Hydrogeomorphic classification of mire ecosystems within the Baker and Pascua Basins in the Region Aysén, Chilean Patagonia: a tool for their assessment and monitoring

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A Ana María, por darme la vida, la curiosidad y la porfía

A Ximena, por ser raíz y regazo, aún en las distancias más insólitas

A Peter y Don Rosamel, por los vitales mates mañaneros

A Marvin, por nuestros sueños de mundo y los caminos por andar

Desde que la espada y la cruz desembarcaron en tierras americanas,
la conquista europea castigó la adoración de la naturaleza,
que era pecado de idolatría, con penas de azote, horca o fuego.
La comunión entre la naturaleza y la gente, costumbre pagana,
fue abolida en nombre de Dios y después en nombre de la Civilización.
En toda América, y en el mundo, seguimos pagando
las consecuencias de ese divorcio obligatorio.

-Eduardo Galeano-
(1940-2015)

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Abstracts

"Hydrogeomorphic classification of mire ecosystems within the Baker and Pascua Basins in the Region Aysén, Chilean Patagonia: a tool for their assessment and monitoring"

Ten unexplored and pristine mires along the Baker and Pascua River Basins in Aysén, Chilean Patagonia, were examined, generating information about their origin, hydrology, geomorphology, stratigraphy, ecology, and carbon and water storage capacities. Eight mire types ecologically differentiable, associated with five main mire types separable by their hydrology and geomorphology were detected, as well as eleven organic substrate types forming mire soils. The information gathered allows for a first estimation of the peat, fresh water and carbon content stored in the mires of Aysén, as well as for an average growth and annual accumulation rate of the peat. Mire types and their associated substrates are systematized in a hydrogeomorphic classification system, integrating important landscape, hydrological, geomorphical, ecological and pedological components. Research and communication about mires in the Chilean Patagonia should be further supported to generate accurate monitoring tools and participative conservation strategies that are replicable for the preservation of these ecosystems and its balance.

Keywords: Patagonia mires, classification of mires, mires geomorphology, mires hydrology, mires ecology, soil organic substrates, mires carbon storage

Zusammenfassung

„Hydrogeomorphische Klassifikation von Moorökosysteme der Einzugsgebiete der Flüsse Baker and Pascua in der Region Aysén, Chilenische Patagonien: ein Werkzeug zu ihre Bewertung und Monitoring“

Zehn unerforschte und natürliche Moore entlang der Flüsse Baker und Pascua in der Region Aysén, im chilenischen Patagonien, wurde untersucht, um Informationen über ihre Entstehung, Hydrologie, Geomorphologie, Stratigraphie, Ökologie und Wasser- und Kohlenstoffspeichervermögen zu gewinnen. Es wurden acht verschiedene ökologische Moortypen identifiziert und fünf Moortypen unterscheidbar durch ihr geohydromorphologisches Setting mit insgesamt elf verschiedenen organischen Moorsubstraten. Die gesammelten Information erlauben erste Abschätzungen der Torf-, Süßwasser- und Kohlenstoffmengen, die in den Mooren Ayséns gespeichert sind, sowie der jährlichen Torfakkumulationsraten. Die Moortypen und die in ihnen vorkommenden organischen Substrate wurden in einem geohydromorphologischen Klassifizierungssystem zusammengefasst, welches wichtige hydrologische, geomorphologische, ökologische, bodenkundliche und landschaftliche Parameter integriert. Forschung und Kommunikation über die chilenischen Moore sollen durch diese Arbeit unterstützt werden, um angemessene Monitoring Tools und partizipative Naturschutzstrategien zu entwickeln, die für die Erhaltung dieser Ökosysteme und ihrer Kreisläufe anwendbar sind.

Schlagwörter: Moore in Patagonien, Klassifikation von Mooren, Moorgeomorphologie, Moorhydrologie, Moorökologie, organische Bodensubstrate, Kohlenstoffspeicherung in Mooren

Resumen

„Clasificación hidrogeomórfica de turberas en las cuencas de los ríos Baker y Pascua en la Región de Aysén, Patagonia Chilena: una herramienta para su evaluación y monitoreo “

Diez turberas prístinas e inexploradas fueron examinadas en las cuencas de los ríos Baker y Pascua en Aysén, Patagonia Chilena, generando información sobre sus orígenes, hidrología, geomorfología, estratigrafía, ecología y capacidad de almacenamiento de carbono y agua. Ocho tipos de turberas ecológicamente diferenciables, asociadas a cinco tipos de turberas separables de acuerdo a su hidrología y geomorfología fueron detectadas, así como once tipos de sustratos orgánicos formando los suelos de las turberas. La información producida permite una primera estimación del volumen de turba, agua dulce y contenido de carbono almacenados en las turberas de Aysén, así como un promedio de crecimiento y acumulación de la turba. Los tipos de turberas y sustratos asociados son resumidos en un sistema de clasificación hidrogeomórfica, integrando importantes componentes paisajísticos, hidrológicos, geomórficos, ecológicos y pedológicos. Debe continuar el apoyo a la investigación y comunicación sobre turberas en la Patagonia Chilena, a fin de generar herramientas precisas y participativas de evaluación y monitoreo en pro de la preservación de estos ecosistemas y su balance.

Palabras clave: turberas de Patagonia, clasificación de turberas, geomorfología de turberas, hidrología de turberas, ecología de turberas, suelos de sustratos orgánicos, almacenamiento de carbono en turberas

Table of Contents

Index of Figures

Index of Tables

List of Abbreviations

AMS:	accelerator mass spectrometry
Ax:	extraccion of aggregates (human-made change)
B:	burn (human-made change)
bB:	blanket bogs
BD:	bulk density
bF:	blanket fens
Bm:	brown mosses
BP:	Bajo Pascua Site
Cal yr BP:	calibrated years before the present
C/N:	carbon to nitrogen content
C:	carbon content
$CaCO_3$:	calcium carbonate
Cmbs:	centimeters below the surface
Cn:	canalization (human-made change)
Corg:	organic carbon
Cpl:	cushion plants
Ct:	cut of trees (human-made change)
D:	digging (human-made change)
DD:	degree of peat decomposition
fFh:	horizon formed by lake organic sediments (organic gyttja) and peat remains under permanent reduced conditions (KA 5)
flH:	flooded hummocks
fMm:	mesotrophic floating mat
fMo:	oligotrophic floating mat
FP:	flood plain
frH:	forest-covered hummocks
FT:	fluvial terrace
FTB:	flow-through bog
g cm^3:	grams per cubic centimeter
GLOF:	glacial lake outburst flood
Gyo:	organic gyttja (peat classification system for Aysén)
Ha:	amorphous peat (KA 5)
Ha:	hectare
HGM:	hydrogeomorphic mire types

Hgmm:	brown moss peat (peat classification system for Aysén)
Hgr:	radicels peat (peat classification system for Aysén)
Hgsc:	*Schoenoplectus* peat (peat classification system for Aysén)
Hha:	*Scheuzeria* peat (KA 5)
Hhi:	*Ericaceae* peat (KA 5)
Hhk:	pine bog peat (KA 5)
hHo:	peat horizon formed by semi-decomposed remains of typical ombrogenic mire plants. Reddish to black colours due to oxidized and hydroxidized iron–manganese unions are visible (KA 5)
hHr:	peat horizon formed by semi-decomposed remains of typical ombrogenic mire plants. Horizon under permanent reduced conditions (KA 5)
Hhsa:	*Sphagnum acutifolia* peat (KA 5)
Hhsu:	*Sphagnum cuspidata* peat (KA 5)
Hhsy:	*Sphagnum cymbifolia* peat (KA 5)
hHw:	peat horizon formed by semi-decomposed remains of typical ombrogenic mire plants. Horizon under altering water tables presenting reduced and oxidative conditions (KA 5)
Hnb:	brown mosses peat (KA 5)
Hnd:	*Cladium* peat (KA 5)
Hne:	cottongras peat (KA 5)
Hnle:	alder carr forest peat (KA 5)
Hnmy:	menyanthes peat (KA 5)
Hnp:	reed peat (KA 5)
Hnq:	*Equisetum* peat (KA 5)
Hnr:	radicels peat (KA 5)
Hoas:	cushion plants peat (peat classification system for Aysén)
Hob:	*Oreobolus* peat (peat classification system for Aysén)
Hoc:	cypress wood peat (peat classification system for Aysén)
Hoi:	ericaceaen peat (peat classification system for Aysén)
Hosa:	*Sp. fimbriatum* peat (peat classification system for Aysén)
Hosy:	*Sp. magellanicum* peat (peat classification system for Aysén)
Hulb:	betula carr forest peat (KA 5)
Hulk:	pine carr forest peat (KA 5)
IMD:	intermountain depression
IPCC:	intergovernmental Panel on Climate Change
KA 5:	German Soil Mapping Directions KA5
km:	kilometer

L:	livestock (human-made change)
LOI:	Lost on Ignition
LR:	Los Remolinos Site
LV:	Lago Vargas Site
ME:	mire ecotypes
mm y^{-1}:	millimeters per year
mm:	millimeters
MWT:	mire water table (in cmbs)
N:	nitrogen content
nHo:	peat horizon formed by semi-decomposed remains of typical geogenic mire plants. Reddish to black colours due to oxidized and hydroxidized iron–manganese unions are visible (KA 5)
nHr:	peat horizon formed by semi-decomposed remains of typical geogenic mire plants. Horizon under permanent reduced conditions (KA 5)
nHw:	peat horizon formed by semi-decomposed remains of typical geogenic mire plants. Horizon under altering water tables presenting reduced and oxidative conditions (KA 5)
N_20:	nitrogen oxide
Pgv:	*Pilgerodendron uviferum*
QP:	Lago Quetru Site
rB:	raised bogs (mire ecotype)
RB:	raised bog (hydrogeomorphic mire type)
Ru:	rushes
S:	slope
SB:	bottom of slope
Sg:	sedges
SL:	sloping bog
Spm:	*Sphagnum magellanicum*
t ha^{-1}:	tons per hectare
TB:	terrestrialization bog
TF:	terrestrialization fen
tHo:	peat horizon formed by semi-decomposed remains of typical transitional mire plants. Reddish to black colours due to oxidized and hydroxidized iron–manganese unions are visible (KA 5)
tHr:	peat horizon formed by semi-decomposed remains of transitional mire plants. Horizon under permanent reduced conditions (KA 5)

tHw:	peat horizons formed by semi-decomposed remains of typical transitional mire plants. Horizon under altering water tables presenting reduced and oxidative conditions (KA 5)
TOM:	total organic matter
Trm:	*Tetroncium magellanicum*
VB:	valley basin
VE:	valley edge
VO:	Villa O'Higgins Site
WSC:	water storage capacity as percentage of the fresh substrate volume

Index of Annexes


Fig. 1: Bogs of Lago Vargas, central catchment of the Baker River (Rodríguez, field work 2012)

1. Introduction

Mires are natural ecosystems dominated by long-lasting waterlogging and water surplus, as well as by vegetation that is able to grow under such conditions. In these areas, the decayed vegetation accumulates into the wet soil surface, remaining partially decomposed due to oxygen deficit, and forming an organic matter layer known as peat (Succow und Jeschke 1986; Blanco y De la Balze, 2004). The accumulation of peat is the base for the formation of mire ecosystems.

Mires proliferated principally in the high latitudes of the Northern and Southern hemispheres after the last glacier retreat, approximately 15.000 to 12.000 yr BP. Due to their saturated conditions, mires conserve organic remains under semi decomposed conditions, being among the most important paleo-biological archives of the history of the postglacial landscape. Containing a water surplus not large enough to produce a permanent water body (e.g. a lake), but enough to maintain soils in sustained humid conditions, mires are a class of wetland, situated between terrestrial and aquatic ecosystems. Their water retention and filtration capacity is crucial for the regulation of nutrient discharges within landscape basins, for the purification of water and for the prevention of inundations. Mires are among the most effective water reservoirs on the planet, retaining >90% of their weigh in water. Because their soils are formed by organic matter accumulation, these ecosystems are the planetary most effectives reservoirs of organic carbon -C_{org}-, covering only 3% of the earth surface (4.16 x 10^6 km^2) but storing 15% to 30% (40-70 x 10^6 t y^1) of the total organic carbon -C_{org}- present on the upper 30 cm of the lithosphere (Joosten and Clarke, 2002). But depending on their hydrological and ecological balance, mires will prevent or contribute for the climate warming. The destruction or degradation of mires, by anthropogenic and natural causes, may turn these ecosystems into emitters of greenhouse gases, not only of carbon dioxide (CO_2, the gasified form of C_{org}), but of methane (CH_4), which has an effect on global warming that is 23 times higher than carbon dioxide (IPCC-International Panel on Climate Change 2007). And last but not least, mires present an enormous specific biodiversity, by which key concepts for their classification should be considered globally, i.e. those dealing with formation processes, but carried out locally, those dealing with special ecological characteristics and appropriate protection measures.

In Chile most mire ecosystems are still under pristine conditions and ecological regions like the Chilean Patagonia, where mires occupy approximately 4.600.000 ha, meaning 70% of the Chilean (CONAF et al. 1999b, actualized in 2010 and Fig. 2), remain yet almost unstudied and vulnerable (CONAF, 1996).

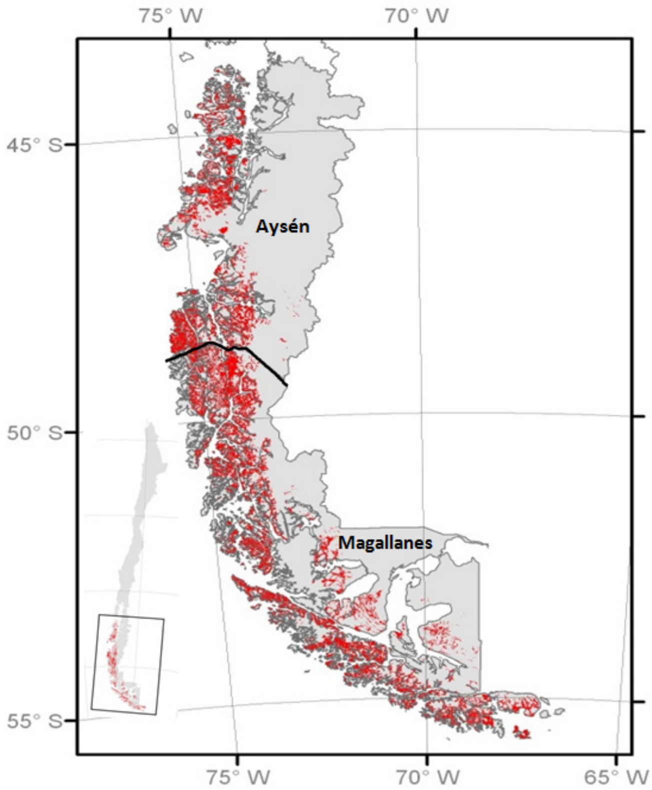


Fig. 2: Mires distribution in the Chilean Patagonia after remote sensing (Torres et al., 2010)

Patagonia is one of the least populated places of the world. It is administratively divided between Chile and Argentina. On the Chilean side, the province of Chiloe and Palena (Region of Los Lagos), as well as the regions of Aysén and Magallanes form part of Chilean Patagonia. Geographically, the Chilean Patagonia limits at the North with the Reloncaví Sound (41°29'46"S), at the South with the Estrecho de Magallanes (53°53'12"S) and at the West with the pacific ocean, running all along the western slope of the Andes Mountain Range and the Argentinean border. Specifically the region of Aysén (43°79´68´´ to 49°28´75´´ SL and 71°02´23´´ to 76°10´01´´ WL) is strongly marked by the footprints of the last glacial retreats, exhibiting a wide diversity of geomorphologies and ecosystems, among them mountains, ice fields, fjords, channels and islands (Fig. 3). Aysén's morphology was strong defined during Late Cretaceous Era, due for the submersion of the

South American Plate under the Nazca and Antarctic Plates. Additionally, the territory is longitudinally crossed by the geographical fault of Liquiñe Ofqui (Rabassa et al., 2005; Kleinebecker, 2007; SERNAGEOMIN, 2011) which is the reason that volcanoes are abundantly present, several of them exhibiting recent activity (e.g. the Hudson volcano presented activity in 1971, 1991 and 2011, after SERNAGEOMIN (2011). The main landscape forms in Aysén, from the West to the East, are archipelagic areas, the Patagonian Ice Fields, the Cordillera de los Andes and the flat eastern relief in the frontier with Argentina. The archipelagic area is formed by an emergent coastal cordillera of acidic igneous rocks, e.g. andesites, diorites and granites. In the continental side, the Cordillera de los Andes presents metamorphosed rocks, affected by tectonic processes, where proliferate crystalline schists that have been penetrated by intrusions of granites and granodiorites.

Also between the Archipelago and the Andes Range, are located two relic ice masses (the largest in current temperate climates): the Northern and the Southern Patagonia Ice Fields, with 4.200 and 13.000 km^2 respectively. They were part of the Patagonian Ice Sheet during the last glacial maximum (26.500 yr BP to 10.000 yr BP), and covered the area where the regional rivers currently run (Pfeiffer et al., 2010).

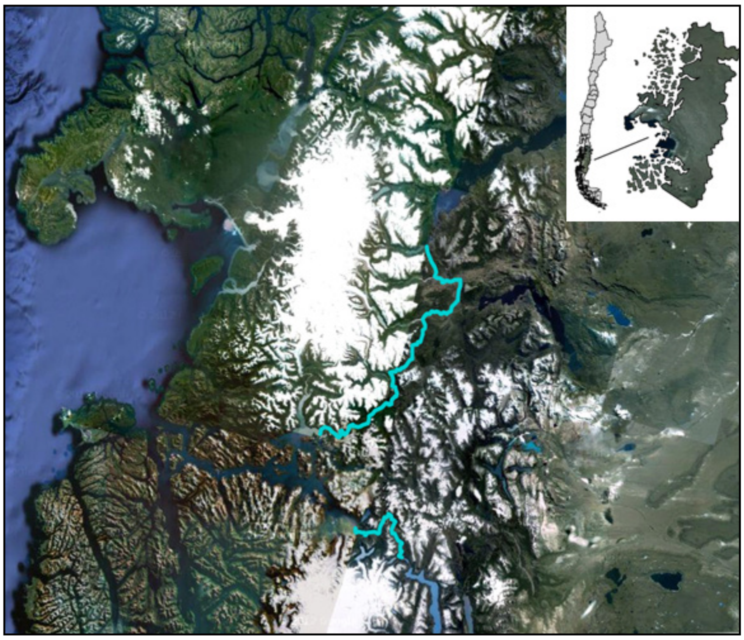


Fig. 3: Satelital view of the Aysén Region, with the North and South Ice Fields and the rivers Baker and Pascua highlighted (TerraMetrics ©, 2010-2012)

The retreat of the Patagonian Ice Sheet eroded the Andes Mountain Range, forming glacial U-shaped valleys (Fig. 4) and allowing glaciers to draining towards the ocean. These valleys, which are typical geomorphologic units in the current riverine zones of Aysén, were mainly formed during the Quaternary, and filled by sedimentary materials transported by powerful rivers during the Holocene. The presence of the remnant Ice Sheets and of the Cordillera de los Andes perform in Aysén a current hydrology characterized by glacial rivers crossing transversally the region from east to westd. During the Holocene, these rivers deposited sediments and enabled the formation of young soils, as well as the development of early vegetation colonies along their basins (Pfeiffer et al., 2010). The climate of Aysén is determined by its orography and oceanic influence. Annual mean temperatures and precipitation vary according to the oceanic influence (Fig. 5).

Fig. 4: Glacier U-shaped valley alongside the Los Ñadis River, basin of the Baker River (Rodríguez 2009).

Temperatures fluctuate between +8 to +9°C varying less along the coast than in continental areas. To the east, a minor maritime influence and the presence of the Andes Mountain Range generate a climatic barrier (Fig. 5 and 6), which is evidenced in a pronounced longitudinal rainfall gradient along a transect among the western coastal zones (Sector Caleta Tortel 47°47‘43‘‘S - 73°31‘56‘‘W) where it rains 3300 mm y^{-1} on average, and the eastern continental zone (Sector Villa O´Higgins, 48°28‘08‘‘S - 72°33‘34‘‘W) where precipitations decrease to 890 mm y^{-1} (DGA-Dirección General de Aguas, 2014).

According to, in this latitude, the windward and the leeward side of the Andes Mountain Range, are separated by a maximal distance of 100 km.

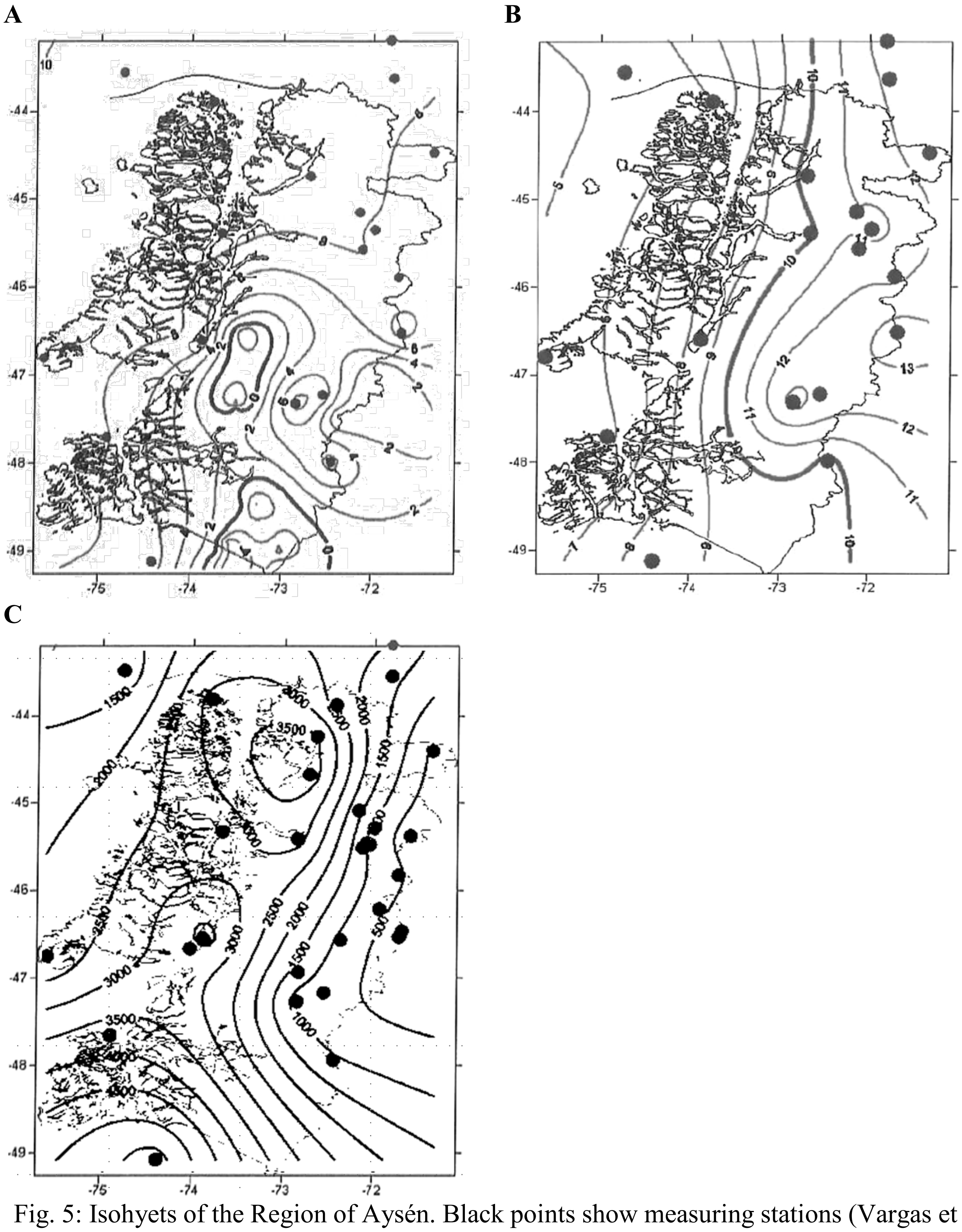


Fig. 5: Isohyets of the Region of Aysén. Black points show measuring stations (Vargas et al., 2007)

A= Annual temperature (°C). B= Thermal amplitude (°C). C= Precipitation (mm)

With a regional territory of 108.494.4 km², with 20% of it covered by the Northern and Southern Patagonia Ice Fields, Aysén has 0.7 inhabitants per km^2, indicating the lowest regional population density and one of the least industrialized landscapes of Chile (INE-Instituto Nacional de Estadísticas, 2012). Southern of Aysén, mires extend continuously through the Pacific fjords and archipelago, into the Region of Magallanes (CONAF et al., 1999b, actualized in 2010). Mires growing in the archipelago are only sporadically and poorly perturbed by artisanal fishermen and cypress-wood cutters, who build improvised camping places (also called *ranchos*) on the islands, inhabiting there during the working season. In comparison, mires in the continent are more exposed to anthropogenic impacts. Only the riverside zones of Aysén were easy to reach during the colonization attempts, at the beginning of the XXth Century. Limited by the Archipelago to the north and west, by the ice fields to the south and by the cold-desert of the Argentinean Pampas to the east, the region remained extremely isolated (Mena, 1928); (Solis Oyarzún, 2008; Mena, 1928) . These factors, added to the high costs of dealing with saturated soils, guaranteed mires to remain undisturbed. Aysén mires represent ecosystems in original natural conditions, offering an inigualable opportunity to research about their origin and ecology, as well as to produce information for future conservation, sustainable use and restoration strategies.

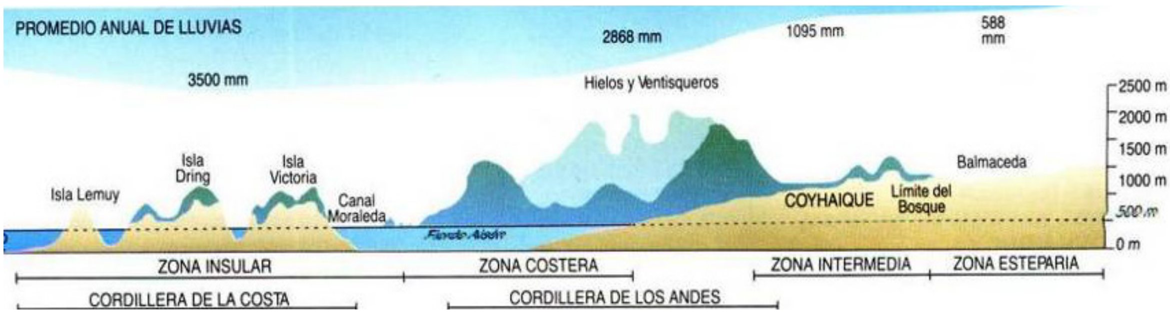


Fig. 6: Pluviometric and Topographic Schema of Aysén (Orrego, 2011)

1.1 State of knowledge

In Chile, some important efforts on mire studies have been made in the last 20 years focusing on the development of protection and management measures, and involving a high interdisciplinarity and common understanding of these ecosystems (Ramírez et al. 2002; Blanco y De la Balze, 2004; León Valdebenito, 2012). However, these researches integrate ecological and climatic areas differing widely from Patagonia (Ramírez et al. 2002), or focuse only on the mire surface excluding the whole stratigraphy (León Valdebenito, 2012) or achieve macroparameters not applicable to distinctive ecosystems. In this form, no specific researches about mires have been made in Aysén. That is difficult to understand since almost 26% of the Peatlands of Chile are located in this Region of Patagonia, representing these ecosystems 10.7 % of Ayséns regional surface (aprox. 1.450.000 ha). One third of mire ecosystems in Aysén are associated with the basins of the largest regional rivers: Baker and Pascua. The basin of the Baker River (170 km long) drains 26.487 km^2, with 17.159 $km^2$of it within the Chilean territory. The Pascua River (95 km long) drains a basin of 14.525 km^2, with 7.155 km^2 of it within the Chilean territory. Both rivers are born on the relic glacial Lakes General Carrera and O'Higgins respectively. The presence of mire ecosystems alongside these river basins increases along an east-west latitudinal sequence (Fig. 7), following the drastic west-east pluviometric gradient stated previously in the both basins.

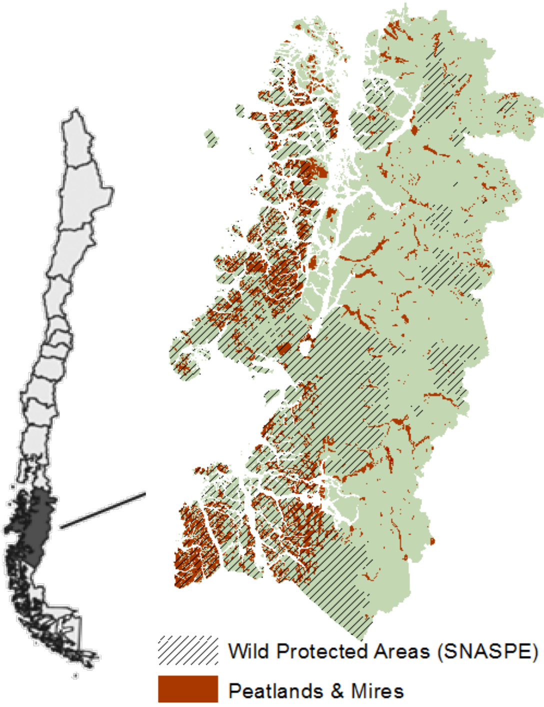


Fig. 7: Distribution of mires and mires in Aysén by remote sensing (CONAF et al., 1999a, actualized in 2010)

According to the reviewed literature, worldwide mires are associated with the existence of Histosols, Fluvisols, Entisols and Gleysols. One of the first investigations about Aysén's soils conducted by Luzio y Casanova (2006) observed the presence of the soil classes Histosols, Fluvisols, Entisols and Inceptisols as being those most commonly found within the estuaries, river mouths and deltas of Aysén. A more recent study done by Pfeiffer et al. (2010) defined Histosols as the common class within kettle holes along the Baker basin and within glacio-fluvial terraces within the Pascua basin. Until 2010, the study of Pfeiffer et al. (2010) is one the only published site-based work mentioning organic soils in the Baker and Pascua basins. Based on the USDA Soil Taxonomy, this author examined soils associated with geomorphological units in both river basins. In kettle holes within the Baker delta, Typic Sulfihemist and Typic Udifolist subgroups were reported, differentiating between the decomposition degree of the organic material. Almost all along the upper basin of the Pascua River organic soils were reported, with a prevalence of the subgroups Aquic Cryofluvent in alluvial fans, Hydric Cryohemist and Typic Cryosaprist on fluvioglacial terraces, Fluvaquentic Sphagnofibrist on moraines, and Hydric Cryofibrist together with Lithic Cryofibrist in stoss and lee topographies. Neither description of the botanic peat composition or substrate orders, nor the bulk densities or ecological status of these ecosystems was mentioned on this study (Fig. 8).

A **B**

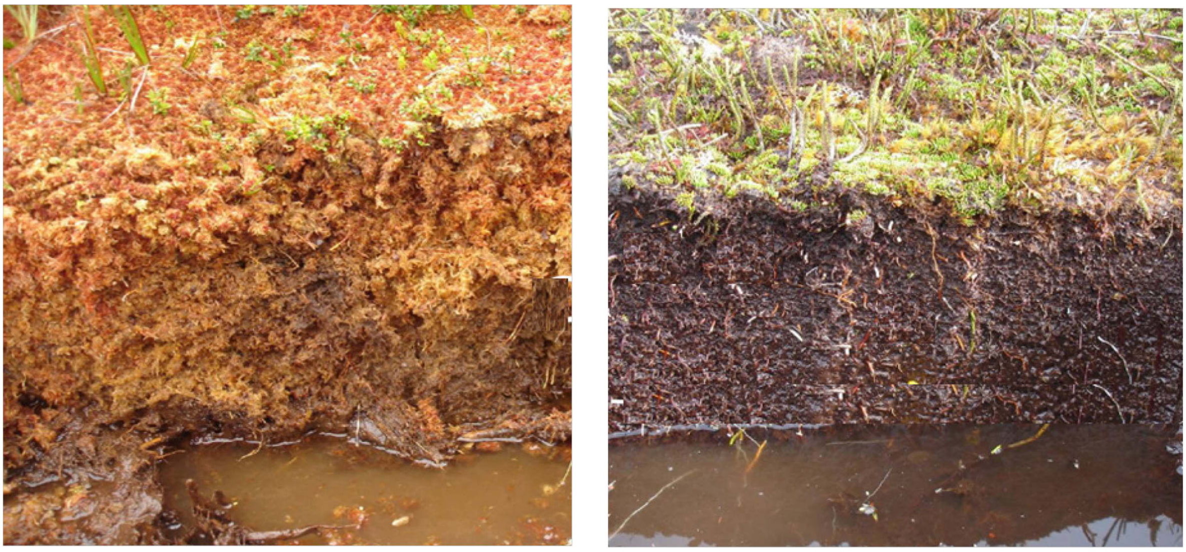


Fig. 8: Histosols formed in the Pascua River Basin-Aysén (Pfeiffer et al. 2010)
A=Udifolist histosol B=Sulfihemist histosol

Researches specialized in mire vegetation in the region of Aysén are scarce. But much more has been made in southern Patagonia, e.g. in the Argentinean Patagonia and Tierra del Fuego (Blanco y De la Balze, 2004; Markgraf and Huber, 2010; Fritz et al., 2011) and across the Magellan Strait at the Chilean side (Kleinebecker, 2007; Fritz, 2012). These works contribute important information with regards the mire vegetation. For example, the presence of *Sphagnum* and *Polytrichum strictum* mosses was used as a marker for the definition of bogs, and the presence of *Drepanocladus sp.* was used to define fens in steppe environments of Southern Patagonia and Tierra del Fuego by Markgraf and Huber (2010). Also the presence of *Sphagnum sp.* was associated with low decomposition grades of peat substrates in bogs of Tierra del Fuego by Fritz et al. (2011).

For the Aysén region, the only large scale available information is based on remote sensing, using data of which just a minimal part was field-tested (SHA, 2008; Torres et al. 2010). Among the available information, a report about vegetation in the Baker and Pascua watersheds revealed the presence of 342 taxa of vascular plants, four of them endemics, and several typical mire species (Rodríguez et al., 2008). Another investigation done by Villagra et al. (2009) focused on lichens occurring in mires within the Baker River Delta (Caleta Tortel) registering forty (40) lichen species, most of them in *Sphagnum magellanicum* and in *Astelia pumila* dominated bogs. Estimations about mires and their nutrient regulation function towards the regional basins have been indirectly achieved (Vargas et al., 2011). Data about plant communities and site indicators for mire classification are lacking. This will contribute information for measurements of physical and biological changes, e.g. the extension and kind of plant communities, advances in terrestrialization or paludification processes, decomposition and organic matter accumulation rates, associated carbon storage and loss rates, etc. this could be particularly useful if anthropogenic interventions (e.g. flow deviation, groundwater extraction, deforestation, soil erosion) or natural landscape changes (e.g. due to climatic change, earthquakes, increased rainfall, drought, vegetation and animal colonization) occur in the region. A first approach for a pedological and ecological classification specialized in mires in the river basins has not been realized. To achieve it, some concepts shall be clarified.

1.2 The classification of mire ecosystems

In the literature mires are fundamentally defined as “ecosystems” where, under natural conditions, a substrate composed by semi-decayed vegetation remains with the name “peat" currently forms, developing the mire soil. Parameters for the definition of mires have been developed for different purposes -e.g. productive or patrimonial- and with different accents –e.g. suitability for agricultural use or for ecological conservation- nevertheless they have much more in common. Mires have been differentiated worldwide according to their morphology, hydrology and ecology. Morphologically, landscape settings like relief, position, inclination and altitude play a key role in the ratio and way in which organic matter accumulates, forms a peat layer and facilitates mires growth. The landscape morphology is closely related to the behaviour and quality of water sources feeding mires. While in mountainous areas mires tend to develop beside springs or in small flat saturated depressions; in valleys they form usually above periodically flooded territories along the central and lower basins of rivers, surrounding terrestrialization lakes or above poor drained flat areas with high precipitation regimes. The kind of available water and parent material dominating a site will define the nutrient regimen and so the plant communities that are able to develop in mires. In other words, mires ecological conditions are also a result of the morphology and hydrology characterizing a site. The same occurs with peat, for which different parameters have been developed according to its use and assigned value. On the other hand, the parameters dealing with characterization of peat are broader in soil classification systems than those dealing with mires. The pH-value of the peat water and cation exchange capacity of the peat soil are aspects recognized in every classification dealing with organic soils. Likewise, calcium carbonate ($CaCo_3$) content, organic carbon content (C_{org}) and nitrogen content (N), their ratio (C/N), the bulk density and the degree of peat decomposition, are also used to assess the conditions of peat as substrate for plant growth. More recently, these parameters have been used to evaluate mire ecosystem functions with regards the prevention of climate change. And last but not less, the colour of peat was usually incorporated into classical research, being excluded by modern studies and replaced by the degree of peat decomposition (e.g. León Valdebenito, personal communication, 2012).

Systems to classify mires have been developed in countries where these ecosystems are significant in the landscape. Categorizations vary widely across the world and the conceptual discussion is not closed. I.e., in Ireland and England mires are called *Bogs*, in Germany *Moore*, in Chile *Mallines* and in Cuba and the Caribbean *Ciénagas*, with different ecosystems being included in the same shared definition: soils, whose substrates are formed by a large quantity of partially decayed organic matter, under saturated conditions. Definitions of ecosystems as “mires” vary in the thicknesses of the peat layer they assume. E.g. in Sweden the assumed peat layer has to be 40 cm thick, while Russia specifies 35 cm and China asserts it must be 30 cm (Krasilnikov et al., 2009) as does Germany (AG Boden, 2005). Peru is a country rich in mountainous blanket mires, which grow extensively in the high Andes relief. In Peru the defined thickness to categorize these ecosystems is only 18 cm, which would be unacceptable in the just mentioned classifications. This variability confirms the existence of a high diversity of ecosystems, while making problematic a standard determination of the global mire surface. At the other end of the scale, very exhaustive and specific classification systems impede the designation of diagnostic mire types and are unable to incorporate the mentioned ecosystem diversity. Visualizing this complexity, Krasilnikov et al. (2009) drew attention to how long the dominance, variability or regularity of mire ecosystems within a country can determine the complexity of classification systems, influencing local definitions for archetypical and transitional types, their relations and their limits. Looking these definitions objectively, a point of differentiation can be established according to the ecological, economical or cultural importance of these ecosystems. For example, the Pantanal, a region located between Brazil, Bolivia and Paraguay, is an area with approximately 15.000 km^2 of mires, making it the world's largest wetland ecosystem. The prevalent water surplus and the dominant tropical climate make the Pantanal a hot spot for flora and fauna biodiversity, and the home of several indigenous populations living of fish, plants and livelihoods provided by this ecosystem. Due to its ecological and cultural importance, the Pantanal has been a World Heritage Site protected by UNESCO since 2000 (Ioris, 2012). In comparison, in Ireland mires play an economic role. Covering 17.2 % of the land, peat is in Ireland the most abundant resource, whilst wood and oil are almost totally lacking. An early utilization of peat for heating is documented by Collier, and Scott (2008), Plunkett et al. (2013) and Connolly and Holden (2011), and an own classification and registers were developed early on 1810-1814 by the "Bog Government Commission", and as a result a very complete map of bog mires was published in 1920 by the Geological Survey (Hammond, 1981). By 1980, 25% of Irish electricity was produced by peat, the most important raw material to fabricate briquettes for domestic and industrial heating up until the present day. Another example is Germany, where 5% of territory is formed by *Moore* (mires), with these ecosystems forming an entire division of the German Pedological Mapping Direction KA 5, as well as terrestrial soils, semi terrestrial soils, semi subhydric and subhydric soils (AG Boden, 2005). In the last 40 years, scientists have complemented the about parameters of the German classification and the "Hydrogenetic and Ecological Mire Types" Succow und Jeschke (1986), made considerations for the "Wise Use of Mires" (Joosten and Clarke, 2002) and developed user friendly tools for the classification of peat substrates (Meier-Uhlherr et al., 2011). In Patagonia, particularly on the Isla Grande de Tierra del Fuego-Argentina, circa 3000 m^3 of peat are harvested for horticultural purposes at year (World Energy Council, 2013). In that country, and after 40 years of cutting and exploitation, mires have begun to be integrated into the national cartography and valorized as Ramsar Sites. This is the case of the *Vinciguerra Glacier* and its associated mires, which in 2009 were designated a Ramsar Site, thus becoming the first place on the entire island to obtain this category (www.ambiente.gov.ar). Chile followed the example of Argentina in the exploitation of peat resources during 1980s, with the Region of Magallanes becoming an important place for peat extraction, increasing slowly nowadays (Fig. 9). Peat is defined in Chile and Argentina as a fossil fuel but its main use is as a raw material to improve horticulture substrates; a use impelled by an increasing demand on the agricultural sector on Latin America. According to recent studies (Centro de Estudios Trapananda-Universidad Austral de Chile, 2007) peat industries in Chile and Argentina normally apply three simplified definitions to differentiate between peat types: *turba rubia* (blond peat), *turba negra* (black peat) and *turba mixta* (mixed peat). Cartographers and landscape analyzers use the USDA classification to facilitate the recognition and planning of the peat harvest and reserve areas (USDA-United States Department of Agriculture, 2014). Interest in obtaining economic value from mires has increased in Patagonia and Tierra del Fuego over the last ten years, but fortunately so has the recognition of these ecosystems. Several maps including their extension and hydrology have been elaborated by governmental environment offices in Argentina and Chile, and an active sequence of studies, conferences and extension initiatives have been undertaken to expand the knowledge about the ecological values and ecosystem services of mires. Likewise, on the Chilean side a group of scientists belonging to the Wildlife Conservation Society have been working since 2010 on projects for environmental education, recognition and protection of mires within the Karukinka Natural Park (www.karukinka.cl), where pristine ecosystems are located in the Valle de la Paciencia (Fig. 10). The different types of purposes behind the classification of peat as a raw material or of mires as ecosystems, affect the parameters for conceptualization and assessment that are used to deal with these ecosystems. In every classification system plays a role if the focus is oriented to the generation of information to support decisions at a local level, to represent specific parameters for landscape use, to understand and protect the biodiversity, to committing international conservation agreements or to be compatible with international soil classification systems.

Fig. 9: Peat harvest in San Juan, Region of Magallanes-Chile (Rodríguez, field work 2012)

Fig. 10: Mires in the Karukinka Natural Park, Tierra del Fuego-Chile (Diego Alarcón, 2012, in www.karukinka.cl,)

The choice of parameters needs to be based on a comprehensive foundation, when it is intended to design a new system for the classification of mires and the assessment of their conditions. Harmonized systems, based on scientific but realizable methods, that are able to provide qualitative but comparable parameters, could improve the available regional data base about Patagonian mires. The same is expected with regards to the decision making processes dealing with the landscape use and planning. In the following chapter a systematization of some of these fundamental parameters is expounded, in order to record standard and useful aspects to be taken into consideration in the development of a classification system for mires along the Baker and Pascua Rivers in Aysén.

1.2.1 Parameters for the classification of mires

1.2.1.1 Water source and regimen

The water chemical conditions and regimen determine the botanical structure and ecological settings of mires. In Tierra del Fuego-Argentina Köpke (2005); Iturraspe (2010) and Iturraspe and Urciuolo (2012) used the "Bog-Fen" hydrological principle to differentiate mires according to their source of incoming water. This principle is widely used in Germany (AG Boden, 2005), Sweden (Rydin et al., 2006) and the USA (Chadde et al., 1998). The designation of mires as "mires" and the differentiation between "Bogs" (*Hochmoore)* or raised ombrogenic mires, formed by surplus of rainfall; and "Fens" (*Niedermoore)* or geogenic mires, formed by groundwater water influence is the most important in the German soil mapping directions KA 5 (AG Boden, 2005), where there is also a third class between bogs and fens is defined as "Transitional Mires" (*Übergangsmoor*). This contains vegetation and characteristics of both types mentioned before. Similar to Germany, in the USA, the classification of mires with regards the sources of incoming water also distinguishes in *Bogs* and *Fens* (Chadde et al., 1998) subdividing the latter into poor, rich and extremely rich. In this classification marsh and sedge meadows are separated from mires, and classified as mineral soils where, although organic matter is produced, it does not remain due to intermittent dry periods accelerating its mineralization. On these ecosystems, the production rate of organic matter is slower than its decomposition rate, which is the crucial difference with mires. What the Sweden, Germany and Finland classification systems have in common is their differentiation between ombrogenous and minerogenous (or geogenous) sites (Tab. 1). These both concepts were translated into the English language as bogs and fens (Rydin et al., 2006).

Tab. 1: Main mire types with regards the source of incoming water in the Swedish, German and Finnish Mire Classification System (modified from Rydin et al., 2006)

Main Type/Subtype	Definition
Ombrogenous	Mire thickness sufficiently developed and thick enough to become isolated from the mineral enriched groundwater, with rain water being the main source of influx
Minerogenous	Water comes into the mire once enriched by the surrounding mineral soils
	2.1.- Topogenous: Flat water table, located in terrains with no outlets, single outlets or both inlets and outlets
	2.2.- Soligenous: Sloping with directional water flow through the peat or on the surface
	2.3.- Limnogenous: Located along lakes, streams or intermittent stream channels presenting periodical floods

Regarding climate change, when correlated with local temperatures and geomorphology, mire water tables are directly related to the accumulation rate, structure and conservation of organic matter decaying on them, and consequently to their carbon accumulation rate. If the mire water table sinks, aeration occurs, followed by the decomposition and finally mineralization of the deposited organic matter (www.carbstor.de; Möller und Heller, 2012). Once that occurs, physically, the water infiltration and retention capability of the soil is affected. Chemically, the organic carbon stored before in the peat turns into carbon dioxide –CO_2- and is released into the atmosphere. On the other hand, if the mire water table rises, and high temperatures dominate the climate, bacterial activity may be facilitated (Iturraspe, 2010). Under anaerobic warm conditions, bacteria use short-chain organic unions as electron-acceptors, producing methane –CH_4- and turning mires ecosystems in emitters of this greenhouse gas (Dierßen und Dierßen, 2001). Other important function of mires is its capacity to filtrate and retain water, regulating its quality and release into the landscape, especially in front of river floods or strong storms episodes. Iturraspe and Urciuolo (2012) reported about natural mires in Tierra del Fuego regulating the concentrations of humic acids and dissolved organic carbon components entering in rivers and water bodies during intense snowmelt and rainy periods. These authors also reported blanket bogs and sloping mires protecting hillsides and control the transport of sediment to the rivers, lowering rates of solid discharges and controlling excesses of water. Based on this crucial role of water in the conservation of mires, in the region of La Araucanía-Chile, Cortés (2009) used the "level of drainage" of these ecosystems, differing between "*high drainage"* when no interruptions of the water level ocurred, "*medium drainage"* when ≤ 20% of the wetland surface was anthropogenic intervened and "*low drainage"* when ≥ 20% of the wetland surface was affected. From the reviewed literature is inferable that the water source of mires is commonly used as parameter to classify their hydrological origin, and that this is intrinsically related to the landscape relief. Additionally, the conditions of naturalness or alteration inflicted on mires are also reflected in their hydrological behavior.

1.2.1.2 Mire conditions

Natural mires are characterized by maintaining their original water table (AG Boden, 2005). Perturbations on the mire water table are a factor of high disturbance on these ecosystems. Several researches confirm that the soil physic is affected by drastic reductions on soil volume and porosity after drainage (Kratz and Pfadenhauer, 2001; Joosten and Clarke, 2002. Chemically speaking, fluctuations on the groundwater level allow soil respiration and oxygenation. The chance of water nutrients to become deposited and integrated into the chemical properties of mires can vary extremely when disturbances in the water regimen do occur (Wallor und Dzialek, 2011; www.dss-wamos.de). These disturbances are particularly sensible to climate change, since the balance of important greenhouse gases (CO_2, CH_4 and N20). According to the mire experts of the Humbold University Evelyn Wallor and Janine Dzialek, renaturation strategies via rewetting show an improvement on the balance of greenhouse gases fixable in soils, confirming that chemical properties on these ecosystems are highly dependent on the water balance. In addition, temperature is the other main driver of peat decomposition, and thus of peat accumulation. Humidity and temperature regulate together the turnover of organic carbon in peat soils, driving the decomposition rate of the organic matter accumulating in the soil. Summarizing, mires can turn mineralized when drainage, pollution and erosion affect their structure and functions. The KA 5 (AG Boden, 2005) defines these processes as *earthification* when referring to *extensive* perturbations, and *strongly earthification* referring to *intensive* perturbations and deterioration of mires conditions. The main reasons for earthification and strong earthification of mires in Germany are defined by (Zauft et al., 2010) as chemical and physical transformations (e.g. eutrophication and drainage respectively) derived of agricultural uses. Eutrophic mires (pH $\geq$5) are further classified in the KA 5 in normal (typical fen plants), calcic (rich in calcium and alkaline pH, e.g. 6.4 to 8.5) or transitional (dominated by typical plants from normal and calcic fens). Similar to Germany, mires are catalogued in Switzerland according to five main parameters dealing with the state of their "natural conditions": a) typical mire type development (plant types and hydrology), b) humidity level, c) humus level, d) nutrient availability and e) woody plant increment (BAFU-Bundesamt für Umwelt, 2006). From these parameters and related to their natural prevailing conditions (high humidity, lower mineralization and pH, oligotrophismus and small number of woody plants), measures for mire protection or restoration can then be derived. These instruments allow differentiations and subsequent control of the conditions and alterations of mires on time and space, under the condition that complementary baselines and monitoring information are available (e.g. spectral imagery from different years about the water table to define variations, or data about carbon content to define carbon cycling and the possible effects of climate change (Harris and Bryant, 2009; Gong et al., 2012; Wu et al., 2011). Other disturbances related to land use and land conversion (e.g. pasture, deforestation, cutover, draining and peat mining) have been identified in large mire areas from Ireland through the comparison of high resolution imagery taken in different years (Connolly and Holden, 2011). All these experiences facilitated the generation of instruments for mires assessment on central and long term. Since mires in Aysén are mostly pristine, and the work dealing with their classification is pioneer in the region, it is expected that the data collected and the specification of the applied methods and procedures, shall facilitate information for future monitoring of their conditions.

1.2.1.3 Hydrogeomorphology

Typifications according to the landscape morphology and hydrology prevailing on the formation of mires were widely developed by Succow und Jeschke (1986) and later by Succow und Joosten (2001). They defined eight “Hydrogenetic Mire Types” (Fig. 11). These authors distinguished between “Horizontal mires” (*Horizontale Moor*e) forming in flat morphologies, and “Inclined mires” (*Geneigte Moore*) forming on sloped morphologies. Horizontal types are water rise mires (*Versumpfungsmoore*) mostly influenced by groundwater; terrestrialization mires (*Verl*and*ungsmoore*) originating from old lakes; kettle hole mires (*Kesselmoore*) located in depressions and fed by superficial runoffs accumulating on their borders; and flood mires (*Überflutungsmoore*), developed along water flows and fed by them during inundation periods. The inclined types are sloping mires (*Hangmoore*), fed by runoffs in sloping areas; percolation mires (*Durchströmungsmoore*), formed due to strong and continuous runoff and groundwater income in sloping areas; spring mires (*Quellmoore*), formed in depressions such as the holes left by old lakes and mostly fed by ground or surface water; and raised mires or bogs

(*Hoch*- or *Regenmoor*), fed mostly by precipitation in a rate that exceeds the existing water losses. Horizontal and inclined mire types are also separated.

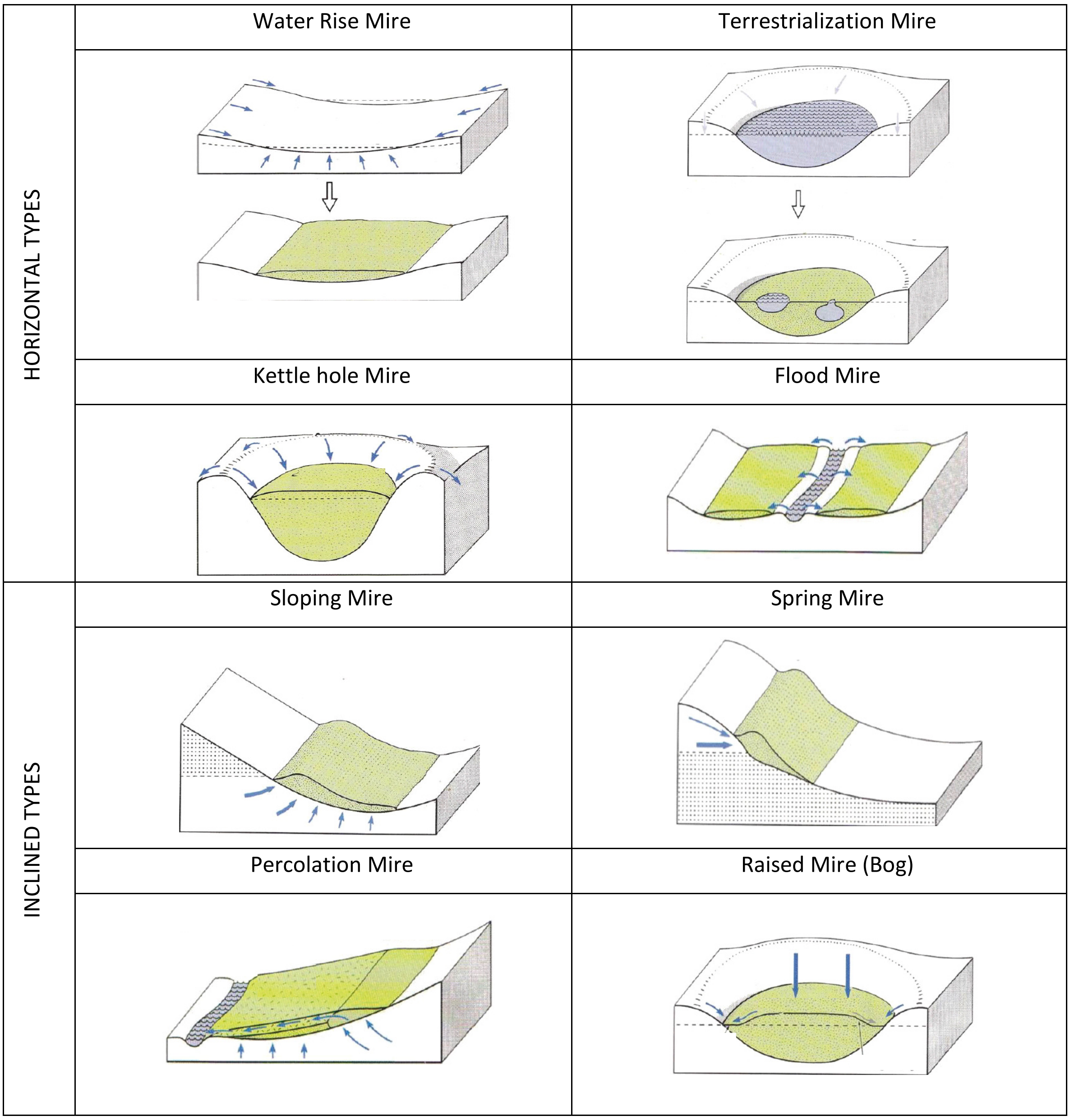
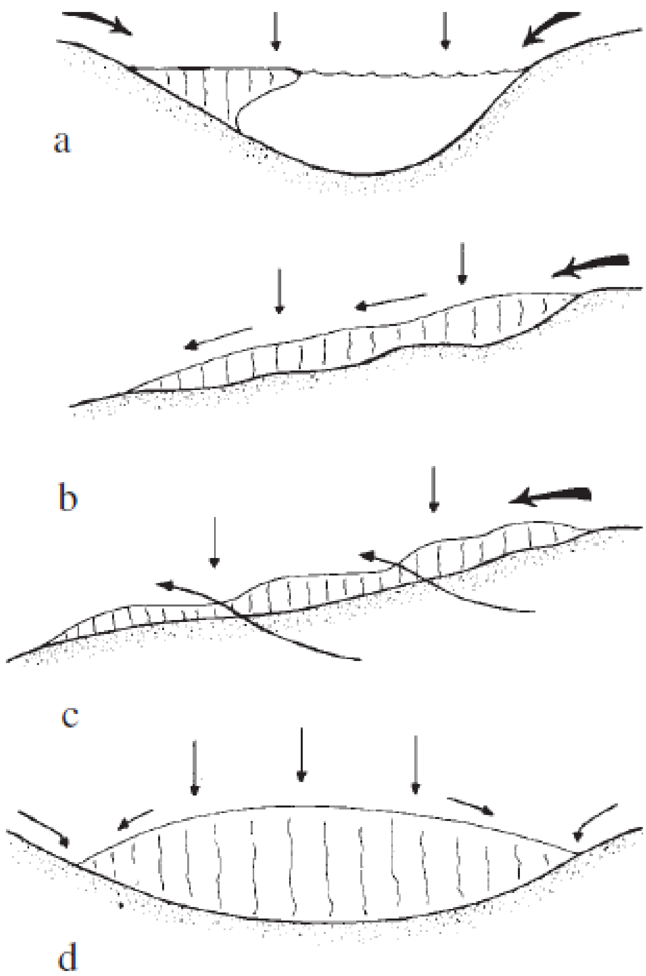


Fig. 11: The eight hydrogenetic mire types (modified from Meier-Uhlherr et al., 2011). Blue arrows indicate the origin of water fluxes into the mire, while the dotted lines show the mire water level.

These hydrogenetic mire types have common elements with the classifications proposed by Chadde et al. (1998) for the Rocky Mountains in the USA (Fig. 12), and by Brinson (1993) and Hope et al. (2009) in Australia. This last incorporated the concept of hydro period regarding sporadic pools and vegetation decay. In Tierra del Fuego, Iturraspe and Urciuolo (2012) used the concept of mire complex to desing mire hydrogenetic types, and the concept of mire system, when these appeared mixed and adjacent in the landscape.



(a) Basin or lake-filled fen, fed primarily by runoffs and secondarily by rainfall surpluses

(b) Flow-through or slope fen, fed principally by runoffs and secondarily by rainfall

(c) Patterned fen, fed mainly by groundwater and runoffs , and secondarily by rainfall

(d) Bog or primarily rainwater-fed mire. Absent in the Northern Rocky Mountains, but exhibited here to illustrate its difference with regards the types above.

Fig. 12: Major mire forms in the Northern Rocky Mountains (Chadde et al., 1998).

1.2.1.4 Ecological types

The vegetation growing on mires is a result of the ecological conditions dominating them. Chemical properties play a key role in peat formation and on the kind of vegetation growing on these organic soils. Levels of calcium carbonate, organic carbon content and pH-value are elements allowing differentiation amongst mire types. Under acidic conditions, vegetation decomposes more slowly than in basic conditions, with the pH being a regulator of the velocity at which organic inputs are mineralized and integrated into the soil. Likewise, vegetation communities are indicators of the acidic, sub-neutral or alkaline status of mires. In order to deal with these aspects, Succow und Jeschke (1986) elaborated an ecological typification for European mires based on a distinction between a) the acidic-base conditions of the water and peat prevailing at the site expressed on the pH-value and b) the nutrient level expressed in the C/N ratio (carbon to nitrogen relation). Succow und Joosten (2001) typified vegetation communities in the mires of North-Eastern Germany (Tab. 2 and Tab. 3).

Tab. 2: pH-values with descriptions groups after (Succow und Joosten, 2001)

pH-value	Description	Group
<2.4	Extreme acidic	Acidic
2.4 – 3.2	Very strong acidic	
3.2 – 4.0	Strong acidic	
4.0 – 4.8	Moderate acidic	
4.8 – 5.6	Weak acidic	Sub-neutral
5.6 - 6.4	Very weak acidic	
6.4 – 7.2	Neutral	Alkaline (Calcic)
>7.2	Basic	

Tab. 3: C/N ratio groups after (Succow und Joosten, 2001)

C/N ratio	Description	Group
<40	Very poor	Oligotrophic
33 to 40	Poor	
26 to 33	Quite poor	Mesotrophic
20 to 26	Moderate	
13 to 20	Strong	Polytrophic
10 to 13	Rich	
7 to 10	Very rich	Eutrophic
<7	Extreme rich	

Oligotrophic-acidic mires are the most colonized by woody plants and moss of the *Sphagnum* type (C/N 50 – 27 and pH 2.7 – 4.8), while mesotrophic-acidic ecosystems were occupied by sedges (C/N 50 – 15 and pH 3 – 7.6). brown mosses, on the other hand, grow comfortably in a wide spectrum of fens, from oligotrophic to eutrophic (C/N 38 – 15) and from acidic to alkaline (pH 4.6 – 7.5). Kleinebecker (2007) differentiated between three botanical types of mires in the Estrecho de Magallanes and the Island of Tierra del Fuego, following a continental-marine climatic gradient from: a) continental *Sphagnum*-bogs, dominated by *Sphagnum* mosses, very poor in nutrients b) blanket-*Sphagnum* mixed mires, dominated by *Sphagnum* mosses and cushion plants like *Astelia pumila* and *Donatia fascicularis* and c) oceanic blanket-bogs, dominated by cushion plants above peaty soils where mineralization was accelerated by the deposition of salts spread by sea spray. In the other side, Chadde et al. (1998) propose the calcium concentration level as a parameter to differentiate among poor fens (2 to 10 mg/l of calcium concentration) dominated by *Sphagnum* mosses and cyperaceae species, rich fens (10 to 30 mg/l of calcium concentration) dominated by mixes of sedges, shrubs and amblystegiaceae mosses, and extremely rich fens (>30 mg/l of calcium concentration) dominated by *Juncus* species. The nutrient regimen is also considered in classifications of peatlands in Canada. Rydin et al. (2006) identified different nutrient milieus associated with specific plant communities in marshes (minerotrophic, eu- to mesotrophicic nutrient regimen, dominated by submergent floating-leaved reeds and tall sedges), swamps (minerotrophic, eu- to oligotrophic nutrient regimen, dominated by forest, herbs, graminoids and bryophytes), fens (minerotrophic, eu- to oligotrophic nutrient regimen, dominated by low trees, shrubs and graminoids) and bogs (oligotrophic regimen conditions, dominated by *Sphagnum* mosses and cyperaceae dwarf shrubs). In Sweden, this is complemented with the pH-value and base richness, differentiating bogs (pH-value 3.5–4.0), poor fens (pH-value 4.0–5.5), intermediate rich fens (pH-value 5–7) and rich fens (pH-value 6.8 – 8.0). However, peatlands can be “floristically rich”, having a higher pH-value and base richness. This richness is different to “nutrient rich”. Indeed, Meier-Uhlherr et al. (2011) reported typical species of bogs such as *Sphagnum* mosses and typical species of fens such as sedges and brown mosses coinciding in calcareous rich fens. Rydin et al. (2006) explain that these ecosystems are productive and at the same time oligotrophic, since phosphorus becomes affected at high calcium concentrations. The nutrient regimen must be carefully considered when defining different peatland types, and always complemented with the existing flora.

1.2.2 Parameters for the classification of mire substrates

1.2.2.1 Botanical composition and horizons

Plants will influence the quantity and quality of organic substrates forming on mires. If mires substrates are composed of vegetal remains (peat) or lake organic sediments (organic gyttja), these will produce a different hydrological and ecological behaviour in front of environmental or anthropogenic stressors. At the same time, substrates are deposited in horizons, which were formed under a complex relation between the organic parent material, the underlying mineral parent material, the mire water table and the climatic and geological conditions of mires. From the combination of both, the botanical composition of a defined organic substrate and the characteristics of the horizon where this was formed, a better understanding of mire ecosystems can be achieved. Physically talking, perennial plants have structures, cell walls and tissues more resistant to decay than deciduous plants. In mires, deciduous plants grow as well, but perennial plants represent the vegetative macrofossils recognizable on peat substrates (Rydin et al., 2006). In Aysén the deciduous tree *Nothofagus betuloides* and *Nothofagus antarctica* grow on borders of continental mires, but are the perennial families sphagnaceae, asteliaceae, ericaceae and cyperaceae those dominating both mire substrates and landscapes. Chemically talking, as explained previously, the dominance of *Sphagnum* mosses has a wide significance. Leaves of dead

Sphagnum mosses have a high cation exchange capacity, accelerating the exchange of hydrogen ions by metal cations and sinking the pH-value of the mire water (Succow und Joosten, 2001), which has repercussions not only for the kind of vegetation growing at each specific ecosystem, but also for the mineralization rate of biomass decaying on them. The botanical species composing the peat in a mire can be combined with the physical and chemical parameters dominating in a mire (e.g. peat bulk density, thickness and area, porosity, C/N ratio and pH) allowing the association of defined rates of water and organic carbon storage to a defined mire type. E.g. through the combination of typical vegetation communities, water levels and land use at a site, scientists of the University of Greifswald identified Gas-Emissions Standard Site Types - GEST (Couwenberg et al., 2008), a method to calculate the potential release of Green House Gases based on these site parameters for mires in Germany. On the other hand, the botanical documentation of substrates in undisturbed mires is a source of primary information about environments and climatic conditions of the past within a region. A macroscopic determination of identifiable plant remains is mostly possible in peat substrates; so long the material is not amorphous enough to impede it. Nevertheless, in the Guidelines for Soil Description (FAO, 2006), which is the world most used soil classification system; this intrinsic botanical composition of peat is almost ignored. In this system, Histosols are the soil group most representative of mires, as these are formed by substrates of incompletely decayed plant remains, and to a lesser grade, by low mineralized admixtures of sand, silt or clay. According to the degree of peat decomposition, a Histosol is classified as fibric (least decomposed), hemic (medium decomposed) or sapric (highly decomposed), nevertheless omitting its botanical composition. The same occurs in the Soil Taxonomy (USDA, 2014), the classification system of the United States and the most applied in Latin America. Since it was designated to classify soil types across a large and diverse country like the USA, the Soil Taxonomy takes very into consideration the occurrence of landscape variability, offering a dynamic classification tool, which combines different properties present on a "soil unit" or pedon to define a "soil type". The definition of organic soils in the Soil Taxonomy is "soils containing three-fourths or more of fibers derived from *Sphagnum, Hypnum* and other mosses in the first 60 cm of upper soil, presenting a bulk density of less than 0.1 g cm^3", resting a detailed attention to the botanical peat types. The KA 5 (AG Boden, 2005) offers an advantage in this point, presenting a protocol to differentiate between peat substrates according to their peat forming vegetation species (Tab. 4). In this system, a differentiation in "peat units" is described among moss peat (dividing between brown moss and *Sphagnum* moss peat), herbal peat, ericaceae peat (from dwarf shrubs), woody peat and amorphous peat (when plant remains are not identifiable). Accumulated lake sediments also form organic substrates and in the KA 5 these are differentiated from peat substrates with the name gyttja (Mudde). Organic gyttja formed by decayed zoo and phytoplankton is designated as "detritus gyttja", which is typical in mires formed in terrestrialization lakes or in periodically flooded river mouths. In the case of nutrient poor and deep lakes of the highlands, "algae gyttja" – Lebermudde- is the type prevailing. In areas of nutrient poor quite waters with enrichment of calcium "calcareous gyttja" –Kalkmudde- should predominate. Also sandy and loamy gyttja can be present in the landscape, forming part of terrestrialization lakes turned into mires.

Tab. 4: Peat substrates classification according to the German Pedological Mapping Directive KA 5 (AG Boden, 2005)

Peat unit	Peat sub-unit	Peat type	Group*			Abbreviation
			Hh	Hu	Hn	
Moss Peat	Pale Moss	Sphagnum cymbifolia	+	(+)		Hhsy
		Sphagnum cuspidata	+	(+)		Hhsu
		Sphagnum acutifolia	+			Hhsa
		Others		(+)		Hhs
	Brown Moss	Several	+	0	0	Hnb
Herbal Peat	Bog Herbal peat	Cottongras	+			Hne
		Scheuzeria				Hha
	Reed peat	Menyanthes		0	0	Hnmy
		Equisetum		0	0	Hnq
		Radicels		0	0	Hnr
		Reed		(+)	+	Hnp
		Cladium		(+)	+	Hnd
Shrub Peat	Bog	Ericaceae	+			Hhi
Woody peat	Bog woody peat	Pine bog	+			Hhk
	Carr forest peat	Pine carr forest		+		Hulk
		Betula carr forest		+		Hulb
		Alder carr forest			+	Hnle
Amorphous	Without identifiable plant remains, assignment acc. to stratigraphy or laboratory analysis		0	0	0	Ha

* Hh= ombrogenic mires (bog); Hu= transitional mires; Hn= geogenic mires (fen); += dominant peat class or almost exclusive on this type; 0= similar in more than one group; (+)= rare to find.

These different substrates belong to three different mire edaphological groups: ombrogenic mires (also called bogs, irrigated mostly or exclusively by rainfalls and colonized by plants adapted to nutrient very poor conditions), geogenic mires (also called fens, irrigated by water enriched by minerals and nutrients and colonized by plants with some nutritional requirements) and transitional mires (a transitional stage between geogenic and ombrogenic mires). Additionally, through the examination of the position, form and composition of a horizon, can be understood the mire formation. To characterize this, the KA 5 (AG Boden, 2005) offers some specific symbology (Tab. 5). The letter H means a horizon formed by semi-decomposed vegetal remains (peat), while the letter F means a horizon formed by lake sediments (organic gyttja). Additional suffix letters are added to this main letters to define pedological characteristics of these materials. So, Fh describes an organic gyttja originated by peat remains.

Tab. 5: Organic horizons classification according to the German Pedological Mapping Directive KA 5 (AG Boden, 2005)

Nomenclature	Definition
hHr, nHr or tHr	Peat horizons (H) typically in the sub-soil, formed by semi-decomposed remains of typical ombrogenic mire plants (h), geogenic mire plants (n) or transitional mire plants (t). Horizon permanent under reduced (r) conditions.
hHw, nHw or tHw	Peat horizons, typically in the upper soil, formed by semi-decomposed remains of typical ombrogenic mire plants (h), geogenic mire plants (n) or transitional mire plants (t). Horizon under altering water tables (w), presenting reduced and oxidative conditions
hHo, nHo or tHo	Peat horizon formed by semi-decomposed remains of typical ombrogenic mire plants (h), geogenic mire plants (n) or transitional mire plants (t). Reddish to black colours due to oxidized and hydroxidized iron–manganese unions are visible (o).
fFh	Horizon formed by lake organic sediments (Organic gyttja) and peat remains under permanent reduced conditions

1.2.2.2 Bulk density

The bulk density of peat soils is calculated as the dry mass per unit of volume (normally in g cm^3). With enough representative samples, an extrapolation in t ha^{-1} can be conducted. The estimation is realized through the extraction of three to five undisturbed soil samples with soil core cylinders of known volume (normally 100 cm^3). Samples are weight immediately after extraction in the field, and later dried in an oven at 105 °C until constant weight (≈48 hrs.) and then reweighed (Blume et al., 2011). The bulk density is the final dry mass of soil in the defined volume. The loss between the initial and final weight is an indicator of the wetness of the soil, water content and aeration. It is an indicator to assess important compounds like organic carbon and nitrogen stored in a defined area. It is also used together with the pore volume, to calculate the infiltration capacity of soil substrates, supporting particularly decisions for agricultural uses (e.g. hydraulic conductivity). Due to the typical coarse pore volume of organic matter, peat substrate have normally a minimal bulk density and a high water infiltration and retention capacity, except in the case of drained and agricultural used peat soils, which compaction increases significantly.

1.2.2.3 Degree of peat decomposition

Decomposition is an indicator of the mineralization grade of the organic matter and the conditions of peat components. Although most peat decomposition occurs above the water table, botanical types, climate and hydrological regimes are also factors interacting closely with the chemistry of peat and driving the decomposition rates. For example, *Sphagnum* peat decomposes more slowly than *Carex* and other lignin rich peat types (Williams and Yavitt, 2003). Due to the action of methane bacteria, the decomposition rate is more accelerated in areas with high temperatures than in cold climates. The more decomposed the peat is, the lower its accumulation rate will be and its release of organic compounds into the environment will be greater, particularly of dissolved organic carbon, phosphor and nitrogen oxide (Jordan et al., 2007). A low degree of decomposition is synonymous with the conservation of the organic matter accumulated under anoxic conditions and low temperature. Due to the importance of peat and its relation with other environmental processes, organic soil classifications include the degree of peat decomposition. The Guidelines for Soil Description developed by the (FAO, 2006) has a five levelled system to codify the degree of peat decomposition, also called *"humification"*. In its guidelines, the FAO typifies peat in three classes: fibric (least decomposed peat), hemic (medium decomposed peat) and sapric (higher decomposed peat). These three classes are codified in six degrees of decomposition from very low (D1) to very strongly decomposed (D5.2). The classification of the WRB is a simplification of the original ten graded scale for peat decomposition developed by (von Post, 1924), which grades are defined according to water colour, textures and plant remnants. The limits between degrees of peat decomposition are discussable in the scale of the FAO. When differencing between fibric (D1 to D3) and hemic material (D4 to D5.1) the qualitative differences of the peat substrates are clear described. On the contrary, the categories hemic (D4 to D5.1) and sapric (D5.2), are only separated by one level (D5.1 to D5.2) although they are qualitatively very different. For this study the (von Post, 1924) will be applied for two reasons: its categories cover optimally the spectrum of variations between the degrees of peat decomposition observed during the field work, and its use is well established in the natural sciences dealing with classification of mires and their ecological functions, which are the orientation points of this work.

1.2.2.4 Colour

The soil colour is a field-oriented tool to estimate mineral and organic compounds present in soils. The Guidelines for Soil Description (FAO, 2006) recommend the Munsell © Color Chart (1994), alongside a site estimation of textural substrate classes. The Munsell Colour Chart is a system to specify colours based on three dimensions: hue, value (lightness) and chroma (colour purity). Regarding soils, this system is a tool to infer specific organic and mineral contents during field examinations. For example, dark colours are indicators of humic organic substances and light colours indicator of mineral ones. Furthermore, dark coloured organic soils are associated with a high degree of peat decomposition, as received by hemic and sapric qualifiers in the Guidelines for Soil Description (FAO, 2006). Classical studies incorporate the colour of peat as a classification parameter. In the case of organic soils, colour alone is not a dependable enough pattern to differentiate among peat types. It should be applied in association with field or laboratory recognition of plant macrofossils. Indeed, recent ecological studies about mires debate the use of the Munsell System (León Valdebenito, 2012), applying only the degree of decomposition scale of (von Post, 1924), with the disadvantage that some botanical types (e.g. ericaceae), as well as some mineral enriched peats seems to be clearly differentiable through their colours, according to own observations (e.g. "ñadis", a word from the mapuche language, used to mentioning reddish peaty soils, typical in lower river basins enriched by volcanic sediments, iron and other mineral inflows).

1.2.2.5 pH-value

The pH-value is a parameter used to measure ecological conditions of mires in studies worldwide. The role of pH-values for the development of plant communities has been demonstrated in different mire ecotypes on the Northern and Southern Hemispheres (Boelcke et al., 1985; Kleinebecker, 2007). The potential liberation or fixation of nutrients available for plant growth will be influenced by the pH-value. Basic pH-values can lead to a surplus of plant nutrients, and consequently a phytoplankton increase and an oxygen decrease at a site, a process known as eutrophication. In this condition, eutrophic environments are associated with neutral and basic pH-values, while oligotrophic conditions to acidic pH-values. At the other extreme bacterial activity increase at pH-values >5.0 (Ivarson, 1977) and with them the fermentation of organic carbon and the decomposition of peat under anaerobic conditions (Loisel and Yu, 2013; Malmer and Wallén, 1999) Under these conditions, pH-values dominating in mires are associated with a defined degree of peat decomposition, with this being lower in sites with an acidic pH-value (<5.0) and higher in sites with a basic pH-value (>7.0). Most mires display low pH-values, which define a low decomposition rate of plant remains and a decelerated release of nourishing compounds. In mires ecosystems where *Sphagnum magellanicum* mosses grow, there takes place a high exchange of hydrogen ions by cations, which also contribute to decrease the pH (Clymo, 1963). Also under the presence of oxidized pyritic materials, typical within tidal environments, pH-values can diminish to <2.0-3.0. The parent material also determines the pH-value of a site. Mires forming directly on igneous or metamorphic rocks are acidic than those forming on sedimentary rocks, with these tending to alkalify (Succow und Joosten, 2001).

1.2.2.6 Calcium carbonate content ($CaCO_3$)

Calcium carbonate ($CaCO_3$) is a compound related to chemically transformed organic carbon and to the presence of calcium rich compounds in the parent material or water of peat soils. Classifications vary in the quantity of diagnostic levels from five to eight, but maintaining a common indicator: the intensity of the effervescence produced by the liberation of carbon dioxide gas, under reaction to 12% HCl solution (AG Boden, 2005).

1.2.2.7 Organic carbon, total nitrogen and carbon and nitrogen ratio

Organic carbon (C_{org}) is fixed and conserved in the semi-decomposed vegetation and organic matter forming mires. It is calculated that >550 Pg t C_{org} are stored in peat soils worldwide. Different organic compounds important for the nourishment of plants and soil organisms are part of the C_{org}, among them lignin, cellulose and wax. Depending on the type of vegetation at a site, different ratios of these compounds will be available, affecting the accumulation/mineralization rate of the peat. Sugars and proteins mineralize faster than cellulose or hemicelluloses, followed by lignin and lignin-derived substances that are more resistant to microbial activity, with these being the main compounds in mires of the lowlands. Some minerals can accelerate the mineralization of the organic carbon fraction prevailing in a landscape, e.g. sodium, iron and sulphur, which are the main compounds in coastal mire ecosystems formed under paludification (Zinck and Huber, 2011). The mineralization of the organic carbon fraction will be also affected by the local climate, with humidity playing an important role for lignin decomposition, which can only happen under oxidative reactions, in oxygenated milieus or sites where dry periods occur. Bacteria and microorganisms need carbohydrates, cellulose, hemicellulose, starch and other C_{org} compounds to fulfill their nourishment requirements. In the case of oligotrophic bogs, where the organic matter remains largely undecomposed, the C_{org} is fixed and not available for bacteria and microorganism nourishment. The transformation of C_{org} compounds into CO_2 (in aerobic conditions) and CH_4 (in anaerobic conditions) that bacteria and microorganisms normally carry out is thus avoided in oligotrophic milieus.

Nitrogen (N) is a chemical element naturally present in organic and inorganic forms in the atmosphere and living organisms of the earth. Nitrogen is the most important nutrient for plants. It is fixed in plant roots, leaves and decayed plant biomass, as well as in humus and soil organisms. In mires, so long as a low degree of peat decomposition prevails, nitrogen will be present at low levels (0.5 to 1.5 % in ombrogenic peat and 1.3 to 3.5 % in geogenic peat after (Succow und Joosten, 2001). If low nitrogen levels are maintained, exogenous plants will not colonize mires, their decayed plant material will remain semi and un-decomposed, and microorganisms will not have the chance to proliferate. If waters enriched by minerals, nutrients or organic compounds (also C_{org}) enter in the mire system, comfortable conditions for microorganism and bacterial activity will be produced, which are the main agents for mineralization of the nitrogen initially fixed in the peat. Once digested by microorganisms and bacteria, nitrogen is available as ammonium and nitrate, incrementing nutrition levels and producing eutrophic conditions within a site. As was explained before, these levels form the main difference between fens and bogs. (Scheffer et al., 2010) documented that mineralization of nitrogen is correlated with the pH-value. According to these authors, the process is realized by microorganisms when pH-value >5.0 and by fungi when pH-value <5.0. Nitrogen can reach critical levels if allogenic nutrients are added, which normally happens artificially via enriched runoffs from agricultural activities or front of drainage and temperature changes. These situations cause nutrient imbalances, making local plants vulnerable to invasive species and susceptible to pests and frost, and leading finally to biodiversity lost. The carbon to nitrogen ratio (C/N) is an indicator of the tropic conditions in a site, which means the availability of nutrients that can be used by plants. Interpreting the C/N ratio together with the pH-value, the ecological conditions of a site can be explained (Succow und Joosten, 2001), and in the case of mire horizons, the C/N ratio of the substrates can be interpreted as the trophic conditions that dominated at the moment of their formation. A high C/N ratio reveals a low mineralization rate of the organic matter, while a low C/N ratio testifies to the contrary. According to recent studies, high C/N rates are consequently related to the retention of C_{org}, to low or no emissions of CO_2, and to no CH_4 production. Loisel and Yu (2013) detected high levels of C_{org} fixed in fen plant remains on the deep horizons of mires in Tierra del Fuego and the Southern Archipelago. Fritz et al. (2011) confirmed zero CH_4 emissions in the *Sphagnum* bogs of Tierra del Fuego-Argentina, due to the presence of these pH-sinkers mosses and dominant low temperatures, which avoid mineralization of peat as well as the availability of C_{org} for microorganism activity. Compared to bogs, the C/N coefficient is lower in fens, which are more extensive in nutrient enriched landscapes where precipitations decrease and water sources terrestrially originated or influenced dominate.

Although mires fulfil a range of ecosystem functions, that is wider for the life on the earth than only as "carbon storage", the quantification of carbon stocks in these ecosystems is currently the most efficient tool to incorporate them into national policies or natural conservation and environmental protection. However the quantification of C_{org} stored in peat soils is controversial, because the related information is incomplete, e.g. if the carbon contribution occurs due the vegetation or microbial decay it is not usually measured separatedly. Likewise, factors affecting the carbon storage rates like temperature, humidity and depth are only contemplated in a minority of the researches, and are mostly measured by different procedures. This prevents an accurate inference of the global carbon stocks present in mires. In the context of climate warming, accelerated industrial development and scarcity of water sources, the risks of mires drainage increase, and with them their probability to turn into emitters of carbon dioxide (CO_2) and nitrogen oxide (N_20), both greenhouse gases.

1.2.3 Commentaries

The examples of parameters presented above are common to classification systems dealing with mires worldwide, and thus a guideline for the development or improvement of new local taxonomies. Nevertheless, these parameters should be applied according to previous examinations of landscape conditions. Regarding to Patagonia, carbonates are present in soils at the eastern flatlands of Argentina (Laurora et al., 2001; Bockheim et al. 2006), where the prints of the paleo-maritime environments remained isolated from the emergent Cordillera de los Andes, but they are absent from the western region dominated by the Andes, and where the study sites here presented are located. On the other hand, while classifications like the KA 5 (AG Boden, 2005) exhibit a special focus on degraded ecosystems, it contains fewer categories to describe the pristine ecosystems such as those existing in Aysén. The landscape-ecology oriented classification developed by Succow und Joosten (2001) is much more suitable, although their intervals should be adapted to the ratios of the local pH-level, C and N of Aysén mires. The same occurs with the botanical types of the KA 5 (AG Boden, 2005), which are based in the German flora. Paying attencion to the special characteristics of the Patagonian geology and hydrology, a hydrogemomorphic classification appears to be properly. At the same time, social and cultural uses have to be considered. As it was explained at the beginning of this chapter, mires are ecosystems conceptualized differently according to their use or significance in a defined culture, economy or environment, thus classification parameters have different backgrounds. Generalizations and adaptations should be achieved cautiously, because once implemented in environmental policies, they will directly influence the management and future decisions about these ecosystems. This is especially significant as regards the definition of peat, which in some countries is applied only when *Sp. magellanicum* mosses are present (e.g. Chile). The same should be observed with regards the peat thickness necessary to classify an ecosystem as mire. Whilst in Germany the peat thickness should reach at least 30 cm, in Peru it only needs to be 18 cm. When in Peru the 30 cm rule was adopted without a previous recognition of the local ecosystems existing in this country, the major part of the mires in the Peruvian part of the Cordillera de los Andes could result undervalued and threatened by drainage or mining requirements, and the water sources of native Andean communities living of small livestock activities could been seriously affected, since these ecosystems play a crucial service in the water purification. Recognition not only of the natural, but also of the social aspects where classifications are needed, are both significant. Among this, national environmental regulations are crucial to support the development of strategies for mire conservation, restoration and sustainable use.

1.3 The legal framework of mires in Chile

In Chile, agreements about mires have been internationally acknowledged in the Ramsar Convention for the Protection of Wetlands, which was signed in 1981. The Ramsar convention involves ecological, economic and cultural parameters in a single environmental policy for mires assessment. It is an exclusive intergovernmental treaty on wetlands, providing the framework for national action and international cooperation for the conservation and the wise use of these ecosystems and their resources (www.ramsar.org). The main reason for the foundation of the convention was halt and revert the loss of wetlands ecosystems that has occurred all over the world since the industrial revolution. Mires are defined as a kind of wetlands, "with a peat deposit that may currently support vegetation that is peat-forming, which may or may not lack vegetation entirely". Ramsar understands peat to be "dead and partially decomposed plant remnants that have accumulated *in situ* under waterlogged conditions". The Ramsar convention focuses on symbolic, ecological and economical valuations, around the concept of "wise use", being ambiguous the way in which each country assesses their mires. Until 2012, in Chile twelve wetland ecosystems became protected under this convention, meaning a total of 913 ha, which is a very small territory compared to the ca. 5.000.000 ha wetland existing in Chile's territory. At the other hand, among the wetlands considered Ramsar sites in Chile, until 2004 no one was a mire (Ruiz & Doberti, 2005). Other international agreements signed by Chile are all them indirectly related to mires: the Kyoto Protocol of the United Nations Framework Convention on Climate Change, the Earth Charter, the Montreal Protocol on Substances that Deplete the Ozone Layer and the Basel Convention for the Control of Transboundary Movements of Hazardous Wastes and their Disposal (United Nations, 1998). Beyond these conventions and agreements, mires are not clearly considered in environmental policies, unlike peat. Peat is defined in Chile in the "Mining Code" (Ministerio de Minería, 1983) as a *"non-metallic resource"*. Since mining activity is the basis of the Chilean economy, potential exploitable mining resources are given special treatment and are considered to be above environmental regulation. This is a kind of "political-policy" inherited from the dictatorial regime (1973-1989). During the democratically elected government of Salvador Allende (1970-1973), mineral resources were nationalized and their capital gain was invested in education, health and infrastructure for the benefit of Chilean people. In 1973 and with the backing of the USA Government, a military coup led by Augusto Pinochet overthrew Allende's government with the support of the armed forces. Under the intellectual guidance of right wing Chilean economists (most of them educated at the University of Chicago with the neoliberal theories of Milton Friedman's and Arnold Harberger), the dictatorship of Augusto Pinochet implemented several reforms to the Mining Code:

"The State has absolute, exclusive, inalienable and *imprescriptible domain of all mine resources, including nitrates, bearing s*and*s, salt mines, coal* and *hydrocarbon deposits* and *other fossil substances with the exception of superficial clays, beyond the property of natural or legal persons over the l*and *where these resources are contained"* (Ministerio de Minería, 1983)

Through the reforms of the Mining Code, the right of the state to allow private enterprises to extract mineral resources in Chilean territory was enshrined, simultaneously generating laws to protect and promote private mining investments:

"The mining concession is a right in rem and *immovable, separate* and *independent of the domain of the surface property, even if they have the same owner, enforceable against the State* and *any person, transferable* and *transmissible; susceptible to mortgage* and *other property rights* and*, in general, of all act or contract…"* (Ministerio de Minería, 1983).

The Mining Code determines that peat extraction does not require an official governmental authorization. A simple investor-landowner agreement is legally sufficient (Hauser 1996). Additionally, extraction rights are able to be conceded by the state to private entrepreneurs, regardless of the landowner or the kind of current land use. Because mining plays a crucial role in the economic development of Chile, projects related to this activity have special governmental support. In 2011, the authorization of the Mina Invierno coal project on the island of Isla Riesco proved that mining development exceeds by far every environmental policy and the wishes of the citizens. Located next to the Marine National Park Francisco Coloane in central of the Alacalufes National Natural Reserve, Isla Riesco is an area with plenty of glaciers, fauna and pristine ecosystems, where there are incipient livestock and tourisms activities taking place (Henríquez, 2011). The island is administrated by the System of Wild Areas Protected by the State- SNASPE (Sistema Nacional de Areas Silvestres Protegidas por el Estado) of the National Forestry Corporation-CONAF. Almost 90% of mires are located within wild protected areas in Aysén. Negative experiences (e.g. Isla Riesco) show, that any attempt to generate measures for the protection or sustainable use of these ecosystems, will be useless if not accompanied by a change in the legal status of peat as a non-metallic resource regulated by the mining code. Meanwhile, the imports of peat for agricultural uses has been increasing by 26% since 2002 (Bennewitz Martinez, 2013). Investors are pressing the government for the concessions of new exploitation areas. Already 18% of total mire areas are acquired in the Magallanes Region. Governmental interest in promoting peat extraction is expanding in Aysén, where technical feasibility studies have been undertaken since 2003 (Centro de Estudios Trapananda-Universidad Austral de Chile, 2007). The development of inventories and the classification and valuation of mires ecosystem services and environmental functions are an urgent issue in Chile, to ensure that these sites do not disappear due to the ignorance of a short term unsustainable economic model.

2. Objectives

The objectives of this research could be synthesized as follows:

1. Provide an identification and description of pristine and so far unstudied mire ecosystems, focusing in their stratigraphic and ecological conditions.
2. Examine physical and chemical characteristics of the existing mire ecosystems and organic substrates
3. Based on the results, propose a hydrogeomorphic and ecological classification of mire ecosystems in the region of Aysén, and a typification of their forming organic substrates.

3. Methods

3.1 Site selection

A literature review of scientific studies directly associated with the basins of the Baker and Pascua rivers was achieved (CONAF et al. 1999a and 1999b; Mella Avila, 1999; SERPLAC, 2005; Orrego y Rodrigo, 2007; Centro de Estudios Trapananda-Universidad Austral de Chile, 2007; Rodríguez et al., 2008; Tauro, 2009; Villagra et al., 2009; Pfeiffer et al., 2010; Barria Sandoval, 2010; Siani et al., 2010; Vargas et al. 2011, amongst others) allowing for a baseline about the knowledge available and possible location of mires in the mentioned territory. Areas containing typical mire vegetation and saturated soils that were mentioned in the literature were corroborated in the available regional cartography. Since the analog cartography was elaborated in coarse resolution (<1:100.000), only digitalized cartography was used (Tab. 6). Particularly the digitalized cartography of the National Corporation for Forestry (CONAF et al., 1999a, actualized in 2010) contributed information about geology, geomorphology, altitude, watersheds and sub-watersheds, seas and lagoons, rivers, soil use, wild protected areas, sedimentation zones, access and roads. The reports produced by this organization were used to compare and visualize both vegetal communities and associations. To reduce margins of error, aerial photography from the Chilean Aerophotometric Service (SAF) and Google Earth imagery were additionally used to compare the extension and location of potential mire areas along the selected riverbasins. The cartographic material is exposed in Tab. 6. Thanks to the literature and cartographical analysis, it was defined that the information reported in previous scientific works about areas presenting typical mire vegetation or vegetation adapted to waterlogged conditions, was mostly coincident with the cartographic registers about "peatlands", "swamps" and "other kinds of wetlands". On the other hand, it was verified that mires distribution in the selected riverbasins also followed an increasing east to west precipitation gradient. These aspects were represented in the decision about the mire sampling areas, focusing on:

- Sites that were morphologically and hydrologically comparable to those reported in the literature containing typical mire flora (*Sphagnum* mosses*, Pilgerodendron uviferum, Marsippospermum grandiflorum, Drosera uniflora* or *Carex magellanica*)
- Sites that were visible or documented in aerial imagery or in digital geographical information systems available for the region
- Sites that covered a rainfall gradient representative of the regional river basins, including

    a) The continental sector, located to the east of the Andes Mountain, exhibiting precipitations under 900 mm y^{-1}

    b) The transitional sector, covering the central basins with a rainfall gradient between 1500 and 2500 mm y^{-1}

    c) The maritime sector, located to the west and including the low basins, with precipitation above 3000 mm y^{-1}

Five sites were selected as representative of those existing in the Baker and Pascua riverbasins (Fig. 13). Additionally, sites were accessible from the Carretera Austral or had a minimal support from the local inhabitants of the surrounding area (motor boats, horses, etc.). In the east, subject to continental influence, the sites of Lago Vargas (47°40’46’’S and 73°03’50’’ W) and Villa O`Higgins (48°28’05’’S and 72°33’18’’ W) were selected, in the transitional zone the site of Lago Quetru (48°28‘08‘‘S and 72°33‘34‘‘W) was selected, and in the zone that is subject to maritime influence in the west, there the sites of Los Remolinos (47°47‘43‘‘Sand 73°31‘56‘‘W) and Bajo Pascua (48°12’53’’S and 73°19’50’’W) were selected. The sites are presented in detail below.

Tab. 6: Cartographic materials used to the sample design

	Information	Source
Digital Cartography	Geology, geomorphology, altitude, watersheds and sub-watersheds, seas and lagoons, rivers, soil use, wild protected areas, sedimentation zones, roads. Date unknown. Scale: 1:100.000. Data type:.shp	(SERPLAC-Secretaría de Planificación y Cooperación-XI REGIÓN 2005).
	Vegetal Communities and Associations. 1999a and 1999b, actualized in 2010. Scale: 1:100.000. Data type: .shp	CONAF et al. 1999a and 1999b, actualized in 2010
Aerial Imagery	GEOTEC: -1:70.000 S15, Chile Chico L14, SAF98, N° 012484 -1:70.000 S15, Chile Chico L15, SAF97, N° 005156 -1:70.000 S15, Chile Chico L15, SAF97, N° 005158 -1:70.000 S15, Chile Chico L17, SAF97, N° 005171 -1:70.000 S15, Chile Chico L16, SAF97, N° 005437 -1:70.000 S16, Campo de Hielo L17, SAF97, N° 005374 -1:70.000 S16, Campo de Hielo L17, SAF97, N° 005324 -1:70.000 S16, Campo de Hielo L16, SAF97, N° 005426	SAF, several years
	Cenes/Spot Image 48°20'33''S/72°52'3''W - 47°24'55''S/73°11'50''W	TerraMetrics © 2010-2012 (Google earth)

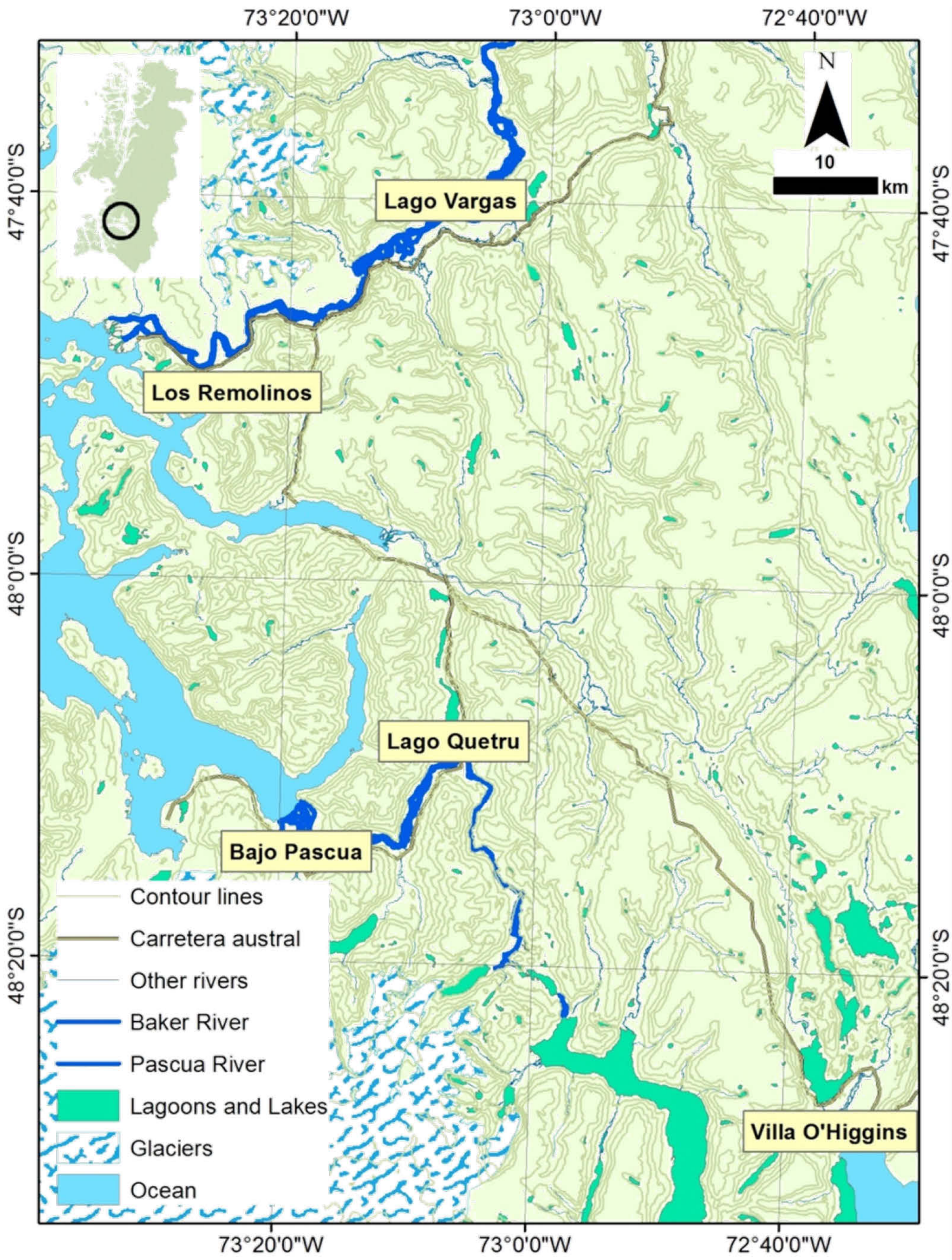


Fig. 13: Mire Sampling Sites in the region of Aysén.

3.1.1 Lago Vargas (LV) Site

Location: Located in a continental sector in the central basin of the Baker River, at 47°40'46'' S and 73°03'50'' W and at an average altitude of 33 m a.s.l. The examined area covered approximately 1450 ha in the central basin of the Baker River (Fig. 14). The site is a small part of a mire system of 5104 ha that stretches from the southern shore of Lago Vargas across almost 40 km to the delta of the Baker River.

Climate: According to different studies (SHA, 2008; Vargas et al. 2007; www.meteoarmada.directemar.cl), the site LV receives a rainfall average of 1300 mm y^{-1} (maximum in July and minimum in January), and has a median annual temperature of 11°C.

Access: According to the cartography, the site was accessible for vehicles through the Pasarela Vargas, which is a small bridge connecting the Carretera Austral (Federal Southern Highway) to an old abandoned military airstrip in the middle of the site (the white line in the centre of Fig. 14).

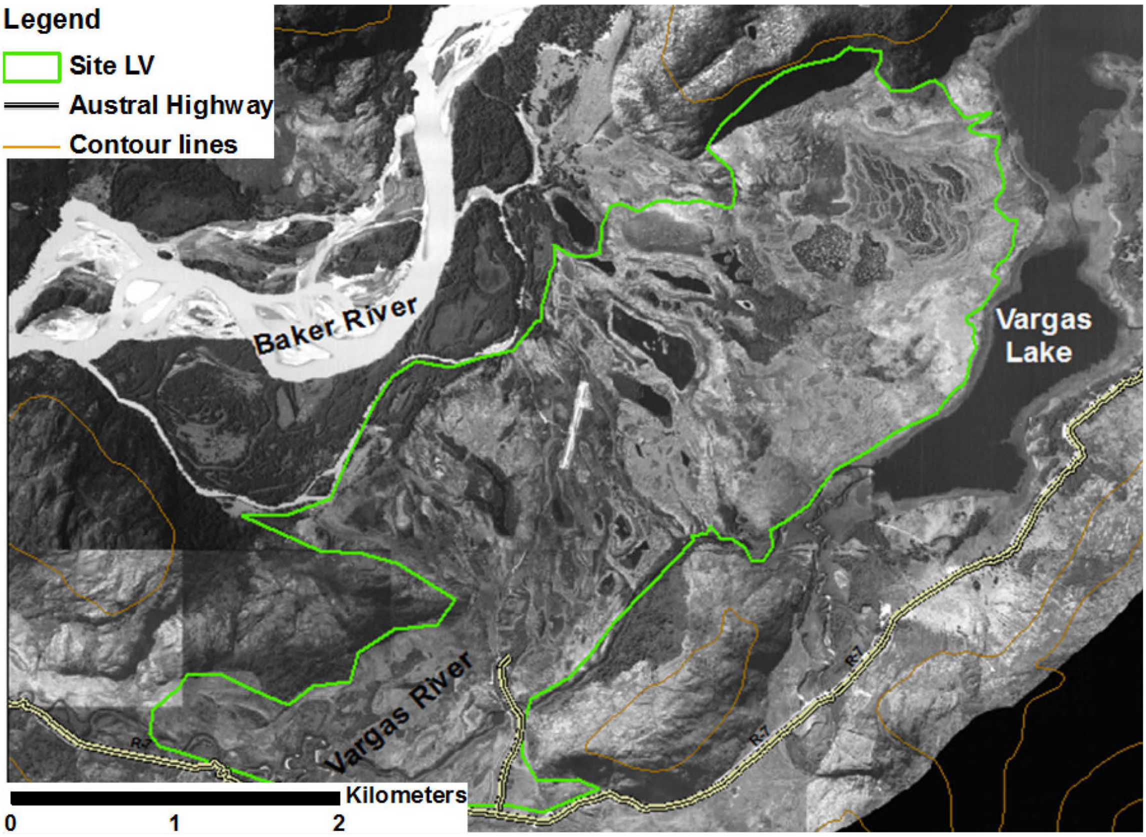


Fig. 14: Aerial imagery of the site LV (picture modified from SAF)

3.1.2 Los Remolinos (LR) Site

Location: Site LR is located at 47°47‘43‘‘S and 73°31‘56‘‘W and at an average altitude of 7 m a.s.l. (Fig. 15). Located in the lower basin of the Baker River, only 4 km away from the oceanic fjords, the site is the final section of the mire system starting in Lago Vargas and ending in Caleta Tortel, stretching along the middle and lower basin of the River Baker. The examined area covered 391 ha.

Climate: Site LR is characterized by a rainfall average of 3300 mm y^{-1} and a median annual temperature of 7°C (DGA, 2014). The maximums for the rainfall and temperature are reached in July and the minimums in January, as occurs in the Lago Vargas (LV) site.

Access: In the cartography the site appeared directly accessible from the Carretera Austral.

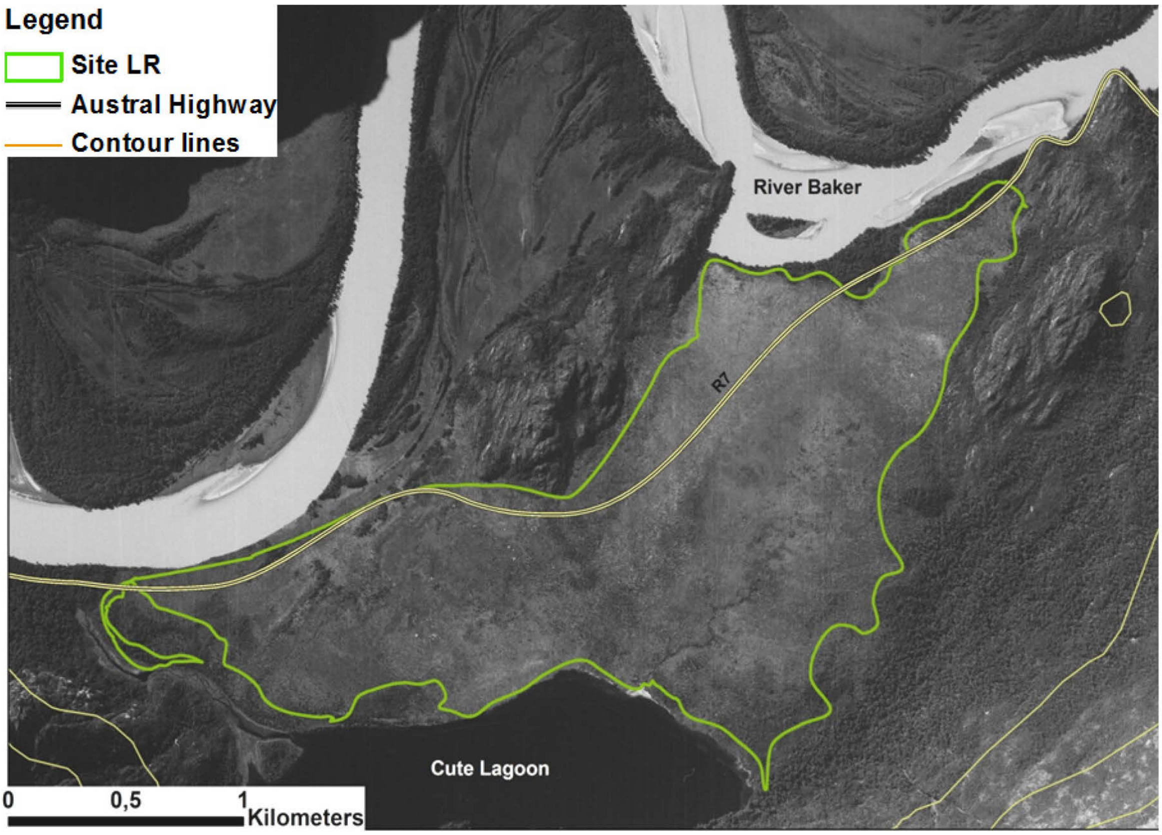


Fig. 15: Aerial imagery of the site LR (picture modified from SAF)

3.1.3 Villa O'Higgins (VO) Site

Location: Site VO is located in the mountains of Villa O'Higgins subject to continental conditions, at 48°28'05''S and 72°33'18''W and at an average altitude of 365 m a.s.l. The area examined covers 4.1 ha (Fig. 16). VO is part of a mire system in the mountainous area known as "Cordón el Mosco", above the town of Villa O`Higgins. It is the site with the greatest proximity to the southern ice field (only 34 km to the west). Site VO was the most continental, at a distance of 64 km from the oceanic fjords.

Climate: Due to the presence of the Cordillera de los Andes Patagonicos (which acts as a climatic divider) the annual average precipitation decreases in VO in comparison to the oceanic site LR, reaching 890 mm y^{-1} (DGA, 2014). Temperatures reach an annual average of 7°C , with 1°C being the minimum and 17°C the maximum (DGA, 2014).

Access: The cartography confirmed that the site was accessible by walking 2 km across the forest from the Carretera Austral at the northern exit of Villa O'Higgins.

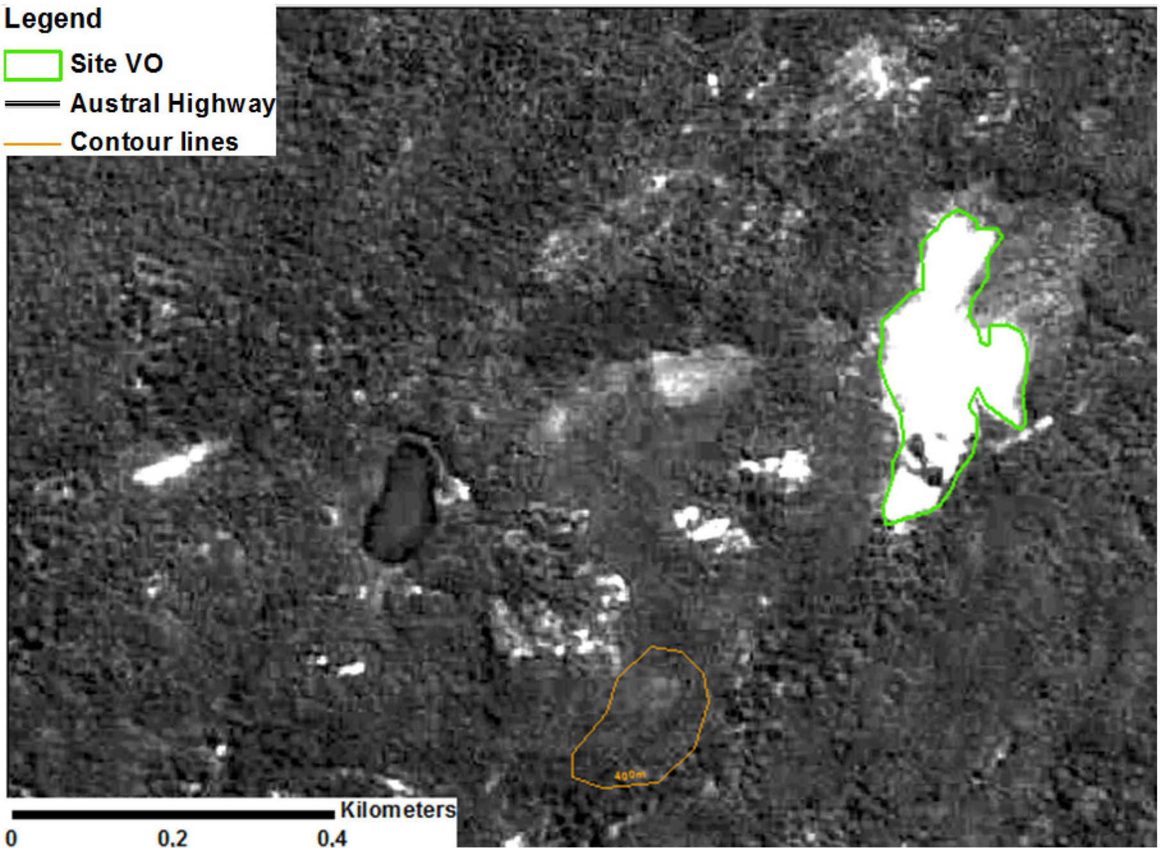


Fig. 16: Aerial imagery of the site VO (picture modified from SAF)

3.1.4 Lago Quetru (QP) Site

Location: Site QP (Fig. 17) is a transitional site located at 48°28‘08‘‘S and 72°33‘34‘‘W, at an average altitude of 29 m a.s.l. in the confluence of the Quetru Lake and the Pascua River, in the central basin of the latter. The site is divided into three parts: QP1 (18.7 ha), QP2 (14.5 ha) and QP3 (17.6 ha).

Climate: In this site, the average annual precipitation reaches 2200 mm y^{-1} (DGA, 2014).and temperatures 11°C (Vargas et al. 2007; www.meteoarmada.directemar.cl). Compared to the rainfall and temperature levels of the sites mentioned above, this increase can be explained by the proximity of QP to the ocean (11 km away).

Access: The cartography confirmed that the site was accessible from the Carretera Austral via a small road used by the military.

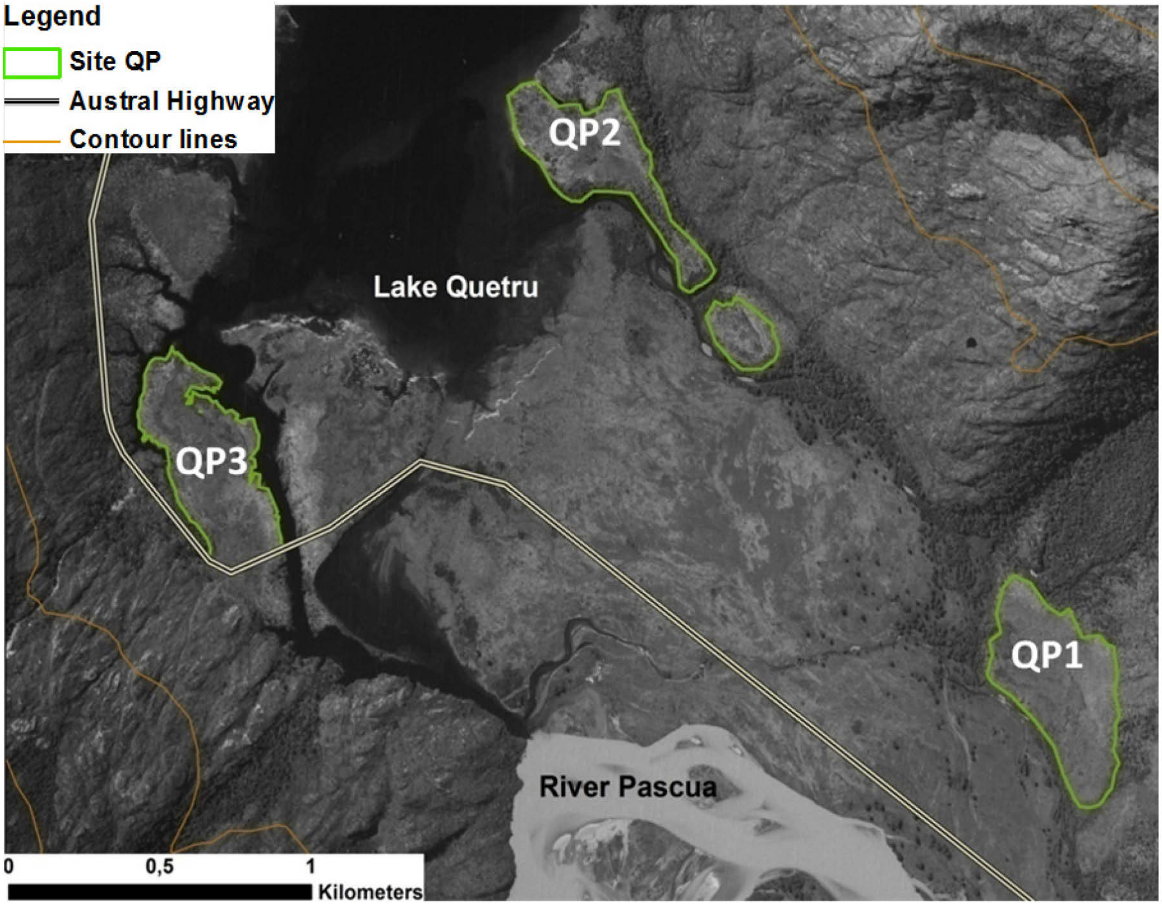


Fig. 17: Aerial imagery of the site QP (picture modified from SAF)

3.1.5 Bajo Pascua (BP) Site

Location: Subject to maritime conditions, site BP is located at 48°12’53’’S and 73°19’50’’W (Fig. 18). Being located 2 to 6 km away from the coastline, this site is the most oceanic of the samples. It was divided into four parts: BP1 (120 ha), BP2 (238 ha), BP3 (6,8 ha) and BP4 (0,9 ha). BP1 and BP2 were located in the valleys at the delta of the Pascua River (altitude of <12 m a.s.l.), whilst BP3 and BP4 were located in the mountains nearby (166 m a.s.l.). In the delta of the Pascua River approximately 378 ha were examined and in the mountainous area a total of 8 ha.

Climate: BP receives an average rainfall of 2700 mm y^{-1} and an average annual temperature of 6,5°C (DGA, 2014).

Access: Access to the site was coordinated with the personnel of the Military Work Corp (Cuerpo Militar del Trabajo), who are constructing this section of the Carretera Austral and are able to take motorized vehicles across the Pascua River onboard a small ferry.

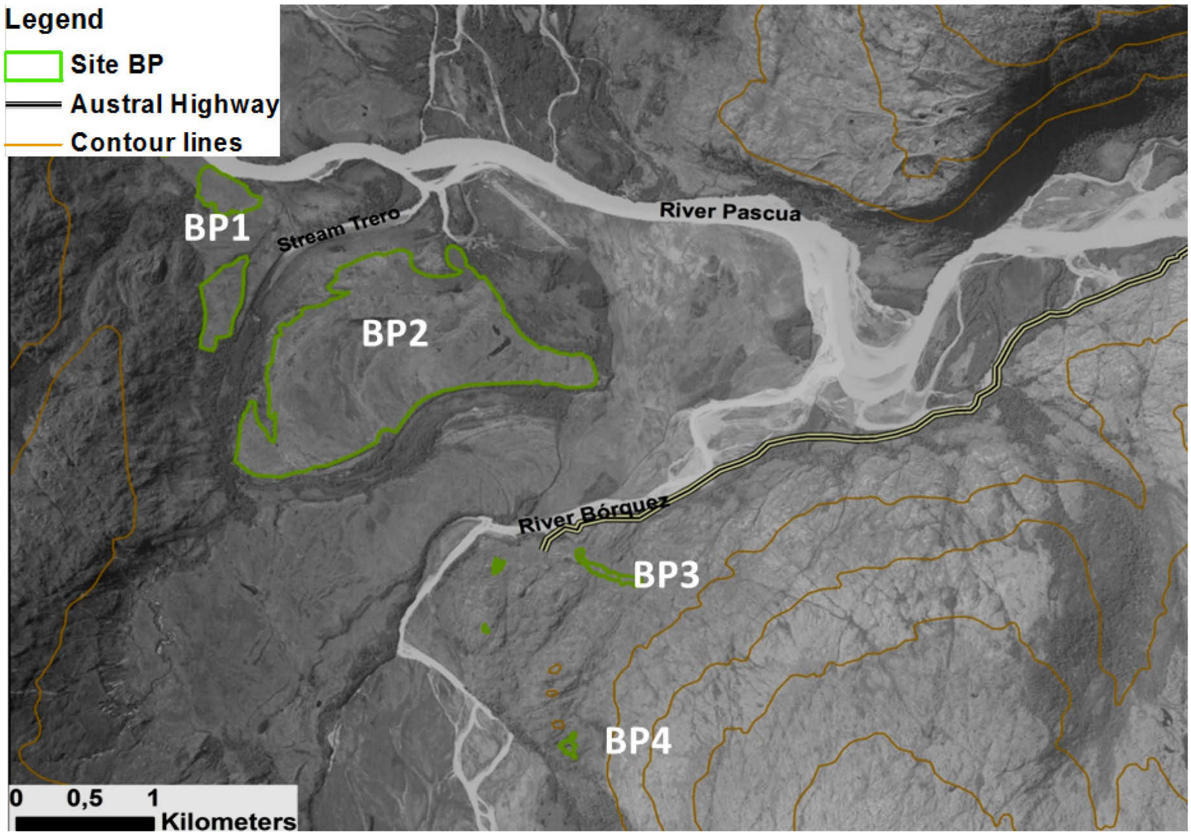


Fig. 18: Aerial imagery of the site BP (picture modified from SAF)

3.2 Sampling design

Sampling areas were programmed to be carried out through cross sections, established along a main line and several transects. The sampling points were positioned within the cross sections at approximately 100 m from each other. The final sampling design is shown in Fig. 19. In the field and in order to achieve the micro-landscape variation, the sampling design was corrected using the following parameters:

a) Spatial variation of vegetation (representation in the sample of Sphagnaceae, Ericaceae, Cyperaceae, etc. dominated areas)

b) Spatial variation of macro and micro-topography (from flatlands to slopes, intermountain depressions, etc.; and from cushion plants to blankets or hummocks)

c) Spatial variation of local hydrology (changes in the soil water level, presence of lagoons and pools, etc.).

3.3 Data collection and analysis

3.3.1 Location and Landscape setting

A GPS Garmin 60 Cs was used to record the geographical positions of the profiles (South American Reference System SIRGAS-Chile_UTM_Zone_18S) and altitude (m a.s.l.). Inclination and exposure were measured with a compass-inclinometer Sunnto MC-2. Landscape hydrology and morphology were defined and delimited by contour line analyses through the digital cartography and aerial imagery mentioned in Tab. 6, using the software Arc-GIS 9.3 and Arc-GIS 10, as well as the data corrected during the field explorations (ESRI 2011). Mire hydrology and morphology were documented according to the categories developed for Germany by Succow und Joosten (2001), for the Rocky Mountains by Chadde et al. (1998) and for South Africa by Ollis et al. (2013).

3.3.2 Vegetation

The main vegetation species (mosses, ferns, grasses, shrubs and arboreal vegetation when present) were observed and their dominance defined according to the percentage cover of each species after Braun-Blanquet (1964) and León Valdebenito (2012) in plots of 12 m^2 around each sampling point. Additionally, the mire vegetation physiognomy was observed, distinguishing between hummocks, cushions, blankets and forest-covered mires after Pisano (1977), Villagra et al. (2009), Kleinebecker (2007) and Iturraspe and Urciuolo (2012).

3.3.3 Soil water level

The mire water table was measured in centimetres below the surface (cmbs) in each profile. Additionally, in the site LR four pipes for continuous measuring were installed following a cross section from the mountains to the river border of the mire, crossing both bogs of *Sp. magellanicum* and of *A. pumila* (Fig. 20, picture B). Measurements in the installed pipes were realized with a light plummet Ø 16 mm (Fig. 20, picture A). Due to logistical constraints (isolation and costs) these measurements were only taken at the Site LR, by a local inhabitant, twice a month from May to October of 2012.

3.3.4 Cores

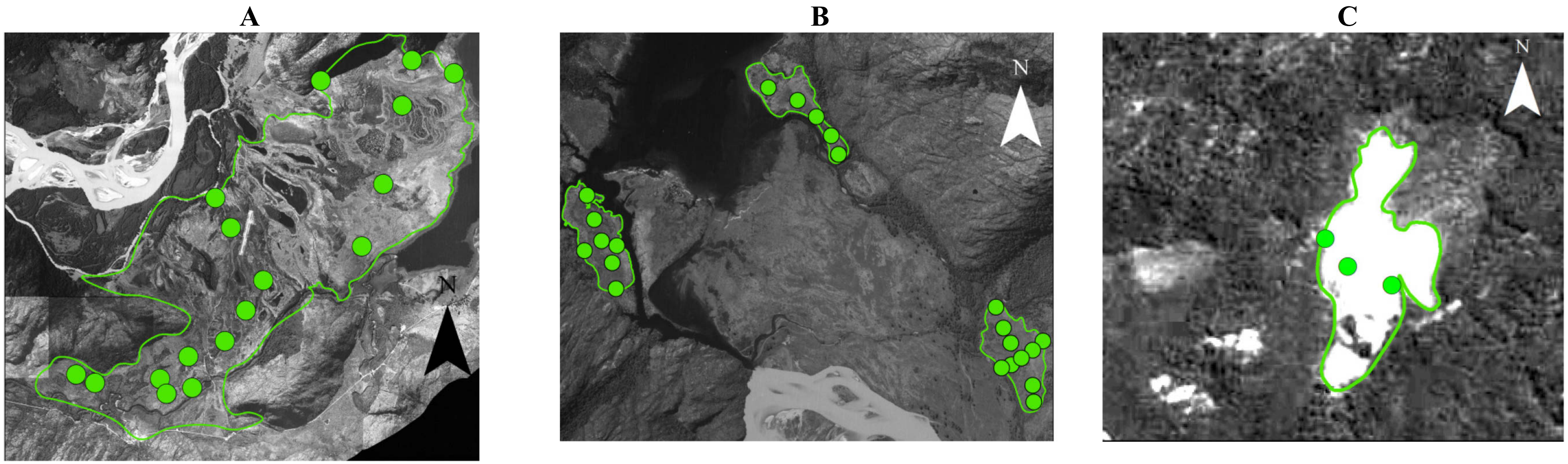
Following the procedures of the KA 5 (AG Boden, 2005), pedogenetic data were collected at each examined profile. First, in the surface of each profile 30 cm^2 of the upper soil material was extracted with help of a shovel, allowing the review of superficial vegetation, roots and humification grade. The process was followed by a stratigraphic examination with penetration by a Eijkelkamp Peat Corer (Fig. 20, pictures C and D), that made feasible the extraction of 50x6x30 cm undisturbed peat samples until the underlying mineral substrate, achieving information about order, structure, composition and thickness of the mire forming horizons. Strong compacted and underlying mineral horizons were sampled with a Pürckhauer Geological drill (Fig. 20, picture E).

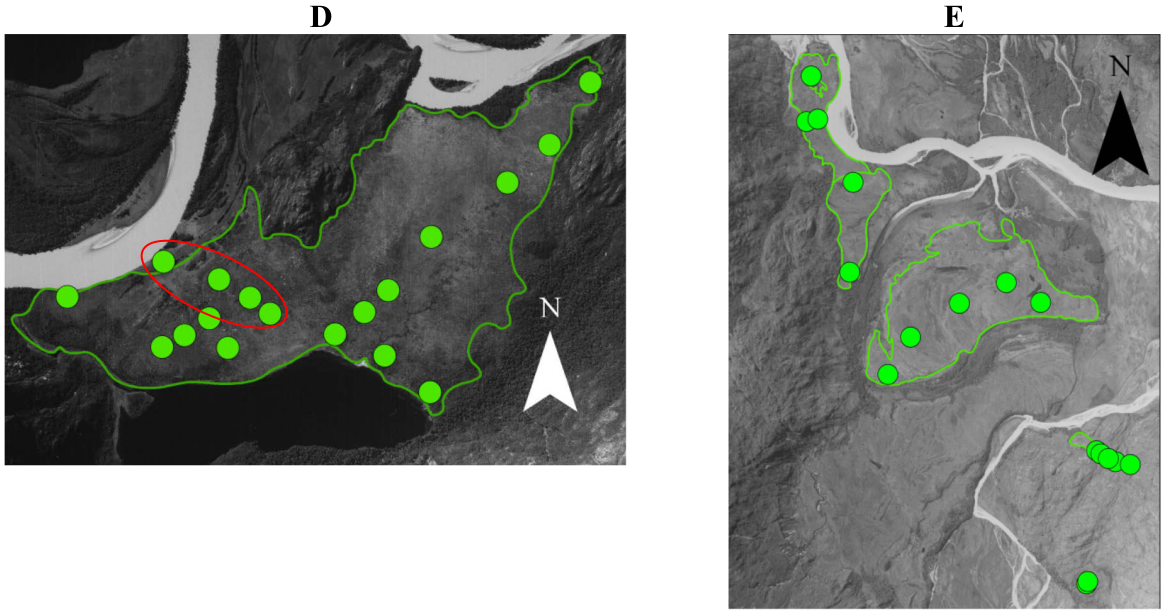
3.3.5 Substrate and horizons

Substrate types were defined according to the composition of the parent materials, differentiating in organic and mineral substrates. Organic substrates (peat and organic gyttja) were defined according to the dominant macrofossils or organic remains, applying the botanical types described in the KA 5 (AG Boden, 2005) and adding to this classification the botanical types endogenous to Patagonia, when these were present. From the order and characteristics of the prevailing substrate types, soil horizons were differentiated also according to the KA 5.

3.3.6 Colour

In order to detect differences among the colours of the substrates, these were documented under the Munsell Colour System during the examination of the extracted cores (Munsell © Color, 1994).





A= Site LV in the Baker River- Central basin (18 Profiles). B= Site QP in the Pascua River- Central basin (23 Profiles). C= Site VO in the mountains of Villa O'Higgins (3 Profiles). D= Site LR in the Baker River- Lower Basin (18 Profiles. Red ellipse shows profiles with pipes for mire water table measurements). E= Site BP in the Pascua River- Lower Basin (19 Profiles).

Fig. 19: Schema of the selected profiles at the study sites LV, VO, LR, BP and QP (pictures modified from SAF)

3.3.7 Degree of peat decomposition

The degree of peat decomposition was defined according to the ten grades scale (H1 to H10) defined by von Post (1924). This definition was enriched with a quantitative description of the decomposed non recognizable plant material (amorphism), and by a qualitative estimation of the material density (consistency) at the moment of the sample extraction. Additionally, consistency offered a first field approximation to the water holding capacity of the peat.

3.3.8 pH-value and carbonates contents ($CaCO_3$)

Peat water was obtained under manual pressure of the peat and collected in a plastic cup holder. Measures of the pH-value were performed through a PCE-PH 20S device. Measures were repeated in every peat horizon diagnosed in the field. Substrate material was collected (also in non peat horizons) and measurements repeated in the laboratory. The categorization of pH-values was carried out according to (Succow und Jeschke, 1986). On the other hand, carbonates were tested by 12% HCl solution, but no reaction in any site was detected. Both procedures were realized following the guidelines of (Blume et al., 2011).

3.3.9 Peat bulk density

187 undisturbed samples were collected from 46 horizons (7 in LV, 6 in LR, 7 in VO, 15 in QP and 10 in BP), in 15 profiles representative of the prevailing flora, stratigraphy and mire soil water level of the whole sampled sites. Samples were taken with penetration cylinders of 100 cm^3 and Ø 53 mm according to McKenzie et al. (2002). Three to five repetitions were taken, extracting material directly from soil horizons to a depth of 50 cmbs (Fig. 21) and indirectly from the Eijkelkamp peat corer when horizons were deeper than 50 cmbs and oversaturated. Samples were weighed with semi-precision scales whilst in the field. Samples were dried at 105 °C for 48 hours until constant weight in a muffle oven. The dry weight was divided by the initial volume (100 cm^3) and interpreted as the BD.

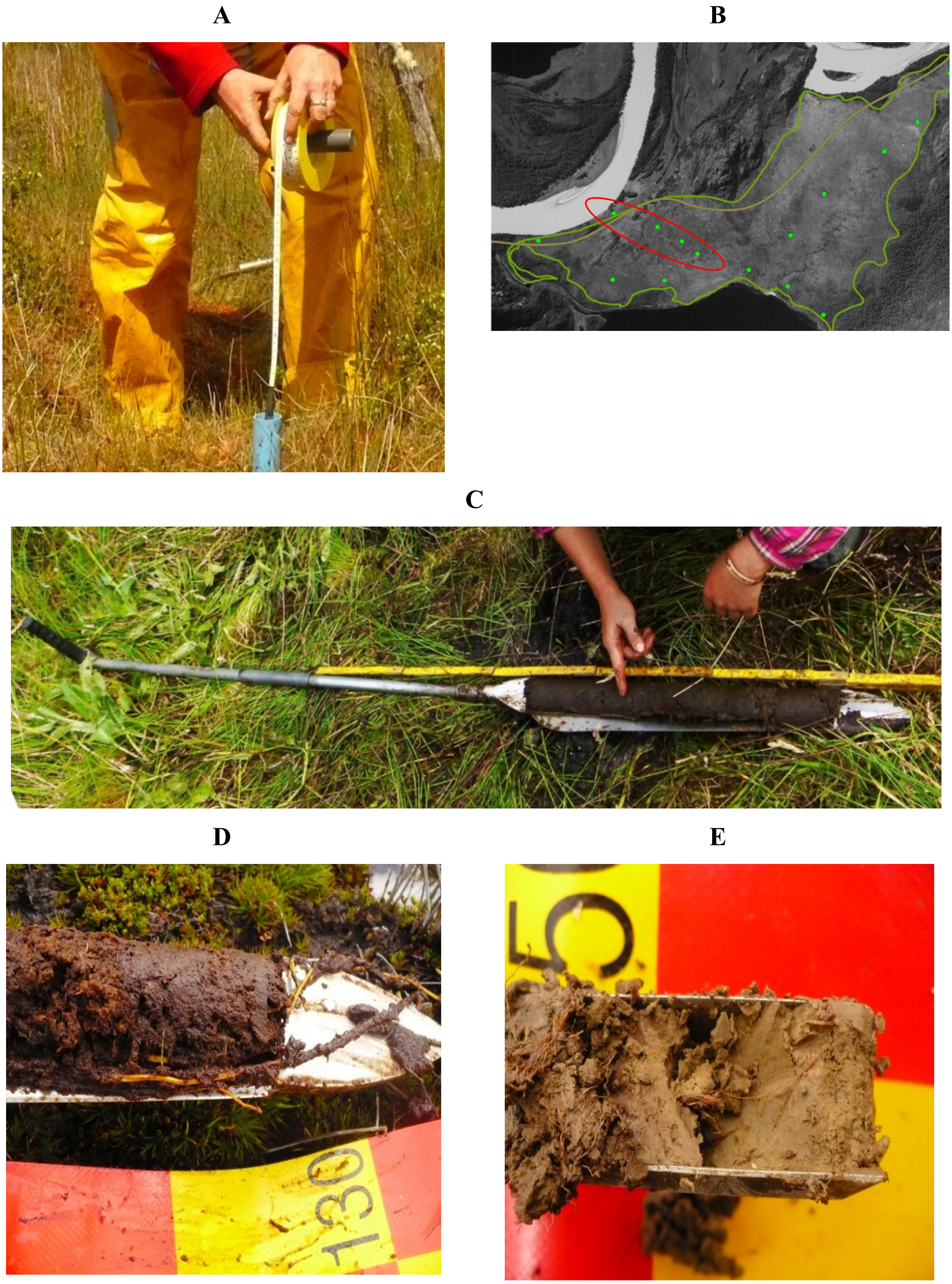


Fig. 20: Instrument for mire water table measures and for examination of substrates in the field (Rodríguez, 2012; picture B modified from SAF).

A= Pipes installed for mire water table measurement with light plummet (Ø 16 mm). B= Profiles where pipes were installed circled in red. C= Eijkelkamp peat corer. D= Peat on the peat corer. E= Mineral sample in a Pürckhauer Geological drill.

3.3.10 Water content of the peat at field capacity

The water content for the universe of substrates was inferred from the bulk density as explained in section 3.4.1. Adhering to (León Valdebenito, 2012) the difference between the weights of the fresh extracted material and the dry material obtained from the bulk density was interpreted as the field water storage capacity of the wet peat. The weight at the moment of the field extraction was considered as the initial volume of the fresh substrate and the water content expressed as % of volume loss of the fresh substrate volume after being oven-dried (Carter and Gregorich, 2008).

Fig. 21: Sample for calculation of the bulk density an field water storage capacity of the wet peat (Rodríguez, field work 2012)

3.3.11 Total organic matter, organic carbon, total carbon, total nitrogen and carbon and nitrogen ratio

For the analysis of the total organic matter (TOM), the organic carbon content (Corg) and the ratio of carbon to nitrogen (C/N ratio), disturbed peat samples were collected from the same horizons as those for the bulk density. For TOM analysis samples were treated by loss on ignition (LOI) based on weighing, then drying, 2 g samples and then igniting them in a muffle furnace at 550°C for four hours. For C_{org} and C/N analysis, samples were dried at 62°C x 48 hrs and examined with an Elementar Analyzer (VARIOMAX-C device, Elemental GmbH, Hanau) following the German (DIN ISO 11464) and the soil analysis guidelines applied by (Alt et al., 2008). Two repetitions were carried out for all the analyses. Results were interpreted together with the bulk density, allowing for the calculation of carbon storage capacity and C/N ratio of the peat substrates.

3.3.12 Radiocarbon dating (^{14}C)

Samples for radiocarbon dating were collected from north to south across the examined river basins in the sites LV, QP1 and BP4 (Tab. 7). One sample per site was collected (three in total), being extracted with the Eijkelkamp peat corer from the deepest peat horizon found in each site. The samples were analyzed at the Poznan Radiocarbon Laboratory by accelerator mass spectrometry (AMS). In the site LV (Lago Vargas), samples were collected from the profile LV1 (210 cmbs). The dated material was a piece of stem wood found in amorphous peat (H9) in a reduced horizon. Samples were not collected in the site LR (Los Remolinos), since recent information produced by Holz et al. (2012) was available. That study focused on a raised bog at Caleta Tortel (10 km south of Los Remolinos) and showed 2855±20 BP years at a depth of 90 cmbs insinuating a peat accumulation ratio of 0.03 cm y^{-1}. Regarding the basin of the Pascua River, due to logistical reasons, samples for radiocarbon dating were not collected in the site VO (Villa O'Higgins), but in the site QP1 and BP4. In QP1, *Sphagnum magellanicum* moss peat samples were collected from the deepest horizon of the profile QP1_2, at a depth of 60 cmbs. Despite its lower depth, the selection of this profile for the radiocarbon dating was based on its significant representativeness of the substrates types found in the site QP. In other words, in QP1_2 almost all the successional stages of the vegetation dominating QP since its formation were represented. In BP4, given that the mountainous sector had the deepest peat horizons, samples for radiocarbon dating were collected there, specifically radicels peat from the profile BP4_2 at 305 cmbs. This profile was also selected because its substrate type (radicels peat) was the most common in the site BP after amorphous peat, and it was possible to extrapolate its date of origin to other similar mires in the area.

Tab. 7: Description of the samples used for radiocarbon dating in the profiles QP1_2, LV1 and BP4_2

Profile	cmbs	Material	Peat substrate	DD
QP1_2	60	Pieces of *Sp. magellanicum* leaves	*Sp. magellanicum*	H3
LV1	210	Pieces of stem wood	Amorphous	H9-H10
BP4_2	305	Pieces of radicels and small root stems	Radicels	H5

3.3.13 Softwares for data representation and analysis

All cartographic materials were analyzed with the software ArcGIS Desktop versions 9.3 and 10 (ESRI, 2011). Illustrations of cross sections were designated with Strater ® version

4 (Smith and Madison, 2014). Schemas of hydrogeomorphic mire types were created with the free and open source software Inkscape version 0.91 (Software Freedom Conservancy, 2013). Statistical analyses were done with the programe IBM SPSS Statistics version 21 (IBM Corp, 2012). The calibration of results for radiocarbon dating ^{14}C was realized with the software OxCal version 4.2 (Ramsey, 2009 and 2015). A summary of all the information collected and measurements are detailed in Tab. 8 and Tab. 9.

Tab. 8: Examined sites (summary)

SITE	Basin	Location	Area (ha)	Height (m a.s.l.)	Km to coast	Sampling Date
Lago Vargas (Abb. LV)	Baker River (central basin)	47°40’46’’S 73°03’50’’W	1450	33	39	Jan-Apr 2012/ 2013
Los Remolinos (Abb. LR)	Baker River (lower basin)	47°47‘43‘‘S 73°31‘56‘‘W	391	7	4	Jan-Apr 2012/ 2013
Villa O’Higgins (Abb. VO)	Lake O’Higgins (Pascua upper basin)	48°28’05’’S 72°33’18’’W	4.1	365	64	Mar-Apr 2013
Lago Quetru (Abb. QP)	Pascua River (central basin)	48°28‘08‘‘S 72°33‘34‘‘W	51	29	11	Jan-Apr 2012
Bajo Pascua (Abb. BP)	Pascua River (lower basin)	48°12’53’’S 73°19’50’’W	325 * 7.7**	<12* 166**	2-7	Feb-Apr 2013

*D=Delta Area**M=Mountains

Tab. 9: Data collected (summary)

SITE	Site. Stratigraphy and Flora		BD, $C_{org,}$ C, TOM and C/N	^{14}C Dating
	Profiles	Horizons	Horizons	Horizons
Lago Vargas (Abb. LV)	18	113	7	1
Los Remolinos (Abb. LR)	18*	77	6	-
Villa O’Higgins (Abb. VO)	3	44	7	1
Lago Quetru (Abb. QP)	23	125	15	-
Bajo Pascua (Abb. BP)	19	111	10	1
Total	81	470	46	3

*In 4 profiles pipes for continuous measuring of the mire water level were installed. Measurments were carried out twice a month for 9 months, using a light plummet Ø 16 mm

4. Results and Discussions

4.1 Characterization of ten mire ecosystems in five sites along the Baker and Pascua Rivers, Aysén-Chile

4.1.1 Lago Vargas Site (LV)

LV is located above an old flood plain of the Baker River and practically bordered by the current course of this river and by the Vargas lake-river system. The final sample design for the site is exposed in Fig. 22. This was decided according to the site vegetation and hydrology. The access was coordinated with the landowner Mr. Rosamel Vargas (domiciled next to the profile LV1). He and a second landowner (domiciled next to the profile LV8) belong to the first colonist families and carry out livestock farming (in the surrounding mountainous valleys) and forestry activities (in the forests bordering LV). Near to the profile LV9 a 200 metre-long airstrip is left over from military exercises carried out in the 1980s during a border conflict between Chile and Argentina.

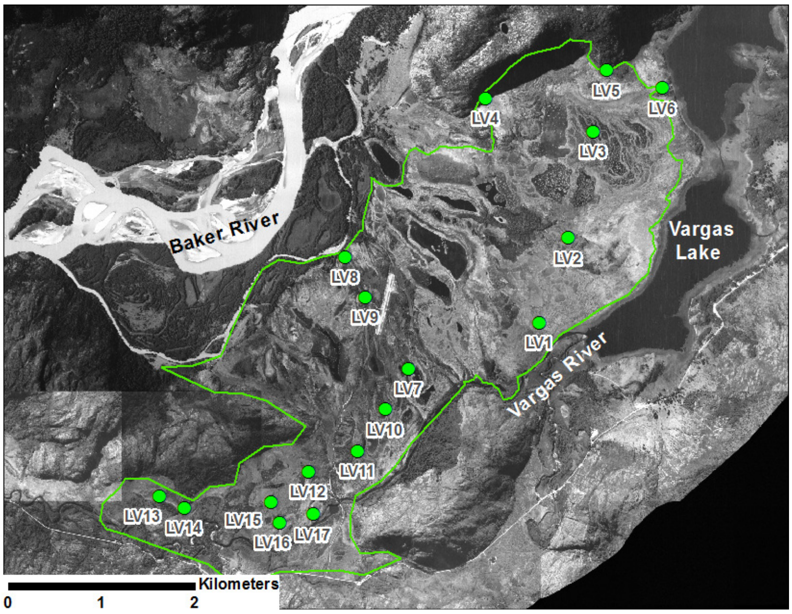


Fig. 22 Final sample design at site LV* (picture modified from SAF).

Borders of the mire system and sampling points in green, Carretera Austral shown as a grey line

Despite of the aforementioned anthropogenic events, the site LV was pristine, judging by its hydrology, vegetation and structure (Fig. 23, picture A). The periphery of LV was demarked by valley edges and slopes, plenty of gallery forests hosting native species such

A

B

C

A=The site lies on an old flood plain of the Baker River, dominated by patches of semi-dense native forest and raised blanket bogs. B= The Vargas River bordering the southern flank of LV. C= In the central and southern parts pools can be seen which have been *Sphagnum* and *Tetroncium magellanicum* hummocky bogs.

Fig. 23: Landscape setting of the site LV (Rodríguez, field work 2012-2013)

as *Nothofagus betuloides* and *Pilgerodendron uviferum* (Fig. 23, picture B). Into the centre, raised bogs of *Sphagnum* mosses and patches of small semi-dense forest appear, growing above sand banks deposited in the past by the Baker River. The central part of LV had plenty of shallow pools colonized with hummocks of *Sphagnum* mosses and the Juncaginaceae *Tetroncium magellanicum*, reaching up to <1.5 m high (Fig. 23, picture C).

4.1.1.1 Vegetation and ecological settings

The dominance of plant species in LV (e.g. the grade of representativeness of a species in a 12 m2 plot) was headed by the family Sphagnaceae. Out of this, 50% of the vegetation was represented by *Sp. magellanicum* (Fig. 24, picture A in red). The species *Sp. fimbriatum* (Fig. 24, picture A in green) was also observed in the site, always associated with the lakeshores or saturated depressions.

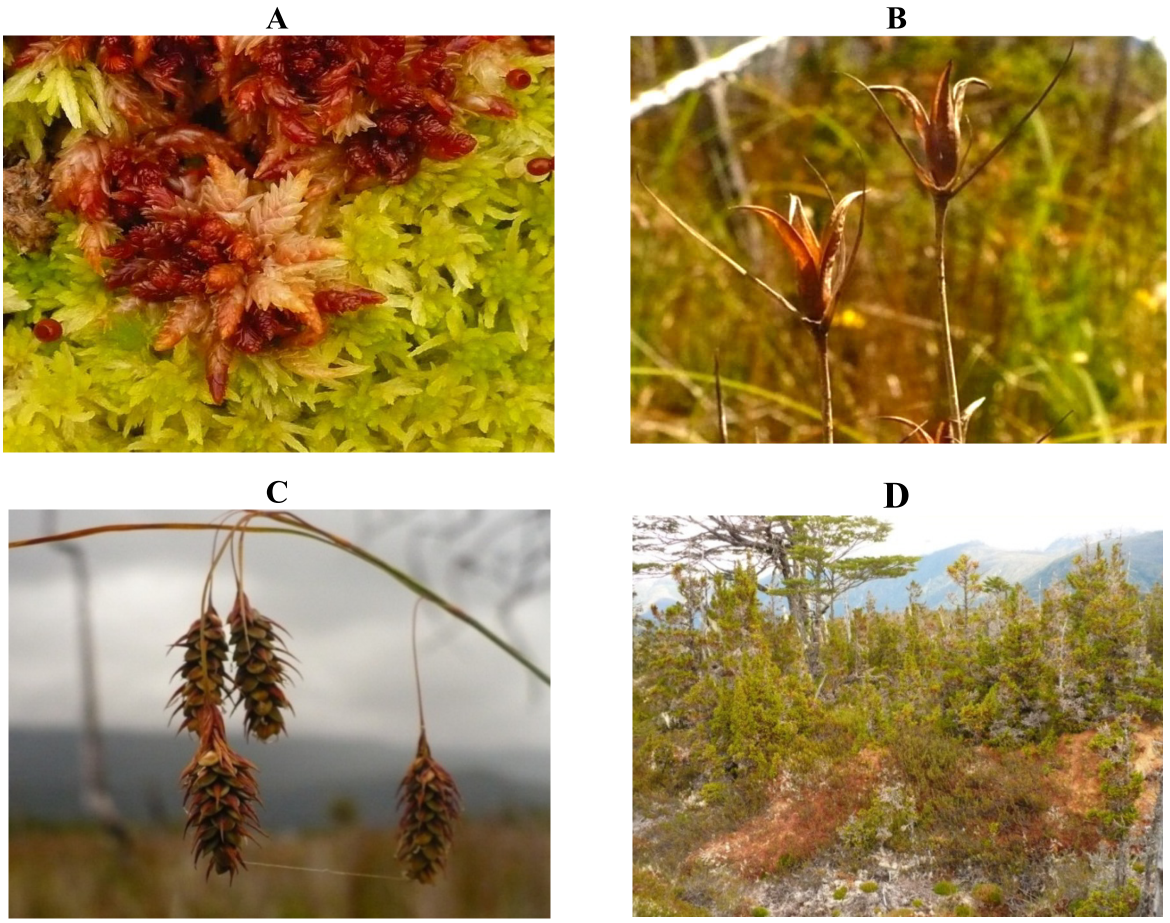


Fig. 24: Main vegetation species in the site LV (Rodríguez, field work 2012-2013)

A=*Sphagnum magellanicum* (above) and *Sphagnum fimbriatum* (below). B= *Marsippospermum grandiflorum*. C= *Carex magellanica*. D= *Pilgerodendron uviferum* (small trees) and *Nothofagus betuloides* (large tree on the left)

This coincides with data reported in mires of Tierra del Fuego (Blanco y De la Balze, 2004), where *Sp. fimbriatum* was defined as an indicator of minerotrophic conditions. *Sp. cuspidatum* was found in two plots in LV. Members of the Cyperaceae family represented 25% of the species diversity, especially with *Carex magellanica* (Fig. 24, picture B and C). LV was also a reservoir of cypress forests (*Pilgerodendron uviferum*, Fig. 24, picture D). Amongst the members of the Ericaceae family, *Pernettya mucronata* and *Empetrum rubrum* were represented with <12% dominance in the site, as well as the Juncaginaceae *Marsippospermum grandiflorum*.

Ecological conditions for vegetation to grow were characterized by upper soils with low pH-values, varying from 3.0 and 5.1. According to the measurements carried out, the northern part of the site (Fig. 25, graphic B) presented pH-values higher than the centre and southern part (Fig. 25, graphics C and D). The northern flank is a valley edge exhibiting water surpluses from the adjacent mountains, where *Sphagnum fimbriatum* mosses dominated and the upper soil presented a pH-value of 5,1 (profile LV5).

In comparison, the central and southern parts presented superficial pools with S*phagnum-Tetrocium magellanicum* hummocky vegetation and strongly acidic conditions, evidencing that rain water is the main hydrological surplus in the area. Additionally, trophic levels were characterized by C/N=56 in the upper soils in the north of the territory (LV3) and C/N=45 in the upper soil to the south of the territory (LV16). These values evidence the acidic-oligotrophic nature of LV and explain its characteristic raised physiognomy.

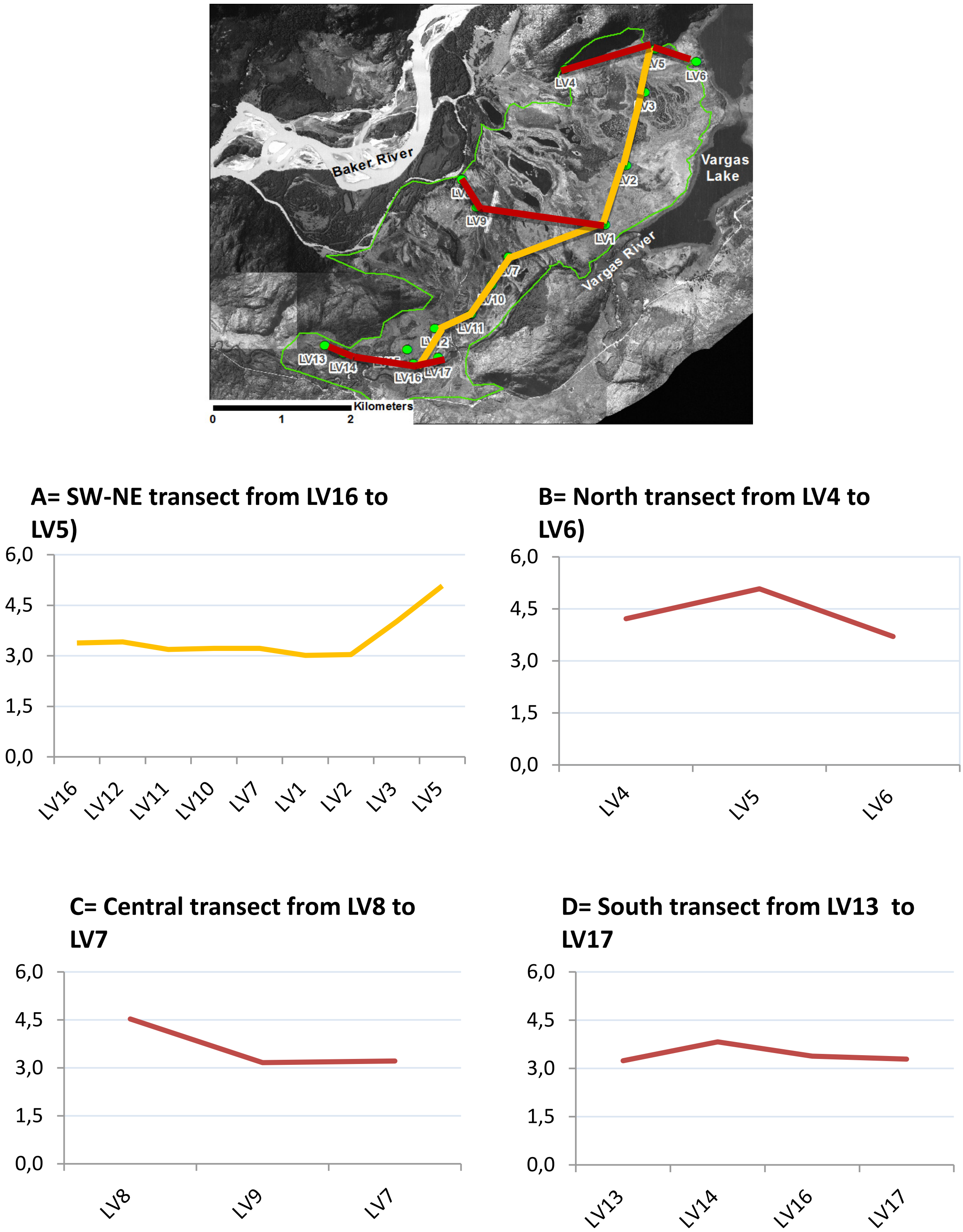


Fig. 25: pH-behaviour in the upper soil of site LV (single measurements in the field)
Water samples for measurements were collected by pressing the peat of the upper 30 cmbs.

4.1.1.2 Hydrology

Annual precipitation associated with the site LV reaches on average 1300 mm y^{-1} (DGA, 2014), with this being the main performer of the site hydrology. The surrounding water bodies (Baker River, Vargas River and Vargas Lake) do not influence the current peat formation, since their water levels are on average two metres deeper than the mire level. Nevertheless, critical rise events in the water level have been reported for the Baker River, during glacial lake outburst floods, strong rainfall and melting periods (Vargas et al., 2007; Tauro, 2009). Despite this, evidence of recent sediment depositions were only detected in marginal areas.

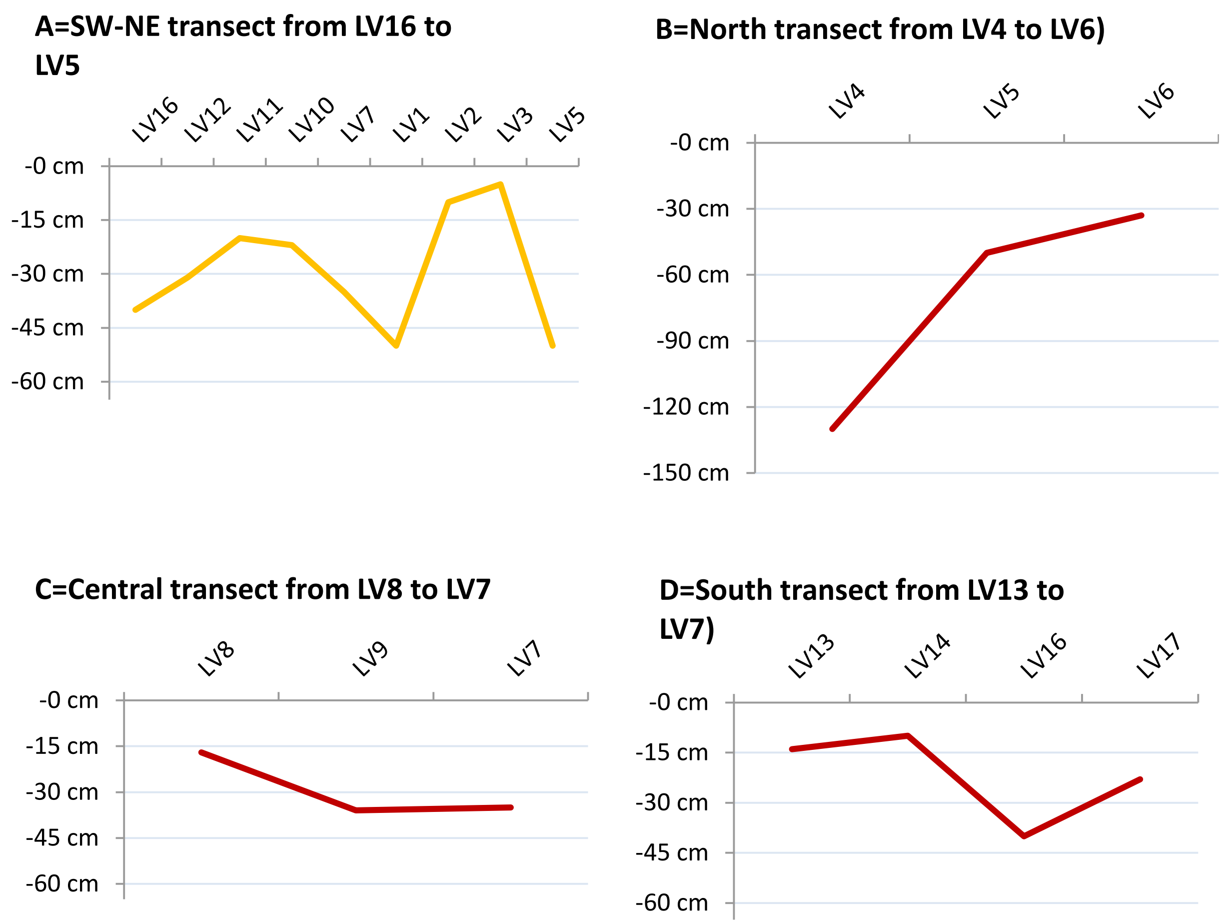
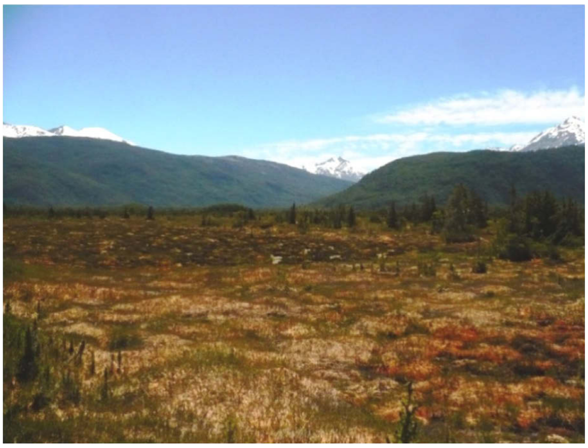


Fig. 26: Depth to the surface of the mire water table in the site LV (cmbs, single measurements)

The average depth of the mire water table was 28 cmbs, remaining homogeneous across and along the mire system, with the exception of areas above the old banks of the Baker River (Fig. 26, graphic A, profile LV1) and sloping sectors (Fig. 26, graphic B, profile LV4 and LV5). The higher mire water tables are produced in low areas at the centre of LV. These areas have plenty of shallow pools colonized by *Sphagnum* and *Tetroncium magellanicum* (Fig. 27, picture A) forming hummocks that emerge up to one metre above the water level. Sedimentation processes (accumulation of detritus) were verified at the botton of these pools. These characteristics are common to mire pools recorded in the raised bogs of Tierra del Fuego (Garraza et al., 2012). The vegetation presented a physiognomic adaptive behaviour according to the water level and landscape morphology. On the flat topographies, when the mire main water table rises enough to flood the vegetation layer, *Sphagnum* mosses formed hummocks that rose above the water level (Fig. 27, picture A). A later successional stage in the vegetation development is represented by the formation of hummock-hollow structures. During a more recent stage, the whole mire system rises above the water level and the *Sphagnum* mosses form carpets covering the whole surface, i.e. forming blankets (Fig. 27, picture B).

A **B**



C

A= *Sphagnum* and *Tetroncium magellanicum* hummocks in a shallow pool. B= *Sphagnum* bogs in an area with a mire water table of 15 cmbs. C= Forest-covered hummocks of *Sphagnum* grow above an old bank of the Baker River, in a site with a mire water table of 18 cmbs and a mineral soil of 60 cmbs.

Fig. 27: Mire water table and diversity in the site LV

Furthermore in even less saturated conditions, at the bottom of slopes and valley basins where the parent mineral material is near to the surface and the mire water table is low enough to allow trees to grow, raised bogs grow as forest-covered hummocks (Fig. 27, picture C). The profiles presenting the richest vegetation diversity were observed in the southern part, which is an area narrowed by a mountainous relief, isolated from open water bodies, and thus protected from mineralized and sediment rich floods, strong wind and extreme climatic events. Fig. 28 details the parameters explained above.

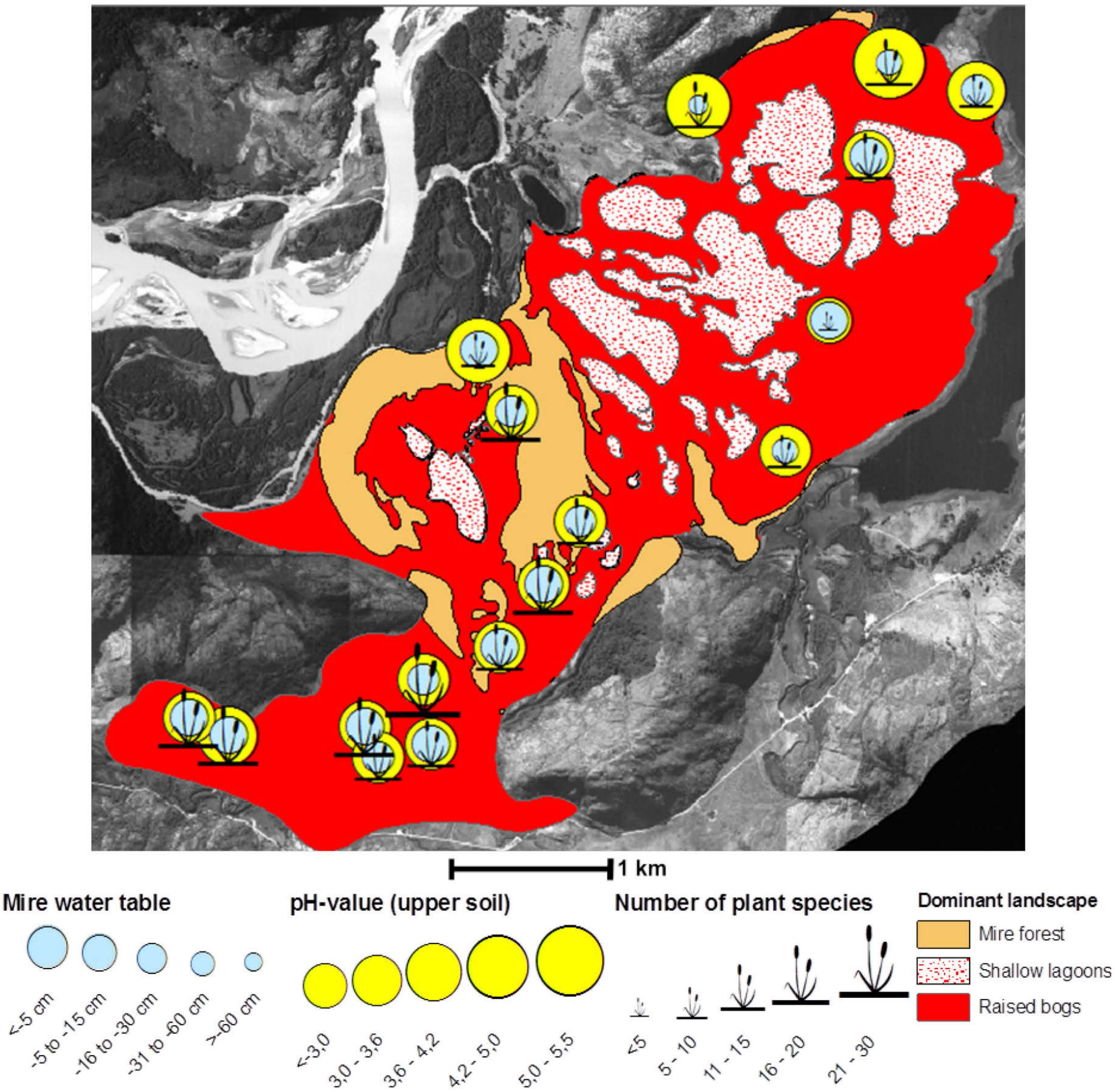


Fig. 28: Simplified overview of the mire water level, pH-value, number of plant species and dominant landscape in the site LV (picture modified from SAF)

At first view, the mire presents a relatively homogeneous water table, and small ecological variations according to the pH-value of the upper soil, which tends to be low in the central and southern part, while increasing in the periphery where nutrient enriched runoffs occur.

The profiles presenting the richest vegetation diversity were observed in the southern part, which is an area narrowed by a mountainous relief, isolated from open water bodies, and thus protected from mineralized and sediment rich floods, strong winds and extreme climatic events. Since the pH-values and water tables in the southern flank are not significantly differentiable from the rest of the site, and due to the fact that the site hydrology is entirely determined by local rainfall, the relief seems to be the factor that is driving the vegetational and ecological diversity of LV. The dominant landscape in LV consisted of raised mires of the bog type, composed of *Sphagnum* mosses.

4.1.1.3 Stratigraphy

The site LV presented typical sequences of superficial horizons of ombrogenic peat under reductive-oxidative conditions, above horizons of ombrogenic and geogenic peat under reductive conditions, lying on a relict horizon of fine sand and loamy sand with oxidation marks.Tab. 10 provides a description of a characteristic profile from Lago Vargas Site (LV11).

Tab. 10: Horizon and substrate properties of the characteristic profile LV11 (after KA 5)

Depth from (cmbs)	Depth to (cmbs)	*Horizon	*Substrates	DD	Colour (Munsell)	**pH1	**pH2	Roots
0	47	hHw	Hhsy	1	10YR4/4	3.92	4.08	Rf1
47	63	hHr	Hhsy-Hnr	2	10YR3/4	4.91	4.64	Rf3
63	70	nHr	Hnr	4	10YR3/2	4.78	4.53	-
70	84	hHr	Hhsy	1	7.5YR3/3	4.1	4.5	-
84	93	nHr	Ha	9	10YR3/2	4.66	4.9	-
93	114	hHr	Hhsy	4	7.5YR3/2	4.45	4.03	-
114	128	nHr	Hnr	5	7.5YR2.5/2	4.28	4.27	-
128	133	nHr	Hnr-Ha	7	7.5YR2.5/2	4.35	4.21	-
133	+133	rGo	fSl	-	10YR3/3	4.64	4.97	-

*hHw=horizon of ombrogenic peat under water fluctuation. nHw= horizon of geogenic peat under water fluctuation. hHr= horizon of ombrogenic peat under reduction. nHr= horizon of geogenic peat under reduction. rGo=Mineral horizon with oxidation marks Hhsy= *Sphagnum magellanicum* peat. Hnr= Radicels peat. Ha= Amorphous peat. fSl= fine loamy sand. **pH1= field and pH2= laboratory measurements.

In addition, profile LV11 (Fig. 29) represents a stereotypical upper horizon of this site, dominated by *Sphagnum magellanicum* peat*,* with the mire water level at 15 cmbs, where the colour and texture of the peat substrate changes significantly, depending on whether it lies on the oxidative (<12 cmbs) or on the reductive horizon (>17 cmbs). Reductive horizons are lighter coloured and have a lower degree of peat decomposition than the oxidative overlying horizons. A transitional horizon (from approximately 13 to 17 cmbs) is visible in between.

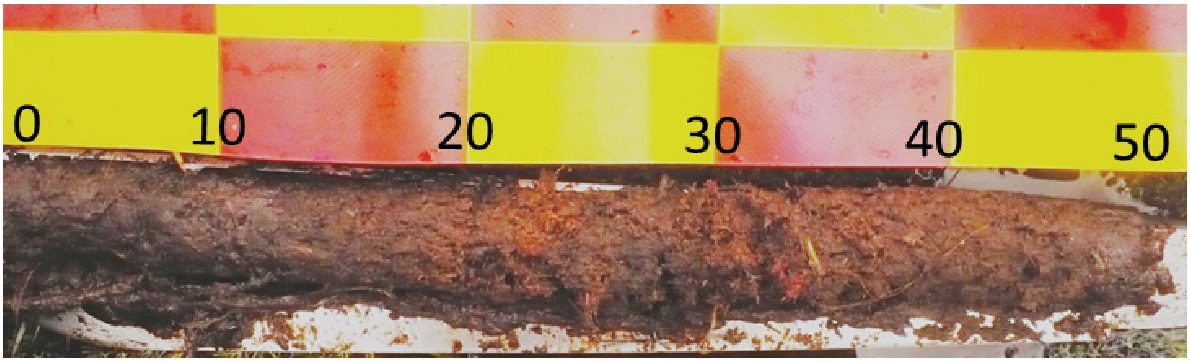


Fig. 29: Core sample in the upper 50 cmbs of the profile LV11 (Rodríguez, field work 2012)

From 0 to 15 cmbs Sphagnum peat, with H5 fluctuating to H4 in the next 15 to 20 cmbs. From 20 to 38 cmbs mixed *Sp. magellanicum* and radicels peat with H3. From 38 to 45 cmbs amorphous peat and *Sp. magellanicum* peat (H6) up 50 cmbs.

The sandy and loamy substrates underlying Lago Vargas were rich in granitic and crystalline materials (Fig. 30, picture A), which are common components of the Andes Mountain Range in Aysén. These substrates were mostly composed of fine and loamy sand above coarse sand (Fig. 30, picture B). The stratification observed (Fig. 31) and the pattern of distribution of forest-covered areas above the old river banks across LV, confirm that the site has its origin in an old meander and a *posteriori* flood plain or similar speed reduced fluvial-shaped environment, between the Baker and Vargas river basins. . This is consequent with theories about the retreat and melting of the Patagonian Ice Sheet during the Holocene, which maintain that huge floods –i.e. the current Aysén rivers- were produced, generating changing water levels in the landscape (Filipová et al., 2010; Glasser et al., 2004).

Conversely, organic substrates were found in a total of 89 horizons at the site LV. These extended up to a maximum depth of 2.3 metres. The plant remains forming most of these substrates belong to the edaphological group of ombrogenic mires (see section 1.2.2.1 and Tab. 4). except in the deeper horizons, where geogenic mire plant remains begin to dominate. Since the mire water table was at an average of 28 cmbs at the time of the field work, it was common to find horizons with a higher degree of peat decomposition above this depth and horizons under reductive conditions under it. These characteristics mentioned are illustrated in Fig. 31.

A **B**

Fig. 30: Geological settings characterizing the site LV (Rodríguez, field work 2012-2013)

A=Granitic gneiss material with quartz bands in the mountains of the Cordillera de los Andes surrounding LV.B=Fine loamy sand sediments underlying the site LV and conserving the traces of the first plants (sedges) growing there

Peat formed by *Sphagnum magellanicum* mosses was found in LV in 32 horizons, presenting degrees of decomposition between H1-H3 and pH-values between 3.2 to 4.5, confirming the occurrence of sustained ombrogenic and mostly saturated conditions in the development of the site. The hydraulic conductivity (velocity at which the water flows through the soil) of this common substrate registered 0.5 cm/sec in the profile LV7. A second peat type formed by *Sphagnum fimbriatum* remains was found in two horizons of LV in the shallow part of a hummock-hollow area, and in a forest-covered blanket at the periphery of the mire system, always forming part of saturated upper horizons (5 to 15 cmbs), exposed to sedimentation but with a very low degree of decomposition (H1-H3) and pH-values of moderate acidity (3.9 to 4.7). A more common peat type (found in 31 horizons) was formed by radicels of different size, typically containing Cyperaceae plants such as *Carex magellanica*. The location of the radicels peat remains in the profile depth shows that Cyperaceae species were among the first vegetation colonizers on the site and they were crucial to the beginning of the mire formation. Peat formed by species such as *Empetrum rubrum* and *Pernettya mucronata* (Ericaceae peat) were found in 7 horizons, at a wide depth spectrum (33 to 167), presenting a degree of decomposition of H4 to H7, and strong to moderate acidic pH-values (3.4 and 4.3). Ericaceae is a family whose species develop optimally around pools in mires and in areas of lower water tables (Laberge et al., 2013). In the stratigraphy of the site LV, Ericaceae peat was an indicator of less humid environments or periods in the development of the mire. Amorphous peat with a degree of peat decomposition >H9, was found in 20 horizons, also in a wide depth spectrum

(5 to 247 cmbs), presenting a degree of decomposition >H9 and pH-values from strongly acidic to very weakly acidic (3.8 to 6.0). Amorphous peat was always associated with upper horizons exposed to changing water tables and to deeper substrates evidencing relict oxidative conditions. Peat formed by remains of the tree *Pilgerodendron uviferum* was considered in this study as a woody peat and named Cypress wood peat. This peat was found in a forest-covered area dominated by *Sphagnum magellanicum* hummocks, above an old fluvial bank of the Baker River, at 48 to 53 cmbs, forming a thin horizon 5 cm thick, presenting a degree of decomposition H5 and a pH-value of 4.2. Peat formed by remains of the *Oreobolus obtusangulus,* an ombrogenic member of the Juncaginaceae family, was considered under its own name as *Oreobolus* peat. This peat was also found only once in the upper horizon of a saturated blanket, at 17 to 35 cmbs, forming a horizon of 18 cm thick. Its degree of decomposition reached H6 and its pH –value 4.1. Organic substrates forming the site LV are summarized in Tab. 11.

Thus to sum up, it was verified that in LV the first peat forming horizons lying at the limit with the mineral parent material were composed of substrates of radicels peat (LV11, LV10, LV7, LV1) and amorphous peat (LV16, LV3 and LV5). Towards the south, the horizons were composed of a mix of *Sphagnum magellanicum* and radicels peat (LV12 and LV16). All of these substrates had a moderate to high degree of peat decomposition (>H4), insinuating intermittent dry periods or changing water levels during their formation. Above these substrates, *Sphagnum m*osses and sedge vegetation remains were found, forming specific horizons of *Sphagnum magellanicum* peat, mixed *Sphagnum* and radicels peat and extensive thick horizons of pure radicels peat, sometimes interrupted by traces of Cypress wood peat. The upper horizons were extensively dominated by *Sphagnum magellanicum,* mixed *Sphagnum* and radicels peat, with a low decomposition degree (H1-H4). Also in the upper levels, cushion plants peat was detected forming a thin horizon in one profile at the southern extreme of the site (LV16). *Sphagnum fimbriatum* peat was observed in areas of sedimentation (LV2) and amorphous peat in areas exposed to changing water levels (LV5).

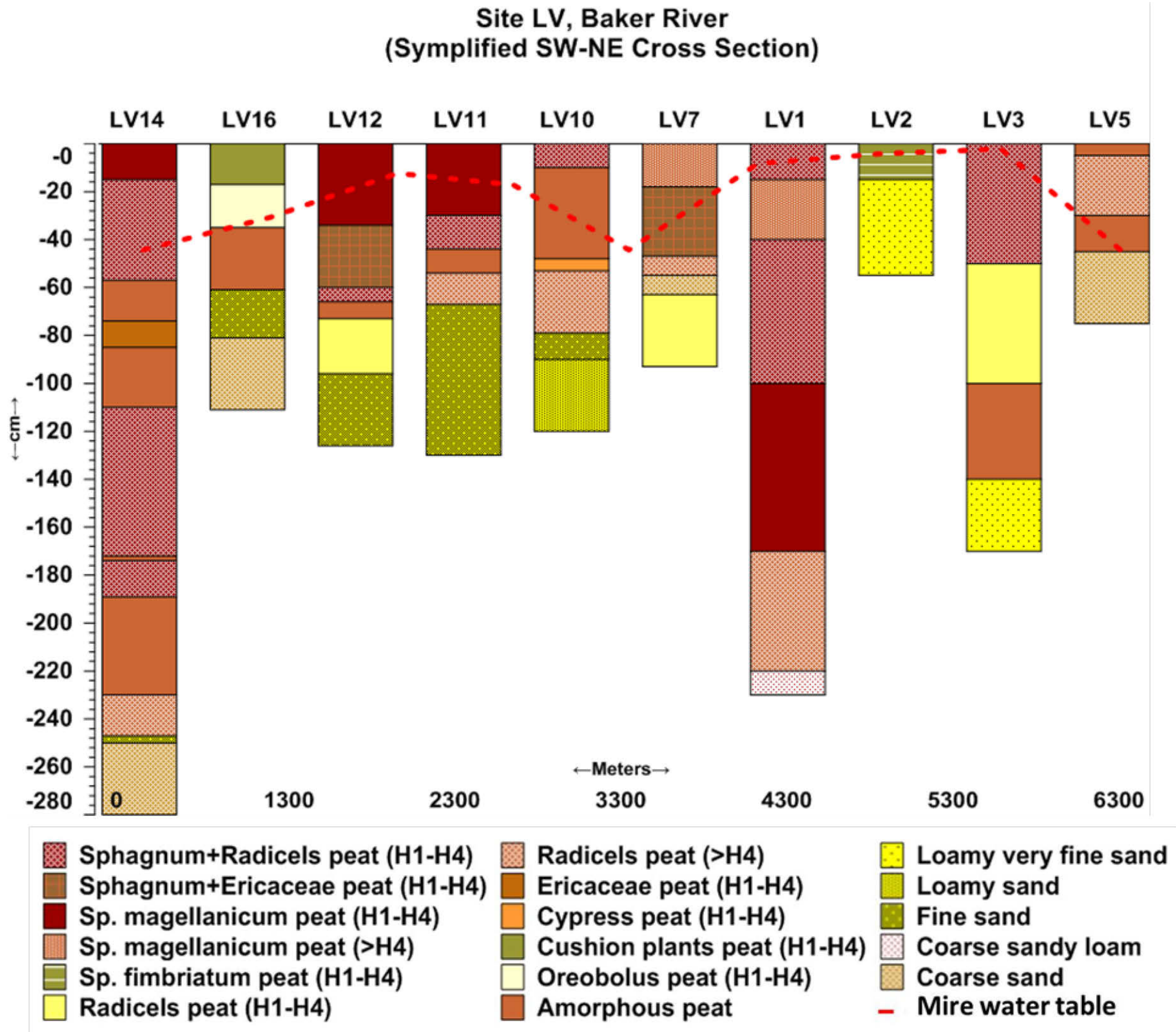


Fig. 31: Simplified SW-NE cross section in the site LV

Tab. 11: Organic substrate types found in the site LV with frequency (n) and spectrums of depth, thickness, degree of peat decomposition and pH-value (field and laboratory average).

Substrate	n	Depth (cmbs)	Thickness (cm)	DD	pH (Avg)
Sp. magellanicum peat	32	10 to 189	5 to 60	H1-H4	3.2 to 4.5
Sp. fimbriatum peat	2	3 to 15	10 to 12	H1 to H3	3.9 to 4.7
Radicels peat	31	10 to 230	2 to 41	H1-H9	3.5 to 4.7
Ericaceae peat	7	33 to 167	5 to 25	H4 to H7	3.4 to 4.3
Oreobolus peat	1	17 to 35	18	H6	4.1
Cypress wood peat	1	48 to 53	5	H5	4.2
Amorphous peat	20	5 to 247	4 to 50	>H9	3.8 to 6.0

4.1.2 Los Remolinos (LR) Site

Los Remolinos (LR) covered an area of 391 ha and was located in a valley basin along the Baker River. The sample design for this site (Fig. 32) was similar to that initially defined and access was possible by walking from the Carretera Austral, with prior permission from the landowner, Mr. José Iñiguez Jara. LR displayed a homogenous and flat morphology, presenting a light northwest exposure. LR was flanked by a mountainous relief, with its southern border adjacent to the Cute Lagoon and the northern border along the Baker River. Also all the north-western flank has been interrupted by the Carretera Austral since 1990-2000 (Fig. 32). The eastern flank of the site was characterized by valley edges, presenting humid environments where forest-covered hummocks and raised bogs of *Sphagnum magellanicum* abounded. In the south, raised bogs were present almost as far as the sandy shore of the Cute Lagoon, and they extended all along a stream that drains from this lagoon on the south-western flank of the mire. In the centre of the site, under the peat cover, patches of burned native forests remain above old sand banks of the Baker River.

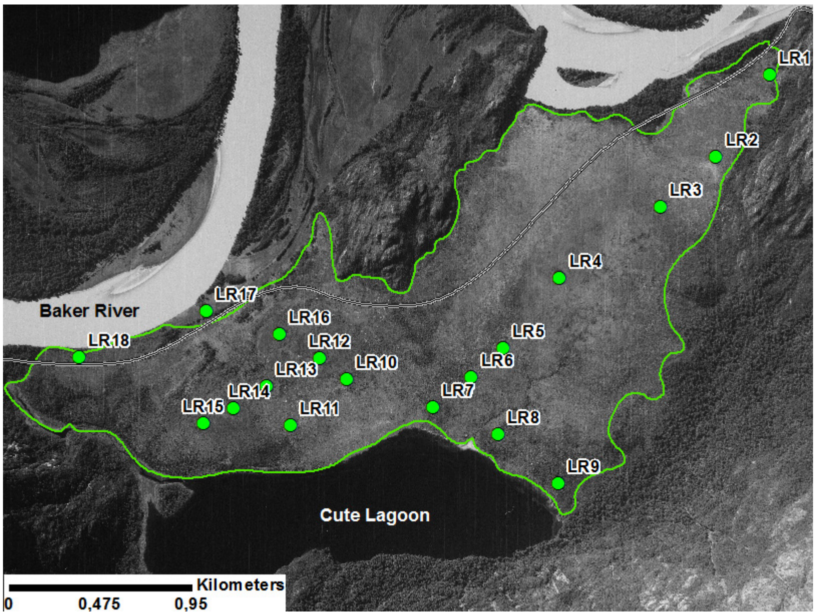


Fig. 32: Final sample design at site LR (picture modified from SAF)

*Borders of the mire system and sampling points in green, Carretera Austral shown as a grey line.

A

B

C

Fig. 33: Landscape setting of the site LR (Rodríguez, field work 2012)

A= The site lies in a valley basin along the Baker River. The Austral Highway (Carretera Austral) crosses the northern flank. Since 2003 this highway connects the small towns along the Baker River (previously only accessible via the river) with the rest of the Aysén Region (Coronel Octavio González, personal communication, 5 February, 2013). B= Blanket bogs with cushion plants. C= Patches of burned semi-dense native forest.

4.1.2.1 Vegetation and ecological settings

The dominant landscape in LR was formed by *Sphagnum magellanicum* raised mires growing associated with the Juncaginaceae species *Marsippospermum grandiflorum* and *Tetroncium magellanicum,* forming these 50% of the site plants dominance (Fig. 34, picture A). In areas with *Sphagnum* hummocks Ericaceae species such as *Pernettya mucronata* and *Empetrum rubrum* were detected (Fig. 34, picture B).

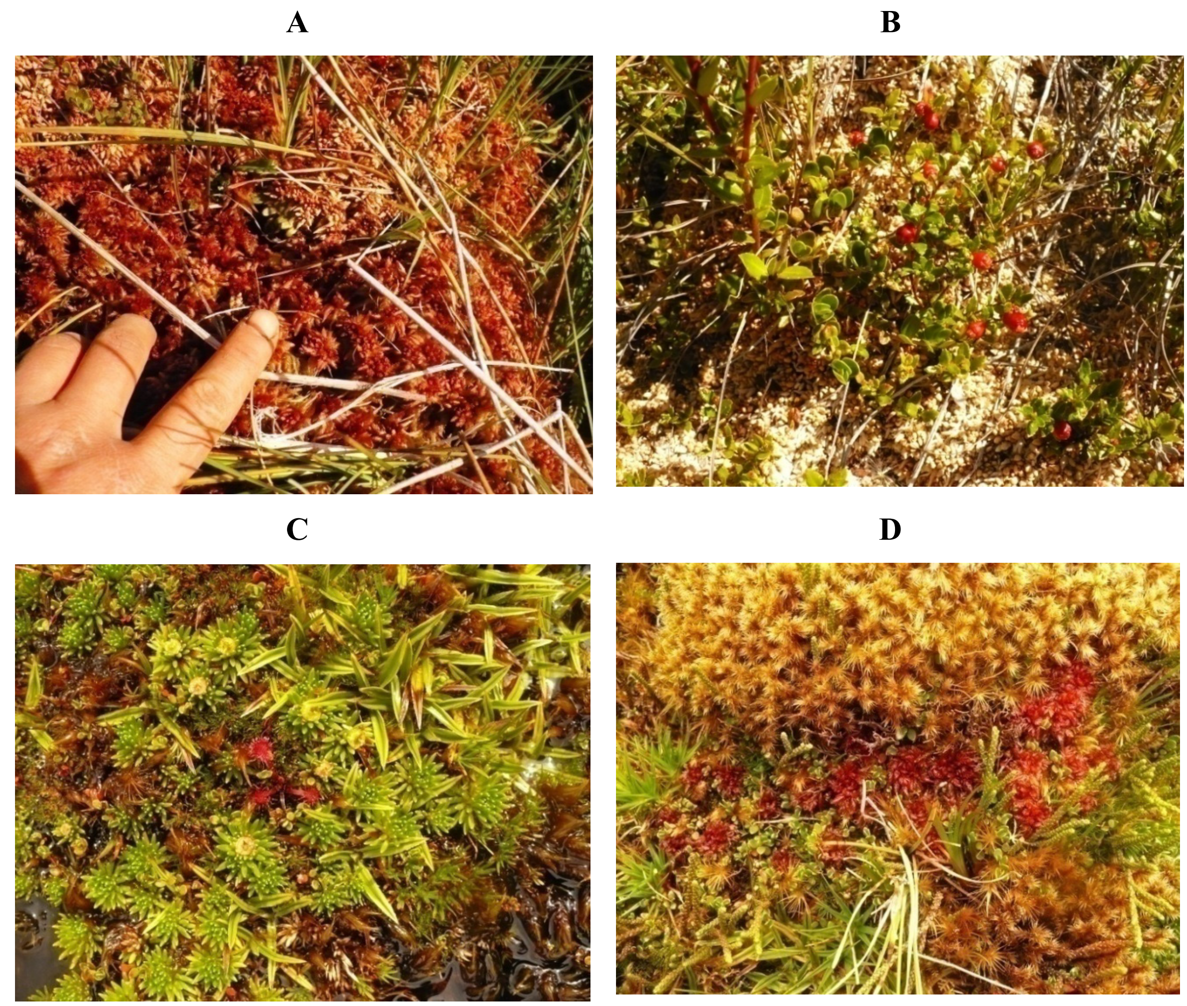


Fig. 34: Main vegetation species in the site LR (Rodríguez, field work 2012)

A= *Sphagnum magellanicum* and sedges growing above. B= *Pernettya mucronata* in a *Sphagnum* hummock. C= Cushion of *Astelia pumila* (pulvinated leaves, right top hand side)*, Donatia fascicularis* (succulent leaves, centre and left hand side) and *Drosera uniflora* (red flowers in the centre). D= Hummock of *Sphagnum magellanicum* (red leaves, centre) colonized by *Racomitrium lanuginosum* (light brown, top), *Oreobolus obtusangulus* (pulvinated leaves, left and bottom), *Lepidotamus fonkii* (green scaled stems on the right) and some undefined brown mosses (on the bottom right hand side).

Extensive blankets formed by cushion plants (*Astelia pumila* and *Donatia fascicularis)* were recorded in the centre of the site, reaching a 30% dominance in the plots investigated in the centre of the site which were common habitats for *Drosera uniflora* (Fig. 34, picture C in red colour). Similar vegetation behaviour is reported in blanket mires formed by cushion plants in Tierra del Fuego (Teltewskaja 2010) and Magallanes (Kleinebecker, 2007). *C. magellanica* and *P. mucronata* reached 20% of the whole site dominance. Several species detected in this site were not typically ombrogenic, e.g. *Sphagnum fimbriatum*, brown mosses and the Podocarpaceae *Lepidothamnus fonkii* (Fig. 34, picture D). Ecological conditions for vegetation to grow were characterized by upper soils with pH-values from 3.0 to 5.5. The lower pH-values (i.e. profiles LR7 and LR9 in Fig. 35) were particularly detected in areas dominated by hummocky vegetation. The higher value (profile LR12 in Fig. 35) was measured in a depression artificially saturated by the Carretera Austral, in the north-western border of the mire (see Fig. 32 above) and dominated by *Sphagnum fimbriatum* and sedge species.

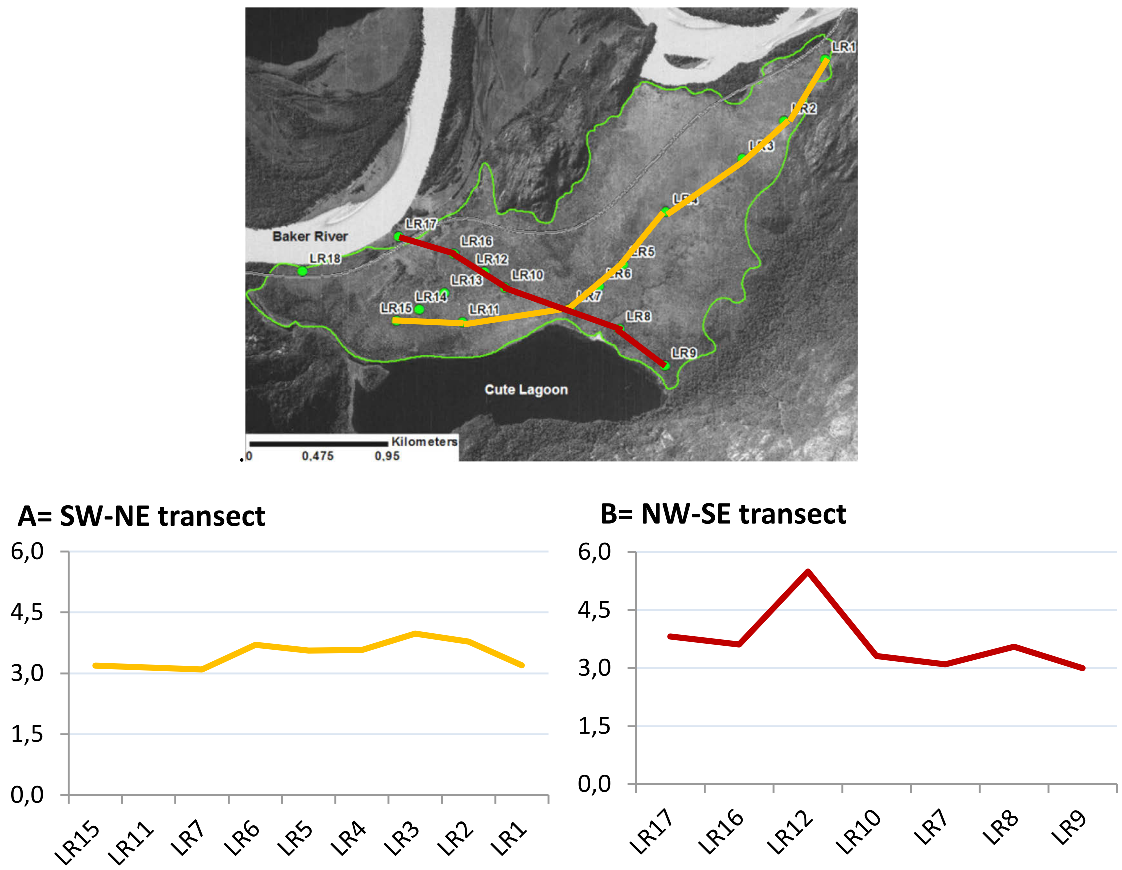


Fig. 35: pH- behaviour in the upper soil of the site LR (single measurements in the field) Water samples for measurements were collected by pressing the peat of the upper 30 cmbs.

The trophic conditions in LR were massively oligotrophic. Areas dominated by *Sphagnum* mosses were characterized by a C/N ratio= 55, while in areas dominated by *A. pumila,* the ratio reached C/N= 45, confirming oligotrophic conditions in the upper soils.

4.1.2.2 Hydrology

Annual precipitation in LR reached 2700 mm y^{-1} (DGA, 2014). A small stream runs through the southern flank of the mire, draining into the Cute Lagoon. The lagoon is flanked by sand banks and approximately 60 cmbs of the mire landscape level. The mire water table in LR presented an average of 13 cmbs and low variations along and across the site (Fig. 36, graphics A and B), except for the profile LR8, which was located in a sand bank preceeding the Cute Lagoon. Additionally, the Baker River is located 1 ½ metres lower than the mire landscape level, being irrelevant for the current peat formation, except in front of glacial lake outburst flood episodes (GLOF), one of which was reported for the site between the 29th. April and 15th. May 2013. Data presented in the Fig. 36, graphic C, evidences the autoregulation of the site to the previous main water table and its hydrological resilience in the face of this abrupt flood occurrence. Areas of high mire water tables (>5 cmbs) showed in particular the dominance of cushion forming plants such as *Astelia pumila* and *Donatia fascicularis*. Specifically *A. pumila* displays mechanisms of adaptation to saturation and nutrient poor conditions. Its extra-large root system (Fig. 37, picture A) is able to transport oxygen in the deeper horizons of the soil, decomposing the surrounding peat to obtain nutrients (Teltewskaja 2010). Another interesting phenomenon observed in the field was the colonization of algae in areas dominated by *A. pumila*. A hypothesis for its development is based on the fact, that this plant generates both, a nutrient surplus in the soil by decomposing the peat around its roots, and water saturation in the surface due to its compact blanket forming morphology. When the temperature increases, the nutrient surplus and the presence of shallow standing water in the soil surface facilitates the colonization of algae, which competes for territory with *A. pumila* (Fig. 37, picture B). Also above the soils colonized by *A. pumila*, plant species were observed that were almost absent in *Sp. magellanicum* dominated sites (i.e. *Donatia fascicularis, Oreobolus obtusangulus*). Thus it can be inferred that *A. pumila* generates special nutritive compounds into the soil. These compounds should be hydrologically transported into the surface, e.g. when saturation occurs due to rain or melting periods (Fig. 37, picture C), which may be contributing to the development of other plants not being able to survive in soils dominated by *Sphagnum* mosses.

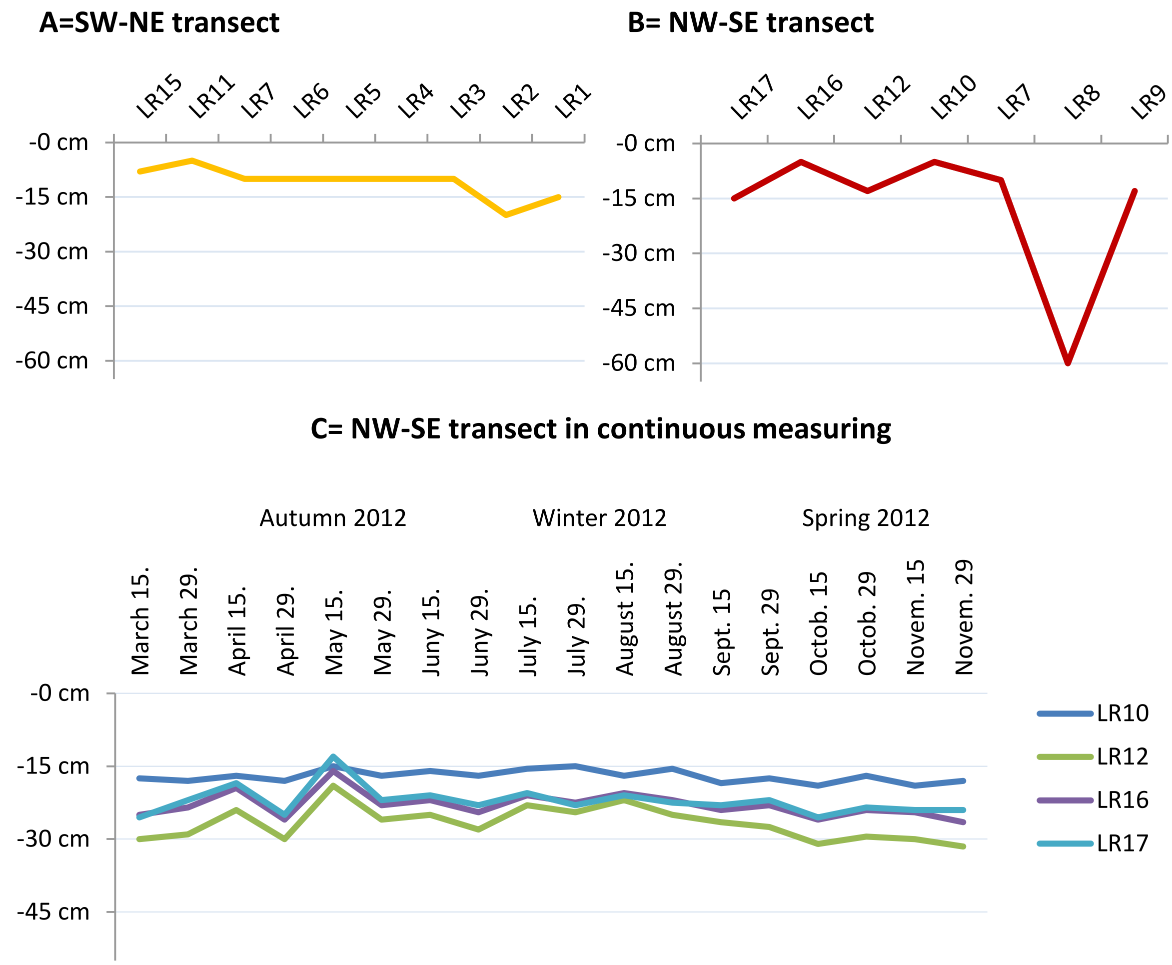


Fig. 36: Depth to the surface of the mire water table in the site LR (cmbs)
A and B= Single measurements. C= Two monthly measurements, from March to November 2012

A difference can be established in the vegetation diversity among areas dominated by bogs of *Sp. magellanicum,* where the diversity is higher, and areas dominated by blankets of cushion plants such as *A. pumila* and *D. fascicularis,* where plants species are more specific. In areas with mineral undergrounds or inputs, e.g. near to the central spot of burned trees, on the shore of Cute Lagoon and in the periphery of the mire where nutrient enriched runoffs may enter, the vegetation is also more diversified than in the centre of the system. It appears that the conditions facilitating the apparition of blanket bogs of cushion plants can not be explained with total validity by the pH settings or the mire water level in LR. Nevertheless, a difference in the site is its increased precipitation rate. Due to its proximity to the Pacific Ocean, the site LR receives a noticeably higher rate of precipitation (2700 mm y^{-1}) than LV (1300 mm y-1). This seems to be the first factor influencing the transition from raised bogs of *Sp. magellanicum* to blanket bogs of cushion plants. Fig. 38 details the parameters explained above for each profile in the site LR. As mentioned above, this is the northern site in the Baker River basin where blankets of *A. pumila* were found. Again the pH-value appears to remain stable in the whole mire, while differences in the water table tend to be more evident. A clear correlation between the water table and the vegetation diversity is not visible.

A

B

C

A=*A. pumila* and its extra-large root system has adapted to survive under saturated and poor nutrient conditions. B=Algae colonizing between cushion plants. C=Water seems to act as a nutrient transporter median, facilitating species abundance and saturation in blankets colonized by *A. pumila.*

Fig. 37: Mire water table and vegetation diversity in the site LR (Rodríguez, field work 2012-2013)

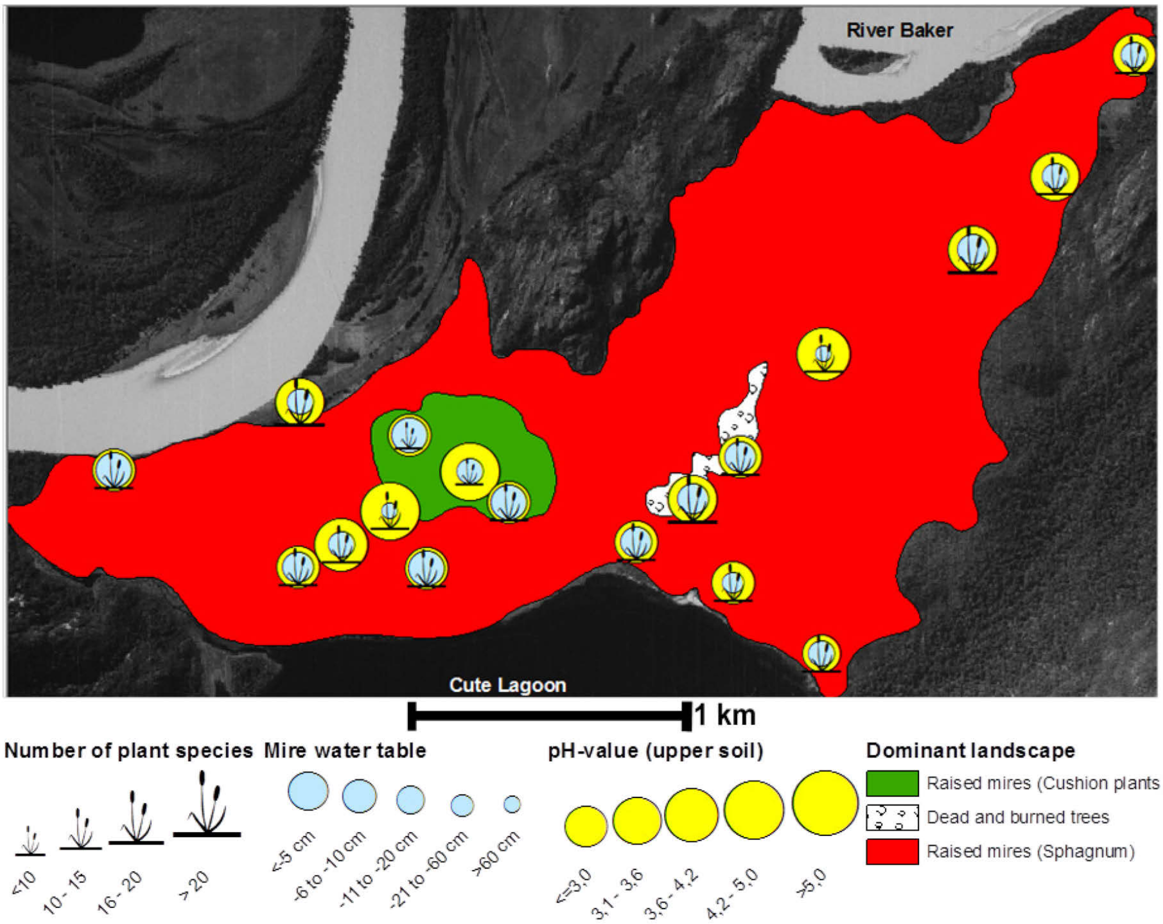


Fig. 38: Simplified overview of the mire water level, pH-value, number of plant species and dominant landscape in the site LR (picture modified from SAF)

4.1.2.3 Stratigraphy

Typical sequences of superficial horizons of ombrogenic peat under reductive conditions (hHr) lying on a relict horizon of loamy sand with oxidation marks (rGo) could be found in LR. This sequence can be appreciated in Tab. 12, which describes the characteristic profile LR11, whose upper soil was dominated by cushion plants (Hoas) of the species *Astelia pumila* and *Donatia fascicularis*. The presence of cushion plants peat in site LR is associated with a wide horizon of amorphous peat (profile LR11 in Fig. 39). Due to the prevailing high mire water table it can be inferred that this amorphous material is produced by the cushion plants root system, and that the peat formed through the natural decay of these plants is only recognizable in the upper horizons. Converserly, most horizons detected on the surface of the mire were entirely formed by low decomposed *Sp. magellanicum* peat, which is consequent with the hypothesis about a recent establishment of the cushion plant *Astelia pumila* in *Sphagnum* mires.

Tab. 12: Horizons and substrates properties of the characteristic soil profile LR11.

From (cmbs)	To (cmbs)	*Horizon	*Substrate	DD	Colour (Munsell)	**pH1	**pH2	Roots
0	30	hHr	Hoas	H1	10YR4/4	3.1	3.3	Rg4
30	65	hHr	Hoas	H4	10YR3/2	3.1	3.2	Rg4
65	90	hHr	Hosy	H6	7.5YR3/3	2.9	3.1	Rg2
90	100	nHr	Ha	H9	10YR3/2	3.0	3.0	Rg1
100	120+	rGo	fSl	-	25Y43	4.5	4.5	-

*hHr= horizon of ombrogenic peat under reduction. nHr= horizon of geogenic peat under reduction. rGo= mineral relict horizon with oxidation marks. Hoas= cushion plants peat. Hhsy= *Sphagnum magellanicum* peat. Ha= Amorphous peat. fSl= fine loamy sand. **pH1= field and pH2= laboratory measurements

A low to moderate degree of peat decomposition (H1-H4) characterized the site LR, insinuating that the water level remained high since the formation of the first peat horizons at LR. Indeed, the site presented a mire water table of 13 cmbs, with the majority of the examined horizons under saturation at the time of the field work.

Fig. 39: Core sample in the upper 100 cmbs of the profile LR11 (Rodríguez, field work 2012-2013)

From 0 to 30 cmbs the cushion structure of *Astelia pumila* and its macrofossils dominate with a low degree of decomposition (H1-H4). From 30 to 65 cmbs, the peat decomposition increases (>H4) and roots continue extending down to 90 cmbs, where a horizon of high decomposed *Sphagnum magellanicum* peat (H6) was found, overlying a last horizon of amorphous material (down to 97 cmbs).

In comparison to the Lago Vargas (LV) site, the mineral parent material underneath the mire LR was formed by different sized sediments, from loamy very fine sand to coarse sandy loam. These materials were transported and deposited through the landscape during the intermittent increases and reductions of Aysén's glacial rivers during the Holocene (Holz et al., 2012). Additionally, the underlying parent material in LR had plenty of oxidation marks, unveiling changing water levels in the paleo-landscape (Fig. 40). Since LR is situated above an old abandoned meander of the Baker River, in a small U-shaped valley, the flood velocity during the deposition of the mixed size sediments found here was stronger, and diminished during the formation of the mire.

A **B**

Fig. 40: Geological settings characterizing the site LR (Rodríguez, field work 2012-2013)

A=Coarse sand with small radicels was the main parent material underlying the mire system at site LR. B=Oxidation marks in the sandy parent material at site LR.

The stratigraphic cross section in the site LR was investigated longitudinally. Its schema and the substrates found are shown in Fig. 41. Peaty horizons extended in LR from the soil surface until a maximal depth of 1,9 meters. Those horizons limiting with the mineral parent material were formed by amorphous peat (LR11, LR7, LR5, LR4, LR3 and LR2) or radicels peat (LR15, LR6 and LR1), followed by horizons formed by a variety of pure and mixed peat types containing *Sp. magellanicum* (LR15, LR7 and LR5), radicels (LR6 and LR1), Ericaceae (LR3 and LR2) and cushion plants peat (LR11). The upper horizons consisted mostly in *Sphagnum magellanicum* peat (LR15, LR7, LR6, LR5, LR4, LR3, LR2 and LR1), interrupted superficially by cushion plants peat in the southern part of the mire (LR11). Specifically, five peat types were found in a total of 57 horizons at the site LR. Amorphous peat was the most common, being present in 21 of the documented horizons. A peat type found for the first time in this site was the cushion plants peat, composed of the decayed remains of *Astelia pumila* and *Donatia fascicularis* plants. Since it was not possible to separate the self-produced peat of the plant *A. pumila*, the cushion plants peat was designated as only the material containing evident macrofossils of the plant, and amorphous peat the decomposed material around the plant root system. *Astelia pumila* is a plant specific to the southern hemisphere tropical and subtropical paleo-flora (Dawson 1963). Its peat in LR exhibited a superficial behaviour, with a depth spectrum of 22 to 55 cmbs. The horizons of cushion plants peat reached a thickness of 10 to 25 cm, presenting decomposition degrees of H1-H4 and very strong acidic pH-values (3.0 to 3.1).

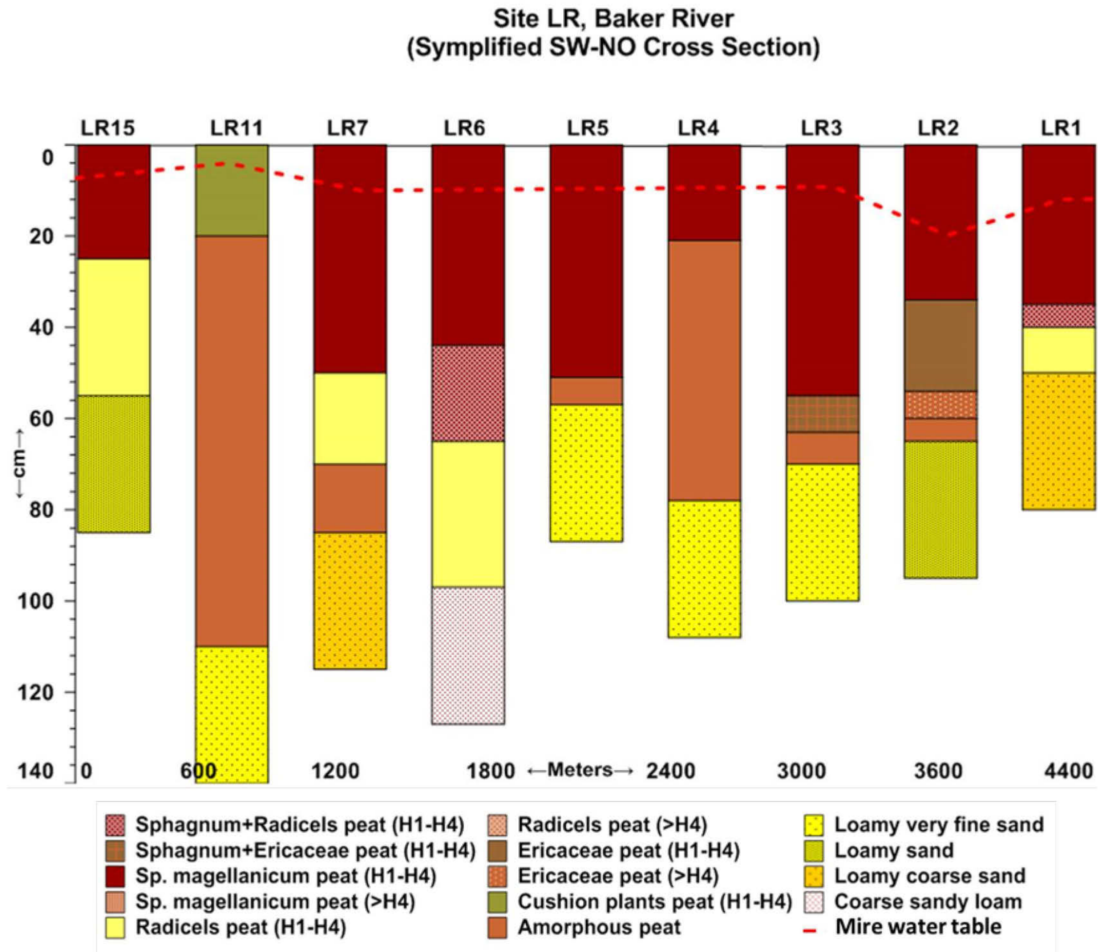


Fig. 41: Simplified SW-NO cross section in the site LR

Tab. 13: Organic substrate types found in the site LR with frequency (n) and spectrums of depth, thickness, degree of peat decomposition and pH-value (field and laboratory average)

Substrate type	n	Depth (cmbs)	Thickness (cm)	DD	pH (Avg)
Sp. magellanicum peat	17	5 to 65	5 to 35	H1 to H4	3.3 to 4.9
Radicels peat	11	35 to 100	5 to 32	H1 to H9	3.6 to 5.3
Ericaceae peat	6	15 to 90	3 to 30	H4 to H7	3.3 to 5.0
Cushion plants peat	2	25 to 55	10 to 20	H5	3.0 to 3.1
Amorphous peat	21	14 to 190	5 to 45	>H9	2.6 to 6.2

The high decomposition of amorphous peat and its presence in the lower horizons of the site LR demonstrate that this was formed under aeration of the substrate, e.g. under a lower mire water table. According to the order and behaviour of the amorphous peat horizons shown previously for Lago Vargas (LV), the presence of this peat is also an indicator of changing water tables in the origin of the mire formation. The pH-values (2.9 to 6.2) of the amorphous peat signal a wide spectrum between very strong to very weak acidic conditions. *Sphagnum magellanicum* peat was found in 17 horizons in the site LR tending to an upper soil presence (spectrum from 5 to 65 cmbs). Its degree of peat decomposition presented lower values, with exception of the profiles LR9 and LR10, where it reached H6. This is explicable in the forest-covered physiognomy that was documented in this part of the mire, where a good aeration of the profiles was produced. The pH-value spectrum of *Sphagnum magellanicum* peat in LR reached between 3.3 to 4.9 demonstrating strong to weak acidic conditions. This peat tends to mix with radicels and Ericaceae peat, insinuating low water tables periods, with an occurrence enough sustained to allow sedges and Ericaceae vegetation to grow. The hydraulic conductivity of this peat, the most disseminated in the site LR, was measured in the field, evidencing a velocity of 0.5 cm/sec. A mixed substrate of *Sphagnum*-Ericaceae peat was observed in 6 horizons, forming thin layers of a maximum of 30 cm thick. An amorphous peat horizon underlying the north-eastern flank of the site LR, seems to be an indicator of a less humid stage of the mire development, maybe after a period of changing water levels.

4.1.3 Villa O'Higgins Site (VO)

The site VO (Fig. 42) lies in an intermountain depression at an altitude of 364 m a.s.l., at the foot of the Cerro Santiago (Santiago Hill), 1 km to the north of the town of Villa O'Higgins. The site was accessible via a trekking path situated behind a local camp site, used with the permission of its owner, Mr. Mauricio Melgarejo (ornithologist and director of the Eco-Camp Tsonek in Villa O´Higgins). The final sample design is shown in Fig. 42. The landscape where VO lies is flanked by slopes and hills plenty of concatenated sloping mires (Fig. 43). The site is humected by percolation runoffs coming from the surrounding relief. These runoffs decant together into a terrestrialization lake located on the southern flank of VO. From the borders to the centre, in order of increasing saturation, VO is dominated by gallery forests, sedge vegetation, *Sphagnum* hummocks, blankets of reeds and brown mosses, and ultimately by swimming plants. VO is also fed by local precipitation (890 mm y^{-1} after DGA, 2014). These three sources of water: standing, runoff and precipitation, maintain VO's surface under permanent saturation.

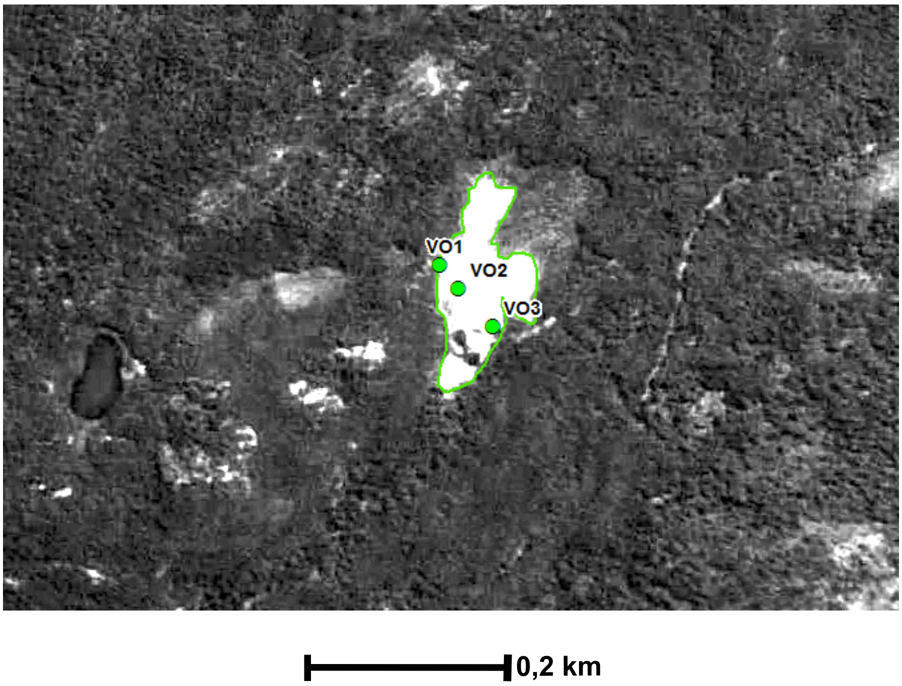


Fig. 42: Final sample design at site VO (picture modified from SAF)

Borders of the mire system and sampling points in green.

4.1.3.1 Vegetation and ecological settings

This site evidenced the lowest plant diversity in the whole sample with only 21 species in total. The site had the highest dominance of mosses per area (30% of the soil vegetation cover) out of the five examined sites. The contribution of nutrients via runoffs seems to produce optimal development conditions for brown moss species at VO. Moreover the semi-aquatic environments presented the highest dominance of *Schoenoplectus californicus* (around 30% of the soil vegetation cover). In addition to VO, this species was marginally present in small pools and lake shores at the sites of LV (Lago Vargas) and QP (Lago Quetru). *Sphagnum* mosses reached 13% of the soil vegetation cover. *Carex* species and particularly *C. magellanica* reached a dominance of 12.5%. *Marsippospermum grandiflorum* represented 2.5% of the soil vegetation cover, while species of the Ericaceae family represented 1%. Species rare in the site were *Apodasmia chilensis* and *Perezia lactucoides*, reconfirming the ecological uniqueness of VO.

A

B **C**

A=The site lies in a intermountain depression in the foothills of the Santiago Hill. B= Runoffs from percolation mires and surrounding mountains decant into the site VO, supplying its small lake (lower part of the picture). C= The Santiago Hill rises up behind. In the foreground, *Schoenoplectus californicus* indicates the limit where the saturated terrain begins in the site VO.

Fig. 43: Landscape setting of the site VO (Rodríguez, field work 2013)

The distribution of species appears to be defined by the mire water level and a nutritional gradient. For example, *Pilgerodendron uviferum* and *Nothofagus dombeyi* were the main species forming the gallery forest in the well-drained borders of VO. As soon as the morphology sinks, a saturated belt surrounds the site, growing on it mosses that are typical of nutrient enriched areas, such as *Sp. fimbriatum* and *Acrocladium auriculatum* (Fig. 44, picture A). These mosses mark a zone of exchange between enriched inflows coming from the mountainous forest, and the mire water. Immediately after this zone, there is a development of *Sp. magellanicum* hummocks occurring (Fig. 44, picture B). They grow up to one metre in height, forming a buffer to the following prairie of sedges and rushes. *Eleocharis melanostachys, Hordeum comosum* and *C. magellanica* grow above the hummocks and displace them as soon as the water level increases. Then *Schoenoplectus californicus* (Fig. 44, picture C) and *Acrocladium auriculatum* begins to dominate.

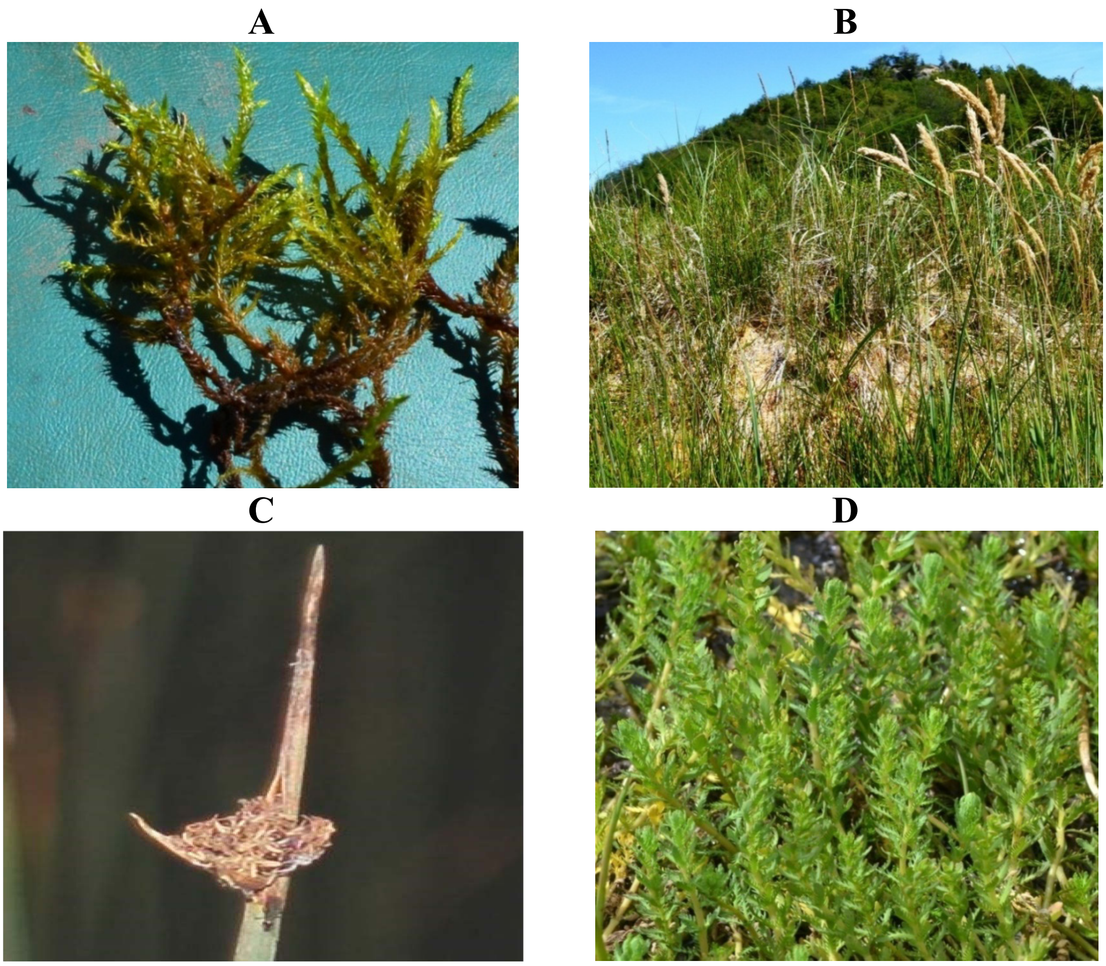


Fig. 44: Main vegetation species in the site VO (gradient from border A to shore D) (Rodríguez, field work 2013).

A= *Acrocladium auriculatum.* B= Hummocks of *Sphagnum magellanicum* covered by *Hordeum comosum.* C= *Schoenoplectus californicus* D= *Myriophyllum quitense*

In the aquatic environment appears the species *Myriophyllum quitense* (Fig. 44, picture D). From the sedge prairie and up to the *Schoenoplectus* floating mats, the soil is covered by brown mosses evidencing nutrient conditions higher than in all other sites, where these are absent or very scarce. The ecological conditions were characterized in the whole mire surface by moderate to mesotrophic levels, with an average C/N of 21. Upper soils presented pH-values from 3.5 to 6.2. The lowest pH-value (Fig. 45, profile VO2) was detected in an area dominated by *Sphagnum* hummocks. The higher pH-value (Fig. 45, profile VO3) was measured in a floating mat of *Schoenoplectus californicus* and *Acrocladium auriculatum*. Water samples for measurements were collected by pressing the peat of the upper 30 cmbs or direct in the mire water table.

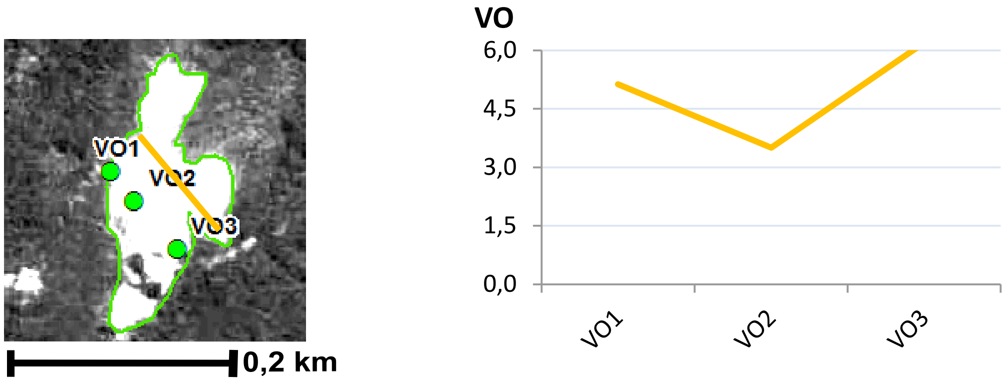


Fig. 45: pH-behaviour in the upper soil of the site VO (single measurements in the field).

4.1.3.2 Hydrology

Annual precipitation in Villa O'Higgins reached 890 mm y^{-1} (DGA, 2014), which was the the lowest rainfall in the whole sample. From the position of VO in the lower part of a catenation of sloping mires located above, it can be inferred that the site hydrology is influenced by geogenic surpluses rather than by rain. These surpluses should consist in water from the mires located above, and in runoffs from the surrounding mountains. Both water sources decant in the site, maintaining the small lake found there (Fig. 47, picture A) and the soil surface constantly saturated (Fig. 47, picture B). Being partially mineral and organic enriched, the flows humidifying the site VO may have induced mesotrophic conditions under which brown mosses, sedges, rushes and reed vegetation develop profusely, occupying shores and depositing decaying remains on the wet surface. Additionally, ecosystems with this residual small water bodies, shape what (Succow und Joosten, 2001) define as semi (surface), sub (in the water column) and infra-aquatic (in the ground of the water body) peat forming processes. Changing levels of the soil water were evidenced on the western flank of VO. This area presented the characteristic "rotten egg" odour: a phenomenon typical in rewetted mires liberating hydrogen sulfide (H_2S) and other gases associated with the decomposition of organic matter (Belyea 1999). The profile VO1 was located between this area and the *Sphagnum* hummocky vegetation. There, the mire water table was 12 cmbs (Fig. 46). After the profile VO1 the water level increased and reached the surface. Fig. 48 shows the parameters stated previously for each profile in the site VO.

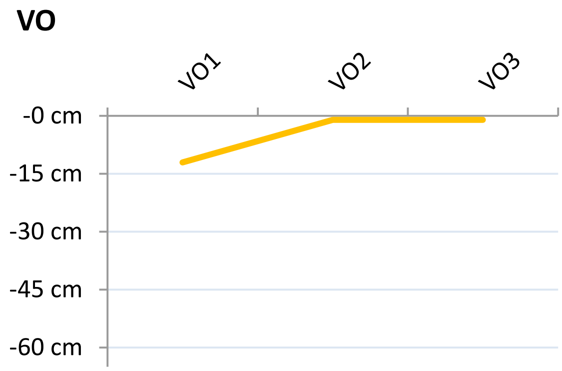


Fig. 46: Depth to the surface of the mire water table in the site VO (cmbs, single measurement)

While the pH-values do not show a clear variation pattern, lower water tables show in VO a clear correlation with the vegetation diversity. Sites presenting similar conditions were confirmed in the aerial imagery (SAF), inferring that these kind of mountainous fens cover >2000 ha distributed in different mountainous depressions around the town of Villa O'Higgins.

Fig. 47: Mire water table and diversity in the site VO (Rodríguez, field work 2013)

A= Runoffs from the surrounding hills and percolation water from peatlands in elevated areas decant into the site VO, maintaining a residual lake and the water table at the surface. B= *Hylorina silvatica* finds a habitat in the saturated soil of site VO.

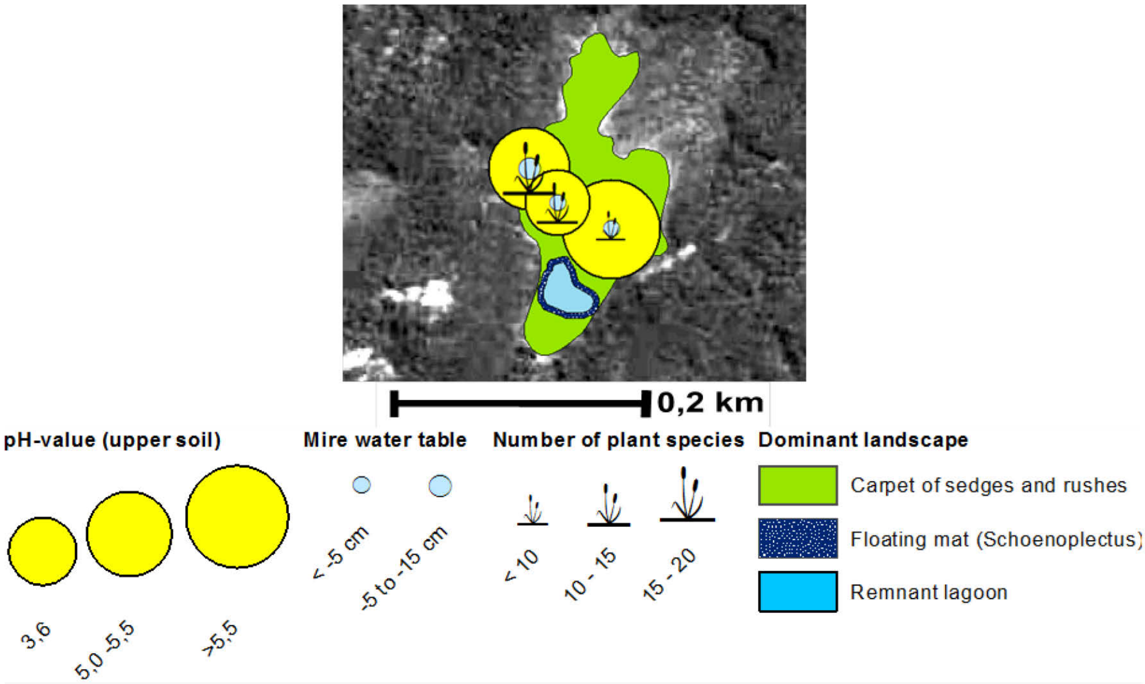


Fig. 48: Simplified overview of the mire water level, pH-value, number of plant species and dominant landscape in the site VO (picture modified from SAF)

4.1.3.3 Stratigraphy

The site VO presented a typical sequence of geogenic peat horizons (nHw) above massive reductive horizons (nHr) interrupted by a water tongue, above deep horizons under oxidative conditions (nHo), lying on a bed of relict and reductive organic gyttja material (rFr). This sequence is appreciable in Tab. 14 14, which gives the description of a characteristic *Schoenoplectus californicus* dominated profile (VO3). The horizons in the upper soil of VO were mostly composed of living brown mosses, *Carex* species and *Sch. californicus*. Below the live vegetation, the underlying substrates had plenty of oxidation marks and prints of the historical groundwater regimen prevailing in the mire (Fig. 49). The mineral under layer horizons in VO were formed by fine-sized sand, loam and clay, divided into two main levels. The deepest horizon was formed entirely by clay loam (Fig. 50, picture B) and free of any plant remains. Above this horizon, a mix of organic gyttja and fine sand was deposited (Fig. 50, picture A), confirming standing water conditions in the past and the fact that VO was formed from a terrestrialization lake in this intermountain depression.

Tab. 14: Horizon and substrate properties of the characteristic soil profile VO3 (after KA 5)

From (cmbs)	To (cmbs)	Horizon	Substrate	DD	Colour (Munsell)	**pH1	**pH2	Roots
0	10	nHw	Hnsc	0	5YR3/1	6.2	5.9	Rg4
10	28	nHr	Hnb	3	5YR3/1	6.5	6.5	-
28	50	nHr	Hnb	2	2.5YR2.5/1	6.6	6.3	-
50	90	Water	H_20	-	-	6.8	6.6	-
90	105	nHr	Hnr	4	5YR2.5/1	6.0	6.1	-
105	135	nHr	Hnr	6	7.5YR2.5/1	6.4	6.0	-
135	157	nHr	Ha	10	5YR2.5/2	5.9	6.1	-
157	270	nHo	Hhc	4	10YR3/2	6.0	6.2	-
270	330	nHo	Hhc	3	7.5YR2.5/1	5.9	5.9	-
330	348	rFr	Fhh	-	7.5YR2.5/1	5.5	5.6	-
348	368	rFr	Fhh	-	5Y2.5/2	4.9	4.8	-
368	387	rFr	Fhh	-	2.5Y3/1	4.9	5.2	-
387	417	rFr	Fhh	-	2.5YR3-Gley	6.3	6.1	-

*hHw= horizon of ombrogenic peat under water fluctuation. nHw= horizon of geogenic peat under water fluctuation. hHr= horizon of ombrogenic peat under reduction. nHr= horizon of geogenic peat under reduction. rFr= relict horizon of lacustrine sediments under reduction. Hnsc= *Schoenoplectus* peat. Hnb= brown moss peat. Ha= amorphous peat. Hhc= Cypress wood peat. H20= water. Fhh= organic gyttja. **pH1= field and pH2= laboratory measurements.

Since no plant remains were present in the loamy very fine material, it can be inferred that the lake originated after the last glacial retreat, as the vegetation had not yet developed in the landscape. The lake would have become terrestrialized during the Holocene, as the vegetation appeared, changing its hydrology which would have been increasingly influenced by the geogenic conditions of the landscape.

In the cores extracted from VO (Fig. 49) the organic gyttja was found repeatedly. On the periphery of the site, horizons of this substrate were present at different depths and orders than in the centre, evidencing that the shore of VO was under the water level but exposed to material inputs or other disturbances in the past. In comparison, in the central area the horizons of organic gyttja remained relatively undisturbed and homogeneous. Above the organic gyttja layer, horizons formed by cypress wood peat were found. Some cypress trees must have fall from the surrounding mountains on the site, at the time when lake was an open water body, decaying there and forming the peat horizons observed in the soil cores.

Fig. 49: Core sample in the upper 50 cmbs of the profile VO1, site VO (Rodríguez, field work 2013).

From 2 to 13 cmbs dominance of brown moss peat and radicels peats distributed in oxidized and bleached bands due to variations in the mire main water table. From 13 to 20 cmbs dominates organic gyttja, with traces of loamy silt material. The mineral material disappears from 20 to 27 cmbs. From this depth the organic gyttja substrate dominates the underlying horizons, and it is only interrupted by traces of *Sphagnum* peat and brown moss peat (37 to 40, 42 to 45 and 46 to 47 cmbs).

A **B**

Fig. 50: Geological settings characterizing the site VO (Rodríguez, field work 2013)

A= Loamy very fine material underlying the site VO. B= Small sand corns are still identifiable in this organic gyttja horizon in the mire VO. This horizon confirms a terrestrialization origin for the site VO.

Above the cypress wood peat layers and until the actual upper soil, changing horizons from radicels to amorphous peat were found, also exhibiting traces of cypress wood peat. These horizons, composed of mixed ombrogenic and geogenic substrates, infer that dry and humid periods succeeded in the formation of VO. Horizons and traces of brown moss peat were diagnosed in all upper horizons, while in the profile VO2, the upper layer of *Sphagnum magellanicum* peat shows a new transition area from fen to bog in the mire at VO. In the profile VO3, a thin horizon of *Schoenoplectus* peat is forming above another of brown mosses, building together a floating mat and starting the process of continuous terrestrialization in the site. This floating mat extends above the residual lake. Profile VO3 was located here.

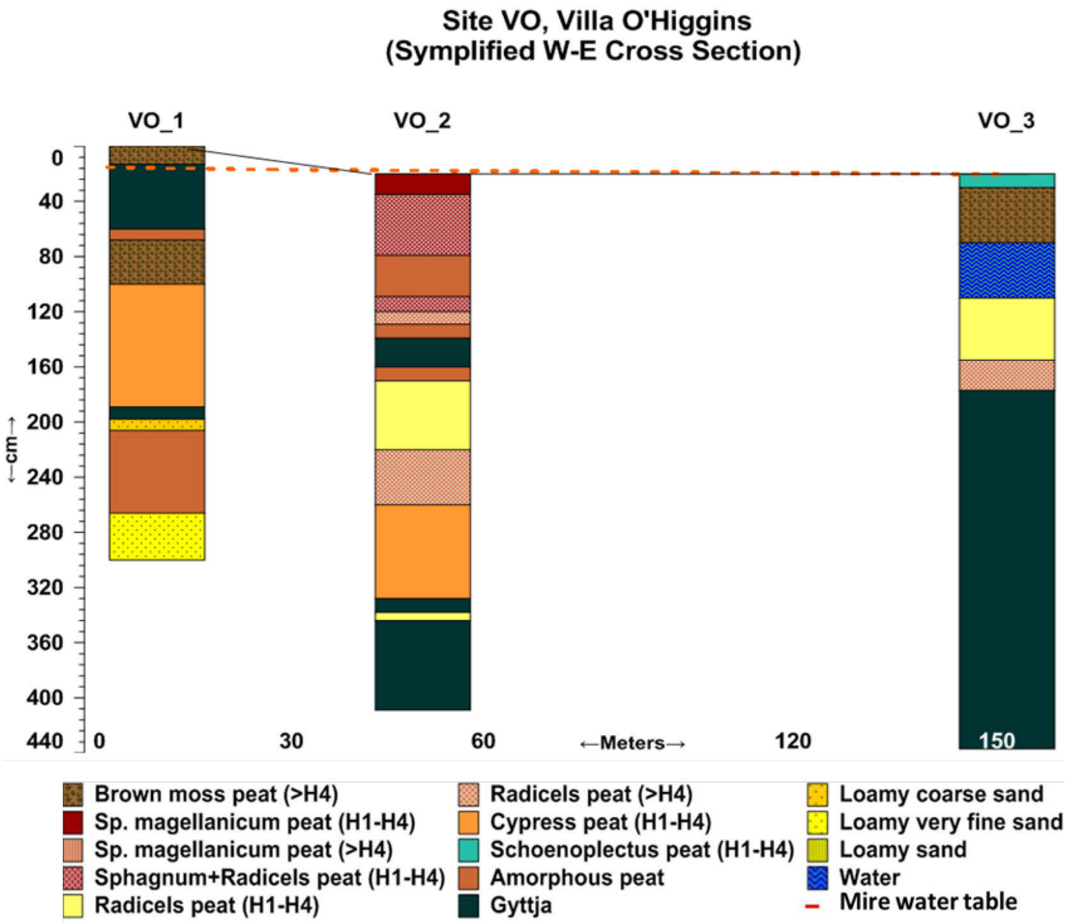


Fig. 51: Simplified W-E cross section in the site VO

Organic substrates found in the site VO are shown in Tab. 15. Amongst these, the most frequent was organic gyttja. This substrate is formed by organic lacustrine sediments decanted into the ground of a still, open water body. Organic gyttja appears in a depth spectrum from 13 to 417 cmbs, depending on the site basin, and in horizons with a thickness that varies from 1 to 30 cm. Its pH varies from 4.0 to 7.3. Amorphous peat is also a substrate present under different depths and pH conditions in the site. It was found in 21% of those diagnosed, in a depth spectrum from 59 to 266 cmbs, in layers from 8 to 89 cm thick. Its pH varied from 4.5 to 6.4. Peat formed by brown mosses presented 8% of the substrates frequency. It was principally found in the upper soil (5 to 50 cmbs), except in the site borders (traces until 80 cmbs), where the nutrient entry of mineralized runoffs and the physical conditions characterized by humidity without saturation are optimal to their development. The degree of decomposition of brown mosses peat reached between H5 to H8, before becoming indistinguishable from amorphous material. Its pH varied between 4.3 to 6.6.

Cypress wood peat represented 8% of the substrates frequency, reaching a depth spectrum from 119 to 140 cmbs and a horizons thickness from 21 to 113 cmbs. The pH of cypress wood peat in VO varied from 5.2 to 6.4 and its degree of peat decomposition from H1 to H5.

Tab. 15: Organic substrate types found in the site VO with frequency (n) and spectrums of depth, thickness, degree of peat decomposition and pH-value (field and laboratory average)

Substrate type	n	Depth (cmbs)	Thickness (cm)	DD	pH (Avg)
Sp. magellanicum peat	3	20 to 100	11 to 20	H1 to H3	3.7 to 7.2
Radicels peat	4	50 to 324	6 to 50	H4 to H6	5.6 to 6.4
Brown mosses peat	4	28 to 68	8 to 22	H1 to H4	4.3 to 6.6
Cypress wood peat	4	119 to 330	21 to 113	H1 to H5	5.2 to 6.0
Amorphous peat	10	59 to 266	8 to 89	>H9	4.5 to 6.4
Organic gyttja	16	13 to 417	1 to 30	-	4.0 to 7.3

Associated with cypress and amorphous peat, it was possible to find radicels peat as well. It was present in a spectrum from 90 to 324 cmbs, in horizons from 6 to 50 cm thickness, with pH from 5.6 to 6.4 and presenting degrees of decomposition between H4 and H6. *Sp. magellanicum* peat was the least common in the sample, with 6% frequency, being present in a depth spectrum from 1 to 100 cmbs, in horizons from 11 to 25 cm thick, with pH-values from 3.7 to 7.2 and a degree of peat decomposition from H1 to H3. The hydraulic conductivity of this peat type was also measured in VO, evidencing 2 cm sec^{-1}, the highest of all *Sp. magellanicum* peat samples examined in this study.

4.1.4 Lago Quetru Site (QP1, QP2 and QP3)

QP lies in the central basin of the Pascua River, exactly in its confluence with the Quetru Lake, at 30 m a.s.l. Three mires were investigated in the site QP, all of them extending from the surrounding slopes into three fluvial terraces of the paleo Pascua River flow: QP1, QP2 and QP3 (Fig. 52).

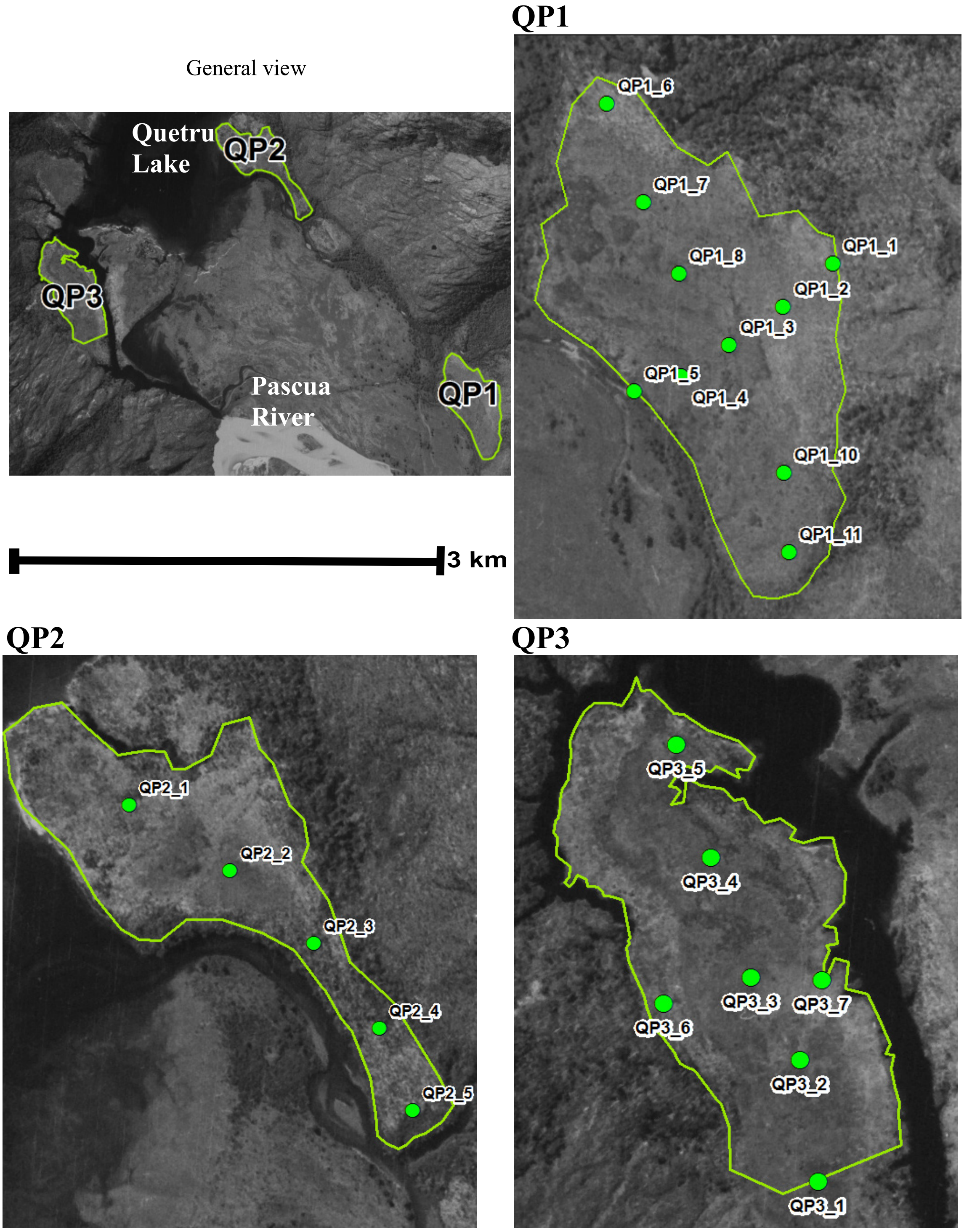


Fig. 52: Final sample design in the sites QP* (pictures modified from SAF)

*Borders of the mire system and sampling points in green.

All mires presented a raised morphology, having plenty of *Sphagnum* bogs in along the borders and cushion plants blankets in their central part. Due to the cushion behaviour of this plant, its surfaces accumulated water during rainy days. All mires were forest-covered in their upper part and saturated in the lower part. Except for QP3 (sectioned since 1990 by the Carretera Austral), the area was pristine. QP1 and QP2 presented an inclination of at least 3,5%, by which they were designated as sloping mires (Fig. 53, pictures QP1 and QP2). In comparison, QP3 (Fig. 53, picture QP3) was located in a flat old fluvial terrace and designated as a normal raised mire.

QP1

QP2

QP3

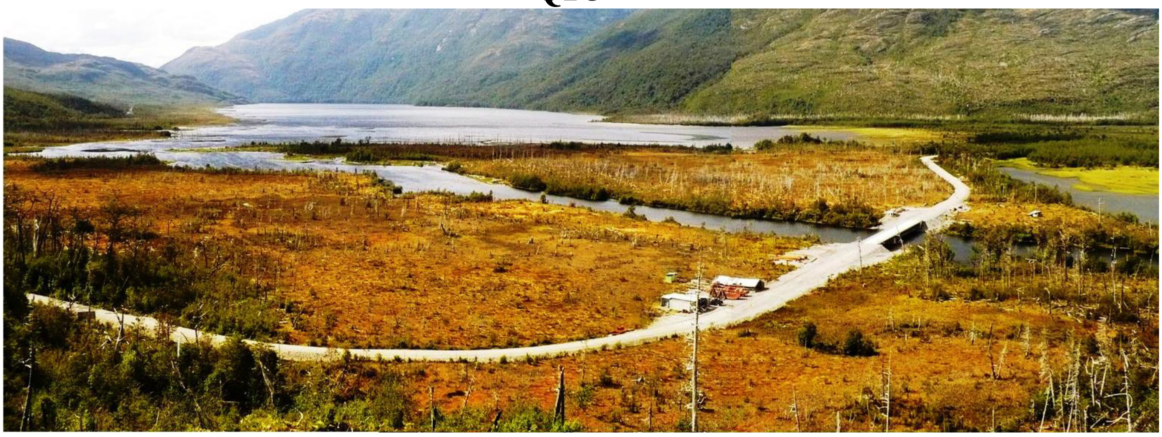


Fig. 53: Landscape setting of the sites QP (Rodríguez, field work 2012)

4.1.4.1 Vegetation and ecological settings

In QP 24 plots were examined. Forty five species were found: 28 in QP1, 29 in QP2 and 35 in QP3. QP3, the mire nearest to the Quetru Lake, presented semi-aquatic species such as

Schoenoplectus californicus. In addition to *Sp. magellanicum*, which formed the base of the vegetation cover, members of the Cyperaceae family defined the plant diversity of this site. *Carex* species presented the highest dominance of the sample, growing above *Sphagnum* mosses and covering up to 50% of the soil surface in several plots (Fig. 54, picture A). A difference was defined according to the vegetation dominance, where sedge vegetation was more abundant in the sloping mires QP1 and QP2 than in the flat mire QP3. Species of the Ericaceae family were found in 19 of the examined plots, including *Empetrum rubrum*, *Pernettya mucronata* (Fig. 54, picture C) and the species *Pernettya pumila,* which was only found out in this site. Amongst the cushion plants, the families Asteliaceae and Donatiaceae were represented by the species *Astelia pumila* and *Donatia fascicularis* respectively (Fig. 54, picture D). They were found in 11 plots.

QP vegetation coincided in its morphology and composition with that of the site LR, characterized by *Sphagnum* hummocks neighbouring *A. pumila* and *D. fascicularis* blankets in different stages of domination.

A common successional behaviour was observed in the QP sites. Areas covered by forests of *Pilgerodendron uviferum* and *Nothofagus betuloides* were present in the well-drained upper and lateral borders. On the downward slope as the inclination declines, *Pernetya mucronata* begin to dominate, followed by blankets of *Sphagnum* moss and patterned spots of *A. pumila* growing in the low flat area. The cushion building behaviour of *A. pumila* facilitates the superficial accumulation of rain water. It appears to be, that the organic compounds liberated by the peat production in the superficial roots of *A. pumila*, maintain the mesotrophic conditions in the upper soils of low terraces, similar to that of sloping areas. This was verified in the site QP1, which C/N ratio in the upper sloping area was C/N= 28, similar to the C/N ratio in its lower terraces, which reached C/N= 27. In the absence of percolation water and *A. pumila* (i.e. site QP3), the trophic levels turn oligotrophic, with the C/N ratio being 41. The highest C/N ratios were detected in areas dominated by *Oreobolus obtusangulus* instead of *A. pumila.*

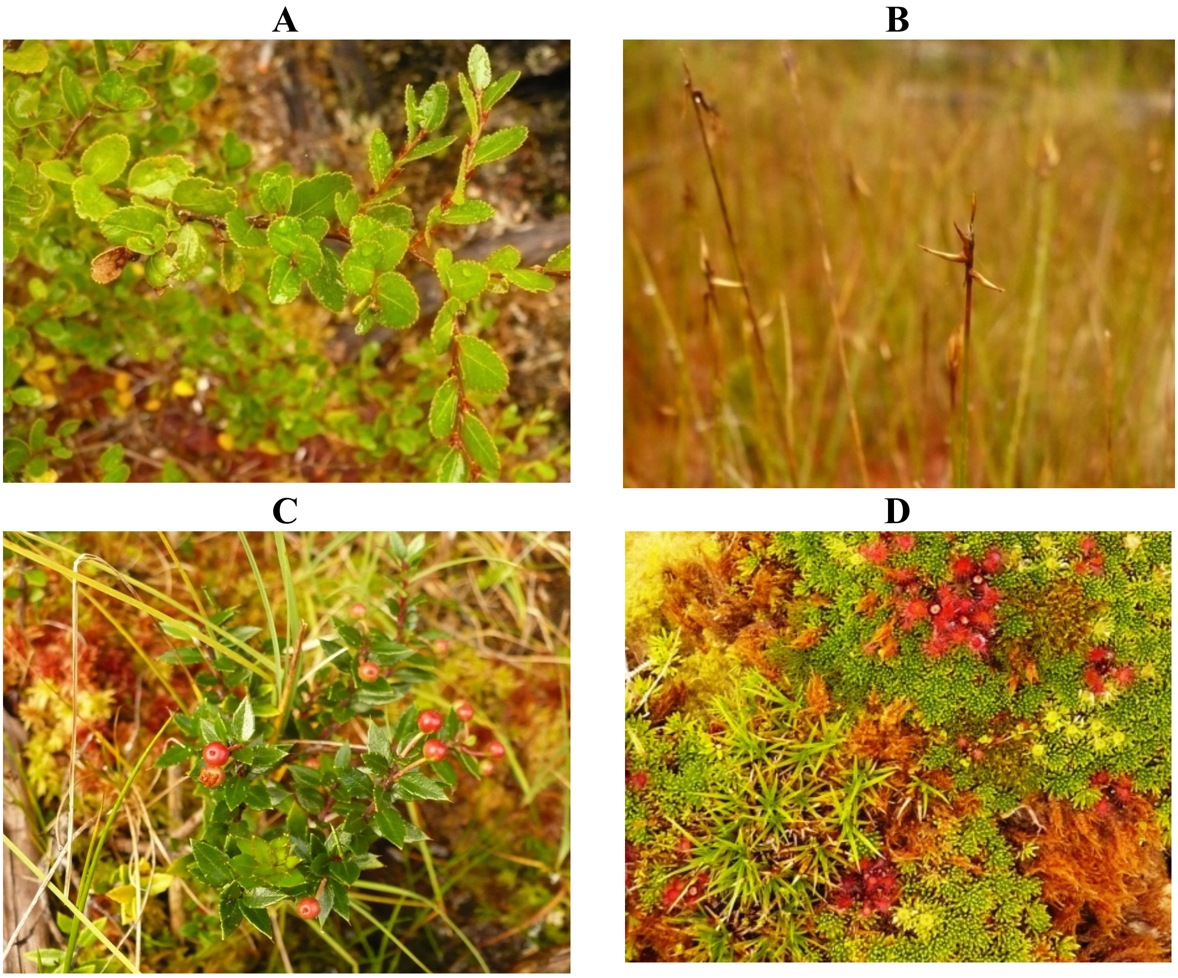


Fig. 54: Main vegetation species in the QP sites (Rodríguez, field work 2012)

A=*Nothofagus betuloides* B=*Carex microglochin,* C= *Pernettya mucronata.* D= cushion of *Donatia fascilularis, Oreobolus obtusangulus, Drosera uniflora* and brown mosses

Concerning the micro relief gradient, raised bogs were observed in the upper and central part of the sloping mires (QP1 and QP2), presenting cushions of *Sp. magellanicum* and *Carex magellanica*. On the other hand, sedimentation dynamics were observed in areas where water accumulation occurred, i.e. where *Astelia pumila* and its associated cushion plants grew. In the field was observed that these dynamics are facilitated by effect of the wind in the superficial accumulated water, particularly in areas with west exposure. Regarding the pH-values, these evidenced strong to moderate acidic conditions (average of 3.4±0.5) remaining similar and steady in the three mires (Fig. 55).

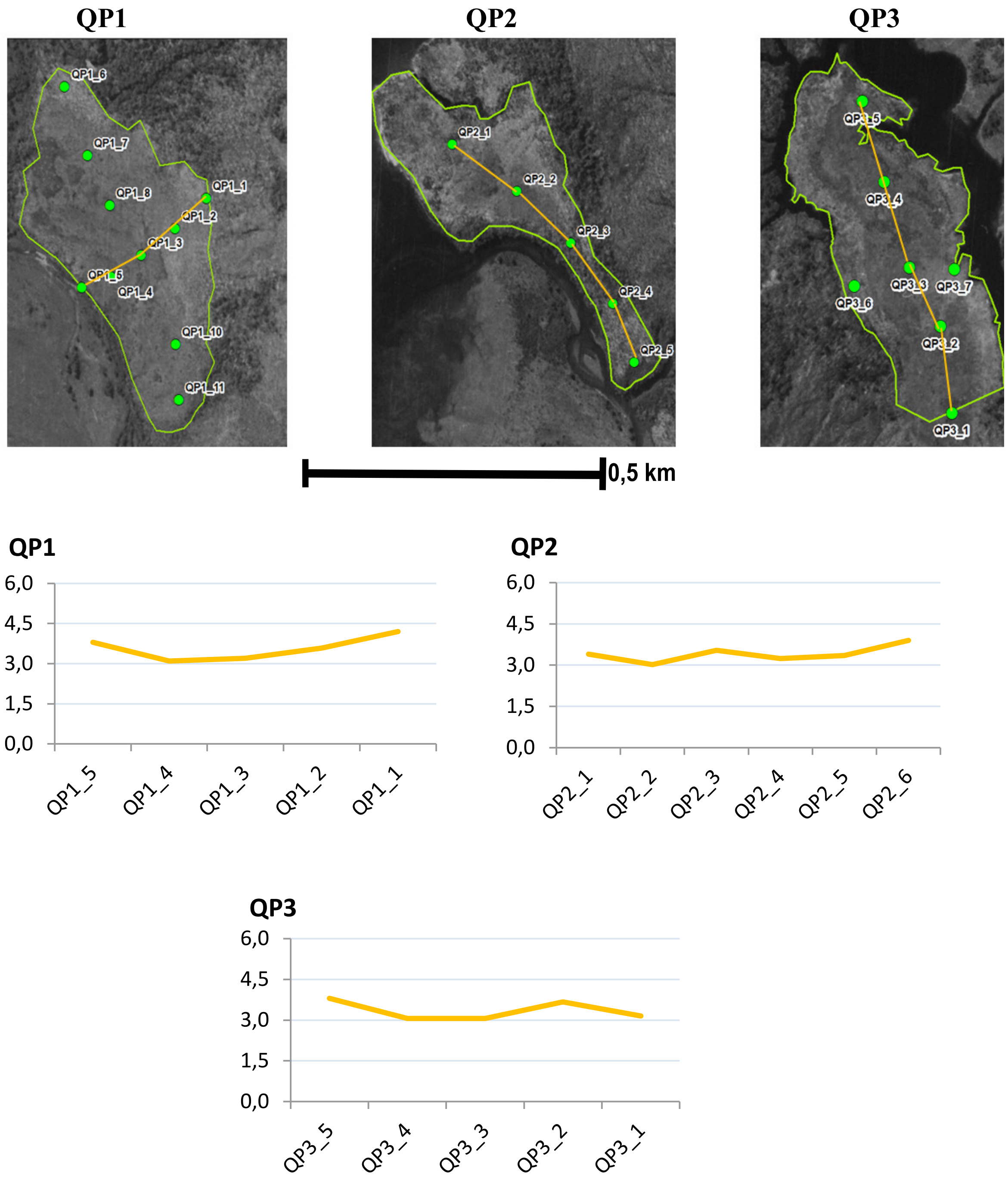


Fig. 55: pH-behaviour in the upper soil of the sites QP (single measurements in the field)

Water samples for measurements were collected by pressing the peat of the upper 30 cmbs.

4.1.4.2 Hydrology

The annual precipitation average of QP reached 2200 mm y^{-1} (DGA, 2014). The pH-values in the site do not overpass 4.2 unveiling that the main water source in the sloping mires of QP comes from rainwater. On the other hand, the mire water table varies with the relief, decreasing in sloping areas (in Fig. 56 profiles QP1_1, QP2_5) and increasing in flat and lower areas (in Fig. 56, profiles QP1_3, QP2_2 and QP3).

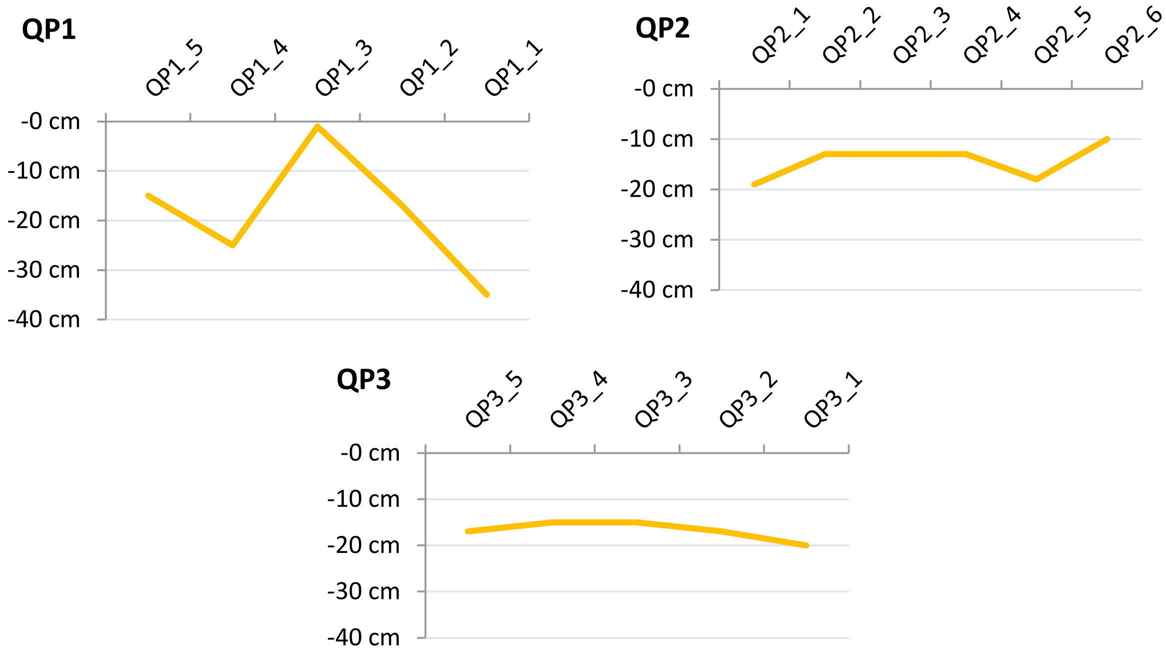


Fig. 56: Depth to the surface of the mire water table in sites QP (cmbs, single measurements)

These relief produced variations of the mire water table, influence a relief dependent vegetation gradient. While percolating through the slope, the rainwater becomes enriched in nutrients and organic compounds, influencing the chemical and trophic conditions of the soils on the downward slope, as was observed in the site QP1. In this mire a buffer zone is produced in the limit between the sloping mire and the raised mire. In the sloping area the vegetation is formed by S*phagnum* mosses, Ericaceae and Juncaginaceae species, after which *Sp. magellanicum* hummocks appear. Downwards the mire ends in low flat terraces colonized by *A. pumila.* The parameters stated previously for each profile in the site QP are shown in Fig. 57. Discrete differences can be established in the three examined mires according to the pH-value-behaviour. This mostly presents higher values on the borders of the mires, but does not show differences among the diversity or form of the vegetation. In comparison, although the mire water table presents small variations, the vegetation presents a clear gradient according to its behaviour, rather than by the acidity or basicity of the upper soil. Consequently according to the saturation level, patches that were forest-covered by *P. uviferum* and *N. betuloides* were detected in well-drained hills or above fossil fluvial banks; sedges such as *C. microglochin* and *Sch. nigricans* were found in those areas where superficial runoffs or mineral water contributions occur, and cushion

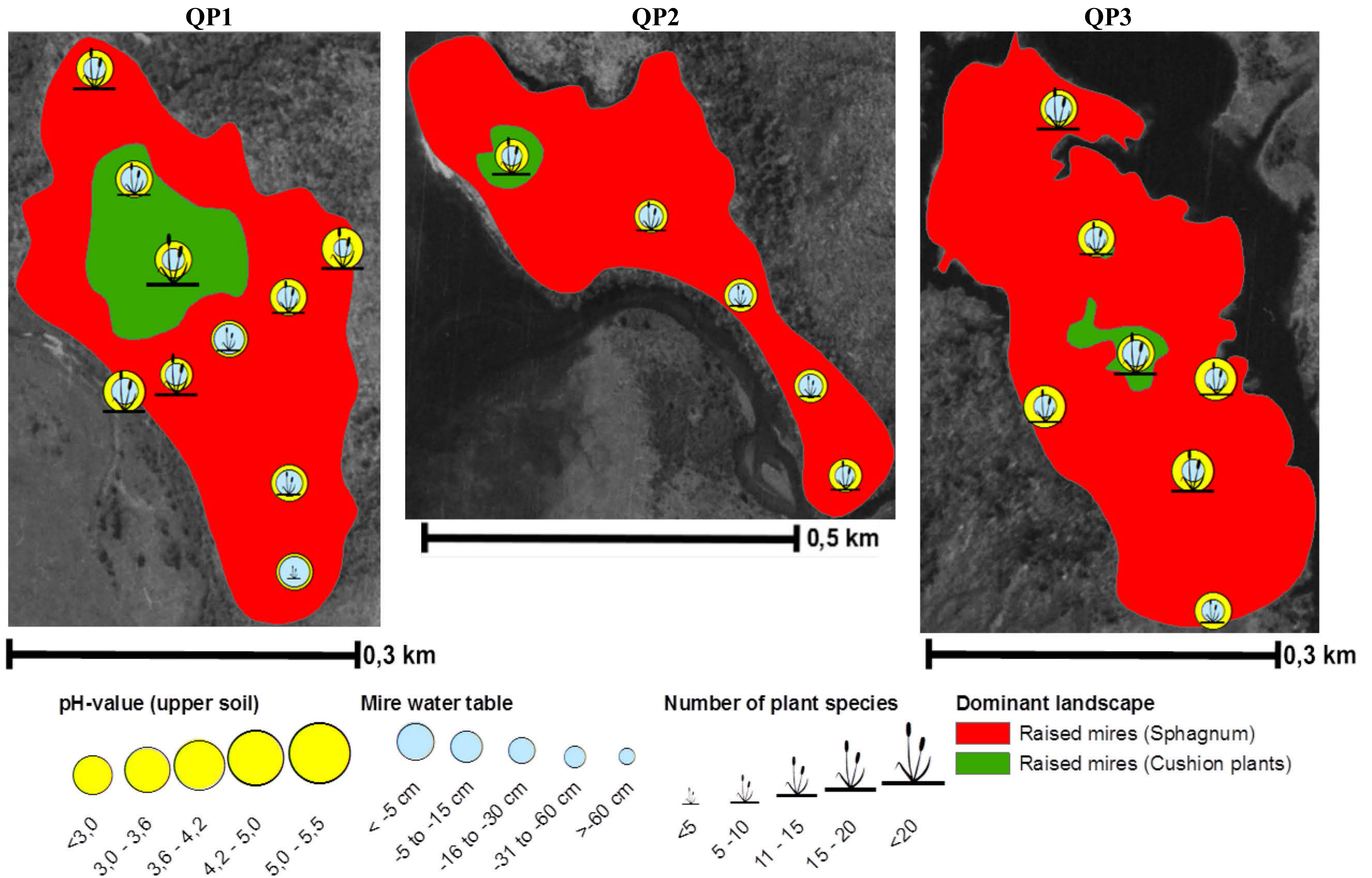


Fig. 57: Simplified overview of the mire water level, pH-value, number of plant species and dominant landscape in sites QP (pictures modified from SAF)

plants such as *A. pumila* and *D. fascicularis* colonized highly saturated lower terraces (Fig. 58, pictures A and B). Lastly, the exposure of the mires to the winds blowing from the ocean across the basin of the Pascua River, seems to define the development of blanket or raised bogs in QP. Therefore the site QP1, the one that is the most exposed to the oceanic winds in this sector of the basin, is also the site exhibiting the largest areas of cushion plants blankets.

A **B**

Fig. 58: Mire water table and diversity in QP1 & QP3 (Rodríguez, field work 2012)

A= Low terraces of the mire QP1 present mire water tables at the surface during rainy periods, allowing organic compounds liberated by *Astelia pumila* to allocate, producing almost mesotrophic conditions in the upper soil. B=In the mire QP3, characterized by ombrotrophic conditions, *Oreobolus obtusangulus* cushions above the mire water table.

4.1.4.3 Stratigraphy

In Tab. 16 describes characteristic profiles of the mires QP1, QP2 and QP3 respectively. QP1_2 presented a superficial ombrogenic peat horizon under water changing conditions (nHw) above reduced horizons of geogenic peat (nHr), lying on a deep horizon of loam (L) and sandy loam (sL) also under reductive conditions (fGr). The order and characteristics of QP2 horizons are similar than in QP1. A significant difference is shown in QP3, where the peat horizons are lying above a relict and reduced horizon of organic gyttja (rFr). Thin horizons and a diversity of substrates were typical insloping areas of the QP sites.

Tab. 16: Horizon and substrate properties of characteristic soil profiles in QP (after KA 5)

	From (cmbs)	To (cmbs)	*Horizon	*Subs-trate	DD	Colour (Munsell)	**pH1	**pH2	Roots
QP1_2	0	55	hHw	Hhsy	2	7.5YR3/4	3.7	3.7	Rf2
	55	90	nHr	Ha	9	7.5YR2.5/3	4.4	4.4	-
	90	95	nHr	Ha	9	10YR3/3	4.7	4.7	-
	95	100	nHr	Ha	9	2.5Y3/3	4.5	4.4	-
	100	200	nHr	Ha	10	2.5Y3/3	4.0	4.0	-
	200	210	fGr	L	.	2.5Y4/2	4.3	4.3	-
	210	230	fGr	sL	-	2.5Y4/3	4.7	4.7	-
Q	0	30	hHw	Hhsy	3	10YR2/2	3.6	3.5	Rf2

	30	40	nHr	Ha	9	10YR2/2	3.7	3.8	R0
	40	50	nHr	Ha	10	7.5YR2.5/2	4.0	4.0	R0
	50	80	fGr	LVFS	-	2.5Y3/3	4.6	4.5	Rf1
QP3_3	0	25	hHw	Hoas	3	5YR2.5/2	3.2	3.2	Rf4
	25	30	hHr	Hhsy	2	7.5YR2.5/2	4.0	4.0	Rf3
	30	55	hHr	Hhi	2	5YR2.5/2	4.2	4.2	Rf2
	55	85	nHr	Hnr	3	5YR3/3	4.7	4.7	Rf1
	85	160	rFr	Fhh	-	5Y4/2	5.0	4.9	Rf1

*hHw= horizon of ombrogenic peat under water fluctuation. nHw= horizon of geogenic peat under water fluctuation. hHr= horizon of ombrogenic peat under reduction. nHr= horizon of geogenic peat under reduction. fGr: fossil mineral horizon under reduction. rFr= relict horizon of lacustrine sediments under reduction. Hhsy= *Sphagnum magellanicum* peat. Ha= Amorphous peat. Hoas= cushion plants peat. Hhi= Ericaceae peat. Fhh= organic Gyttja. L= loam. sL= sandy loam. LVFS: loamy very fine sand. **pH1= field and pH2= laboratory measurements.

Fig. 59 is representative of the upper 50 cmbs of substrate dominating in the sloping mire QP1. In particularly the low part of sloping sites like QP1, most exposed to the effects of water changing levels, exhibited the main substrate variation of the whole site. Additionally, the mineral parent materials underlying the mires of QP were composed of loamy fine sands and loamy very fine sands (Fig. 60). In the mire QP1 (the most inclined QP site), coarse and loamy coarse sands were observed forming the mineral parent material. Only in the site QP3, characterized by a flat morphology and adjacent to the Quetru Lake, loamy material presenting coarse sand was found, probably forming part of a relic bank of the lake. The material found is very similar to that detected in the sites LR and LV adjacent to the Baker River, by which is inferable that rises in the soil water level (paludification) also gave origin to the mire in QP. Nevertheless, the amorphous component is more present in QP than in any other site, insinuating that in this site the periods of low water tables were long enough to allow mineralization to occur.

Fig. 59: Core sample in the upper 50 cmbs of a profile at site QP1 (Rodríguez, field work 2012)

Living *Sphagnum magellanicum* mosses up to 15 cmbs, mixed *Sphagnum magellanicum* and radicels peat H2 from 15 to 35 cmbs, radicels peat H5 from 35 to 45 cmbs, amorphous peat mixed with loamy sand in the deeper horizons.

Fig. 60: Geological settings characterizing the site QP1

A=Loamy very fine sand with remains of amorphous peat in the limit with the mineral parent material at site QP1. B=Grains of coarse sand in the limit mixed with Sphagnum peat at site QP2.

On the other hand, organic horizon found in QP presented mostly reductive conditions up to 20 cmbs, except in the mire QP1. There, the inclined relief defined deeper water tables in the upper area. Horizons did not exceed 100 cm in thickness, reaching a maximum of 230 cmbs (profile QP1_3) and presenting a wide diversity of substrates (Fig. 61). In QP1 the lower horizons were distributed in thin layers, revealing the effects of fluctuating water levels and thereby the development of different peat forming vegetation types. In contrast, the mires QP2 and QP3 presented homogeneous and continuous horizons (e.g. formed by substrates *Sp. magellanicum* peat and mixed *Sphagnum*-radicels peat). In QP seven main substrate types were detected (Tab. 17). The most frequent was amorphous peat, present in 38 horizons. Its high degree of decomposition demonstrates that its formation was defined by aeration of the peat, i.e. a lower mire water table. The pH spectrum (3.4 to 4.9) indicates strong acidic to weak acidic conditions. *Sp. magellanicum* peat was the second most frequent peat in the site, being findable in 32 horizons in a depth spectrum as wide as *amorphous* peat (5 to 230 cmbs). It is highly probable that this last was formed by *Sphagnum* mosses, since they are the most dominant in all the horizons and commonly succeed the amorphous adjacent to the mineral parent material in the catotelm. The *Sp. magellanicum* peat presented a wide pH spectrum (2.5 to 5.3 or very strong acidic to weak acidic). Radicels, Ericaceae and cushion plants peat were only found in 10 to 11 horizons of QP. Far less common were cushion plants peat (4 horizons), *Oreobolus* peat (1 horizon) and cypress wood peat (1 horizon). All the last common types presented low degrees of decomposition and strong acidic to moderate acidic pH-values (3.1 to 4.7). An exceptional substrate found in QP was organic gyttja, detected forming one horizon in the mire QP3. This substrate, an indicator of old standing water bodies, presented a weak acidic pH-value of 5,1, i.e. the highest in the whole site QP. Similar to VO, the stratigraphic evidence allows for the assumption that terrestrialization dynamics dominated the origins of the mire QP3. This was the only mire presenting an organic gyttja horizon of QP (QP3_3). Last of all, the hydraulic conductivity of *Sp. magellanicum* peat was tested in a sloping area of QP, exhibiting a very low velocity of ≈0.1 centimetres of water liberation per second (data for profile QP1_1). Thus, it can be inferred that this substrate provides an important function by filtering water discharges in the groundwater aquifers, and decelerating its entry into the landscape after strong precipitation.

Tab. 17: Organic substrate types found in the sites QP with frequency (n) and spectrums of depth, thickness, degree of peat decomposition and pH-value (field and laboratory average)

Substrate type	n			n	Depth (cmbs)	Thickness (cm)	DD	pH (Avg)
	QP1	QP2	QP3					
Sp. magellanicum peat	13	5	13	32	5 to 230	5 to 75	H1 to H5	2.3 to 5.3
Radicels peat	8	1	2	11	5 to 130	5 to 65	H1 to H3	3.1 to 4.7
Ericaceae peat	6	1	3	10	30 to 190	10 to 40	H1 to H3	3.7 to 4.3
Cushion plants peat	2	0	2	4	10 to 95	15 to 45	H1 to H3	3.2 to 3.7
Oreobolus peat	2	0	1	3	5 to 30	5 to 20	H1 to H2	3.5 to 3.7
Cypress wood peat	1	0	0	1	11 to 20	9	H4	4.0
Amorphous peat	22	8	8	38	10 to 210	5 to 100	<H9	3.4 to 4.9
Organic gyttja	0	0	1	1	<210	60	-	5.1

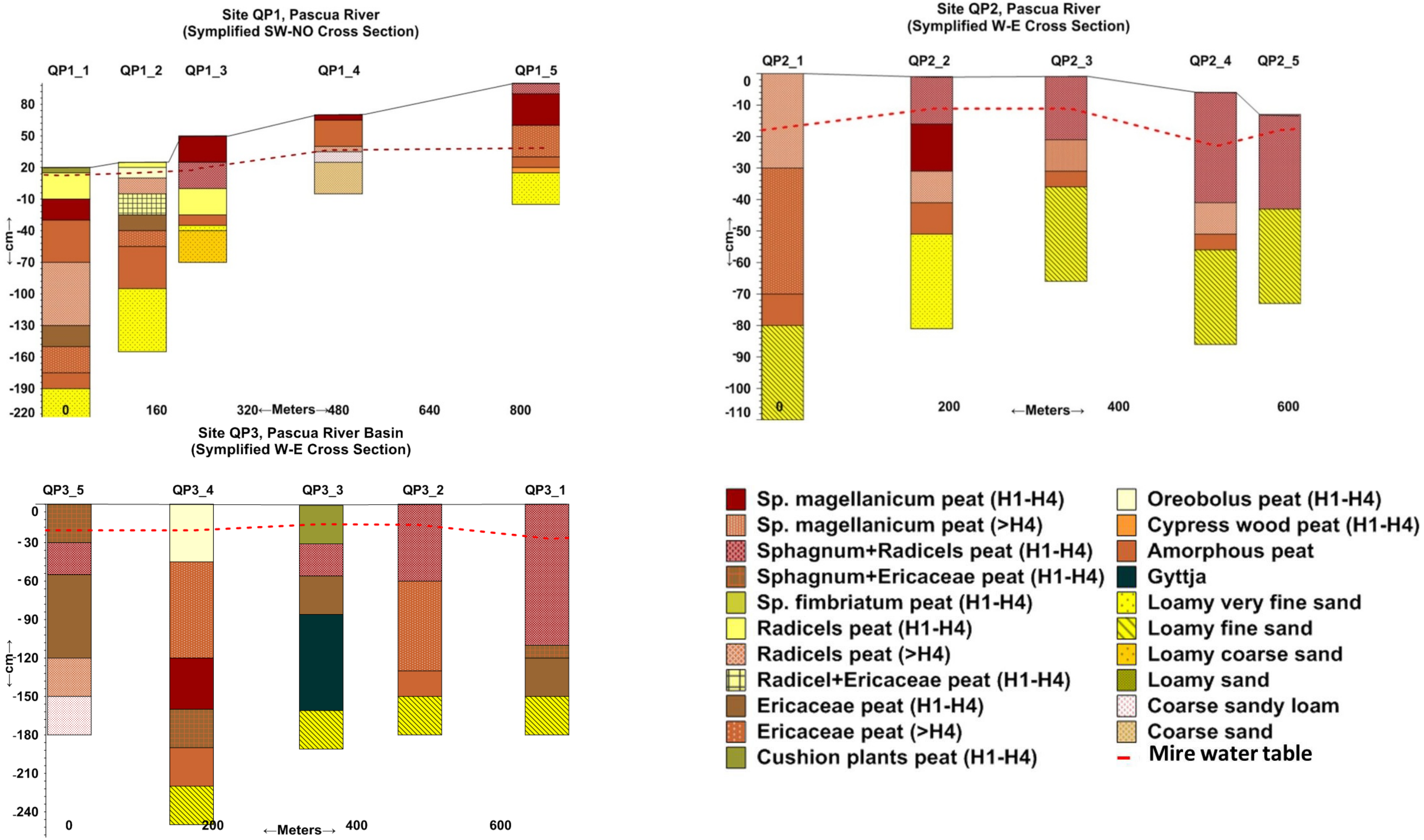


Fig. 61: Simplified cross section for selected profiles of the mires of sites QP

4.1.5 Bajo Pascua Site (BP1, BP2, BP3 and BP4)

The site BP lies at the mouth of the Pascua River, 2 km away from the coast. Excluding the current construction of the Carretera Austral on the border of site BP1, the four mires examined in BP (BP1, BP2, BP3 and BP4) were totally pristine. The final sampling design is exposed in Fig. 62. The mire BP1 presented a small to medium inclination of 1% to 6% and was located at the foot of a slope, whose relief was sculpted by the previous course of the Pascua River, creating an old fluvial terrace. The mire BP2 was located above an old flood plain of the same river, and did not presented inclination. In comparison, the mires BP3 and BP4 were located at 166 m a.s.l., the first on a inclined hill (9%) and the second in a intermountain depressions. Similar to the sites QP and LR, the mires BP1 and BP2 presented a raised morphology, but in comparison to QP and LR, where *Sphagnum* hummocky mires dominated and cushion plants blanket bogs were occasional, in the whole lower basin of the Pascua River cushion plants blankets were dominant. These landscape settings are shown in Fig. 63.

4.1.5.1 Vegetation and ecological settings

In BP 17 plots were examined. A gradual decrease of species with the altitude was observed in BP. BP1 was the most diversified presenting all 45 species detected as main mire plants, followed by BP2 (39 species), BP3 (38 species) and BP4 (17 species). Species common to all plots were *Myrteola nummularia* and *Dicranoloma imponens* (Fig. 64, pictures B and D). *A. pumila, D. fascicularis* (both visible in Fig. 64, pictures A and C) and *Sp. magellanicum* were present in 16 plots. *T. magellanicum* (present in 15 plots), *Nothofagus betuloides* and *Schoenus rhyzosporoides* (both present in 14 plots), as well as *Pilgerodendron uviferum* and *Lepidothamnus fonkii* (both found in 13 plots) were also abundant in BP. Rare species found only in one plot were *Desfontaina spinosa, Berberis microphyla, Maitenus boaria* and *Maytenus magellanica.* But the rarest species was *Caltha sagittata,* with a single register in the site BP. According to their dominance and role as peat forming plants, the main species in the sites sampled in BP were *Astelia pumila* (average dominance of 40% in the vegetation cover), *Donatia fascicularis* (average dominance of 35%), *Oreobolus obtusangulus* (average dominance of 27%), *Marsippospermum grandiflorum* (average dominance of 25%), *Dicranoloma imponens* (average dominance of 20%) and *Sphagnum magellanicum* (average dominance of 19%).

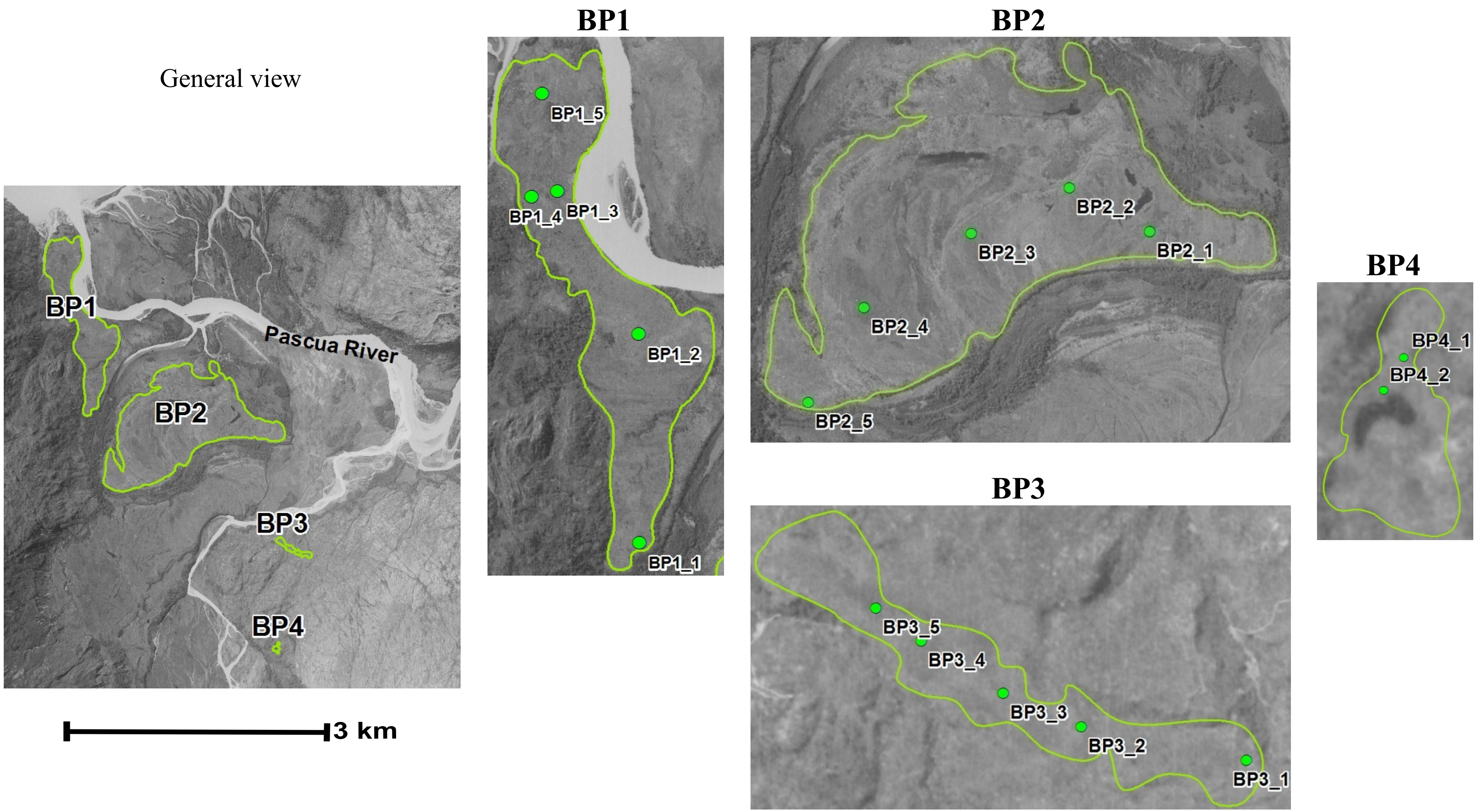


Fig. 62: Final sample design in the sites BP* (pictures modified from SAF)

*Borders of the mire system and sampling points in green.

BP1

BP2

BP3

BP4

Fig. 63: Landscape setting of the sites BP (Rodríguez, field work 2013)

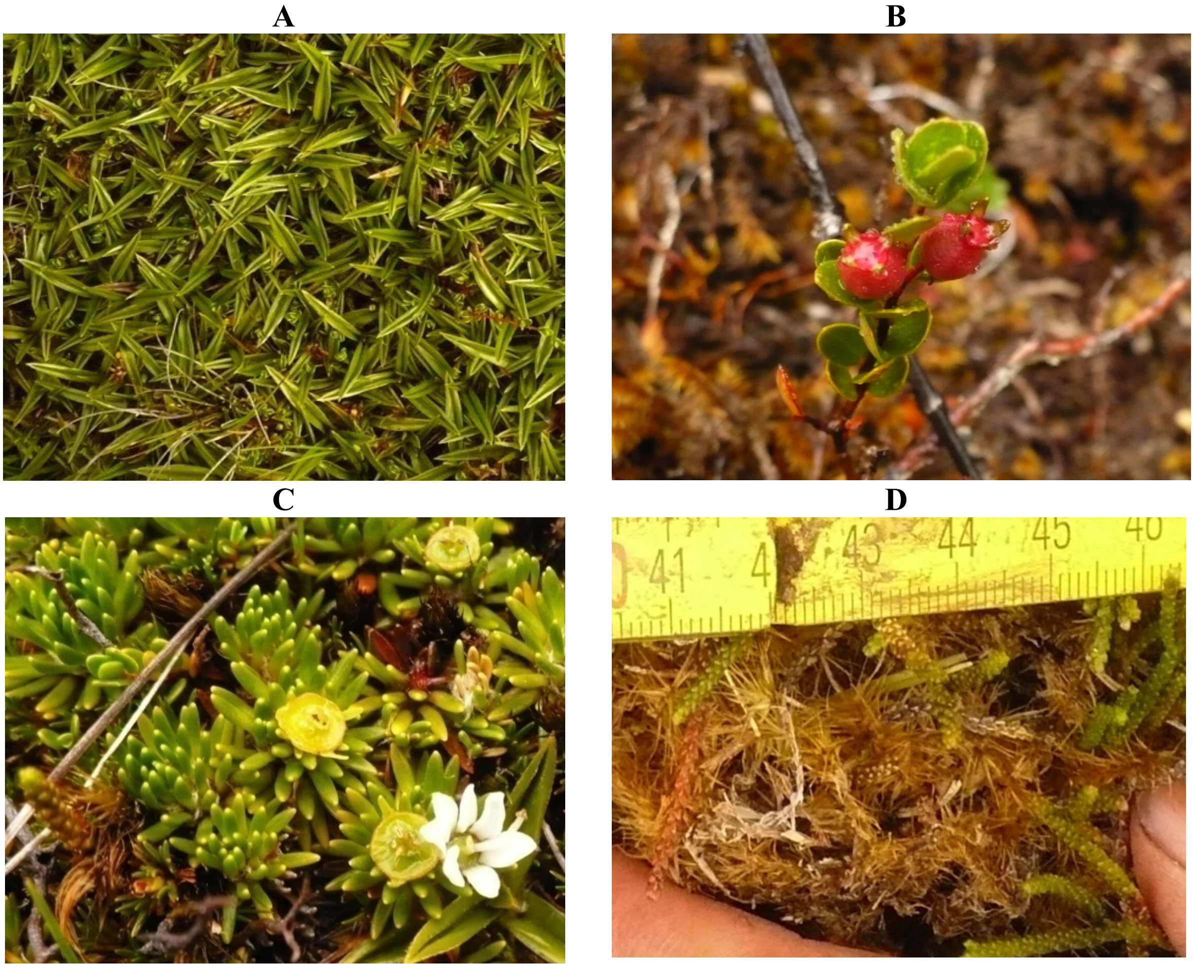


Fig. 64: Main vegetation species in sites BP (Rodríguez, field work 2013)

A= *Astelia pumila*. B= *Myrteolea nummularia*. C= *Donatia fascilularis* with flower D= *Dicranoloma imponens* mixed with *Lepidothamnus fonkii.*

The species *A. pumila* reached its maximal dissemination in mountainous areas (45% of the vegetation coverage in BP4). This *A. pumila* and *M. grandiflorum* were the most dominant species in BP1. In BP2 *D. fascicularis, L. fonkii, O. obtusangulus* and *T. magellanicum* dominated; in BP3 *A. pumila, D. fascicularis, L. fonkii* and *Sp. magellanicum,* and in BP4 *A. pumila, O. obtusangulus* and *M. grandiflorum.* The pH-values in the upper soils evidenced strong to moderate acidic conditions (average of 3.7 ±0.8) and remained almost steady in BP1, BP2 and BP4, while small variations were observed in BP3 (Fig. 65). With an average pH-value of 3.6±0.5, no significant differences were observed among the pH-values of sites dominated by *A. pumila, O. obtusangulus, Sp. magellanicum,* while sites dominated by *Sch. californicus*, *M. grandiflorum, C. magellanica* exhibited increments with an average pH-value of 4.5±0.2. But the trophic conditions for vegetation to grow varied in these mires. In the upper soils dominated by *Sp. magellanicum* in the low valleys the C/N ratio varied between 26 to 64 (BP2_2).

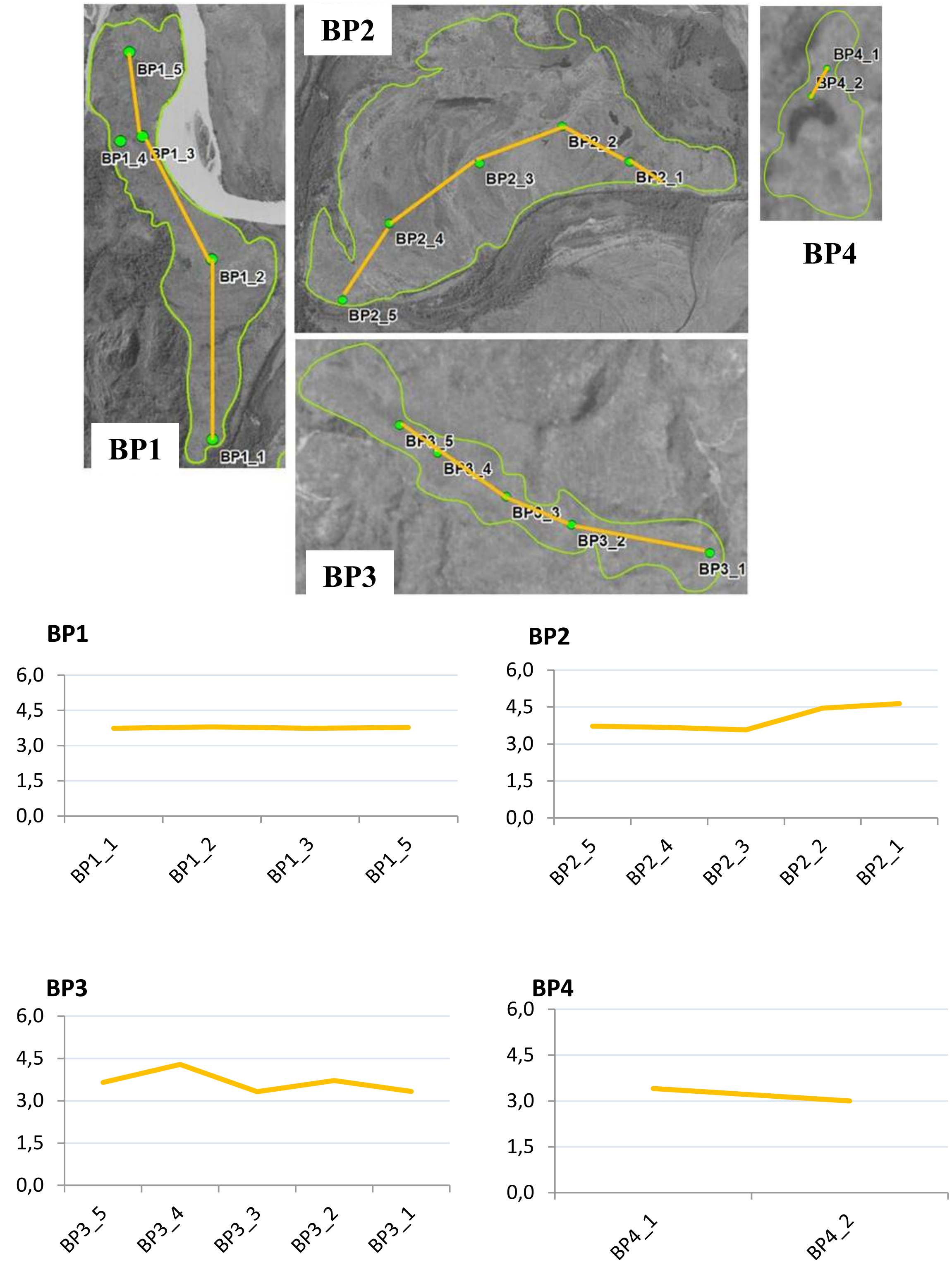


Fig. 65: pH-behaviour in the upper soil of sites BP (single measurements in the field) (pictures modified from SAF)

Water samples for measurements were collected by pressing the peat of the upper 30 cmbs.

In areas dominated mainly by *A. pumila* the ratio was C/N=26 (BP1_3). A higher value was observed in the mire BP4, dominated by *A. pumila* and some patches of *Sp. magellanicum,* where the ratio was C/N= 38 (BP4_1). Due to its terrestrialization origin but current oligotrophic conditions, the mire BP4 is special. Floating and bank vegetation colonizes the edges of a remnant lake in BP4, extending as swimming mats from the shore into the water surface. The species *A. pumila, D. fascicularis* and *Oreobolus obtusangulus* are the main peat formers of this ecosystem, besides the presence of *Sp. magellanicum*. These last three species form rafts with their roots and rhizomes that are sufficiently strong and stable enough to float and to continue developing above the water surface of the remnant lake. Due to the acidic pH-value in the water column, the humification of the organic matter contributed by the floating plants is limited on the clear remnant lake of BP4, by which plant remains decant and accumulate at the bottom of the lake forming organic gyttja substrates which in the long term will occupy and replace the ground of the aquifer.

4.1.5.2 Hydrology

Annual average rainfall in the site BP reaches 2700 mm y^{-1} and the annual average temperature 6.5°C (Vargas et al. 2007; www.meteoarmada.directemar.cl). In areas with intermountain depressions, precipitation forms small standing water bodies which later produce terrestrialization mires, or drain downhill forming flow-through (percolation) mires. The behaviour of the mire water tables in the mires of BP (Fig. 66) presented variations according to the landscape morphology, with these being lower in the sites BP2 and BP4, which presented flat micro-reliefs, and higher in the sites BP1 and BP3, characterized by sloping structures. Additionally, the mire BP4 presented the highest mire water table of the site BP. The mire BP1 presented a small runoff on its southern flank, while open water bodies were absent in most of its central and northern surface (Fig. 67, picture A). On the contrary, pools with differentiated vegetation from shore to shore were typical in the mire BP2 (Fig. 67, picture B). And as mentioned above, BP4 presented a pristine and oligotrophic remnant lagoon (Fig. 67, picture C), whose northern shore drained through a low inclined hill, forming an approximately 300 m flow-through area (Fig. 67, picture D). The main vegetation in this drainage area was formed by grasses (*C. magellanica, Sch. nigricans, H. comosum*). Downhill and after reaching an inclined intermountain depression, the drainage system turns into a channel (Fig. 67, picture E). Along this channel, the vegetation cover becomes dominated by *Sp. magellanicum* hummocks forest-covered by *Nothofagus* and small cypress trees, evidencing the proximity to the surface of the mineral parent material. After 300 m the runoff disappears, giving way again to downhill percolation dynamics.

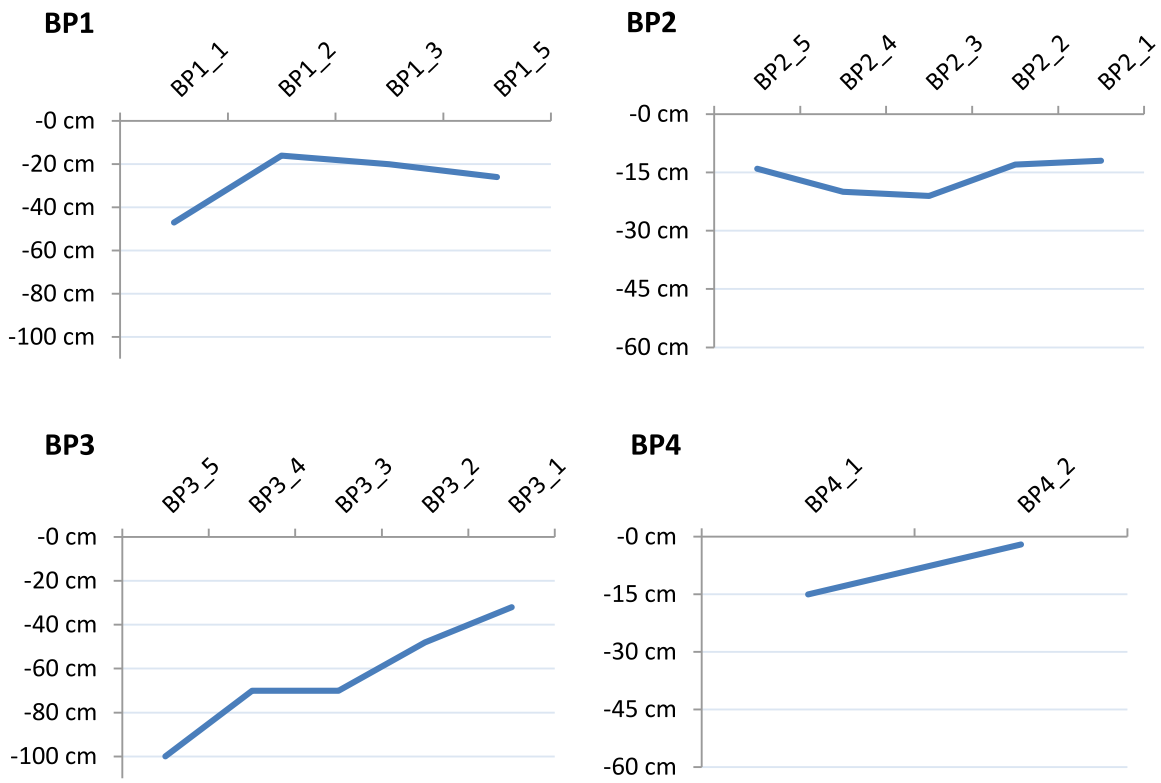


Fig. 66: Depth to the surface of the mire water table in sites BP (cmbs, single measurements)

Around 1300 m north of BP4 is the mire BP3 (Fig. 67, picture F), which is the accumulation area of diverse runoffs falling from the surrounding mountains. The ecological conditions of each mire seems to be determined by the main source of water irrigating them. BP1 presented two trophic levels. While the northern flank exhibited typical vegetation adapted to oligotrophic conditions, the southern flank, crossed by the mentioned small stream, exhibited strong acid-mesotrophic upper soil conditions (pH-value average=3.8 and C/N=26). BP2 (located in an old flood plain of the Pascua River) was principally irrigated by rain, presenting on average moderately acidic pH-values (4.0) and the most oligotrophic upper soil conditions of all the sites examined in the region (C/N=65). BP3, formed from percolation water but widely influenced by rainfall, presented upper soils with strong acid-mesotrophic conditions (pH-value average=3.7 and C/N=21). Whilst BP4, originated from a terrestrialization glacial lake and currently highly irrigated by rain, presented strong acid-oligotrophic conditions (pH-value average=4.0 and C/N=38).

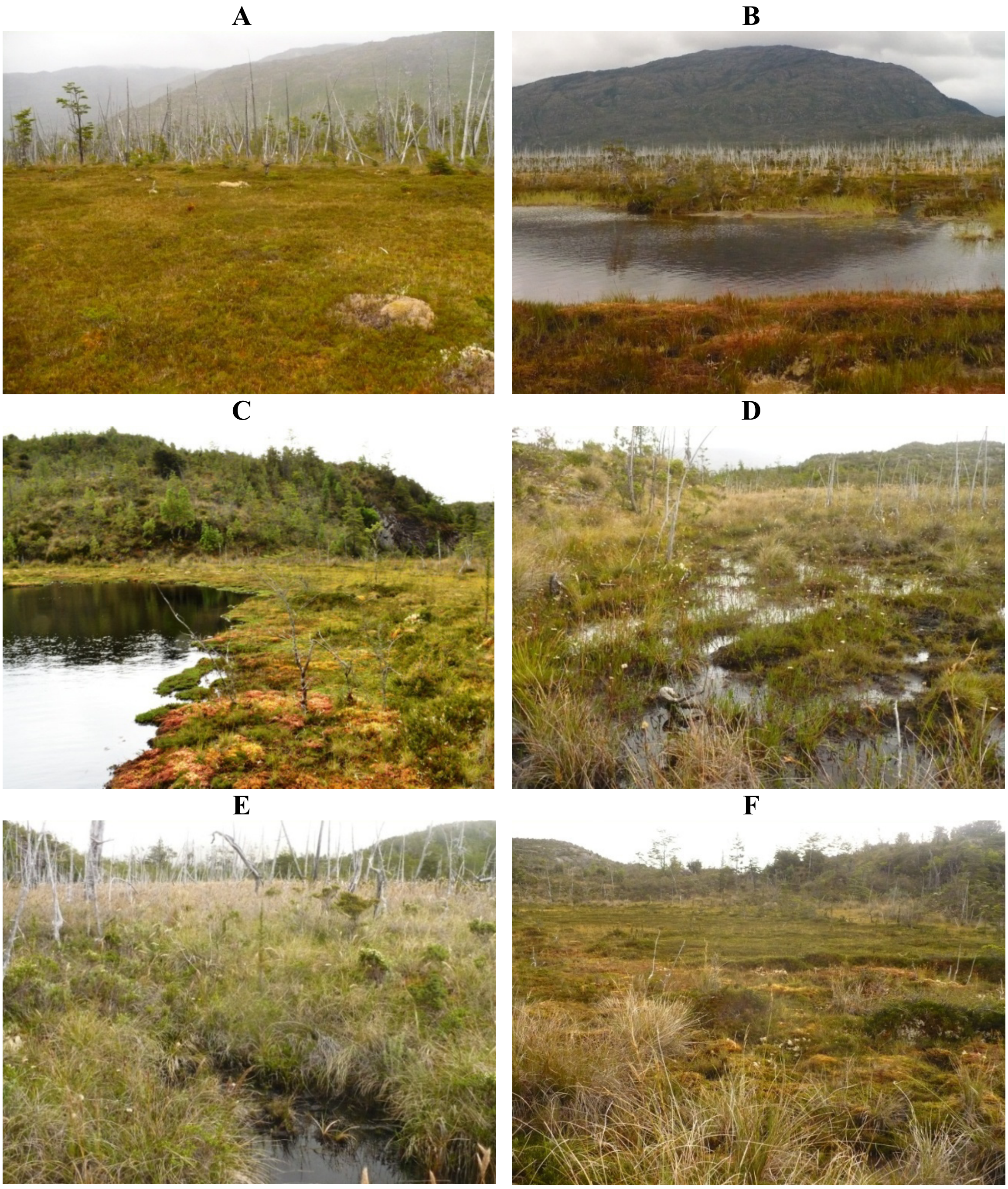


Fig. 67: Mire water table and diversity in the sites BP (Rodríguez, field work 2013)

A= Open water bodies were absent in the northern and central area of BP1. F= superficial pools with sedimentation process in *Sphagnum* dominated raised mires in the site BP2. C= oligotrophic lagoon at mire BP4. D= Lagoon drainage and its percolation mire dominated by sedges and dead trees. E= channel presenting forest-covered *Sphagnum*-*Carex* hummocks. F= the channel drains subterraneously in the mire BP3.

In Fig. 68, in addition to the account of the main variables explained below, the mires are described according to their dominant landscape. As mentioned before, BP1 presented a mixed structure, where both types of *Sphagnum* raised bogs and cushion plants blankets bogs, are spatially associated. Additionally, BP1 presented along its southern flank a higher abundance of bogs colonized by *Carex* species than in the northern flank. The mire BP2 replicates the structure and relation between *Sphagnum* bogs and cushion plants blankets found in the sites LR and QP. The mires BP3 and BP4 are almost exclusively dominated by cushion forming species. Furthermore, the mountainous mire BP4 presents a remnant lake, which is the evidence of its glacial and terrestrialization origin, the same as VO but exhibiting a pH-value significantly lower and a C/N ratio significantly higher than that site.

4.1.5.3 Stratigraphy

Fig. 68 shows the characteristic profiles of the mires BP1 to BP4 respectively. BP1_2 presented a superficial ombrogenic peat horizon under water changing conditions (hHw). This horizon lies above reduced horizons of geogenic peat (nHr), which consecutively lie on a deep horizon of medium sand under reductive conditions (fGr). In BP2_2 the horizons of ombrogenic peat extend down to 150 cmbs, lying on reduced horizons of geogenic peat (nHr), above a mineral layer of fine sand. In BP3_3 the frequency and thickness of horizons formed by geogenic peat is larger than in BP2_2, but the mineral parent material (fine sand) is the same. A significant difference was observed in BP4, where the peat horizons are lying above a relict and reduced horizon of organic gyttja (rFr), the same as in the sites QP3 and VO. The mineral parent materials underlying the mires of BP were composed of different sized sands mixed with loamy materials. In Addition, the core sample exposed in Fig. 69 shows, from left to right, the types and order of the substrate in the upper 50 cmbs at mire BP4_2. Cushion plants peat with a degree of peat decomposition H3 is present in the first 12 cmbs, and with H5 from 12 to 30 cmbs. Amorphous peat with bleached bands due to variations in the depth of the groundwater table is present down to 30 cmbs. Sites in the low valleys (BP1 and BP2) were particularly dominated by loamy coarse sand (Fig. 70, picture A), medium sand and fine sand; while in the mountainous mires BP3 and BP4 the dominant underlying mineral material were fine sand (Fig. 70, picture B) and coarse sand.

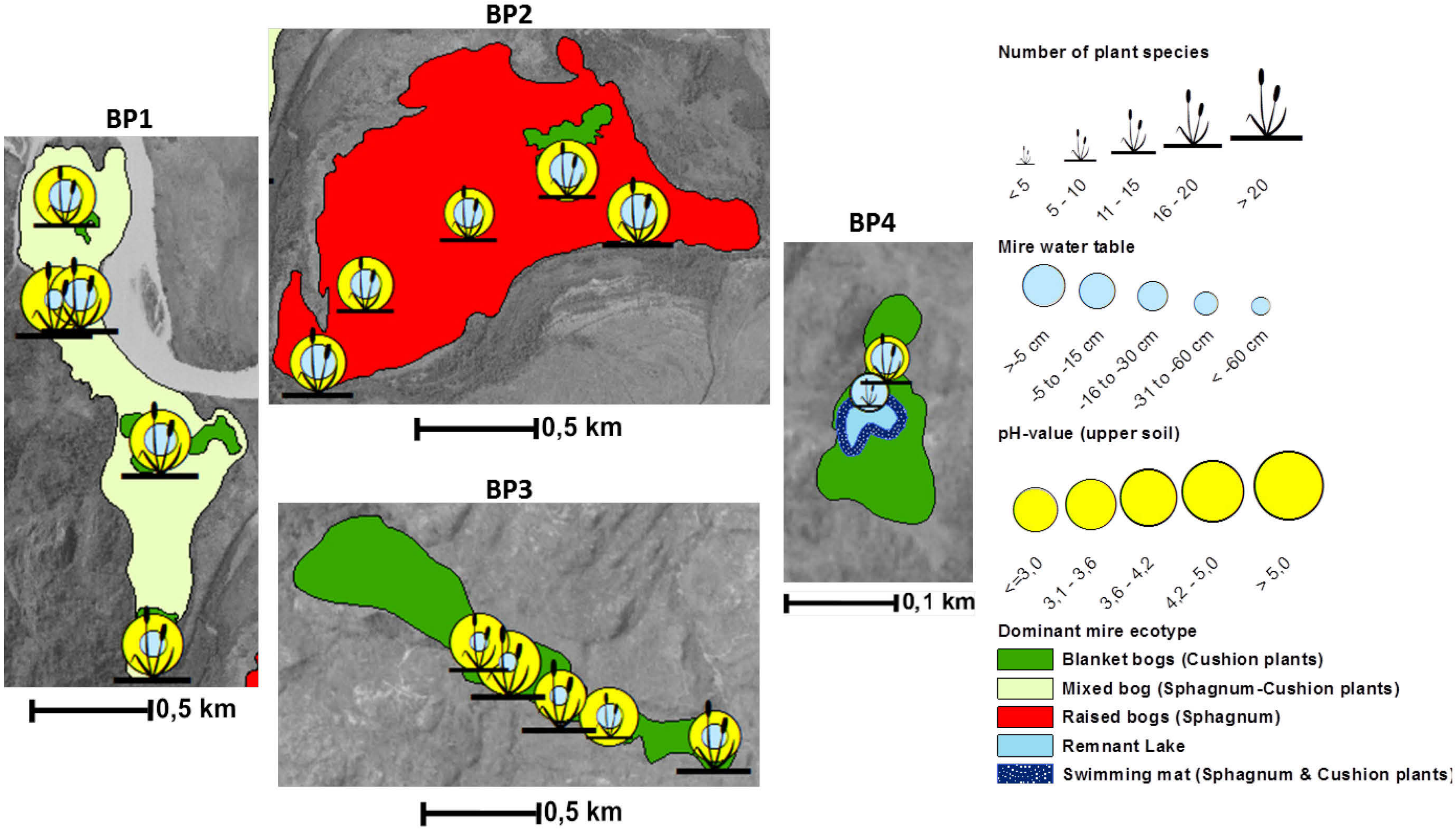


Fig. 68: Simplified overview of the mire water level, pH-value, number of plant species and dominant landscape in sites BP (pictures mod. from SAF)

Tab. 18: Horizon and substrate properties of characteristic soil profiles of sites BP

	From (cmbs)	To (cmbs)	*Horizon	*Substrate	DD	Colour (Munsell)	**pH1	**pH2	Roots
BP1_2	18	54	hHw	Hoas	3	5YR2.5/2	4.0	4.1	Rg4
	54	63	nHr	Ha	9	7.5YR2.5/3	4.0	3.9	R0
	63	68	nHr	Ha	9	2.5YR2.5/2	4.0	4.0	R0
	68	74	nHr	Ha	9	5YR3/2	3.8	3.8	R0
	74	85	hHr	Hhsy	7	2.5YR2.5/2	4.0	3.9	R0
	85	92	nHr	Hnr	4	7.5YR2.5/2	4.2	4.3	R0
	92	105	nHr	Hnr	4	7.5YR2.5/3	4.3	4.3	R0
	105	116	nHr	Ha	9	10YR3/2	4.5	4.5	R0
	116	120	nHr	Ha	10	10YR3/2	4.5	4.5	R0
	120	131	nHr	Ha	9	10YR3/2	4.5	4.6	R0
	131	140	fGr	mS	9	2.5Y3/3	4.4	4.2	R0
BP2_2	0	42	hHw	Hhsy	2	10YR5/6	4.5	4.5	R0
	42	52	hHr	Hhsy	3	10YR4/4	4.7	4.7	R0
	52	100	hHr	Hhsy	4	10YR3/4	4.4	4.5	R0
	100	108	hHr	Hhsy	3	10YR3/6	4.2	4.2	R0
	108	150	hHr	Hhsy	4	7.5YR4/6	4.8	4.7	R0
	150	199	nHr	Hnr	4	10YR3/3	4.2	4.2	R0
	199	210	nHr	Hnr	7	10YR3/2	4.4	4.3	R0
	210	252	fGr	fS	-	2.5Y4/2	5.0	5.1	R0
BP3_3	0	12	hHw	Hoas	9	2.5YR2.5/1	3.3	3.3	Rg5
	12	38	nHr	Hnr	4	2.5YR2.5/1	4.2	4.2	R0
	38	65	nHr	Hnr	8	7.5YR2.5/2	4.1	4.1	R0
	65	77	nHr	Ha	9	7.5YR2.5/3	4.0	4.1	R0
	77	90	nHr	Hnr	6	10YR2/2	4.9	4.9	R0
	90	100	nHr	Hnr	6	10YR3/2	4.8	4.8	R0
	100	135	nHr	Ha	10	7.5YR2.5/2	4.6	4.5	R0
	135	150	fGr	fS	6	2.5YR2.5/1	4.7	4.6	R0
BP4_2	0	41	hHr	Hoas	9	7.5YR2.5/2	3.9	4.0	Rg5
	41	48	nHr	Hnr	4	7.5YR2.5/3	3.9	3.8	R3
	48	166	nHr	Ha	9	5YR3/2	3.9	4.0	R2
	166	215	nHr	Hnr	8	10YR3/1	3.9	4.1	R0
	215	245	hHr	Hhi-Hnr	6	10YR3/1	4.2	4.2	R0
	245	320	nHr	Hnr	6	10YR3/2	4.7	4.6	R0
	320	340	rFr	Fhh	-	10YR3/6	5.1	5.1	R0

*hHw= horizon of ombrogenic peat under water fluctuation. nHw= horizon of geogenic peat under water fluctuation. hHr= horizon of ombrogenic peat under reduction. nHr= horizon of geogenic peat under reduction. fGr= fossil mineral horizon under reduction. rFr= relict horizon of lacustrine sediments under reduction. Hhsy= *Sphagnum magellanicum* peat. Ha= amorphous peat. Hoas= cushion plants peat. Hhi= ericaceae peat. Fhh= organic gyttja. mS= medium sand. fS= fine sand. H_20= water. **pH1= field and pH2= laboratory measurements.

Fig. 69: Core sample in the upper 50 cmbs of the profile BP4_2 (Rodríguez, field work 2013)

In the figure, the vital primary roots of cushion plants dominate until 12 cmbs, while their secondary roots extend longer (in this profile until 90 cmbs.). Cushion plants peat starts at 12 cmbs (H7) until 17 cmbs. The following visible horizon is composed of amorphous material, where Cyperaceae and Ericaceae plant remains were found. Additionally, the bleached bands visible between the depth 33 and 40, seems to be the prints of an old stand of the mire main water table.

A specific characteristic of mire BP4 was its terrestrialization origin, evidenced by a horizon of organic gyttja lying direct above the coarse sand parent material (Fig. 70, picture C). The mires BP1 and BP2 presented mostly reductive conditions at an average of 21 cmbs, with a maximum of 41 cmbs and a minimum of 12 cmbs. In comparison, in the mountainous mires BP3 and BP4, the mire water tables presented a higher intra and inter mire variation. Oxidized and reduced horizons were both present at site BP3, while horizons in the site BP4 were all under reduced conditions. Organic horizons reached a maximal depth of 324 cmbs and varied widely in their composition and thickness (Fig. 71). The largest organic horizon was observed in the profile BP4_2. This was composed of amorphous peat, reaching a maximal thickness of 118 cm and a maximal depth of 166 cmbs. The mire BP1 presented a high component of amorphous material, indicating mineralization processes, which could be the evidence of a changing water table or of a decomposition accelerated by nutrient inputs coming from the adjacent hills. In comparison, the site BP2 presents a higher mire water table, less proximity to hills and thus less sources of mineral enrichment, which could be the explanation for a lower presence of amorphous material in its horizons. Nevertheless, the underlying substrates in BP2, were mostly formed by radicels peat with a >H4 degree of peat decomposition, by which it can be inferred that the formation of the site was affected by changing water tables and increasing rainfall and temperatures, with these last two being the dominant in northern Patagonia since the Holocene period (Glasser et al. 2004; Abarzúa et al. 2004; Aravena et al. 2009; Siani et al. 2010). As result, the rainwater avoided the peat aeration, and delayed typical possible mineralization processes via nutrient enrichments derived from groundwater movements.

A

B

C

A=coarse sand with oxidation signs under Sphagnum peat horizons at the mire BP1. B= medium sand in the mineral parent material of the mire BP2. C= limit between an organic gyttja horizon and the fine to medium sand underneath layer in the mire BP4.

Fig. 70: Geological settings characterizing the site BP (Rodríguez, field work 2013)

The origin of the mire BP4 in a elevated area of the adjacent mountains, has its explanation in the beginning of the last glacial retreat. Since that period, fragments of ice from the glaciers remain anchored in the mountainous areas, melting and forming small lakes. These small lakes got warmer, received precipitation and became terrestrialized during the Holocene. Depending on their position in the mountainous relief and in the surrounding landscape, mires forming from terrestrialization lakes receive more or less input of mineral enriched water. In the case of coastal mires the rainfall is the main hydrological compound, beyond the old melted glacial water. This is consistent with studies about the regional climate history carried out by Heusser (1995), who reported that since the late Holocene, the landscape in Patagonia has been more influenced by precipitation than by glacial processes. This is the case of BP4 (Fig. 71), which, despite its terrestrialization, presented upper soil horizons under strong acid-oligotrophic conditions. On the other hand, BP3 formed from the percolation water coming from the surrounding hills but nowadays it is widely influenced by rainfall, by which its dominant upper soil conditions are strong acid-mesotrophic.

In BP eight main substrate types were detected (Tab. 19). The most frequent was amorphous peat, present in 41 horizons. Its dissemination is higher in mires receiving flow-through enriched water (BP1 and BP3) which, associated with the detected strongly acidic to weakly acidic pH-values, allows for the inference of an origin defined by aeration and by chemical acceleration via nutritive mineral and organic inputs. The distribution of amorphous peat reaches a wide spectrum of depths and thickness. The same happens with radicels peat, which was the second most common substrate reaching the maximal depth (320 cmbs). It was particularly disseminated in BP2 and BP3 and presented a wide spectrum of decomposition degrees. *Sphagnum magellanicum* peat was the third most frequent in the site, being observed in 19 horizons. *Sp. magellanicum* peat presented very similar conditions and association to Radicels peat, which was also observed in the live vegetation layer, where *C. magellanica, Sch. nigricans* and *H. comosum* practically occupied the surface of hummocks and cushions of *Sp. magellanicum* mosses. But the depth spectrum of *Sp. magellanicum* peat was more superficial than that of radicels peat, by which it can be inferred *Carex* plants developed before than *Sphagnum m*osses in the site. Cushion plants, Ericaceae and *Oreobolus* peat followed to the aforementioned substrate types. The hydraulic conductivity observed for cushion plants peat in the sites BP3 and BP4 presented a higher velocity (average of 1.5 cm/sec for the profiles BP3_1=1.5 cm/sec and BP4_2=2 cm sec^{-1}), than that detected in *Sphagnum* peat for the sites BP1 and BP2 (average of 0.8 cm sec^{-1} for the profiles BP1_3=0.9 and BP2_2=0.6). This behaviour replicates the results obtained in QP and LR, by which the tendency is that sites dominated by a landscape of raised mires of *Sphagnum* mosses forming bogs should in general present a lower hydraulic conductivity than sites dominated by raised mires of cushion plants forming blankets. Another peat type found in the area was *Sp. fimbriatum,* which again was found as a bordering species, in this case of the mire BP2, confirming a tendency to occupy areas where nutrient inputs occur. A last substrate was also found which was organic gyttja, detected forming a massive horizon in the mire BP4. This substrate, an indicator of sedimentation processes in standing water bodies, presented a weakly acidic pH-value of 5.1 which was the highest in the site BP.

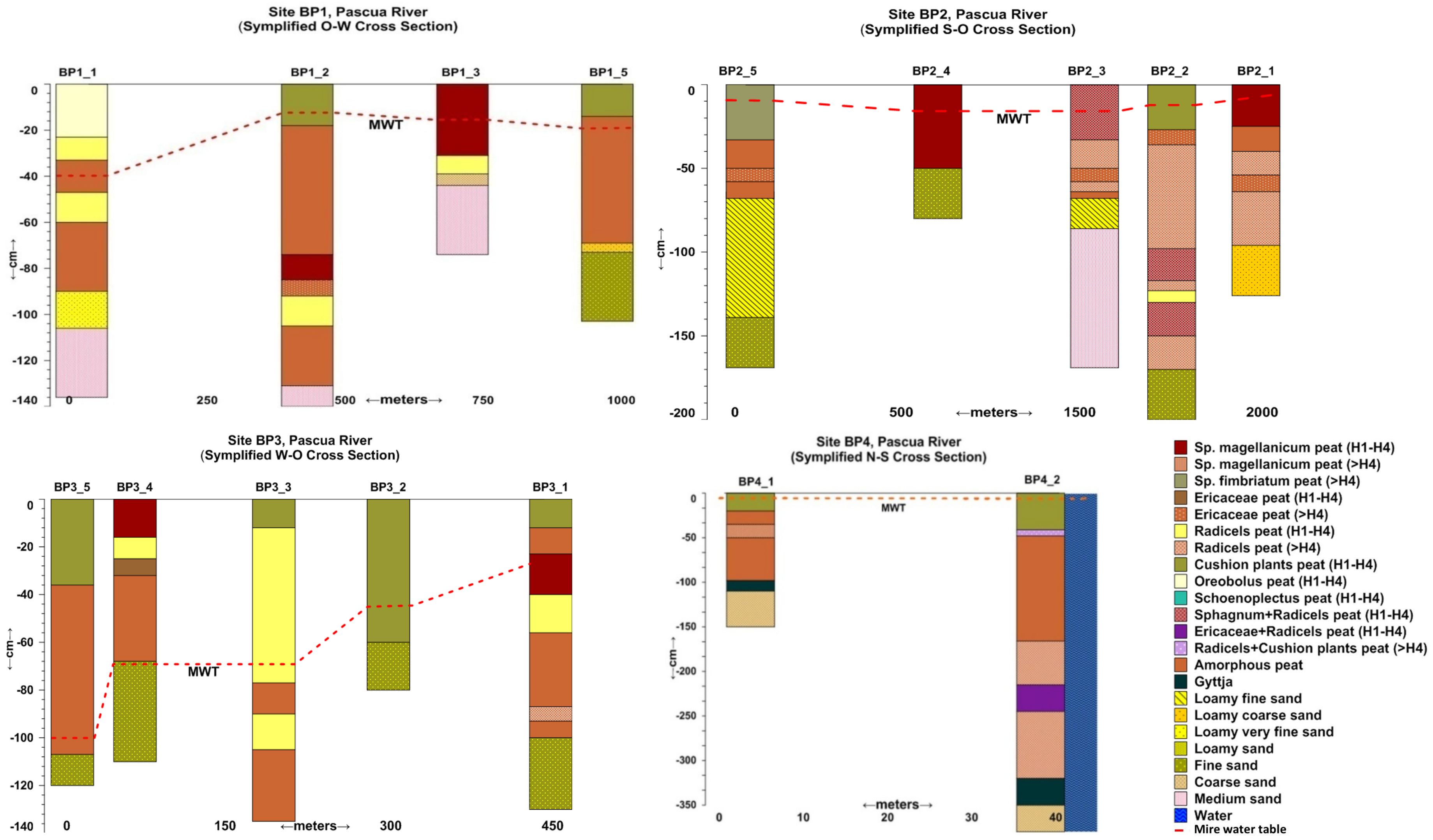


Fig. 71: Simplified cross sections for selected profiles of the mires of sites BP

Tab. 19: Organic substrate types found in the sites BP with frequency (n) and spectrums of depth, thickness, degree of peat decomposition and pH-value (field and laboratory average)

Substrate type	n				Total n	Depth (cmbs)	Thickness (cm)	DD	pH (Avg)
	BP1	BP2	BP3	BP4					
Sp. magellanicum peat	3	8	7	1	19	0 to 150	5 to 48	H2 to H7	3.3 to 4.8
Sp. fimbriatum peat	1	1	0	0	1	7 to 33	26	H7	4.5
Radicels peat	11	11	10	3	30	0 to 320	5 to 75	H2 to H8	3.3 to 4.9
Ericaceae peat	2	2	1	1	4	25 to 245	7 to 30	H3 to H8	4.1 to 4.5
Cushion plants peat	1	1	2	2	8	0 to 54	12 to 41	H3 to H9	3.4 to 4.5
Oreobolus peat	0	0	0	0	2	0 to 23	10 to 23	H2 to H3	3.7 to 4.0
Amorphous Peat	12	12	11	3	41	8 to 166	3 to 118	=>H9	3.7 to 5.1
Organic Gyttja	0	0	0	1	1	98 to 110	12	-	5.1

4.1.6 Discussion

This chapter explains some of the most important factors determining the landscape settings, vegetation, ecology, hydrology, stratigraphy and substrate composition of ten mires examined in the sites LV, LR, VO, QP and BP. The most representative and common geomorphic units where the examined mires were detected are intermountain depressions, slopes and at the bottom of slopes, valley basins, valley edges, flood plains and fluvial terraces. Additionally, the most representative water sources influencing the examined mires are rain water, small ponds, streams, lagoons, lakes, valley rivers, pools of standing water and the mire water table itself. Particularly this last, the mire water table, seems to be the determiner of the vegetation diversity in all the examined sites, influencing even more than the pH-value, which, as commented before, does not vary significantly from site to site. Furthermore, the mire water table and the landscape morphology seem to be the drivers of physiognomic adaptive behaviours in the vegetation of the examined mires (e.g. LV and LR).

Regarding the depth of the examined mires, a median of 76 ±74 cmbs was observed. The maximal depths were observed in the sites VO (417 cmbs) and LR (350 cmbs), while the most superficial sites were QP2 (80 cmbs), BP1 (131 cmbs) and BP3 (150 cmbs). The detected substrates forming the investigated mire soils corroborate that the sites were originated by terrestrialization (VO and BP4) or paludification (LV, LR, QP1, QP2, BP1, BP2 and BP3); and in some cases by both processes at different times (QP3). These processes are related to hydrological changes derived from the last glacial retreat, during which the landscape water level increased considerably. On the other hand, and according to the mentioned literature, during the Holocene heavy rainfall characterized the region. Despite this, considering the finding of large horizons composed of radicels and amorphous peat substrates (the first formed under low water tables, the second under aeration or oxidation) in the lower horizons of the examined sites, it was corroborated that several periods of dryness have occurred in between. The examined mires were located at an average altitude of 18 m a.s.l. in the river basin areas and of 201 m a.s.l. in the mountainous areas. Their distance from the ocean varied from 2 to 64 km. On the other hand, 63% of the examined sites presented a north related exposure (N=9%, NE=32% and NW=22% of the examined sites). Also according to the data collected about the inclination of these ecosystems, they are characterized by a dominant flat morphology (68% of the profiles were located in areas with no or <3.5% inclination), specially associated with deltas and river basin reliefs (LV, LR, QP3, BP2). This changes when mires are located in mountainous areas (QP1, QP2, BP1, BP3), where a light to strong inclination was detected (from 3.5 to even 27%). Regarding the ecological properties of the studied ecosystems along the Baker and Pascua rivers, raised morphologies and acid-oligotrophic ecological conditions were mostly observed, which are distinctive of the local precipitation rate (e.g. sites LV, LR, QP3, BP2). Additionally, the relief was a factor of differentiation in the mire formation. When the relief is inclined, mires adopt a sloping morphology (e.g. sites QP1, QP2, BP1 and BP3), producing a new hydrological constellation, where internal percolations take place (e.g. sites QP1 and BP3) or inclusive flow-through runoffs (e.g. site BP1). Mires in sloping areas tend to present mesotrophic conditions on the downward slope (e.g. sites QP1 and BP1), which seems to be caused by the percolating/flooding water producing erosion through the slope respectively. Both dynamics may liberate nutrients and organic compounds, influencing the chemical conditions and trophic levels of the peaty soils on the downward slope. Conversely, in mountainous areas, mires originated by terrestrialization in intermountain depressions were detected. In mountainous areas where precipitation tends to decrease and runoffs become the main water sources, mires turn definely mesotrophic, exhibiting a higher nutrient availability than ecosystems fed exclusively by rainfall (e.g. site VO). According to these main characteristics in the morphology and hydrology observed in the ten examined sites, a first differentiation in five Hydrogeomorphic Mire Types can be proposed for the Baker and Pascua Rivers: Raised bogs (formed in flat reliefs, fed only by rain water), Sloping bogs (formed on slopes, fed by both rain water and surface runoffs), Flow-through bogs (Sloping mires channelized, fed by both rain water and lateral percolation), Terrestrialization bogs (formed from old relict glacial lakes in elevated areas, fed by rain water, by percolation and presenting a superficial runoff through the mire) and Terrestrialization fens (formed from a remnant lake in landscape depressions, fed mostly by surface runoffs and percolating groundwater). These archetypical Hydrogeomorphic Mires will be explained in detail in chapter 4.4.2. A second differentiation can be made deriving from the specific physiognomies and plant communities found in the different sites, under which eight main Mire Ecotypes can be discriminated: raised bogs, flooded hummocks, forest-covered hummocks, blanket bogs, mixed bogs, blanket fens, oligotrophic floating mats and mesotrophic floating mats. These types are associated with particular vegetation communities. Raised bogs, flooded hummocks and forest-covered hummocks are dominated by *Sp. magellanicum* mosses. They are archetypal in continental areas or in coastal areas protected from the oceanic wind; while mostly blanket bogs dominated by cushion plants are the distinctive in coastal areas. In mountainous areas close to the coast, although high precipitation dominates, runoffs become nutrient rich due to their contact with the surrounding relief, by which mires in those areas are also fed by nutrient enriched waters. There, the ecological type mixed bog formed by *Sphagnum* mosses and the cushion plants *Astelia pumila* and *Donatia fascicularis* appears. Also in mountainous areas, some mires located in depressions present small open waters, where these mentioned plants develop oligotrophic floating mats as a strategy to occupy the area (i.e. to "terrestrialize" the area), as is the case of the site BP4. In comparison, in mountainous areas far away from the coast, precipitation decreases and a higher nutrient availability due to mineralized water inputs allows vascular plants to grow, forming blanket fens of sedges, rushes, reeds and brown mosses (e.g. VO). Also in mires like VO, if open waters are present, the aforementioned plants develop mesotrophic floating mats as part of their occupation strategy, accelerating the terrestrialization of the lake and turning it into a mire. These archetypical Mire Ecotypes are detailed in chapter 4.4.3.

Lastly but no less important, at a specific level, it was corroborated that cushion plants are important drivers of the ecological conditions in the mires of Aysén. As was mentioned before, this is particularly the case for *Astelia pumila*, which affects enormously the superficial and subterranean ecological conditions of the sites it colonizes. In the study sites it was observed that cushion plants retard the drainage of the water accumulated after rain events on the mire surface, driving sedimentation and erosion processes, which are intensified by the action of the strong Patagonian winds. On the other hand, subterraneously, the nutrient intake strategy of *Astelia pumila*, is based on a "self made" decomposition of the organic material surrounding its roots. In this chapter it was corroborated for Aysén the hypothesis developed by Fritz (2012), Teltewskaja (2010), Abel (2009) and Kleinebecker (2007) for mires in Magallanes and Tierra del Fuego, about the action of salt cations, which increase the nutrient conditions of the upper soil, favouring the settlement of *A. pumila* to colonize and displace coastal *Sp. magellanicum* dominated mire landscapes. It was also found that the intensity of the exposure to the oceanic salt enriched wind or westerlies further determines the permanency of the raised mires of *Sphagnum* mosses forming bogs (e.g. in areas close to the coast but protected from the wind this exposure is lower, as in LR) or the development of raised mires of cushion plants forming blankets and its dominance over the former (e.g. BP3 and BP4, whose location at 166 m a.s.l. and NW exposure). Aysén mire landscapes present an interesting and pristine diversity. Nevertheless, cushion plants, the new inhabitants, are widely disseminated and strong colonizers, and as was warned by Fritz (2012) regarding the mire landscapes of Tierra del Fuego, their settlement is being favoured by nitrogen contributing activities. In Aysén, nitrogen contributing activities are related to forest burning, livestock expansion and to the construction of large infrastructures producing green house gases (roads and dams). At a global level, the increase of the atmospheric contamination is another accelerator of this ecological change. All these are factors contributing nitrogen and other nutrients that may affect the current soil balance in Patagonian acid-oligotrophic mires. Thus, it is to be expected, that in the next century, the still existing coastal mire landscape dominated by raised bogs of *Sp. magellanicum* mosses, will turn into blanket bogs formed by cushion plants and other vascular species.

4.2 Overview of the organic substrates types in the mires of Aysén and their physical and chemical characteristics

In the last 15.000 years, undisturbed mire ecosystems have captured, in the organic substrates forming their soils, more carbon dioxide from the atmosphere than is currently captured in the world's forests (Loisel and Yu, 2013). This quantity of carbon almost equals the carbon fixed in the whole planetary biomass (Joosten and Clarke, 2002). Mire soils are the most important reservoirs of water and fertile soils in dry areas of the world (Grobler et al., 2004). Additionally, in sub-alpine areas, their huge water absorbing capacity and slow hydraulic conductivity is crucial for the moderation of runoffs, and for the prevention of erosion and eutrophication processes, that otherwise could affect low valleys and aquifers (Hope et al., 2009). Mire soils are also temperature regulators, allowing seeds and plants to survive during hard winters and summers. The ecological settings of mire soils, e.g. their lower pH-values and trophic levels, provide a niche where specific species can live, increasing the biodiversity of our planet. Thus, undisturbed peat soils are an invaluable source of knowledge for the conduction of conservation programs and restoration processes in mires already destroyed or affected. All these functions are associated with the physical and chemical characteristics of the organic substrates forming mire soils. As was exposed in Tab. 9, in this study 81 profiles were examined, whereby a universe of 470 horizons was diagnosed: 448 formed by peat and 32 by organic gyttja. All horizons were sampled, whereby 470 substrates samples were collected. This chapter contributes information about the parameters mentioned above for eleven substrate types found in this study.

4.2.1 Depth to the surface

The median depth of the substrates in the sample universe (n=470) was 76 cmbs and varied particularly from type to type (Fig. 72). Regarding each substrate type, this presented a considerable homogeneity in their distribution along the different soil profiles. *Sp. fimbriatum* peat, *Schoenoplectus* peat, *Oreobolus* peat and cushion plants peat showed a superficial tendency occupying a median depth of 13 to 24 cmbs in the examined soil profiles, with standard deviations between 11 to 13 cmbs. *Sp. magellanicum* peat, amorphous peat, radicels peat and Ericaceae peat presented central depth tendencies with medians between 44 and 86 cmbs and standard deviations between 40 and 60 cmbs. Cypress wood peat and organic gyttja presented median depths of 215 and 263 cmbs, showing the higher standard deviations of the sample, with 107 and 140 cmbs respectively.

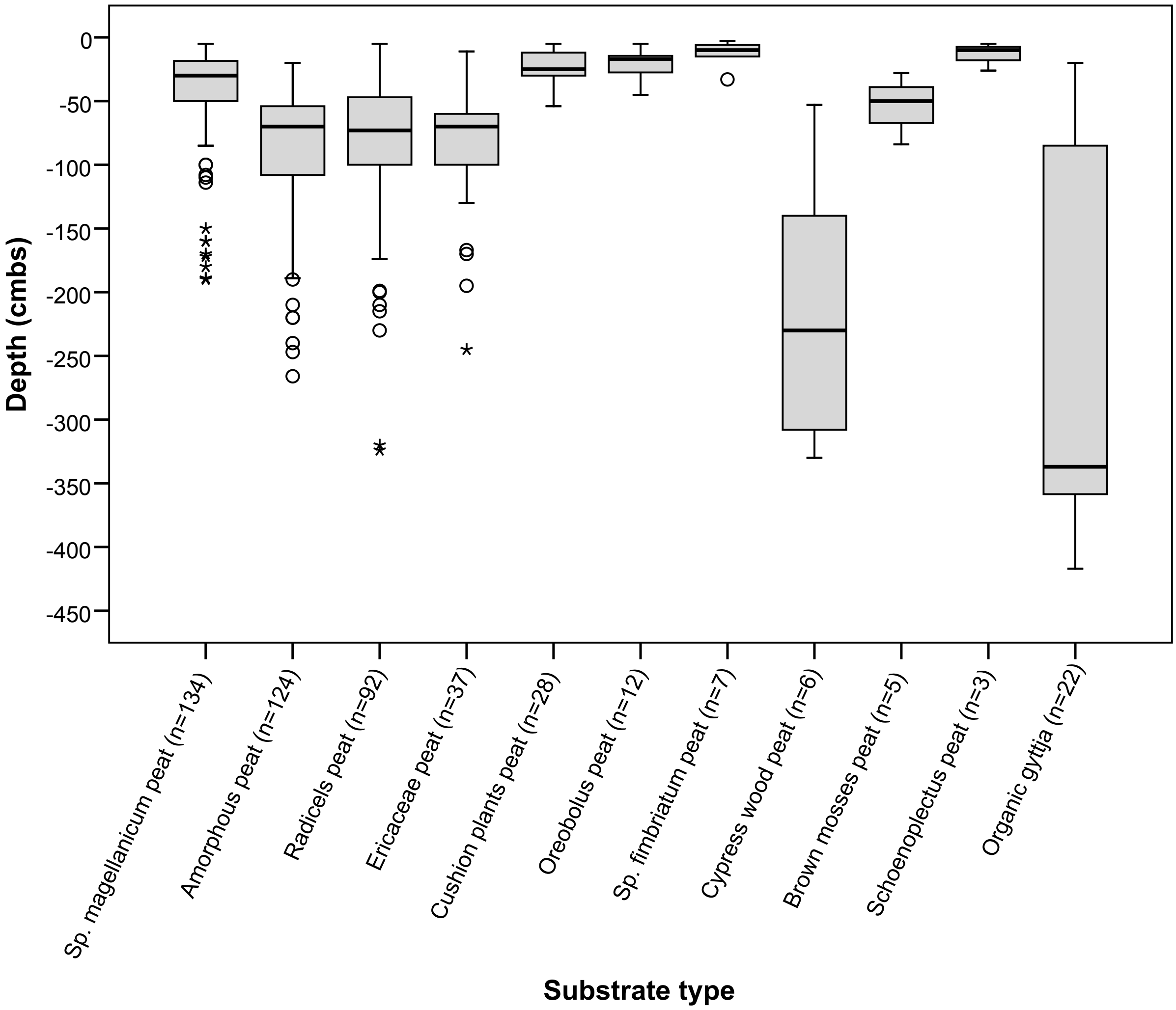


Fig. 72: Depth to the surface for all organic substrate types in the mires of Aysén (n=470)

4.2.2 Horizon-substrate combinations

Since the average mire water table was located at a depth of 22±20 cmbs, 77% of the substrates were located in horizons under reduced conditions (Fig. 73). Of these reduced horizons, 43% were composed of geogenic peat “nHr” and 35% by ombrogenic peat “hHr”. Another 18% of the samples were located in horizons directly influenced by the fluctuations of the mire water table and 11.5% of these water fluctuation horizons were composed of geogenic peat “nHw” and 6% by ombrogenic peat “hHw”. The remaining 5% of the samples –composed of organic gyttja- were located in fossil lake-ground horizons under reductive conditions “fFr”. No horizons deeply damaged by drainage, compaction or burn were detected. Nevertheless, 41 profiles (especially in the sites LV, LR and BP3) evidenced superficial damages due to fire (until 20 cmbs), while another 11 profiles evidenced damages due to both burning and cutting activities (QP1 and QP2).

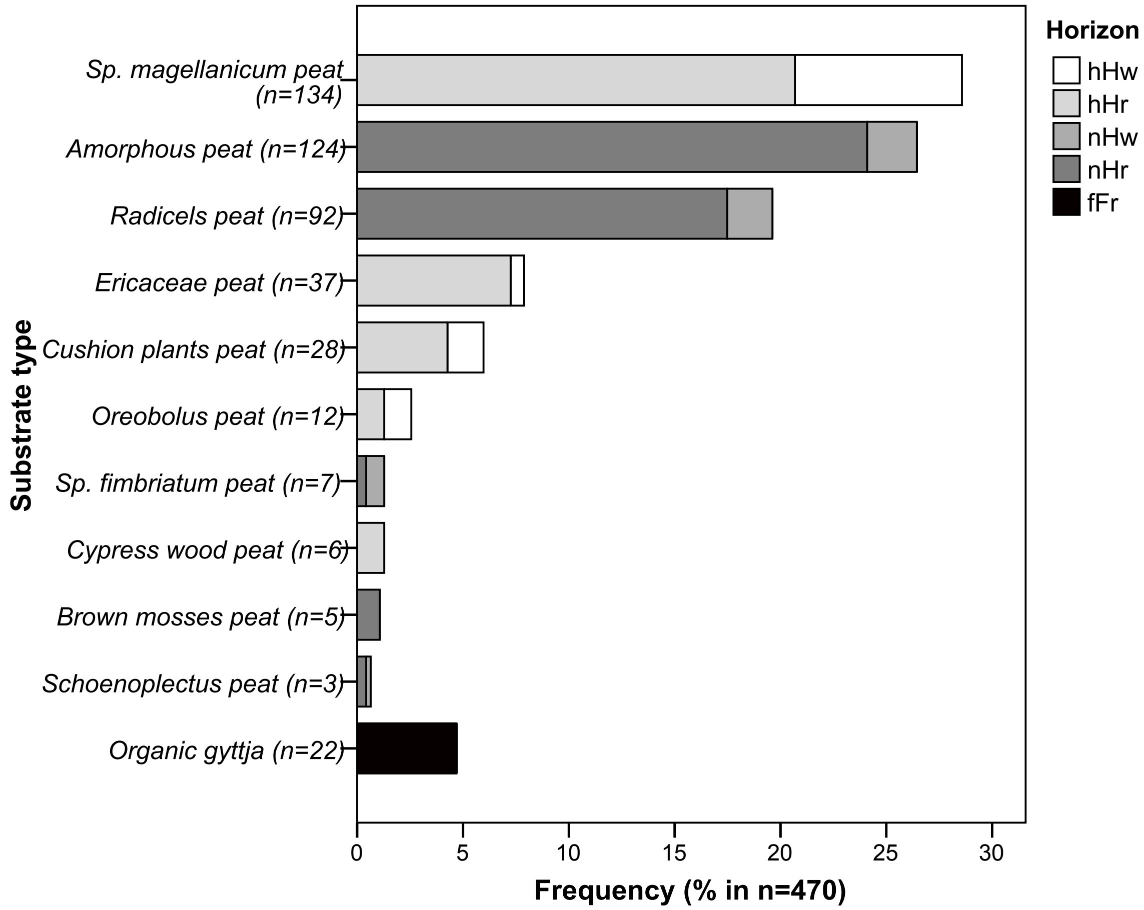


Fig. 73: Horizon substrate combinations and their frequency in the whole sample of organic substrate types. Classification after the KA 5 (AG Boden, 2005)

Abbreviations of horizon categories after the German Pedological Mapping Directive -KA 5- (AG Boden, 2005) are exposed on the sections 1.2.2.1 and 1.2.2.2 (Tab. 4 and Tab. 5).

4.2.3 Colour

As Fig. 74 shows, light brownish to reddish tones were the tendencies in the colour spectrum of *Sp. magellanicum* peat. Brownish, reddish, olive and yellowish tones were the colours dominating the amorphous and the radicels peats. Ericaceae peat, cushion plants peat and *Oreobolus* peat were dominated by all these colours in dark tones, but presented some incidental red tints. Whereas olive to grey yellowish tones were the tendency in *Sp. fimbriatum* peat, brown moss peat and *Schoenoplectus* peat, the organic gyttja substrate presented browny yellowish tones. Substrates with aboundant samples showed more variation in their colour (*Sp. magellanicum* peat, amorphous peat) whereby a particular colour dominance by substrate can not be assumed and only interpreted as colour tendency.

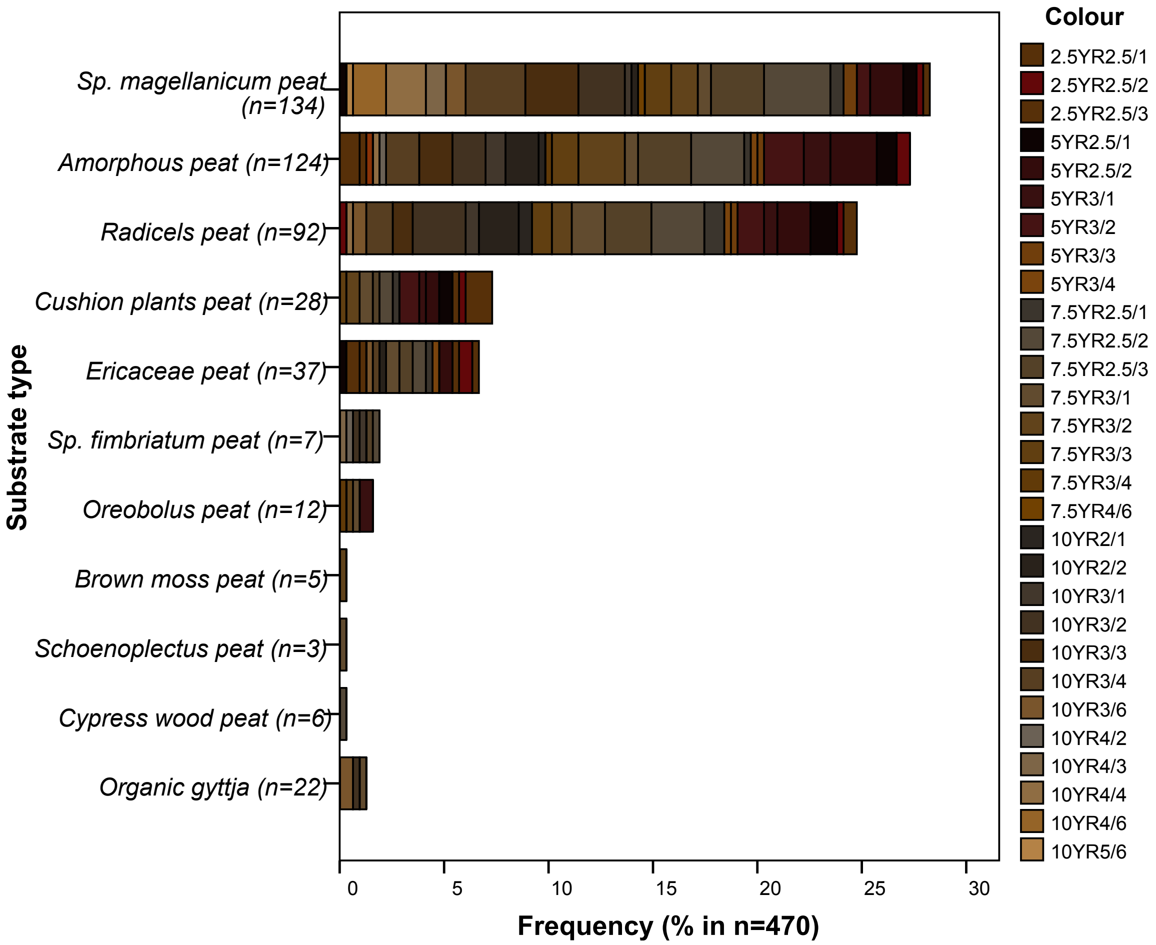


Fig. 74: Spectrum of colours observed in all organic substrates types. Categories according to the (Munsell © Color 1994)

*Due to technical limitations of the software SPSS, the colours visible in the graphic are only schematic and for acute comparisons the table detailing colour descriptions by peat type presented in Annex 4 must be used.

4.2.4 Degree of peat decomposition after the von Post field test procedure

The degree of peat decomposition according the (von Post, 1924) field test procedure was investigated for the universe of peat samples (n=448). The results (Fig. 75) show that 56% of the samples presented degrees of decomposition of H3 (29%) and H4 (27%). Another 30% presented degrees of decomposition of H9 (14%) and H10 (16%). The remaining 14% of the peat samples presented degrees of decomposition between H5 (2%), H6 (6%), H7 (4%) and H8 (2%). The substrates presenting the lower levels of decomposition (H3 to H4) were particularly *Sp. magellanicum* peat (95% of the samples from this substrate type) and Ericaceae peat (68% of the samples from this substrate type). On the other hand, 30% of the peat samples exhibited degrees of H9 to H10; being of course represented by the entity of samples of amorphous peat. Although the substrate radicels peat mainly presented a degree of decomposition of H3 to H4 (57% of the samples from this substrate type), this was the substrate exhibiting the widest dissemination, and cases of higher decomposition degrees were also detected.

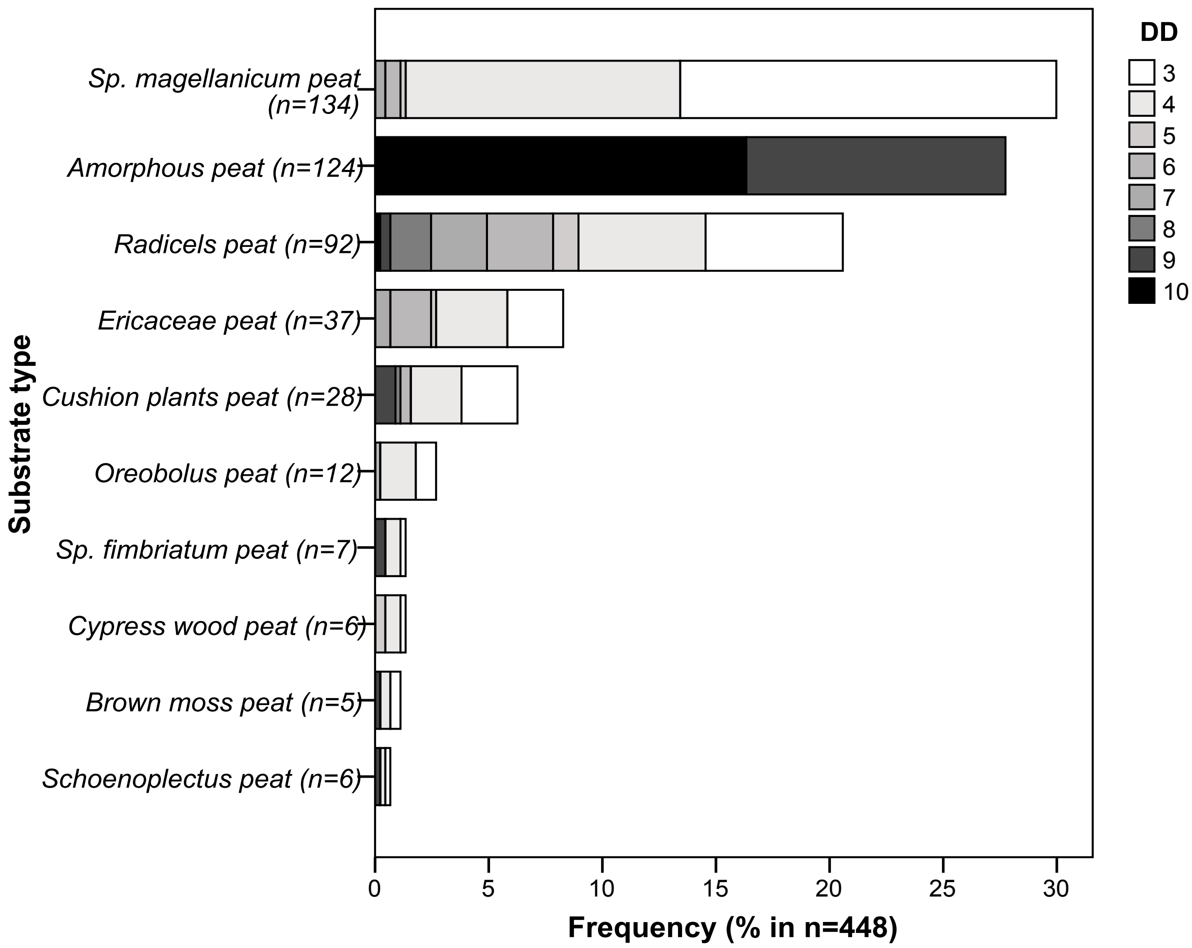


Fig. 75: Degree of peat decomposition detected in samples of peat substrates in Aysén. Categories after (von Post, 1924).

4.2.5 Bulk density

The average bulk density was 0.09 g cm^3. According to the results for all the substrates (Fig. 76), these can be separated into three groups. *Schoenoplectus* peat, *Sp. magellanicum* peat, cypress wood peat and Ericaceae peat presented medians <=0.07 g cm^3 belonging to the group with a low bulk density. Cushion plants peat, *Oreobolus* peat, radicels peat, *Sp. fimbriatum* peat, amorphous peat and brown moss peat presented medians between 0.09 to 0.11 g cm^3, being among those substrates with moderate bulk density. Whilst the substrate organic gyttja with a median >=20 g cm^3 is situated in the group of substrates with a high bulk density. All peat substrates showed a standard deviation of 0.01 g cm^3 in this variable, while for organic gyttja the value was 0.03 g cm^3. The lowest bulk density was observed in samples of *Sp. magellanicum* peat collected in the sites LR, LV and BP1, with values of 0.03; 0.04 and 0.05 g cm^3 respectively. The highest values were observed in samples of organic gyttja collected in the site VO, which exhibited a median 0.20 g cm^3.

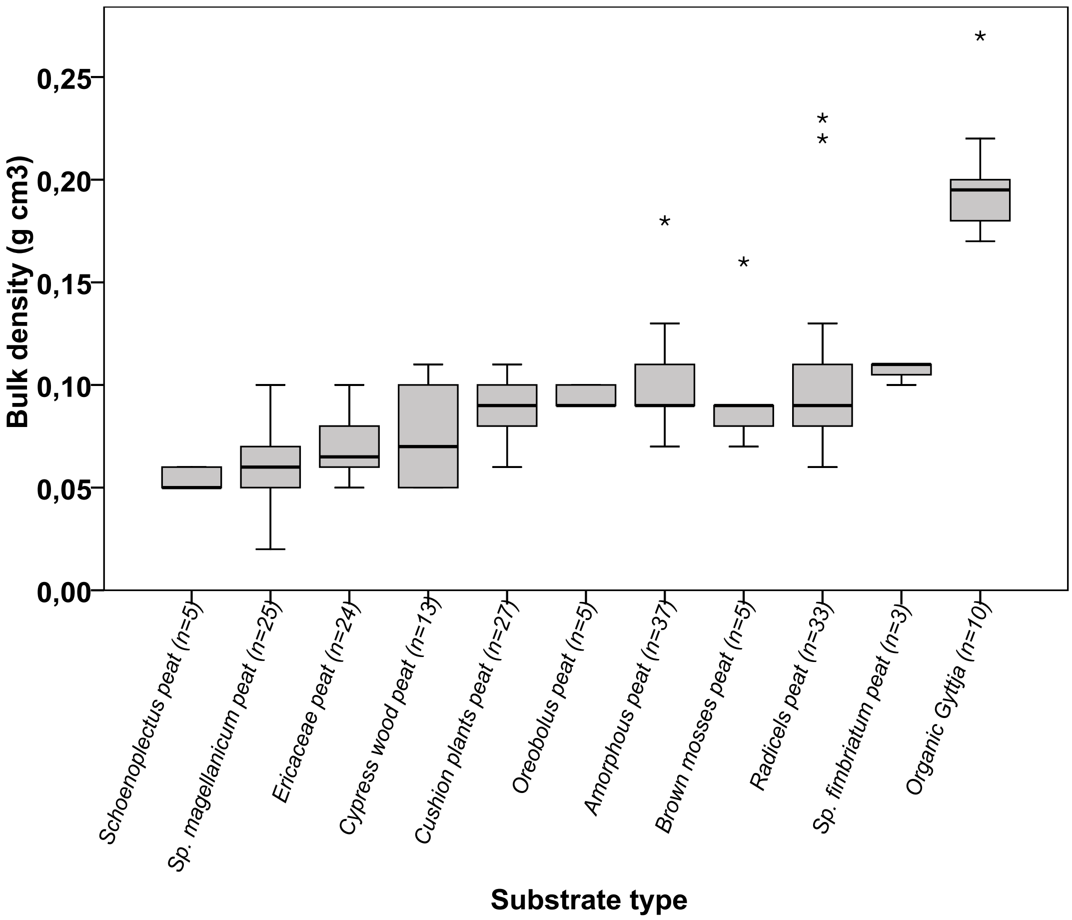


Fig. 76: Bulk density values for different organic substrate types of Aysén (n=189)

4.2.6 Water holding capacity of the substrate

The universal median for the water holding capacity of the substrates was 91% of the substrate volume at field capacity. The organic gyttja substrate exhibited the lowest median with only 80% of water holding capacity. Substrates following this water holding capacity were *Sp. fimbriatum* peat, amorphous peat and brown moss peat, with a median of 90%. Cypress wood peat, cushion plants peat and radicels peat presented a median of 91%. Peat types showing a higher water holding capacity were *Sp. magellanicum* peat, Ericaceae peat and *Oreobolus* peat, which presented a median of 93%, while *Schoenoplectus* peat presented the highest median with 95% of water in its fresh substrate volume. The universal standard deviation was 3.6%. Nevertheless, radicels peat and *Sp. magellanicum* peat presented the highest std. variations (4.2 and 4.4). On the contrary, Ericaceae peat and cushion plants peat with standard deviations of 1.1 and 0.8 presented the lowest variation. The lowest single value (79%) was observed in a sample of organic gyttja substrate extracted from the site VO, and the highest (98%) in a sample of radicels peat extracted in the mire BP3 (Fig. 77).

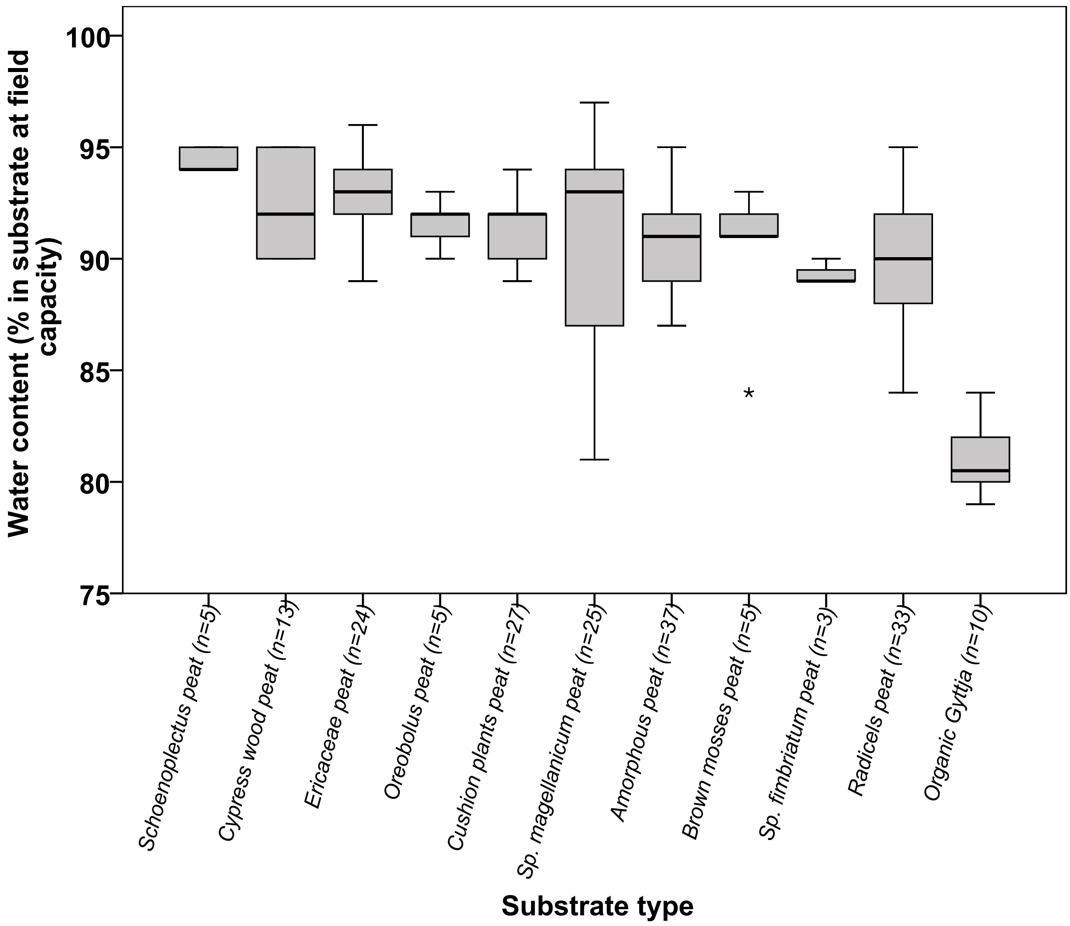


Fig. 77: Water holding capacity of all substrates at field capacity (n=189)

4.2.7 pH-value

Since the pH-value measured in the field almost equalled the values measured in the laboratory, the values used in this section are the field values (Fig. 78). The universal median (n= 470) reached a moderate acidic level after Succow und Joosten (2001) with 4.2±0.7. The lowest median presented a strongly acidic value, being observed in cushion plants peat, *Oreobolus* peat (both with 3.7) and *Sp. magellanicum* peat (3.9). The highest median presented weak acidic pH-value, being detected in the substrates brown moss peat (5.6). organic gyttja (5.4) and *Schoenoplectus* peat (5.3). The substrates presenting the lowest internal variations in their pH-value were *Oreobolus* peat (std. deviation ±0.2), cushion plants peat (std. deviation ±0.5), and Ericaceae peat (std. deviation ±0.5), while the substrates presenting the highest internal variations were brown moss peat (std. deviation ±0.1) and cypress wood peat (std. deviation ±0.9).

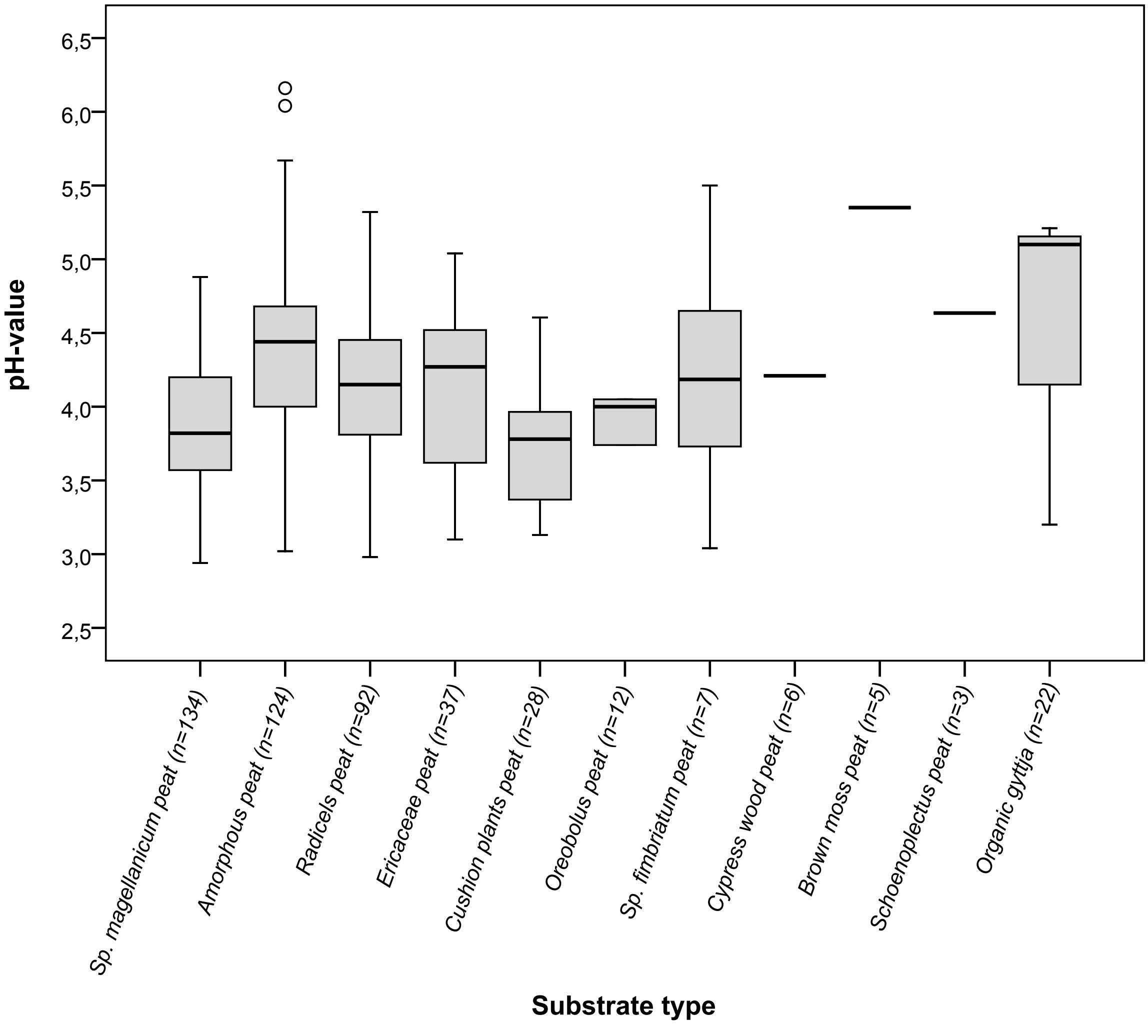


Fig. 78: pH-values for different organic substrate types of Aysén (n=470)

As observed in Fig. 79 the ombrogenic (LV, LR, QP1, QP2, QP3; BP1, BP2, BP3 and BP4) or geogenic nature (VO) of the different sites turns evident when grouping the medians of their pH-values. Thus a very light increment is observed in the medians according to the distance of the sites to the coast (e.g. the continental site LV, compared to the more maritime sites QP and BP), while a drastic increment is observed when the hydrological settings become mineralized and less influenced by rainfall (e.g site VO compared to all the other sites).

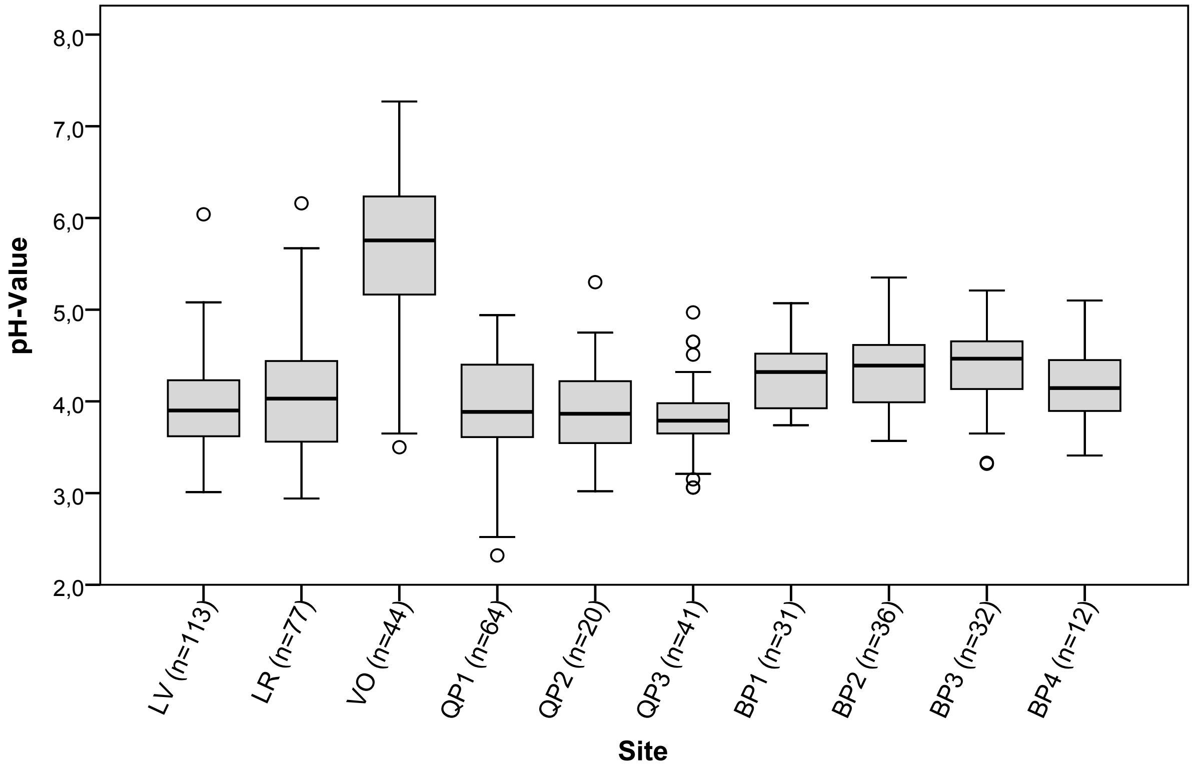


Fig. 79: pH-values interpreted by site, based on samples for different organic substrate types of Aysén (n=470)*

* Abbreviations of the sites are described in Tab. 7 after section 3.3.13

4.2.8 Organic carbon content and total carbon content (DM%)

The organic carbon -C_{org}- in the total dry matter (Fig. 80) presented a median of 46% for all peat samples, and 47% including the organic gyttja. Due to this minimal variation, the results are explained here for the universe of samples. The media varied between 26% and 54%, with the highest medians represented by ericaceae peat (54%), *Oreobolus* peat (52%) and radicels peat (51%). Substrates with the lower median were *Sp. fimbriatum* peat (26%) and brown moss peat (31%). These values are lower than the median of the organic gyttja substrate (40%). The lowest value was found in a sample of amorphous peat and the highest in a sample of radicels peat (14% and 57% respectively). Amorphous peat and cypress wood peat presented the highest variation (std. deviation of 16% and 24% respectively). The total carbon content exhibited a behaviour almost identical to the behaviour of the C_{org},, with median 48%±9.8%, oscillating from 28% (*Sp. fimbriatum* peat*)* to 55% (Ericaceae peat). The minimal value was found in a sample of amorphous peat (14%) and the highest in a sample of radicels peat (58%). Amorphous peat presented the highest standard deviation

(23%), what is explicable by the multifacetic location of this peat, which is exposed to aeration and mineralization when located on the surface; and on the contrary, enriched via percolation with fresh formed peat rich in C_{org} when located in underneath saturated layers. No correlation was found between the C_{org} and the depth (Pearson's correlation coefficient p=-0.07; Anova combined significance α=0.24), presenting the C_{org} a homogeneous distribution along the soil profiles, similar to the results found by León Valdebenito (2012) in the 40 cmbs of mires in Chiloé.

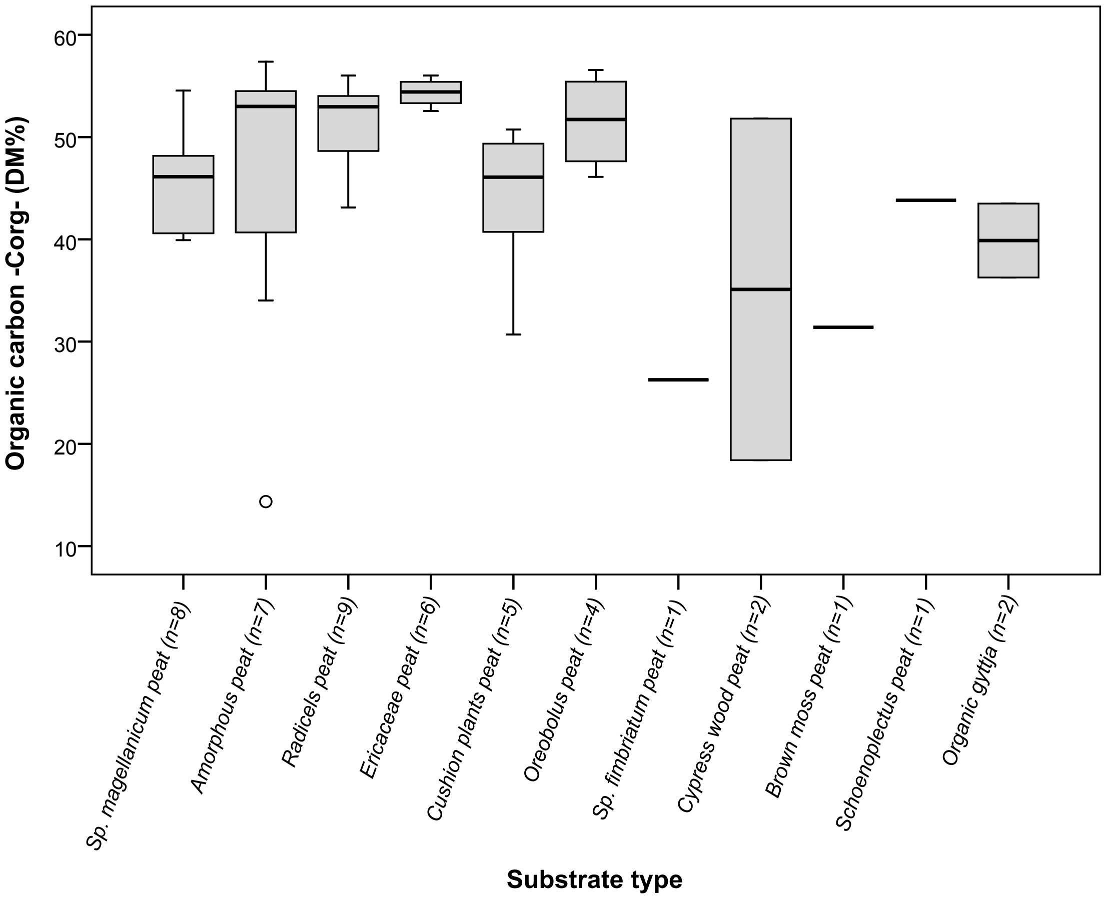
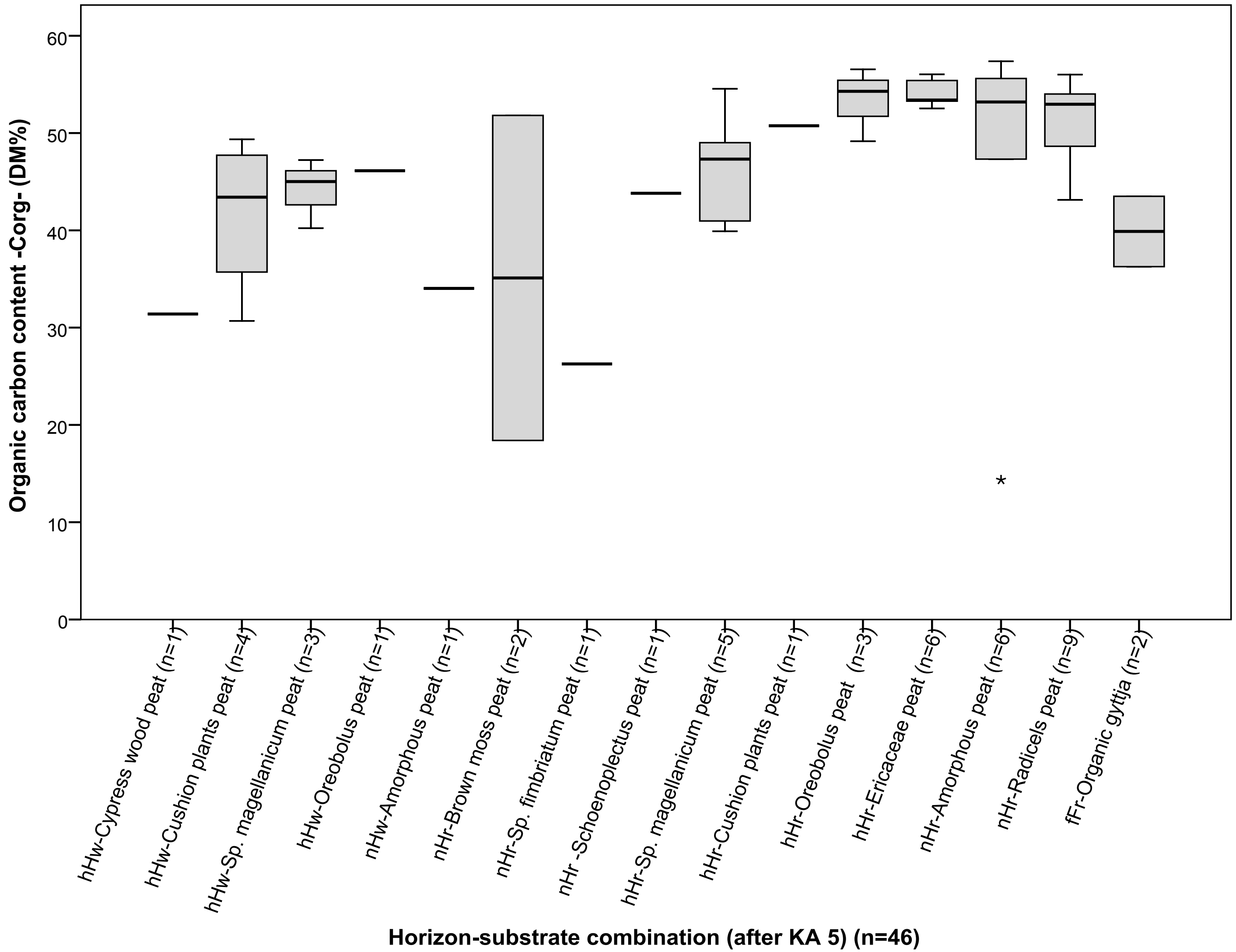


Fig. 80: Organic carbon content for different organic substrate types of Aysén (n=46)

Observing the horizon-substrate combinations -HSC- (Fig. 81), geogenic and ombrogenic peat located in horizons under reduction presented in general a higher C_{org} median (46%) than those located in horizons of water fluctuation (41%). In particular a high median was found in reduced horizons of Ericaceae peat (55%) and *Oreobolus* peat (54%), while the lower median was observed in a reduced horizon of *Sp. fimbriatum* peat. Interpreting these results for each site (Fig. 82), the highest C_{org} content was evidenced in the mires located in the central Pascua River: QP1, QP2 and QP3 with medians of 53%, 53% and 55% respectively. In the site VO the lowest median was detected with 35%.



*Sorted by ombrogenic to geogenic substrate types, from ascending medians from left to right, from horizons under fluctuation –hHw and nHw- to horizons under reduction –hHr and nHr. Abbreviations of horizon categories after the German Pedological Mapping Directive -KA 5- (AG Boden, 2005).

Fig. 81: Organic carbon content interpreted by horizon substrate combinations in mires of Aysén (n=46)

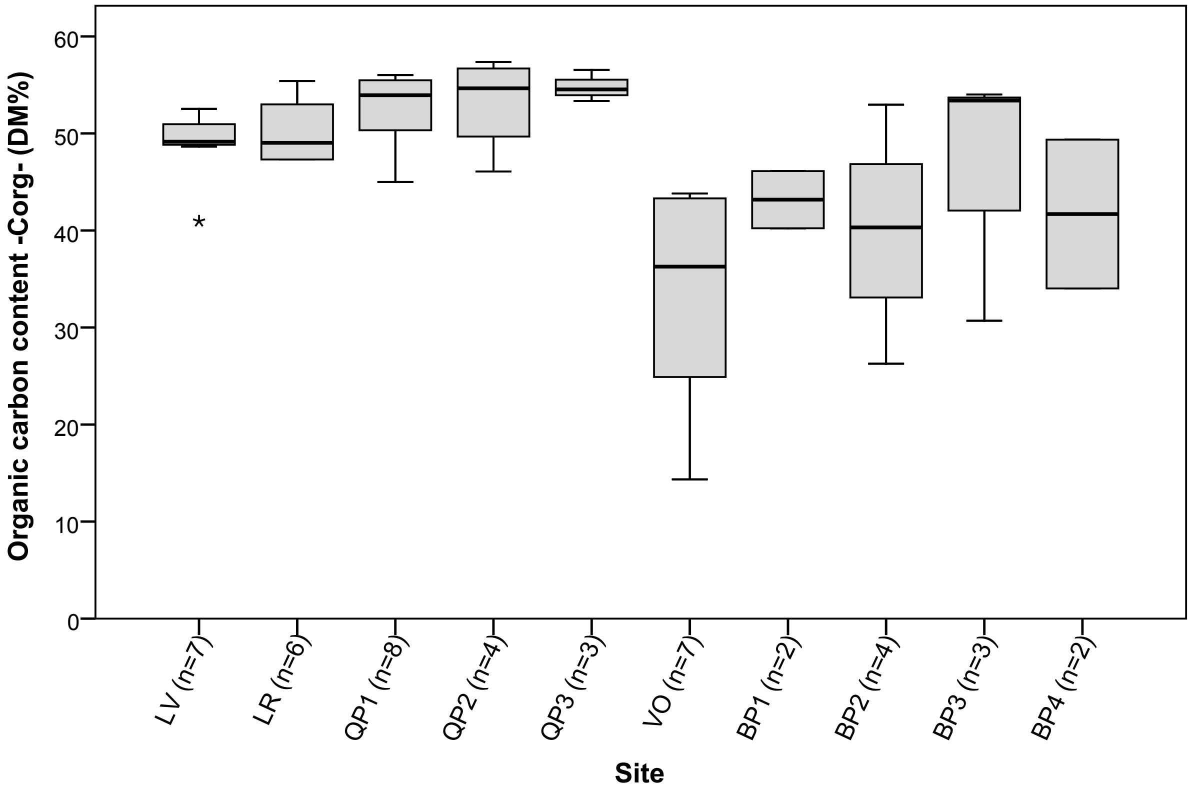


Fig. 82: Organic carbon content interpreted by mire sites of Aysén (n=46)

* Abbreviations of the sites are described in Tab. 7 after section 3.3.13

4.2.9 Organic matter after loss by ignition

According to recent studies the relation between the soil organic matter and the soil organic carbon in mires varies between 1.8 to 2.0 (Klingenfuss et al., 2014). Results for the collected data (Fig. 83 and Tab. 20) evidenced a high proximity to these SOM/SOC ratios with 1.83±0.26, corroborating the values obtained for the total organic carbon -C_{org}- and total carbon –C- content. Excluding the organic gyttja, the universal median for the soil organic matter content was 85%±14%. The lowest SOM/SOC ratio was found in a sample of Ericaceae peat (1.81) and the highest in samples of cypress wood peat (2.73). The Ericaceae peat showed the highest variation, whereby the lower values were detected in samples from sloping areas (where peat mineralization takes place via percolation along the slope) and the highest values were represented in samples collected in raised mires of flat reliefs. The organic gyttja substrate located normally between the lower end of the peat soil and the mineral parent material underneath the mire , presented the lowest total organic matter of the universal of samples (47%), but it was high enough to be considered as organic gyttja (AG Boden, 2005). Also *Sp. fimbriatum* peat and brown moss peat, found in edges and areas exposed to sedimentation and mineral enrichment, presented values significantly below the sample median, with 52% and 65% respectively.

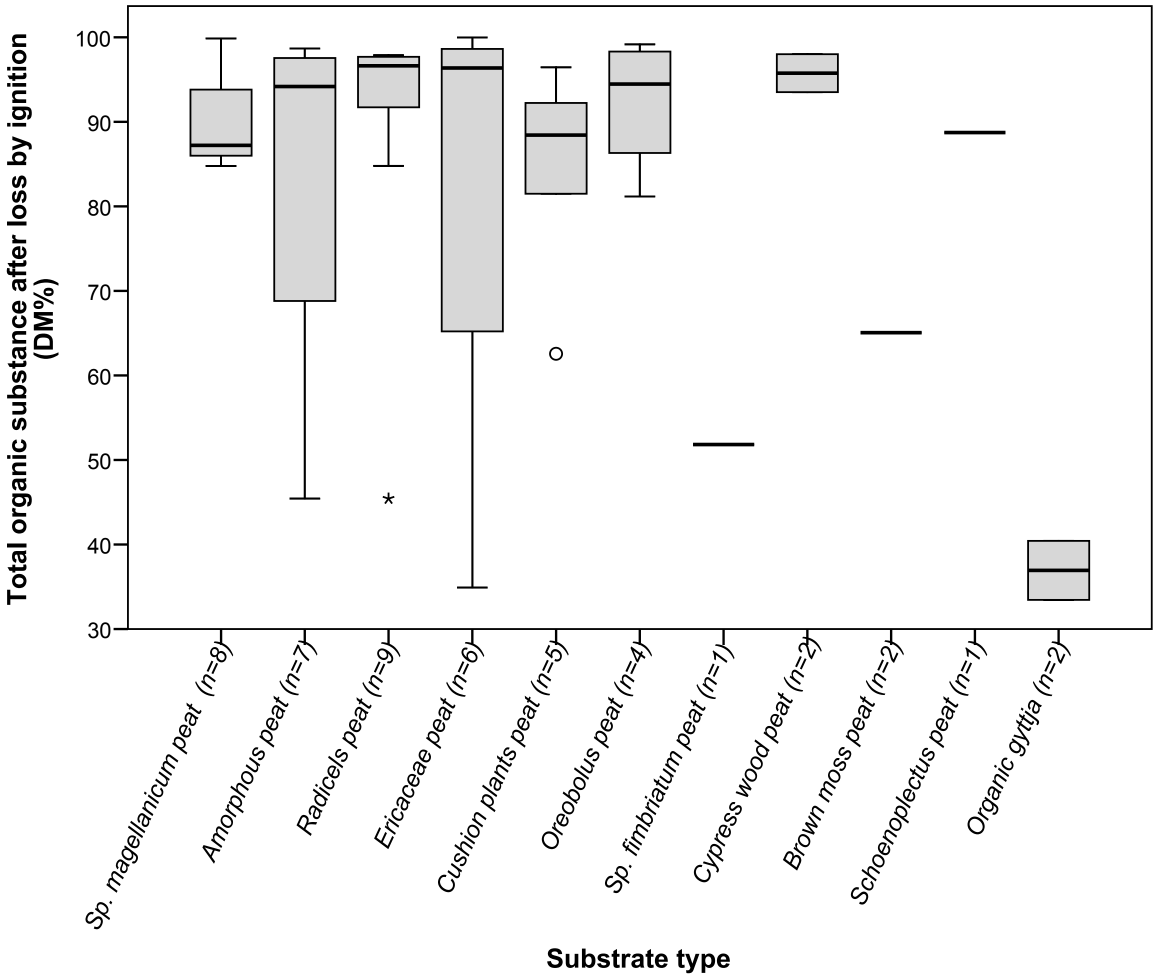


Fig. 83: Organic substance after loss by ignition for different organic substrate types of Aysén (n=46)

Tab. 20: SOM/SOC ratios for different substrate types of Aysén (n=46)

Substrate	N	SOM	SOC	SOM/SOC
All peat types (without organic gyttja)	46	85.10	46.51	1.83
Sp. magellanicum peat	8	89.84	45.53	1.97
Amorphous peat	7	88.42	45.01	1.96
Radicels peat	8	94.76	51.23	1.85
Ericaceae peat	6	97.58	54.01	1.81
Cushion plants peat	6	84.23	43.52	1.94
Oreobolus peat	4	94.81	51.53	1.84
Sp. fimbriatum peat	1	51.83	26.27	1.97
Cypress wood peat	2	95.76	35.11	2.73
Brown moss peat	1	65.06	31.4	2.07
Schoenoplectus peat	1	88.73	43.81	2.03
Organic gyttja	2	47.44	39.89	1.19

4.2.10 Total nitrogen content (DM%)

The total nitrogen content for all samples (organic gyttja included) presented a median of 1.4% varying between 1% and 1.8% (Fig. 84). The substrates presenting the lowest median were cypress wood peat (1%) and *Sp. magellanicum* peat (1.11%); while those presenting the highest medians were Ericaceae peat and organic gyttja peat (1.83 and 1.78 respectively). The lowest single value was found in a sample of *Sp. fimbriatum* peat (N=0.76%) and the highest in a sample of amorphous peat (N=2.95%). The universal standard deviation reported was 0.44%, being cypress wood peat and *Oreobolus* peat the substrates exhibiting the lowest intra variation (std. deviations of 0.12% and 0.16% respectively) and organic gyttja and amorphous peat the substrates with the highest intra variation (Std. deviations of 0.73% and 0.71% respectively). According to the horizon-substrate combination –HSC- (Fig. 85) substrates located in water fluctuation horizons exhibited a slightly higher total nitrogen content median (N=1.4%) than those located in horizons under reduction (N=1.3%) insinuating major decomposition of the organic compounds in the former. Particularly low in nitrogen content are horizons of *Sp. magellanicum* peat under reduced conditions (median N=0.8), while reduced horizons of Ericaceae peat and organic gyttja appear to be the richest in nitrogen content (median N=1.8% in both of them). Interpreting the results for each territory, the total nitrogen content in the amorphous peat showed higher values in the sites BP and QP (2.90% to 2.95%), particularly when located under cushion plants peat. The total nitrogen content varied widely, and independent of the position in the riverbasin or of the proximity to the coast (Fig. 86). Nevertheless, it is observable that the soils of the site BP1 presented the lowest N content median (1%) and those of QP2 the highest (2%).

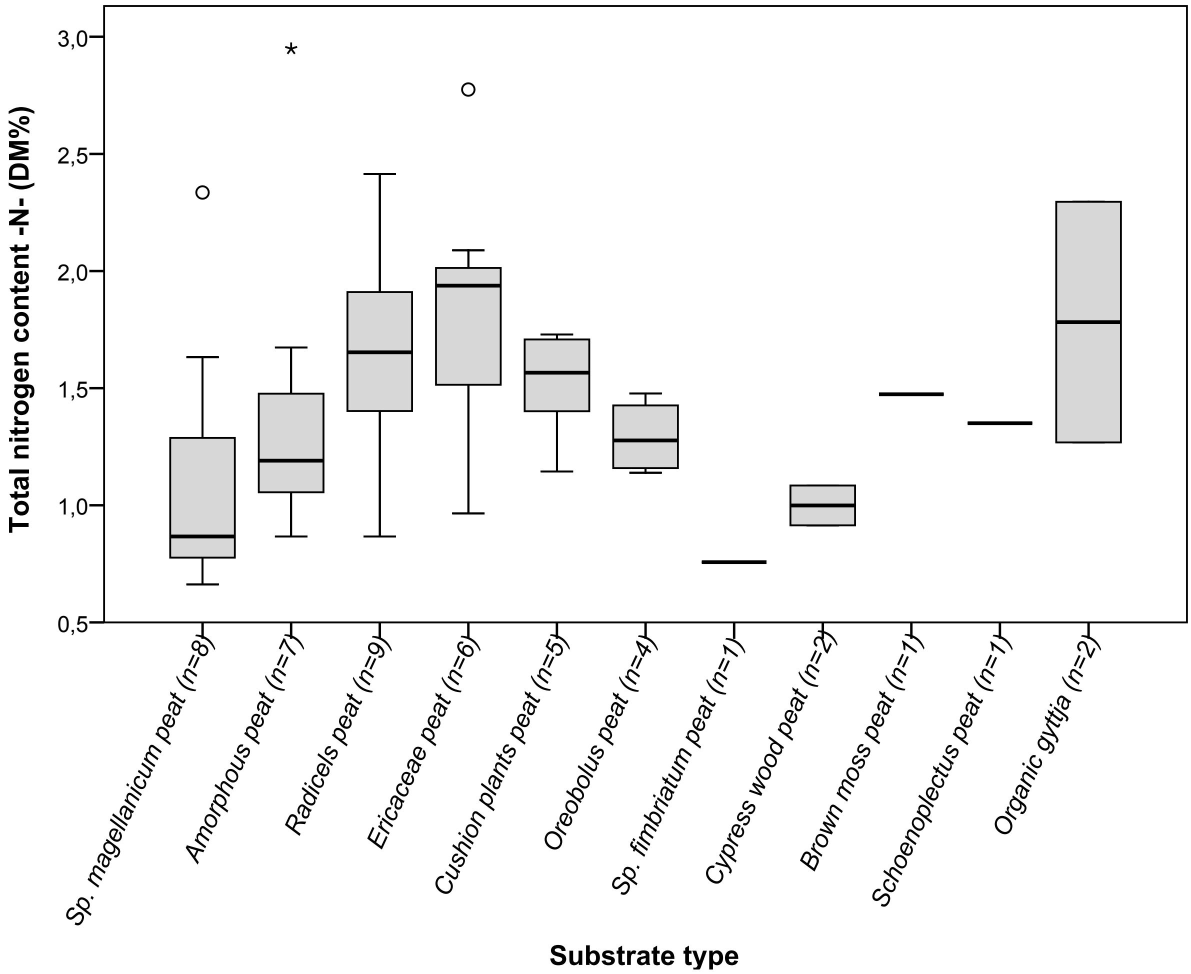
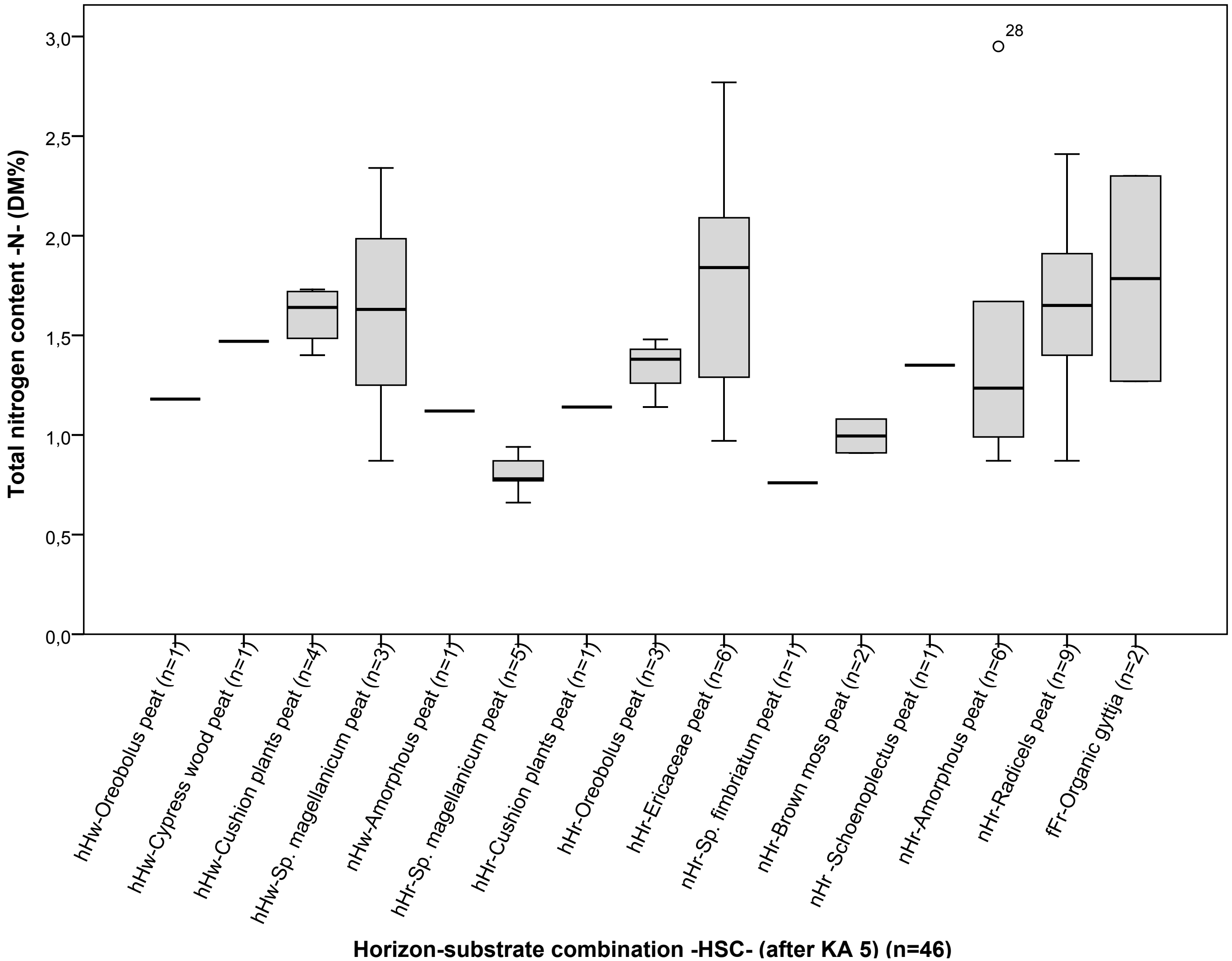


Fig. 84: Total nitrogen content for different organic substrate types of Aysén (n=46)



*Sorted by ombrogenic to geogenic substrate types, from ascending medians from left to right, from horizons under fluctuation –hHw and nHw- to horizons under reduction –hHr and nHr). Abbreviations of horizon categories after the German Pedological Mapping Directive -KA 5- (AG Boden, 2005) are detailed in the sections 1.2.2.1 and 1.2.2.2 (Tab. 4 and Tab. 5).

Fig. 85: Total nitrogen content interpreted by horizon substrate combinations in mires of Aysén (n=46).

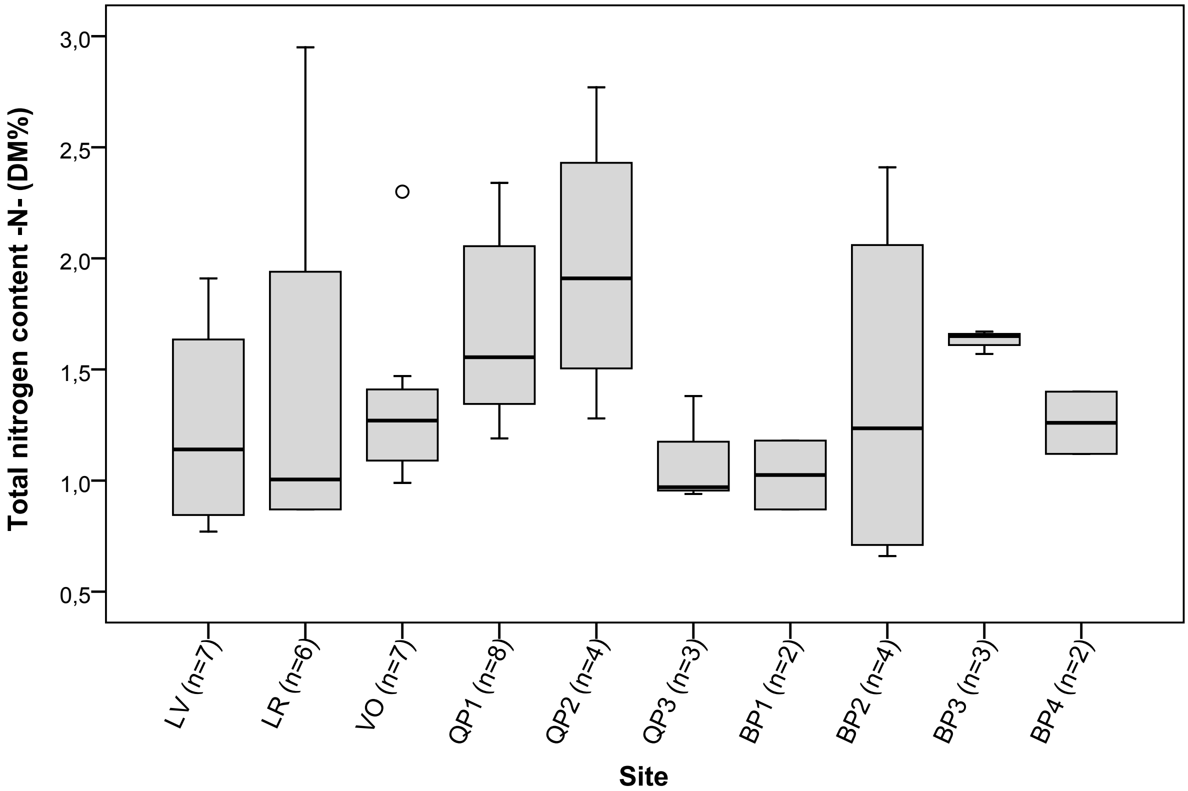


Fig. 86: Total nitrogen content interpreted by mire sites of Aysén (n=46)

* Abbreviations of the sites are described in Tab. 7 after section 3.3.13

4.2.11 Carbon to nitrogen ratio C/N

For the universal of samples chemically examined in this study (Fig. 87), the C/N ratio exhibited oligotrophic conditions with a median C/N=35, varying from moderate mesotrophic (C/N=23 for brown moss peat) to very poor oligotrophic conditions (C/N=50 for *Sp. magellanicum* peat. The lowest median was found in the organic gyttja (23); while *Sp. magellanicum* peat presented the highest median (50). The lowest single value was observed in a sample of amorphous peat (C/N=15) and the highest in a sample of *Sp. magellanicum* (C/N=68). The standard deviation for the universe of samples reported 13, being *Oreobolus* peat the substrate showing the lowest intra variation (std. deviation=3.2) and cypress wood peat the substrate with the highest intra variation (std. deviation=28). Regarding the horizon-substrate combination (Fig. 88), reduced horizons were those presenting the highest C/N levels (median C/N=38), in comparison with the water fluctuation horizons (C/N=31). All sites evidenced oligotrophic conditions, with the exception of QP2 and VO, which evidenced mesotrophic conditions (C/N=29 and C/N=26 respectively). Amongst the sites, there were slight differences between the medians of those dominated by *Sp. magellanicum* peat (LV with C/N=46, LR with C/N=43 and QP3 with C/N=51) and those dominated by cushion plants peat (BP3 with C/N=30 and BP4 with C/N=35) as is observed in Fig. 89. The most significant differences were evidenced comparing these values with the median of the site VO (C/N=26), dominated by brown moss peat, and organic gyttja substrates. Nevertheless, the site QP2, dominated by *Sp. magellanicum* and cushion plants peat, and the site BP3, dominated by cushion plants peat also showed mesotrophic conditions (C/N=29 and C/N=30 respectively).

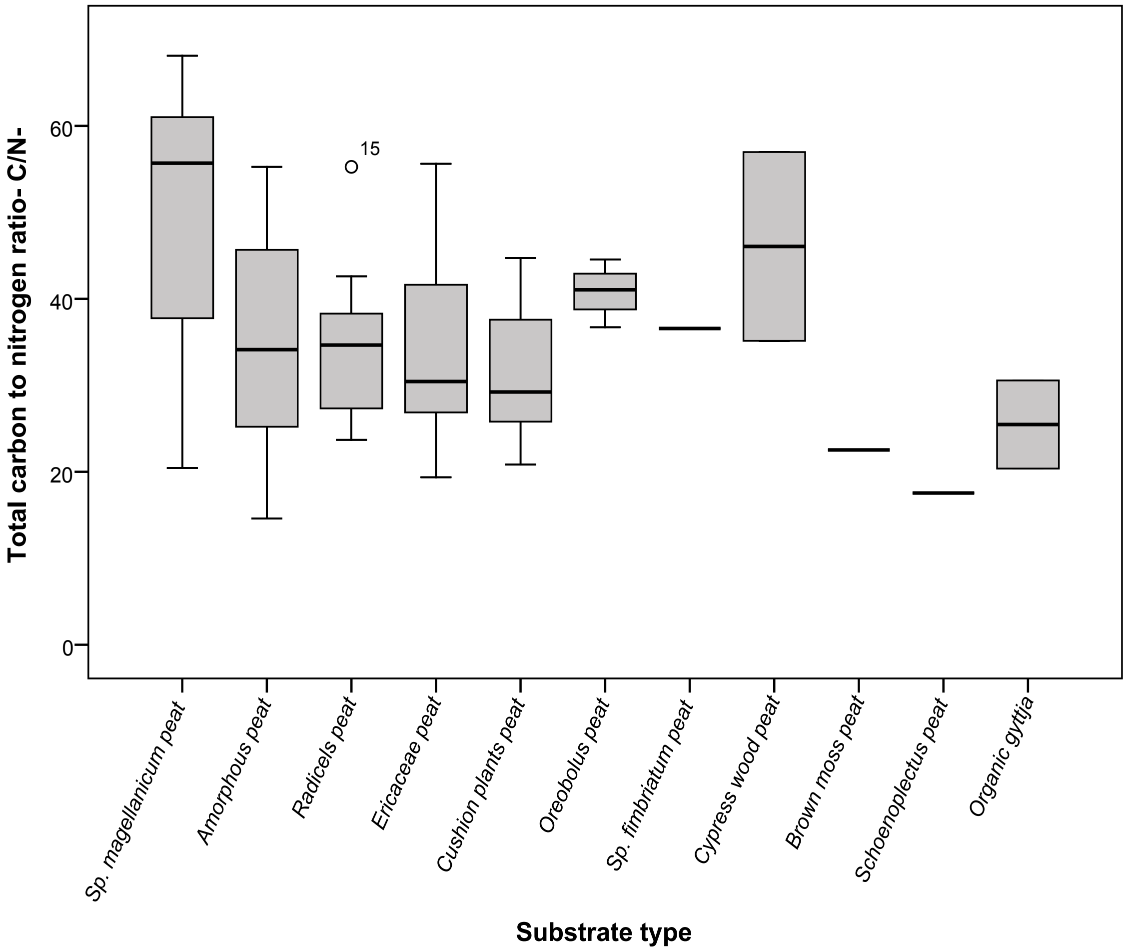
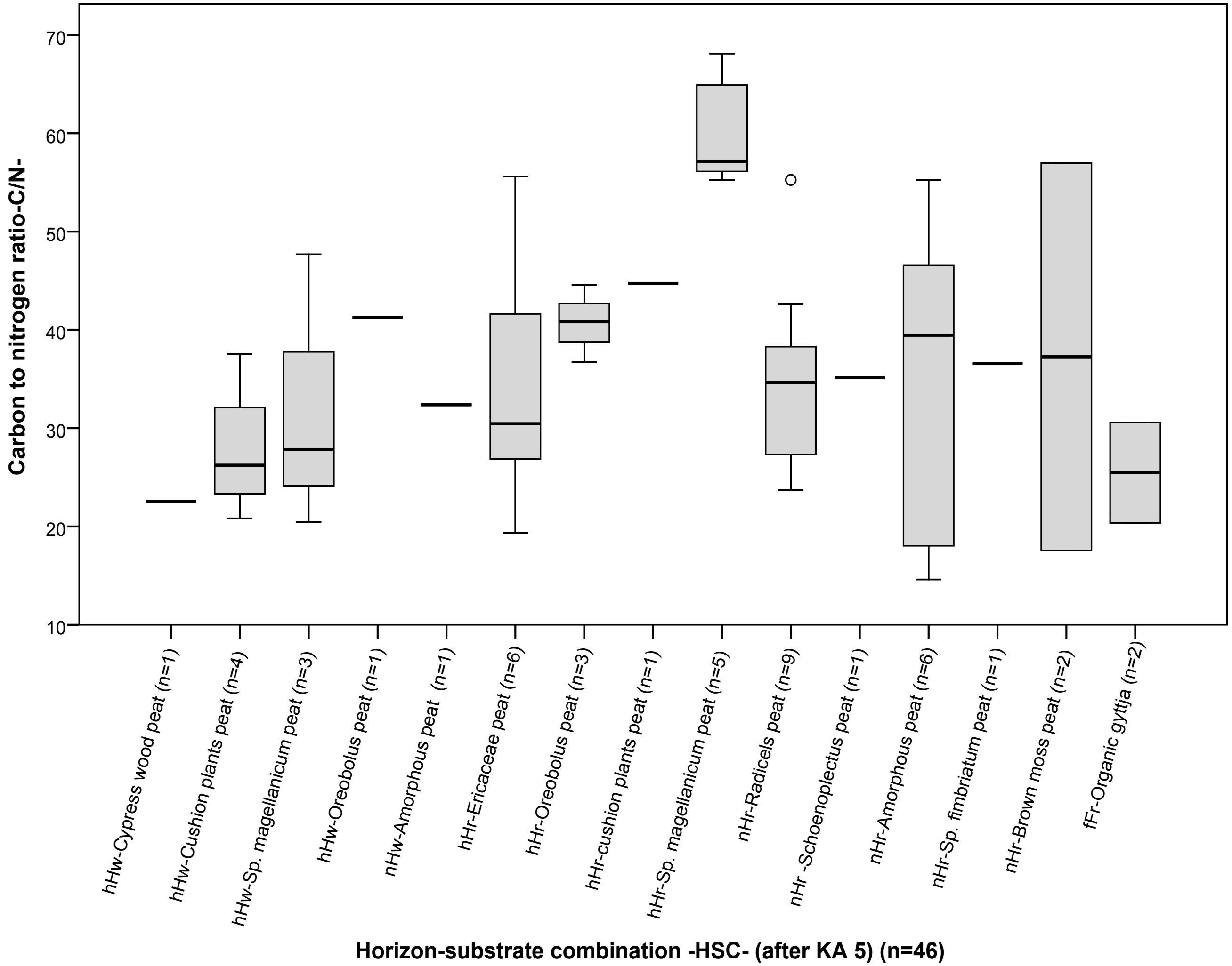


Fig. 87: Carbon to nitrogen ratio for different organic substrate types of Aysén (n=46)



*Sorted by ombrogenic to geogenic substrate types, from ascending medians from left to right, from horizons under fluctuation –hHw and nHw- to horizons under reduction –hHr and nHr. Abbreviations of horizon categories after the German Pedological Mapping Directive -KA 5- (AG Boden, 2005) are exposed on the sections 1.2.2.1 and 1.2.2.2 (Tab. 4 and Tab. 5).

Fig. 88: Carbon to nitrogen ratio interpreted by horizon substrate combinations in mires of Aysén (n=46)

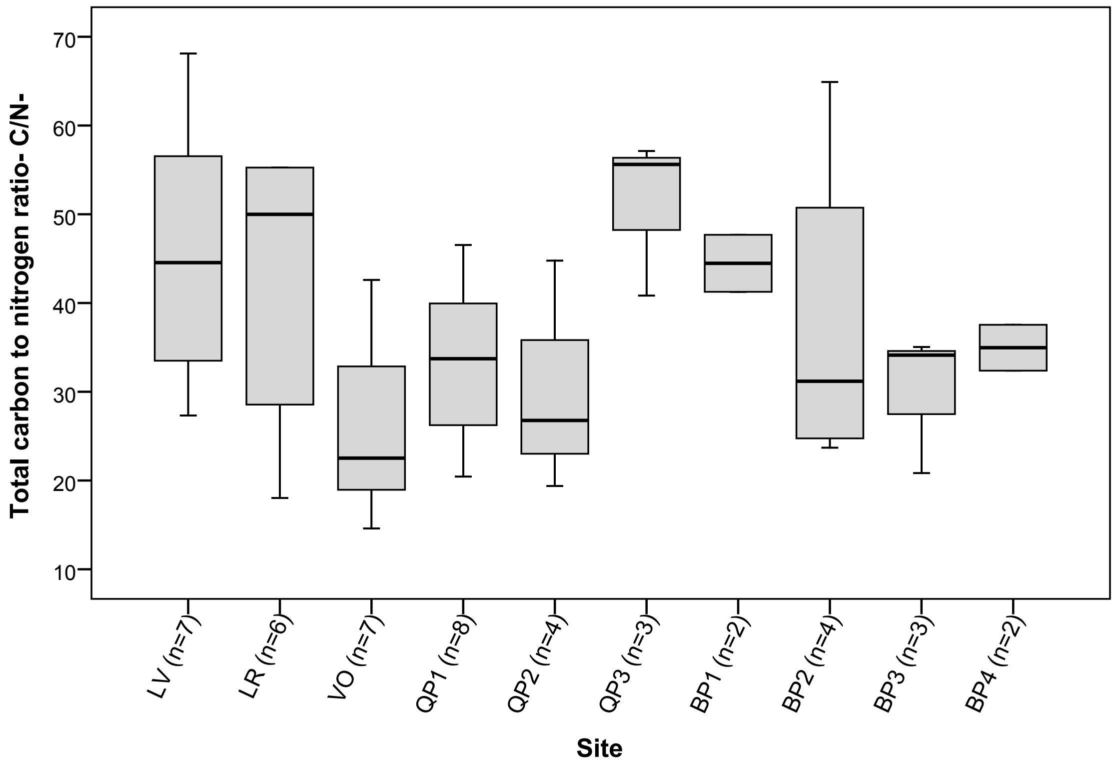


Fig. 89: Carbon to nitrogen ratio interpreted by mire sites of Aysén (n=46)

* Abbreviations of the sites are described in Tab. 7 after section 3.3.13

4.2.12 Discussion

Eleven organic substrate types were found forming the soils of the ten mire sites examined along the Baker and Pascua River. According to their botanical composition, peat substrates found out were *Sp. magellanicum* peat, *Sp. fimbriatum* peat, Ericaceae peat, radicels peat, cushion plants peat, *Oreobolus* peat, cypress wood peat, brown moss peat, *Schoenoplectus* peat and amorphous peat. An organic gyttja substrate was also found. The substrates demonstrated clear variations in their physical properties. The location of the substrates across the depth of the profiles, particularly in the depth layers, indicates two different processes of mire formation. The organic gyttja, shown in the deepest layers of VO, BP4 and QP3, is the only substrate confirming that terrestrialization processes dominated the origin of those sites, while in all the other sites the detected peat substrates confirmed that paludification processes dominated their origins. Overall, the substrate types and their depth, insinuate that all ecosystems originated under geogenic conditions, while their transformation into an ombrogenic regimen becomes visible only in the two metres below the surface, where i.e. *Sp. magellanicum* peat and Ericaceae peat appear. Coherent with that, the homogeneity in the distribution along the depth of the substrates *Sp. magellanicum* peat, Ericaceae peat, cushion plants peat*, Oreobolus* peat*, Sp. fimbriatum* and *Schoenoplectus* peat insinuates that most of the sites selected in this study presented common development stages. That is the vegetation decaying and forming these substrates should have existed under similar conditions. Due to the different (and remote from each other) locations of the examined sites, it is inferable that the similar conditions they shared were climatic, and that they were dominant enough to exceed other factors influencing the peat development (pH, relief, nutrient inputs via runoffs). On the other hand, the wide presence of amorphous peat at several depths impedes the assumption of the dominance of a defined peat formation process in horizons dominated by this substrate. This is particularly confusing when the amorphous substrate is located in the central and deep horizons of sites currently covered by rushes (VO) or cushion plants (BP4, LR), making it difficult to determine if cushion plants peat or *Oreobolus* peat developed in the layers and became amorphous peat, or if the latter formed due to successional dry periods. Future studies conducting microscopy determination of seeds, macrofossils and pollen types in the peat will undoubtedly contribute to solve this incognito.

As regards the colour of the substrates, although some tones tend to be particular to some specific substrates, the wider the sample was for a substrate type, the more varied was the colour spectrum. Therefore, assumptions about specific colours for each substrate can only be interpreted as tendencies, at least until new investigations including balanced sample quantities for each substrate are carried out.

Regarding the degree of decomposition of the peat substrates the results in the examined mires confirm successions of aeration, marked by the presence of amorphous peat with H9 to H10 in a sizeable number of the examined horizons; and successions of water surpluses, represented by the main part of peat substrates with degrees of decomposition H3 to H4. Additionally, the 14% of the peat substrates with intermediate degrees of decomposition (H5 to H8) represent a transition stage between both successions. Nevertheless, this interpretation is only valid for mires free of cushion plants. In ecosystems dominated by these species it is not possible to differentiate if these successions obey earlier and later climatic phases (i.e. of dryness and water surplus), or if the presence of these plants, which drive accelerated aeration processes with their root system in the deeper horizons, are responsible for the decomposition of a good part of the peat in the mires they colonize (Fritz, 2012; Teltewskaja, 2010; Abel, 2009; Kleinebecker, 2007). Despite this the ample presence of amorphous peat in the underlying horizons of all the sites should have been a factor of success in the settlement of cushion plant species above *Sp. magellanicum* mires since the late Holocene, by facilitating their feeding strategy, once some individuals settled in a site and their roots reached these already decomposed and "ready to eat" amorphous peat horizons.

The results for bulk density on the other side (median of 0.09 g cm^3), showed higher values than those reported for Chiloé (León Valdebenito, 2012, reported a median of 0.029 g cm^3 for different peat types in the first 40 cmbs), and those reported for Magallanes and Tierra del Fuego (Loisel and Yu, 2013, reported a median of 0.07 g cm^3 including *Sphagnum,* radicels and amorphous peat types). There is a clear tendency of the bulk density to increase with the depth, with the exception of the cypress wood peat, which maintains a lower bulk density despite the depth at which it is located in the soil.

Values obtained for the water holding capacity of the substrates, show that the peat substrates found in the region of study consist of up to 95% of water, and that this capacity, including the organic gyttja, varies between 81% and 95% of the substrate volume at field capacity. This is also a wider variability than those reported by León Valdebenito (2012) for peat types of the Island of Chiloé (90% to 94%) and by (Loisel and Yu, 2013) for Tierra del Fuego (87% to 93%). The values determined in this study show that most substrates with low bulk densities (*Sp. magellanicum* peat*,* Ericaceae peat*, Schoenoplectus* peat) present a higher storage capacity than the substrates with moderate and higher densities, existing a negative correlation between these variables and evidencing how important the conservation of the current natural not compacted peat density is to the fulfillment of water retention and filtering functions in ecosystems containing these substrates. To be more precise, mire ecosystems in Aysén are among the most important rainwater reservoirs. This capacity of peat substrates plays also a crucial role to the moderation of runoffs in the mountainous areas of Aysén. Mire ecosystems of Aysén are therefore natural preventers of erosion and eutrophication processes that could otherwise affect the valleys and rivers of the region.

Among the chemical characteristics of the examined substrates, the pH-value indicates strong to moderate acidic ecosystems in all sites except VO, which presented a pH spectrum from acidic to neutral. Independent of their distance from the coast, these ecosystems maintain their acidity in areas of intensive precipitation, remaining slightly moderate acidic close to the ocean (sites in BP area). That can be explained by the effect of salt depositions, which was also reported by Haraguchi et al. (2003) in Japan and by Gorham (1991) in Ireland. In comparison, eastwards from the Andes Mountain Range, where both precipitation and the sea spray from the coast decrease, the pH-value in mire soils increase definitely, being influenced by mineralized runoffs and melting water (VO).

Results for organic carbon and total carbon content, narrow correlated to each other, evidenced the absence of secondary carbonates in the examined substrates, coherent with the acidic nature of the local geology formed mainly of granite. At the same time, the majority of the substrates were disposed in horizons under reduction, presenting higher carbon rates than those exposed to water fluctuations. The total organic substance evidenced in all substrates a main organic composition, inclusive in the organic gyttja, which under the German Classification System with >30% of organic matter is considered as this category (AG Boden, 2005). Nevertheless, the lower total organic substance observed for *Sp. fimbriatum* peat is a peculiar case. This sample was extracted from the edges of the site BP2, at a depth of 15 cmbs and exhibited a decomposition degree of H6. The substrate presented a bulk density low enough (0.09 g cm^3) and a water storage capacity high enough (90%) to reject the possibility of mineral content in the sample. Additionally the high C/N=37 in this peat evidenced clear oligotrophic conditions, which despite the degree of decomposition H6, argues against a high level of mineralization. An explanation for this is that a large part of the substrate volume must be formed of ashes deposited during the burning of the forests as part of the timber industry exploiting the cypress wood (*Pilgerodendron uviferum),* an activity that has been carried out in the area over the last 20 years (Rosamel Vargas, personal communication, January 2012). On the other hand, the high organic matter content of the cypress wood peat can be explained by the property of this wood to retain water, guaranteeing a slow decomposition once it has been deposited in the soil. Coherent with this last point, the observed absence of correlation between the carbon content and the depth unveils that the examined mires are young ecosystems, formed by substrates whose chemical conditions still remain undisturbed since their formation. These results are consistent with corroborations widely reported for young mires, which evidence that in these ecosystems the natural low decomposition in the C-fixing organic matter in the catotelm is still minimal (Gorham, 1991; Turunen et al., 2004; León Valdebenito, 2012). The ratios of carbon content and total organic matter varied similarly, but some of the examined substrates have significantly higher variations (e.g. Cypress wood peat). This is explained by the different microreliefs of the areas where the samples were taken, presenting these parameters higher variations in areas under constant saturation (and consequently less disturbation). Such variations between the carbon content and the total organic matter in a same substrate type are also reported by Turunen et al. (2004) and by León Valdebenito (2012).

The total nitrogen content in ecosystems dominated by *Sp. magellanicum* peat showed comparatively lower values than the ecosystems dominated by cushion plants peat, radicels peat and Ericaceae peat. This confirms that over cushion plants, sedges and rushes, *Sphagnum* species present an intrinsic adaptation to low nutrient environments. Recent studies realized in Tierra del Fuego by Fritz (2012) confirm that anthropogenic increases in the current *N* levels can dramatically affect the nutrient sequestration mechanisms of *Sphagnum* moss, making these species atrophy and their current habitats highly vulnerable to the colonization of vascular plants. In Patagonia, those vascular plants colonizing mires that were primarily occupied by *Sphagnum* mosses are specifically cushion plants with root systems adapted to saturated conditions, like the species *Astelia pumila*, *Donatia fascicularis* and the species of the Juncaginaceae family *Oreobolus obtusangulus*. Coastal mires investigated in this study, specifically the site BP, are dominated by these cushion plants, meaning a similar vegetation pattern to that widely reported for pristine mires along the coastal areas of Tierra del Fuego, where the action of salt cations increase the nutrient conditions of the upper soil and thus the developing chances of these species (Fritz, 2012; Teltewskaja, 2010; Abel, 2009; Kleinebecker, 2007).

The median in the C/N=35 is similar to the median C/N=31 found out by León Valdebenito (2012) in mires of Chiloé and quite lower than the median C/N=250 reported by Kleinebecker (2007) in mires of Tierra del Fuego and Magallanes. Consistent with the results about the C and N content, the C/N ratio interpreted together with the pH-value, evidences that the examined mires vary from oligotrophic-strong acidic to mesotrophic-acidic ecosystems. According to the collected data, extreme acidic conditions can be found in sites dominated by *Sphagnum* moss and moderate acidic conditions in sites dominated by sedges and rushes, where the ecosystems present also mesotrophic conditions. These ecological settings imply a low to moderate availability of plant nutrients in all the sites, leading to a high exclusivity of species, as well as a very slow nutrient metabolism and exchange with the environment. This last point plays a crucial role in the prevention of massive releases of the organic compounds contained in the peat, into the regional fresh water bodies and aquifers (eutrophication), i.e. during glacial lake outburst phenomena (GLOF) and strong rainfall events, both very common in the basins of Aysén.

Considering the current calculated area covered by mires in Aysén (approx. 1.450.000 ha after CONAF et al. (1999a, actualized in 2010), the average depth of the organic substrate layers (76 cmbs) and the average bulk density for peat substrates excluding the organic gyttja (0.09 g cm^3), the quantity of peat stored in all mires in the region of Aysén can be preliminarily estimated at 1.305.000.000 m^3. In addition, with an average water holding capacity of 91% of the fresh substrate volume (including the Gyttja), it can be preliminarily deduced that mire ecosystems of Aysén are able to retain approximately 1.180.000.000 m^3 of fresh water in the landscape, forming huge water reservoirs. Considering the average nitrogen content of 1,44% of the total dry matter measured for the universal sample (including the organic gyttja) can be deduced that mires in Aysén are retaining aproximatedly 13 tons of nitrogen per hectar, which means a storage capacity of 18.700.000 tons of nitrogen for the regional mire ecosystems. Taking into consideration the average carbon content of 46% for the universe of samples including the organic gyttja, and extrapolating this for the regional territory covered by mires in Aysén, a carbon storage capacity of >414 t C_{org} ha can be preliminarily estimated, which is almost four times higher than the 116 t ha^{-1} calculated by León Valdebenito (2012) for mires of Chiloé. In this form a carbon storage capacity of >600 millions t C_{org} can be presumed for all mire ecosystems in the region of Aysén. More analysis has to be done to correct and improve this measurement, including particularly differences among the chemical and physical settings of the different substrate types and accurate data about the thickness and extensions of mire ecosystems in the regional landscapes.

Despite the current pristine conditions of the examined mires, anthropogenic activities associated with forest burning, livestock management and the construction of large infrastructures (highways and dams) are increasing in the region of Aysén, affecting the C/N ratio in mires. That can definitely affect, and in a very short term, the ecological balance achieved over thousands of years by these ecosystems and therefore the whole mire landscape of Aysén. The current ecological conditions of regional mires should be monitored to prevent undesired changes in the current balance of regional landscapes and ecosystems.

4.3 Radiocarbon dating ^{14}C

4.3.1 Mires formation calibrated age for the sites LV, QP1 and BP3 under accelerator mass spectrometry (AMS)

In LV, the calibrated results show with 95% confidence the date of 3535±35 cal yr BP as the beginning of the mire formation in LV1 (Fig. 90, picture A). In QP1_2, the calibrated results show with 95% confidence the date of 745±30 cal yr^{-1} BP as the beginning of the mire formation (Fig. 90, picture B). In BP4_2, the calibrated results show with 95% confidence the date of 4800±40 cal yr^{-1} BP as the beginning of the mire formation in BP4 (Fig. 90, picture C). Calculations for peat accumulation are based on Punning et al. (1993) and explained in Annex 24 and results exposed as follows.

4.3.2 Discussion

Compared with samples taken by Holz et al. (2012) in a raised bog of Caleta Tortel (39 km distant from LV, at 90 cmbs, which showed 2855 ±20 yr BP), the calibrated age obtained for the sample of LV (3535±35 yr BP at 210 cmbs) insinuates a peat annual accumulation rate of 0.06 cm yr^{-1}, higher than the 0.04 cm yr^{-1} reported by Holz et al. (2012) for Caleta Tortel. An explanation for this variation can be the closeness of Caleta Tortel to the ocean (located at sea level). According to Kleinebecker (2007) salt enriched sea spray is a factor accelerating the decomposition of organic matter in peaty soils near coastal regions, reducing the peat able to accumulate in a site. Coherent with that, a peat annual accumulation rate of ≈47 gr m^2 yr^{-1} in LV1 is the lowest of the three sampled sites.

The results for the site QP1 can be also discussed with those reported by Holz et al. (2012) for a *Sphagnum* peat layer at 60 cmbs in the mire Leal (048°42' S – 073°75' W, in the north upper basin of the Quetru Lake, only 14 km distance from the site QP1, at 30-40 m a.s.l.). The radiocarbon dating of Holz et al. (2012) showed 1735 ±15 cal yr BP in the mire Leal. The results for the site QP1 (745±30) demonstrate a twice higher peat annual average growth rate (0.08 cm yr^{-1}) than in the mire Leal (0.03 cm yr^{-1}) and the highest peat annual accumulation rate (≈64 gr m^2 yr^{-1}) of the three sampled sites. The site QP1 is 11 km away from the ocean and the site Leal 25 km. Located in a fluvial terrace direct above the Pascua River, the site QP1 is more susceptible to the westerly wind coming from the Pacific Ocean than the mire Leal, protected by mountains in the northern flank ob the Quetru Lake basin.

The sloping morphology of the site QP1 seems to generate a hydrological constellation where more and diversified plants find a niche to exist, generating more vegetation productivity, and thus more litter accumulation leading to peat formation. This phenomena was also described for the North Hemisphere by Frolking et al. (2001). In other words, the site QP is a transition between typical continental oligotrophic conditions and typical maritime mesotrophic conditions, where wider vegetation productivity takes place, allowing a higher peat accumulation rate than in coastal and continental areas.

Regarding the results obtained for BP4 (4800 ±40 yr BP), taking into consideration the age (4800 yr BP) and the depth of the extracted peat material (305 cmbs), a peat annual average growth of 0.06 cm yr^{-1} and a peat annual accumulation rate of ≈51 gr m^2 yr^{-1} were preliminarily inferred. Since BP4 was a low-alpine mire, whilst most mires dated in the current literature are river-basin associated, it could not be compared with other regional datations.

Considering the three examined sites (Fig. 90, picture D), the average growth of the peat for the mires in the Baker and Pascua River can be preliminarily estimated at 0.07±0.01 cm yr^{-1}. Also a positive balance can be defined for the peat annual accumulation in the area, with a rate of 54±9 g/m^2 yr^{-1}. This rate is lower than the 94 g/m^2 yr^{-1} calculated for maritime *Sphagnum* mires reported in the Island of Chiloe by León Valdebenito (2012), and higher than the average of 34 gr m^2 yr^{-1} reported for continental *Sphagnum* mires of Finland (Tolonen and Turunen, 1996; *in* León Valdebenito, 2012), confirming the mixture of the selected sampling sites: LV1 in a continental area, QP1 in a transitional-inclined area and BP4 in a maritime-low alpine area.

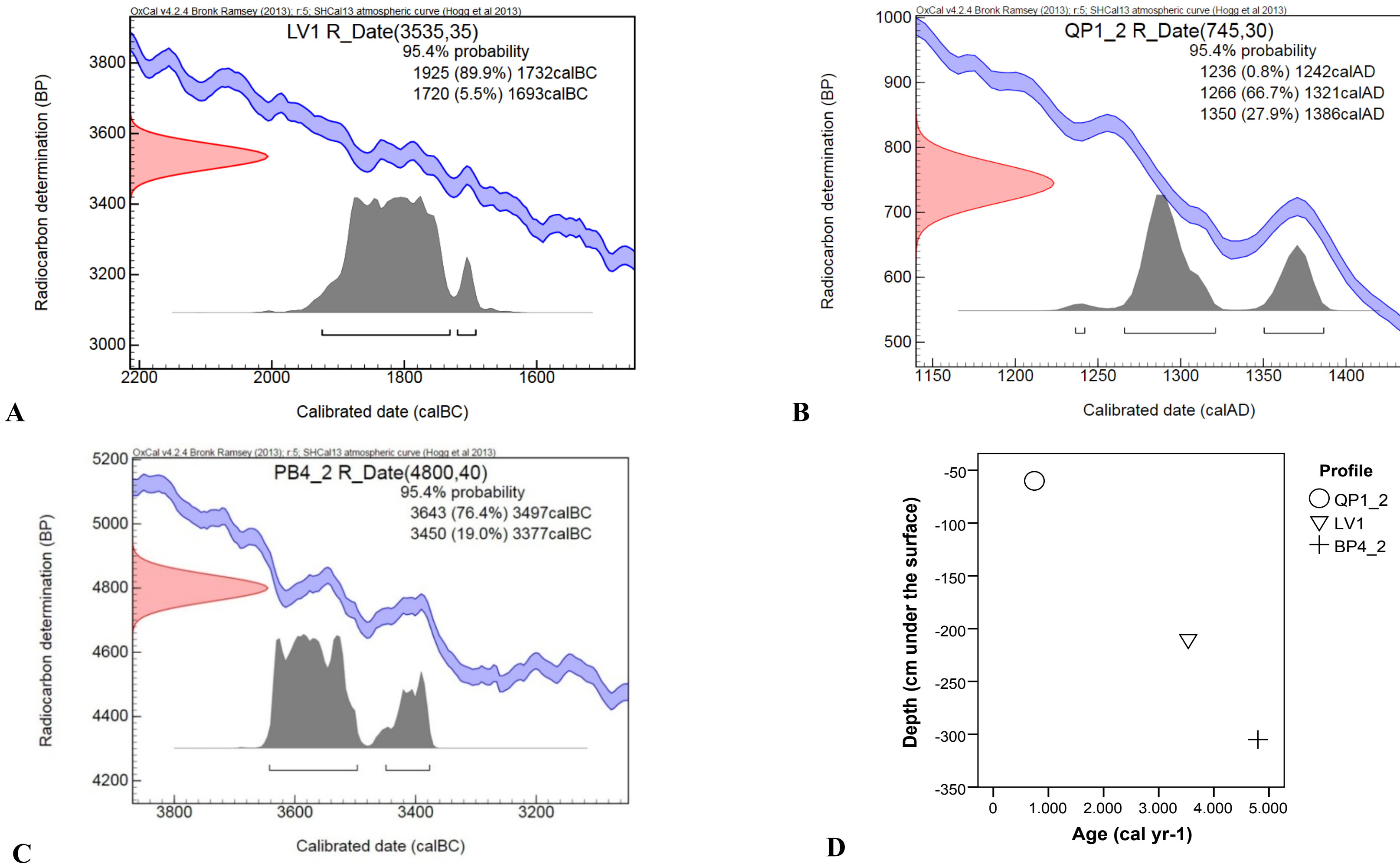


Fig. 90: Radiocarbon analysis under accelerator mass spectrometry (AMS) and calibration for selected examined mires

A= QP_2, B= LV1 and C= PB4_2. D=Age/Depth distribution of the samples. Left axis illustrates the radiocarbon determination and its normal distribution (pink). Variations are shown in the uneven double purple line. The grey distribution shows the most plausible date for the origin of the sites. (Laboratory analysis performed under the method of accelerator mass spectrometry (AMS) by the Poznań Radiocarbon Laboratory in Poland). Calibration done with the software OxCal (Ramsey, 2015).

4.4 Proposal of a system for the hydrogeomorphic and ecological classification of mires and organic substrates in the Baker and Pascua Rivers, Aysén-Chile

Through this work it has been corroborated that mire ecosystems in the Baker and Pascua rivers present particular hydrological, geomorphologic and ecological settings, that make them differentiable. At the same time, the substrates composing the soils of the examined mires were also distinguishable according to their botanical settings, as well as by their physical and chemical properties. Based on these specific characteristics of the ecosystems found during this study, and as a means of conclusion, the following section of text presents a proposal for the classification of mires along the Baker and Pascua river basins in Aysén. The classification is divided into four levels (Tab. 21). The first level of classification refers to the main landscape settings (geomorphologic and hydrological units) where mire formation takes place. The second level of classification discriminates between five hydrogeomorphic mire types, deduced from the morphology, water sources and stratigraphy of the mires, and by their typical substrate composition. Also in this level the dynamics of origin and development of these ecosystems are explained. The third level separates eight stereotypical mire ecotypes, focusing on the current main vegetation diversity and physiognomy of the examined mires as a result of the prevailing trophic conditions, water level and relief of a site. The fourth level of classification proposes a compendium of keys for the identification of the eleven different organic substrate types forming the soil of mires detected along the Baker and Pascua river basins.

Tab. 21: Explanation of the four levels of hydrogeomorphic and ecological classification of mires and their soil organic substrates in the Baker and Pascua Rivers, Aysén-Chile

Level of Classification	Focus
First	Main relief and hydrology allowing mire formation
Second	Five hydrogeomorphic mire types differentiated according to their morphology, water sources and stratigraphy
Third	Eight mire ecotypes separated by vegetation diversity and physiognomy
Fourth	Eleven organic substrate types divided by their texture and recognizable plant macrofossils.

4.4.1 First level of classification: main relief and hydrology allowing mires formation in the examined sites

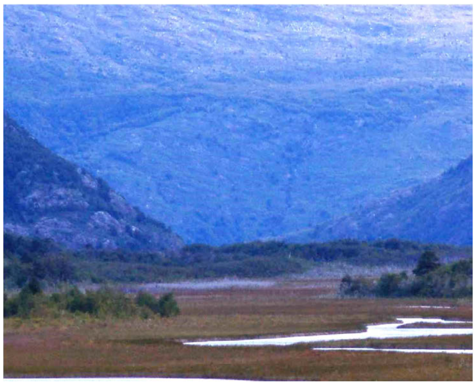
The relation of the landscape geomorphology and hydrology with regards to the formation of mires has been widely reported (Succow und Joosten, 2001; Wallor und Dzialek, 2011; Zepp, 2013). Specific geomorphic units hosting mires in the examined river basins are intermountain depressions (Fig. 91, picture A), where mires form in saturated areas receiving a mix of standing water, lateral runoffs and precipitation. As was observed in site VO and BP4, the deep horizons of mires located there consist of organic gyttja, confirming their origin in small lakes, probably formed by melted pieces of ice left over from the last glacial retreat. These lakes experienced terrestrialization processes. Mire formation was also observed on slopes (Fig. 91, picture B) lying directly on the bedrock close to the surface and presenting horizons with <60 cm thickness. Such ecosystems are called percolation mires in Germany -*Durchströmungsmoor*- (Ringler, 2005). Mires lying above slopes are wetted by rainfall or by mountain streams, depending on their development stage. Mires also form at the bottom of slopes (Fig. 91, picture C), acting as transitional ecosystems between the mountains and the valleys, terraces or floodplains. There, nutrient, sediment and water accumulation allows trees to develop above the peaty soils. Mires at the bottom of slopes are also reported in Southern Germany (Ringler 2005), under the name Edge-dam mires (*Talrand-Stauwassermoore*). Also glacial U-shaped valleys (Fig. 91, picture D) present mire formation in the low lands. Their substrates are usually mixed mineral and organic material, facilitating forest development in shallow peaty areas. Also on lowlands, valley edges (Fig. 91, picture E) in the basin areas adjacent to mountains or hills produce water accumulation, allowing for a faster formation of peat. There, peat horizons have a higher thickness and diversity. Mires are also found on flood plains (Fig. 91, picture F). Originated by the fluvial deposition of fine to medium sand sediments (<630 µm after the KA 5) in old meanders, these morphologies display a homogenous and flat stratigraphy with fine sediments and iron oxide layers. The permeability of the underlying layers is low enough to enable constant saturation of the upper soil. Flood plains differ from valley basins, because of their vaster non-glacial but water shaped extension. Fluvial terraces (Fig. 91, picture G), formed by depositions of fluvial sediments on the shores of glacial rivers, are also a geomorphic setting facilitating the formation of mires.

A

B

C

D



E

F

G

A= mire in an intermountain depression at site VO. B = mire at the bottom of a slope at site VO. C= mire at the foot of a slope at site QP. D= mire in a valley basin at site LR. E= mire at a valley edge at site LR. F= mire on a flood plain at site LV. G= mire on a fluvial terrace at site BP1

Fig. 91: Geomorphologic units presenting typical mire formation (Rodríguez, field work 2012-2013)

Their parent material consists of fine to medium sandy sediments in the upper layers (<630 µm after the KA 5) and coarse sandy sediments in the deeper layers (>630 µm after the KA 5). The mentioned geomorphic units can be grouped according to their relief as shown in Fig. 92.

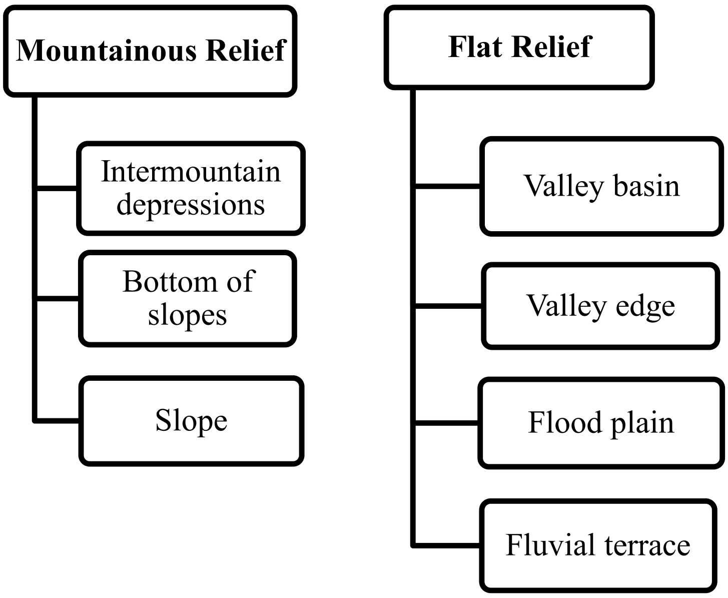


Fig. 92: Geomorphic units related to mire formation in Aysén

On the other hand, the hydrological units facilitating mire formation in the sites of study were very difficult to determine exactly, especially in the mountainous and periglacial areas examined. Several previous works confirm these difficulties, pointing out that quality and magnitude of hydrological events show a high variability according to the relief, which influences mire formation and ecology differently (Brinson, 1993; Klein et al., 2013). Aysén presents a mountainous-periglacial lansdcape, marked by the Andes Mountain Range and the Patagonian Ice Sheet, exhibiting a high hydrological and relief-defined diversity related to mire ecosystems. On these landscapes, organic and mineral depositions are hydrologically transported. While precipitation is nutrient poor, it was observed that the terrestrial influenced water of glacial rivers contributes mineral sediments (grey to turquoise colour), the water from mountains and valley streams supplies organic nutrients (brown colour), and the water of lacustrine rivers adds both, organic and mineral materials (green transparent colour). Common to all mires in Aysén but differing in intensity, is the influence of rain water. It accumulates in areas where cushion vegetation forms strong intertwined blankets, e.g. *Astelia pumila* and *Donatia fascicularis* (Fig. 93, picture B). There, soil drainage is hindered and rainfall infiltration is decelerated, remaining on the surface and forming small pools. One part of the pool's water will evaporate and the second part will infiltrate and contribute to the mire water table, interacting with this and becoming acidic (pH-value <3.5), due to the pH-value sinking effect of neighbouring Sphagnum mosses (Clymo, 1963; Succow und Joosten, 2001). Besides rainfall, the landscape groundwater is the most important hydrological factor allowing mire formation worldwide (Reichholf, 1988), but under the climatic conditions along the examined river basins in Aysén, the current stage of the mire formation occurring there is further influenced by rainfall, apart from the site VO. Streams and similar small runoffs with constant and intermittent floods are particularly related to mires located on slopes and intermountain depressions (Fig. 93, picture A). These hydrologic units mobilize mostly organic matter from the upper forests into the valley basins and fluvial terraces. Their pH-value ratios fluctuated between 3.5 and 5.0 according to measurements taken from streams in the sites LR, QP and BP. Runoffs in mountainous areas can also become percolation water feeding sloping mires (Site BP1). Lagoons and lakes (Fig. 93, picture C) can also be mire forming units in mountainous regions or low valleys. Birds and amphibians were observed in these ecosystems, favouring plant dispersion and nutrient surplus. Additionally, lagoons and lakes linked to the mires of Aysén provide aquatic vegetation, contributing to their ecological diversity. The pH-value of these to mires associated lagoons and lakes fluctuates among 4.5 and 5.0. Small standing water ponds marked as pools in this work (Fig. 93, picture D) are common in mires of fluvioglacial valleys. These ponds are part of the mire water table, and classified under the group Mire Water (Fig. 94). These pools present pH-values from 2.5 to 4.0 and typical *Sphagnum-Tetroncium magellanicum* hummocky vegetation, emerging until up to one metre above the water level. At the bottom of the ponds, sedimentation processes were confirmed during the field work, especially occurring around the *Sphagnum-Tetroncium* hummocks. Core samples extracted from these hummocks showed that the underlying substrates are also formed by radicels peat. This evidence makes it inferable that the preceding landscape conditions were considerably less saturated than in the present. As the currently flooded state is a recent one, it is possible to hypothesize that the formation of these ponds is linked to rises in the mire water table, e.g. due to increased water availability from glaciers and mountain snow as a result of global warming (Rosenblüth et al., 1997; Bertrand et al., 2012; Lenaerts et al., 2014).

Rivers like the Pascua, Baker and Vargas run adjacent to different mire systems in the low valleys of Aysén. The rivers of Aysén are mostly loaded with glacial and mineral sediments, compared to the small streams, which are mostly laden with brown organic matter (Fig. 93, picture E). The pH-value measured in the water of the Rivers Baker, Pascua and Vargas fluctuated between 5.0 and 5.5. These neighbouring rivers have an influence on them during sporadic flooding. Glacial lake outburst floods (GLOF) are common in the River Baker, and one of them actually took place in the second week of May 2012 (see Fig. 36 in section 4.1.2.2). Sediment discharges in mires adjacent to the riparian zone were verified in the field. Similar phenomena are also reported during melting periods and extreme rainfall events (Vargas et al., 2007; Tauro, 2009). Thus, it is to be expected that rivers eventually influence the adjacent mires, despite these having an independent mire main water table. On the other hand, all mires have their own mire water table (Fig. 93, picture F), which is shaped by the water retention capacity, by the chemical properties of the peat, and by the water surpluses landing in the mire (runoffs, rainfall, fluctuations in the groundwater level, etc.). The mire water has a characteristic pH, which varies between 3.5 and 7.0 due to these factors, acidifying after rain events and alkalifying near to runoffs. According to these geomorphic and hydrological characteristics, five Hydrogeomorphic Mire Types can be inferred as representative of mires in the two river basins examined, as is shown in the next section. These hydrologic units can be grouped according to their nature in a) atmospheric water, b) terrestrial water and c) mire own water as Fig. 94 summarizes.

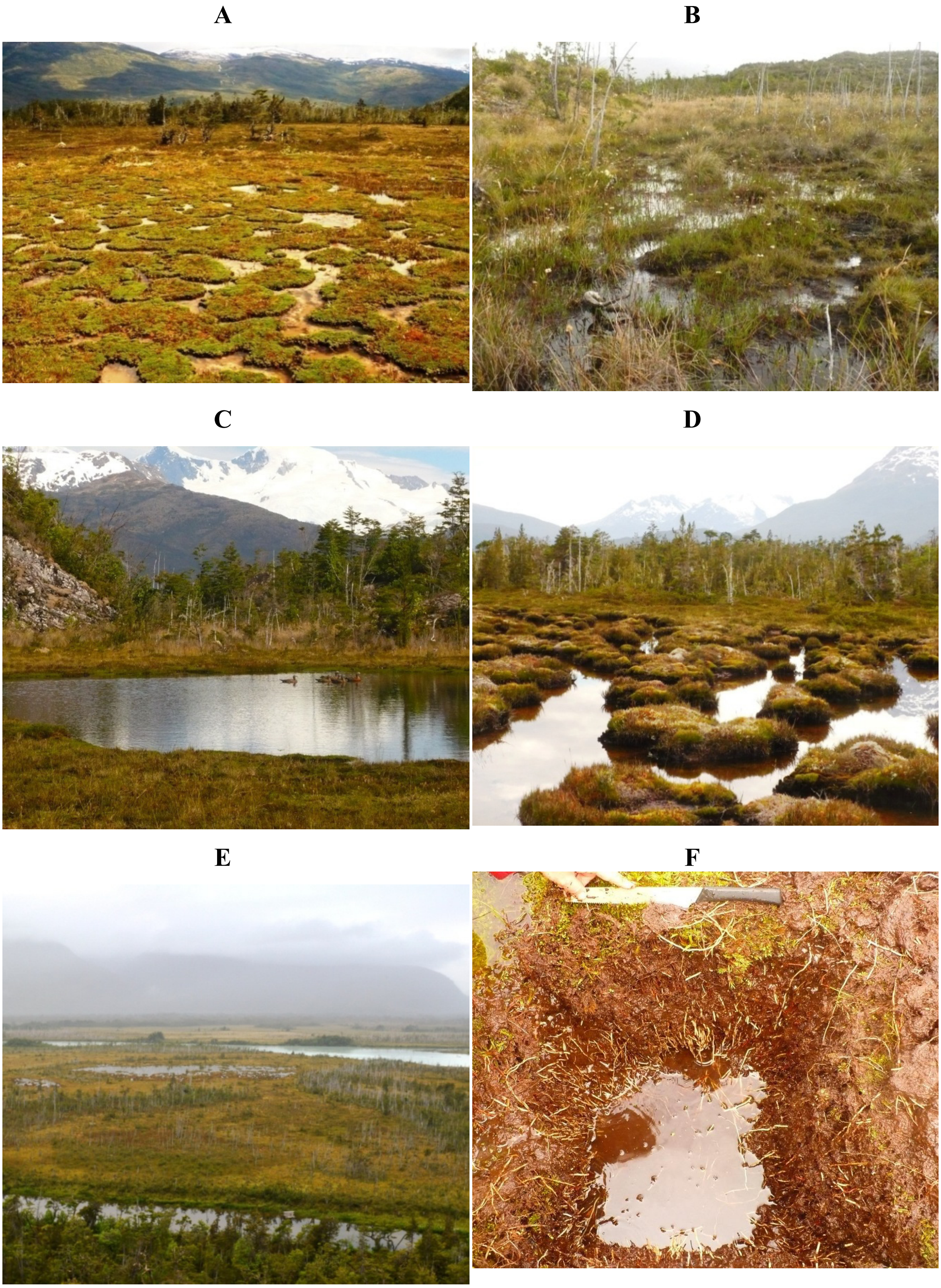


Fig. 93: Main hydrological units related to mires in Aysén (Rodríguez, field work 2012-2013)

A= rain water saturating an area colonized by cushion plants (Site QP). B= mountain stream feeding a mire (Site BP). C= mire with a central lagoon at the top of a mountain (Site BP). D= hummocks growing in a shallow pool (Site LV). E= Trero River (front) laden with brown organic material and Pascua River (behind) charged of glacial sediments (Site BP). F= mire main water table (Site LR)

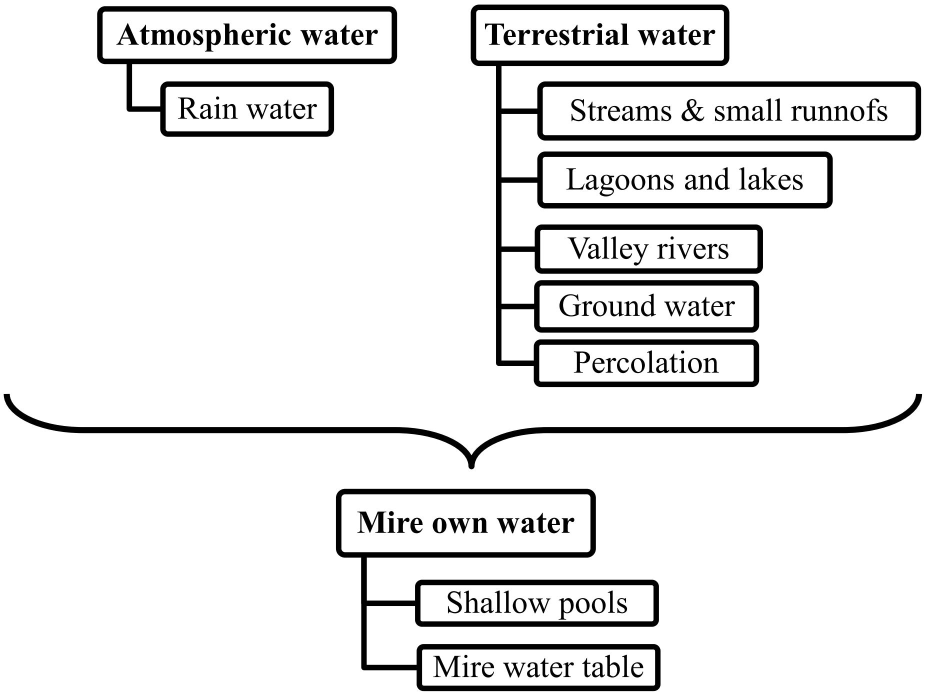


Fig. 94: Hydrologic units related to mire formation in Aysén

4.4.2 Second level of classification: hydrogeomorphic mire types

The concept hydrogeomorphic mire type means the discrimination of mires according to stereotypes that resume their hydrological and geomorphic characteristics. In the sites examined in Aysén, five hydrogeomorphic mire types can be recognized: raised bogs, sloping bogs, flow-through bogs, terrestrialization bogs and terrestrialization fens. Raised bogs are formed on flat relief and fed almost solely by rain water. Sloping bogs are formed on slopes, fed mainly by rain water, but also by percolation and lateral inflows. Flow-through bogs are also formed on slopes, presenting a central channel and additionally being irrigated by rain water and lateral runoffs. Terrestrialization bogs are formed from old relict glacial lakes in mountainous areas and are fed by both rain water and surface runoffs. Terrestrialization fens are formed from remnant lakes in landscape depressions and fed mostly by surface runoffs, percolation and groundwater. A detailed description of each hydrogeomorphic mire type is shown in this section.

4.4.2.1 Raised Bogs

Raised bogs are widely reported in rainy regions of the world (Cowenberg et al., 2005; Fritz, 2012; Mc Donald, 2009). These are ecosystems with a domed morphology which rises significantly above the landscape average level. These mires form in areas where rainfall exceeds the drainage and evapo-transpiration of the soil and they are fed exclusively by rain, being ombrogenic ecosystems. Despite this, raised bogs have a geogenic origin in Aysén, since most of them were detected growing above relic geogenic peaty horizons formed under paludification or terrestrialization. In other words, raised bogs are secondary ecosystems.

Current peat forming vegetation

Raised bogs dominated by *Sphagnum magellanicum* mosses are present all along the examined river basins. In coastal areas raised bogs are present in patches or are totally displaced by cushion plants species like *Astelia pumila* and *Donatia fascicularis*, forming blanket bogs. Particularly *Astelia pumila* and *Donatia fascicularis* species find specific habitats to develop above *Sphagnum* mires in coastal areas, forming patches and extending in circumference until they displace the previously dominating mosses. Also the water level can drive ecologic variations in raised bogs. In continental areas with high precipitation ponds and small pools of rain water accumulate. There, raised bogs can form hummocks composed of *Sphagnum magellanicum* mosses and the Juncaginaceae *Tetroncium magellanicum*, which can reach up to 150 cm in height (e.g. site LV). In continental areas with high precipitation, where the peat layer is still shallow enough to allow trees to grow, the *sphagnum* layer vegetation develops hummocks that cover the lower trunks of cypress trees, forming forest-covered hummock landscapes (e.g. LV). So, the current peat forming vegetation has a limited diversity in raised bogs, with merely a few main species *Sphagnum magellanicum*, *Pilgerodendron uviferum, Tetroncium magellanicum, Carex magellanica, Sphagnum fimbriatum, Pernettya mucronata* and *Marsippospermum grandiflorum.*

Hydrology

Raised bogs are fed exclusively by rain water. The peat formation takes place independently from the mire water table. This last presents an average level of 20±16 cmbs, but extreme variations can be found. For example, in the examined sites mire water tables from 4 to 130 cmbs were detected. A simplified and stereotypical schema of a raised bog is shown in Fig. 95.

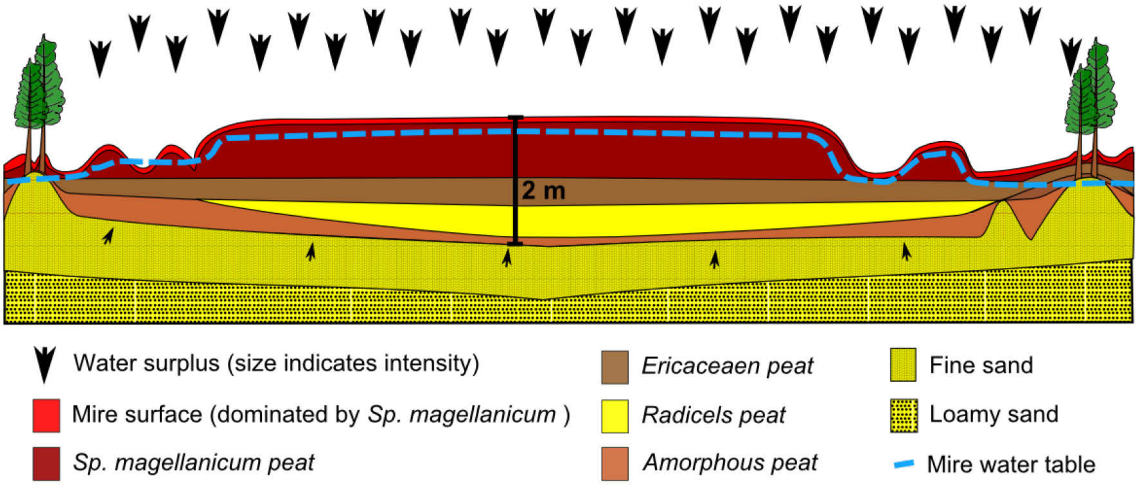


Fig. 95: Morphology, stratigraphy and hydrology of a raised bog (simplified schema)

Stratigraphy

Raised bogs in Aysén reach an average depth of 200 cm but can go as deep as 350 cm, presenting emblematic wide horizons of Ombrogenic peat above horizons of Geogenic peat, over loamy and fine sand parent materials. Raised bogs present typical substrate types (Fig. 96). The most common ombrogenic peat types in order of descending frequency are *Sphagnum magellanicum* peat, Ericaceae peat, cushion plants peat, *Oreobolus* peat and cypress wood peat. Under these, the geogenic peat types most common in raised bogs are in order of descending frequency amorphous peat, radicels peat, *Sp. fimbriatum* peat, brown moss peat and *Schoenoplectus* peat. The amorphous peat, as was explained before, is a typical indicator of water fluctuation and dry periods occurring in the mire. When the mire has its origin in a terrestrialization ecosystem, the substrate organic gyttja can be found. The majority of of non-amorphous peat substrates in raised bogs are very low to low decomposed (H3-H4). Considering all the horizons found in raised bogs, these ecosystems present a median pH-value of 4.0±0.6, covering a spectrum of 2.9 to 6.1 and decreasing significantly on the surface due to the action of *Sphagnum magellanicum* mosses (see Fig. 35, Fig. 55 and Fig. 65 in the chapters above). On the other hand, the average C/N ratiofor all examined horizons on raised bog ecosystems (including organic gyttja) exhibited a median of 45±14, evidencing oligotrophic conditions (see sections 4.1.4.1; 4.1.2.1, 4.1.4.1 and 4.1.5.1 above).

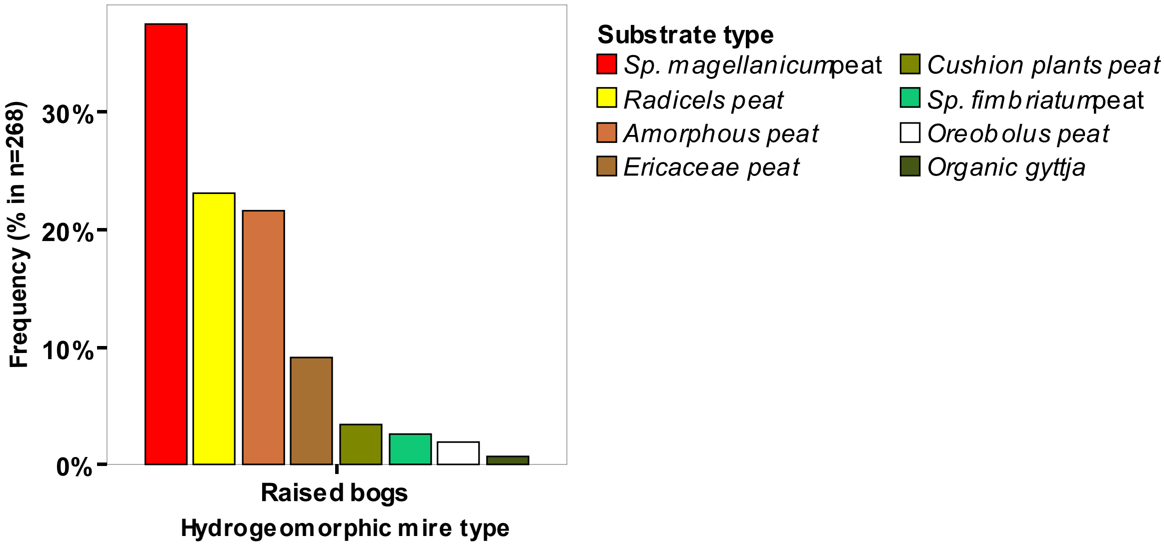


Fig. 96: Typical substrate types in raised bogs (n=268)

Distribution

Raised bogs are located in the lower basin of both the Pascua and Baker Rivers, specifically in valley basins, valley edges, flood plains and fluvial terraces. There, mires were observed especially in the sites LV, LR, QP3 and BP2 (Fig. 97).

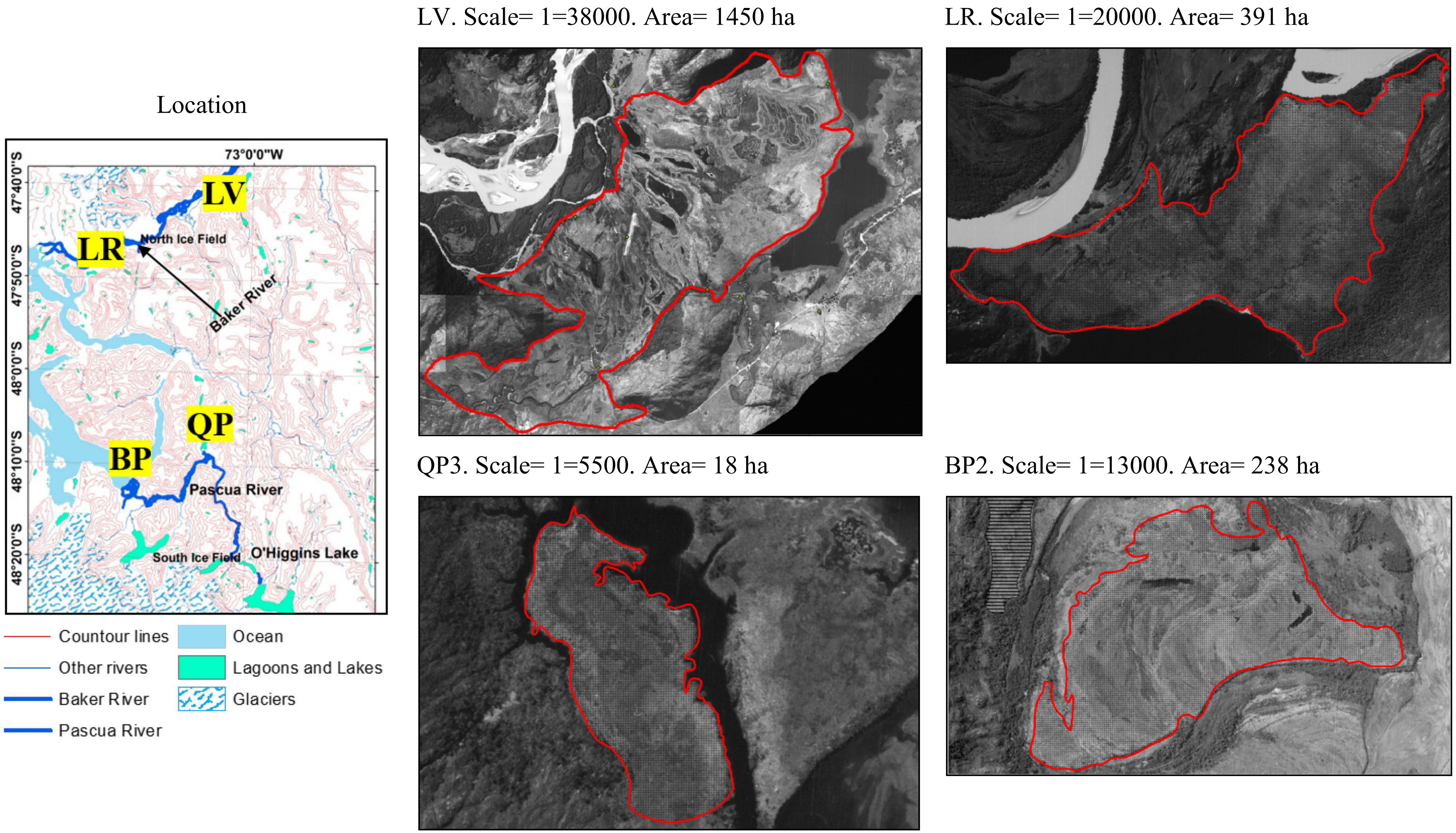


Fig. 97: Distribution and area of raised bogs examined in the sites LV, LR, BP and QP (modified from SAF)

4.4.2.2 Sloping Bogs

Sloping mires presenting minerotrophic conditions are reported in Germany (Jensen, 1961), in the U.S.A. (Chadde et al., 1998), in South Africa (Ollis et al., 2013) and are also present in Kyrgyzstan (own observations). In comparison, considering the vegetation and domed form of sloping bogs in Aysén, these present a current ombrogenic development. As their name indicates, sloping bogs grow presenting 3% to 9% inclination, and in Aysén they are principally present in sub-mountain and low alpine sectors. The current peat forming layer is mainly moistened by rainfall, presenting a convex morphology elevated from the landscape level. Sloping bogs originated in soils moistened by percolation waters, but their current peat formation is influenced principally by rainwater.

Current peat forming vegetation

The current vegetation is distributed in a water level gradient in sloping mires. The well drained upper area presents a *Sp. magellanicum* flat carpet, which is forest-covered by *Nothofagus dombeyi* and *Pilgerodendron uviferum* trees. On the downward slope the trees diminish and are replaced by shrubs of *Empetrum rubrum*, which can adapt to fluctuating saturated and dry conditions. The lower part of the slope is usually colonized by ombrogenic adapted rushes and sedges such as *Marsippospermum grandiflorum* and *Carex magellanica*. In the saturated lowest areas, patches of *Sp. magellanicum* and *Astelia pumila* associated with *Donatia fascicularis* definitively prevail. In other words, sloping bogs are forest-covered on their upper part, becoming raised bogs in their central-lower part where cushions of *Sp. magellanicum, C. magellanica* and *M. grandiflorum* prevail and finishing in blankets of cushion plants such as *A. pumila* and *D. fascicularis* on their lower part.

Hydrology

Sloping bogs originate in soils wetted by a mix of rainfall and percolation waters. Whilst rainfall is the main water source feeding the current peat forming layer in sloping bogs (i.e. the acrotelm), percolation water flowing laterally from the sides and upper part of the slope, influences the peat horizons underneath. Percolation inputs entering into a sloping bog are composed largely by rainfall. The high rainfall also infiltrates and moves through the soil vertically. Thus, the influence of the mineralized inputs in the forming peat layers is almost neutralized. Additionally, sloping mires present a domed shape, practically forming the raised bogs of the inclined areas, differing from these in the chemical and physical conditions of the peat layers underneath, which are more decomposed and thinner. An average mire water level of 31±27 cmbs characterized the examined sloping mires. These varied from 1 to 100 cmbs, tending to increase on the downward slope, sometimes even reaching the surface. According to these variations sloping mires tend to be forest-covered in their upper part and flooded in their lower part. The water level increases on the downward slope, allowing a higher peat accumulation and thickness in the lower areas than in the upper areas, and at the same time the development of trees is hindered. A simplified and stereotypical schema of a sloping bog is shown in Fig. 98.

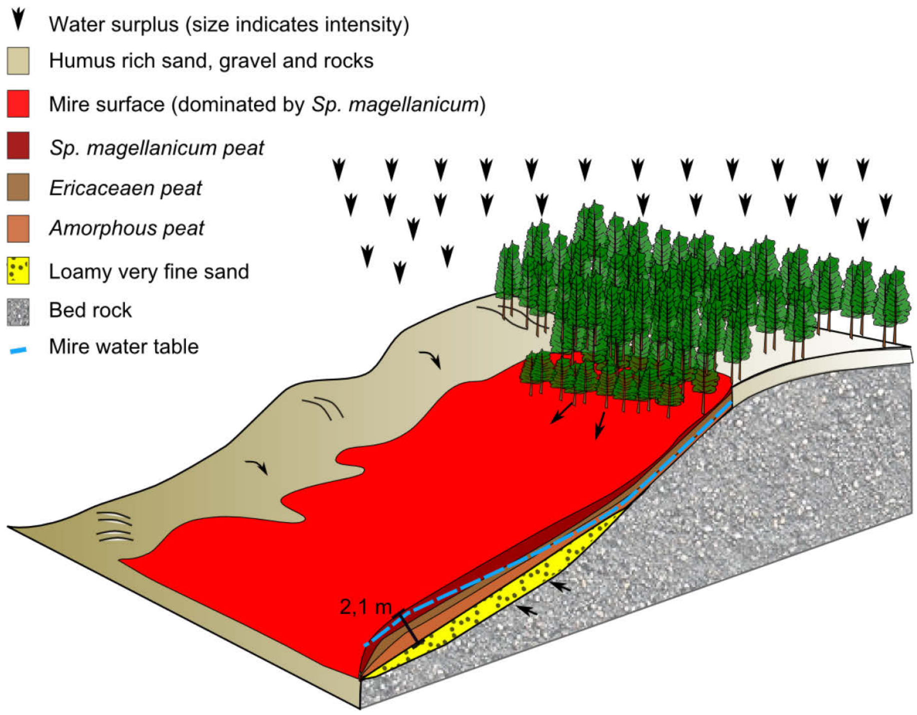


Fig. 98: Morphology, hydrology and stratigraphy of a sloping bog (simplified schema)

Stratigraphy

The median depth for the sloping bogs was 60 cmbs, with areas where the maximum depth was -2.1 m. These ecosystems present a characteristic stratigraphy of an ombrogenic peat horizon above geogenic peat, all lying over a mineral parent material of coarse to fine sized sand and loamy sand. Namely, sloping bogs are secondary ecosystems in Aysén. Considering their small size, sloping bogs occur as mires with diversified substrates, reflecting an adaptation to different water surpluses and different nutrient levels. Therefore, there are characteristic substrate types forming the sloping mires (Fig. 99). Among the ombrogenic peat types, the most common, in order of descending frequency, are *Sphagnum magellanicum* peat, Ericaceae peat, *Oreobolus* peat and cypress wood peat. The geogenic peat types most common in sloping mires are, in order of descending frequency, amorphous peat and radicels peat. An increment of Ericaceae peat was observed in sloping mires compared to raised bogs. Cushion plants peat is not present in the inclined area of sloping mires, but it is found on the lower ones, where the surface becomes flat and inundated. The majority of the peat in sloping mires presents degrees of decomposition from H3 to H4 (55% of the peat in QP1, QP2, BP1 and BP3). The decomposition of the underneath substrate increases quickly with the depth. For example, in the sites QP1, QP2, BP1 and BP3 amorphous peat represented 37% of the examined horizons, specifically those before the underlying mineral parent material.

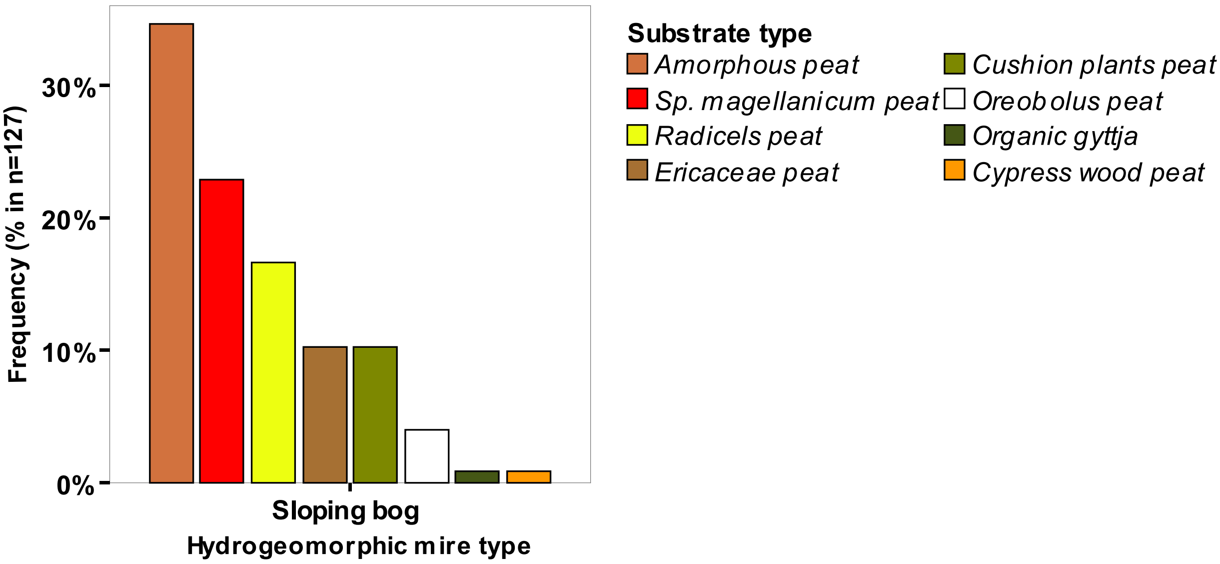


Fig. 99: Typical substrate types in sloping bogs (n=127)

According to soil cores extracted in the sloping areas of the sites QP and BP, it could be confirmed that the peat accumulation occurs in thin horizons along the mire, increasing in thickness on the downward slope. This implies different chemical and physical conditions in the under layers, corroborating percolation processes through the mire. On the other hand, considering all the horizons encountered in the sloping mires, these ecosystems present a median pH-value of 4.1±0.6, covering a spectrum from 2.3 to 5.3 (see Fig. 55 and Fig. 65 in the chapters above), while their C/N ratio presented a median of 32±9 (see sections 4.1.4.1 and 4.1.5.1).

The trophic level increases particularly in the upper horizons on the downward slope, where the effect of percolation water is lower than on the upward slope (e.g. as was mentioned for the site QP1 in the section 4.1.4.1)

Distribution

Sloping mires were found in low alpine sectors and low inclined slopes (Fig. 100). The sites QP1, QP2 and BP1 presented sloping mires marking a transition between the mountains and the low valleys of the Pascua basin. The sloping mire in the site BP3 was located in a intermountain depression.

4.4.2.3 Flow-through bogs

The flow-through bog is a type of mire growing across a slope with low inclination (≤5%) and presenting a small channel or stream running through it. The water of the small channel flows at a velocity which is low enough to permit saturation and periodical flooding of the lateral-connected terrain, the development of vegetation, and consequently, peat formation. In the U.S.A., Chadde et al. (1998) characterize under “flow-through bog” one of the major mire forms of the northern Rocky Mountains (U.S.A.), which are fed by percolating runoffs and by rainfall channelizing through the mire. In Germany, Schumann, and Joosten (2008) gave the name of “Spring-mire” to the ecosystems moisturized (moistened) by spring water on slopes and inclined areas. In South Africa, the concept of “channelled wetland” designs channelized ecosystems in valley bottoms (Ollis et al., 2013). Flow-through bogs of Aysén can be considered as a category integrating all the water sources (rainfall, lateral inputs, percolations and channel-flows) contained in these mentioned classifications. The peat level can even develop in the watercourse up to a height that covers and occupies the whole channel. The southern flank of the site BP1 is an example of a flow-through bog.

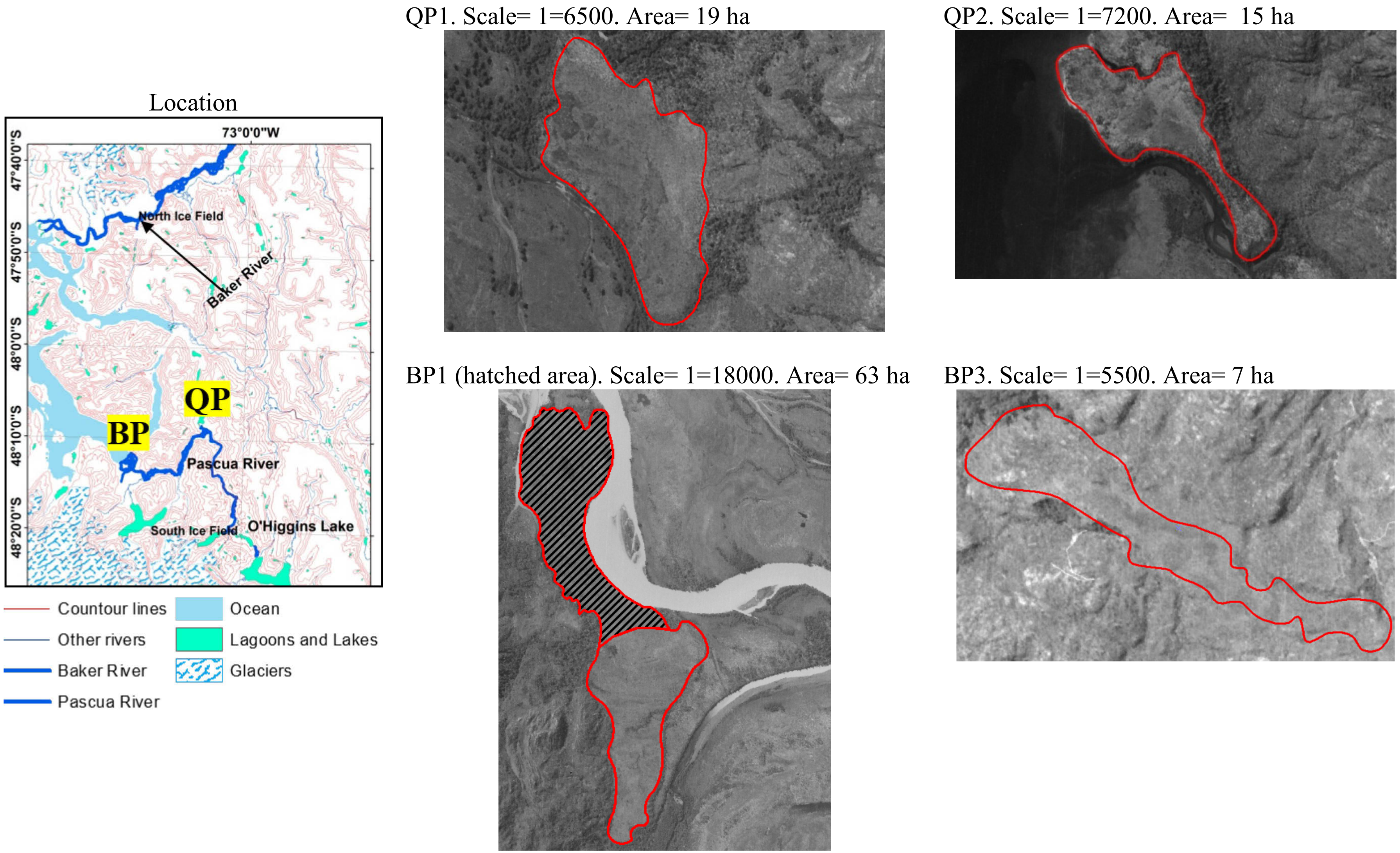


Fig. 100: Sloping bog mires examined in the sites BP and QP (Modified from SAF)

Current peat forming vegetation

When considering the site BP1, flow-through bogs are among the mires presenting the widest peat forming vegetation diversity, including *Sphagnum* species (*Sp. magellanicum*, *Sp. fimbriatum)*, brown mosses (*Dendroligotrichum dendroides, Dendroligotrichum squamosum)*, cushion plants (*Astelia pumila, Donatia fascicularis*), *Carex* species *(C. magellanica, C. chillanensis)*, and other vascular plants such as *Oreobolus obtusangulus*, *Drosera uniflora* and *Lepidothamnus fonkii,* amongst others. Flow-through bogs are dominated by mixed bogs presenting cushion plants and *Sp. magellanicum* mosses.

Hydrology

Although rainfall is the main hydrologic component in the coastal areas of Aysén, a particular type of small stream is what makes flow-through bogs hydrologically distinctive. Due to their inclination, these ecosystems exhibit the marks of major water dynamicity more than ecosystems with convexes or flat morphologies. Evidence of this is the major diversity of plant species, as is the different peat decomposition. In this way, depending on the rain or snow melting intensity, the intensity of the mire hydrological dynamicity will also be of influence (e.g. through periodical floods of the stream affecting the encompassing terrain with intervals of inundations and dryness, or through lateral flows and horizontal percolations influencing the edges of the mire), driving in this way different decomposition degrees and botanical peat types in flow-through bogs. In the flow-through bogs examined in this study, an average mire water level of 29±16 cmbs was registered, showing a spatial variation spectrum from -16 to 47 cmbs in depth. That is to say these ecosystems are hydrologically very dynamic.

A simplified and stereotypical schema of a flow-through bog is shown in Fig. 101.

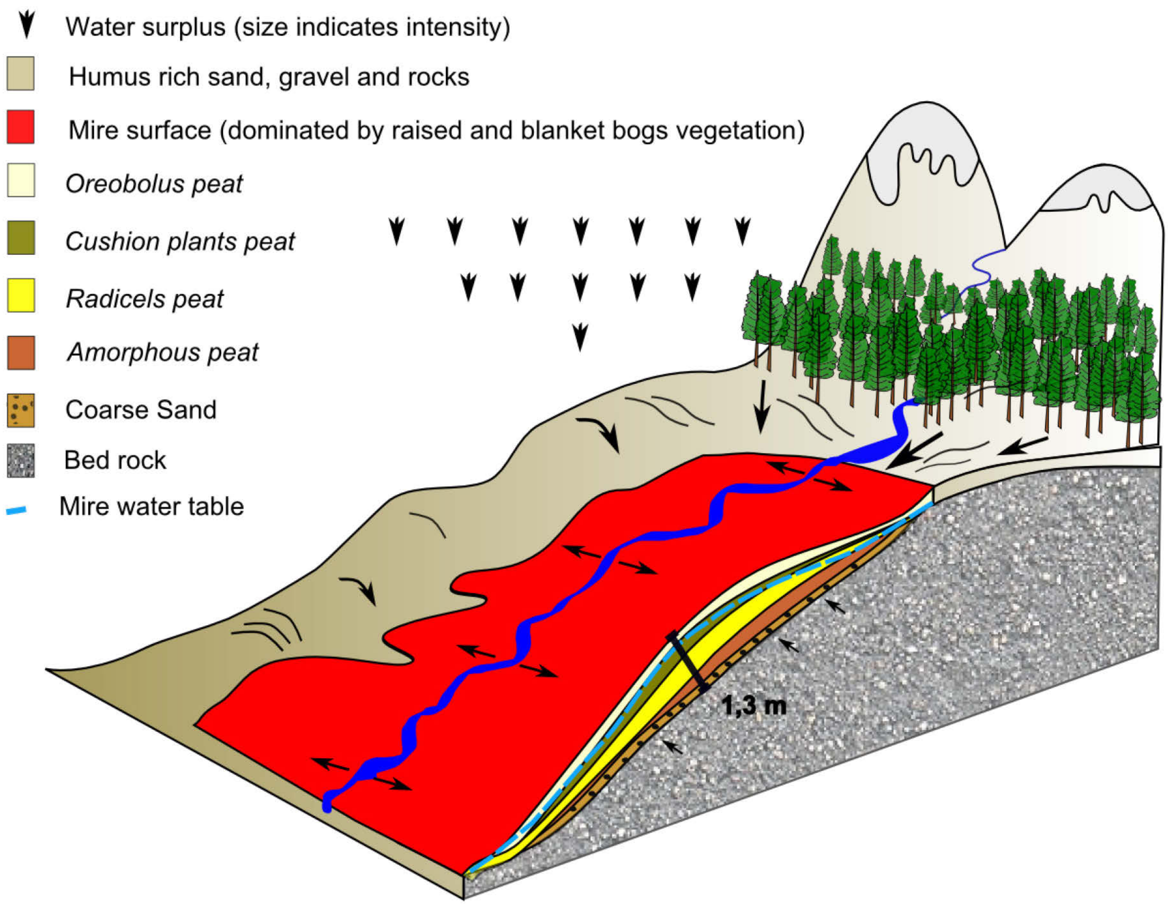


Fig. 101: Morphology, hydrology and stratigraphy of a flow-through bog (simplified schema)

Stratigraphy

Taking the site BP1 as an example, the stratigraphy of the flow-through bog is characterized by a median of 72 cmbs and a maximum of 130 cmbs. These ecosystems consist of a very thin ombrogenic peat horizon, above geogenic peat horizons, or sometimes only geogenic peat horizons, lying directly over the bedrock of the slope, normally composed of coarse to fine sands. Depending on the current peat forming layer (if it is ombrogenic peat above geogenic peat, or only geogenic peat over the parent material), these ecosystems will be primary or secondary. Flow-through bogs present some typical substrate types (Fig. 102). The most common are amorphous peat and the geogenic substrate radicels peat. Among the ombrogenic peat types, the most common, in order of descending frequency, are *Oreobolus* peat, cushion plants peat and *Sphagnum magellanicum* peat.

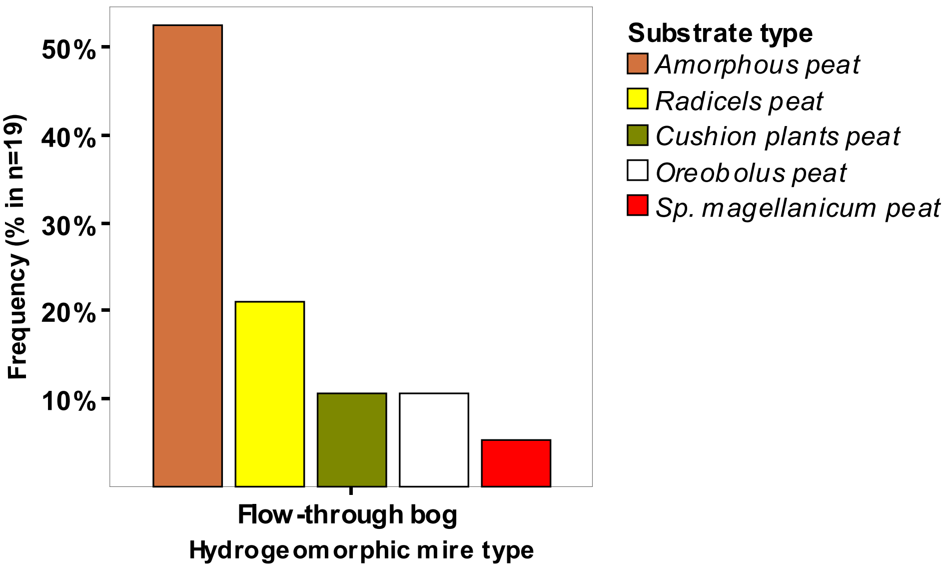


Fig. 102: Typical substrate types in flow-through bogs (n=19)

Considering all the horizons found in flow-through bogs, these ecosystems exhibit a median pH-value of 4.2±0.3, covering a spectrum from 3.7 to 4.6 (see Fig. 65). The C/N in flow-through bogs can reach an average of 34±11, which varies with the depth. For example in BP1 this parameter showed C/N= 26 in the upper peat layer, confirming a higher nitrogen availability as an effect of the running water across the mire than in the deeper horizons, where a C/N= 41 was found, evidencing nutrient poor conditions (see section 4.1.5.1 above). Nevertheless, the degree of peat decomposition increased quickly below the superficial ombrogenic peat horizon (approx. 10 cmbs). This was confirmed in the site BP1, where 60% of the sampled underlying horizons were composed by amorphous peat (H9 to H10), while those in the current peat forming layer presented degrees of decomposition from H3 to H4 (e.g. QP2). This evidence shows that the current formation of ombrogenic peat in flow-through bogs is periodically affected by water fluctuations, inducing the decomposition of the peat in the overlying substrate. Furthermore, recently formed ombrogenic peat of *Sp. magellanicum* is characterized by a low bulk density (≤0.07 g cm^3), whereby after intensive rainfall or floods, the available decomposed peat on the surface can be washed through percolation into the underlying horizons, increasing the presence of decomposed material on them. Additionally, although the superficial water fluctuations are the reason for the current mesotrophic conditions on the surface of flow-through bogs, it appears that the inputs of rain water via infiltration in these coast-mountainous ecosystems are intensive enough to reach the catotelm composed by amorphous and radicels peat, and induce oligotrophic conditions.

Distribution

Although only one flow-through bog (Fig. 103) was examined in this study, specifically the site BP1, a wide distribution of this sort of mire in the surroundings was observed, hence this may be one of the main hydrogeomorphic types occurring at the river mouths in the rainy areas of Aysén.

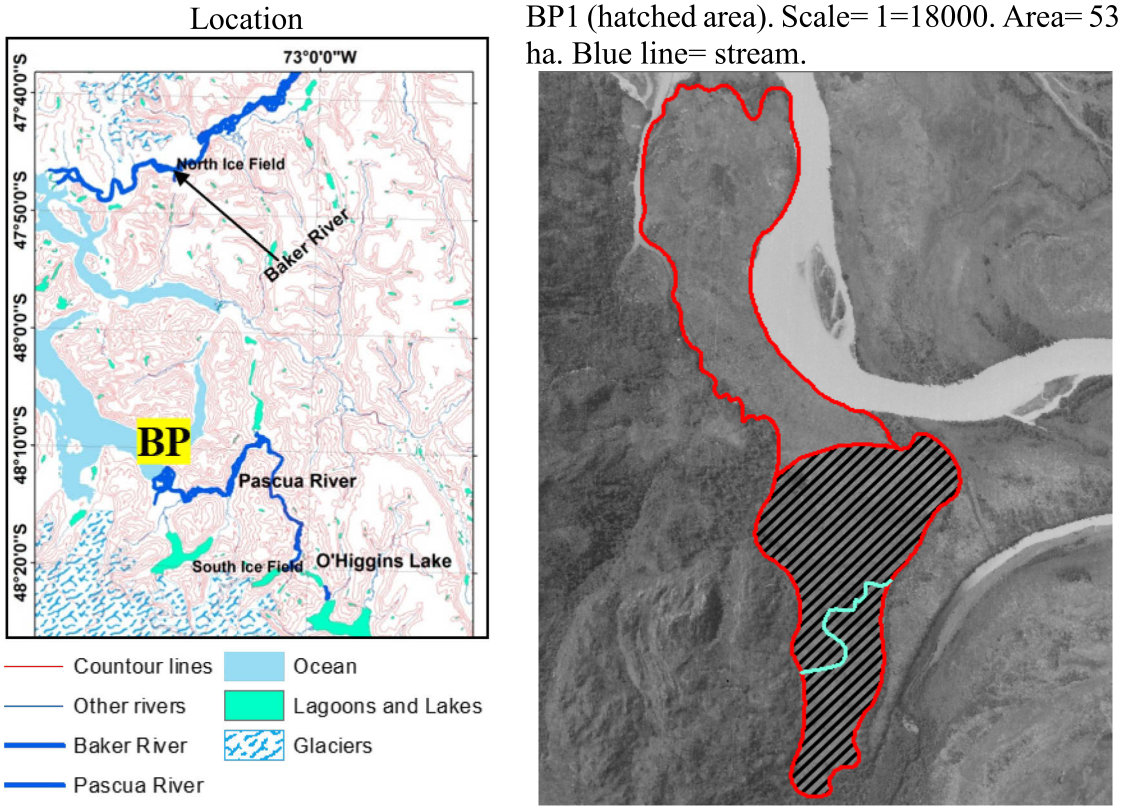


Fig. 103: Flow-through bog mire examined in site BP1 (modified from SAF)

4.4.2.4 Terrestrialization Bog

Terrestrialization mires are widely reported in the literature (Succow und Jeschke, 1986; Schumann and Joosten, 2008; Grootjans et al., 2010; Zhang et al., 2012) and due to their geogenic origin they are classified as primary mires. For the region of Aysén, a terrestrialization bog is conceptualized as an ombrogenic stage of a mire originated by terrestrialization. Terrestrialization bogs are mountainous ecosystems in Aysén, which have originated from pieces of ice left over from the last glacial retreat that anchored in low-alpine areas near the coast during the last glacial retreat. These anchored ice pieces melted and formed small lagoons. As in all standing waters, some organic and mineral materials turned into sediment at the bottom, forming a substrate known as organic gyttja. Over time, the organic gyttja accumulates and slowly replaces the volume occupied by the water, forming a new and vertically growing horizon. Additionally, organic materials are contributed laterally by the vegetation growing on the shore or floating in the water body and decaying onto the horizon. In this way, mires become terrestrialized from the shore to the centre by substrates formed by the shore vegetation; and from the centre to the shore by substrates formed by the floating vegetation. Once the soil of the system emerges, and semi-aquatic vegetation dominates the system, the terrestrial formation of peat engulfs the aquatic formation of organic gyttja until the remnant lagoon disappears. A central remnant lagoon and floating mats of vegetation can be found on terrestrialization bogs. The high precipitation rates of the maritime areas in Aysén (e.g. 2700 to 3300 mm yr-1 are reported by the DGA in the mouths of the Pascua and Baker Rivers respectively) favour the formation of typical raised bog vegetation in these mires, presenting a domed morphology. That is to say their bog condition is a successional stage after the terrestrialization, under which the influence of rainwater surmounts that of the mire water level and of the central remnant lagoon.

Current peat forming vegetation

Terrestrialization bogs are characterized by a vegetation gradient starting with the domination of Cyperaceae (*C. magellanica*) and Juncaginaceae species (*T. magellanicum*) in the less saturated edges of the mire. The gradient continues into the centre with hummocks of *Sp. magellanicum* mosses, and ends in blankets of *A. pumila* and *D. fascicularis* which turn into floating mats confined in the remnant water. In terrestrialization bogs, similar to that reported for mires in Magallanes and Tierra del Fuego (Kleinebecker, 2007; Abel, 2009; Teltewskaja, 2010; Grootjans et al., 2010), where *A. pumila* grows above *Sp. magellanicum* mosses, this plant replaces them and forms the most actual vegetation.

Hydrology

A small central lake is the distinctive hydrological component of terrestrialization bogs. However, these mires in their current bog phase are for the most part more influenced by rainfall, even though it is altogether correct to speak of mixed water sources. Due to its mountainous location, they may also receive lateral inputs from the surrounding relief. The mire water table observed for the terrestrialization bog at site BP4 was of 15±16 cmbs, without variations over the domed mire level and across to the central remaining lake. A simplified and stereotypical schema of a Terrestrialization Bog is shown in Fig. 104.

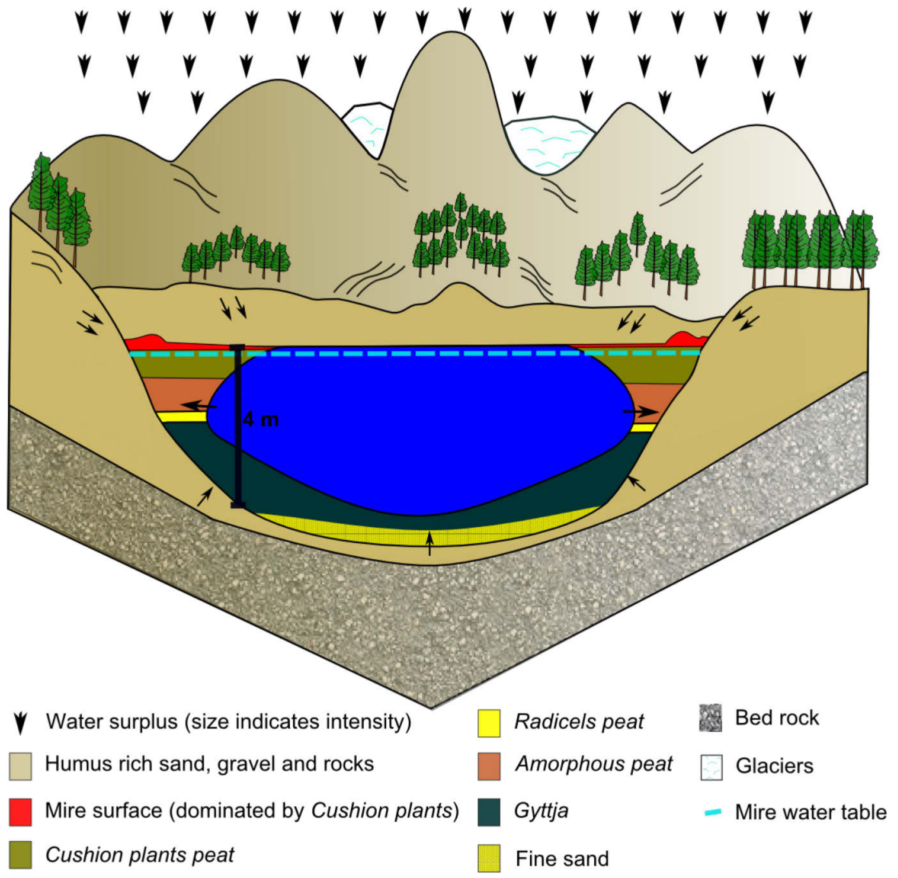


Fig. 104: Morphology, hydrology and stratigraphy of a terrestrialization bog (simplified schema)

Stratigraphy

The median depth in terrestrialization bogs was 141 cmbs, with areas where the maximum depth was 340 cmbs. These ecosystems present typical substrate types (Fig. 105), characterized by ombrogenic peat horizons of cushion plants peat, above geogenic peat horizons of amorphous peat above an horizon of organic gyttja, all over coarse to fine sands. Terrestrialization bogs are less prone to floods, percolations and runoffs, presenting homogeneous horizons and little substrate variation, with degrees of decomposition varying from H3 to H8 in the non-amorphous material. Peat accumulation occurs in large horizons along the mire. The most characteristic substrate of terrestrialization bogs is organic gyttja, which forms from organic supplies decanting at the bottom of still water bodies. Apart from the organic gyttja, ombrogenic and geogenic peat types can also be found in terrestrialization bogs. Among the ombrogenic peats, the most common, in order of descending frequency, are cushion plants peat, *Sphagnum magellanicum* peat and Ericaceae peat. The most common geogenic peat types are amorphous and radicels peat.

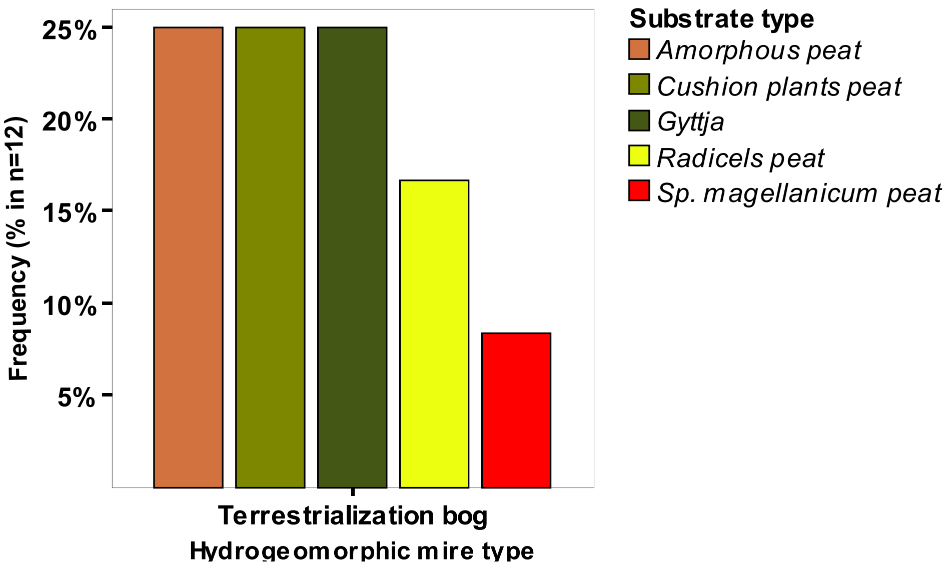


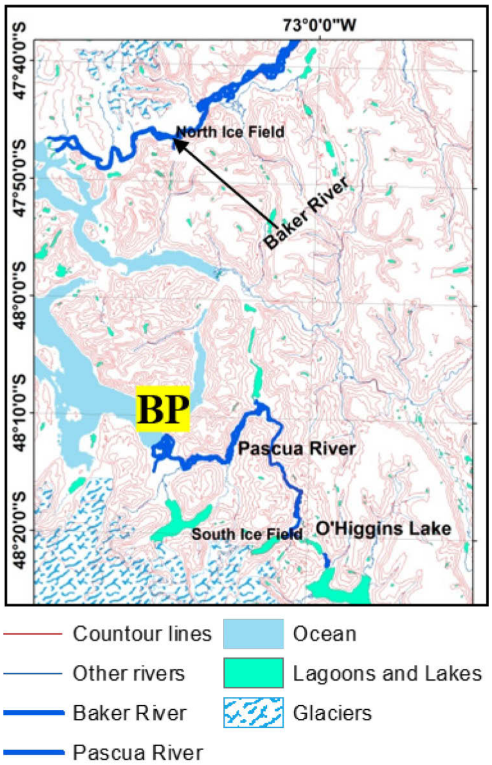
Fig. 105: Typical substrate types in terrestrialization bogs (n=12)

It is difficult to define if the amorphous peat in terrestrialization bogs was originated due to the root system of *Astelia pumila* (cushion plant dominating these sites), or due to fluctuations in the mire water level. Terrestrialization bogs show a wide presence of cushion plants peat in their upper horizons, underneath ample horizons of amorphous peat and marginal deposits of Ericaceae peat, radicels peat and *Sphagnum* peat, most of them mixed with each other or enclosed in the amorphous peat material. Although *A. pumila* is the main species in terrestrialization bogs, these isolated plant remains in the deeper horizons suggest that the preceding terrestrialization of these sites were dominated by species other than *A. pumila*. This plant tends to colonize sites where *Sphagnum* mosses, *Carex magellanica, Oreobolus obtusangulus* and other peat forming plants already developed a peaty soil. Since *A. pumila* prefers poor nutrient saturated sites for its settlement, it is probable that the current amorphous material was formed by those peats still found as marginal deposits (Ericaceae peat, radicels peat and *Sphagnum* peat), and that these were low decomposed before *A. pumila* established in the site. Considering all horizons reviewed in the site BP4, the substrates composing terrestrialization bogs can be characterized by an average pH-value of 4.2±0.5. The values varied in a spectrum from 3.4 to 5.1 (see Fig. 65 above). The average C/N ratioreached of 34±3.7 (see section 4.1.5.1 above). These values evidence strong acidic and oligotrophic conditions for terrestrialization bog ecosystems.

Distribution

Located on the top of a low alpine terrace near the mouth of the Pascua River, the site BP4 is the stereotype of a terrestrialization bog (Fig. 106). Considering that the sub-coastal areas of Aysén and Magallanes present mountainous relief and longitudinally increasing rainfall, it is expected that similar ecosystems extend across the entire Patagonian archipelago.

Location



BP4 (hatched area). Scale= 1=3500. Area= 1 ha. Lighted polygon= remnant lagoon.

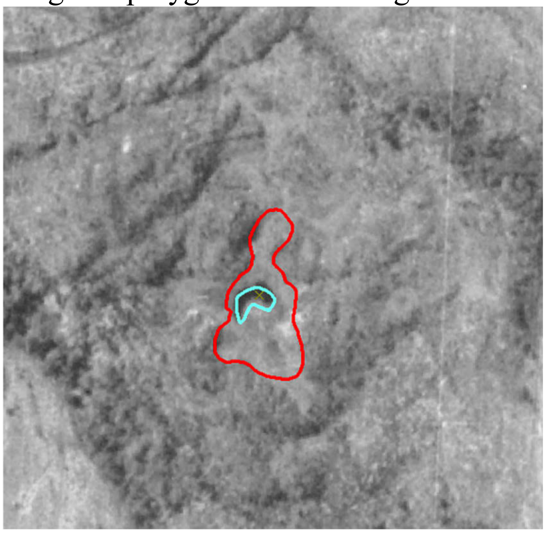


Fig. 106: Terrestrialization bog examined in site BP4 (picture modified from SAF)

4.4.2.5 Terrestrialization Fen

Terrestrialization fens were already recorded in Germany by Succow and Lange in 1984 under the name of "Ancient lake mires", and since then they have been widely mentioned in the literature for different regions of the world (Succow und Joosten, 2001; Ringler, 2005). Terrestrialization fens have a flat morphology, obeying the shrinkage and sagging processes. Terrestrialization fens form in places where standing water bodies were volumetrically occupied by plant remains and organic materials, which formed sediment at the bottom (primarily as organic gyttja, and later as peat), giving way to a semi-aquatic to terrestrial ecosystem, i.e. a mire. Compared with terrestrialization bogs that are widely determined by rainfall water, terrestrialization fens are principally influenced by nutrient enriched water inputs in the form of runoffs, percolation and groundwater. A central remnant lagoon and floating mats of vegetation are distinctive elements in terrestrialization fens. These hydrogeomorphic types mostly have a flat morphology, almost level with the soil water and the standing water of their remnant lagoon. However, ombrogenic peat can also be formed above geogenic horizons that are thick enough to separate from the nutrient rich mire water level.

Current peat forming vegetation

Pilgerodendron uviferum and *Nothofagus dombeyi* are the main species on the borders of terrestrialization fens. In the middle, nutrient enriched areas are signalized by the mosses *Sp. fimbriatum* and *Acrocladium auriculatum*. Where the peat layer becomes thick enough to separate from the mire water table, some *Sp. magellanicum* hummocks manage to develop, marking a small oligotrophic area. But sedge*s (Hordeum comosum)* and in particular rushes *(Schoenoplectus californicus)* and the reed *Eleocharis melanostachys*, are the main peat forming plants in these ecosystems.

Hydrology

As in terrestrialized bogs, a small remnant lagoon is the distinctive hydrological component of terrestrialized fens. Lateral runoffs enriched by organic and mineral substances present on the surrounding soils are the main water surpluses of these ecosystems, followed by the ground water, i.e. terrestrialized fens are for the most part more influenced by mineralized water than by rainfall. Their water table is almost at the surface (e.g. in the site VO it was 4 to 12 cmbs). Since floating mats act as a buffer between the remnant lagoon and in the soil fixed mire area, floods do not normally affect these ecosystems and water fluctuations behave vertically. These ecosystems present a high homogeneity in their horizon formation. A simplified and stereotypical schema of a terrestrialization fen is shown in (Fig. 107)

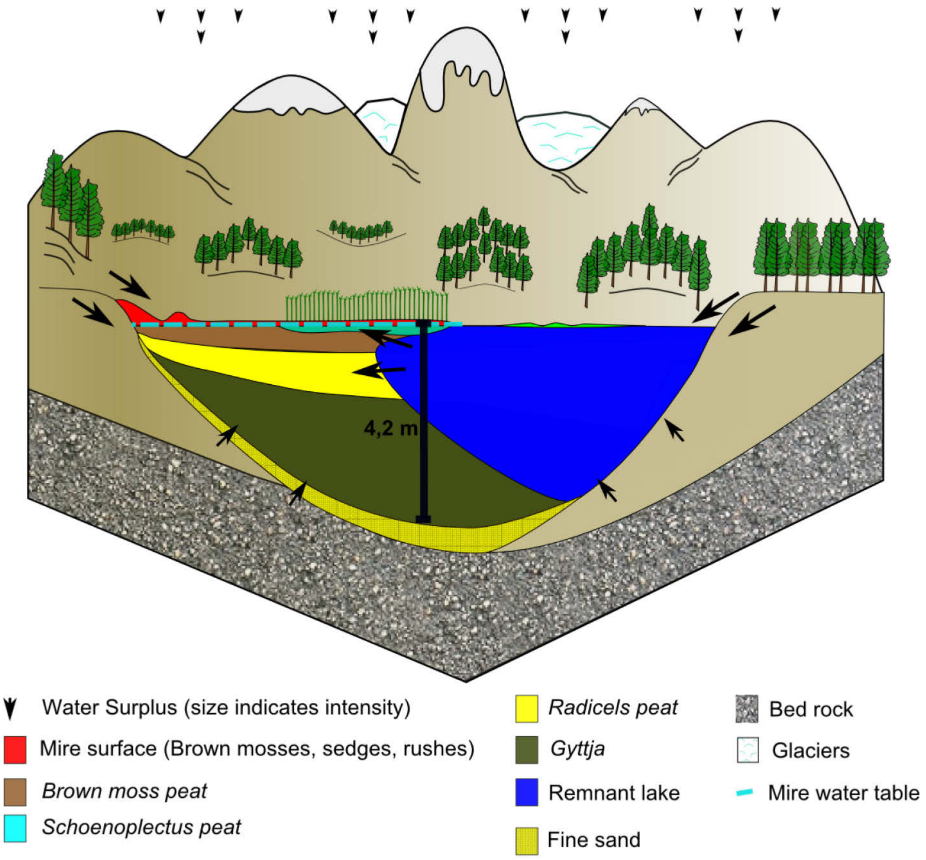


Fig. 107: Morphology, hydrology and stratigraphy of a terrestrialization fen (simplified schema)

Stratigraphy

Considering the site VO, the median depth in terrestrialization fens reached 181 cmbs, with maximum values around 420 cmbs. These ecosystems present a stratigraphy characterized by geogenic peat horizons of brown moss peat, radicels peat and/or *Schoenoplectus* peat, above amorphous peat, above a horizon of organic gyttja, all over silty loam or fine sand. As ecosystems formed from still water bodies, terrestrialization fens present homogeneous horizons and little substrate variation. Their degree of peat decomposition varies from H3 to H8 in the non-amorphous material, with this last always presenting >H9. Peat accumulation occurs in large horizons along the mire. The most characteristic substrate of terrestrialization fens is organic gyttja, which formed 36% of the horizons found in VO. The peat types most commonly found in VO are, in order of descending frequency, amorphous peat, radicels peat, brown moss peat and *Schoenoplectus* peat (4%). Their comparative frequency is exposed in Fig. 108. Horizons of *Sp. magellanicum* peat can be also detected, specifically above thick geogenic horizons that are elevated from the mire water table and whose main input is currently rain water. Since these mires are surrounded by native forest, cypress wood remains forming patches of peat are also to be found. Considering all the examined horizons, the substrates composing the horizons of terrestrialization fens can be characterized by a pH-value of 5.6±0.9, varying from 3.5 (*Sp. magellanicum* peat) to 7.3 (organic gyttja) (see Fig. 45 above) and presenting a C/N=20 in the upper soil, evidencing mesotrophic conditions (see section 4.1.3.1 above).

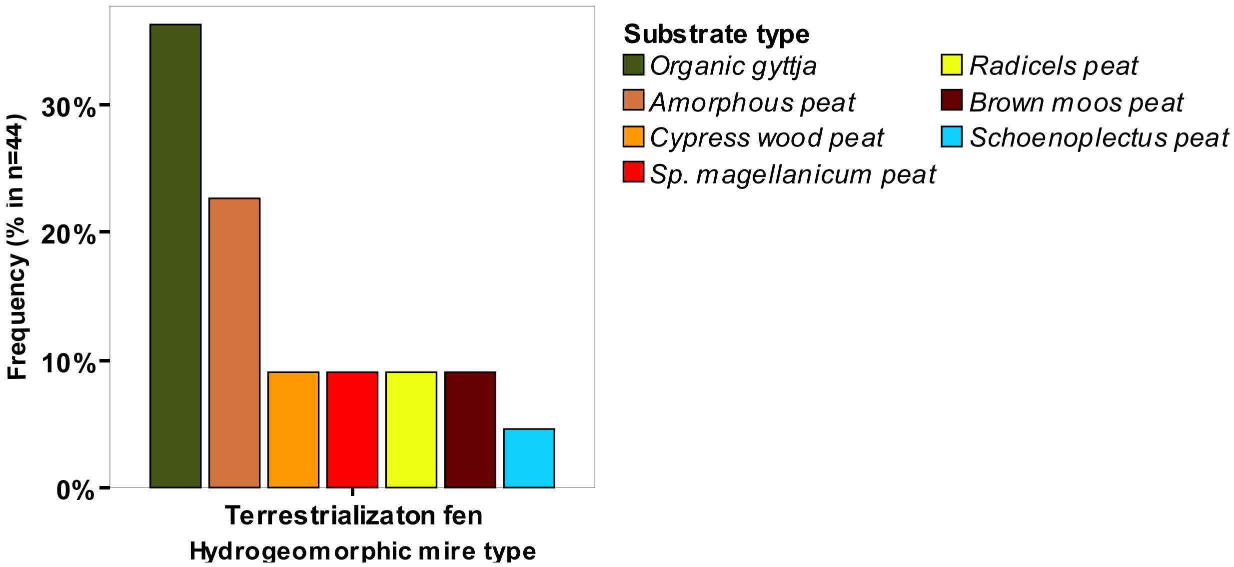
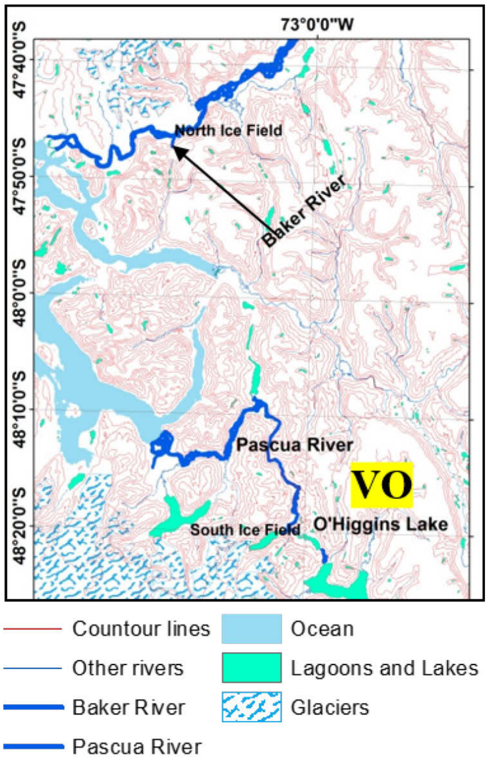


Fig. 108: Typical substrate types in terrestrialization fens (n=44)

Distribution

Terrestrialization fens were detected through aerial pictures and confirmed through personal explorations in the sector of Villa O'Higgins (Fig. 109). The site VO was the most representative regarding vegetation and relief. The formation of these ecosystems is to be expected in the eastern sector of Aysén, in different landscape morphologies with superficial inflows, with mineral enriched inputs the primary water source of these mires.

Location



VO. Scale= 1=6000. Area= 4.1 ha. Polygon highlighted in blue= remnant lagoon

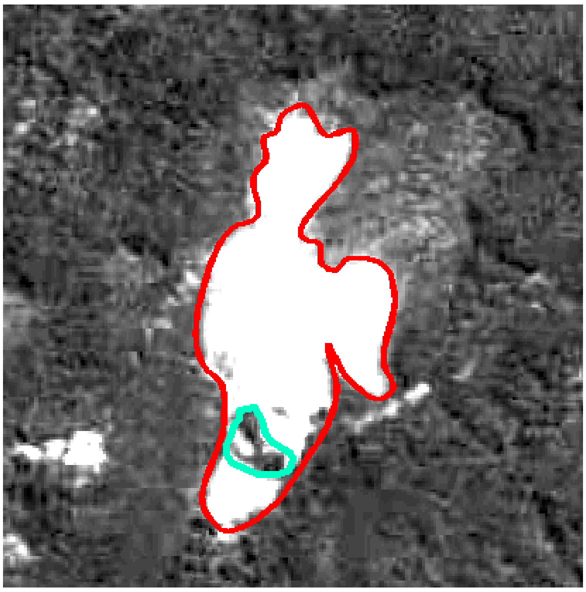


Fig. 109: Terrestrialization fen examined in site VO (modified from SAF)

4.4.2.6 Classification in primary and secondary hydrogeomorphic mire types

As was explained in the above section, each hydrogeomorphic mire type presents a characteristic origin and development according to their water surplus and relief. On the other hand, and as was exposed above, the hydrogeomorphic mire types can be separated as proposed by Succow und Joosten (2001) according to their successional stage in primary and secondary ecosystems. For example, flow-through bogs and terrestrialization fens are primary mire ecosystems, which developed directly above the mineral parent material, mainly influenced by surface runoffs and percolating groundwater. Sloping bogs, terrestrialization bogs and raised bogs belong to the category of secondary ecosystems, which originated above the pre-existing primary ecosystem. In secondary mires, the accumulation of peat led to surface elevation that causes the vegetation to be increasingly independent from the surface runoff and groundwater, configuring an ecosystem with predominating rain water influence. The hydrogeomorphic types are summarized according to their successional development in Fig. 110.

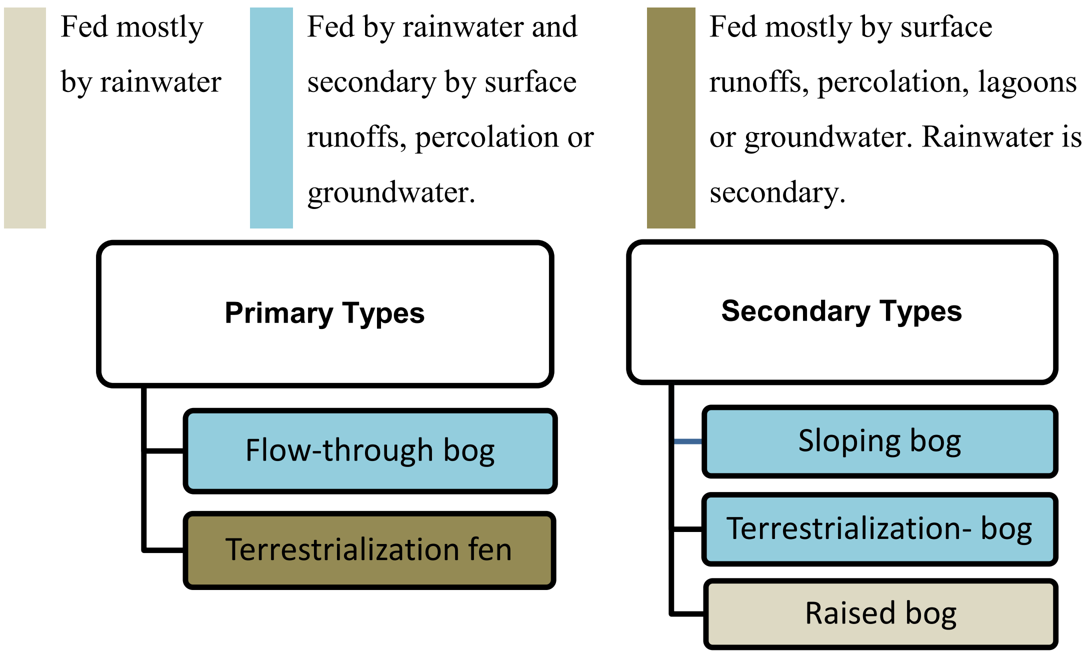


Fig. 110: Hydrogeomorphic mire types of Aysén classified according to their primary and secondary successional types

As Fig. 111 illustrates, the maritime continental gradient predominating in Aysén is reflected in the distribution of the hydrogeomorphic mire types.

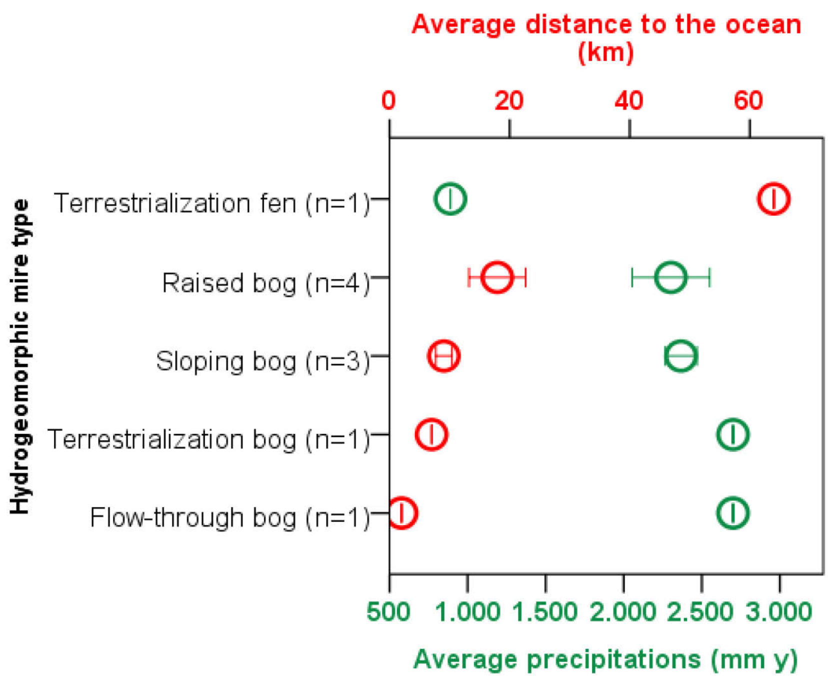


Fig. 111: Distribution of HGMT according to rainfall and distance to the ocean

During this research some recurrent archetypes of vegetation diversity and physiognomy were observed, which were representative of the ecological conditions prevailing in the hydrogeomorphic mire types along the Baker and Pascua Rivers. These archetypes were synthesized into eight main mire ecotypes, which are described in detail in the next section.

4.4.3 Third level of classification: mire ecotypes

Plant communities can be considered as indicators of the soil acidity, water level and nutrient conditions of a site, and have been used as keys to peatland classification worldwide (Succow und Joosten, 2001; Kleinebecker, 2007; Keßler et al., 2011). Since in this work a close similarity was found in the data about the chemical and nutritional status of the examined sites (with the single exception of the site VO), the concept *Mire Ecotype* is proposed as a better option to differentiate amongst the different plant communities forming part of the mire types classified above. The concept discriminates between eight main stereotypes of vegetation diversity and physiognomy observed in the ten examined mires along the Baker and Pascua Rivers. These mire ecotypes are:

1. Raised bogs dominated by mosses of the species *Sphagnum magellanicum*
2. Flooded hummocks dominated by mosses of the species *Sp. magellanicum* and by the Juncaginaceae *Tetroncium magellanicum*
3. Forest-covered hummocks dominated by mosses of the species *Sphagnum magellanicum* and *Pilgerodendron uviferum*
4. Blanket bogs dominated by cushion plants such as *Astelia pumila* and *Donatia fascicularis*
5. Mixed bogs dominated by raised and blanket bog plants
6. Oligotrophic floating mats dominated by cushion plants such as *Astelia pumila* and *Donatia fascicularis*
7. Blanket fens dominated by brown mosses, sedges and rushes
8. Mesotrophic floating mats dominated by blanket fens plants

Differing from the ecologic classification proposed by Succow und Joosten (2001), these eight mire ecotypes are more differentiable according to their C/N than according to their pH-values (Fig. 112).

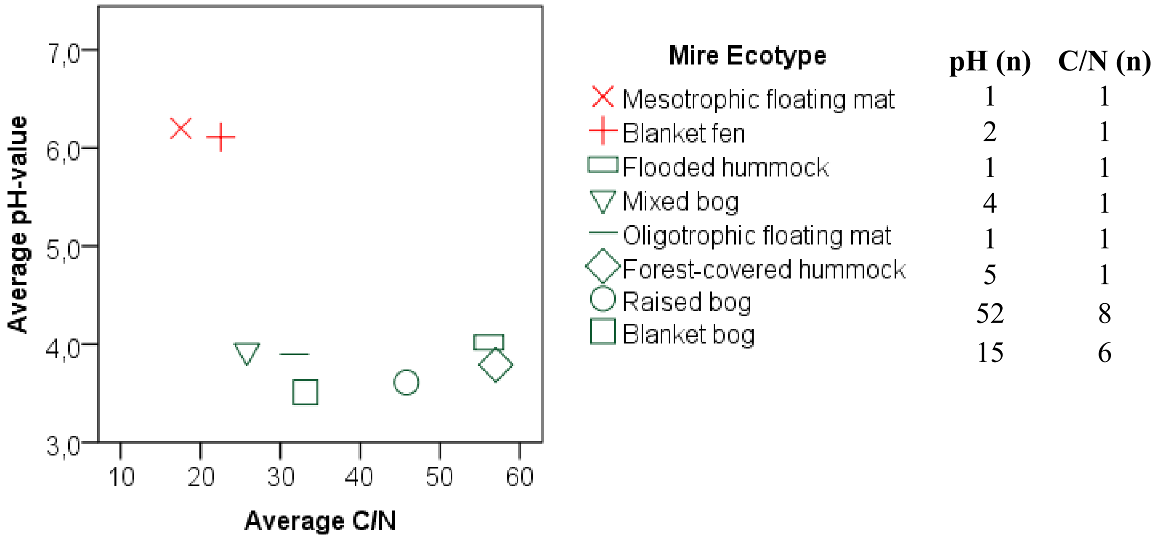


Fig. 112: Distribution of mire ecotypes according to their upper soil pH-value and C/N

The variation of mire ecotypes is driven by three main factors. The first one is the influence of rainfalls. A clear gradient is evidenced from areas where precipitations surpase 1300 mm y^{-1}, and ME present oligotrophic conditions, to areas where the rainfall decrease to 890 mm y^{-1}, and ME present mesotrophic conditions. The second factor is the intensity of oceanic exposure. A gradient is produced from trans-andes continental ME dominated by sedges, rushes and brown mosses, transiting to continental oligrotrophic ME dominated by *Sphagnum* mosses and ending in maritime moderate oligrotrophic ME where cushion plants like *Astelia pumila* prevail. A third factor is the water level in the mire. Water levels above the surface allow specialized vegetation, i.e. floating mats, to develop, while water levels under the surface allow mosses, vascular plants and even forest-covered colonized ME to develop. All ME presented as follows are only a resumed expression of the diversity of ecosystems associated to the particular hydrogeomorphic mire types detected during this study.

4.4.3.1 Raised bogs of *Sphagnum magellanicum*

Kleinebecker (2007) classified *sphagnum*-bogs as the most continental of three main botanical types of mires in the Magellan Strait and on the Island of Tierra del Fuego. In this study, it was corroborated that this ecotype occurs along a geographical continuum, which C/N varies from 31 to 65, with a median of 44.6 and the pH-value from 2.5 to 5.5. These values varied according the hydrogeomorphic mire type (Tab. 22). *Sphagnum magellanicum* mosses are the dominant species in raised bogs. Other disseminated species growing above the *Sphagnum* mosses cover are in order of descending frequency *Carex magellanica, Marsippospermum grandiflorum, Empetrum rubrum,* and *Tetroncium magellanicum.* Also the species *Nanodea muscosa, Myrtheolia nummularia, Drosera uniflora* and *Pernettya mucronata* are present in these ecotypes, varying in abundance according to the dominance or retreat/recession of these main species. This ME represented 72 % of the total mire areas examined in this study (2297 ha) and was mostly associated with the hydrogeomorphic mire types raised bogs and sloping bogs. The site LV was almost totally dominated by this ecotype (Fig. 113), but it was also widely disseminated in the sites of LR, QP1, QP2, QP3 and BP2. Also extends to the maritime areas (e.g. BP2, which is 2 km away from the coastline).

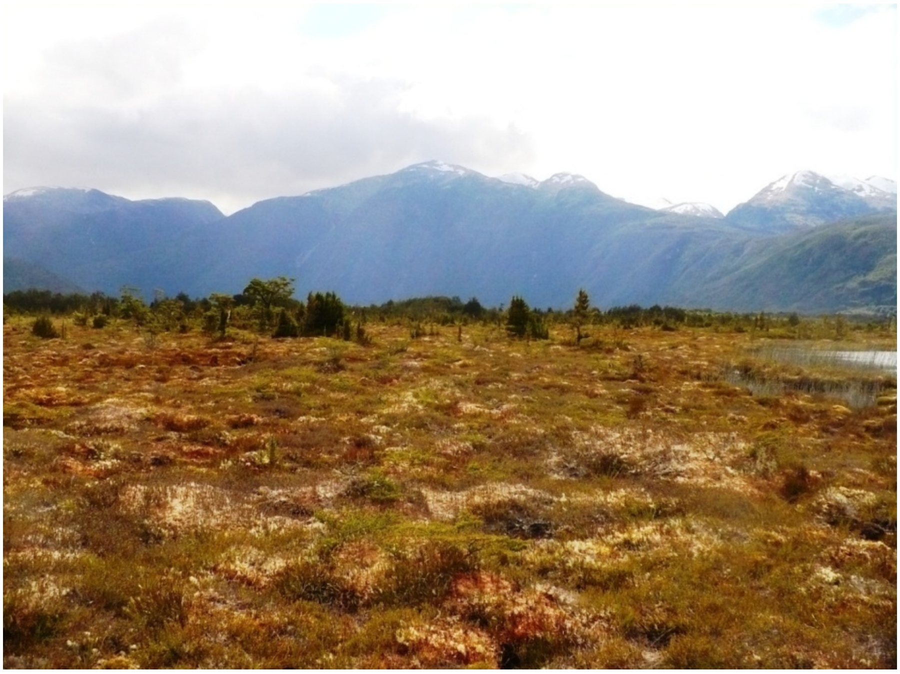


Fig. 113: Raised bog ecotype dominated by *Sp. magellanicum* in the site LV

However in comparison to the observations of this author, it seems to be that the mountainous archipelagic relief of Aysén attenuates the intensity of the salt enriched westerlies, which in the coastal areas of southern Patagonia increases the soil nutrition level, contributing to the displacement of raised bogs by blanket bogs of cushion plants. In other words, in Aysén, this ecotype variation is determined, not only by proximity to the ocean, but by the intensity of the exposure to the salt enriched westerlies coming from the Pacific Ocean. Raised bog ecotypes are particularly present in areas of heavy rainfall, with rates reaching 1300 to 3300 mm y^{-1}. They were found in a wide longitudinal spectrum from 39 to 2 km distant from the ocean, always less than 50 m a.s.l. This ecotype can develop exposed to all points of the compass, mostly preferring flat relief. Nevertheless a small section was detected in areas with up to 9% inclination, and very exceptionally up to 27%.

4.4.3.2 Flooded hummocks of *Sphagnum magellanicum* and *Tetroncium magellanicum*

This ecotype was exclusively found in continental areas (39 km distant from the coast) with a median rainfall of 1300 mm y^{-1} and less than 50 m a.s.l. associated with flat areas with a north-easterly exposure. They develop in shallow territories and depressions inside raised mires, where the rain water accumulates and joins the mire water table, together forming small pools or flooded areas over the mire landscape. In these flooded areas, typical hummocky vegetation grows forming isolated cushions that rise over the water level. These cushions can reach up to 150 cm in height. In other words, these hummocks are an example of how the water level drives ecological and morphological variations in raised bogs. The C/N sampled in one profile presented 56. The pH-value detected in the upper soil presented a median of 4.4. Besides the distinctive *Sphagnum magellanicum* mosses, a characteristic species of this ecotype is the Juncaginaceae *Tetroncium magellanicum*, which grows above the *Sphagnum* layer. Since the hummock morphology offers an ecological niche protected from the surrounding saturation, similar species to those found in raised bogs can also be found in this ecotype (*Carex magellanica, Marsippospermum grandiflorum, Empetrum rubrum, Nanodea muscosa, Myrtheolia nummularia, Drosera uniflora, Pernettya mucronata* and *Empetrum rubrum),* while in the flooded area, the moss *Sphagnum cuspidatum* was found. This mire ecotype was exclusively associated with the hydrogeomorphic mire type raised bog in the site LV (Fig. 114), and in the site BP2. It represented 11% of the total mire areas examined in this study (2.297 ha).

Fig. 114: Flooded hummocks ecotype with *Sp. magellanicum* and *T. magellanicum*. Site LV

4.4.3.3 Forest-covered hummocks of *Sphagnum magellanicum* and *Pilgerodendron uviferum*

This ecotype appears in raised mires situated in areas with a median rainfall of 1300 to 3300 mm y^{-1}, specifically where the peat layer is still thin enough to allow trees to grow through, independent of the distance from the coast. These ecosystems develop below 50 m a.s.l., present north-east, south-east and north-west exposures, and inclinations between 2% to 3,5%. Such conditions commonly occur in mires situated above old flood plains, where fossil sand banks elevate almost up to the mire surface, offering mineral rich and stable substrates for these trees to develop. In particular native trees manage to develop above raised mires. As the trees grow, the surrounding raised bog vegetation climbs through their steams, forming hummocks around them, and producing a forest-covered hummocks physiognomy. A sample of C/N taken in a forest-covered hummock presented a value of 57. The pH-value varied from 3.2 to 4.5. It was common in the sites LR (Fig. 115) and LV. A minority was detected on the upper slope of the sites QP1 and QP2.

Fig. 115: Forest-covered hummocks ecotype, dominated by *Sp. magellanicum* and *Pilgerodendron uviferum* trees. Site LR

As well as in flooded ecosystems, these hummocks are also formed by the *Sphagnum-Tetroncium* combination and their associated plant diversity, while the arboreal layer is composed of species adapted to high precipitation such as *Pilgerodendron uviferum* (known as Cypress of the Guaitecas, due to its abundance in the Guaitecas Archipelago) which is the southernmost conifer in the world and one that tolerates the highest rate of saturation. Joining the patches of cypress in less saturated areas, *Nothofagus betuloides* and *N. antarctica* are abundant as well. This ME represented 8.5% of the total mire areas examined in this study (2297 ha). This ecotype was exclusively associated with the hydrogeomorphic mire type Raised bog.

4.4.3.4 Blanket bogs of cushion plants (*Astelia pumila* and *Donatia fascicularis*)

The concept *blanket* is used in this work to describe plants with a tough-cohesive roots structure, forming dense covers on the landscape. Kleinebecker et al. (2008) mentioned “Blanket-Bogs” as the most maritime of three main botanical types of mires along the Magellan Strait and on the Island of Tierra del Fuego. This author observed that this ecotype forms above peaty soils where mineralization was accelerated by the deposition of salt enriched sea spray. In Aysén particularly, the settlement of cushion plants occurs above previous existing raised bogs ecotypes, which become replaced by blanket bogs. In the mountainous relief of Aysén, the proclivity of these ecotypes seems to be associated with the intensity of their exposure to the oceanic westerlies. In Aysén, the blanket bog ecotype appears in raised mires situated in areas with a rainfall gradient from 2200 to 3300 mm y^{-1}., under to 170 m a.s.l., growing mostly in flat areas with an inclination of <3.5% although exceptionally up to 9%. Blanket bogs present a recurrent north-easterly exposure, but can develop well on north-west and south-west exposed relief. According to samples taken from the upper soil of blanket bogs the C/N varied from 21 to 45, with a median of 32.2 and the pH-value from 2.9 to 4.5. These values varied according to the hydrogeomorphic mire type (Tab. 22). The main cushion plants in this ecotype are *Astelia pumila* and *Donatia fascicularis,* associated with *Oreobolus obstusangulus.* Non-cushion plant species joining them are *Sp. magellanicum, Myrteolia nummularia, Dicranoloma imponens, Drosera uniflora* and the sedges *Schoenus nigricans* and *S. rhyzosporoides.* Blanket bogs were dominant in the hydrogeomorphic mire types terrestrialization bog and flow-through bog. In sloping bogs and raised bogs, blanket bogs were secondary. This ME represented 5.7% of the total mire areas examined in this study (2297 ha). In the sites BP3 (Fig. 116) and BP4 this ecotype had its maximal representation, also being present in the sites LR, QP1, QP2, QP3, BP1 and BP2.

Fig. 116: Blanket bog ecotype dominated by the cushion plants *Astelia pumila* and *Donatia fascicularis*, and presenting also *Drosera uniflora*. Site BP3

4.4.3.5 Mixed bogs of cushion plants and *Sp. magellanicum* mosses

Under „Blanket-Sphagnum mixed mire“, Kleinebecker (2007) described those mires containing characteristics of both continental raised bogs and maritime blanket bogs of mires along the Magellan Strait and on the Island of Tierra del Fuego. In Aysén, this ecotype is almost exclusive to coastal areas between 2 and 11 km distant from the ocean. It appears associated with high rainfall (median of 2700 mm y^{-1}, developing in low alpine areas below 50 m a.s.l. with a 3.5% inclination, and mostly presenting an easterly exposure and secondarily a southerly and northern one. Besides the rainfall, the mixed bog ecotype is also influenced by runoffs irrigating the mire surface. From these mixed vertical and horizontal water sources, mixed bogs ecotypes form, presenting vegetation and characteristics from both raised and blanket bogs. A sample for C/N taken from the upper soil of a mixed bog presented a value of 26. The pH-value varied from 3.7 to 4.5. In mixed bogs typical patches of *Sp. magellanicum, Astelia pumila* and *Donatia fascicularis* grow together. The podocarpaceae *Lepidothamnus fonkii* was another species developing in this ME. It represented a 2% of the total mire areas examined in this study (2.297 ha). Mixed bogs are primarily associated with the hydrogeomorphic mire type Flow-through bog. The site BP1 is a stereotype of a mixed bog (Fig. 117).

Fig. 117: Mixed bog ecotype along the stream of a Flow-Through Mire in the site BP1, presenting *Sp. magellanicum, Oreobolus obtusangulus, Tetroncium magellanicum, Lepidothamnus fonkii* and *Astelia pumila*

4.4.3.6 Oligotrophic floating mats of cushion plants

Oligotrophic floating mats are a typical component in remnant lagoons of terrestrialization bogs. Like all floating mats, they are formed by a web of roots and tissues of living plants, as well as by the organic remains that accumulate in between. These ecotypes are peat forming, as well as definers of the characteristic organic gyttja substrate forming at the bottom of still water bodies in the process of terrestrialization. Plants growing in floating mats are adapted to the surrounding ecological conditions. If rain surpluses exceed the influence of mineralized water from runoffs, lateral inflows and groundwater, then oligotrophic conditions will prevail in the remnant water body of a terrestrialized bog and an oligotrophic floating mat can be formed. This ecotype was detected in the site BP4 (Fig. 118), where precipitation reaches 2700 mm $year^{-1}$and represented 0.2% of the total mire area examined in this study (2297 ha). Additionally, the site was a subalpine terrace at 166 m a.s.l. and with an easterly exposure. Due to the height, the site was rigorously exposed to the oceanic westerlies, presenting a profuse development of cushion plants (*A. pumila* and *D. fascicularis*), similar to in the blanket bogs. Additionally Juncaginaceae species, such as *Oreobolus obtusangulus* (which also form cushions) and mosses such as *Sp. magellanicum* and *Dicranoloma imponens,* were present in the mat. A sample for C/N calculation taken on a mesotrophic floating mat showed a value of 38. The pH presented a value of 3.9. Similar floating mats are reported in the mires of the Rocky Mountains, presenting resilience to floods and exhibiting almost only vertical water fluctuations, by which they are recommended as exceptional sites for monitoring ecological transformations on mires (Chadde et al., 1998).

Fig. 118: Oligotrophic floating mat dominated by cushion plants (*Astelia pumila* and *Donatia fascicularis*). Site BP4

4.4.3.7 Blanket fens of brown mosses, sedges and rushes

In the literature, fens are defined as minerotrophic ecosystems whose water inputs have been nutrient enriched via percolation through the mineral soil, the bedrock or via runoff across the surrounding mineral rich relief (Rydin et al., 2006; Chadde et al., 1998; Reichholf, 1988). On the other hand, as was explained before, the concept *blanket* is used in this work to describe plants with a tough roots structure, which form dense covers on the landscape. To summarize blanket fens are, for the purposes of this work, a typical ecotype in mires irrigated by mineral enriched water surpluses; formed by vegetation whose roots form tough-cohesive carpets. Blanket fens are the archetype in the site VO. The site is located at 365 m a.s.l. and although a distance of only 64 km separates the site from the ocean, rainfall diminishes significantly, reaching 890 mm yr^{-1}. This ecotype was detected, presenting an easterly exposure and a 3.5% inclination. VO is the stereotypical ecotype in mires where mineralized water inputs define the site ecology. A sample taken for C/N calculation showed a value of 23. The pH-value was from 5.1 to 6.2. The main species were *Schoenoplectus californicus* growing above a layer of brown mosses such as *Acrocladium auriculatum, Pyrrhobryum mnioides*, *Scleropodium purum*, *Achropyllum magellanicum* and *Dicranoloma imponens.* Other plant species of this ecotype are *Hordeum comosum, Carex magellanica*, *Carex chillanensi*s, *Juncus scheuzerioides* and *Juncus procerus*. Species rare in all other mire types were *Apodasmia chilensis* and *Perezia lactucoides*. *Sphagnum magellanicum* cushions can be found but they are isolated in areas of the mire elevated from the mire water level. Once the mire water increases, sedges and rushes dominate the vegetation cover. This gradient from nutrient-poor to mesotrophic conditions within a single mire complex was also reported for mires in the Rocky Mountains in the U.S.A. (Chadde et al., 1998). This mire ecotype represented 0.6% of the total mire areas examined in this study (2297 ha). It was exclusive to the hydrogeomorphic mire type terrestrialization fen, and only represented in the site VO (Fig. 119).

Fig. 119: Blanket fen ecotype, dominated by *Schoenoplectus californicus* (dark green) *Eleocharys melanostachys* (light grey) and other diverse sedges. Site VO

4.4.3.8 Mesotrophic floating mats of brown mosses, sedges and rushes

Mesotrophic floating mats were detected in the remnant lagoon of the site VO (Fig. 120), in the mountains of Villa O'Higgins at a height of 365 m a.s.l., behind the Southern Ice Field. There rainfall reached 890 mm yr^{-1}. The floating mats observed were part of an easterly exposed terrestrialized fen which did not present inclination. The main vegetation form present in this ecotype is the species *Schoenoplectus californicus*. On the soil of the mat, the brown mosses *Scleropodium purum* and *Achropyllum magellanicum* also sustain the mat with their vegetal tissues. A small minority of sedge species such as *Eleocharis melanostachys, Hordeum comosum, Carex magellanica* and *C. chillanensis* can also be observed in the denser areas of this ecotype, while *Myriophyllum quitense* is the last species to disappear in the open water body. The floating mat in VO presented a C/N=20 and a pH-value of 7.0. This ecotype represented only 0.2% of the mire area examined in this study (2297 ha), being exclusive to the site VO.

Fig. 120: Mesotrophic floating mat dominated by *Schoenoplectus californicus* (dark green), brown mosses (*Scleropodium purum* and *Achropyllum magellanicum* in the base level*)* and *Myriophyllum quitense* (light green plant floating in the water) at site VO.

4.4.4 Association of Hydrogeomorphic Mire Types and Mire Ecotypes

Mire ecotypes are associated with specific hydrogeomorphic mire types (Fig. 121). These relations are given according to the specific ecologic conditions dominating on each site. In this way, in strong-acidic milieus (pH= 4.0±0.6), with very poor-oligotrophic conditions (C/N= 45±14) and a high mire water table (14.8±8 cmbs) like that presented by raised bogs, the most disseminated ME were raised bogs of *Sphagnum magellanicum*, flooded hummocks of *Sphagnum magellanicum* and *Tetroncium magellanicum*, forest-covered hummocks of *Sphagnum magellanicum* and *Pilgerodendron uviferum* and blanket bogs of cushion plants. On sloping bogs presenting moderate-acidic milieus (pH= 4.1±0.6) with poor-oligotrophic upper soils (C/N= 32±9) and moderate mire water table (33±26 cmbs), the most common mire ecotypes were raised bogs of *Sphagnum magellanicum*, mixed bogs of plants from both raised and blanket bogs, and blanket bogs of cushion plants.In terrestrialization bogs with moderate-acidic pH (4.2±0.5) and very poor-oligotrophic upper soils (C/N= 34±4), and presenting a high mire water table (15 cmbs), an oligotrophic floating mat was found. This mat was growing as an extension of a blanket bog, evidencing the origin and successional stage of one type of mountainous mire that was under represented in this study (0.9 ha), but widely observed along the rainy coastline of Aysén during the field work. In flow-through bogs with moderate-acidic (pH= 4.2±0.5) and moderate-mesotrophic upper soils (C/N= 20±3.5), and presenting a moderate mire water table (31 cmbs), mixed bogs and blanket bogs were the archetypical mire ecotype.

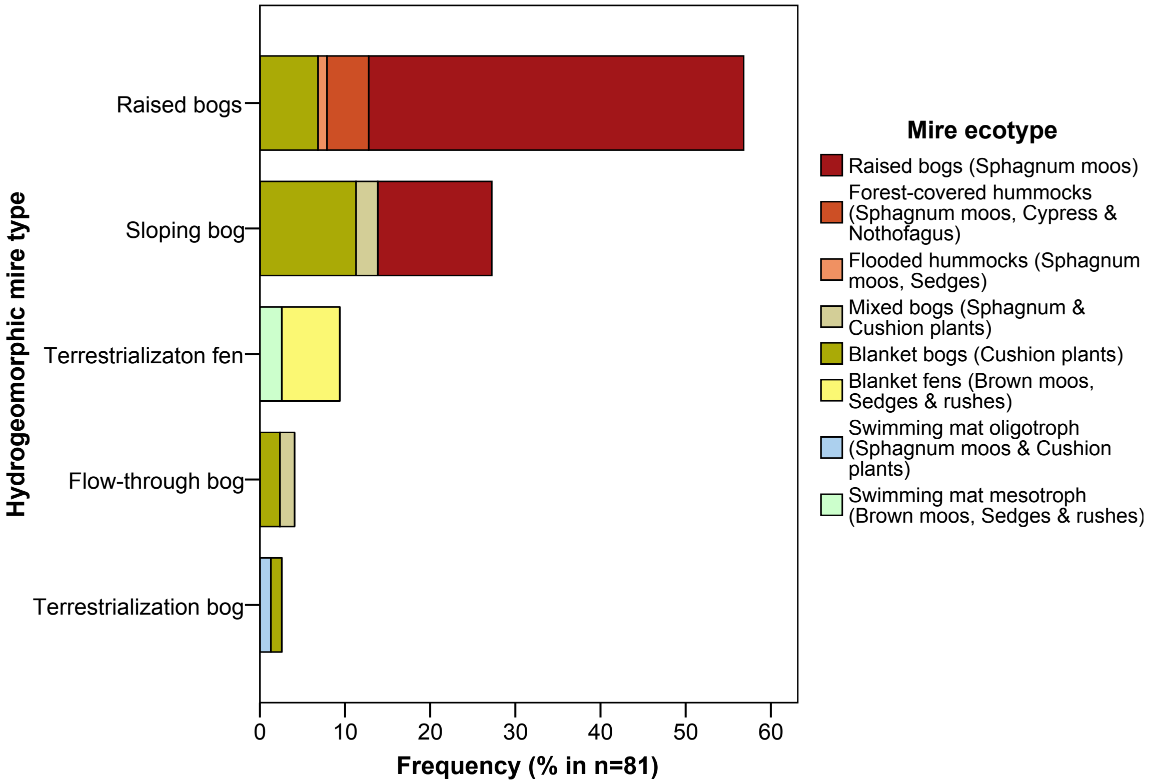


Fig. 121: Association between hydrogeomorphic mire types and mire ecotypes.

Terrestrialization fens presenting sub-neutral (pH= 5.6±0.9) and mesotrophic conditions (C/N= 26±0.9) and presenting an extremely high mire water table (3±2.5 cmbs), were the only hydrogeomorphic mire type in the whole sample where blanket fens and mesotrophic floating mats of brown mosses, sedges and rushes were observed. These relations are shown in detail in Tab. 22. Additionally, the current spatial distribution of the different mentioned hydrogeomorphic mire types and mire ecotypes categories is described in Tab. 23 and illustrated in the following cartography.

Tab. 22: Hydrogeomorphic mire types and their associated mire ecotypes, with characteristic site conditions (C/N and pH-value in the mire surface, and depth of the mire water table)

Hydro-geomorphic mire type	Mire ecotype (*typical vegetation*)	C/N median	N	pH median	N	Mire water table median (cmbs)	N
Raised bog	rB (*Spm*)	46 ±10.3	6	3.7±0.6	38	22±18	38
	frH *(Spm, Pgv)*	56	1	3.8±0.5	5	21±9	5
	flH (*Spm, Trm*)	57	1	4.4	1	5	1
	bB *(Cpl)*	45	1	3.4±0.6	6	11±5	6
	Total	*46±14*	*9*	*3.7±0.6*	*50*	*14.8±8*	*50*
Sloping bog	rB (*Spm*)	34±4.2	2	3.4±0.4	14	20±16	13
	bB *(Cpl)*	27±3.8	3	3.7±0.3	10	43±31	7
	Total	*32±9*	*5*	*4.1±0.6*	*24*	*33.3±25.7*	*23*
Flow-through bog	bB *(Cpl)*	41	1	3.8	1	16	1
	mB *(Spm, Cpl)*	26	1	3.7	1	47	3
	Total	*26±0.5*	*2*	*3.6±0.3*	*2*	*31.5±21.9*	*2*
Terrestrialization bog	bB *(Cpl)*	32	1	3.4	1	15	1
	fMo *(Cpl)*	38	1	3.9	1	15	1
	Total	*34±4*	*2*	*3.7±0.4*	*2*	*15*	*2*
Terrestrialization fen	bF *(Bm, Sg, Ru)*	23	1	5.1	1	5±5	2
	fMm *(Bm, Sg, Ru)*	18	1	6.2	1	1	1
	Total	*20±3.5*	*2*	*5.8±0.8*	*2*	*3±2.5*	*3*
Total		*34±4*	*20*	*4.2±0.7*	*81*	*19.8±8.3*	*81*

*Abbreviations of the mire ecotypes: rB= raised bogs, flH= flooded hummocks, frH= forest-covered hummocks, bB= blanket bogs, bF= blanket fens, fMo= oligotrophic floating mat, fMm= mesotrophic floating mat. Abbreviations of the dominant vegetation: (Spm)= *Sphagnum magellanicum*, (Trm)= *Tetroncium magellanicum*, (Pgv)= *Pilgerodendron uviferum*, (Cpl)= Cushion plants, (Bm)= Brown mosses, (Sg)= Sedges, (Ru)= Rushes

Tab. 23: Area (ha) of the different hydrogeomorphic mire types and their associated mire ecotypes in the examined sites

Hydrogeomorphic Mire Type	Mire Ecotype*	Area (ha) by Site										
		LV	LR	VO	QP1	QP2	QP3	BP1	BP2	BP3	BP4	Total
Raised bog	rB (*Spm*)	997.0	368.3	.	15.0		17.0	.	238.0	.	.	1649.3
	flH (*Spm, Trm*)	255.4	.	.	.	.	.	.	.	.	.	255.4
	frH *(Spm, Pgv)*	198.2	.	.	.	.	.	.	.	.	.	198.2
	bB *(Cpl)*	.	23.0	.	3.7		.6	.	24.8	.	.	52.6
	Total	*1450.6*	*391.3*	.	*18.7*		*17.6*	.	*262.8*	.	.	*2155.5*
Sloping bog	rB (*Spm*)					14.0						14.0
	bB *(Cpl)*	.	.	.	.	.5.	.	62.6	.	6.8	.	69.9
	Total	.	.	.	.	*14.5.*	.	*62.6*	.	*6.8*	.	*83.9*
Flow-through fen	mB *(Spm, Cpl)*	.	.	.	.	.	.	44.4	.	.	.	44.4
	bB *(Cpl)*	.	.	.	.	.	.	8.3	.	.	.	8.3
	Total	.	.	.	.	.	.	*52.7*	.	.	.	*52.7*
Terrestrialization bog	bB *(Cpl)*	.	.	.	.	.	.	.	.	.	.7	.7
	fMo *(Cpl)*	.	.	.	.	.	.	.	.	.	.1	.1
	Remnant lagoon	.	.	.	.	.	.	.	.	.	.1	.1
	Total	.	.	.	.	.	.	.	.	.	*.9*	*.9*
Terrestrialization fen	bF *(Bm, Sg, Ru)*	.	.	3.8	.	.	.	.	.	.	.	3.8
	fMm *(Bm, Sg, Ru)*	.	.	.1	.	.	.	.	.	.	.	.1
	Remnant lagoon	.	.	.2	.	.	.	.	.	.	.	.2
	Total	.	.	*4.1*	.	.	.	.	.	.	.	*4.1*
Total mires examined (ha)		*1450*	*391.3*	*4.1*	*18.7*	*14.5*	*17.6*	*115.3*	*262.8*	*6.8*	*.9*	*2296.7*

(*Abbreviations see Tab. 22)

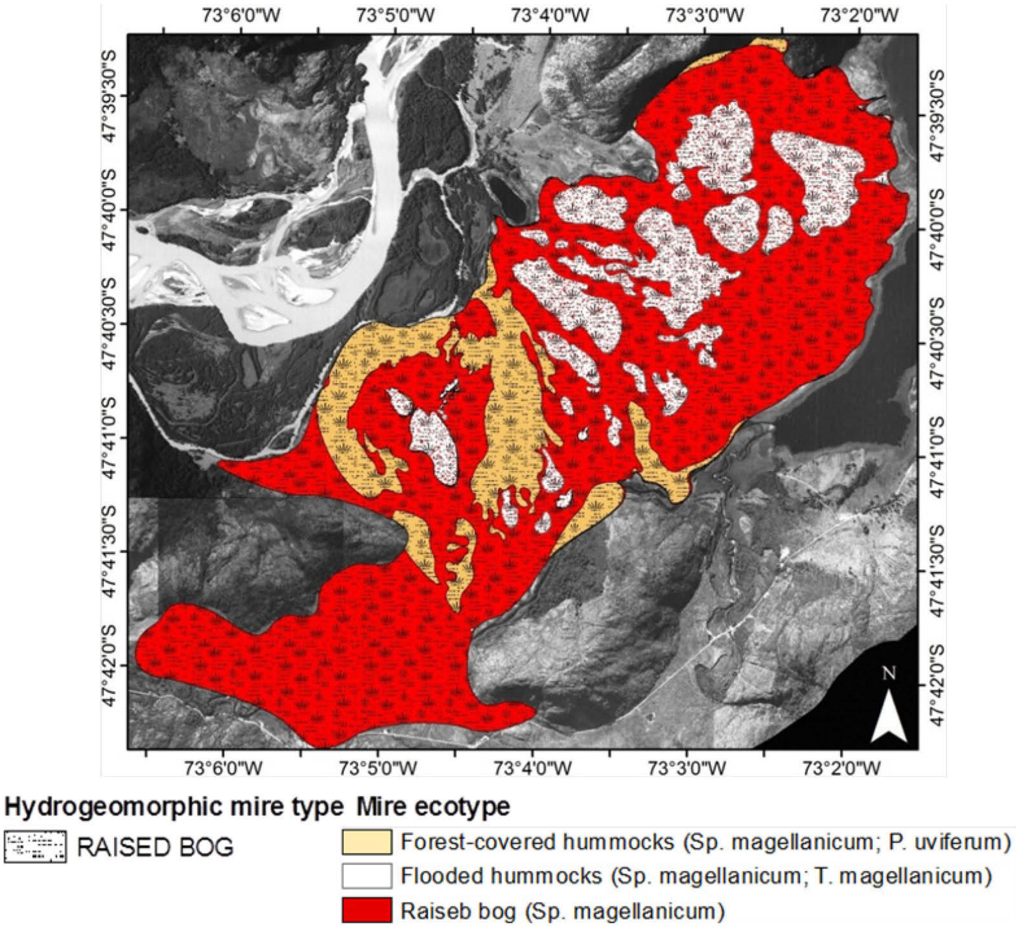


Fig. 122: Distribution of mires in the site LV (1=30.000)

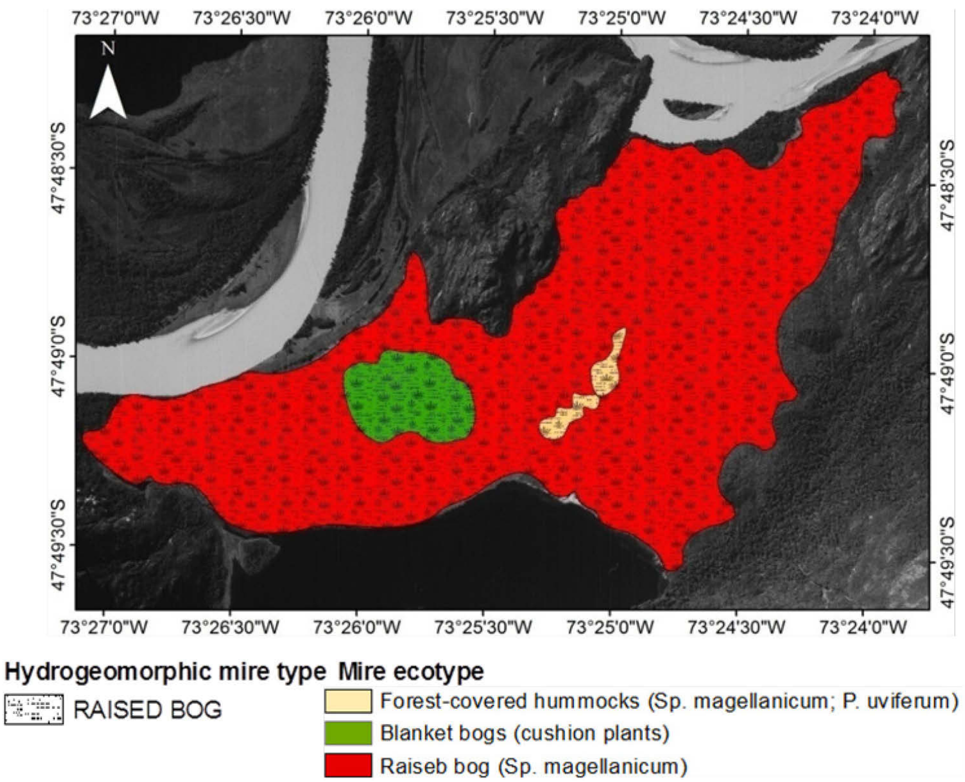


Fig. 123: Distribution of mires in the site LR (1=15.000)

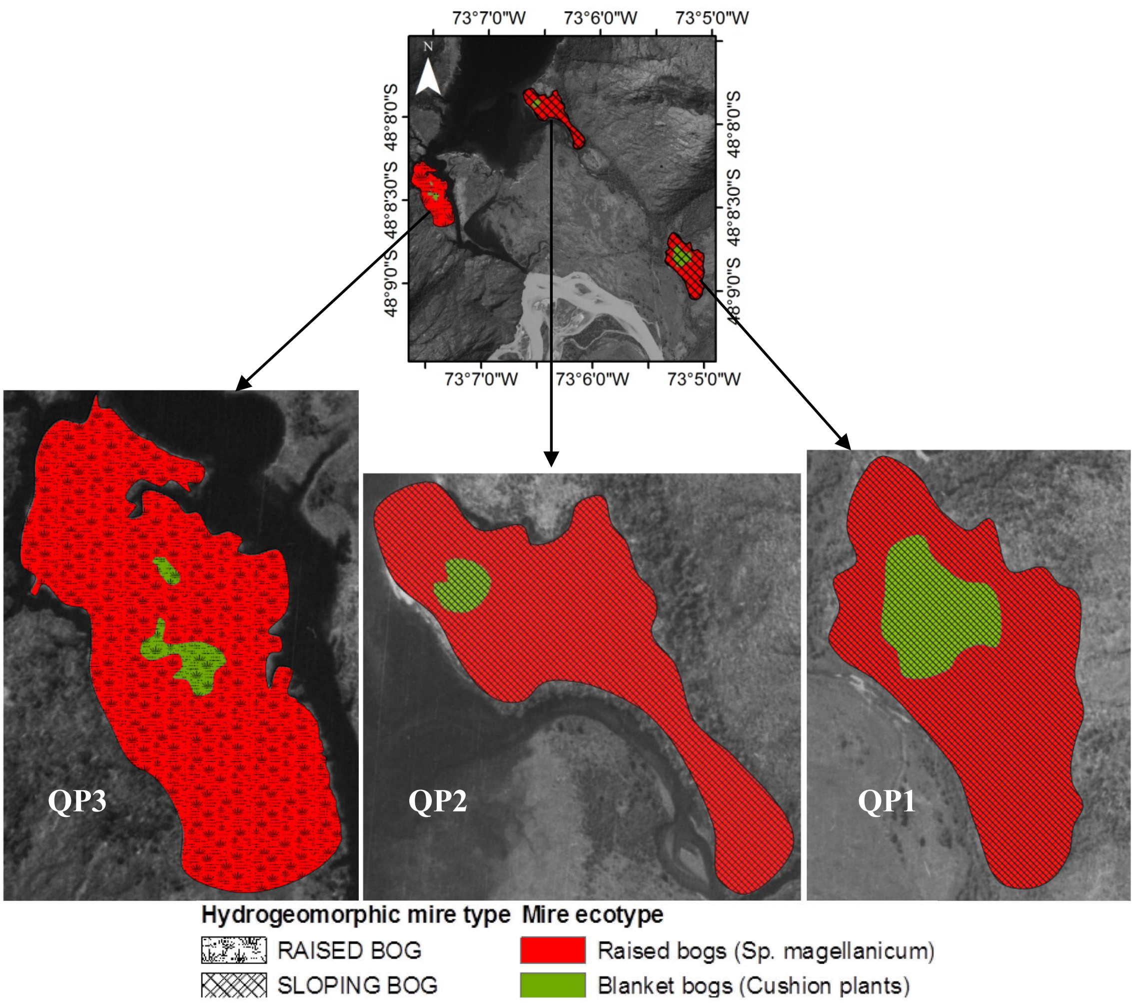


Fig. 124: Distribution of mires in the sites QP1, QP2 and QP3 (1=5.000)

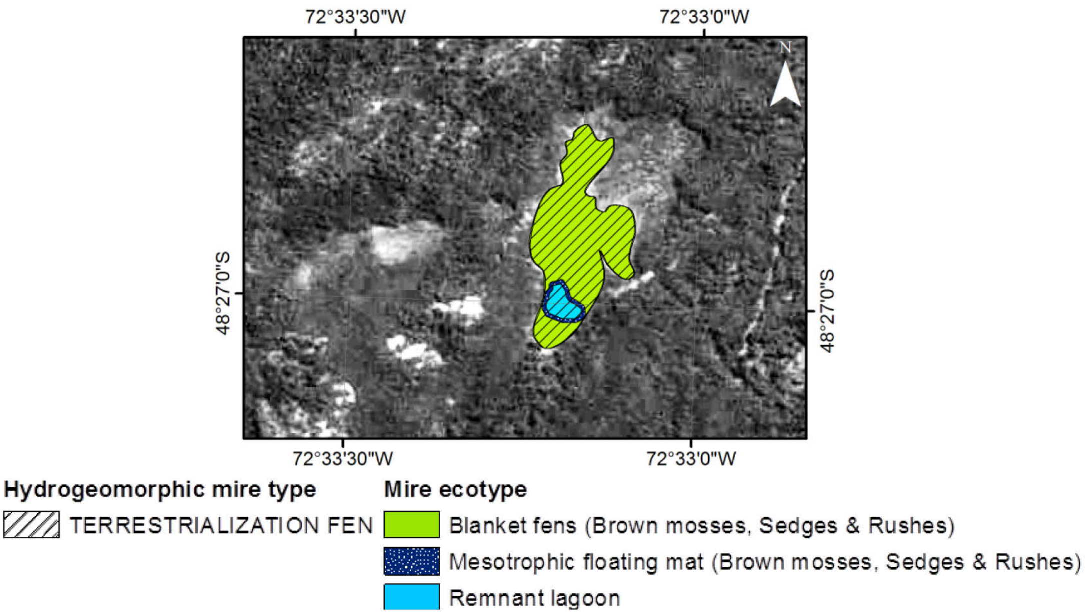


Fig. 125: Distribution of mires in the site VO (1=4.000)

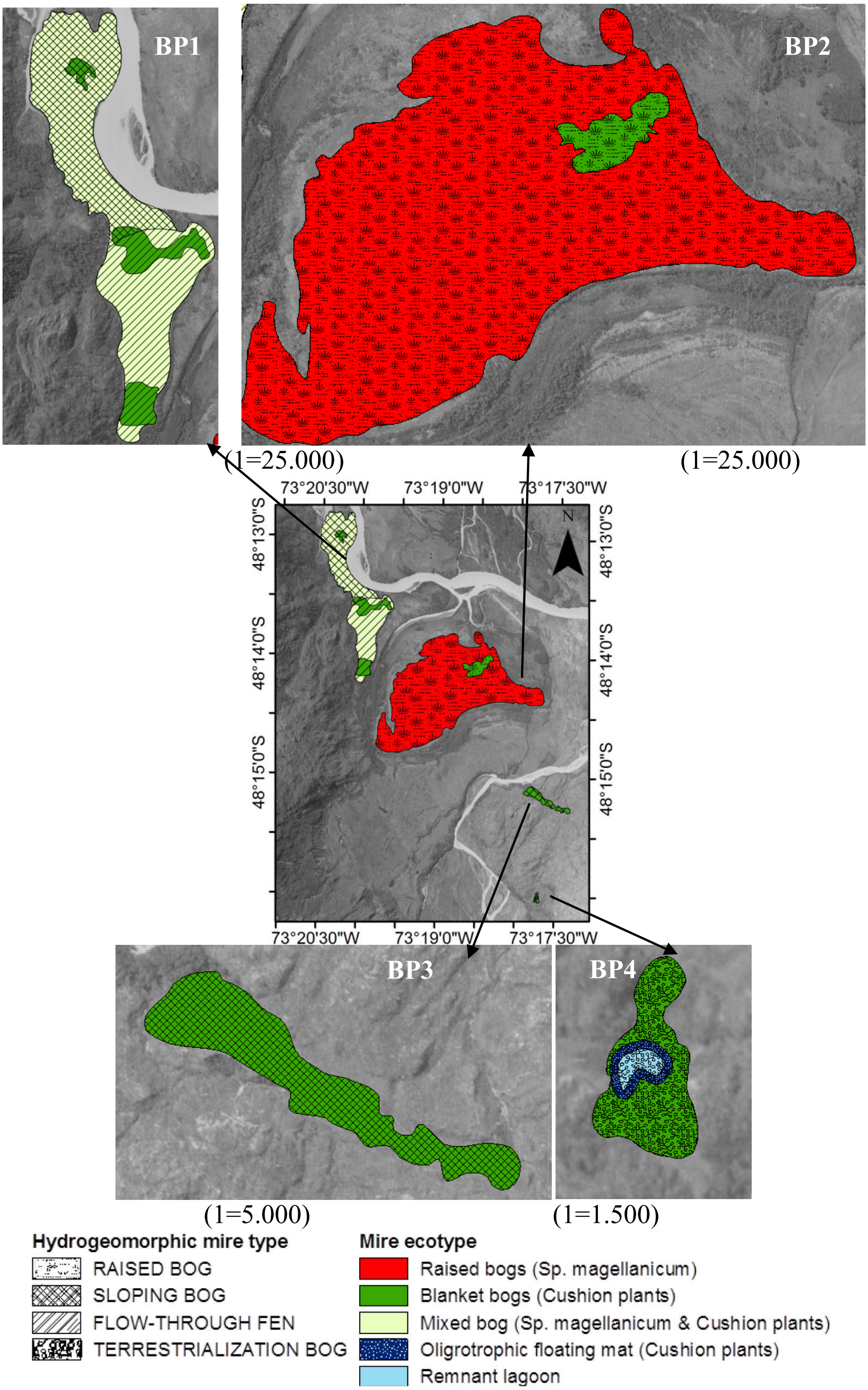


Fig. 126: Distribution of mires in the sites BP1, BP2, BP3 and BP4 (different scales)

4.4.5 Fourth level of classification: keys for the organic substrates

The classification of the different substrates compounding the peat soils of Aysén detailed in the next section is conceptually and graphically inspired by the German Soil Mapping Directions (AG Boden, 2005) and in the Description of Mire Substrates realized by Meier-Uhlherr et al. (2011; www.mire-substrates.com) from the Eberswalde-University of Applied Sciences for Sustainable Development. As in those works, this chapter is oriented to the praxis and field work dealing with mires, portraying the ideal, typical and essential ecological characteristics of the different peat types found during this research. This includes forming conditions, landscape association and occurrence in hydro-morphologic mire types, typical plant communities and eco-trophic conditions. The explanation presented here is based on stereotypical peats, by which several mixed peat materials and other kinds of substrates are omitted. The contribution of new peat types in the future, as a result of new research into the topic in Patagonia, is expected. To facilitate the use of this section, peat types shown in this chapter are grouped and sub-grouped according to their main physical characteristics (Fig. 127).

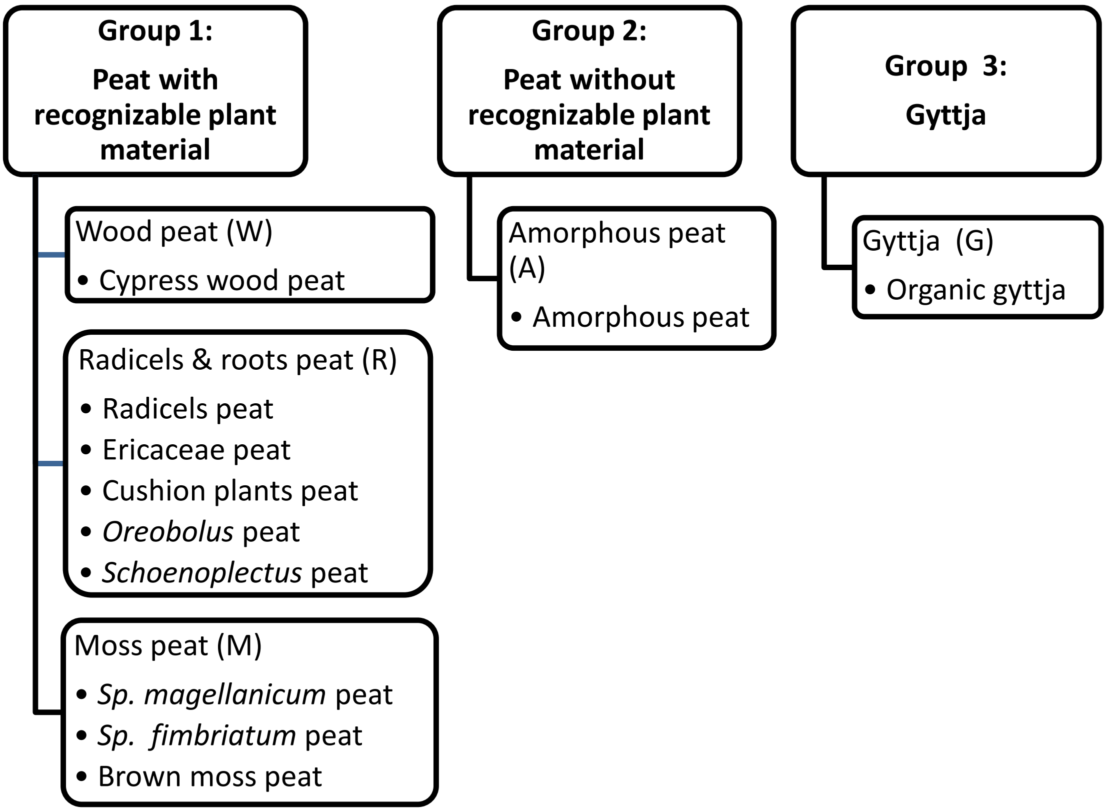


Fig. 127: Organic substrate types in mires of Aysén categorized in groups and subgroups

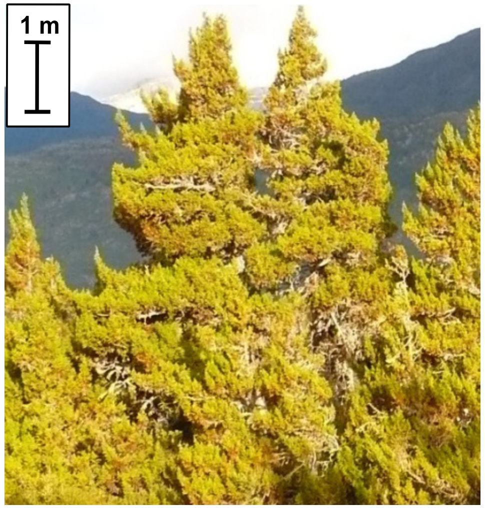
Group 1 presents those peats whose substrates contain macrofossils, plant remains or vegetative structures, which are recognizable or dominant enough to assign the substrate a botanical category. Hence, this group contains peats typically found in the mire surface and in deep horizons under sufficiently anoxic conditions for the vegetative residues or structures to remain. Depending on the dominating plant material, the sub-groups of wood, radicels and roots and moss peat can be differenced. Group 2 includes those peat types that, due to a strong grade of decomposition, terrestrialization (decomposition and blending of the peat with mineral material) or strong terrestrialization, are no longer able to be put into a botanic category. Amorphous peat is the result of a strong decomposition process, being found in terrestrial ecosystems. Group 3 includes organic gyttja which, as was exposed before, is a substrate formed by sedimentation processes at the bottom of lakes and standing water bodies. The name of the mire substrates can be abbreviated to facilitate the data collection during the field work. A list of names is explained in Tab. 24. Some of them are based on the German Soil Mapping Directives (Hhsy=Hosy, Hhsa=Hosa, Hhi=Hoi, Hnr=Hgr, Hnb=Hgmm, Ha=Ha and Fhh=Gyo) and the rest on the native names of the substrate botanical types (Hoas, Hoob, Hoc, Hgsc). Their main characteristics are summarized and shown on the following pages.

Tab. 24: Abbreviations for the different mire substrate types of Aysén

Group	**Peat Type**	**Abbreviation**
W	Cypress wood	Hoc (H: Humus, o: ombrogenic, c: ciprés)
R	Radicels	Hgr (H: Humus, g: geogenic, r: radicels)
	Ericaceae	Hoi (H: Humus, o: ombrogenic, i: family Ericaceae)
	Cushion plants	Hoas (H: Humus, o: ombrogenic, as: *Astelia pumila* and other cushion plants)
	Oreobolus	Hob (H: Humus, o: ombrogenic, ob: *Oreobolus*)
	Schoenoplectus	Hgsc (H: Humus, g: geogenic, sc: *Schoenoplectus*)
M	*Sp. magellanicum*	Hosy (H: Humus, o: ombrogenic, sy: *Sphagnum* class *cymbifolia,* species *Sp. magellanicum*)
	Sp. fimbriatum	Hosa (H: Humus, o: ombrogenic, sa: *Sphagnum* class *acutifolia,* species *Sp. fimbriatum*)
	Brown moss	Hgmm (H: Humus, g: geogenic, mm: musgos marrón-brown moss)
A	Amorphous	Ha (H: Humus, a: amorphous)
G	Organic gyttja	Gyo (Gy: Organic gyttja, o: organic)

Peat forming plant

Pilgerodendron uviferum



Appearance

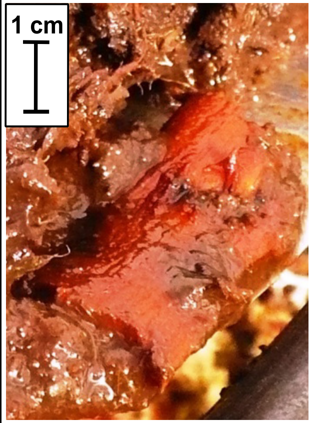
Cypress wood peat with DD H3

Cypress Wood Peat/Turba de Ciprés (Hoc)

Properties= cypress wood peat is common in the surface of the HGMT raised bogs and in the depth layers of the HGMT terrestrialization fens. Is the archetypical peat forming in the underground of the ME forest-covered hummock. Accompanying plant remains are *Sp. magellanicum*, brown mosses, *Carex magellanica* and *Nothofagus dombeyi.* Colour is brown to light brown.

DD= H3-H5 (n=7)	**pH-value=** 3.7–6.0 (n=7)
BD (g cm^3) = 0.05-0.07 (n=13)	**C/N** = 35–57 (n=2)
Water storage capacity= 90%-92% (n=13)	

Macrofossils



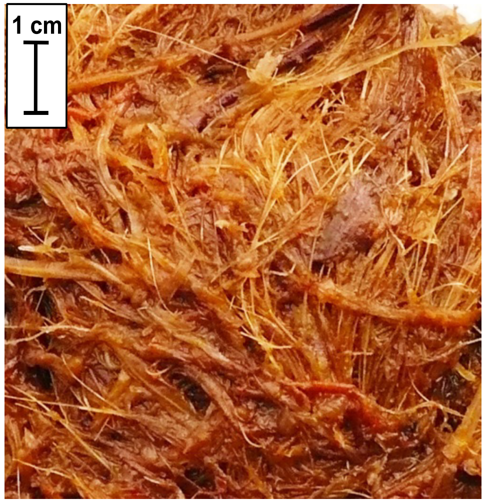
Current forming mire ecotype: forest covered hummocks

Peat forming vegetation

C. Magellanica/M grandiflorum

Appearance

Radicels peat with DD= H3-H4

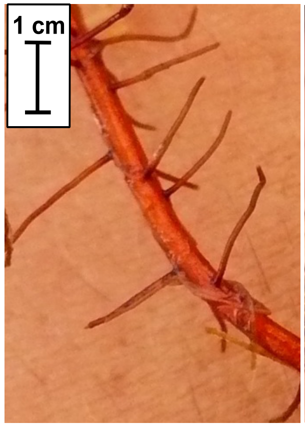


<u>Radicels Peat /Turba de Radicelas (Hgr)</u>

Properties= present in almost all HGMT, especially in terrestrialization fens, flow-through bogs and raised bogs. Current maximal formation based on *Carex magellanica* in the ME blanket fen. Also in the ME *Sphagnum* bogs and forest covered-hummocks, where *Marsippopermum grandiflorum* forms the peat Yellow to brown colour. Fine and coarse roots remains, tubular or compacted are abundant. Plant remains of *Sphagnum* and brown mosses, *Empetrum rubrum* and *Lepidotamus fonkii* can be found on it.

DD= H3-H8 (n=92)	**pH-value=** 3.0 -6.4 (n=92)
BD (g cm^3)= 0.07-0.1 (n=33)	**C/N=** 24-55 (n=9)
Water storage capacity= 83%-98% (n=33)	

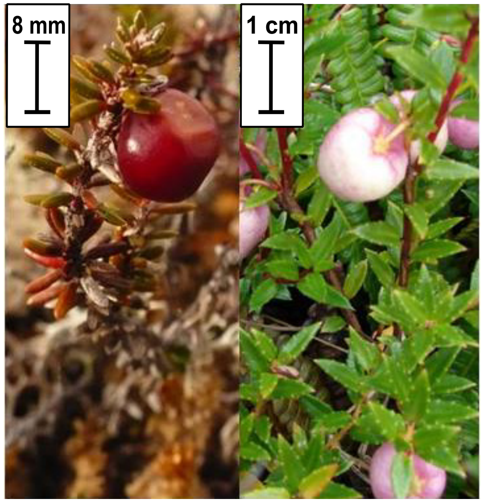
Macrofossils



Current forming mire ecotype: Blanket fen (left) and *Sphagnum* bog (right)

Peat forming vegetation

Empetrum rubrum/Pernettya mucronata



Appearance

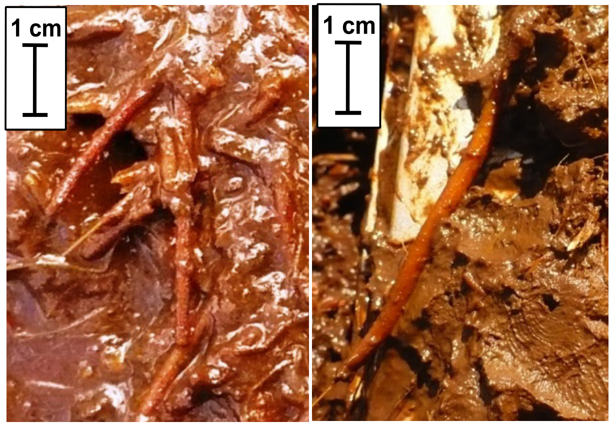
Ericaceae peat with DD= H4

<u>Ericaceae Peat/Turba de Ericaceas (Hoi)</u>

Properties= archetypical peat of the HGMT raised bog and sloping bog. Current formation in sloping or hummocky areas of the ME raised bogs, where the water level is below the surface, allowing vascular plants to grow. Characteristic reddish-brown colour with dark reddish small stems. Accompanying plant remains are *C. magellanica, M. grandiflorum* and *Sp. magellanicum* mosses.

DD= H3-H7 (n=37)	**pH-value=** 3.1 - 5.0 (n=37)
BD (g cm^{3})= 0.06-0.07 (n=24)	**C/N=** 19-56 (n=6)
Water storage capacity= 91%-94% (n=24)	

Macrofossils



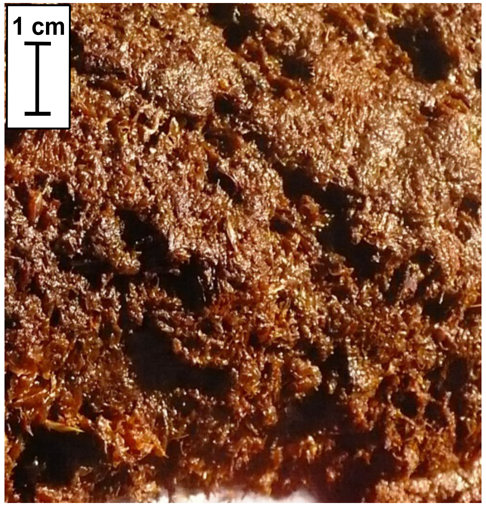
Current forming mire ecotype: raised bogs in sloping areas

Peat forming vegetation

Astelia Pumila

Appearance

Cushion plants peat with DD=H3

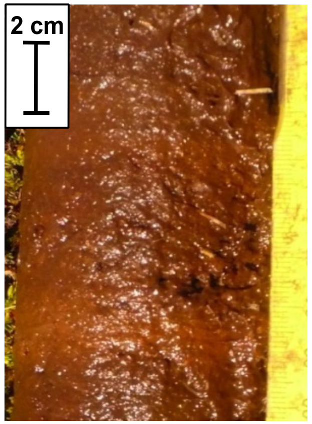


<u>Cushion Plants Peat/Turba Pulvinada (Hoas)</u>

Properties= typical peat in the ME blanket bog (HGMT raised bog), mixed bog (HGMT Flow-through bog) and oligotrophic floating mat (HGMT terrestrialization bog). When high decomposed dominates a loose structure and a very reddish colour (see left picture of macrofossils), whilst under low decomposition a fixed structure and dark brown colour dominates (see right picture of macrofossils). Remains of *Sp. magellanicum* peat, *Oreobolus obtusangulus*, and brown mosses can be present.

DD=H3 – H8 (n=28)	**pH-value=** 3.1–4.6 (n=28)
BD (g cm^3)= 0.08-0.11 (n=27)	**C/N=** 21 – 45 (n=6)
Water storage capacity= 90%-92% (n=27)	

Macrofossils



Current forming mire ecotype: blanket bogs (left) and oligotrophic floating mats (right)

Peat forming vegetation

Oreobolus obtusangulus

Appearance

Oreobolus peat with DD=H4

<u>*Oreobolus* Peat/Turba de *Oreobolus* (Hob)</u>

Properties= rare peat. Detected growing associated to the ME blanket bog in the HGMT flow-through bog, and to the borders of flooded hummocks in the HGMT raised bogs. Typical dark red to dark brown colour. Moderate fixed texture, presenting coarse and fine tubular root remains and mostly low decomposition degree. Accompanied by radicels of *Donatia fascicularis* (in blanket bogs), and by *Marsippospermum grandiflorum* (in border of flooded hummocks)

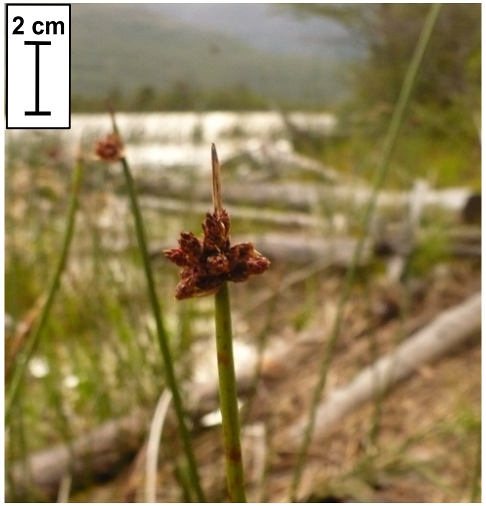
DD= H3 – H6 (n=12)	**pH-value=** 3.5–4.1 (n=12)
BD (g cm^3)= 0.8-0.9 (n=5)	**C/N=** 38-45 (n=4)
Water storage capacity= 91%-94% (n=5)	

Macrofossils

Current forming mire ecotypes: blanket bogs (left) and border of flooded hummocks (right)

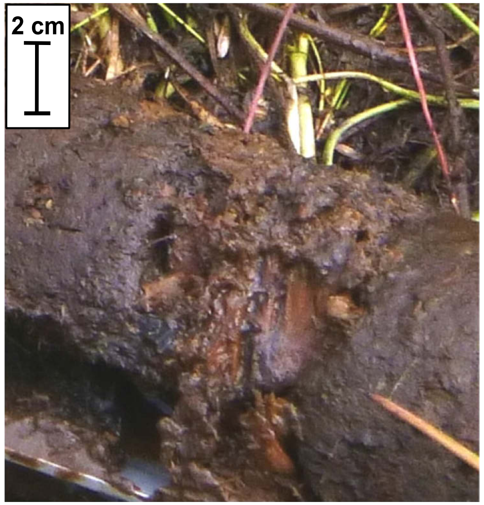
Peat forming vegetation

Schoenoplectus californicus



Appearance

Schoenoplecuts peat with DD=H6



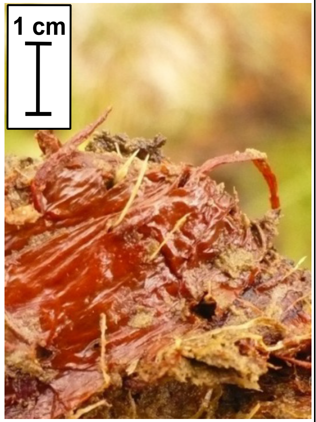
<u>*Schoenoplectus* Peat/Turba de *Schoenoplectus* (Hgsc)</u>

Properties= rare peat. Found only in the ME mesotrophic floating mat of the HGMT terrestrialization fen. Colour dark brown to black but if oxidative conditions are present, macrofossils can be reddish. Loose structure Low to moderate decomposition degree, with some macrofossils that made it identifiable and differentiable from the abundant accompanying brown mosses peat.

DD= H3-H6 (n=3)	**pH-value=** 4.6-6.2 (n=3)
BD (g cm^3)= 0.05-0.06 (n=5)	**C/N=** 35 (n=2)

Water storage capacity= 94-95% (n=5)

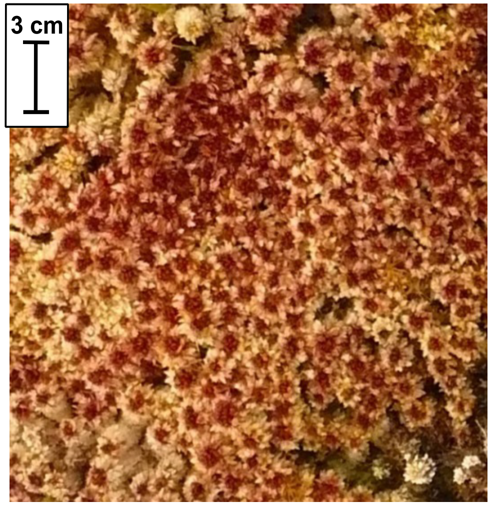
Macrofossils



Current forming mire ecotypes: mesotrophic floating mats

Peat forming vegetation

Sphagnum magellanicum



Appearance

Sp. magellanicum peat with DD=H3

<u>*Sp. magellanicum* Peat/Turba de Pompón (Hosy)</u>

Properties= archetypical peat of the HGMT raised bogs and sloping bogs. Also typical in flow-through bogs and less in terrestrialization bogs. Forming currently in the ME raised bog, forest covered hummock, flooded hummock, mixed bog and less in blanket bogs. Accompanied by Ericaceae and Cyperaceae plant remains. Depending on its DD, has a bulky to creamy structure. Its colour varies from reddish yellow (pure), to dark reddish (Ericaceae remains) and brown (Cyperaceae remains*)*.

DD= H3-H7 (n=134)	**pH-value =** 2.3-5.5 (n=134)
BD (g cm^3)= 0.03-0.07 (n=25)	**C/N=** 20–68 (n=8)
Water storage capacity= 84%-97% (n=25)	

Macrofossils

Current forming mire ecotypes: raised bogs (left) and forested hummocks (right)

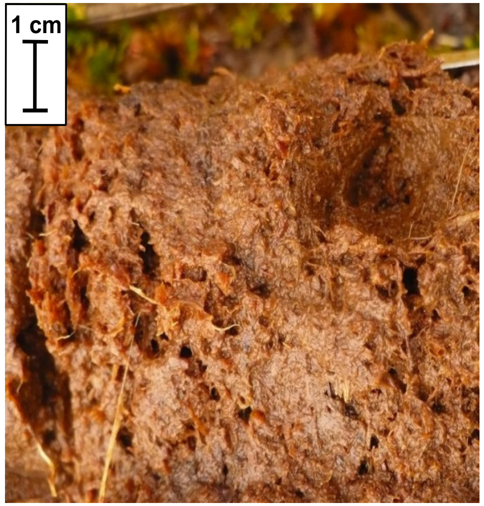
Sphagnum fimbriatum Peat/Turba Fímbrica (Hosa)

Peat forming vegetation

Sphagnum fimbriatum

Appearance

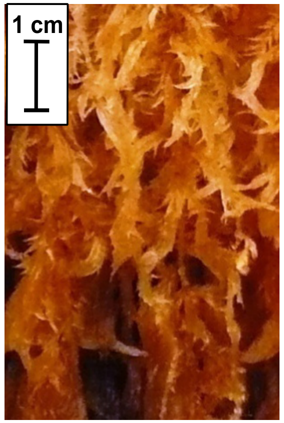
Sp. fimbriatum peat with DD=H7



Properties= rare peat, found only where *Sp. fimbriatum* currently grows, in saturated borders of the HGMT sloping bog, as well as in the HGMT raised bog associated to saturated depressions in the border of the ME flooded hummock. Light brown to brown colour. Accompanying plant remains are radicels from Cyperaceae plants.

DD= H3- H7 (n=7)	**pH-value**= 3.0-5.5 (n=7)
BD (g cm^3)= 0.09-0.12 (n=3)	**C/N=** 37 (n=1)
Water storage capacity= 90%-95% (n=3)	

Macrofossils



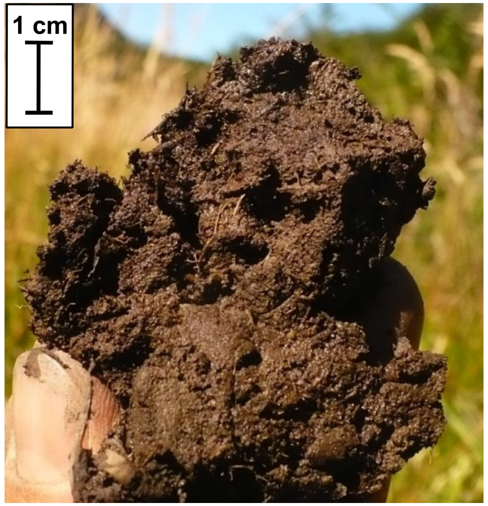
Current forming mire ecotypes: saturated depressions in the border of flooded hummocks

Peat forming vegetation

Acrocladium auriculatum

Appearance

Brown Mosses peat with DD=H6



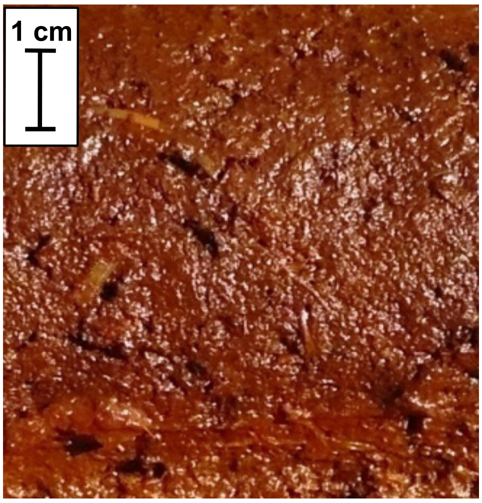
<u>Brown moss peat/Turba musgo marrón (Hgmm)</u>

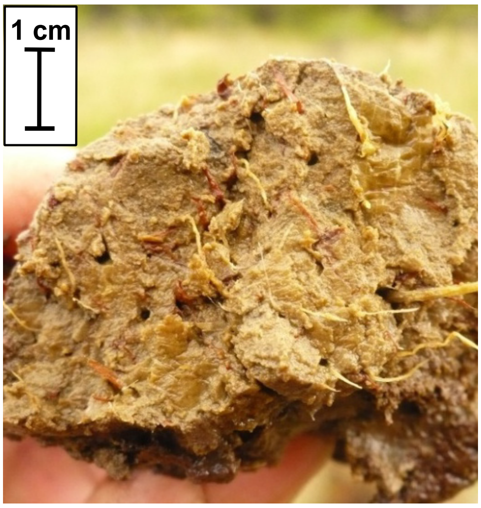
Properties= archetypical peat of the HGMT terrestrialization fen, where the water of the mire is enriched by lateral inputs. Also present in the HGMT flow-through bog, associated to areas where nutrients are conveyed into the surface by flow fluctuations. Currently forming in the ecotypes blanket fens and mesotrophic floating mats, and less in mixed bogs. Dark reddish to very dark brown colour is characteristic, as well as a compact to loose structure, depending on the DD.

DD= H3-H6 (n=5)	**pH –value=** 4.3-6.6 (n=5)
BD (g cm^3)= 0.07-0.11 (n=5)	**C/N=** 23 (n=1)
Water storage capacity= 91%-93% (n=5)	

Macrofossils

Current forming mire ecotypes: blanket fens (left) and mesotrophic floating mats (right)

<table>
<tr><th colspan="3"><u>Amorphous Peat/Turba Amorfa (Ha)</u></th></tr>
<tr><td rowspan="4">Appearance
Amorphous Peat DD=H9-H10

</td><td colspan="2">Properties= present in all HGMT, indicator of intermittent dry periods, and of the presence of Aerenchyms. These can be the specie Sch. californicus in the ME blanket fens and mesotrophic floating mats, and the cushion plant A. pumila in all ME where this grows and feed by degrading the peat with its oxygenating rooting system</td></tr>
<tr><td>DD= H9-H10 (n= 124)</td><td>pH-value= 3.0-6.4 (n= 124)</td></tr>
<tr><td>BD (g cm^3)= 0.09-0.12 (n=37)</td><td>C/N= 15-55 (n=7)</td></tr>
<tr><td colspan="2">Water storage capacity= 86%-94% (n=37)</td></tr>
</table>

<table>
<tr><th colspan="3"><u>Organic gyttja/ Gyttja Orgánica (Gyo)</u></th></tr>
<tr><td rowspan="4">Appearance
Organic gyttja

</td><td colspan="2">Properties= indicator of standing water ecosystems (e.g. old lagoons and lake bottoms). Forming in remnant lakes of the HGMT terrestrialization bogs and terrestrialization fens. Although it was not registered in small pools inside raised bogs, this is an environment where this substrate could potentially form. Its organic matter content varies from >15% to <30%, and owing to its high bulk density, it a substrate with an organic carbon content similar to that of peat substrates.</td></tr>
<tr><td>pH-value= 3.2-7.3 (n=22)</td><td>BD (g cm^3)= 0.17-0.27 (n=10)</td></tr>
<tr><td colspan="2">C/N= 20-31 (n=2)</td></tr>
<tr><td colspan="2">Water storage capacity: 75%-84% (n=10)</td></tr>
</table>

4.4.6 Overview of the classification system

In this section, a system for the classification of mires along the Baker and Pascua river basins is proposed. This system includes four classification levels (First Level: main relief and hydrology, Second Level: hydrogeomorphic mire types, Third Level: mire ecotypes and Fourth Level: organic substrate types). These levels and their relations are detailed in Fig. 128. The categories proposed for each classification level of this work will allow an overview about the ecosystems existing in the specific examined area and their current pedological and ecological conditions. These categories are not absolute and can be improved, in order to include new mire types existing in the territory, as soon as exploration and research on this topic can be advanced in the region.

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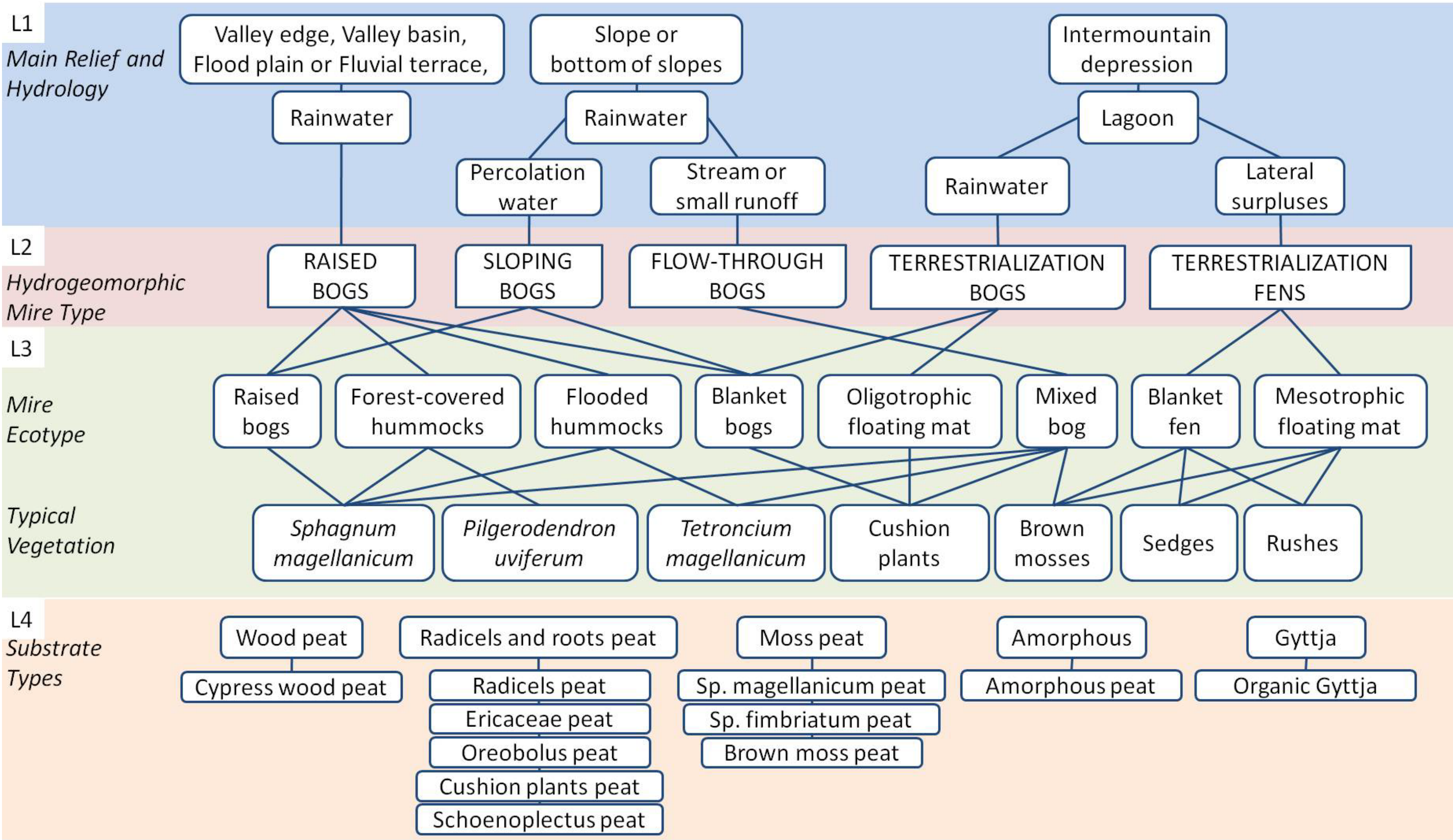


Fig. 128: Overview of the Mire Classification System and its four levels.

4.5 Threats to mires along the Baker and Pascua River Basins

Aysén was the last Chilean region to be colonized. There are migratory antecedents only since the beginning of the 20th Century, and hence the human density and impact is very low, from past times up to the present. Nevertheless, intensive landscape use is a reality, and despite the pristine conditions of the examined mires, several threats are endangering their permanence. The major threat to mires in Aysén's territory is the ignorance about their diversity and ecological status. There is a generalized lack of information about current physical and biological properties of mires in the region, their main causes of stress, the threats they face and the lack of further knowledge to understand their possible transformation as a result of climate change. Indeed, this situation is confirmed by the existence of only one wetland protected under the Ramsar Convention in the whole of Chilean Patagonia: Bahia Lomas – Region of Magallanes, with only 58.9 ha. This deficit has been reported in a quantity of research (Filipová et al. 2010; Orrego y Rodrigo, 2007 and Pfeiffer et al., 2010). In addition to Blanco y De la Balze (2004), who collected together a couple of works dealing with mires renaturation and protection in Tierra del Fuego, there is one investigation about continental and coastal mires in the Region of Magallanes (Kleinebecker, 2007), and a small renaturation experience on a harvested bog, documented by the Chilean National Institute for Agricultural Research (INIA-KAMPENAIKE, 2010). Compared with Magallanes, there is a lack of studies about mires in Aysén, with only indirect research existing which focuses on productive issues (e.g. application of land capability classification systems in (CIREN, 2005) and studies on flora and soils (Rodríguez et al. 2008; Pfeiffer et al. 2010), all of them lacking an ecological and pedological understanding of mires, their dynamics, threats and possible conservation strategies. Following a "lake-river-fjord" catena, mires along the watersheds of the Rivers Baker and Pascua present ecological adaptations to different climatic regions, mostly under undisturbed conditions when compared with those of the northern hemisphere and the rest of Patagonia, which have being drained, cut and exploited in the last century. Archipelagic mires are more isolated and less affected by human activities and therefore more protected than those linked to continental areas, which face a greater anthropogenic impact. For these reasons, this research focused on continental mires, because although these ecosystems are still in pristine conditions, their documentation seems imperative since they are more exposed to human intervention.

On the other hand, like many glacial regions of the world, Aysén is severely affected by global warming. Solid rainfall is decreasing and temperatures are increasing, accompanied by heat waves, which are very dangerous for the subsistence of the over 21.000 km^2 of glaciers and ice fields existing in the region. Over the last five years the receding/retreat of the Patagonian Ice Fields reached an average of 6 km^2 y^{-1} (Romero et al., 2008). In addition, increased temperatures liquefy and warm up the available precipitation, affecting the volume of regional ice bodies, contributing to recurrent glacial lake outburst floods (GLOF phenomena) in Patagonia, disturbing the flood-pulse into all regional watersheds ecosystems, specially of mires all along the Baker and Pascua river basins, whose input-output balance of nutrients and organic matter has been severely affected during such episodes (Vargas et al., 2011). Another consequence of strong caudal increases is the occurrence of peat landslides in mires growing directly along rivers in Aysén. This phenomenon has been also reported in mires forming above low developed soils in the northern hemisphere (Dykes and Selkirk-Bell, 2010). In mires neighbouring Aysén rivers, these landslides seem to be increased by floods or droughts (Fig. 129, picture D). Such threats are expected to increase as result of global warming.

As well as climate change, the expansion of the cattle and forestry frontier is a significant threat for mires in Aysén. Over two million hectares of land and forest were burned since the colonization to clear the land for the introduction of livestock (Orrego y Rodrigo, 2007). At present, fires caused by humans are particularly associated with the extraction activities of Cypress de las guaitecas wood (*Pilgerodendron uviferum)*, a species abundant in the surroundings of raised bogs. The last green and vital cypresses in the Region of Aysén are located in the low and middle mountainous areas associated with raised bogs, where they remain protected from the fire by the dominating waterlogged conditions. This species of cypress tree is the world's southernmost conifer, presenting the highest adaption to waterlogged conditions amongst the native trees. It is also a valuable construction material (Donoso Zegers, 1993). Its cutting is facilitated by burning twigs and needles of the trees while they are still planted (Fig. 129, picture A). This makes the trees lighter for transport by human and animal force, once they have been chopped down. Additionally forestry areas are intervened, not only by burning, but also by provisional camps and animal traction used to reach the logging areas (Fig. 129, picture B). The Carretera Austral is another factor of disturbance for regional mires, as in some areas the peat layer was removed to extract aggregates for the construction of paths and roads, especially in mountainous zones (Orrego y Rodrigo, 2007), with significant drainage and erosion effects for the whole mire complex. This is the case in Site QP1 (Fig. 129, picture C). A more imminent threat was the hydro-electrical energy project Hidroaysén (www.hidroaysen.cl), which attempted to build five dams in the Baker and Pascua Rivers, signifying the perturbation of mire ecosystems downstream. In May 2014 and under the government of Michele Bachellet, Hidroaysén was cancelled and its realization forbidden for the next 7 years (Howard, 2014; Artaza y López, 2014). Under this project all mires in the Baker River Basin will be affected (e.g. sites LV and LR). According to the Centre for the Investigation of Natural Resources (CIREN, 2005), 27% of Aysén regional surface is directly or indirectly affected by erosion. Nevertheless, the existence of mires associated with the Baker and Pascua rivers is still relatively free from risk. To keep it that way, more knowledge about these ecosystems has to be produced, in order to contribute a basis to their understanding, preservation and sustainable management.

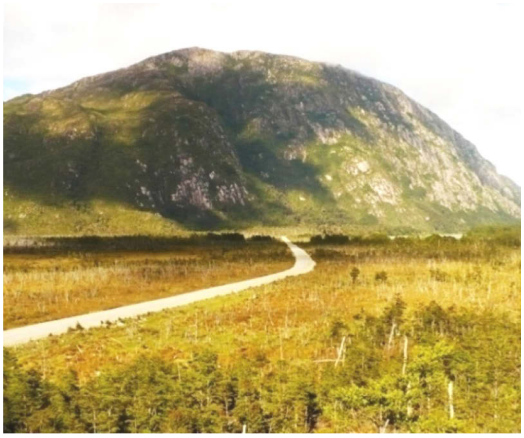
All these mentioned threats are especially dangerous to mires located in valley basins, valley edges, flood plains and fluvial terraces of Aysén as the sites LV, LR, QP1, QP2, QP3, BP1 and BP2 are, with the most threatened being the raised mires and sloping mires (Fig. 130).

Mires located in mountainous and remote areas are less prone to anthropogenic impacts. For example, the site BP4 was one of the most pristine in the whole study, being a refuge for wild endangered species like the Ruddy-headed Goose (*Chloephaga rubidiceps,* Fig. 131*,* picture A), which is the smallest amongst the five species of South American geese, and the Huemul (*Hypocamelus bisulcus,* see Fig. 131, picture B), one of only three species of South Andean deers. Also the site VO, in the mountains of Villa O'Higgins, is neighbouring an Eco-Camp used only for eco-tourism activities. This was the most pristine mire of the whole study, presenting ecological conditions good enough to host the amphibian *Hylorina silvática* and *Nannophryne variegata* (Fig. 131*,* pictures C and D), which belong to the regional endangered endemic fauna (Mella Avila, 1999). According to personal communications with Mauricio Melgarejo (2013) humid areas like the site VO are important feeding and watering habitats for a variety of birds and also for huemuls (*Hypocamelus bisulcus*). Mires like the terrestrialization fen of the site VO can be endangered by conversion into grasslands and by intentional fires. Since they present a mixed peat production, where pure *Sphagnum* mosses are a minority, they are not endangered by peat cutting activities. Before new (potential or real) threats arise, new information about Aysén mires should be developed, and more knowledge about these ecosystems has to be produced, in order to contribute a basis to their understanding, preservation and sustainable management.

A

B

C



D

E

A= Intentional fires for cypress extraction at site LV. B= Temporary camps for Cypress extraction at site LR. C= Intrusion of the Carretera Austral at site LR. D= Extraction of sand and gravel for construction uses from the subsoil of the mire QP1. E= Peat landslides in the mire BP2 neighbouring the Pascua River.

Fig. 129: Disturbances in the examined mires along the Baker and Pascua rivers

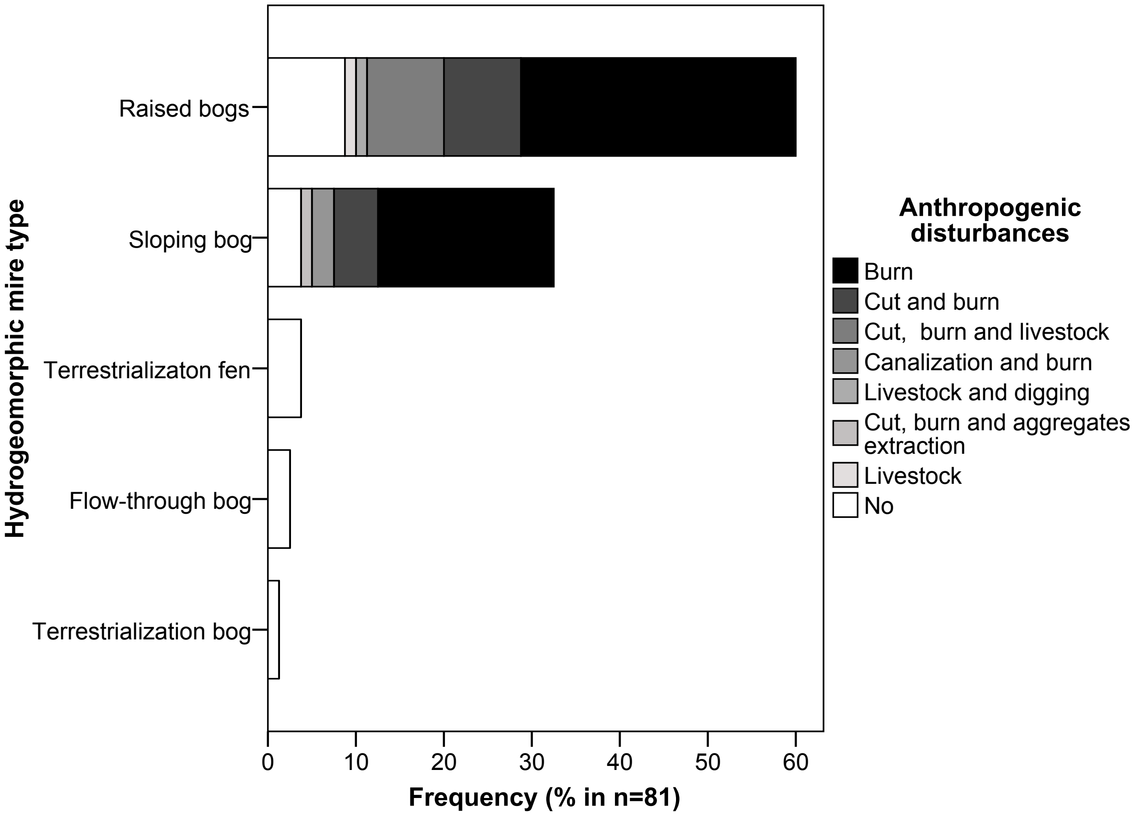


Fig. 130: Anthropogenic disturbances detected by hydrogeomorphic mire type (all sampled profiles).

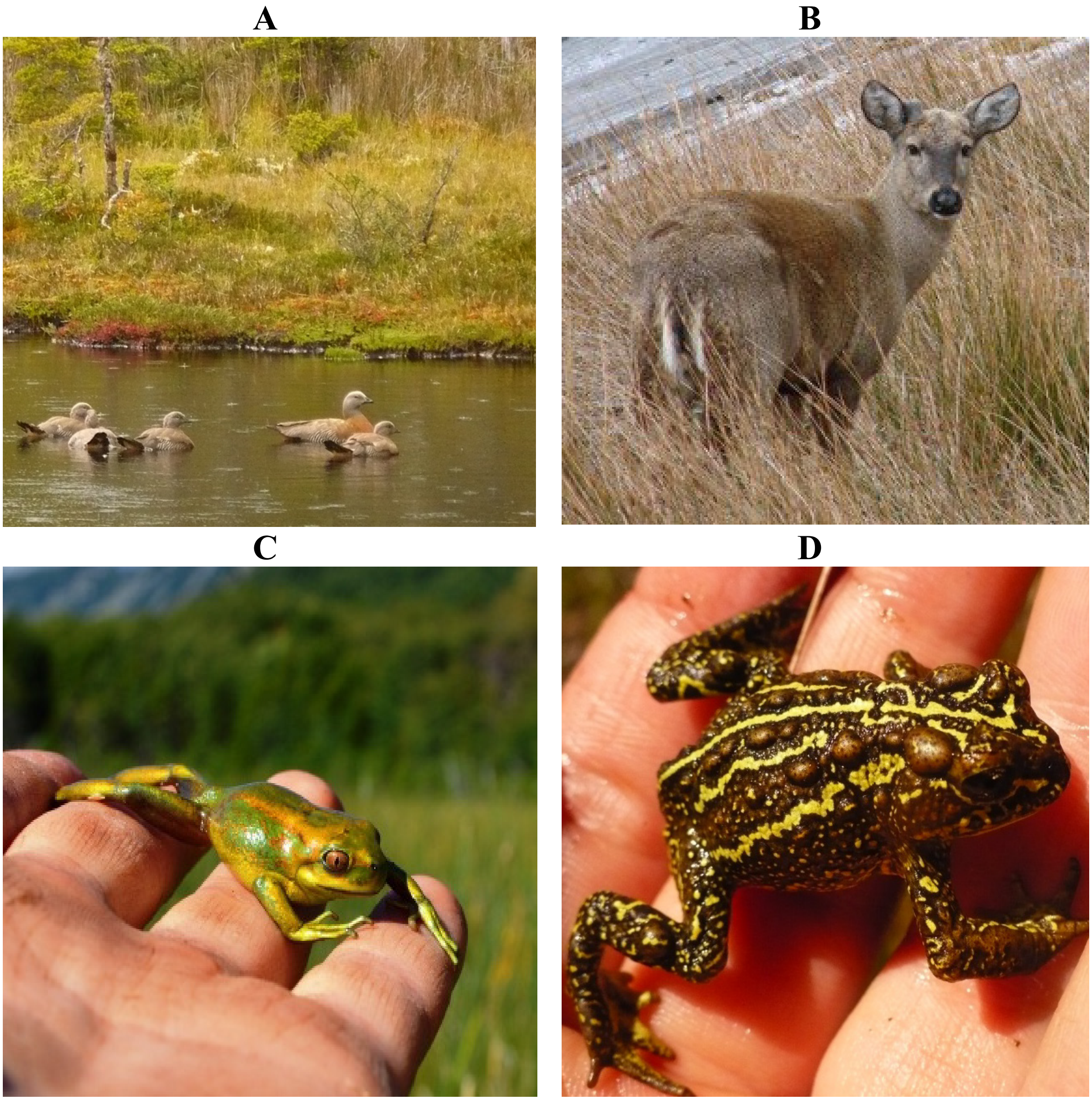


Fig. 131: Fauna inhabiting pristine mire ecosystems of Aysén

A= The terrestrialization bog at site BP4 is the habitat of the Ruddy-headed Goose (*Chloephaga rubidiceps*). B= The site BP4 is also the habitat of the South American deer called Huemul (*Hypocamelus bisulcus*) (Picture courtesy of Ricardo Ordonez Hernandez). C= The terrestrialization fen at site VO is a refuge for *Hylorina silvática*. D= Also for *Nannophryne variegata*.

5. Conclussions

Through the examination of ten mires along the Baker and Pascua river basins, this work raises new data about unstudied ecosystems in the Chilean Patagonia, and develops a method to carry out further monitoring and assessment activities related to mires and peatlands in the region. Through the data collected, this research corroborates that mires in Aysén have mostly a northerly exposure and their dissemination occurs extensively over valley basins, valley edges, flood plains and fluvial terraces, as well as in mountainous areas, occupying slopes, the bottom of slopes and intermountain depressions. It was also found out, that mires change in physiognomy and ecology according to their exposure to the oceanic winds, mire water level and relief. It was observed that the main water surpluses of these mires come from rain water, percolation water, lateral surpluses, streams and small lagoons inside the mires. Additionally, the studied mires present their own hydrology composed of the mire water table and sometimes by shallow pools of standing water. On the other hand, according to the stratigraphic evidences, the study determined that the examined mires were originated through terrestrialization (VO and BP4), paludification (LV, LR, BP2); by both (QP3) or by superficial runoffs in sloping areas (QP1, QP2, BP1 and BP3). All these origins are associated with water fluctuations occurring since the last glacial retreat, influenced by intermittent periods of dryness during the Holocene, and by strong rainfall with maritime concentration and seasonal melting periods in the present day. It was possible to conclude, that all ecosystems are geogenic originated, while their transformation into ombrogenic mires is recent, being visible only in the superficial horizons composed of *Sp. magellanicum* peat, Ericaceae peat*, Oreobolus* peat and cushion plants peat. Moreover, the sites present a similarity in their underlying substrates, insinuating that they share common development stages and have an origin under similar climatic conditions, and that these conditions were dominant enough to exceed other factors influencing the peat development (pH, relief, nutrient inputs via runoffs).

The results in this study do not allow differentiating if the wide presence of amorphous peat at several depths in mires dominated by cushion plants is related to aeration processes that cushion plants produce in the underlying horizons; or if the amorphous peat founded was formed before due to successional water fluctuations and dry periods occurring in the past. Nevertheless, it is suspected that the presence of amorphous horizons (peat "ready to eat") favoured the settlement of cushion plants species over *Sp. magellanicum* mires in the regional coastal mires. Future studies determining seeds, macrofossils and pollen types in the peat could help to solve this incognito. Nevertheless, this research allowed to corroborate for Aysén the hypothesis developed by Fritz (2012), Teltewskaja (2010), Abel (2009) and Kleinebecker (2007) for Southern Patagonia and Tierra del Fuego, about the action of the sea spray over the nutrient conditions in the upper soils, which favours the settlement of cushion plants in raised mires and the displacement of *Sp. magellanicum* species. Furthermore, this research found out that it is the intensity of the exposure to the oceanic salt enriched westerlies that determines the development and dominance of blanket bogs (formed by cushion plants) over raised bogs (formed by *Sp. magellanicum*). Additionally, since the settlement of cushion plant species is being favoured by nitrogen contributing activities, (associated in Aysén with fires provoked by humans, livestock expansion, construction of roads and dams, and globally to atmospheric contamination increases) it is expected that in the next century, the mire landscapes composed of raised bogs of *Sp. magellanicum* mosses will turn into blanket bogs formed by cushion plants and even other vascular species.

Based on the examined ecosystems, this work contributes data to typify some ecologic indicators of pristine conditions for mires in Aysén, among them a low bulk density (median=0,09 g^{-1} cm^3) and a high water holding capacity (median=91%), with mires of *Sp. magellanicum* peat, Ericaceae peat and *Schoenoplectus* peat being crucial to the fulfillment of water retention and filtering functions in the regional landscapes. It was also observed that mires containing substrates as cushion plants peat, radicels peat, *Oreobolus* peat and brown moss peat, forming mostly in mountainous areas, are crucial to the moderation of runoffs and to the prevention of erosion processes. Above all the wet organic substrates in the healthy saturated mires of Aysén were determined as those regulating the temperature of the sub-soil, allowing seeds and plant roots to survive during the dry, hot summers that have prevailed in the last decade as well as during the hard Patagonian winters.

The ten sites examined in this study presented a mire average depth of 76 cmbs, an average bulk density of the peat of 0.09 g cm^3 and a water retention capacity for the peat substrate fraction of 91%. When linking this information to regional data sources about the area of Aysén's mire landscapes (aprox. 1.450.000 ha after CONAF et al., 1999a, actualized in 2010), it preliminary and approximately possible to deduce that >1.305.000.000 m^3 of peat and >10 billions $m^3$of fresh water are approximately stored in the mires of Aysén.

Additionally, visualizing these mires as organic carbon reservoirs, the collected data show a preliminary average carbon storage capacity of 414 t C_{org} ha^{-1}, meaning >600 millions t C_{org} stored in the peat of Aysén's regional mires.

Through this study the age of formation of three representative mire sites was determined, including a raised bog at site LV (3535±35 yr BP), a sloping bog at site QP1 (745±30 yr BP) and a terrestrialization bog at site BP4 (4800±40 yr BP). These results show that when mires present a diversified hydrology (e.g. sloping mires) diversified plants will find a niche to grow, resulting in the production of different litter types and eventually in higher peat production. This is the case for the sloping mire QP1, whose peat production was calculated in 0,8 mm y^{-1}. On the contrary, it was corroborated that the dominance of one species, added to high decomposition degrees in the lower horizons of mires, can drive shrinkage processes, producing lower peat accumulation rates, even in raised mires (e.g. LV= 0.06 cm y^{-1}) or in high saturated mires (e.g. site BP4= 0.06 cm y^{-1}). Summarizing, the average growth of the peat for the sites under study can be preliminarily estimated at 0.07±0.01 cm y^{-1}, with an annual peat accumulation rate of 54±9 gr m^2 y^{-1}.

Finally, this research contributes representative information about the most important factors determining the hydrologic, geomorphologic, stratigraphic and ecological characteristics of mires along a rainfall and continental-maritime gradient in the area of the Baker and Pascua Riverbasins in Aysén-Chile. This information allows to consider that the examined ecosystems vary in their stratigraphy, presenting different substrate types; in their morphology presenting raised, sloping and flat tendencies; in their ecology from strongly acidic-very poor oligotrophic to weakly acidic–moderate mesotrophic; and in their typical vegetation driving changes in the current peat formation. From these data, a four-level system to facilitate the hydrogeomorphic classification of mires in Aysén is proposed:

- The First Level differentiates between the different geomorphologic and hydrological settings allowing mire formation, focusing on the relief unit where the mire lies and in the source of terrestrial or atmospheric water feeding it.
- Based on these main water surpluses and mire hosting relief, the Second Level proposes five Hydrogeomorphic Mire Types: raised bogs (formed in flat reliefs, fed only by rain water), sloping bogs (formed in slopes, fed by both rain water and surface runoffs), flow-through bogs (which form also on slopes, fed by both rain water and by a small central stream), terrestrialization bogs (formed from small lagoons in intermountain depressions

close to the coast, fed primarily by rain water enriched by sea spray and secondarily by surface runoffs) and terrestrialization fens (formed from a remnant lagoon in mountainous depressions away from the maritime influence, fed mostly by surface runoffs and percolating groundwater).

- The Third Level discriminates among types of physiognomies and plant communities dominating in each hydrogeomorphic mire type. These types are called mire ecotypes and there are eight of them: raised bogs (dominated by *Sp. magellanicum*), flooded hummocks (dominated by *Sp. magellanicum* and *Tetroncium magellanicum*), forest-covered hummocks (dominated by *Sp. magellanicum* and *Pilgerodendron uviferum*), blanket bogs (dominated by cushion plants), mixed bogs (dominated by plants from raised bogs and blanket bogs), oligotrophic floating mats (dominated by cushion plants), blanket fens (dominated by brown mosses, sedges and rushes) and mesotrophic floating mats (dominated also by brown mosses, sedges and rushes).
- Furthermore according to their main botanical components or materials, a Fourth Level differentiates between the eleven organic substrate types forming the soils of the ten examined sites,: *Sp. magellanicum* peat, *Sp. fimbriatum* peat, Ericaceae peat, radicels peat, cushion plants peat, *Oreobolus* peat, cypress wood peat, brown moss peat, *Schoenoplectus* peat, amorphous peat and organic gyttja.

It is expected that new mire types will be found to exist in the territory, as soon as exploration and research on the topic makes advances in the region. The ecological conditions dominating in the mires of Aysén should be monitored to prevent undesired changes in the current balance of regional landscapes and ecosystems.

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Annexes

Annex 1: Data Fig. 72: Depth to the surface organic substrate in mires of Aysén (n=470)

Substrate type	Depth (cmbs)				
	Min	Median	Max	Std. deviation	n
Sp. magellanicum peat	5	44	190	41	134
Amorphous peat	5	86	266	51	124
Radicels peat	5	85	324	60	92
Ericaceae peat	11	80	195	40	37
Cushion plants peat	5	24	54	13	28
Oreobolus peat	5	21	45	11	12
Sp. fimbriatum peat	3	13	33	10	7
Cypress wood peat	53	215	330	107	6
Brown moss peat	13	45	84	27	5
Schoenoplectus peat	5	14	26	11	3
Organic gyttja	20	263	417	140	22
Total	*3*	*76*	*417*	*74*	*470*

Annex 2: Data Section 4.2.1

Site	Depth (cmbs)				
	Min	Median	Max	Std. deviation	n
LV	3	61	247	50	113
LR	5	59	350	49	77
VO	5	176	417	134	44
QP1	5	71	210	55	64
QP2	5	39	80	21	20
QP3	5	61	220	54	41
BP1	8	60	131	34	30
BP2	7	80	210	52	36
BP3	12	59	150	37	32
BP4	20	141	340	114	12
Total	*3*	*76*	*417*	*74*	*470*

Annex 3: Data Fig. 73: Horizon substrate combinations and their frequency in the whole sample of organic substrate types. Classification after the KA 5 (AG Boden, 2005)

Substrate type	Horizon (count)					
	hHw	nHw	hHr	nHr	fFr	n
Sp. magellanicum peat	37	0	97	0	0	134
Amorphous peat	0	11	0	113	0	124
Radicels peat	0	10	0	82	0	92
Ericaceae peat	3	0	34	0	0	37
Cushion plants peat	8	0	20	0	0	28
Oreobolus peat	6	0	6	0	0	12
Sp. fimbriatum peat	0	5	0	2	0	7
Cypress wood peat	0	0	6	0	0	6
Brown moss peat	0	0	0	5	0	5
Schoenoplectus peat	0	1	0	2	0	3
Organic gyttja	0	0	0	0	22	22
Total	*54*	*27*	*163*	*204*	*22*	*470*

Annex 4: Data Fig. 74: Spectrum of colours observed in all organic substrates types. Categories according to the Munsell © Color Chart (1994)

	Substrate type (n by colour)											
Colour	*Sp. magellanicum* peat	Amorphous peat	Radicels peat	Ericaceae peat	Cushion plants peat	*Oreobolus* peat	*Sp. fimbriatum* peat	Cypress wood peat	Brown moos peat	*Schoenoplectus* peat	Organic gyttja	n
7.5YR2.5/2	19	16	8	5	2	2	1	1	0	0	0	54
7.5YR2.5/3	9	11	10	7	1	0	1	0	0	0	0	39
5YR2.5/2	7	9	5	6	4	0	0	0	0	0	0	31
7.5YR2.5/1	8	7	5	1	1	2	0	2	0	0	3	29
10YR3/2	9	8	8	0	0	0	1	1	0	0	2	29
10YR3/4	11	5	4	1	1	1	0	0	0	0	0	23
7.5YR3/1	4	4	6	2	2	1	0	0	0	1	2	22
5YR2.5/1	8	3	6	1	3	1	0	0	0	0	0	22
10YR2/2	5	9	6	1	0	0	0	0	0	0	1	22
7.5YR3/2	6	8	3	0	2	1	0	0	1	0	0	21
10YR3/3	8	5	3	0	0	1	0	0	0	0	0	17
5YR3/2	3	6	4	0	3	0	0	0	0	0	0	16
7.5YR3/3	4	4	3	0	2	0	1	1	0	0	0	15
10YR3/1	2	5	2	1	0	0	1	0	1	1	1	14
5YR3/1	0	4	2	0	1	2	0	0	1	1	0	11
10YR4/4	8	1	1	0	0	0	0	0	0	0	0	10
2.5YR2.5/2	1	2	1	3	2	0	0	0	0	0	0	9
10YR2/1	3	2	2	0	0	0	0	0	1	0	1	9
2.5YR2.5/1	1	0	2	0	4	0	0	0	1	0	0	8
10YR3/6	3	0	2	1	0	0	0	0	0	0	2	8
2.5Y3/3	0	4	0	2	0	0	0	0	0	0	1	7
7.5YR3/4	0	1	2	2	0	1	0	0	0	0	0	6
5YR3/3	2	1	3	0	0	0	0	0	0	0	0	6
10YR4/6	5	0	0	0	0	0	0	0	0	0	0	5
5YR3/4	0	1	1	1	0	0	0	1	0	0	0	4
10YR4/2	0	2	0	0	0	0	1	0	0	0	1	4
2.5YR3/1	0	0	0	0	0	0	0	0	0	0	3	3

10YR4/3	2	0	0	0	0	0	1	0	0	0	0	3
2.5Y4/4	1	0	0	1	0	0	0	0	0	0	0	2
2.5Y4/1	0	1	0	1	0	0	0	0	0	0	0	2
2.5Y3/2	0	0	2	0	0	0	0	0	0	0	0	2
10YR5/3	2	0	0	0	0	0	0	0	0	0	0	2
Gley12/5N	0	0	0	0	0	0	0	0	0	0	1	1
7.5YR4/6	1	0	0	0	0	0	0	0	0	0	0	1
5Y5/2	0	1	0	0	0	0	0	0	0	0	0	1
5Y4/2	0	0	0	0	0	0	0	0	0	0	1	1
5Y2.5/2	0	0	0	0	0	0	0	0	0	0	1	1
2.5YR2/2	0	0	1	0	0	0	0	0	0	0	0	1
2.5YR2/1	0	0	0	1	0	0	0	0	0	0	0	1
2.5Y3/1	0	0	0	0	0	0	0	0	0	0	1	1
10YR5/8	0	1	0	0	0	0	0	0	0	0	0	1
10YR5/6	1	0	0	0	0	0	0	0	0	0	0	1
10YR5/4	1	0	0	0	0	0	0	0	0	0	0	1
10YR2.5/1	0	1	0	0	0	0	0	0	0	0	0	1
Total	*134*	*124*	*92*	*37*	*28*	*12*	*7*	*6*	*5*	*3*	*22*	*470*

Annex 5: Data Fig. 75: Degree of peat decomposition detected in samples of peat substrates

Substrate	DD								
	H3	H4	H5	H6	H7	H8	H9	H10	n
Sp. magellanicum peat	74	54	1	3	2	0	0	0	134
Amorphous peat	0	0	0	0	0	0	51	73	124
Radicels peat	27	25	5	13	11	8	2	1	92
Ericaceae peat	11	14	1	8	3	0	0	0	37
Cushion plants peat	11	10	0	2	0	1	4	0	28
Oreobolus peat	4	7	0	1	0	0	0	0	12
Sp. fimbriatum peat	1	4	0	0	0	0	2	0	7
Cypress wood peat	1	3	2	0	0	0	0	0	6
Brown moos peat	2	2	0	0	0	0	1	0	5
Schoenoplectus peat	1	1	0	0	0	0	1	0	3
Total	*132*	*120*	*9*	*27*	*16*	*9*	*61*	*74*	*448*

Annex 6: Data Fig. 76: Bulk density values for different organic substrate types of Aysén

Substrate	Bulk Density (g cm3)				
	Min	Media	Max	Std. deviation	n
Sp. magellanicum peat	.03	.06	.07	.01	8
Amorphous peat	.09	.10	.12	.01	7
Radicels peat	.07	.09	.10	.01	9
Ericaceae peat	.06	.07	.07	.01	6
Cushion plants peat	.08	.09	.11	.01	5
Oreobolus peat	.08	.09	.09	.01	4
Sp. fimbriatum peat	.09	.09	.09	.	1
Cypress wood peat	.05	.06	.07	.01	2
Brown moss peat	.10	.10	.10	.	1
Schoenoplectus peat	.06	.06	.06	.	1
Organic gyttja	.18	.20	.22	.03	2
Total	*.03*	*.09*	*.22*	*.03*	*46*

Annex 7: Data Fig. 77: Water holding capacity of all substrates at field capacity (n=189)

Substrate	Water Holding Capacity (% substrate volume at field capacity)				
	Min	Media	Max	Std. deviation	n
Sp. magellanicum peat	81	91	97	5	25
Amorphous peat	83	90	95	2	37
Radicels peat	79	89	95	4	33
Ericaceae peat	87	92	96	2	24
Cushion plants peat	89	91	94	1	27
Oreobolus peat	90	92	93	1	5
Sp. fimbriatum peat	89	89	90	1	3
Cypress wood peat	90	92	95	2	13
Brown moss peat	84	90	93	4	5
Schoenoplectus peat	94	94	95	1	5
Organic gyttja	75	81	84	3	10
Total	*75*	*90*	*97*	*4*	*189*

Annex 8: Data Fig. 78: pH-values for different organic substrate types of Aysén (n=470)

Substrate	pH-value				
	Min	Media	Max	Std. deviation	n
Sp. magellanicum peat	2.32	3.85	7.16	.61	134
Amorphous peat	3.02	4.42	6.42	.65	124
Radicels peat	2.98	4.20	6.42	.59	92
Ericaceae peat	3.10	4.04	5.04	.46	37
Cushion plants peat	3.06	3.70	4.61	.45	28
Oreobolus peat	3.47	3.72	4.05	.22	12
Sp. fimbriatum peat	3.04	4.26	5.50	.79	7
Cypress wood peat	3.69	5.05	5.97	.92	6
Brown moss peat	4.28	5.59	6.62	.97	5
Schoenoplectus peat	4.64	5.32	6.20	.80	3
Organic gyttja	3.20	5.37	7.27	.89	22
Total	*2.32*	*4.19*	*7.27*	*.74*	*470*

Annex 9: Data Fig. 79: pH-values interpreted by site, based on samples for different organic substrate types of Aysén (n=470)

Site	pH-value				
	Min	Media	Max	Std. deviation	n
	.	.	.	.	1
LV	3.01	3.96	6.04	.49	113
LR	2.94	4.02	6.16	.67	77
VO	3.50	5.64	7.27	.85	44
QP1	2.32	3.95	4.94	.55	64
QP2	3.02	3.93	5.30	.56	20
QP3	3.06	3.81	4.97	.42	41
BP1	3.74	4.25	5.07	.36	31
BP2	3.57	4.32	5.35	.43	36
BP3	3.32	4.36	5.21	.45	32
BP4	3.41	4.22	5.10	.51	12
Total	*2.32*	*4.19*	*7.27*	*.74*	*470*

Annex 10: Data Fig. 80: Organic carbon content for different organic substrate types (n=46)

Substrate type	Organic carbon content -Corg- (DM%)				
	Min	Median	Max	Std. deviation	n
Sp. magellanicum peat	39.91	45.53	54.54	5.07	8
Amorphous peat	14.35	45.01	57.37	15.63	7
Radicels peat	43.12	51.23	56.01	4.26	9
Ericaceae peat	52.54	54.01	56.03	1.38	6
Cushion plants peat	30.70	41.77	50.75	8.45	5
Oreobolus peat	46.12	51.53	56.55	4.75	4
Sp. fimbriatum peat	26.27	26.27	26.27	.	1
Cypress wood peat	43.81	47.81	51.81	5.66	2
Brown moss peat	31.40	31.40	31.40	.	1
Schoenoplectus peat	18.40	18.40	18.40	.	1
Organic gyttja	36.27	39.89	43.50	5.11	2
Total	*14.35*	*46.23*	*57.37*	*10.00*	*46*

Annex 11: Data Fig. 81: Organic carbon content by horizon substrate combinations Aysén (n=46)

Horizon-substrate combination (acc. to KA5)	Organic carbon content -Corg- (DM%)				
	Min	Median	Max	Std. deviation	n
hHw-Cypress peat	31.40	31.40	31.40	.	1
hHw-Cushion plants peat	30.70	39.98	49.36	8.07	4
hHw-*Sp. magellanicum* peat	40.23	44.16	47.23	3.58	3
hHw-*Oreobolu*s peat	46.12	46.12	46.12	.	1
nHw-Amorphous peat	34.03	34.03	34.03	.	1
nHr-*Sp. fimbriatum* peat	26.27	26.27	26.27	.	1
nHr -*Schoenoplectus* peat	18.40	18.40	18.40	.	1
nHr-Brown moss peat	43.81	47.81	51.81	5.66	2
hHr-Sp. *magellanicum* peat	39.91	46.35	54.54	6.03	5
nHr-Amorphous peat	14.35	46.84	57.37	16.28	6
hHr-Cushion plants peat	50.75	50.75	50.75	.	1
nHr-Radicels peat	43.12	51.23	56.01	4.26	9
hHr-*Oreobolus* peat	49.15	53.33	56.55	3.79	3
hHr-Ericaceae peat	52.54	54.01	56.03	1.38	6
fFr-Organic gyttja	36.27	39.89	43.50	5.11	2
Total	*14.35*	*46.23*	*57.37*	*10.00*	*46*

Annex 12: Data Fig. 82: Organic carbon content interpreted by mire sites of Aysén (n=46)

Site	Organic carbon content -Corg- (DM%)				
	Min	Median	Max	Std. deviation	n
LV	40.96	48.89	52.54	3.79	7
LR	47.32	50.19	55.40	3.47	6
VO	14.35	32.98	43.81	12.27	5
QP1	45.01	52.57	56.01	4.13	8
QP2	46.08	53.19	57.37	5.04	4
QP3	53.35	54.81	56.55	1.62	3
BP1	40.73	43.43	46.12	3.81	2
BP2	26.27	39.84	52.96	10.90	4
BP3	30.70	46.03	54.01	13.28	3
BP4	33.01	38.80	49.36	9.16	3
Total	*14.35*	*46.23*	*57.37*	*10.00*	*46*

Annex 13: Data Fig. 83: Organic matter after loss by ignition for organic substrates (n=46)

Substrate	Total organic substance after loss by ignition (OS %)				
	Min	Media	Max	Std. deviation	n
Sp. magellanicum peat	84.78	89.84	99.87	5.89	8
Amorphous peat	67.86	88.42	98.66	13.56	7
Radicels peat	84.79	94.76	97.88	4.26	9
Ericaceae peat	95.52	97.58	99.98	1.83	6
Cushion plants peat	62.56	84.23	96.45	13.31	5
Oreobolus peat	91.16	94.81	99.17	4.11	4
Sp. fimbriatum peat	51.83	51.83	51.83	.	1
Cypress wood peat	93.51	95.76	98.00	3.17	2
Brown moss peat	65.06	65.06	65.06	.	1
Schoenoplectus peat	88.73	88.73	88.73	.	1
Organic gyttja	42.45	47.44	52.43	7.06	2
Total	*42.45*	*88.44*	*99.98*	*13.99*	*46*

Annex 14: Data Fig. 84: Total nitrogen content for different organic substrates (n=46)

Substrate	Total nitrogen content -N- (DM%)				
	Min	Media	Max	Std. deviation	n
Sp. magellanicum peat	.66	1.11	2.34	.58	8
Amorphous peat	.87	1.44	2.95	.71	7
Radicels peat	.87	1.66	2.41	.51	9
Ericaceae peat	.97	1.80	2.77	.63	6
Cushion plants peat	1.14	1.51	1.73	.25	5
Oreobolus peat	1.14	1.30	1.48	.16	4
Sp. fimbriatum peat	.76	.76	.76	.	1
Cypress wood peat	.91	1.00	1.08	.12	2
Brown moss peat	1.47	1.47	1.47	.	1
Schoenoplectus peat	1.35	1.35	1.35	.	1
Organic gyttja	1.27	1.79	2.30	.73	2
Total	*.66*	*1.45*	*2.95*	*.55*	*46*

Annex 15: Data Fig. 85: Total nitrogen content interpreted by horizon substrate combinations (n=46)

Horizon-substrate combination (KA5)	Total nitrogen content -N- (DM%)				
	Min	Media	Max	Std. deviation	n
nHw-Amorphous peat	1.12	1.12	1.12	.	1
hHw-*Oreobolus* peat	1.18	1.18	1.18	.	1
hHw-Cypress wood peat	1.47	1.47	1.47	.	1
hHw-Cushion plants peat	1.40	1.60	1.73	.15	4
hHw-*Sp. magellanicum* peat	.87	1.61	2.34	.74	3
hHr-*Sp. magellanicum*	.66	.80	.94	.11	5
hHr-Cushion plants peat	1.14	1.14	1.14	.	1
hHr-*Oreobolus* peat	1.14	1.33	1.48	.17	3
hHr-Ericaceae peat	.97	1.80	2.77	.63	6
nHr-*Sp. fimbriatum* peat	.76	.76	.76	.	1
nHr-Brown moss peat	.91	1.00	1.08	.12	2
nHr-amorphous peat	.87	1.49	2.95	.77	6
nHr-Radicels peat	.87	1.66	2.41	.51	9
nHr -*Schoenoplectus* peat	1.35	1.35	1.35	.	1
fFr-Organic gyttja	1.27	1.79	2.30	.73	2
Total	*.66*	*1.45*	*2.95*	*.55*	*46*

Annex 16: Data Fig. 86: Total nitrogen content interpreted by mire sites of Aysén (n=46)

Site	Total nitrogen content -N- (DM%)				
	Min	Media	Max	Std. deviation	n
LV	.77	1.25	1.91	.47	7
LR	.87	1.44	2.95	.85	6
VO	.99	1.37	2.30	.44	7
QP1	1.19	1.68	2.34	.44	8
QP2	1.28	1.97	2.77	.63	4
QP3	.94	1.10	1.38	.25	3
BP1	.87	1.03	1.18	.22	2
BP2	.66	1.39	2.41	.83	4
BP3	1.57	1.63	1.67	.05	3
BP4	1.12	1.26	1.40	.20	2
Total	*.66*	*1.45*	*2.95*	*.55*	*46*

Annex 17: Data Fig. 87: Carbon to nitrogen ratio for different organic substrate types of Aysén (n=46)

Substrate type	Carbon and nitrogen ratio -C/N-				
	Min	Median	Max	Std. deviation	n
Sp. magellanicum peat	20.44	49.68	68.11	17.05	8
Amorphous peat	14.61	35.11	55.26	15.00	7
Radicels peat	23.70	34.70	55.26	9.94	9
Ericaceae peat	19.37	34.06	55.62	12.83	6
Cushion plants peat	20.83	31.23	44.73	8.73	6
Oreobolus peat	36.72	40.84	44.55	3.21	4
Sp. fimbriatum peat	36.57	36.57	36.57	.	1
Cypress wood peat	35.14	46.06	56.97	15.44	2
Brown moss peat	22.53	22.53	22.53	.	1
Schoenoplectus peat	17.55	17.55	17.55	.	1
Organic gyttja	20.37	25.47	30.57	7.21	2
Total	*14.61*	*36.82*	*68.11*	*13.50*	*47*

Annex 18: Data Fig. 88: Carbon to nitrogen ratio interpreted by horizon substrate combinations (n=46)

Horizon-substrate combination (acc. to KA5)	Carbon and nitrogen ratio -C/N-				
	Min	Media	Max	Std. deviation	n
hHw-Cypress wood peat	22.53	22.53	22.53	.	1
hHw-Cushion plants peat	20.83	27.71	37.55	7.04	4
hHw-*Sp. magellanicum* peat	20.44	31.99	47.69	14.09	3
nHw-Amorphous peat	32.38	32.38	32.38	.	1
hHw-*Oreobolus* peat	41.26	41.26	41.26	.	1
hHr-Ericaceae peat	19.37	34.06	55.62	12.83	6
nHr-Radicels peat	23.70	34.70	55.26	9.94	9
nHr -*Schoenoplectus* peat	35.14	35.14	35.14	.	1
nHr-Amorphous peat	14.61	35.56	55.26	16.38	6
nHr-*Sp. fimbriatum* peat	36.57	36.57	36.57	.	1
nHr-Brown moss peat	17.55	37.26	56.97	27.87	2
hHr-*Oreobolus* peat	36.72	40.70	44.55	3.92	3
hHr-Cushion plants peat	44.73	44.73	44.73	.	1
hHr-*Sp. magellanicum* peat	55.26	60.30	68.11	5.82	5
fFr-Organic gyttja	20.37	25.47	30.57	7.21	2
Total	*14.61*	*36.92*	*68.11*	*13.63*	*46*

Annex 19: Data Fig. 89: Carbon to nitrogen ratio interpreted by mire sites of Aysén (n=46)

Site	Carbon and nitrogen ratio -C/N-				
	Min	Media	Max	Std. deviation	n
LV	27.33	45.73	68.11	15.15	7
LR	18.04	42.85	55.26	16.03	6
VO	14.61	26.20	42.61	10.21	7
QP1	20.44	33.36	46.55	8.93	8
QP2	19.37	29.42	44.77	10.81	4
QP3	40.83	51.19	57.11	9.00	3
BP1	41.26	44.48	47.69	4.55	2
BP2	23.70	37.75	64.91	18.97	4

BP3	20.83	30.00	35.05	7.96	3
BP4	32.38	34.97	37.55	3.66	2
Total	*14.61*	*36.92*	*68.11*	*13.63*	*46*

Annex 20: Data Fig. 121: Association between hydrogeomorphic mire types and mire ecotypes.

	Hydrogeomorphic mire type					
Ecotype	Raised bogs	Flow-through bog	Terrestrialization fen	Terrestrialization bog	Sloping bog	n
Raised bogs	270	0	0	0	0	270
Forest-covered hummocks	28	0	0	0	0	28
Flooded hummocks	0	0	0	0	0	0
Blanket bogs	53	43	0	6	0	102
Mixed bogs	0	20	0	0	0	20
Swimming mat oligotroph	0	0	0	6	0	6
Swimming mat mesotroph	0	0	12	0	0	12
Blanket fens	0	0	32	0	0	32
Total	*351*	*63*	*44*	*12*	*0*	*470*

Annex 21: main field data for all soil cores sorted alphabetically
(See end of the table for abbreviations of fields HGM, ME, Substrate, Roots, Inclination, Relief and Human-made changes)

Site	Profile	HGM	ME	Depth (cmbs)	Horizon (KA5)	Substrate	pH-value	DD	MWT (cmbs)	Colour (Munsell)	Roots (KA 5)	Exposure	Inclination (KA 5)	Height (m.a.s.l)	Km to ocean	Rainfall (mm/y)	Relief	Human made changes	Current use
1	BP1	FTB	mB	13	hHw	Hob	3.7	**4**	47	5YR3/1	R5	N	N2	10	2	2700	FT	No use	No use
1	BP1			23	hHw	Hob	4.0	**3**	47	5YR3/1	R5								
1	BP1			33	nHw	Hgr	3.9	**3**	47	10YR3/6	R3								
1	BP1			47	nHr	Ha	4.3	**10**	47	5YR2.5/1	R1								
1	BP1			60	nHr	Hgr	4.2	**4**	47	7.5YR2.5/2	R1								
1	BP1			80	nHr	Ha	4.6	**10**	47	10YR3/2	R1								
1	BP1			87	nHr	Ha	4.6	**10**	47	7.5YR3/3	R1								
1	BP1			90	nHr	Ha	4.6	**10**	47	5YR2.5/1	R1								
2	BP1	FTB	bB	18	hHr	Hoas	3.8	**3**	16	5YR2.5/1	R0	S	N3	11	2	2700	FT	No use	No use
2	BP1			54	hHr	Hoas	4.0	**3**	16	5YR2.5/2	R4								
2	BP1			63	nHr	Ha	4.0	**9**	16	7.5YR2.5/3	R0								
2	BP1			68	nHr	Ha	3.9	**9**	16	2.5YR2.5/2	R0								
2	BP1			74	nHr	Ha	3.8	**9**	16	5YR3/2	R0								
2	BP1			85	hHr	Hosy	4.0	**7**	16	2.5YR2.5/2	R0								
2	BP1			92	nHr	Hgr	4.2	**4**	16	7.5YR2.5/2	R0								
2	BP1			105	nHr	Hgr	4.3	**4**	16	7.5YR2.5/3	R0								
2	BP1			116	nHr	Ha	4.5	**9**	16	10YR3/2	R0								
2	BP1			120	nHr	Ha	4.5	**9**	16	10YR3/2	R0								
2	BP1			131	nHr	Ha	4.5	**9**	16	10YR3/2	R2								
3	BP1	SL	mB	13	hHw	Hosy	3.7	**3**	20	7.5YR2.5/2	R0	S	N3	11	2	2700	FT	No use	No use
3	BP1			31	hHr	Hosy	4.3	**5**	20	7.5YR2.5/2	R0								
3	BP1			39	nHr	Hgr	4.9	**4**	20	10YR3/1	R0								
4	BP1	SL	mB	8	nHw	Hgr	4.5	**7**	100	5YR3/2	R3	E	N3	11	2	2700	FT	Ct, B, Ax	Militar Camp
4	BP1			30	nHw	Ha	5.1	**9**	100	5YR3/1	R2								

Site	Profile	HGM	ME	Depth (cmbs)	Horizon (KA5)	Substrate	pH-value	DD	MWT (cmbs)	Colour (Munsell)	Roots (KA 5)	Exposure	Inclination (KA 5)	Height (m.a.s.l)	Km to ocean	Rainfall (mm/y)	Relief	Human made changes	Current use
5	BP1	SL	mB	14	hHw	Hoas	3.8	**7**	26	5YR2.5/1	R5	E	N3	19	2	2700	FT	B	No use
5	BP1			26	hHr	Hoas	3.8	**4**	26	5YR2.5/2	R5								
5	BP1			40	hHr	Hoas	4.3	**6**	26	5YR3/2	R5								
5	BP1			50	nHr	Ha	4.4	**9**	26	5YR2.5/2	R5								
5	BP1			57	nHr	Ha	4.7	**9**	26	5YR2.5/1	R5								
5	BP1			63	nHr	Ha	4.7	**9**	26	5YR3/1	R2								
5	BP1			69	nHr	Ha	4.2	**9**	26	10YR2.5/1	R5								
1	BP2	RB	rB	26	nHr	Hgsc	4.6	**6**	12	7.5YR3/1	R5	N	N0	13	2	2700	FP	B	No use
1	BP2			50	nHr	Hgmm	5.4	**6**	12	7.5YR3/2	R2								
2	BP2	RB	bB	13	hHr	Hoas	4.5	**3**	13	7.5YR3/3	R5	W	N0	8	2	2700	FP	B	No use
2	BP2			42	hHr	Hosy	4.5	**3**	13	10YR5/6	R4								
2	BP2			52	hHr	Hosy	4.7	**4**	13	10YR4/4	R4								
2	BP2			100	hHr	Hosy	4.4	**3**	13	10YR3/4	R0								
2	BP2			108	hHr	Hosy	4.2	**4**	13	10YR3/6	R0								
2	BP2			150	hHr	Hosy	4.8	**4**	13	7.5YR4/6	R0								
2	BP2			199	nHr	Hgr	4.2	**7**	13	7.5YR3/2	R0								
2	BP2			210	nHr	Hgr	4.4	**7**	13	7.5YR3/3	R0								
3	BP2	RB	rB	25	hHr	Hoas	3.6	**7**	21	5YR3/2	R0	E	N0	16	2	2700	FP	B	No use
3	BP2			40	nHr	Ha	3.8	**9**	21	5YR3/3	R0								
3	BP2			54	nHr	Ha	3.9	**9**	21	7.5YR2.5/1	R0								
3	BP2			64	hHr	Hoi	4.1	**3**	21	7.5YR2.5/2	R0								
3	BP2			72	nHr	Ha	4.6	**9**	21	5YR2.5/2	R0								
3	BP2			86	nHr	Ha	4.8	**10**	21	5YR3/2	R2								
3	BP2			96	nHr	Hgr	4.4	**7**	21	7.5YR3/2	R1								
4	BP2	RB	rB	27	hHr	Hoas	3.7	**8**	20	7.5YR3/2	R3	E	N1	15	2	2700	FP	No use	No use
4	BP2			36	nHr	Ha	3.7	**9**	20	5YR3/2	R3								

Site	Profile	HGM	ME	Depth (cmbs)	Horizon (KA5)	Substrate	pH-value	DD	MWT (cmbs)	Colour (Munsell)	Roots (KA 5)	Exposure	Inclination (KA 5)	Height (m.a.s.l)	Km to ocean	Rainfall (mm/y)	Relief	Human made changes	Current use
4	BP2			47	nHr	Hgr	3.7	**6**	20	5YR3/2	R3								
4	BP2			52	nHr	Ha	3.8	**9**	20	7.5YR3/3	R1								
4	BP2			65	nHr	Ha	3.7	**9**	20	5YR3/2	R3								
4	BP2			98	nHr	Hgr	4.2	**6**	20	7.5YR3/3	R4								
4	BP2			117	nHr	Hgr	4.4	6	20	10YR3/4	R4								
4	BP2			123	nHr	Ha	4.4	9	20	10YR3/4	R4								
4	BP2			130	nHr	Hgr	4.5	7	20	5YR3/3	R1								
4	BP2			150	nHr	Hgr	4.7	7	20	5YR2.5/2	R4								
4	BP2			155	nHr	Hgr	4.9	7	20	10YR2/2	R0								
4	BP2			170	nHr	Hgr	4.5	6	20	10YR2/1	R0								
5	BP2	RB	rB	7	nHw	Hosa	3.7	7	14	7.5YR2.5/2	R5	N	N1	12	2	2700	FP	Ct, B	Forestry
5	BP2			33	nHr	Hosa	4.5	7	14	7.5YR2.5/3	R6								
5	BP2			41	nHr	Ha	4.3	9	14	5YR3/1	R6								
5	BP2			50	nHr	Ha	4.2	9	14	5YR2.5/2	R6								
5	BP2			58	hHr	Hoi	4.3	4	14	5YR2.5/2	R1								
5	BP2			64	nHr	Ha	4.9	9	14	5YR3/1	R1								
5	BP2			68	nHr	Ha	4.9	9	14	5YR2.5/2	R1								
1	BP3	SL	bB	12	hHw	Hoas	3.3	3	42	2.5YR2.5/1	R1	NE	N3	85	7	2700	S	B	Forestry
1	BP3			23	nHw	Ha	4.2	10	42	10YR5/8	R1								
1	BP3			35	hHw	Hosy	4.4	4	42	2.5YR2.5/1	R1								
1	BP3			40	hHw	Hosy	3.9	4	42	10YR2/2	R1								
1	BP3			46	nHr	Hgr	4.7	4	42	5YR3/1	R1								
1	BP3			56	nHr	Hgr	4.5	4	42	7.5YR2.5/2	R1								
1	BP3			87	nHr	Ha	4.5	9	42	7.5YR3/2	R1								
1	BP3			93	nHr	Hgr	4.6	4	42	10YR3/2	R1								
1	BP3			100	nHr	Ha	4.9	9	42	10YR3/1	R1								

Site	Profile	HGM	ME	Depth (cmbs)	Horizon (KA5)	Substrate	pH-value	DD	MWT (cmbs)	Colour (Munsell)	Roots (KA 5)	Exposure	Inclination (KA 5)	Height (m.a.s.l)	Km to ocean	Rainfall (mm/y)	Relief	Human made changes	Current use
2	BP3	SL	bB	12	hHw	Hoas	3.7	3	100	7.5YR3/1	R0	W	N2	83	7	2700	S	B	Forestry
2	BP3			30	hHw	Hoas	4.6	4	100	7.5YR3/2	R0								
3	BP3	SL	bB	12	hHw	Hoas	3.3	7	70	2.5YR2.5/1	R1	NE	N3	91	7	2700	S	B	No use
3	BP3			38	hHw	Hoas	4.2	4	70	2.5YR2.5/1	R2								
3	BP3			65	nHw	Hgr	4.1	8	70	2.5YR2.5/1	R3								
3	BP3			77	nHr	Hgr	4.0	8	70	7.5YR2.5/2	R1								
3	BP3			90	nHr	Ha	4.9	10	70	7.5YR2.5/3	R1								
3	BP3			100	nHr	Hgr	4.8	6	70	10YR2/2	R3								
3	BP3			105	nHr	Hgr	4.6	6	70	10YR3/2	R3								
3	BP3			135	nHr	Ha	4.7	10	70	7.5YR2.5/2	R0								
3	BP3			150	fFr	Gyo	5.2	-	70	10YR3/2	R0								
4	BP3	SL	bB	16	hHw	Hoi	3.7	3	100	2.5YR2/1	R4	NE	N3	92	7	2700	S	B	No use
4	BP3			25	nHw	Hgr	4.2	4	100	2.5YR2/2	R0								
4	BP3			32	hHw	Hoi	4.5	4	100	10YR3/6	R0								
4	BP3			43	nHw	Ha	4.8	9	100	10YR3/4	R4								
4	BP3			58	nHw	Ha	4.6	10	100	10YR3/3	R4								
4	BP3			68	nHw	Ha	4.8	10	100	7.5YR3/4	R4								
5	BP3	SL	bB	20	hHr	Hoas	3.9	4	15	5YR3/1	R2	W	N3	90	7	2700	S	B	No use
5	BP3			36	hHr	Hoas	4.5	6	15	5YR3/2	R2								
5	BP3			54	nHr	Ha	4.6	9	15	5YR2.5/2	R3								
5	BP3			61	nHr	Ha	4.3	10	15	7.5YR2.5/3	R3								
5	BP3			77	nHr	Ha	4.3	10	15	7.5YR2.5/3	R4								
5	BP3			107	nHr	Ha	4.3	10	15	7.5YR2.5/2	R5								
1	BP4	TB	bB	20	hHr	Hoas	3.4	3	15	7.5YR3/1	R1	N	N1	166	7	2700	IMD	No use	No use
1	BP4			35	nHr	Ha	4.1	10	15	7.5YR3/2	R1								
1	BP4			50	hHr	Hosy	4.2	7	15	7.5YR2.5/3	R0								

Site	Profile	HGM	ME	Depth (cmbs)	Horizon (KA5)	Substrate	pH-value	DD	MWT (cmbs)	Colour (Munsell)	Roots (KA 5)	Exposure	Inclination (KA 5)	Height (m.a.s.l)	Km to ocean	Rainfall (mm/y)	Relief	Human made changes	Current use
1	BP4			98	nHr	Ha	4.3	9	15	7.5YR2.5/3	R0								
1	BP4			110	fFr	Gyo	5.1	-	15	10YR3/6	R0								
1	BP4			340	fFr	Gyo	5.1	-	15	10YR3/6	R0								
2	BP4	TB	fMo	41	hHr	Hoas	3.9	4	15	7.5YR2.5/2	R4	NE	N0	166	7	2700	IMD	No use	No use
2	BP4			48	hHr	Hoas	3.9	8	15	7.5YR2.5/3	R0								
2	BP4			166	nHr	Ha	3.9	9	15	5YR3/2	R0								
2	BP4			215	nHr	Hgr	3.9	8	15	10YR3/1	R0								
2	BP4			245	fFr	Gyo	4.2	-	15	10YR3/1	R0								
2	BP4			320	nHr	Hgr	4.7	5	15	10YR3/2	R0								
1	LR	RB	rB	40	nHr	Hgr	3.6	3	15	7.5YR3/1	R0	NW	N0	6	4	3300	VE	Ct, B, L	Forestry
1	LR			50	nHr	Hgr	4.2	3	15	7.5YR3/1	R2								
1	LR			350	fFr	Gyo	3.2	-	15	7.5YR3/1	R0								
2	LR	RB	rB	12	hHw	Hosy	3.8	3	20	7.5YR3/1	R4	NW	N0	7	4	3300	VE	Ct, B, L	Forestry
2	LR			34	hHr	Hosy	4.7	3	20	7.5YR3/1	R3								
2	LR			54	hHr	Hoi	4.5	3	20	7.5YR3/1	R0								
2	LR			60	nHr	Ha	4.4	10	20	7.5YR3/1	R0								
2	LR			65	nHr	Ha	4.5	10	20	10YR3/1	R0								
3	LR	RB	rB	21	hHr	Hosy	4.0	4	10	10YR3/2	R3	NW	N0	7	4	3300	VB	Ct, B, L	Forestry
3	LR			55	hHr	Hosy	4.2	3	10	10YR3/3	R3								
3	LR			63	nHr	Ha	4.6	10	10	10YR3/3	R3								
3	LR			70	nHr	Ha	4.5	10	10	10YR3/3	R3								
4	LR	RB	rB	10	hHr	Hosy	3.6	4	10	7.5YR2.5/2	R4	NW	N0	8	4	3300	VB	Ct, B, L	Forestry
4	LR			21	hHr	Hosy	3.8	4	10	7.5YR2.5/3	R4								
4	LR			30	nHr	Ha	3.7	10	10	7.5YR3/2	R4								

Site	Profile	HGM	ME	Depth (cmbs)	Horizon (KA5)	Substrate	pH-value	DD	MWT (cmbs)	Colour (Munsell)	Roots (KA 5)	Exposure	Inclination (KA 5)	Height (m.a.s.l)	Km to ocean	Rainfall (mm/y)	Relief	Human made changes	Current use
4	LR			45	nHr	Ha	4.3	10	10	7.5YR3/2	R4								
4	LR			70	nHr	Ha	4.3	10	10	7.5YR3/2	R4								
4	LR			78	nHr	Ha	4.5	10	10	7.5YR3/2	R4								
5	LR	RB	frH	41	hHr	Hosy	3.6	3	10	7.5YR3/2	R6	NW	N1	8		3300	VB	Ct, B	Forestry
5	LR			51	hHr	Hosy	3.9	3	10	7.5YR3/3	R6								
5	LR			57	nHr	Ha	4.5	10	10	7.5YR3/3	R6								
6	LR	RB	frH	32	hHr	Hosy	3.8	4	15	10YR4/6	R3	NW	N1	7	4	3300	VB	B	Forestry
6	LR			44	hHr	Hosy	3.9	3	15	10YR4/6	R2								
6	LR			65	nHr	Hgr	4.1	3	15	10YR3/4	R2								
6	LR			97	nHr	Hgr	4.2	3	15	10YR3/3	R0								
7	LR	RB	rB	35	hHr	Hosy	3.7	3	10	10YR4/6	R2	NW	N1	7	4	3300	VB	B	Forestry
7	LR			50	hHr	Hosy	4.0	4	10	10YR4/6	R3								
7	LR			70	nHr	Hgr	4.3	3	10	10YR3/4	R2								
7	LR			85	nHr	Ha	4.7	10	10	10YR3/4	R1								
8	LR	RB	rB	10	hHw	Hosy	3.6	4	60	7.5YR2.5/1	R2	NW	N0	6	4	3300	VB	B	Forestry
9	LR	RB	rB	20	hHr	Hosy	3.1	3	10	7.5YR2.5/1	R2	NW	N0	6	4	3300	VB	B	Forestry
9	LR			33	hHr	Hosy	3.5	6	10	7.5YR2.5/2	R1								
9	LR			50	nHr	Ha	3.7	10	10	7.5YR2.5/3	R2								
10	LR	RB	bB	18	hHr	Hosy	2.9	3	13	5YR3/2	R1	NW	N0	6	4	3300	VB	B	Forestry
10	LR			24	hHr	Hosy	3.3	6	13	5YR3/3	R1								
10	LR			45	nHr	Ha	3.8	10	13	7.5YR2.5/3	R2								
11	LR	RB	rB	10	hHr	Hoas	3.1	4	5	2.5YR2.5/1	R2	NW	N0	7	4	3300	VB	B	Forestry
11	LR			20	nHr	Ha	3.0	10	5	2.5YR2.5/2	R2								
11	LR			65	hHr	Hoi	3.1	6	5	2.5YR2.5/2	R0								
11	LR			100	nHr	Hgr	3.1	8	5	7.5YR2.5/2	R1								
12	LR	RB	bB	10	hHr	Hoas	3.3	3	4	2.5YR2.5/2	R2	NW	N0	7	4	3300	VB	B	Forestry

Site	Profile	HGM	ME	Depth (cmbs)	Horizon (KA5)	Substrate	pH-value	DD	MWT (cmbs)	Colour (Munsell)	Roots (KA 5)	Exposure	Inclination (KA 5)	Height (m.a.s.l)	Km to ocean	Rainfall (mm/y)	Relief	Human made changes	Current use
12	LR			35	hHr	Hoas	3.1	3	4	2.5YR2.5/2	R1								
12	LR			65	hHr	Hoi	3.3	3	5	2.5YR2.5/2	R0								
12	LR			110	nHr	Hgr	3.0	3	4	7.5YR2.5/3	R0								
12	LR			140	nHr	Ha	3.0	10	5	7.5YR2.5/2	R1								
12	LR			160	nHr	Ha	3.3	10	5	5YR3/4	R2								
12	LR			190	nHr	Ha	3.0	10	5	5YR2.5/2	R0								
13	LR	RB	rB	10	nHw	Hosa	5.5	4	13	10YR3/1	R0	NW	N0	6	4	3300	VB	L	L
14	LR	RB	rB	5	hHw	Hosy	4.2	3	15	10YR3/1	R2	NW	N0	6	4	3300	VB	Ct, B, L	L
14	LR			15	hHr	Hosy	4.4	3	15	10YR3/2	R2								
14	LR			30	hHr	Hoi	5.0	3	15	2.5Y3/3	R5								
15	LR	RB	rB	10	hHr	Hosy	4.4	4	10	10YR3/2	R0	NW	N0	6	4	3300	VB	Ct, B	Forestry
15	LR			25	hHr	Hosy	4.1	4	10	10YR3/3	R0								
15	LR			30	hHr	Hosy	4.9	3	10	10YR3/2	R0								
15	LR			35	hHr	Hosy	4.4	3	10	10YR3/4	R0								
15	LR			40	nHr	Hgr	4.7	3	10	10YR3/6	R0								
15	LR			55	nHr	Hgr	5.3	4	10	10YR2/2	R0								
16	LR	RB	bB	30	hHr	Hosy	3.6	3	5	10YR4/4	R2	NW	N0	8	4	3300	VB	B	Forestry
16	LR			50	hHr	Hosy	3.8	3	5	7.5YR2.5/3	R0								
16	LR			65	nHr	Hgr	4.7	3	5	7.5YR3/1	R1								
16	LR			90	nHr	Hgr	4.1	3	5	7.5YR3/1	R2								
16	LR			100	nHr	Hgr	4.2	4	5	10YR3/2	R0								
17	LR	RB	rB	20	hHr	Hosy	3.2	4	8	10YR4/4	R0	NW	N1	7	4	3300	VB	B	Forestry
17	LR			30	hHr	Hosy	3.5	4	8	10YR4/4	R0								
17	LR			65	hHr	Hosy	4.0	4	8	5YR2.5/2	R0								
17	LR			80	nHr	Hgr	4.1	3	8	7.5YR2.5/1	R0								
17	LR			95	nHr	Ha	6.2	10	8	7.5YR3/1	R2								

Site	Profile	HGM	ME	Depth (cmbs)	Horizon (KA5)	Substrate	pH-value	DD	MWT (cmbs)	Colour (Munsell)	Roots (KA 5)	Exposure	Inclination (KA 5)	Height (m.a.s.l)	Km to ocean	Rainfall (mm/y)	Relief	Human made changes	Current use
17	LR			100	nHr	Ha	5.7	10	8	7.5YR3/3	R2								
18	LR	RB	rB	40	hHr	Hosy	3.6	3	4	7.5YR2.5/2	R0	NW	N1	8	4	3300	VB	B	Forestry
18	LR			52	hHr	Hosy	3.8	4	4	7.5YR2.5/3	R2								
18	LR			65	hHr	Hosy	4.0	4		2.5Y4/4	R2								
18	LR			65	hHr	Hoi	4.7	3	5	7.5YR3/1	R0								
18	LR			87	nHr	Hgr	4.1	3	6	7.5YR3/1	R0								
18	LR			90	nHr	Hgr	4.2	4	5	10YR3/2	R0								
18	LR			90	hHr	Hoi	4.4	4	4	2.5Y4/4	R0								
18	LR			96	hHr	Hoi	4.8	6		2.5Y4/1	R0								
18	LR			98	nHr	Ha	4.8	10		10YR2/2	R0								
1	LV	RB	rB	15	hHw	Hosy	3.0	3	50	7.5YR2.5/2	R0	NE	N0	33	39	1300	FP	B	No use
1	LV			20	hHw	Hosy	4.0	4	50	7.5YR2.5/2	R0								
1	LV			30	hHw	Hosy	3.4	3	50	5YR2.5/2	R0								
1	LV			40	hHw	Hosy	3.6	3	50	5YR2.5/2	R0								
1	LV			50	hHr	Hosy	3.6	4	50	5YR2.5/2	R0								
1	LV			80	nHr	Hgr	3.8	3	50	5YR2.5/2	R2								
1	LV			100	nHr	Hgr	3.8	3	50	5YR2.5/2	R0								
1	LV			160	hHr	Hosy	3.8	3	50	5YR2.5/1	R0								
1	LV			170	hHr	Hosy	4.3	3	50	5YR2.5/2	R0								
1	LV			220	nHr	Ha	4.3	10	50	5YR2.5/2	R0								
2	LV	RB	rB	3	nHw	Hosa	3.0	4	10	10YR4/2	R0	NE	N0	33	39	1300	FP	No use	No use
2	LV			15	nHr	Hosa	3.9	4	10	10YR4/3	R4								
2	LV			25	hHr	Hosy	4.6	3	10	7.5YR2.5/3	R0								
2	LV			55	nHr	Ha	4.8	10	10	2.5Y4/1	R0								
3	LV	RB	flH	15	hHw	Hosy	4.0	3	5	10YR4/3	R3	NE	N0	34	39	1300	FP	No use	No use
3	LV			50	hHr	Hosy	4.0	3	5	10YR4/4	R3								

Site	Profile	HGM	ME	Depth (cmbs)	Horizon (KA5)	Substrate	pH-value	DD	MWT (cmbs)	Colour (Munsell)	Roots (KA 5)	Exposure	Inclination (KA 5)	Height (m.a.s.l)	Km to ocean	Rainfall (mm/y)	Relief	Human made changes	Current use
3	LV			80	nHr	Hgr	4.2	4	5	10YR4/4	R3								
3	LV			100	nHr	Hgr	4.7	3	5	10YR3/3	R3								
3	LV			140	nHr	Ha	4.9	10	5	10YR3/3	R3								
4	LV	RB	rB	15	nHw	Hgr	4.2	4	130	2.5Y3/2	R4	S	N0	33	39	1300	VE	Ct, B, L	Forestry
4	LV			20	nHw	Ha	4.4	10	130	2.5Y3/3	R1								
4	LV			35	nHw	Ha	4.9	10	130	10YR2/2	R1								
5	LV	RB	rB	5	nHw	Hgr	5.1	3	50	10YR2/1	R6	NE	N0	32	39	1300	VE	Ct, B, L	Forestry
5	LV			30	nHw	Ha	3.9	10	50	10YR2/2	R6								
5	LV			45	nHw	Ha	4.6	10	50	10YR2/2	R6								
6	LV	RB	rB	10	hHw	Hosy	3.7	4	33	10YR3/6	R0	W	N0	33	39	1300	FP	B	No use
6	LV			30	hHw	Hosy	3.7	4	33	10YR3/6	R0								
6	LV			40	nHr	Hgr	3.6	3	33	10YR3/4	R2								
6	LV			54	nHr	Hgr	3.8	5	33	7.5YR2.5/3	R2								
6	LV			65	hHr	Hoi	3.6	5	33	7.5YR2.5/2	R3								
6	LV			75	hHr	Hoi	4.3	6	33	10YR3/4	R0								
7	LV	RB	frH	18	hHw	Hosy	3.2	3	35	10YR3/3	R0	NE	N1	34	39	1300	FP	B	Forestry
7	LV			28	hHw	Hosy	3.6	3	35	10YR3/4	R2								
7	LV			33	hHw	Hosy	3.8	3	35	7.5YR3/2	R3								
7	LV			47	hHr	Hoi	4.3	4	35	10YR2/2	R0								
7	LV			55	nHr	Ha	4.7	9	35	10YR3/3	R0								
7	LV			63	nHr	Ha	4.9	9	35	10YR3/4	R3								
8	LV	RB	frH	5	nHw	Hosa	4.5	4	17	7.5YR3/3	R4	NE	N1	35	39	1300	FP	L,D	L
8	LV			15	nHw	Hosa	4.7	3	17	10YR3/2	R3								
8	LV			22	nHr	Hgr	4.6	8	17	7.5YR2.5/3	R1								
8	LV			55	nHr	Ha	4.9	9	17	7.5YR3/2	R3								

Site	Profile	HGM	ME	Depth (cmbs)	Horizon (KA5)	Substrate	pH-value	DD	MWT (cmbs)	Colour (Munsell)	Roots (KA 5)	Exposure	Inclination (KA 5)	Height (m.a.s.l)	Km to ocean	Rainfall (mm/y)	Relief	Human made changes	Current use
8	LV			65	nHr	Ha	6.0	10	17	10YR2/2	R3								
9	LV	RB	rB	13	hHw	Hosy	3.2	3	36	7.5YR2.5/2	R1	SE	N0	35	39	1300	FP	No use	No use
9	LV			18	hHw	Hosy	3.9	3	36	7.5YR2.5/3	R2								
9	LV			40	nHr	Hgr	3.9	3	36	7.5YR2.5/3	R5								
9	LV			52	hHr	Hosy	3.7	4	36	5YR3/3	R2								
9	LV			67	nHr	Hgr	3.7	4	36	5YR3/4	R2								
9	LV			90	nHr	Hgr	4.1	6	36	5YR2.5/1	R0								
9	LV			110	nHr	Hgr	4.2	3	36	5YR2.5/2	R0								
9	LV			114	nHr	Ha	4.5	9	36	5YR3/2	R2								
10	LV	RB	rB	10	hHw	Hosy	3.2	4	22	10YR3/3	R0	N	N0	35	39	1300	FP	No use	No use
10	LV			20	hHw	Hosy	3.8	3	22	10YR3/4	R1								
10	LV			34	hHr	Hosy	3.9	3	22	10YR3/2	R2								
10	LV			48	nHr	Hgr	4.2	7	22	10YR2/2	R0								
10	LV			53	hHr	Hoc	4.2	5	22	7.5YR2.5/2	R4								
10	LV			79	nHr	Ha	4.4	9	22	7.5YR2.5/2	R2								
11	LV	RB	frH	20	hHr	Hosy	3.8	3	20	10YR3/3	R2	SE	N1	33	39	1300	FP	Ct, B	Forestry
11	LV			30	hHr	Hosy	3.9	3	20	10YR3/4	R0								
11	LV			44	hHr	Hosy	4.2	3	20	10YR3/2	R0								
11	LV			54	nHr	Hgr	4.1	4	20	10YR2/2	R0								
11	LV			67	nHr	Ha	4.3	9	20	7.5YR2.5/2	R0								
12	LV	RB	rB	34	hHr	Hosy	4.2	4	31	7.5YR2.5/2	R0	W	N0	33	39	1300	VB	B	Light Forestry
12	LV			60	hHr	Hosy	4.4	3	31	7.5YR2.5/3	R0								
12	LV			66	hHr	Hosy	4.4	3	31	10YR3/2	R2								
12	LV			73	nHr	Hgr	4.1	7	31	5YR2.5/1	R0								
13	LV	RB	rB	10	nHw	Hgr	3.2	4	14	5YR3/1	R3	N	N0	33	39	1300	VB	No use	No use
13	LV			40	nHr	Hgr	3.7	6	14	5YR3/2	R4								

Site	Profile	HGM	ME	Depth (cmbs)	Horizon (KA5)	Substrate	pH-value	DD	MWT (cmbs)	Colour (Munsell)	Roots (KA 5)	Exposure	Inclination (KA 5)	Height (m.a.s.l)	Km to ocean	Rainfall (mm/y)	Relief	Human made changes	Current use
13	LV			50	nHr	Hgr	3.6	3	14	7.5YR2.5/3	R4								
13	LV			68	nHr	Hgr	3.8	4	14	5YR3/2	R2								
13	LV			78	hHr	Hoi	3.9	6	14	7.5YR2.5/3	R0								
14	LV	RB	rB	15	hHr	Hosy	3.8	3	10	7.5YR3/2	R0	W	N0	33	39	1300	VB	No use	No use
14	LV			32	hHr	Hosy	4.0	4	10	7.5YR3/3	R0								
14	LV			57	hHr	Hosy	3.6	4	10	10YR4/6	R0								
14	LV			62	hHr	Hoi	3.4	4	10	5YR3/4	R0								
14	LV			74	nHr	Hgr	3.7	8	10	5YR2.5/1	R0								
14	LV			85	nHr	Hgr	3.6	8	10	5YR2.5/2	R0								
14	LV			110	hHr	Hoi	3.6	7	10	7.5YR2.5/3	R0								
14	LV			160	hHr	Hosy	3.7	4	10	5YR2.5/1	R0								
14	LV			167	hHr	Hoi	3.5	7	10	5YR2.5/2	R0								
14	LV			172	hHr	Hosy	3.6	3	10	5YR3/2	R0								
14	LV			174	nHr	Hgr	3.5	6	10	7.5YR2.5/1	R0								
14	LV			189	hHr	Hosy	3.6	4	10	7.5YR3/3	R0								
14	LV			230	nHr	Hgr	3.6	6	10	2.5YR2.5/1	R0								
14	LV			247	nHr	Ha	3.8	9	10	7.5YR2.5/2	R0								
15	LV	RB	rB	13	hHw	Hosy	3.2	4	24	10YR3/3	R0	SW	N0	32	39	1300	VB	Ct, B	Light Forestry
15	LV			23	hHw	Hosy	3.4	4	24	10YR3/4	R0								
15	LV			32	hHr	Hosy	3.9	4	24	7.5YR2.5/3	R0								
15	LV			56	nHr	Ha	4.1	9	24	7.5YR2.5/2	R1								
16	LV	RB	rB	17	hHr	Hob	4.1	4	15	7.5YR3/1	R0	N	N0	36	39	1300	VB	B	Light Forestry
16	LV			35	hHr	Hob	4.1	6	15	7.5YR3/2	R2								
16	LV			48	nHr	Hgr	3.9	7	15	10YR3/2	R0								
16	LV			61	nHr	Hgr	3.9	3	15	7.5YR2.5/1	R0								

Site	Profile	HGM	ME	Depth (cmbs)	Horizon (KA5)	Substrate	pH-value	DD	MWT (cmbs)	Colour (Munsell)	Roots (KA 5)	Exposure	Inclination (KA 5)	Height (m.a.s.l)	Km to ocean	Rainfall (mm/y)	Relief	Human made changes	Current use
17	LV	RB	rB	11	hHw	Hoi	3.4	3	40	7.5YR2.5/1	R3	SE	N0	34	39	1300	VB	Ct, B	Forestry
17	LV			29	nHw	Hgr	3.5	7	40	7.5YR2.5/2	R0								
17	LV			40	nHr	Hgr	3.7	6	40	7.5YR3/2	R0								
17	LV			44	nHr	Hgr	3.6	3	40	5YR2.5/1	R0								
17	LV			60	nHr	Hgr	3.9	8	40	10YR2/2	R0								
17	LV			67	nHr	Ha	4.0	9	40	7.5YR2.5/2	R0								
18	LV	RB	rB	24	hHr	Hosy	3.3	4	23	10YR4/3	R0	NE	N0	34	39	1300	FP	B	No use
18	LV			47	hHr	Hosy	4.0	3	23	10YR4/4	R0								
18	LV			63	hHr	Hosy	4.2	3	23	10YR3/4	R0								
18	LV			70	nHr	Hgr	4.3	4	23	10YR3/2	R0								
18	LV			84	hHr	Hosy	4.2	3	23	7.5YR3/3	R0								
18	LV			93	nHr	Ha	4.2	9	23	10YR3/2	R0								
18	LV			114	hHr	Hosy	4.2	4	23	7.5YR3/2	R0								
18	LV			128	nHr	Hgr	4.3	5	23	7.5YR2.5/2	R0								
18	LV			133	nHr	Hgr	4.6	7	23	7.5YR2.5/2	R0								
19	LV	RB	rB	13	hHw	Hosy	3.1	3	26	10YR3/3	R0	SW	N0	33	39	1300	FP	Ct, B	Forestry
19	LV			19	hHw	Hosy	3.6	3	26	10YR3/4	R0								
19	LV			29	hHr	Hosy	3.2	4	26	10YR4/4	R2								
19	LV			33	nHr	Hgr	3.8	4	26	10YR3/2	R3								
19	LV			52	nHr	Ha	3.9	10	26	10YR3/1	R3								
19	LV			67	nHr	Ha	4.2	9	26	10YR4/2	R4								
1	QP1	SL	rB	25	hHw	Hosy	4.2	4	35	10YR3/3	R0	NE	N3	30	11	2200	S	B	Forestry
1	QP1			50	hHr	Hosy	4.8	3	35	10YR3/4	R0								
1	QP1			75	hHr	Hosy	4.9	3	35	10YR4/4	R0								
1	QP1			80	nHr	Ha	4.9	10	35	10YR4/4	R1								
1	QP1			85	nHr	Ha	4.9	10	35	10YR3/4	R0								

Site	Profile	HGM	ME	Depth (cmbs)	Horizon (KA5)	Substrate	pH-value	DD	MWT (cmbs)	Colour (Munsell)	Roots (KA 5)	Exposure	Inclination (KA 5)	Height (m.a.s.l)	Km to ocean	Rainfall (mm/y)	Relief	Human made changes	Current use
2	QP1	SL	rB	5	nHw	Hgr	3.6	4	17	7.5YR3/3	R0	NE	N3	29	11	2200	FT	B	Forestry
2	QP1			15	hHw	Hob	3.7	3	17	7.5YR3/4	R0								
2	QP1			30	nHr	Hgr	4.4	6	17	7.5YR2.5/3	R5								
2	QP1			50	nHr	Hgr	4.7	3	17	10YR3/3	R4								
2	QP1			65	hHr	Hoi	4.7	4	17	2.5Y3/3	R0								
2	QP1			80	hHr	Hoi	4.5	6	17	2.5YR2.5/2	R2								
2	QP1			120	nHr	Ha	4.5	10	17	2.5Y3/3	R0								
2	QP1			180	nHr	Ha	4.0	10	17	2.5Y3/3	R0								
3	QP1	SL	rB	10	hHr	Hoas	3.2	3	1	7.5YR2.5/1	R3	NE	N3	29	11	2200	FT	No use	No use
3	QP1			30	hHr	Hoas	3.7	3	1	7.5YR2.5/2	R3								
3	QP1			90	nHr	Ha	3.4	10	1	7.5YR2.5/3	R3								
3	QP1			120	hHr	Hoi	3.7	7	1	7.5YR3/4	R3								
3	QP1			180	hHr	Hosy	3.2	4	1	7.5YR2.5/2	R3								
3	QP1			190	hHr	Hoc	3.7	4	1	7.5YR3/3	R3								
4	QP1	SL	rB	15	hHw	Hosy	2.5	3	25	7.5YR2.5/1	R4	SW	N2	30	11	2200	FT	B	Light Forestry
4	QP1			40	hHr	Hosy	2.3	3	25	7.5YR2.5/2	R4								
4	QP1			75	nHr	Hgr	3.1	3	25	2.5YR2.5/2	R4								
4	QP1			130	nHr	Hgr	3.6	3	25	7.5YR2.5/3	R0								
5	QP1	SL	rB	10	hHw	Hosy	3.8	4	15	7.5YR2.5/1	R2	NE	N4	28	11	2200	FT	B	No use
5	QP1			30	hHr	Hosy	3.9	3	15	7.5YR2.5/2	R3								
5	QP1			40	nHr	Hgr	4.2	3	15	7.5YR3/4	R3								
5	QP1			55	nHr	Hgr	3.9	3	15	7.5YR3/4	R2								
5	QP1			70	hHr	Hoi	3.8	3	15	7.5YR2.5/2	R0								
5	QP1			90	nHr	Hgr	3.8	3	15	7.5YR3/1	R0								
5	QP1			180	nHr	Ha	4.3	10	15	7.5YR2.5/1	R2								

Site	Profile	HGM	ME	Depth (cmbs)	Horizon (KA5)	Substrate	pH-value	DD	MWT (cmbs)	Colour (Munsell)	Roots (KA 5)	Exposure	Inclination (KA 5)	Height (m.a.s.l)	Km to ocean	Rainfall (mm/y)	Relief	Human made changes	Current use
6	QP1	SL	rB	10	hHw	Hob	3.5	4	20	7.5YR2.5/1	R0	NE	N4	29	11	2200	SB	B	Light Forestry
6	QP1			30	hHr	Hob	3.6	3	20	7.5YR2.5/2	R0								
6	QP1			65	nHr	Ha	3.9	10	20	7.5YR2.5/2	R0								
6	QP1			85	nHr	Ha	4.0	10	20	7.5YR2.5/3	R0								
6	QP1			100	hHr	Hoi	4.3	4	20	7.5YR2.5/3	R2								
6	QP1			110	nHr	Ha	4.6	10	20	10YR3/2	R2								
7	QP1	SL	bB	5	hHw	Hob	3.5	4	15	7.5YR2.5/1	R4	NE	N3	29	11	2200	FT	B	Light Forestry
7	QP1			15	hHr	Hob	3.5	3	15	7.5YR2.5/2	R1								
7	QP1			30	nHr	Ha	3.9	10	15	7.5YR2.5/3	R2								
7	QP1			50	nHr	Hgr	3.9	3	15	7.5YR2.5/3	R3								
7	QP1			65	hHr	Hoi	4.0	4	15	7.5YR2.5/3	R2								
7	QP1			80	nHr	Ha	4.0	10	15	7.5YR2.5/3	R1								
7	QP1			110	nHr	Ha	4.5	10	15	7.5YR2.5/2	R3								
7	QP1			120	nHr	Ha	4.5	10	15	2.5Y4/2	R3								
7	QP1			150	nHr	Ha	4.6	10	15	2.5Y4/2	R2								
8	QP1	RB	bB	5	hHw	Hoas	3.2	4	20	5YR2.5/1	R2	NE	N1	30	11	2200	FT	B	Light Forestry
8	QP1			30	nHr	Hgr	3.7	4	20	5YR2.5/1	R2								
8	QP1			50	hHr	Hosy	3.6	4	20	5YR2.5/1	R0								
8	QP1			90	nHr	Ha	3.8	10	20	5YR2.5/2	R0								
8	QP1			150	nHr	Ha	3.8	10	20	7.5YR2.5/2	R2								
8	QP1			170	hHr	Hoi	3.8	4	20	7.5YR2.5/3	R2								
8	QP1			195	hHr	Hoi	4.3	4	20	7.5YR2.5/3	R0								
8	QP1			210	nHr	Ha	4.4	10	20	2.5Y3/3	R0								
9	QP1	SL	rB	10	hHw	Hosy	3.2	3	15	10YR3/1	R3	NE	N2	30	11	2200	FT	B	Light Forestry

Site	Profile	HGM	ME	Depth (cmbs)	Horizon (KA5)	Substrate	pH-value	DD	MWT (cmbs)	Colour (Munsell)	Roots (KA 5)	Exposure	Inclination (KA 5)	Height (m.a.s.l)	Km to ocean	Rainfall (mm/y)	Relief	Human made changes	Current use
9	QP1			30	hHr	Hosy	4.2	3	15	10YR3/2	R3								
9	QP1			40	hHr	Hosy	4.6	4	15	10YR3/2	R2								
9	QP1			70	hHr	Hoi	4.0	4	15	7.5YR2.5/3	R0								
9	QP1			80	nHr	Ha	3.9	10	15	7.5YR2.5/2	R3								
9	QP1			85	nHr	Ha	4.1	10	15	10YR3/2	R2								
10	QP1	SL	rB	5	hHw	Hosy	3.6	3	60	7.5YR2.5/1	R0	NE	N3	28	11	2200	FT	Cn, B	Forestry
10	QP1			30	hHw	Hosy	3.7	3	60	7.5YR2.5/2	R0								
10	QP1			35	nHw	Hgr	4.5	4	60	7.5YR2.5/3	R0								
11	QP1	SL	rB	10	hHw	Hosy	3.3	3	13	7.5YR3/1	R0	NE	N2	28	11	2200	FT	Cn, B	Forestry
11	QP1			25	nHw	Ha	4.8	10	100	7.5YR3/2	R1								
1	QP2	SL	bB	30	hHr	Hoas	3.4	4	19	7.5YR3/3	R0	SW	N3	29	11	2200	SB	B	No use
1	QP2			70	hHr	Hoi	3.8	3	19	7.5YR3/4	R0								
1	QP2			75	nHr	Ha	4.1	10	19	7.5YR3/1	R0								
1	QP2			80	hHr	Hoi	4.2	6	19	10YR3/1	R0								
2	QP2	SL	rB	15	hHr	Hosy	3.0	3	13	10YR2/1	R0	SW	N3	30	11	2200	SB	B	No use
2	QP2			30	hHr	Hosy	3.6	4	13	10YR2/2	R0								
2	QP2			40	nHr	Ha	3.7	10	13	10YR2/2	R0								
2	QP2			50	nHr	Ha	4.0	10	13	7.5YR2.5/2	R0								
3	QP2	SL	rB	20	hHr	Hosy	3.5	3	13	7.5YR2.5/1	R3	SW	N2	30	11	2200	SB	Ct, B	Forestry
3	QP2			30	hHr	Hosy	3.6	4	13	7.5YR2.5/2	R3								
3	QP2			35	nHr	Ha	4.2	10	13	10YR3/2	R3								
4	QP2	SL	rB	16	hHr	Hosy	3.2	3	13	7.5YR2.5/1	R1	SW	N3	29	11	2200	S	Ct, B	Forestry
4	QP2			35	hHr	Hosy	3.6	4	13	7.5YR2.5/2	R5								
4	QP2			45	nHr	Ha	4.2	10	13	7.5YR2.5/1	R5								
4	QP2			50	nHr	Ha	4.8	10	13	10YR2/2	R5								
5	QP2	SL	rB	20	hHr	Hosy	3.4	3	18	10YR2/1	R3	SW	N2	29	11	2200	S	Ct, B	Forestry

Site	Profile	HGM	ME	Depth (cmbs)	Horizon (KA5)	Substrate	pH-value	DD	MWT (cmbs)	Colour (Munsell)	Roots (KA 5)	Exposure	Inclination (KA 5)	Height (m.a.s.l)	Km to ocean	Rainfall (mm/y)	Relief	Human made changes	Current use
5	QP2			45	hHr	Hosy	5.3	3	18	10YR2/2	R1								
5	QP2			60	nHr	Ha	4.6	10	18	7.5YR2.5/2	R2								
6	QP2	SL	rB	5	hHw	Hosy	3.9	3	10	10YR2/1	R4	SW	N2	28	11	2200	SB	Ct, B	Forestry
6	QP2			30	hHr	Hosy	4.3	3	10	10YR2/2	R3								
1	QP3	RB	rB	5	hHw	Hosy	3.2	3	20	10YR3/4	R0	NE	N0	30	11	2200	FT	B	Forestry
1	QP3			25	hHr	Hosy	3.7	3	20	10YR3/4	R5								
1	QP3			60	hHr	Hosy	3.8	4	20	7.5YR2.5/3	R0								
1	QP3			80	hHr	Hosy	3.4	4	20	5YR2.5/2	R0								
1	QP3			110	hHr	Hosy	3.5	4	20	5YR2.5/1	R0								
1	QP3			120	hHr	Hoi	3.7	4	20	5YR2.5/2	R0								
2	QP3	RB	rB	10	hHw	Hosy	3.7	3	17	5YR2.5/1	R0	NE	N0	30	11	2200	FT	B	Forestry
2	QP3			35	hHr	Hosy	3.7	3	17	5YR2.5/1	R0								
2	QP3			60	hHr	Hoi	3.8	6	17	7.5YR2.5/2	R0								
2	QP3			130	hHr	Hoi	4.0	6	17	5YR2.5/1	R0								
3	QP3	RB	bB	10	hHw	Hoas	3.1	3	15	10YR3/4	R3	NE	N0	29	11	2200	FT	B	Forestry
3	QP3			25	hHr	Hoas	3.2	4	15	5YR2.5/2	R3								
3	QP3			30	hHr	Hosy	4.0	4	15	7.5YR2.5/2	R3								
3	QP3			30	hHr	Hoas	4.0	4	15	5YR2.5/2	R3								
3	QP3			55	hHr	Hosy	4.1	4	15	7.5YR2.5/2	R3								
3	QP3			55	hHr	Hoi	4.2	4	15	5YR2.5/2	R3								
3	QP3			85	nHr	Hgr	4.7	4	15	5YR3/3	R3								
3	QP3			85	hHr	Hoi	4.5	3	15	7.5YR2.5/2	R3								
3	QP3			160	fFr	Gyo	5.0	-	15	5Y4/2	R3								
4	QP3	RB	rB	45	hHr	Hob	3.5	4	20	5YR2.5/1	R5	NE	N0	30	11	2200	FT	B	Forestry
4	QP3			120	hHr	Hoi	3.5	3	20	5YR2.5/2	R5								
4	QP3			160	hHr	Hosy	3.7	3	20	5YR3/2	R5								

Site	Profile	HGM	ME	Depth (cmbs)	Horizon (KA5)	Substrate	pH-value	DD	MWT (cmbs)	Colour (Munsell)	Roots (KA 5)	Exposure	Inclination (KA 5)	Height (m.a.s.l)	Km to ocean	Rainfall (mm/y)	Relief	Human made changes	Current use
4	QP3			190	hHr	Hosy	3.8	4	20	5YR2.5/1	R5								
4	QP3			220	nHr	Ha	3.4	10	20	7.5YR2.5/2	R0								
5	QP3	RB	rB	10	hHw	Hosy	3.1	3	15	5YR2.5/1	R0	NE	N0	30	11	2200	FT	B	Forestry
5	QP3			25	hHr	Hosy	3.2	4	15	5YR2.5/2	R2								
5	QP3			30	hHr	Hosy	4.0	4	15	7.5YR2.5/2	R3								
5	QP3			55	hHr	Hoi	4.2	4	15	5YR2.5/2	R2								
5	QP3			120	nHr	Hgr	4.7	4	15	5YR3/3	R2								
6	QP3	RB	rB	14	hHw	Hob	3.8	4	20	10YR3/3	R3	NE	N0	28	11	2200	FT	Ct, B	Forestry
6	QP3			25	hHr	Hob	3.7	4	20	10YR3/4	R0								
6	QP3			32	hHr	Hosy	3.7	3	20	7.5YR3/2	R0								
6	QP3			40	nHr	Ha	3.8	10	20	10YR4/2	R0								
6	QP3			60	nHr	Ha	4.3	10	20	5Y5/2	R1								
7	QP3	RB	rB	5	nHw	Ha	3.9	10	20	10YR3/1	R2								
7	QP3			10	hHw	Hosy	3.8	4	17	7.5YR3/1	R3	NE	N0	30	11	2200	FT	B	Forestry
7	QP3			13	hHw	Hosy	3.8	3	17	7.5YR2.5/1	R2								
7	QP3			20	hHr	Hosy	3.9	6	17	7.5YR3/2	R3								
7	QP3			30	hHr	Hosy	3.9	3	17	7.5YR2.5/2	R3								
7	QP3			45	nHr	Ha	3.9	9	17	10YR2/2	R3								
7	QP3			55	nHr	Ha	3.8	9	17	7.5YR2.5/2	R2								
1	VO	TF	bF	5	nHw	Hgsc	5.1	3	12	10YR3/1	R0	E	N1	366	64	890	IMD	No use	No use
1	VO			13	nHr	Hgmm	5.2	4	12	10YR3/1	R0								
1	VO			20	fFr	Gyo	5.8	-	12	10YR2/1	R0								
1	VO			27	fFr	Gyo	5.2	-	12	10YR3/2	R0								
1	VO			39	fFr	Gyo	5.6	-	12	10YR2/2	R0								
1	VO			46	fFr	Gyo	5.7	-	12	7.5YR3/1	R0								
1	VO			68	nHr	Ha	4.5	9	12	10YR3/1	R0								

Site	Profile	HGM	ME	Depth (cmbs)	Horizon (KA5)	Substrate	pH-value	DD	MWT (cmbs)	Colour (Munsell)	Roots (KA 5)	Exposure	Inclination (KA 5)	Height (m.a.s.l)	Km to ocean	Rainfall (mm/y)	Relief	Human made changes	Current use
1	VO			84	nHr	Hgmm	4.3	4	12	10YR2/1	R0								
1	VO			100	nHr	Ha	4.5	9	12	10YR2/1	R0								
1	VO			189	nHr	Ha	5.7	9	12	10YR2/1	R0								
1	VO			220	fFr	Gyo	7.3	-	12	7.5YR2.5/1	R0								
1	VO			266	nHr	Ha	6.2	9	12	7.5YR2.5/1	R0								
1	VO			315	fFr	Gyo	4.0	-	12	Gley12/5N	R0								
2	VO	TF	fMm	15	hHr	Hosy	3.5	4	1	10YR5/3	R0	E	N1	366	64	890	IMD	No use	No use
2	VO			39	hHr	Hosy	5.4	3	1	10YR5/4	R0								
2	VO			59	hHr	Hosy	5.5	4	1	10YR2/2	R0								
2	VO			89	nHr	Ha	6.4	9	1	10YR2/2	R0								
2	VO			100	hHr	Hosy	5.3	3	1	10YR5/3	R0								
2	VO			109	nHr	Ha	6.3	9	1	7.5YR2.5/1	R0								
2	VO			119	nHr	Ha	6.4	9	1	7.5YR3/1	R0								
2	VO			140	hHr	Hoc	5.3	4	1	5YR3/4	R0								
2	VO			150	nHr	Ha	5.5	9	1	7.5YR2.5/1	R0								
2	VO			200	nHr	Hgr	5.6	5	1	7.5YR2.5/1	R0								
2	VO			240	nHr	Ha	5.1	9	1	7.5YR2.5/1	R0								
2	VO			308	hHr	Hoc	5.2	5	1	7.5YR2.5/1	R0								
2	VO			324	nHr	Hgr	5.9	5	1	2.5Y3/2	R0								
2	VO			330	fFr	Gyo	5.1	-	1	7.5YR2.5/1	R0								
2	VO			334	fFr	Gyo	6.1	-	1	10YR4/2	R0								
2	VO			354	fFr	Gyo	5.2	-	1	2.5Y4/2	R0								
2	VO			358	fFr	Gyo	6.4	-	1	2.5Y3/3	R0								
2	VO			359	fFr	Gyo	6.2	-	1	2.5YR3/1	R0								
2	VO			389	fFr	Gyo	6.2	-	1	2.5YR3/1	R0								

Site	Profile	HGM	ME	Depth (cmbs)	Horizon (KA5)	Substrate	pH-value	DD	MWT (cmbs)	Colour (Munsell)	Roots (KA 5)	Exposure	Inclination (KA 5)	Height (m.a.s.l)	Km to ocean	Rainfall (mm/y)	Relief	Human made changes	Current use
3	VO	TF	fMm	10	nHr	Hgsc	6.2	4	1	5YR3/1	R4	E	N0	366	64	890	IMD	No use	No use
3	VO			28	nHr	Hgmm	6.5	3	1	5YR3/1	R3								
3	VO			50	nHr	Hgmm	6.6	3	1	2.5YR2.5/1	R3								
3	VO			105	nHr	Hgr	6.0	4	1	5YR2.5/1	R2								
3	VO			135	nHr	Hgr	6.4	6	1	7.5YR2.5/1	R3								
3	VO			157	nHr	Ha	6.0	9	1	5YR2.5/2	R3								
3	VO			270	hHr	Hoc	6.0	4	1	10YR3/2	R3								
3	VO			330	hHr	Hoc	5.9	3	1	7.5YR2.5/1	R3								
3	VO			400	fFr	Gyo	5.5	-	1	7.5YR2.5/1	R3								
3	VO			405	fFr	Gyo	4.9	-	1	5Y2.5/2	R3								
3	VO			410	fFr	Gyo	pH-value	-	1	2.5Y3/1	R3								
3	VO			417	fFr	Gyo	3.7	-	1	2.5YR3/1	R3								

Abbreviations:

HGM-Hydrogeomorphic mire types: RB= raised bog. SL= sloping bog. FTB= flow-through bog. TB= terrestrialization bog. TF= terrestrialization fen.

ME-Mire ecotypes: rB= raised bogs, flH= flooded hummocks. frH= forest-covered hummocks. bB= blanket bogs. bF= blanket fens. fMo= oligotrophic floating mat. fMm= mesotrophic floating mat.

Substrate: Hosy = *Sp. magellanicum* peat. Hosa= *Sp. fimbriatum* peat. Hoi= ericaceae peat. Hoc= cypress wood peat. Hob= *Oreobolus* peat. Hoas = cushion plants peat. Hgr= radicels peat. Hgsc= *Schoenoplectus* peat. Hgmm= brown moss peat. Ha= amorphous peat. Gyo= organic gyttja.

Roots (intensity after KA 5): R0= no roots. R1= very weak R2= weak. R3= medium. R4= strong. R5= very strong. R6=extreme strong to roots cushion.

Inclination (intensity after KA 5): NO= no inclination. N1= 2 until <3,5%. N2= 3,5 until <9%. N3= 9 until 18%. N4= 18 until 27%.

Relief: FT= fluvial terrace. IMD= intermountain depression. S=slope. SB= bottom of slope. VE= valley edge. VB= valley basin. FP= flood plain.

Human made changes: B= burn. Ct= trees cut. L= livestock. Cn= canalization. D= digging. Ax= extraccion of aggregates.

Annex 22: Physical and chemical analyses data for all substrates sorted alphabetically by site
(See end of Annex 23 for abbreviations)

Site	Profile	HGM	ME	Depth (cmbs)	Substrate	DD	pH-value (upper soil)	Horizon	BD (avg. n=3)	WSC (avg. n=3)	Corg (n=1)	C (n=1)	N (n=1)	C/N (n=1)	LOI (avg. n=2)
BP1	BP1_1	FTB	bB	-23	Hob	4	4.0	nHw	.09	91	46.12	48.62	1.18	41.26	91.46
BP1	BP1_3	FTB	mB	-16	Hoas	3	4.3	hHw	.09	92	40.73	44.06	1.71	25.80	81.49
BP2	BP2_2	RB	rB	-31	Hosy	3	4.7	hHw	.05	93	40.23	41.34	.87	47.69	87.02
BP2	BP2_2	RB		-54	Hgr	8		nHr	.10	91	52.96	57.23	2.41	23.70	97.69
BP2	BP2_4	RB	rB	-50	Hosy	3	3.7	hHr	.06	91	39.91	42.99	.66	64.91	87.42
BP2	BP2_5	RB	rB	-27	Hosa	6	3.7	nHr	.09	90	26.27	27.69	.76	36.57	51.83
BP3	BP3_3	SB	bB	-36	Hoas	3	4.2	hHw	.09	90	30.70	32.61	1.57	20.83	62.56
BP3	BP3_3	SB		-77	Hgr	7		nHr	.07	98	54.01	57.93	1.65	35.05	96.62
BP3	BP3_3	SB		-105	Ha	9		nHr	.12	88	53.39	57.11	1.67	34.13	96.44
BP4	BP4_1	TB	bB	-35	Hoas	4	4.1	hHw	.10	91	49.36	52.63	1.40	37.59	92.24
BP4	BP4_1	TB		-160	Ha	10		nHw	.09	92	34.03	36.31	1.12	32.38	67.86
BP4	BP4_2	TB	fMo	-20	Hoas	3	4.3	hHw	.10	92	33.01	34.01	1.07	31.78	65.43
LR	LR11	RB	bB	-30	Hoas	3	3.0	hHr	.08	91	50.75	51.18	1.14	44.73	96.45
LR	LR11	RB		-60	Ha	10		nHr	.09	91	53.00	53.20	2.95	18.04	94.18
LR	LR11	RB		-150	Hgr	8		nHr	.10	91	47.32	47.91	.87	55.26	95.43
LR	LR2	RB	rB	-34	Hosy	3	4.7	hHr	.03	97	47.32	47.91	.87	55.26	86.93
LR	LR2	RB		-54	Hoi	3		hHr	.06	94	55.40	55.32	1.94	28.55	99.47
LR	LR2	RB		-150	Ha	10		nHr	.10	86	47.32	47.91	.87	55.26	93.43
LV	LV10	RB	frH	-53	Hoc	3	4.2	hHr	.05	92	51.81	52.09	.91	56.97	98.00
LV	LV14	RB	flH	-57	Hosy	4	3.6	hHr	.04	86	40.96	44.04	.78	56.12	89.34
LV	LV14	RB		-85	Hgr	8		nHr	.08	93	50.10	52.21	1.91	27.33	91.72
LV	LV14	RB		-172	Hoi	7		hHr	.06	91	52.54	56.12	1.74	32.34	96.65
LV	LV14	RB		-189	Hosy	4		hHr	.07	84	49.01	52.32	.77	68.11	98.29
LV	LV14	RB		-247	Hgr	6		nHr	.09	83	48.64	52.88	1.53	34.66	94.00
LV	LV16	RB	rB	-40	Hob	3	3.9	hHr	.09	93	49.15	50.73	1.14	44.55	97.46
QP1	QP1_2	SB	rB	-5	Hgr	3	3.7	nHr	.09	93	55.35	55.56	1.81	30.74	97.88

QP1	QP1_2	SB	rB	-15	Hob	9	3.7	hHr	.08	94	54.29	54.25	1.48	36.72	91.16
QP1	QP1_2	SB		-50	Hgr	4		nHr	.08	93	53.60	53.70	1.40	38.29	96.92
QP1	QP1_2	SB		-80	Hoi	6		hHr	.07	93	53.43	53.82	1.29	41.62	96.07
QP1	QP1_3	SB	bB	-25	Hosy	3	3.7	hHw	.07	92	45.01	45.43	1.63	27.83	84.78
QP1	QP1_3	SB		-50	Hosy	4		hHw	.06	94	47.23	47.74	2.34	20.44	85.06
QP1	QP1_3	SB		-75	Hgr	6		nHr	.09	90	56.01	56.62	2.30	24.65	97.80
QP1	QP1_3	SB		-85	Ha	10		nHr	.10	90	55.61	55.41	1.19	46.55	98.66
QP2	QP2_1	SB	bB	-30	Hoas	4	3.4	hHw	.11	90	46.08	46.11	1.73	26.67	88.43
QP2	QP2_1	SB		-70	Hoi	3		hHr	.07	93	53.28	53.74	2.77	19.37	95.52
QP2	QP2_1	SB		-75	Ha	9		nHr	.09	94	57.37	57.27	1.28	44.77	98.65
QP2	QP2_1	SB		-80	Hoi	4		hHr	.07	93	56.03	56.12	2.09	26.87	97.78
QP3	QP3_4	RB	rB	-43	Hob	4	3.5	hHr	.09	93	56.55	56.14	1.38	40.83	99.17
QP3	QP3_4	RB		-120	Hoi	5		hHr	.07	94	53.35	53.69	.97	55.62	99.98
QP3	QP3_4	RB		-190	Hosy	3		hHr	.06	95	54.54	53.86	.94	57.11	99.87
VO	VO1	TB	bF	-27	Hgmm	4	5.2	nHw	.10	90	31.40	33.21	1.47	22.53	65.06
VO	VO1	TB		-46	Gyo	-		fFr	.22	79	43.50	46.75	2.30	20.37	52.43
VO	VO1	TB		-100	Ha	9		nHr	.10	89	14.35	14.46	.99	14.61	69.75
VO	VO2	TB	bF	-135	Hgr	8	5.7	nHr	.10	90	43.12	46.69	1.10	42.61	84.79
VO	VO2	TB		-150	Hoc	8		hHr	.07	90	43.81	47.45	1.35	35.14	88.73
VO	VO2	TB		-350	Gyo	-		fFr	.18	82	36.27	38.77	1.27	30.57	42.45
VO	VO3	TB	fMm	-28	Hgsc	4	6.5	nHr	.06	95	18.40	19.03	1.08	17.55	93.51

Annex 23: Vegetation species in each site and their spectrum of dominance (%)

Species	Family	Spectrum of dominance (in %) within each examined site									
		LV	**LR**	**VO**	**QP1**	**QP2**	**QP3**	**BP1**	**BP2**	**BP3**	**BP4**
Acrocladium auriculatum (Mont) Mitt.	Amblystegiaceae	5 to 15	15 to 20	30 to 50	1 to 5	5 to 10	1 to 5	1 to 5	1 to 5	1 to 5	10 to 40
Apodasmia chilensis (Gay) Briggs et Johnson (cania)	Restionaceae			1	5 to 60	5 to 15	1 to 5	25 to 30	5 to 10	1 to 5	
Astelia pumila (J.R.Forst.) Gaudich	Asteliaceae		10 to 30		5 to 20	5 to 20	1 to 5	50 to 90	5 to 10	40 to 80	95
Baccharis patagonica Hook. & Arn	Compositae	1 to 5			10 to 20	5 to 20	1 to 5	1 to 5	5 to 10	5 to 10	10 to 20
Berberis ilicifolia L.f.	Berberidaceae	1 to 5	1 to 5		5 to 30		1 to 5		1 to 5		
Berberis microphylla G. Forst	Berberidaceae	1 to 5		15 to 30	1 to 5	1 to 5	1 to 5		1		
Blechnum chilense (Kaulf.) Mett.	Blechnaceae	30 to 50	5 to 50	15 to 30	5 to 20	5 to 40	1 to 5	5 to 25	15 to 40	1 to 15	5 to 25
Blechnum magellanicum (Desv.) Mett.	Blechnaceae					5 to 20	1 to 5	1 to 5			
Blechnum penna-marina (Poir.) Kuhn	Blechnaceae	1 to 5					1 to 5	5 to 25			
Caltha sagittata (Cav.) Bercht. & J.Presl	Ranunculaceae		1 to 5	1 to 5			1 to 5		1		
Carex chillanensis Phil.	Cyperaceae	5 to 15	15 to 30	5 to 15	5 to 30	5 to 25	10 to 30	1 to 5		1 to 10	
Carex magellanica Lam.	Cyperaceae	5 to 50	15 to 30	5 to 25	10 to 60	10 to 50	10 to 60	15 to 60	5 to 30		
Carex microglochin Wahlenb.	Cyperaceae				5 to 50	5 to 30	5 to 10	50 to 90	50 to 90	5 to 50	40 to 90
Chiliotrichium diffusum (G.Forst.) Kuntze	Asteraceae			5 to 15		10 to 20	5 to 10	5 to 10		1 to 5	
Chusquea montana Phil.	Poaceae	5 to 15			10 to 40	5 to 50	5 to 10	1 to 35	10 to 50	5 to 30	5 to 20
Dendroligotrichum dendroides (Hedw.)	Polytrichaceae	1 to 5				5 to 25	5 to 15			1 to 5	
Dendroligotrichum squamosum (Hook.f. & wils) Broth.	Polytrichaceae	15 to 30	5 to 15		5 to 30	5 to 20	5 to 15		5 to 10	10 to 20	
Desfontaina spinosa Ruiz & Pav.	Desfontainiaceae										
Dicranoloma imponens (Mont.) Renauld	Dicranaceae	15 to 30	15 to 30		5 to 10	5 to 20	5 to 20	5 to 10	5 to 20	5 to 25	5 to 40
Donatia fascicularis J.R.Forst. & G.Forst.	Donatiaceae	15 to 30	30 to 50		10 to 40	5 to 30	5 to 20	20 to 40	10 to 25	35 to 40	35
Drimis winteri (Forst & Forst)	Winteraceae	5 to 15			15 to 50	5 to 20	5 to 30	1 to 5	5 to 20	1 to 5	
Drosera uniflora Willd.	Droseraceae	5 to 15	5 to 20	1 to 5	1 to 5	5 to 10	5 to 30	1 to 20		1 to 5	1 to 5
Eleocharis melanostachys (d'Urv.) C.B.Clarke	Cyperaceae			20 to 30	5 to 30	5 to 20	5 to 30				
Embothrium coccineum J.R.Forst. & G.Forst.	Proteaceae	5 to 15					5 to 30	20 to 40	5 to 30	5 to 40	5 to 10
Empetrum rubrum (Vahl ex Wild)	Ericaceae	5 to 15	1 to 5	1	5 to 30	15 to 30	5 to 40	10 to 30	20 to 40	5 to 30	10 to 30
Festuca magellanica Lam.	Poaceae	15 to 30	15 to 30	1 to 5	5 to 40	10 to 35	5 to 50	5 to 10	10 to 30		
Gackstroemia magellanica (Lam.) Trev.	Lepicoleaceae	50 to 90	50 to 90	5 to 15	5 to 40	30 to 90	5 to 90	5 to 30	50 to 80	5 to 60	1 to 5

Species	Family	Spectrum of dominance (in %) within each examined site									
		LV	**LR**	**VO**	**QP1**	**QP2**	**QP3**	**BP1**	**BP2**	**BP3**	**BP4**
Gunnera magellanica Lam.	Gunneraceae		1 to 5								
Hieracium patagonicum Hook.f.	Compositae			1 to 5							
Hordeum comosum J. Presl	Poaceae				15 to 40					1 to 5	
Hymenophyllum dentatum Cav.	Hymenophyllaceae	1 to 5	15 to 30		5 to 30					1 to 5	
Hymenophyllum secundum Hook. & Grev.	Hymenophyllaceae							1 to 5	1 to 5		
Juncus procerus E. Mey	Juncaginaceae							1 to 5	1 to 5		
Juncus scheuchzerioides Gaudich.	Juncaginaceae	1 to 5									
Lepidothamnus fonkii Phil.	Podocarpaceae	5 to 15	5 to 15					5 to 15	1 to 5	5 to 10	1 to 5
Luzuriaga marginata (Gaertn.) Benth.	Alstromeriaceae		1 to 5	1 to 5				1 to 5		1 to 5	
Marsippospermum grandiflorum (L.f.) Hook.	Juncaginaceae	5 to 15	5 to 30	1	5 to 60	5 to 20		5 to 30	15 to 40	10 to 25	1 to 5
Maytenus chilensis Phil.	Celastraceae			5 to 15				1			
*Maytenus magellanica (*Lam) Hook. F.	Celastraceae								1		
Myrteola nummularia (Poir.) Berg	Myrtaceae	1 to 5	5 to 10		5 to 20	5 to 20	5 to 30	5 to 10	5 to 10	5 to 10	5 to 10
Myriophyllum quitense	Santalaceae			30							
Nothofagus antarctica (G. Forst) Oerst	Nothofagaceae		5 to 15		1 to 5	5 to 10		1 to 10			
Nothofagus betuloides (Mirb) Oerst.	Nothofagaceae		5 to 15	5	10 to 30	10 to 30		5 to 10	10 to 15	1 to 15	1 to 5
Nothofagus dombeyi (Mirb.) Oerst.	Nothofagaceae			1 to 5				5 to 10	5 to 30	1 to 5	
Oreobolus obtusángulus Gaudis	Cyperaceae	5 to 15	5 to 20		1 to 5			5 to 30	5 to 25	5 to 40	5 to 20
Perezia lactucoides (Vahl) Less.	Compositae			1							
Pernettya mucronata (L.f.) Hook. & Arn.	Ericaceae	5 to 15	5 to 30	30 to 50	1 to 5	5 to 25	15 to 20	1 to 5			
Pernettya pumila (L. f.) Hook.	Ericaceae		1 to 5	1 to 5							
Philesia magellanica J.F. Gmel.	Philesiaceae	1 to 5	1 to 5					5 to 10	1 to 5		
Pilgerodendron uviferum (D.Don) Florin	Cupressaceae	5 to 50		5 to 10				5 to 10	10 to 20	5 to 10	1 to 5
Pseudopanax laetevirens (Gay) Franchet	Arialaceae	5 to 15	1 to 5		5 to 15			5 to 30	5 to 20		1 to 5
Pseudoscleropodium purum (Hedw.) M. Fleisch	Brachytheciaceae	1 to 5						1 to 5	1 to 5		1 to 5
Pyrrhobryum mnioides (Hook.) Manuel	Rhizogoniaceae		1 to 5	1 to 5							
Racomitrium lanuginosum (Hedw.) Brid	Grimmiaceae		1 to 5								
Raukaua laetevirens (Gay) Frodin	Araliaceae										

Species	Family	Spectrum of dominance (in %) within each examined site									
		LV	LR	VO	QP1	QP2	QP3	BP1	BP2	BP3	BP4
Salix fragilis L.	Salicaceae		15 to 30		1 to 5	5 to 10					
Schoenoplectus californicus (C.A.Mey.) Soják	Cyperaceae			50 to 90			5 to 15			1 to 5	
Schoenus nigricans L.	Cyperaceae			5 to 15							
Schoenus rhynchosporoides (Steud.) Kuek	Cyperaceae			5 to 15	1 to 5	1 to 5	1 to 5	5 to 10	1 to 5	10 to 15	5 to 10
Senecio chionophilus Phil.	Compositae			1 to 5							
Sphagnum cuspidatum Ehrh. ex Hoffm	Sphagnaceae				1 to 5						
Sphagnum fimbriatum Wilson	Sphagnaceae	5 to 15	5 to 15	5 to 50							
Sphagnum magellanicum Brid.	Sphagnaceae	30 to 90	20 to 80	15	40 to 70	40 to 70	40 to 70	5 to 20	60 to 80	1 to 15	5 to 10
Taraxacum officinale (L.) Weber ex F.H.Wigg	Compositae	1 to 5	1 to 5				1 to 5		1 to 5		
Tetroncium magellanicum Willd.	Juncaginaceae	5 to 50	5 to 30		5 to 25	20 to 40	5 to 25	5 to 10	5 to 15	1 to 5	1 to 5

Annex 24: Calculation of the peat annual average growth and the peat accumulation rate

From the obtained ^{14}C calibrated ages, the peat annual average growth was calculated for each site, as the cuocient between the thickness and the calibrated ^{14}C age BP in the lower limit of the deepest peat layer in the profile. Results were interpreted in cm yr^{-1}. The formula was designed based on the proposal of Punning et al. (1993) as follows:

$$\mathbf{G = \frac{t}{y}}$$

where G= peat annual average growth (cm yr^{-1})

t= profile thickness

y= ^{14}C age BP in the lower limit of the deepest peat layer in the mire

The results for the peat annual average growth for each profile are resumed in Tab. 25

Tab. 25: Peat annual average growth for the profiles LV1, QP1 and BP4 (cm yr^{-1})

Profile	T	y	G (cm yr^{-1})
QP1_2	60	745	0,08
LV1	210	3535	0,06
BP4_2	305	4800	0,06

The peat annual accumulation rate was calculated as the multiplication between the average bulk density and thickness of each profile, divided by the calibrated ^{14}C age BP in the lower limit of the deepest peat layer in the profile. Results were exposed in gr m^2 yr^{-1}. The formula was the following:

$$\mathbf{A = \left(\frac{BD\ (P\mathit{x}) * t}{y}\right) * 10000}$$

where A= peat annual accumulation rate (gr m^2 yr^{-1})

BD (Px)=peat bulk density average for the profile

t= profile thickness

y= ^{14}C age BP in the lower limit of the deepest peat layer in the mire

The results for the peat annual accumulation rate for each profile are resumed in Tab. 22

Tab. 26: Peat annual accumulation rate for QP1, LV1 and BP4 (gr m^2 yr^{-1})

Profile	BD (P*x*)	t	y	A (gr m^2 yr^{-1})
QP1_2	0,08	60	745	64,43
LV1	0,09	210	3535	47,52
BP4_2	0,09	305	4800	50,83

Declaration of originality

I, Ana Carolina Rodríguez, hereby declare that this dissertation entitled "Hydrogeomorphic classification of mire ecosystems within the Baker and Pascua Basins in the Region Aysén, Chilean Patagonia: a tool for their assessment and monitoring" is my own original work and that any ideas, techniques, quotations, or any other material from the work of other people included in my thesis, published or otherwise, have been properly acknowledged and referenced in the text. I certify that no part of this thesis has been published or submitted for publication in any form or as part of another dissertation.

I declare me self in acknowledgment of the doctorate regulations from 2005 of the Faculty of Life Science of the Humboldt Universität zu Berlin

Berlin, 7th May 2015

Ana Carolina Rodríguez Martínez