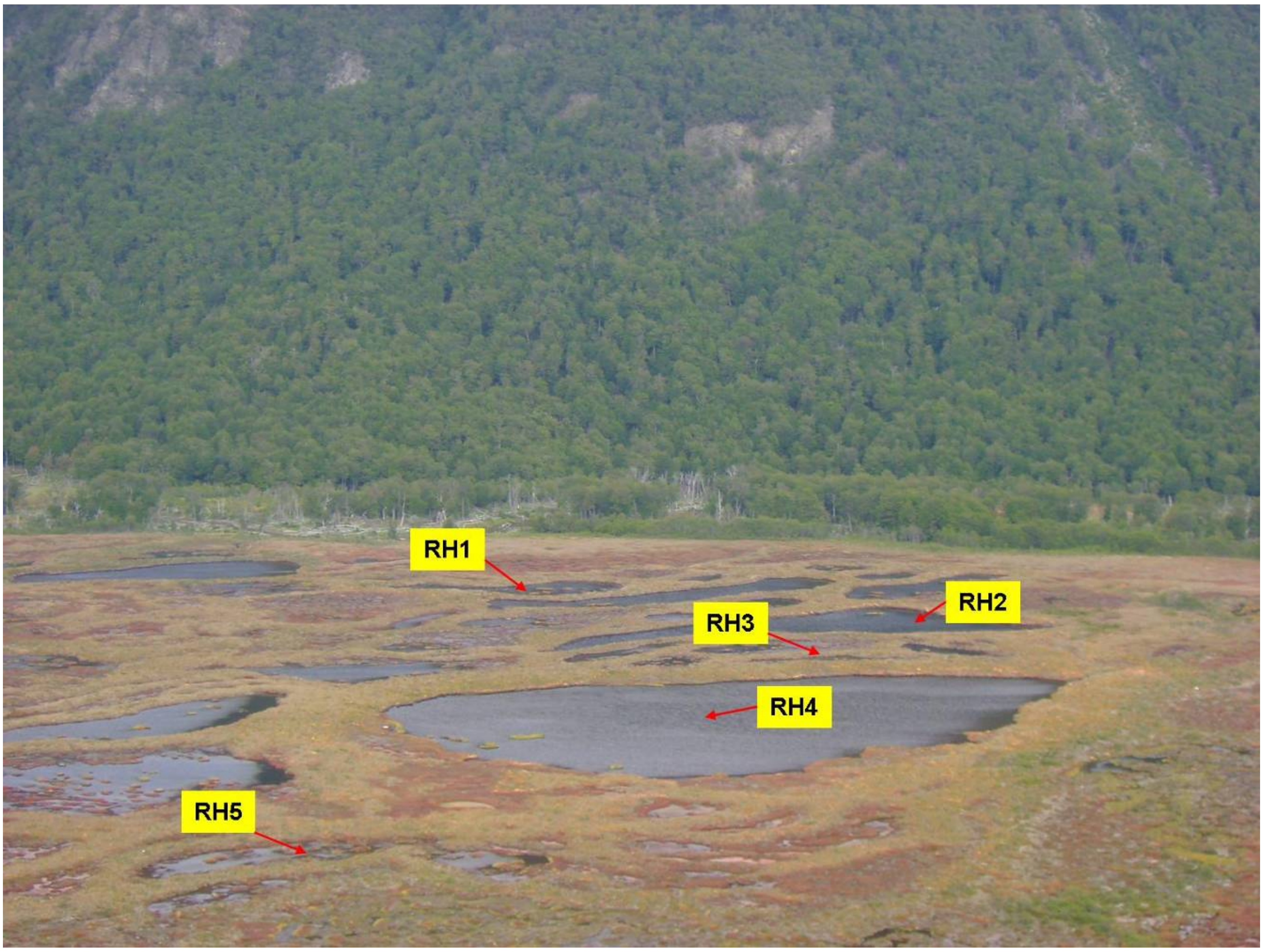

Figure 1. View across the Rancho Hambre Mire Complex from the north. The labels indicate the five pools that were studied in detail (see Figure 2).

from open water to the drier surroundings of water bodies on six Fuegian mires. The hydroseral succession towards terrestrial conditions was reflected by impoverishment in the diversity of these communities.

Within this framework, the present study had three main objectives:

1) to record the meteorological conditions on Rancho Hambre and analyse them in relation to long-term records;
2) to investigate the influence of meteorological, hydrological and morphometric features on the limnological properties of representative sample pools; and
3) to characterise these pools on the basis of limnological properties.

METHODS

Sampling sites

Rancho Hambre Mire Complex (54° 47´S, 68° 19´W) is located in the Tierra Mayor valley, among the southernmost ridges of the Andes and about 50 km from Ushuaia City (Figure 2). The peripheral drainage network originates mainly from upslope rivulets (Iturraspe *et al.* 1998, Grootjans *et al*. 2010). The central area is domed and has been classified as an ombrotrophic peat bog (Roig 2004), fed only by precipitation and snowmelt (Roig & Roig 2004). The vegetation is dominated by the peat-forming moss *Sphagnum magellanicum* Bridel., and water in the peatland has much lower electrical conductivity (EC) than that in the surrounding watercourses (Grootjans *et al.* 2010).

A large fraction of the surface of Rancho Hambre is covered by standing water bodies (pools). Five of these, located along a transect crossing the peat bog, were selected to represent different morphometric characteristics (Figures 1 and 2, Table 1). RH1, RH2 and RH4 were large, deep water bodies, of which RH4 was the largest; whilst RH3 and RH5 were very shallow (depth < 50 cm). All were sampled on eight occasions during the annual ice-free periods (October–April) between October 2008 and April 2010.

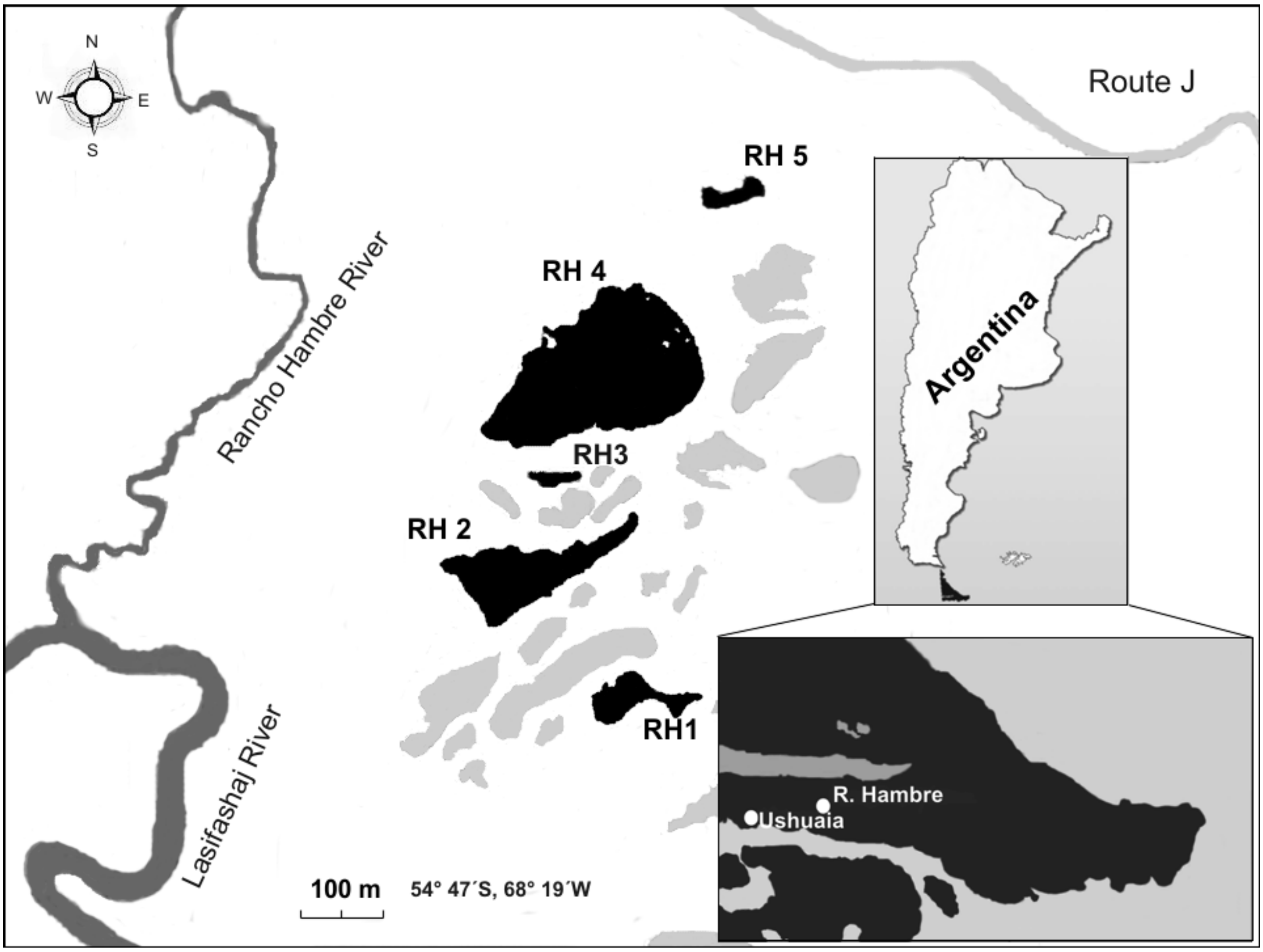

Figure 2. Map of the Rancho Hambre Mire Complex indicating main water bodies (shaded areas). Within the group of standing water bodies on the bog dome, the studied pools are shaded black. The two inset maps show the locations of (above) Tierra del Fuego Province (shaded black) within Argentina; and (below) Rancho Hambre relative to Ushuaia City.

Table 1. Locations and morphometric features of the five water bodies studied at Rancho Hambre. *SDI*: shoreline development index (see Equation 1 for derivation).

Pool ID	**RH1**	**RH2**	**RH3**	**RH4**	**RH5**
Latitude (S)	54° 44′ 52.87″	54° 44′ 48.61″	54° 44′ 46.75″	54° 44′ 41.51″	54° 44′ 39.35″
Longitude (W)	67° 49′ 29.44″	67° 49′ 31.66″	67° 49′ 32.21″	67° 49′ 31.69″	67° 49′ 26.7″
Maximum length (m)	81.9	162.9	50.7	195.7	34.5
Maximum width (m)	28.5	66.2	10.5	122.9	12.7
Maximum depth (cm)	95	150	33	150	33
Perimeter (m)	238	445	115	555	162
Area (m^2)	1824	5976	137.4	16190	542
SDI	1.6	1.6	2.1	1.2	2.0

One to four sampling sites were selected within each water body, according to its size. Three sampling points (shore, water surface and bottom) were established in RH1 and RH2, and four points (north and south shores, water surface and bottom) in Pool RH4. Pools RH3 and RH5 were sampled from the shore. The geographical positions of the sampling sites were determined using a Garmin Etrex GPS. The maximum depths of the pools were measured using a weighted line, morphometric features (maximum length, maximum width, perimeter) were measured on Google Earth images, and areas were determined from printed images using a digital polar planimeter. Shoreline development index *SDI*, which describes the regularity of the shoreline, was calculated as

$$SDI = \frac{P}{2\sqrt{\pi A}} \qquad [1]$$

where *P* is the perimeter and *A* is the area of the pool (Hutchinson 1957). Thus, for a given area, a perfectly circular pool has the lowest possible *SDI* value (= unity) and *SDI* increases with increasing departure from this plan shape.

Meteorological measurements

Local weather conditions were measured with a DAVIS automatic weather station located near Rancho Hambre River, within 1 km of the pools, from February 2009 onwards. Hourly measured variables included air temperature, humidity, precipitation, and wind speed and direction; from which daily and monthly mean values were calculated. From June 2008 to May 2010, sub-surface (0.25–0.30 m depth) water temperature was measured hourly in the smallest and largest water bodies (RH3 and RH4 respectively) as well as in the peat (at 0.30 m depth) using Ondotori TR-52i thermo recorders (accuracy: ± 0.3 °C). These instruments are water resistant, and each incorporates a temperature probe and a data logger.

Hydrological measurements

Water levels in the pools were measured at intervals of about three weeks from December 2008 onwards by using lengths of PVC pipe inserted vertically into the pool floors as stage posts. The coefficient of variation (CV) of the water level in each water body was calculated as (standard deviation/ average)*100. Because RH4 lay in a hollow and thus had a small closed catchment at microtopographical scale, water table depth around this water body was measured using dipwells with closed bases arranged along four transects radiating outwards from the pool. The dipwells were 40 mm diameter plastic pipes with two diametrically opposite rows of 6 mm perforations at 3 cm intervals along their entire lengths, inserted vertically to 1.30 m depth. Two dipwells were installed on the transect that lay in the narrow southern margin of the catchment, and three were installed on each of the other three transects (Figure 3). Water levels were measured as depths below the tops of the pipes using a metal tape measure. After a topographic survey performed using a PENTAX R-326EX total station, all water level measurements were referenced to sea level. For each sampling occasion, the height of the water surface in each dipwell relative to the water level in Pool RH4 (relative water table level rWTL) was also calculated.

Physical and chemical measurements

On each sampling date a multi-probe (HORIBA, Japan) was used to measure temperature, pH, EC and dissolved oxygen (DO) *in situ*. Oxygen saturation percentage (OS %) was estimated using DO and water temperature data.

Water samples for chemical measurements were collected in acid-washed plastic bottles. Solute concentrations were measured using a Hach DR 2800 spectrophotometer (Hach Company, USA), with appropriate reagents for each analysis, following numbered methods from the Hach DR 2800 Spectro-photometer Procedures Manual (www.hach.com). Samples were filtered through Millipore APFF filters (pore diameter 0.7µm). Those for ammonium (NH_4-N) were preserved at pH 2 and 4 °C and analysed according to the salicylate method No. 8155. Nitrate (NO_3-N) and phosphate (PO_4-P) samples were preserved at -20 °C and analysed using the cadmium reduction (No. 8192) and ascorbic acid (No. 8048) methods, respectively. Dissolved inorganic nitrogen (DIN) was calculated as the sum of ammonium plus nitrate. Unfiltered samples for total nitrogen (TN), phosphorus (TP) and hardness were preserved at -20 °C until analysis. TN and TP were determined by acid digestion with potassium persulphate and boric acid (APHA 2005) followed by NO_3-N and PO_4-P determinations. Total hardness was determined by the calmagite colorimetric method No. 8030.

Suspended solids were obtained by filtering the water samples onto calcinated, pre-weighed Millipore APFF filters. Dry mass was determined according to APHA (2005).

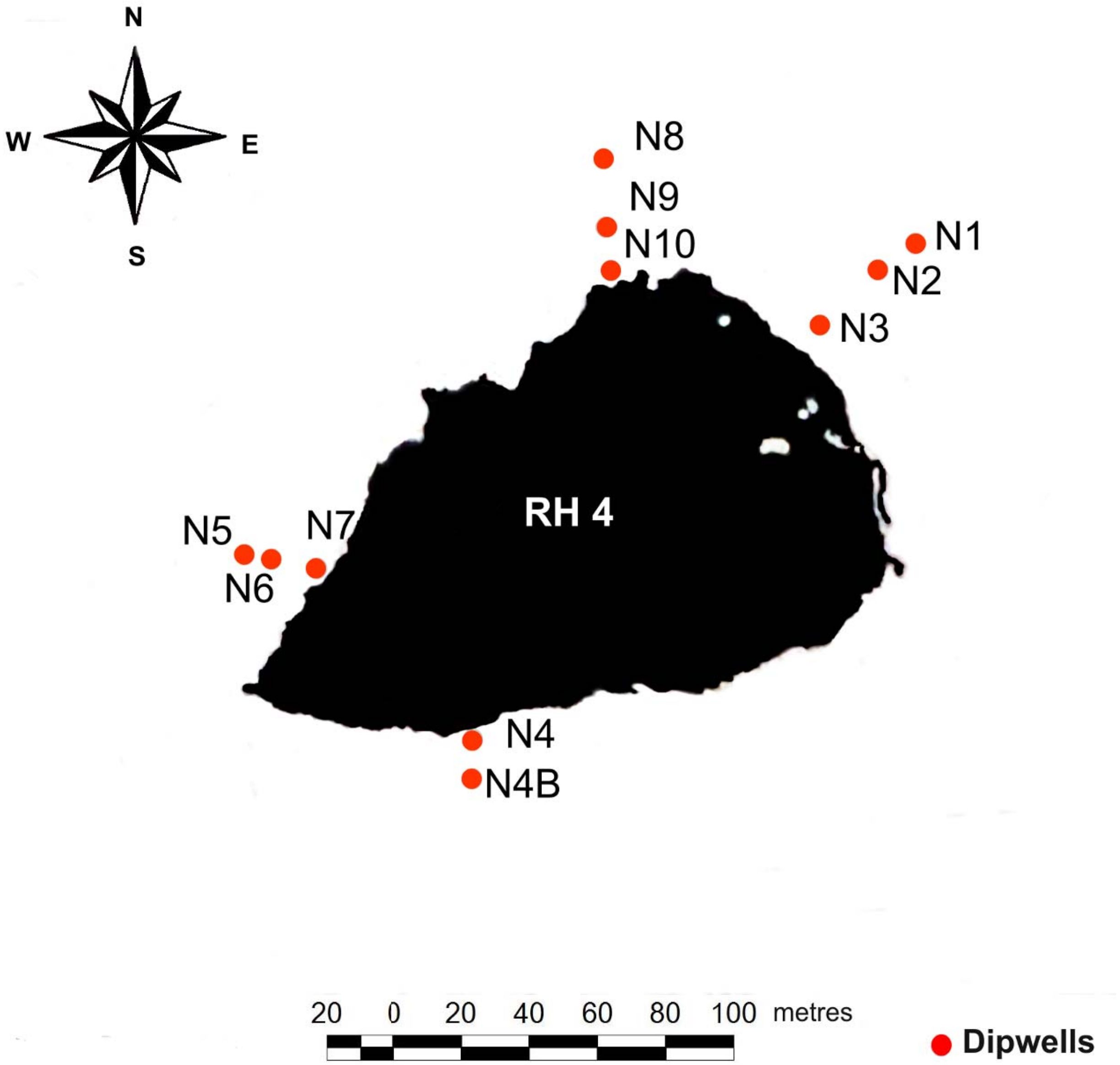

Figure 3. Map of Pool RH4 showing the positions of the dipwells (N1–10) that were placed within the local catchment around the water body.

Data analysis

A correlation matrix was built for each water body,containing meteorological variables (air temperature; accumulated precipitation 1, 3, 7 and 14 days before sampling date; and wind speed) and limnological variables (water temperature, pH, EC, DO, suspended solids, total hardness, DIN, TN, PO_4-P and TP), using the sampling dates for which both types of data were available (February 2009 to April 2010). This analysis used SPSS Statistics 17.0 software. As many of these data were not normally distributed, non-parametric Spearman coefficients were used (Zar 2010). A Principal Component Analysis (PCA) of limnological variables was performed using NTSYSpc 2.2 software, in order to characterise the five pools and analyse the dynamics of their abiotic (physical and chemical) features.

RESULTS

Meteorological data

Figure 4 shows hourly air, water (RH3 and RH4) and peat temperatures between June 2008 and May 2010. In winter, peat temperature was always higher than water temperature, the shallow study pools were frozen solid and the deep ones had surface ice layers more than one metre thick. The ice in the water bodies thawed in early October in both years, immediately after pronounced increases in air

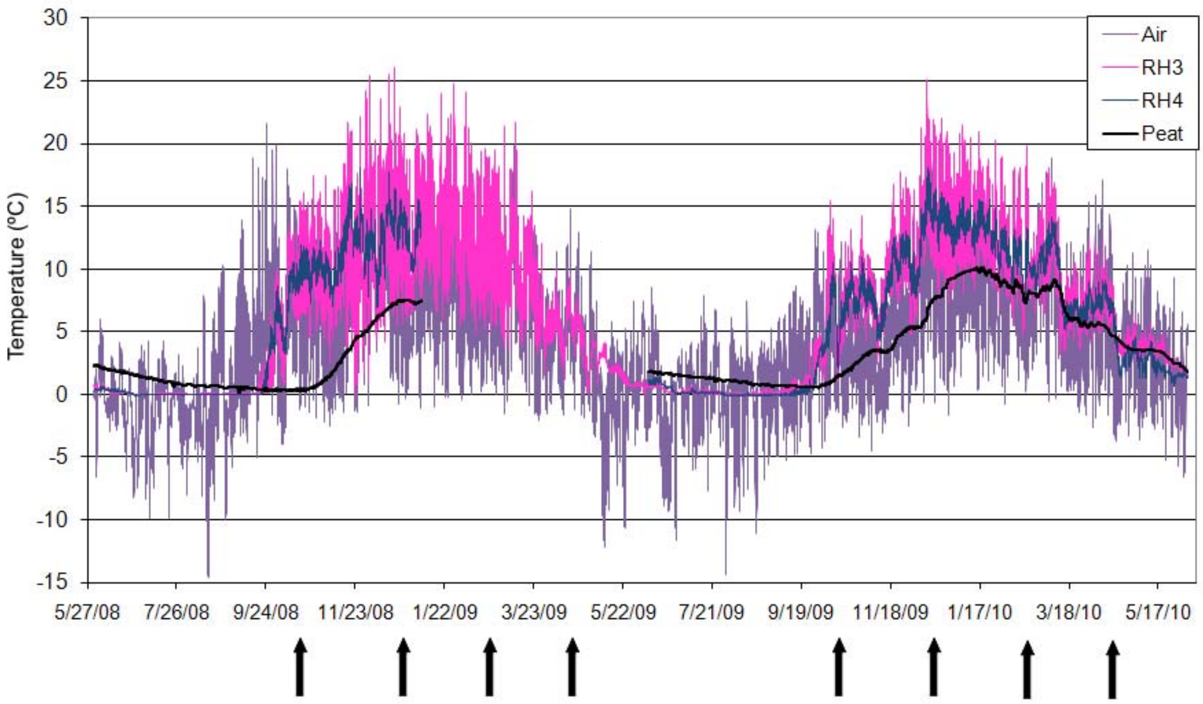

Figure 4. Hourly temperature readings for air, peat and water in the smallest (RH3) and largest (RH4) of the sampled water bodies, over the period June 2008 to May 2010 (date format on abscissa is mm/dd/yy). The arrows indicate limnological sampling dates. Sensor malfunctioning interrupted data collection in RH4 and peat between January and May 2009.

temperature. Air temperature, as well as that of the smallest water body (RH3), showed marked diurnal variation over the unfrozen period; whereas the temperatures of the largest water body (RH4) and the peat were clearly more stable.

The monthly mean air temperatures recorded during our study (-0.7–8.5 °C) (Figure 5) lay within the range registered for Rancho Hambre since 1999 (-4.1–11.4 °C). Absolute minimum and maximum temperatures over the study period were -12.9 and 21.1, respectively. Calculation of the annual mean temperature per ice-free period (October to March inclusive) showed distinctly that the open water period of 2009–2010 was cooler than that of any of the previous six summers. Monthly precipitation averaged 60 mm over the study period, with maxima (> 100 mm) in August 2009, January 2010 and February 2010 and a minimum value (<27 mm) in September 2009 (Figure 5). Abundant snowfall accounted for the high precipitation in August 2009. Interestingly, air temperature and precipitation varied similarly from September 2009 to April 2010, except for a delay between the temperature increase in December and the heavy rainfall that followed in January. The prevailing wind direction over the entire study period was westerly, coinciding with the west–east orientation of the pools and the valley itself, and mean wind speeds for the sampling months ranged from 5.3 km h^{-1} to 8.7 km h^{-1} (Figure 6). The maximum wind speed recorded was 104.6 km h^{-1}.

Hydrological features

Field observations suggested that small-scale local topography played an important role in the hydrology of the pools. Small “ranges” of *Sphagnum* hummocks colonised by *Nothofagus* saplings divided the area into small catchments. Some of the pools within these catchments were interconnected by natural surface channels. Of the three large water bodies sampled, RH1 and RH4 had inflows and/or outflows but RH2 did not.

Water levels in the five pools were recorded while their surfaces were ice-free (Figure 7). The pool with the most variable water level was RH2 (CV= 29%), due to its hydrological isolation. Water level variation in the small, shallow pools RH3 (CV=18 %) and RH5 (CV=11 %) was similar to that in RH1 (16 %), and the large pool RH4 (CV=7 %) was the most stable. Water levels in all of the water bodies are plotted together in Figure 7f. The data provided no evidence for subsurface inter-

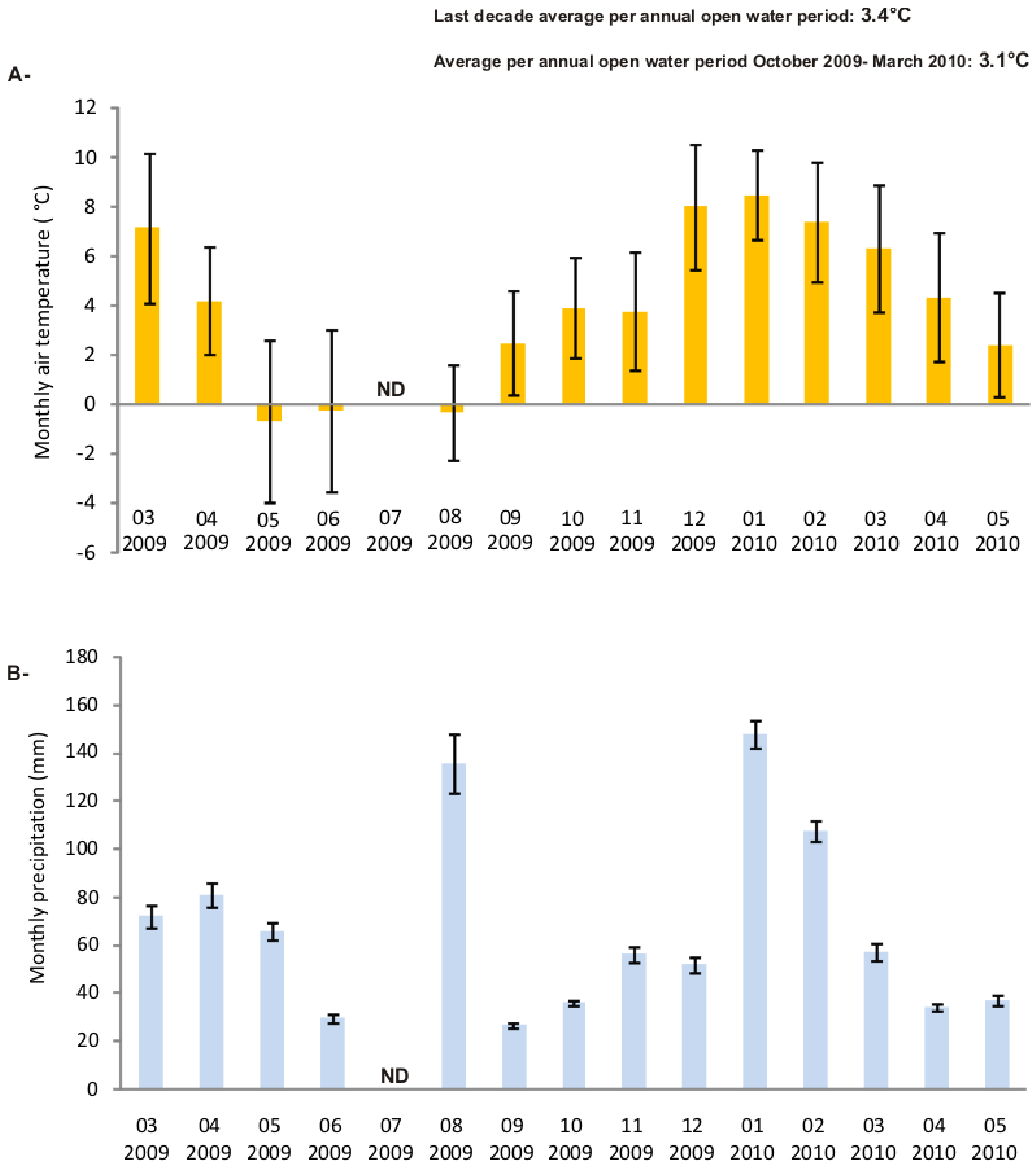

Figure 5. (A-) Monthly air temperature and (B-) monthly precipitation measured at Rancho Hambre over the study period based on daily average values. ND: no data. Bars indicate ± SD.

connections between water bodies, as their water levels were located at different heights even though some of them were only a few metres apart.

Figure 8 shows the temporal variation in relative water table levels (rWTL) recorded around RH4. The water table in the surroundings was always higher than the water level in RH4 (rWTL > 0), and the increase in rWTL with increasing distance from the water body indicates that there was constant sub-surface seepage toward RH4. The dipwells could be divided into two groups on the basis of differences in seepage behaviour over time. Those in the first group (N1–N3 and N5–N7) showed similar variations in water level over time, whereas rWTL values differed strongly among N4B–N4 and N9–N10. Dipwell N4B was located on a small "ridge"

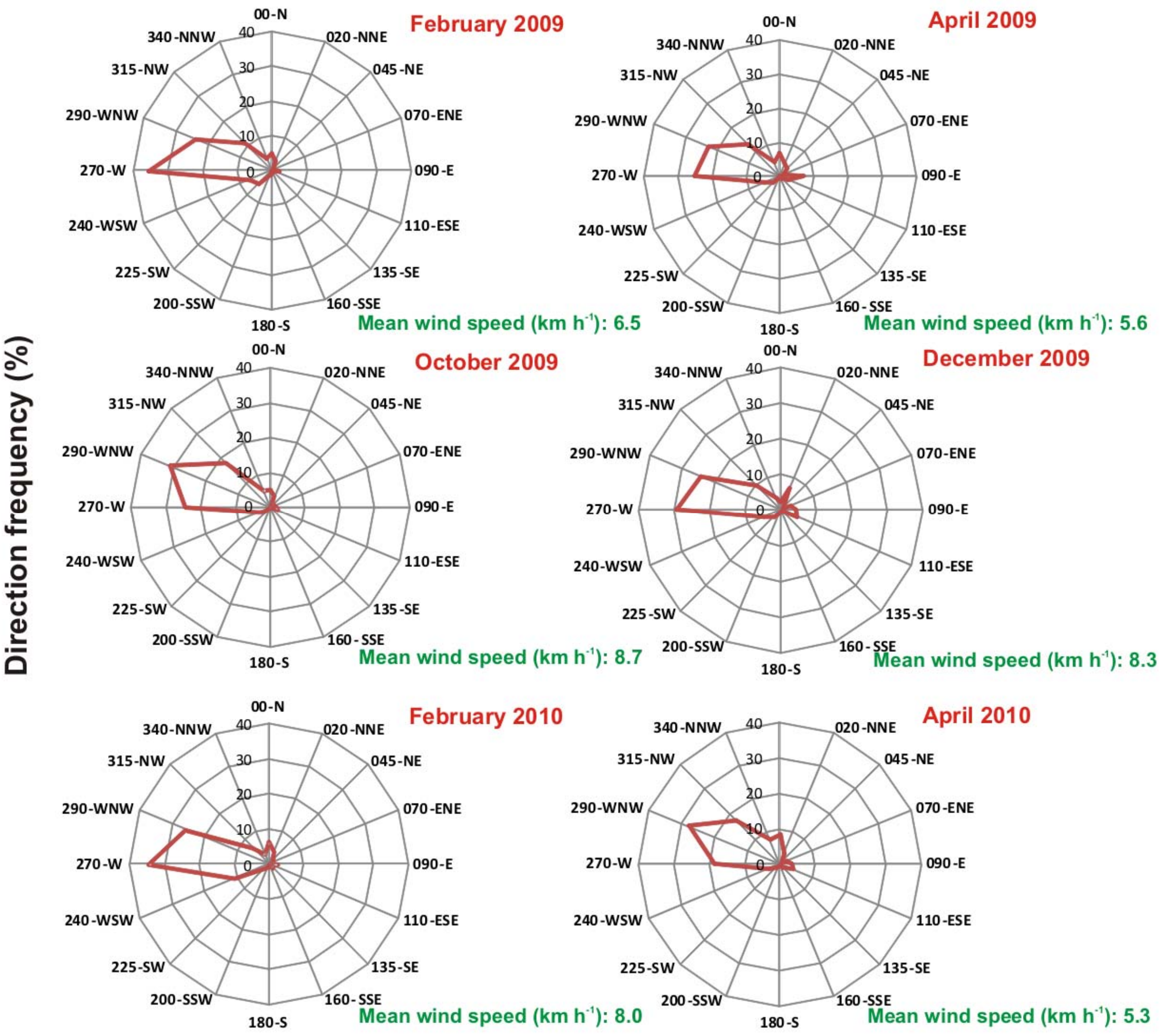

Figure 6. Prevalent wind directions (% frequencies, scale 0–40 %) and monthly mean wind speeds (km h^{-1}) recorded at Rancho Hambre from February 2009 to April 2010.

separating RH3 from RH4, and the attenuated rWTL curve of N4 suggests that part of the runoff travelled in the opposite direction, most probably toward RH3. On the other hand, N9 was located in a constantly saturated *Sphagnum* patch at much lower altitude than N8. In this case, the smaller rWTL range at N10 suggests that part of the runoff from N8 accumulated in this patch and did not reach N10.

Physical and chemical features

Temperature, pH, DO and EC were homogeneously distributed (CV< 10%) in the three deep water bodies (RH1, RH2, RH4) over the entire study period due to mixing caused by the steady westerly winds. Suspended solids, total hardness and solute concentrations showed higher CV which did not exceed 100 %. Mean water temperatures for the five water bodies were between 8.5 °C and 11.8 °C with an overall variation range of 1.1–25.0 °C (Table 2). The large water bodies (RH1, RH2, RH4) presented both lower average values and narrower ranges than the small, shallow ones (RH3, RH5). The latter also showed generally higher values and wider ranges for EC and suspended solids. Total hardness, in turn, varied little and had lower values in RH3 and RH5, revealing their more ombrotrophic character. Values of pH varied little over time but separated the pools into two groups, namely: RH1 and RH4 (mean pH ≈ 6) and RH2, RH3 and RH5 (mean pH ≈ 4.5). For all five pools, mean DO was ≥ 10 mg L^{-1} with an overall range of 7.6–14.0 mg L^{-1}, and oxygen saturation was always > 60 %.

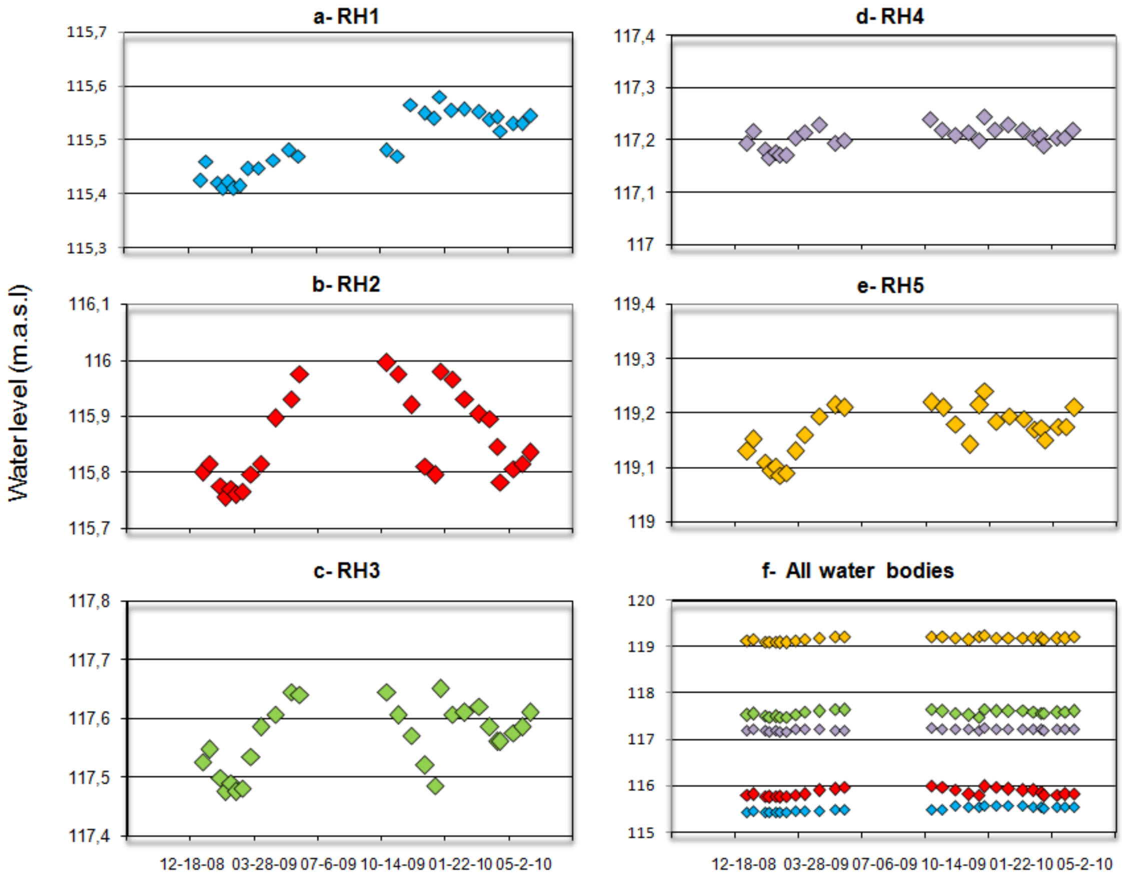

Figure 7. (a- to e-): temporal variation of water level (in metres above sea level) recorded in each water body from December 2008 onwards; (f-): the same data shown as a composite graph for all water bodies studied, colour coded as in (a- to e-). The ordinate timespan is the same for all graphs.

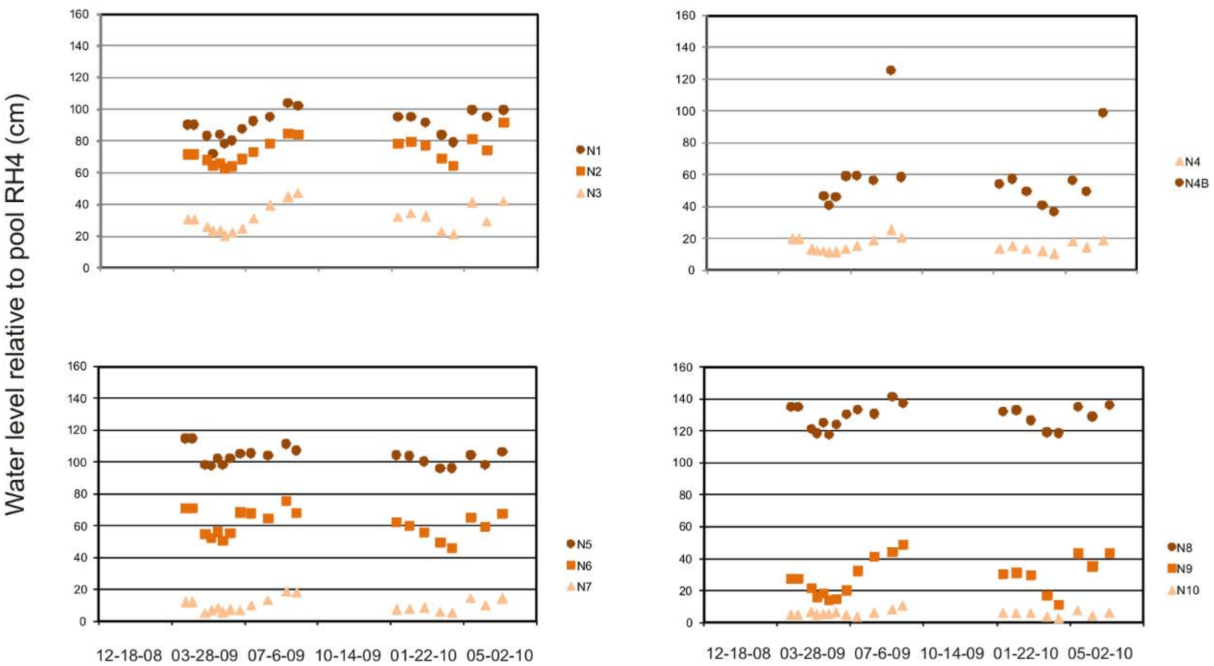

Figure 8. Temporal variation of water table levels around Pool RH4, expressed as heights above the level of the water surface in the pool (i.e. as rWTL). Each graph shows data for one of the dipwell transects in Figure 3, the uppermost set of points representing the most distant dipwell from the pool and the lowermost set of points the dipwell closest to the pool. The ordinate timespan is the same for all graphs.

Table 2. Abiotic features recorded at each of the five pools over the study period. Mean values are given, with observed minimum and maximum values in parentheses. The pools are arranged in order of increasing area. EC: electrical conductivity; DO: dissolved oxygen; OS: oxygen saturation; DIN: dissolved inorganic nitrogen.

Pool ID	**RH3**	**RH5**	**RH1**	**RH2**	**RH4**
Area (m^2)	137.4	542	1824	5976	16190
Number of readings (*n*)	8	8	23	22	32
Temperature (°C)	11.8 (3.2–25.0)	10.6 (1.7–20.0)	8.8 (2.2–17.3)	8.6 (1.1–17.0)	8.5 (2.4–15.0)
pH	4.5 (3.6–5.4)	4.6 (4.1–5.4)	5.7 (5.0–7.1)	4.5 (3.8–5.5)	6.3 (5.8–7.0)
EC (µS cm^{-1})	33.1 (10.0–82.0)	25.6 (5.5–50.0)	23.6 (14.0–26.0)	22.8 (8.7–24.0)	29.8 (16.0–60.0)
DO (mg L^{-1})	10.4 (8.7–13.0)	9.9 (8.6–11.5)	10.5 (8.2–14.0)	11.3 (7.6–14.0)	10.6 (7.6–12.0)
OS (%)	100 (73–134)	93 (74–112)	93 (83–114)	101 (63–135)	94 (63–118)
Suspended solids (mg L^{-1})	5.5 (0.4–20.0)	4.1 (0.3–11.0)	2.1 (0.7–3.7)	2.3 (0.9–8.3)	6.1 (1.6–7.0)
Total hardness (mg equiv. $CaCO_3$ L^{-1})	22.0 (7.5–43.3)	22.3 (10.9–36.4)	25.7 (7.0–41.4)	24.2 (6.8–46.2)	30.5 (11.0–42.5)
DIN (µg L^{-1})	57 (10–103)	35 (0–73)	48 (7–102)	57 (7–239)	43 (19–107)
Total N (µg L^{-1})	7305 (1980–11330)	9479 (3410–30000)	5317 (1430–10100)	6293 (1980–11916)	6859 (2400–26000)
PO_4-P (µg L^{-1})	61 (30–130)	31 (20–50)	62 (27–93)	45 (23–77)	34 (10–60)
Total P (µg L^{-1})	169 (90–308)	195 (77–420)	206 (113–477)	172 (92–187)	164 (88–257)
TN:TP (by weight)	52.1 (15.0–104.4)	62.9 (11.7–132.9)	36.0 (10.0–69.4)	39.3 (10.6–64.4)	50.2 (7.5–128.4)
DIN:PO_4-P (by weight)	1.2 (0.1–2.4)	1.6 (0.0–3.7)	0.9 (0.1–1.5)	0.8 (0.1–1.5)	1.5 (0.7–3.1)

Most of the dissolved inorganic nitrogen (DIN) in the pools was present as ammonium, and nitrates were undetectable in most samples. DIN was low at all sites (mean 48 µg L^{-1}, range 0–239 µg L^{-1}) and represented a very small fraction of the total N (mean 7050 µg L^{-1}, range 1430–30000 µg L^{-1}). In contrast, dissolved phosphate accounted for around 25 % of the total P present (mean values 47 µg L^{-1} and 181 µg L^{-1} respectively) (Table 2). Ratios of TN:TP always exceeded the Redfield ratio (7.2:1 by weight), which represents the proportion of net uptake by phytoplankton (Guilford & Hecky 2000). Minimum TN:TP values for the different water bodies ranged from 7.5 to 15.0 and were recorded immediately after the spring thaw, while the range of maximum values was 64.4–132.9 and did not relate to any specific sampling date. In turn, DIN:PO_4-P ratios were much lower than the Redfield ratio, varying between 0.0 and 3.7. Both the total and the dissolved concentrations in all of the sampled water bodies were within the same range; thus, temporal fluctuations within each water body exceeded the spatial variation across the whole set at any given sampling.

In RH1 and RH4, EC was negatively correlated with accumulated precipitation at three and seven days prior to the sampling date (r_{RH1} = -0.61, -0.56; r_{RH4} = -0.65, -0.77; in all cases $p < 0.05$), indicating a dilution effect. However, in the shallow pools RH3 and RH5, EC was positively correlated with

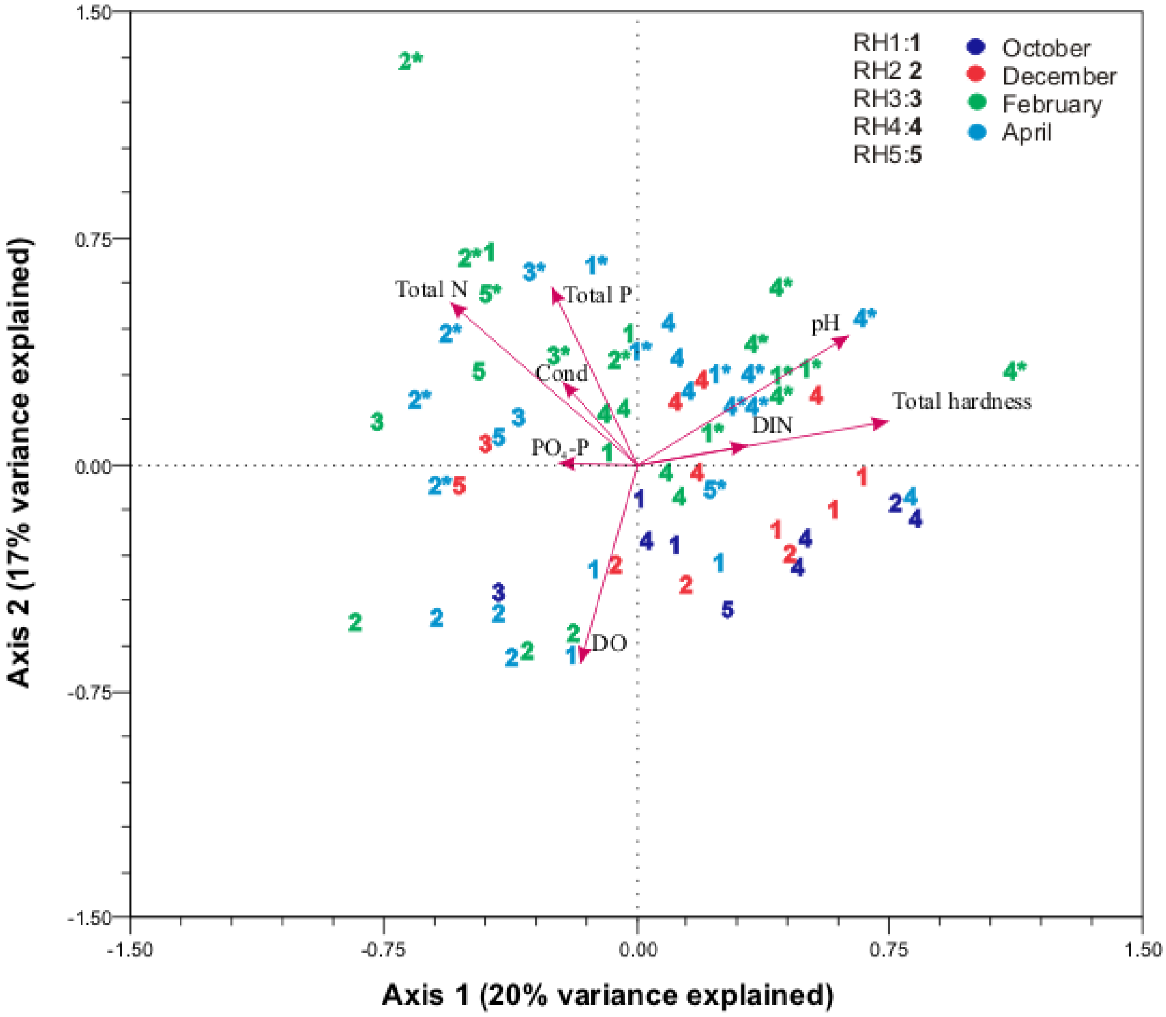

Figure 9. Ordination of samples by Principal Component Analysis (PCA) based on abiotic features, from February 2009 onwards. Numbers 1 to 5 indicate the corresponding water bodies (RH1 to RH5). Samples collected in February and April 2010 are labelled with asterisks (*).

temperature ($r_{RH3+RH5}$ = 0.84; $p < 0.05$), presumably due to salt concentration resulting from the evaporation that was clearly apparent on sunny, warm summer days.

Figure 9 shows the results of the PCA performed on limnological data for the period February 2009 to April 2010. The two first axes explain 37 % of the total variance. The positioning of samples along the first axis (20 % of variance) represents a minero–ombrotrophic status gradient in which RH1 and RH4 have higher scores, associated with higher values of total hardness (eigenvector = 0.75) and pH (eigenvector = 0.63). The second axis (17 % of variance) ordinates the samples along a temporal gradient, with most late summer (February) samples having higher scores and those collected under the coldest conditions (October) represented by lower scores which can be associated with high DO (eigenvalue = -0.65). High TP (eigenvalue = 0.59) and TN (eigenvalue = 0.54) are associated with high scores on this axis. The wide inter-annual variability in these data is demonstrated by the fact that most February and April 2009 samples are positioned in the lower section of the diagram, while February and April 2010 samples are located in the upper part.

DISCUSSION

The character of a peat bog depends on the influence of ground water and on the chemistry of its open water bodies (Holden 2006, Iturraspe 2010). When bogs are partially fed by ground water (minerotrophic conditions), pH and hardness tend towards higher values, whereas the water in dome-shaped bogs fed only by precipitation is softer and more acidic (ombrotrophic conditions; Holden 2006, Rydin & Jeglum 2006, Iturraspe 2010). This is partly due to the high cation exchange capacity of *Sphagnum*, which takes up base cations and liberates protons (Clymo 1964, Roig & Roig 2004, Rydin & Jeglum 2006). Individual pools in the same bog can show very different chemical features, even when they are only a few metres apart. This diversity in abiotic conditions is crucial for the biodiversity of the communities inhabiting the water bodies of Rancho Hambre (Mataloni & Tell 1996).

While the balance between temperature and precipitation accounts in general for the water level fluctuations observed in this study—noticeably the overall decline during the dry, warm December of 2009—size and hydrological connectivity (presence of surface inflows and/or outflows) must be invoked to explain the differences in patterns of water level fluctuation between different water bodies. Among the deep pools, the largest (RH4) had the most stable water level, while the deepest and most hydrologically isolated (RH2) was the most variable. RH1 showed intermediate variation together with the shallow pools (RH3 and RH5), which in turn had the most extreme temperature and EC values among all studied water bodies. Due to their shallowness, temperature-driven evaporation affected a larger proportion of total volume in the shallow water bodies and thus increased ion concentrations, as revealed by the positive correlation between these variables. Despite such local variations, the EC values recorded at Rancho Hambre were all within the low range typical for peat bogs (Iturraspe 2010).

The influence of pool size on physical and chemical attributes was also evident from water temperature data. The smallest pools showed not only higher temperatures but also wider diurnal variations than the largest ones. Low values of pH and total hardness revealed the ombrotrophic character of the shallowest pools (RH3 and RH5); whilst the largest, hydrologically connected water bodies (RH1 and RH4) were more minerotrophic (higher hardness and pH values). The hydrological variability of RH2 was reflected by the wide temporal variation of its limnological features as shown by the PCA plot. These different patterns account for the lack of overall correlations between meteorological and limnological attributes.

One vital environmental factor likely to regulate phytoplankton production (and hence the biomass of all communities) is nutrient limitation (Tilman *et al.* 1982). The measured concentrations of solutes coincided with those generally reported for peat bogs, from bog-lakes in Hungary (Borics *et al.* 2003) to a small tropical peat bog in eastern Bhutan (Sharma & Bhattarai 2005). Ranges of TN exceeded those of TP by 1–2 orders of magnitude, reflecting results reported by Mataloni (1999) for seven peat bogs in Tierra del Fuego. According to Downing & McCauley (1992), TN:TP reflects the nutrient source of a system, with high ratios characterising natural, undisturbed catchments which export much more N than P. This would explain the occurrence of minimum values immediately after the spring thaw (reflecting the "internal" conditions for each pool); and the subsequent increase as the pools received water from their small catchments and as precipitation, both of which are richer in N than P. The high ratios did not necessarily reflect P-limitation of the phytoplankton biomass, since TP concentrations were at least 77 $\mu g\ L^{-1}$ and thus in excess of the level regarded as limiting for phytoplankton growth (Downing & McCauley 1992). However, the maximum DIN:PO_4-P ratio was roughly half the Redfield ratio, indicating that algal growth would be N-limited. Therefore, the question of which of these elements (if either) limits autotrophic production needs to be addressed experimentally. Meanwhile, it is highly desirable to continue characterising the chemical environment using both ratios.

Iturraspe & Roig (2000) found a decline in horizontal water flow at a few decimetres depth in the acrotelm and no vertical water flow through the catotelm in a *Sphagnum* bog. This would explain the differences in limnological features between neighbouring pools belonging to different sub-catchments separated by hummocks (in which the acrotelm/catotelm boundary bulges upwards), rendering small-scale local topography a crucial factor for the diversity of planktonic communities within the same bog. Iturraspe (2010) showed that, in small closed catchments within ombrotrophic bogs, there is continuous water drainage through the acrotelm towards pools. This holds for RH4, around which the position of the water table varied through time depending on rainfall but was always higher than the pool water level (all rWTL values positive). The resulting complementary source of (seepage) water would account for the hydrological stability and minerotrophic features of this water body.

According to the PCA results (Figure 9), several factors seem to combine to determine the characteristics of the water bodies. Topographically determined hydrological connectivity largely influenced the minero/ombrotrophic status of the water bodies by furnishing water sources other than direct rainfall. Topography also modulated the changes in water level due to evaporation losses, and changes in dependent chemical variables such as EC. The higher evaporation losses and large diurnal variations in water temperature at RH3 can be associated with its shallowness. In turn, the limnological effects of connectivity and morphometry vary over two different timescales: while a number of abiotic features such as dissolved oxygen, total N and total P showed seasonal variations, inter-annual weather variability could regulate the intensity of such changes.

The results of this study allow us to characterise the limnological properties of five representative pools on the Rancho Hambre peat bog. The relationships found between meteorological, hydrological, morphometric and limnological features allow us to propose an interpretative model for limnological characterisation that reveals high environmental diversity in both time and space. This may help to explain the high diversity of phytoplankton communities previously recorded in this peat bog and constitutes a valuable tool for understanding the spatial distribution, structure and dynamics of planktonic meta-communities. The same interpretative model will next be tested as a template for the investigation of other Fuegian peat bogs, with a view to developing a baseline data archive for future monitoring of their behaviour and possible alterations.

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Editors: Richard Payne and Olivia Bragg

Author for correspondence:
Gabriela Mataloni, Peatonal San Martin 3563, San Martin, Provincia de Buenos Aires, Argentina.
Postal Code: 1650; Tel: +5411 45807300; E-mail: mgmatal@yahoo.com , gmataloni@unsam.edu.ar