Ecohydrological features of some contrasting mires in Tierra del Fuego, Argentina

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SUMMARY

In November 2005, Tierra del Fuego (Argentina) hosted the biennial conference and field excursion of the International Mire Conservation Group (IMCG). The group considered the vegetation, hydrology, peat stratigraphy and possible management options for about 20 mires which were visited during a seven-day excursion. We report here some field observations and measurements of electrical conductivity (EC_{25}) in five mires which have been selected to encompass the most important ecohydrological features of the mires of Tierra del Fuego. Existing and new data on landscape topography and vegetation were combined in three-dimensional drawings. These drawings are actually conceptual models which could underpin further ecohydrological research, and proved to be very useful as a basis for discussions amongst conference participants about possible ecohydrological relationships. The mires that were studied developed under a wide range of climatic conditions and included fens and bogs. The bogs typically developed from lakes or fens and most are now dominated by *Sphagnum magellanicum*. This species forms large hummocks, and can invade weakly-buffered fens. Most of the mires were well preserved, but effects of human impact - such as road building and peat extraction - were also noticeable.

KEY WORDS: ecohydrology, IMCG, landscape setting, mire types, *Sphagnum magellanicum* bogs.

INTRODUCTION

The mires of the Argentinian province of Tierra del Fuego are numerous and exhibit wide variety (Blanco & de la Balze 2004), but they have little legal protection and it is feared that many will be lost to peat extraction in the near future (Iturraspe & Urciuolo 2005). The biennial field excursions of the International Mire Conservation Group (IMCG) aim to promote international exchange of information and experience relating to mires and factors affecting them, and also to assist local mire researchers in planning conservation measures and 'wise use' practices (see http://www.imcg.net/). The group visited Tierra del Fuego between 21 November and 01 December 2005. Past and present conditions of *ca*. 20 mires were discussed and, for some of them, peat profiles were described and the electric conductivity (EC_{25}) of surface water and groundwater was measured.

The aim of this paper is to provide a rough overview of the different mire types which shows how they are related and how hydrological conditions have influenced their development. For this purpose, we developed three-dimensional drawings which integrate existing information derived from literature with additional field measurements and the observations of a large group of mire experts. These 'working models' are obviously not definitive representations of the ecohydrological functioning of the mires, but rather tools to aid conceptualisation and starting-points for further research. They are presented here to assist in focusing further research on this topic, and to increase awareness of the high value of the almost-intact mire systems of Tierra del Fuego.

METHODS

The mires of Tierra del Fuego

Climate is an important influence on the structure and functioning of Patagonian ecosystems (Paruelo *et al*. 1998). Precipitation is high on the south-west coast and declines to the north-east (Auer 1965, Mauquoy & Bennett 2006). The precipitation gradient can be related to differences in vegetation, which ranges from sub-Antarctic forests in the south to humid-gramineous steppe in the north (León *et al*. 1998).

The mires of Tierra del Fuego (Figure 1) cover a total area of approximately 2,700 km^2, with

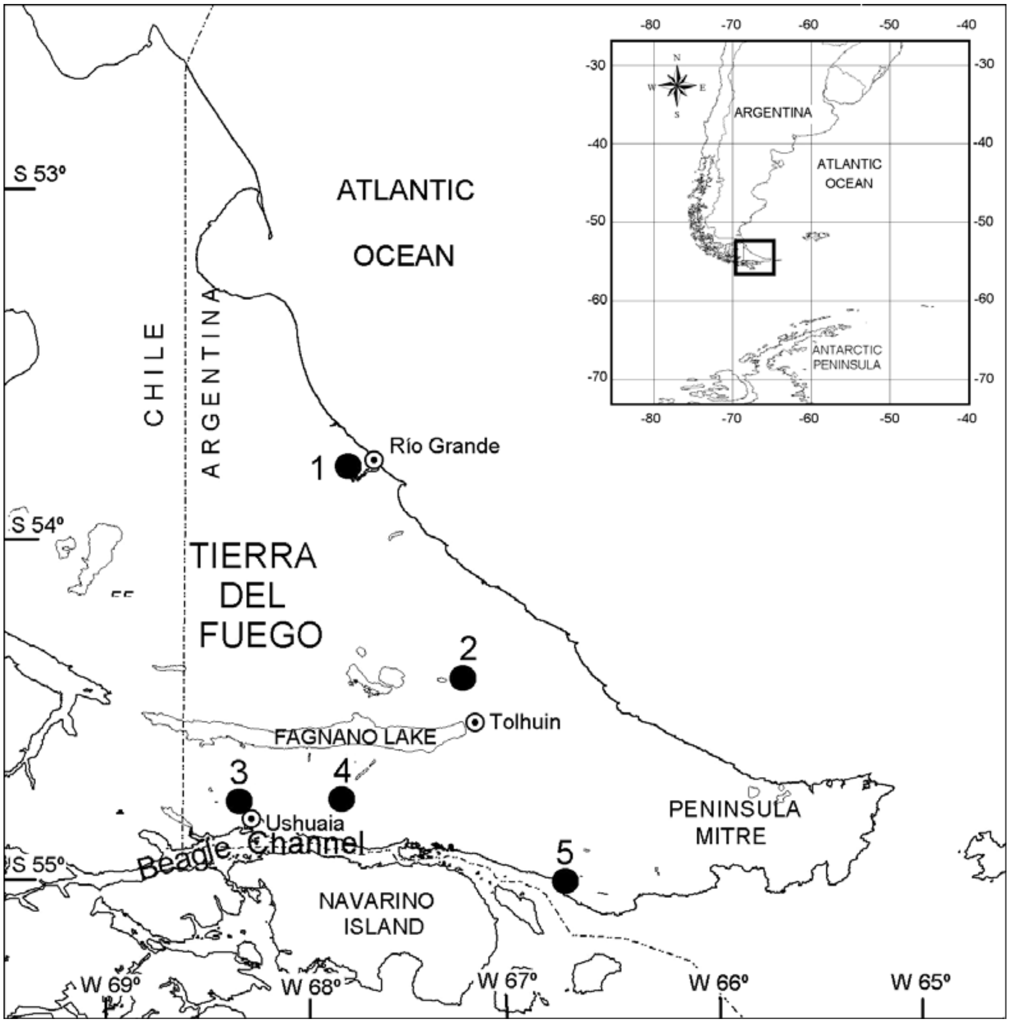

Figure 1. Locations of Tierra del Fuego (inset) and the mires discussed in this article, namely: Maria Behety Fen (1), Maria Cristina Fen (2), Andorra Mire (3), Rancho Hambre Mire (4) and Moat Mires (5).

2,400 km^2 in the uninhabited eastern part known as Peninsula Mitre (Iturraspe *et al*. 2009). Although they have been studied since 1917 (Bonarelli 1917), the work that is most frequently cited in literature on Fuegian Archipelago peatlands is that of Auer (1965). He classified bogs on the basis of stratigraphy, vegetation type and precipitation; using the term 'bogs' in a very general way to include both ombrogenous mires and minerotrophic fens ('steppe bogs'). He distinguished three main bog regions, namely:

(i) steppe bogs in the Fuego Patagonian Steppe (also called the "Magellanic Steppe" by León *et al.* 1998) with annual precipitation <400 mm;

(ii) *Sphagnum* bogs in the area with deciduous beech forests, where annual precipitation is 400–800 mm; and

(iii) rainy-region bogs in the Magellanic Moorland with annual precipitation >1000 mm.

The large mires of Tierra del Fuego have often developed along the bottoms of valleys, on highland prairies and on low-gradient slopes (Rabassa *et al*. 1996). Wetlands occupy 15–20% of the Magellanic Steppe area (Roig *et al.* 1985) and are locally termed "vegas". They are situated in low-lying, rather flat areas with groundwater discharge and sometimes temporary surface runoff. Not all vegas are peatlands, however. Collantes & Faggi (1999) distinguished between permanently and temporarily waterlogged vegas. The first category (mostly south of the Rio Grande River) has peat soils, whereas the soils of the second category have variable organic matter content depending on water availability.

Sphagnum bogs occur in the area with deciduous forests, where there is a clear precipitation surplus throughout the year. These raised bogs are species-poor but extremely diverse at higher organisational levels (Baumann 2006). Most of them have only one *Sphagnum* species - *Sphagnum magellanicum* - which forms hummocks, hollows and all the other complex structures that are typical of bogs. Fens also occur in the southern part of Tierra del Fuego, often in combination with *Sphagnum* bogs. The eastern side of Tierra del Fuego experiences the most oceanic conditions; and here the forest and mires are dominated, respectively, by the evergreen *Nothofagus betuloides* and cushion plants (e.g. *Astelia* spp.) (Iturraspe *et al.* 2009).

The human population density of the province of Tierra del Fuego is low (6 persons km^{-2}), and the rural index is much lower because most people live in urban areas. Consequently, there seems to be relatively little human pressure on the mires. Cattle breeding is an important economic activity in the northern and central regions of the province, and most of the fens are still used for hay production (Anchorena 1985, Anchorena *et al.* 2001). Over recent decades, however, interest has developed in extracting peat for the Argentinean compost market (Iturraspe & Urciuolo 2004).

Field observations

The mires discussed in this article are situated in the Magellan Steppe near Rio Grande (Maria Behety Fen), in an intermediate zone on the Ecotone Steppe near Tolhuin (Maria Cristina Fen), and in the Magellanic Moorland (Figure 1). Ecohydrological models of the mires, which integrated existing knowledge with relevant field measurements and observations, were constructed in order to facilitate discussion of their past and present conditions. For this we used relief and vegetation features obtained from the excursion guide (Iturraspe & Urciuolo 2005) and field data on peat type and peat depth obtained by coring, electrical conductivity (a measure of total dissolved minerals in the water), and flow directions of surface water. For further reading on ecohydrological approaches using such conceptual ‘working models’ we refer to Grootjans & Van Diggelen (2009). The approach is ‘quick and dirty’ but can be very useful in developing hypotheses about mire development, hydrological functioning, and restoration potential where damage has occurred.

Peat coring was carried out using a closed chamber Russian peat corer. Electrical conductivity (EC) was measured with portable EC/temperature equipment (WTW, Germany). At Maria Behety Fen and Maria Cristina Fen, where EC was measured in piezometers which had been installed by Aaron Perez Haase, only the highest values measured at one metre below the surface were recorded because stratification of groundwater and precipitation water had occurred in the upper sections of the piezometers. In most cases, peat thickness was estimated from one or two cores only. No indication of peat thickness is given for the Moat mires due to lack of representative data for this topographically variable landscape. Nomenclature of plant species follows Moore (1983).

RESULTS

Maria Behety Fen

Maria Behety Fen (53º 48' S, 67º 52' W; 20 m a.s.l.) lies within an almost treeless landscape (Figure 2). The hills are covered by low-productivity grasslands with *Festuca gracillima*, and the low-lying areas by sedge fen vegetation dominated by *Hordeum halophilum* and *H. lechleri* with *Caltha sagittata, Carex gayana, Carex macrosolen* and *Trichlochin palustris*. The peat layer is almost three metres thick and consists almost entirely (260 cm) of fen peat interspersed by thin mineral layers. It is underlain by a 70 cm layer of lake sediments.

There had been some very heavy rain showers immediately prior to the site visit, and low-lying areas were flooded because the small stream was unable to accommodate all of the surface discharge, and had overflowed. EC measurements in a small spring and in some piezometers (Figure 3) indicated that the fen was fed by groundwater with relatively low electrical conductivity (220–350 µS cm^{-1}). One piezometer which had a filter one metre below the surface yielded an extremely high EC value (3,500 µS cm^{-1}). Stagnant surface water and the water in the stream also had high EC values.

Maria Cristina Fen

The Ecotone Steppe is characterised by low rounded hills, gentle slopes and a mosaic of bogs, fens and forests. The distribution of the peatlands is closely linked to glacial geomorphology (Coronato *et al*. 2006).

Maria Cristina Fen (54º 24' S, 67º15' W; 165 m a.s.l.) occupies a narrow valley with a small central stream, and is bordered on both sides by forest (Figure 4, Figure 5). Most of the fen is covered by sedge vegetation, but there are locally extensive patches of *Sphagnum magellanicum* bog. Small streams draining the forested hillslopes discharge surface water into the fen, the rivulets disappearing completely within *ca*. 20 m of the mire edge as the water disperses into the peat.

Figure 2. General view of Maria Behety Fen (left), showing the partly flooded sedge fen vegetation and low-productivity grassland on the surrounding slopes. The valley is grazed by sheep. A large spring (right) supplies the downstream part of the fen with groundwater.

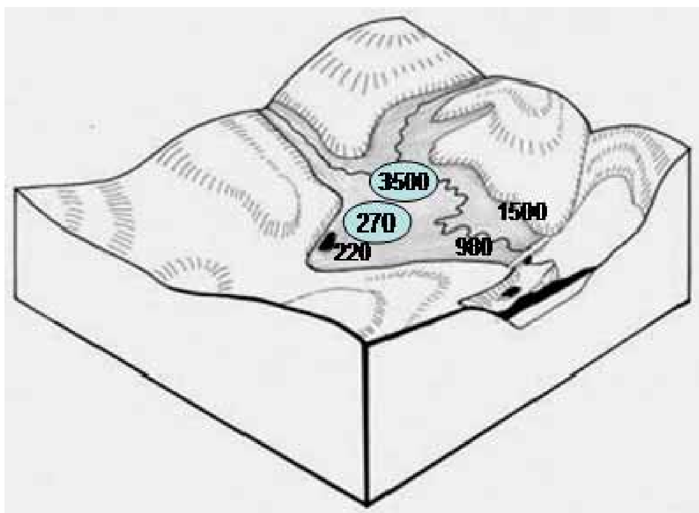

Figure 3. Electrical conductivity (EC in µS cm^{-1}) measurements recorded on Maria Behety Fen (28 November 2005). The values shown within (blue) ellipses were measured in piezometers, and the others in surface water.

The electrical conductivity of surface water from the hillslopes is rather low (117 µS cm^{-1}) and the water can be traced flowing between the large *Sphagnum* carpets until it reaches the small stream in the centre of the valley. The new tarred road along the edge of the fen influences the discharge of the two streams entering from the hillside. One stream has been diverted into a ditch which discharges into the other stream, whose increased flow in turn enters the valley *via* a culvert. However, this has not caused erosion in the fen at the point of entry. Local iron-rich groundwater pools at the valley margin have high EC values (240 µS cm^{-1}), indicating groundwater discharge.

Very high EC values (550–650 µS cm^{-1}) were measured in the piezometers installed by Aaron Haase on the eastern side of the valley. These values are in the range for calcareous groundwater.

Large tussocks of *Sphagnum magellanicum* have invaded the fen vegetation. Where the tussocks have merged, a shallow carpet of *Sphagnum magellanicum* bog is formed on top of the fen. EC values measured in the surface water between *Sphagnum magellanicum* hummocks were low (113 µS cm^{-1}).

Soil descriptions showed that this mire originated as a lake. A shallow (50cm) lake deposit was found just above the mineral substratum, and this was overlain by a thick (266 cm) sedge peat layer. *Sphagnum* peat was found only in the top 30 cm of the profile, indicating that invasion by *Sphagnum magellanicum* had started very recently.

Figure 4. General view of Maria Cristina fen showing sedge vegetation with large *Sphagnum magellanicum* hummocks (top left). The fen discharges groundwater and surface water into a very small stream (<1 m wide) (top right). Large hummocks of *Sphagnum magellanicum* are developing near the fen margin (bottom left). At a later stage, these hummocks merge to form a thin blanket of S*phagnum magellanicum* (bottom right).

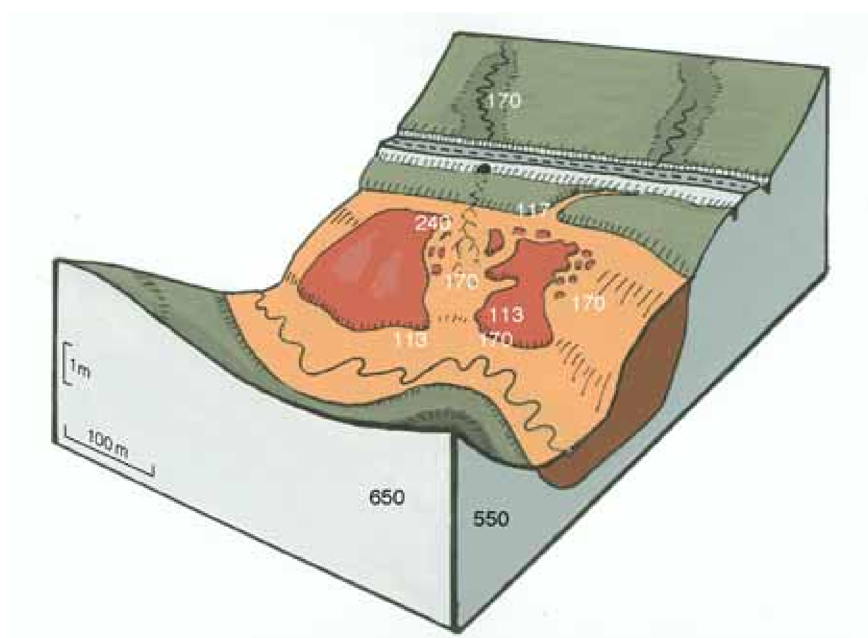

Figure 5. EC values (in $\mu S\ cm^{-1}$) measured in groundwater (black digits) and surface water (white digits) at the Maria Cristina Fen on 27 November 2005. Red: *Sphagnum magellanicum* bog; orange: fen.

Andorra Mire

The Andorra mire (54º 75' S, 68º 33' W; 200 m a.s.l.) is a large raised bog complex situated in a valley between large mountains of the Andes, which provide good shelter from strong winds. Forests of *Nothofagus pumilo* and *N. antarctica* are present on the lower slopes of the hills.

Four large *Sphagnum* bogs overlie an extensive fen system which is now visible only at the valley margins (Figures 6–8), the *Sphagnum* peat having overgrown the fen (radicell) peat (Baumann 2006). Small rivers between the bogs carry groundwater and surface water into the Arroyo Grande River. The whole system slopes towards the end of the valley.

The vegetation of the fen is quite diverse and includes species such as *Carex banksii*, *C. curta*, *Koeleria fueguina*, *Caltha sagittata*, *Acaena magellanica* and *Gentiana magellanica*. Small spring forests with *Nothofagus* carr are situated on thin peat where much groundwater discharges. This spring environment is very unstable and dynamic, and there is considerable erosion of the peat here. Some parts are extremely wet and most of the trees have died or fallen over (Figure 7). Other locations have been drained by erosion channels, and dense scrub has developed around these. Channels dug by beavers have added further drainage.

The bogs are characterised by very dense *Sphagnum* vegetation and very low (<5%) cover of vascular plants. The shrub layer is dominated by *Empetrum rubrum* and *Nothofagus antarctica*. Important sedges and herbs are *Tetroncium magellanicum*, *Carex magellanica*, *Rostkovia magellanica* and *Marsippospermum grandiflorum*. *Sphagnum magellanicum* dominates hummocks, lawns and pools. It grows most vigorously in hummocks at the fen–bog transition, where

Figure 6. General view of the Andorra mire, whose singular appearance (top left) arises from the red/orange colour of *Sphagnum magellanicum*. This species can grow so rapidly that it overgrows other living *Sphagnum* layers (top right). At the margin of the bog adjacent to the Arroyo Grande River, the advancing wall of *Sphagnum* can be as high as three metres (bottom left). The small stream emerging from the bog margin discharges precipitation water from the bog (only) across the lower-lying lagg, which is covered by the minerotrophic species *Sphagnum fimbriatum* (bottom right).

Figure 7. Fen habitats at the margins of Andorra Mire. Groundwater-fed springs on shallow peat cannot sustain the growth of large trees (top left). Spring rivulets which also receive surface water from small streams on the surrounding hillsides erode into the marginal fen (top right). The less-damaged parts of the fen discharge groundwater *via* so-called 'soaks', which are very wet with slow groundwater flow (bottom left). *Caltha sagittata* (bottom right) is a characteristic species of such groundwater-fed soaks.

hummocks rising to more than one metre above the water table and poor fen vegetation are common. On the other hand, *Sphagnum falcatulum* and *Sphagnum cuspidatum* occur only in pools, where their biomass is usually very low. Apparently, the growth of *Sphagnum* species is severely limited in open water bodies.

Peat cores were examined at four locations which are shown in Figure 8. Core 1 consisted of well-preserved *Carex* fen peat 250 cm thick, of which only the top 10 cm was decomposed. Between the large *Sphagnum* bogs (Core 2), the fen peat was 300 cm thick and interrupted at about 240–250 cm depth by a thin sandy layer, which indicates that intensive flooding occurred after a period of undisturbed fen development. Core 3 had *Sphagnum* peat to a depth of only *ca*. 50 cm. Fen peat appeared at a depth of 150 cm and ended at 700 cm. Core 4 sampled peat to a depth of more than 1200 cm. The bog peat was more than 600 cm thick, indicating that bog formation started many centuries ago.

A beaver dam at the upper end of the bog has raised the water level by *ca*. 150 cm, creating a large pond of nutrient-rich water from a surface stream (EC 130 µS cm^{-1}) across parts of the bog and the adjacent forest. EC values of about 130 µS cm^{-1} also occur in the rivulets that cross the bog. Some small rivulets have also formed in the narrow lagg zone, but EC values here are low (*ca*. 40 µS cm^{-1}).

Rancho Hambre

This bog complex (54º 45' S, 67º 49' W; 140 m a.s.l.) is located in a wide glacial valley (Figure 9) which is fed mainly by rain (*ca*. 700 mm year^{-1}) and surface water. Most of the surface water originates from two upslope rivulets (Figure 10). This water has a relatively high EC of 100–200 µS cm^{-1}. The bog between the two rivulets has a very low EC of 14–50 µS cm^{-1}. The surface water from the hill is collected by a ditch alongside the road and this

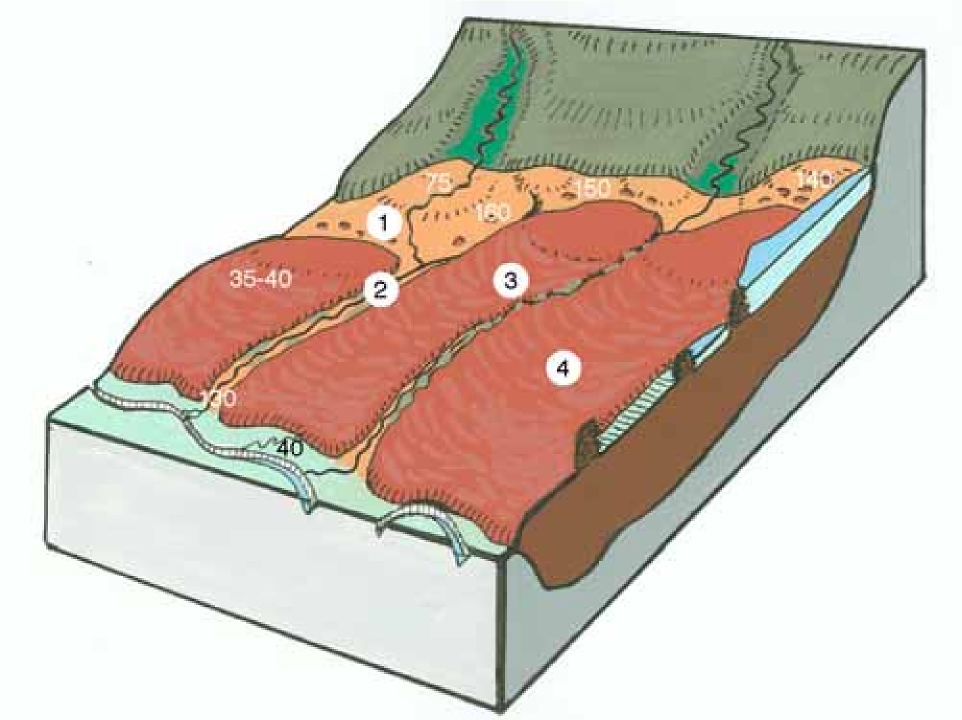

Figure 8. Sketch of the Andorra mire showing the EC values (in μS cm^{-1}) measured in surface water (white digits) on 23 November 2005. The white circles indicate the locations where peat profiles were described. *Sphagnum magellanicum* bog is shown in red, fen in orange and open water in blue.

water is channelled into the mire complex by two culverts. This means that the water from the slope is concentrated into two streams. As a result, the water sometimes floods previously non-flooding areas, and its erosive power has increased. This recent change in water flow, combined with beaver activity, has probably caused local death of *Nothofagus* scrub at the mire margins.

Peat profile descriptions showed that the peat is 390 cm thick. A basal layer of lake sediment is overlain by 110 cm of *Tetroncium* radicell peat with some *Sphagnum* remains and about 10 cm of radicell and sedge peat. Remarkably, the thick upper layer of *Sphagnum* peat is interrupted after 150 cm by 20 cm of *Tetroncium* and *Carex* radicell peat, whose upper surface lies 70 cm below the present ground level. The composition of this radicell peat resembles a vegetation type that is commonly found at the margins of pools, especially those that are connected to nutrient-rich groundwater.

Moat Mires

The mire landscape in Moat (54º 56’ S, 66º 41’ W; 400 m a.s.l.) is characterised by abundant peat-forming cushion plants such as *Donatia fascicularis* and *Astelia pumila*. Bogs dominated by *Sphagnum magellanicum* are also present, but they are relatively small and occur only in sheltered locations with vegetation indicative of nutrient enrichment (e.g. Poaceae and *Nothofagus*; Figure 11). The exposed peat plains are dominated by *Astelia pumila*, a cushion pant which forms rigid ‘blankets’ and sometimes real hummocks, and gives the mire a green appearance. *Donatia fascicularis* is also present, but less frequent. As distance from the coast increases, the occurrence of *Astelia* mire decreases, whereas the frequencies of *Sphagnum* mire, *Marsippospermum grandiflorum* and *Empetrum rubrum* increase.

Figure 12 shows an impression of the mire landscape near Moat. The whole landscape is covered by peat whose thickness ranges from 50 to 900 cm. *Nothofagus betuloides* grows in tree form on well-drained peaty slopes, and forms dense forest patches on sandy hills (drumlins) and rock outcrops. A lake is present at the highest point of the blanket bog system. This is more than four metres deep and sheltered from the wind by trees and two small hills. *Sphagnum magellanicum* dominates the area around the lake, where the EC values measured were in the range 60–95 μS cm^{-1}. There is an *Astelia pumila* mire slightly below the summit. This has numerous

Figure 9. General view of the Rancho Hambre mire complex showing large pools within the *Sphagnum* bog (top left). The bog itself is enclosed by surface water gullies with small islands of *Sphagnum magellanicum* (top right). *Sphagnum* has died in some exposed areas, probably due to desiccation, but *Sphagnum* growth has re-started from the pools (bottom left). Where surface water discharge from the surrounding valleysides has been concentrated as a result of road-building, small forest tickets have been drowned (bottom right).

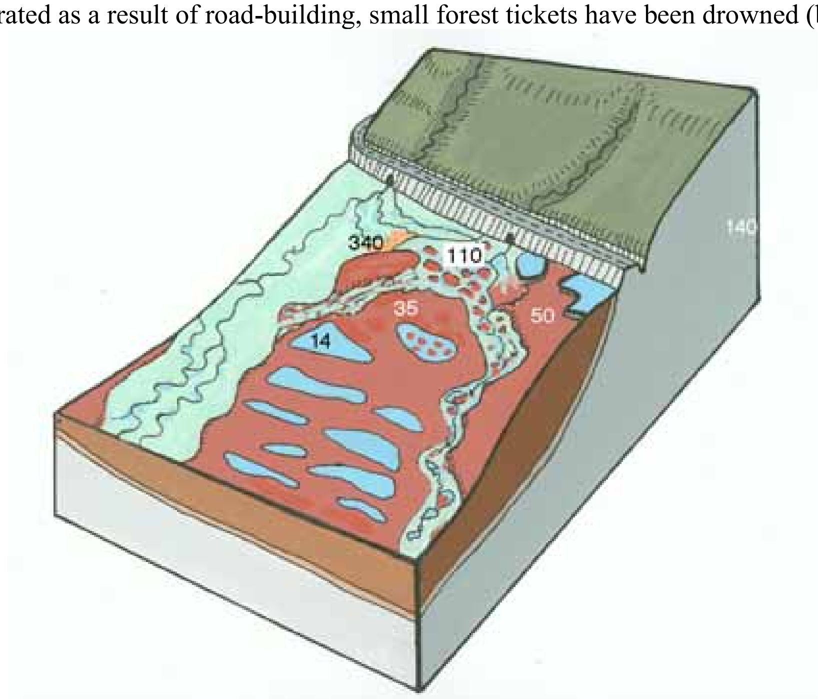

Figure 10. Impression of the Rancho Hambre mire complex. Large *Sphagnum magellanicum* bogs (red) with large pools are intersected by shallow surface water channels (green-blue) containing small *Sphagnum* bog islands. Digits show EC values ($\mu S\ cm^{-1}$) measured in surface water on 25 November 2005. The white rectangle indicates the location where a peat profile was described. Blue: open water; grey/green: forest.

Figure 11. View across the dense *Astelia pumila* carpet at Moat Mires (top left). Within these very exposed mires, *Sphagnum magellanicum* hummocks and lawns are restricted to the sheltered margins of pools (top right). Some exposed flat areas have extensive dead *Sphagnum*, but the *Sphagnum* is recovering in more sheltered areas (bottom left). *Sphagnum* growth can be very abundant on sheltered slopes (bottom right).

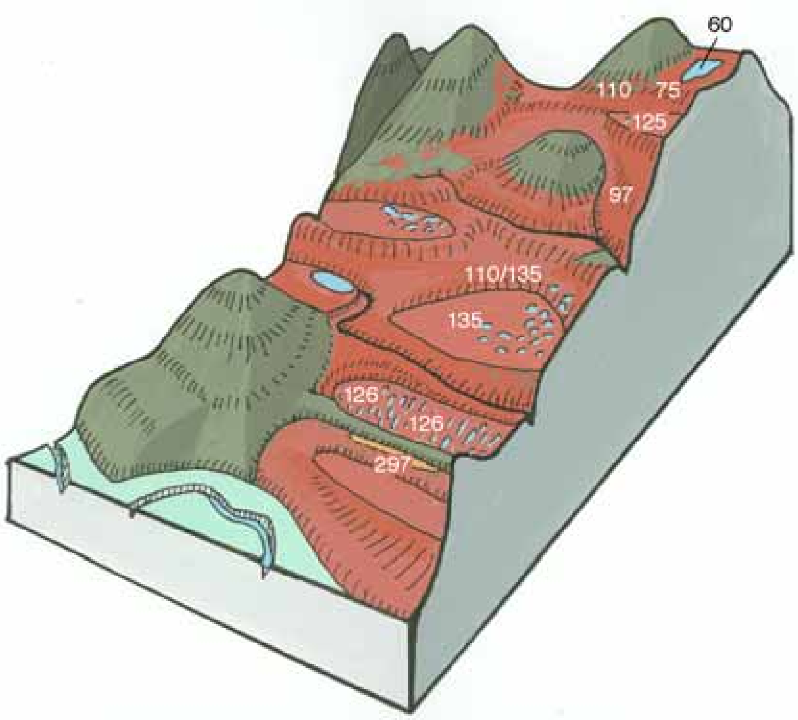

Figure 12. Impression of the extensive blanket bog at Moat mires. Cushion plants dominate on the plateaux, but there are S*phagnum magellanicum* hummocks on more sheltered slopes and in forests (grey). EC values (μS cm^{-1}) were measured in the surface water on 26 November 2005.

pools with higher EC values (125 μS cm^{-1}). Here, *Sphagnum magellanicum* appears to be confined to the pools by the surrounding *Astelia pumila* carpet, even though it is a hummock-forming species.

Examination of the peat profile showed that the development of *Astelia* is relatively recent. In the area cored, *Astelia* peat is present to a depth of *ca*. 100 cm and this is underlain by 400 cm of *Sphagnum* and *Tetroncium* peat. The lowest parts of the profile are dominated by root and wood peat with occasional fragments of *Tetroncium* and *Empetrum*. The *Astelia*-*Sphagnum* interface is not well defined because the *Astelia* peat is highly decomposed. Surprisingly, densely-packed living *Astelia* roots were found up to 150 cm below the surface.

DISCUSSION

Mire development in Tierra del Fuego appears to follow the classic pattern described by Weber (1902) and Moore & Bellamy (1974) for European mires, in that most of the mire systems started as lakes or fens and then became bogs. In the north-eastern Fuegian Steppe, evaporation rates are too high and precipitation insufficient (Blanco & de la Blaze 2004) to support *Sphagnum* growth. Thus, *Sphagnum* mires are more common in the south-west and decline towards the north-east. This is also totally consistent with the spatial pattern of annual precipitation totals.

The large water-holding capacity of dense lawns and hummocks of *Sphagnum magellanicum* (Köpke 2005) may explain why hummocks can grow to heights exceeding 100 cm above the water table. Such large hummocks of *Sphagnum magellanicum* often occur in fens where groundwater inflow has decreased but the bicarbonate content is still too high to allow the development of extensive *Sphagnum* lawns (*cf*. Lamers *et al*. 1999). When small local lenses of rainwater are formed, the mixing of rainwater and groundwater may provide a large supply of CO_2, which could enable *Sphagnum magellanicum* to grow sufficiently vigorously to out-compete vascular plants and initiate hummock formation.

Maria Behety Fen

According to Iturraspe & Urciuolo (2002), the mean annual precipitation at Río Grande for 1974–2001 was 333 mm, while the mean annual potential evapotranspiration for the same period was 610 mm. Thus, a high water balance deficit arises during the summer months. Rainwater-fed bogs cannot grow under such conditions, and the mires of this region are mainly fens fed by groundwater. Bahety Fen regularly dries out during the summer, except for the large spring.

EC values measured in local springs were only 220–350 μS cm^{-1}, so it is unlikely that the very high EC values (>1000 μS cm^{-1}) measured in the surface water reflect groundwater discharge. Rather, they probably resulted from the dissolution of salt which had accumulated in the surface layers of the soil during dry weather by the heavy rain which fell shortly before the site visit.

Maria Christina Fen

This mire is situated in a transitional zone from mountain range to steppe, where precipitation (500 mm $year^{-1}$) and potential evapotranspiration are in equilibrium. The thin *Sphagnum magellanicum* carpet is a recent phenomenon. The peat profile did not indicate that bog formation had occurred in the past, and it is inferred that the discharge of ground and surface water was previously too large to permit *Sphagnum* growth. The most interesting feature of the fen is that the peat can apparently ‘absorb’ not only groundwater flow but also surface water from the flanking hillslopes.

It is unclear why *Sphagnum* growth is now so vigorous. The shift from fen to bog may be related to human impact, for example the introduction of cattle, but it is more likely that some hydrological changes have occurred during the last century. The interplay between human impacts and hydrological changes warrants further investigation.

Andorra Mire

Peat formation in parts of Andorra Mire started some 9,300 ^{14}C years ago (Borromei *et al*. 2007), simultaneously with other bogs in the vicinity (Heusser 1995). *Sphagnum magellanicum* growth probably began several thousand years later. We think that stream water from the surrounding slopes previously entered the fen at its margins and crossed the mire either as seepage through the peat or as a very small stream (Figure 13). This route is no longer available because development of the bog has progressively diverted this flow around its margins, triggering much erosion. Ongoing erosion further weakens the inhibiting influence of mineral- rich groundwater on *Sphagnum* invasion. Extreme rainfall and snowmelt events may also have affected development of the present drainage pattern.

Several eroding spring systems were found, and these have caused much drainage leading to vigorous growth of scrub. Shifting groundwater flows create opportunities for trees at one location,

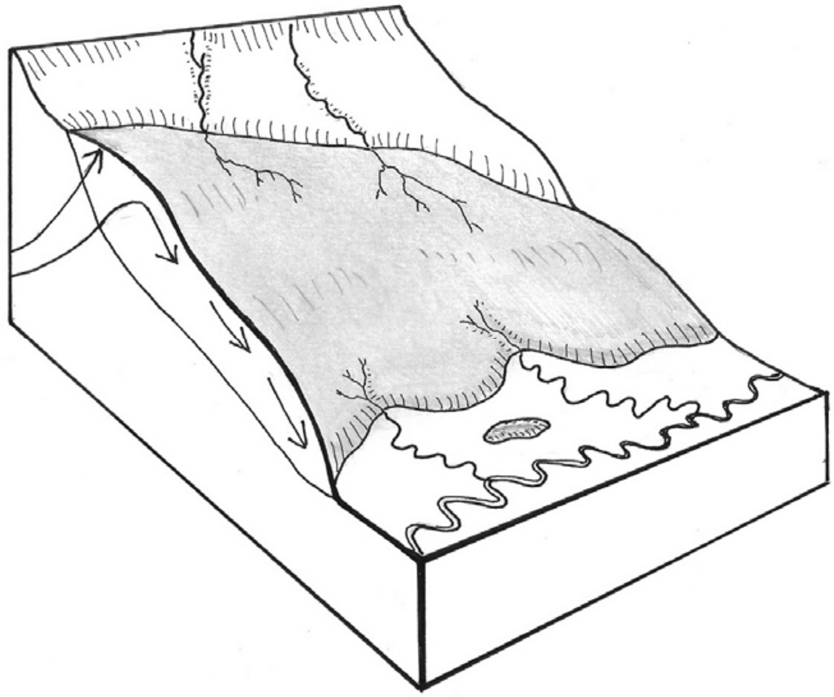

Figure 13. Impression of the Andorra fen before formation of the *Sphagnum magellanicum* peat.

but may drown trees elsewhere so that strong winds can easily blow them over. The presence of dry drainage channels suggests that groundwater and surface water flows may sometimes shift position, altering the spatial pattern of drainage. Some subsurface flow still occurs *via* 'soaks' through the fen which are marked by abundant *Caltha sagittata*. All of the soaks and eroding streams eventually converge on three rivulets which discharge into the main Arroyo Grande river.

Andorra Mire is an excellent example of a mire complex that shows all possible stages of mire formation and interaction between fen and bog. The current initiative to establish it as a Ramsar site, and thus to halt the ongoing extraction of peat from its periphery is, therefore, fully justified.

Rancho Hambre Mire

Sphagnum magellanicum is again the dominant bog species at Rancho Hambre but, in contrast to the situation at Andorra Mire, the discharge of groundwater appears to be very limited. We found only a very small zone with discharge of iron-rich groundwater. When we visited the mire, surface water flow was very active in small watercourses and pool systems. The effect of mineral-rich surface water in preventing the establishment of *Sphagnum* lawns is demonstrated by the predominance of *Sphagnum magellanicum* hummocks and the lack of pool vegetation. Substantial water table fluctuations and an anoxic root zone may further inhibit *Sphagnum* growth.

The mire originated as a lake which became filled with peat. *Sphagnum* growth began at a very early stage, but the peat contains many radicells, possibly from *Tetrontium magellanicum.* The preponderance of poor fen vegetation and the presence of *Sphagnum fimbriatum* suggest that the inflowing groundwater has low pH and buffering capacity, so that rainwater influence supporting the establishment of *Sphagnum* vegetation could arise early in bog development.

Road building appears to have concentrated the flow of surface water into the culverts, and the death of all of the small forest thickets on the western flank of the valley is most likely due to a consequent increase in the frequency of flooding. A small forest at the eastern side of the mire has been drowned as a result of dam-building by beavers.

Moat Mires

At regional scale, *Astelia* mires occur mostly under conditions of perhumid climate with strongly desiccating winds, high annual rainfall (800–5000 mm yr^{-1}), low summer temperatures and mild winters (Pisano 1983, Tuhkanen 1992, Kleinebecker *et al*. 2007). Continuous leaching by rain means that the landscape is generally very poor in soligeneous minerals and nutrients (Pisano 1983, Zarin *et al*. 1998). Annual rainfall may exceed 800 mm in Moat (Iturraspe *et al*. 2009), and the apparent affinity of *Astelia* vegetation with coastal locations may in fact reflect a similar climatic pattern at the scale of the Moat valley (Roig & Collado 2004).

In the Moat mire system, large *Sphagnum* hummocks occur only in sheltered locations with low EC values (indicating low evapotranspiration) on forested slopes and close to thickets of small trees (see also Auer 1965). In areas that are exposed to the wind, *Astelia pumila* dominates and *Sphagnum magellanicum* is 'pushed back' to the low-lying pools and their margins. This may reflect the desiccating effect of wind on *Sphagnum* biomass production. Pools dominated by *Sphagnum magellanicum* have higher EC values than *Astelia* sites. Groundwater may enter these pools, introducing additional mineral nutrients, when water levels are high. In fact, the highest EC values (*ca*. 300 $\mu S\ cm^{-1}$) - and luxuriant swamp vegetation - were found at both sides of a mineral ridge, indicating influxes of mineral-rich groundwater originating from the ridge itself.

The peat stratigraphy shows that *Astelia pumila* invaded the Moat mires, replacing *Sphagnum*, 2,630 ^{14}C years ago (Heusser 1995). *Sphagnum magellanicum* apparently lacks the ability to recolonise once it has been out-competed by *Astelia pumila*. However, further investigation is needed to unravel the factors influencing competition between these two species. Our field observations suggest that inhibited *Sphagnum* growth (lack of hummocks) due to desiccation and lack of nutrients may favour the development of *Astelia pumila* cushions, and that wind may play an important role in preventing the recolonisation of dry *Astelia* cushions by *Sphagnum*.

CONCLUSION

Tierra del Fuego is a veritable observatory for near-natural mire formation in a remote part of the world which is, nevertheless, very close to urban areas with a well-developed infrastructure for tourism. Most of the mires have been little affected by human activity so far, although people have influenced fens in particular since the beginning of the 20th century. Peat extraction by small local enterprises may not seem a serious threat to the large variety of mire types in Tierra del Fuego, but other global examples have shown that local activity may develop rapidly into large-scale mechanised operations capable of depleting local peat reserves within a very short time period. Hopefully the mires we visited in Tierra del Fuego will remain available for future generations to enjoy as living ecosystems with their special biodiversity. Although the variety of species is low, many of them are endemic and cannot be found outside this limited area. Nowadays, even large peat companies agree that horticultural and energy peat should not be extracted from pristine mires. Alternative non-destructive forms of land use should be developed and promoted for peatlands here. It is encouraging that Ushuaia City Council has given support to a provincial plan to acknowledge the Andorra Valley Glacier and the magnificent Andorra Mire as a Ramsar site. We hope that further similar initiatives will follow.

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