

Chapter 8

The Ecosystem Services Provided by Peatlands in Patagonia



Rodolfo J. Iturraspe and Adriana B. Urciuolo

Abstract Peatlands are distinctive wetlands of Patagonia that represent a valuable natural heritage due to its near-pristine conditions and the wide range of the ecosystem services (ES) they provide. The objective of this chapter is to review the state of knowledge about the ES of Patagonian peatlands and the related processes that explain them. Some of these services, such as carbon storage, carbon sink, flood control, and water supply, are outcomes of complex biotic and abiotic interactions that take place in these ecosystems. We identified and classified ES of Patagonian peatlands in nonmonetary terms, following the guidelines of the Common International Classification of Ecosystem Services (CICES) V5.1. Different peatlands may contrast in the quality or essence of respective ES; therefore, the analysis of the ES significance requires information from local studies based on scientific knowledge and field data. We supply evidence obtained from study cases and discuss the accuracy of current estimations of carbon storage in Patagonian peatlands, as well as the peat bogs efficiency on the flood and the erosion control.

Keywords Peatlands · Ecosystem services · Patagonia · Carbon store · Peatland hydrology

1 Introduction

Ecosystem services (ES) are defined as the contributions that ecosystems make to human well-being, according to the Common International Classification of Ecosystem Services – CICES (Haines-Young and Potschin 2017). As a response to the multiple worldwide evidence of degradation and unsustainable use of ecosystems, the concern with the valuation of ecosystem functions, goods, and services

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raised substantially in the last decades of the twentieth century, as well as publications with different approaches to this matter. Daily (1997) provided a comprehensive description of ES, and De Groot et al. (2002) proposed a conceptual framework and typology for describing, classifying, and valuing ecosystem functions, goods, and services.

The Millennium Ecosystem Assessment (MEA) was called for the United Nations, and more than 2000 authors and reviewers worldwide were committed. The MEA (2005) report emphasizes the idea that human well-being depends on ecosystems and proposed for ES a conceptual, methodological, and application-decision-making framework. Some years later, CICES resulted as a response to the need to adjust the MEA framework in the way to ES are described, and in the identification of the final services that link to the goods and benefits that are valued by people. The first version CICES V4.3 published in 2013 was upgraded afterward to the CICES V5.1 (Haines-Young and Potschin 2017).

Before the MEA(2005) report, Joosten and Clarke (2002) performed a first frame encompassing peatland values and functions.

“Peat is the incomplete decayed remains of the plants that grew on what was once the surface” (Clymo et al. 1998), and peatlands are lands that accumulate or have accumulated peat (Joosten and Clarke 2002). More extended definitions are available for peat and peatlands (e.g., Ivanov 1981; Rydin et al. 2006). A mire is a peatland where peat is being formed and accumulating. This word distinguishes a degraded peatland from that remains in an almost natural state. The majority of peatlands in Patagonia are mires; they extend 2000 km through the length of Patagonia, from the Cape Horn in the extreme south to the Region X in Chile and the Province of Neuquén in Argentina. Most of these peatlands have remote locations; however, Patagonia is undergoing dynamic transformations and progressive pressures over the environment that are threatening some of them.

Historically, in different regions of the world, people have ignored, minimized, or denied the benefits of peatlands and have regarded them as a difficulty for human settlement, terrestrial connectivity, and production. Consequently, in the past centuries, several countries of the Northern Hemisphere have drained, large extensions of bogs and fens, changing the land use to agriculture, forestry, and urbanization, among others.

There are no local studies about the public perception of peatland values, but it seems to be still low in Patagonia, both in Chile and in Argentina, where many people appreciate peatlands less than any other ecosystem, even some of them ignore what a peatland is.

Patagonian peatland-related knowledge has been improved through the last two decades, with the predominance of biological, ecological, hydrological, and paleoclimatic approaches. Comparatively, oriented studies to hold scientific evidence on the scope and the effectiveness of peatlands ES are scarce.

Several authors analyzed peatland ES in the framework of MEA and CICES for countries or regions of the Northern Hemisphere (e.g., Whitfield et al. 2011). We aim to replicate such analysis, focusing specifically on the ES of Patagonian mires, seeing their particular features and the social context that involves them.

The objective of this chapter is to review the state of knowledge about the ES of Patagonian peatlands, as well as discuss the related processes that explain particular features of them, with special attention in such correspond to the carbon cycle control and the hydrological regulation.

2 Peatlands Features and Distribution in Patagonia

Patagonia presents a wide variety of peatland types. Peat-forming plants, hydrology, climate, chemical proprieties of mineral soil, land geomorphology, and more factors determine particular characteristics that distinguish them and give place to many questions about its ecology, hydrology, ES, and management.

Some typical features of peatlands are:

- Peatlands are the result of a millenary process started after the ice retreat of the last glaciation.
- Older peatlands in Patagonia have basal ages over 18,000 years. The mean age of peatlands in the region is 12,400 years (Loisel 2015).
- Peatlands are wetlands recognized as such by the Ramsar Convention.
- Peatlands have been resilient to high variations of climatic cycles throughout the Holocene period; nevertheless, they are highly vulnerable to human activity.
- Peatlands are ecosystems that support living organisms of special biodiversity.
- Peatlands are highly vulnerable to changes in their hydrological regime.

A widespread distribution of peatlands, which is greater than in other temperate regions of the Southern Hemisphere, is a characteristic of Patagonia, where peatlands may be found on plains and mountains, from hyper-humid Pacific islands to the semiarid steppe. However, the best conditions for their development correspond to humid and oceanic environments, moderate slopes, and altitude below 600 m ASL. Some examples of places where vast peatland systems are concentrated are southeastern Tierra del Fuego (TDF) Argentina, Navarino withadjaent islands, western TDF between 53 40' and 54 20'S latitude, Brunswick Peni nsula and the Obstruction Sound zone.

Neither Argentina nor Chile has available complete inventories. It is necessary to improve or complete a regional evaluation of the peatland surface area (Loisel 2015, Vega-Valdés and Domínguez Díaz (2015). A survey by CONAF et al. (1999) later cited by Arroyo et al. (2005) determined a wetland extension of 32,000 km² in the Magallanes Region, 11,500 km² in Aysén, and 573 km² in Los Lagos, totalizing 44,000 km² in the Chilean Patagonia. The report explains that the majority of these wetlands are peatlands. This has motivated that the areas determined by CONAF as wetlands have been assumed as peatland areas, which is not strictly true. A remote sensing-based study by Ruiz and Doberty (2005) determined, in the XII Magallanes Region, a total peatland surface of 22,700 km² (in rounded numbers). Vega-Valdés and Domínguez Díaz (2015) adjusted it to 21,000 km², which is 11,000 km² less than the wetland extent measured by CONAF (1999, 2012) in the Magallanes Region. Supposing that the entire wetland area (12,000 km²) assigned to the X and

XI regions corresponds to peatlands, the total in the Chilean Patagonia would be around 33,000 km², as a preliminary approximation. Not the entire referred wetland area corresponds to peatlands, and on the other hand, there might be unidentified peatlands below the forest canopy.

In Argentina, most peatlands are located in TDF, where they cover 2700 km² (Iturraspe et al. 2012). Several authors (Carretero 2004, Perotti et al. 2005, Fuertes-Lasala et al. (2008), Chimner et al. 2011, Iturraspe 2016) indicate peatlands spread in low coverage rates along the Andean forest eco-region of the continental Argentinean Patagonia. The negative W-E precipitation gradient results in a bogs-fens-wet meadows succession. There is no documented information of this peatland extent, but it would reach between 250 and 300 km². Thus, the full extension of peatlands in the Argentinean Patagonia would be around 3000 km². Under the assumptions considered for the Chilean peatland area, the total peatland extension in Patagonia would be near 36,000 km², as a preliminary estimation based on the available documented data.

In addition to raised bogs and graminaceous fens, the special climate features of Patagonia determine unique wetland ecosystems that frequently accumulate peat.

The swamp forest (locally named *Tepual*) is a typical wetland from northern and central Chilean Patagonia, located in poorly drained lands dominated by *Tepualia stipularis*. These tree branches sprout profusely from the base and normally form a dense tangle 5–8 m high above the black surface of stagnant water, rich in organic matter (OM) (Veblen and Schlegel 1982). The horizontal growth develops complex structures accumulating large amounts of biomass, which leads to the formation of arboreal soils, and almost impenetrable nets of trunks (Bannister et al. 2017). These waterlogged OM deposits usually form a peat layer 0.30 to 1 m thick (Holdgate 1961).

Anthropogenic peatlands (*pomponales*) are *Sphagnum* wetlands, originated in the late nineteenth century, after burning or clear-cutting of wide forest areas of Chile, in places with poor drainage (Díaz et al. 2008). Moss fibers grow with very high rates in these ecosystems, but since its recent origin, peat accumulation has been weak or null.

Cushion bogs dominate hyperoceanic wind-exposed western areas in southern Chile, mixed with communities of sedges and graminoid fens (Pisano 1977).

In Argentina, *Sphagnum* bogs prevail in mountain valleys and transitional areas of TDF, while fens are frequent in the forest-steppe ecotone. Ninety percent of this peatland area is concentrated east of longitude 66°30'W. Cushion plants with dense roots have colonized deep *Sphagnum* bogs in coastal lands. Inland, *Sphagnum* bogs occupy wide mountain valleys, and mixed plant communities cover blanket bogs at rounded hills.

Wet meadows (*mallines, vegas*) are productive ecosystems on seasonally saturated soils by groundwater feeding. The water table level (WTL) is normally highly variable, but peat accumulation may occur if groundwater remains stable close to the surface. These wetlands offer water availability and habitat for biodiversity in the contrasting semiarid surrounding environment. Wet meadows cover 4–5% of the extra-Andean Patagonian steppe, but just some of them accumulate peat.

The Fig. 8.1 shows examples of different peatland environments.

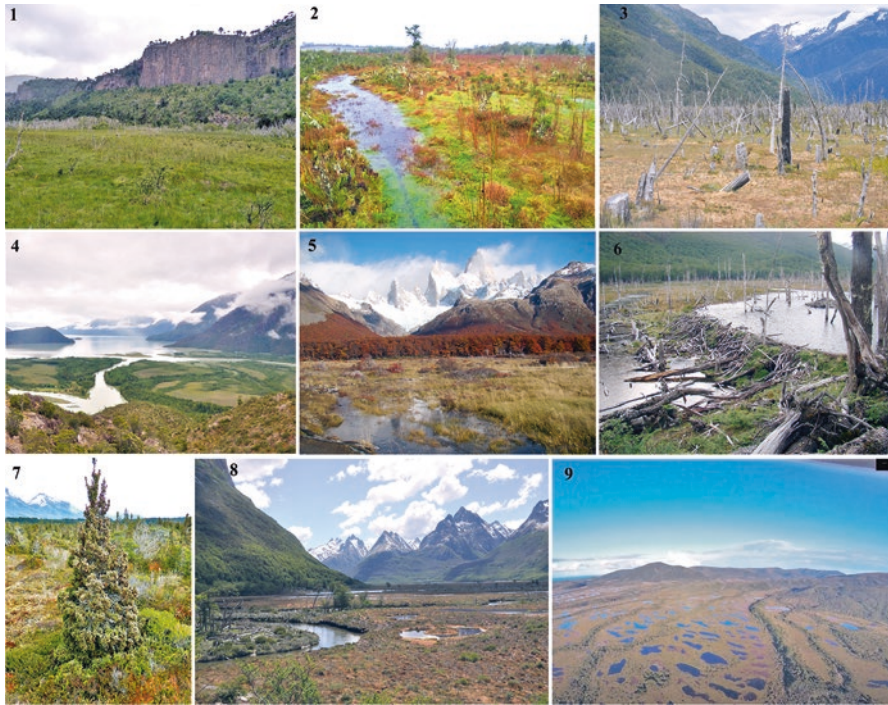


Fig. 8.1 Contrasting peatlands of Patagonia. (1) Northern fen bounded by basalts, near Aluminé, Neuquén, Arg., 41° 05'S Lat. (2) Wet anthropogenic peatland in Chiloe. (3) Anthropogenic peatland near Tortel, Aysén, Ch. (4) Fen in the Baker river mouth, Tortel, Aysén, Ch. (5) Peat wet meadows near Chaltén, Santa Cruz, Arg. (6) *Sphagnum* bog with a beaver dam in the Karukinka Reserve, TDF Ch. (7) *Sph.* bog with Guaitecas Cypress (*Pilgerodendron uviferum*) near Obstrucción Sound, Magallanes, Ch. (8) *Sph.* bog in Carbajal Valley, near Ushuaia, TDF, Arg. (9) Wide bog with pools and gallery forest, López Valley, Peninsula Mitre, eastern TDF, Arg

3 Ecosystem Services of Peatlands in Patagonia

We summarize the ES of peatlands of Patagonia, following the Common International Classification of Ecosystem Services (CICES) version 5.1. CICES classification has a hierarchical structure, whose highest level is organized into three sections related to the type of contribution to human well-being that the ecosystems support. Such sections are (a) the provisioning of material and energy needs, (b) regulation and maintenance of the environment for humans, or (c) the non-material characteristics of ecosystems that affect physical and mental human states. Table 8.1 includes ES that specifically Patagonian peatlands supply, including goods and examples of benefits derived from them. After that, we analyze and discuss more significant ES provided by peatlands in the region.

Table 8.1 Peatland ecosystems services and goods following the CICES V.1 classification

Final service			Benefits provided by peatlands (examples)	
Section	Division	Group/class	Possibly compatible with peat accumulation	Peat consuming
Provisioning	Biomass	Cultivated terrestrial plants for nutrition, materials, or energy		Tree plantations in drained peatlands (i.e., Chiloe)
		Wild plants for nutrition materials or energy	Plants, flowers, fruits, or related products used in medicines or sold for medicinal purposes	
			Compost from plants materials Wood from wild trees and shrubs for fuel and materials (e.g., Chiloe) Peat moss biomass	
		Fibers and other material of wild plants for fertilizer/soil improvement		Peat as soil improver Peat as a substrate component Organic peat blankets Peat as fuel for personal use
		Fibers of wild plants for direct use or processing		<i>Sphagnum</i> fiber harvesting for export, family economy support
		Reared animals for nutrition, materials	Cattle, sheep livestock	
		Wild animals for nutrition and materials	Guanacos	
		Wind energy	Altitude of peatland areas in Chiloe makes them suitable for wind energy generation	Infrastructure can produce partial peatland damages
	Water	Water for nutrition, material or energy	Drinking water Water for irrigation	

(continued)

Table 8.1 (continued)

Final service			Benefits provided by peatlands (examples)	
Section	Division	Group/class	Possibly compatible with peat accumulation	Peat consuming
Regulating and maintaining services	Transformation of biochemical or physical inputs	Bioremediation	Detoxification in land/soils and freshwater	Waste water cleaning
		Filtration/sequestration	Clean water supply though filtration of atmospheric pollutants	Waste water cleaning
	Regulation of physical, chemical, biological conditions	Control of erosion rates	Maintenance of soil and water quality for human/productive activities	
		Buffering and attenuation of mass movement	Protection of people and goods Mitigation of hazards and extreme events damages Sediment retention Contrib. to the population safety	
		Flood control	Flood damage reduction and prevention	
		Fire protection	Wet and undrained mires may act as firebreaks	
		Maintaining habitats	Conservation of biodiversity	
		Regul. chemical condition of freshwater by living processes	.Drinking Water supply	
		Regul. chemical composition atmospheric C storage/sink	Contribution to mitigation of Global Climate change	

(continued)

Table 8.1 (continued)

Final service			Benefits provided by peatlands (examples)	
Section	Division	Group/class	Possibly compatible with peat accumulation	Peat consuming
Cultural services	Direct, in situ, and outdoor interactions with living systems that depend on presence in the environmental setting	Peatland features that enable activities promoting health or enjoyment through active or immersive interactions	Opportunity for outdoor recreation, walking/hiking, skiing. Tourist-related services	Trips by using ATVs, 4x4 cars, or intensive walking producing ecosystem damages
		Peatland features that enable activities promoting health or enjoyment through passive or observational interactions	Wildlife watching and environment and landscape that provide a sensory experience (i.e., flowers, plants, animals, etc.)	
		Peatland features that enable scientific investigation or the creation of traditional ecological knowledge	Research opportunities: stratigraphic archive function and pollen record Paleoclimate knowledge	
		Characteristics of peatlands that enable education and training	Opportunities to understand, communicate, and educate about mire values: Educational-guided tours, subject matter for wildlife programs, hydrological issues	
		Characteristics of peatlands that are resonant in terms of culture or heritage	Historic records, archeological artefacts preservation in peat	

(continued)

Table 8.1 (continued)

Final service			Benefits provided by peatlands (examples)	
Section	Division	Group/class	Possibly compatible with peat accumulation	Peat consuming
		Characteristics of peatlands that enable aesthetic experiences	Peatland landscape observation, appreciation of landscape for art and literature. Opportunities for recreational and tourism activities	
	Indirect, remote, often indoor interactions with living systems with no presence in the mire setting	Elements of peatlands used for entertainment or representation	Peatlands landscape that provides a sensory experience, which may lead to the benefit of inspiration for art or can be directly used in art (i.e., films, soundtracks, etc.)	
			Ex situ viewing experience of nature through different media	

3.1 Provisioning Services

3.1.1 Peat and Fiber Provision

The peat mining activity started in Patagonia in the 1970s in Carbajal Valley, near Ushuaia city, TDF (Iturraspe and Urciuolo 2004), which progressively increase in the following decades. Peat is used as a substrate component for industrial and home production of flowers, tobacco, and garden or fruit plants. Vertical gardens and organic blankets for oil spill treating are some additional uses. Peat extraction in Argentina is concentrated in 38 sites of TDF. In Chile, main places are TDF, the Province of Magallanes, and Los Lagos Region.

Peat extraction results in the drainage of peatlands that increases both the organic matter decomposition and CO₂ emissions due to the consequent peat aerobic conditions produced by the WTL lowering. The cutting of the upper layer eliminates the ecosystem's living plants; therefore, it annuls the bog function as a CO₂ sink.

Anthropogenic peatlands of northern Chilean Patagonia are subject to *Sphagnum* fiber harvesting. In contrast to the extracted peat, that is sold domestically, the moss harvested is totally exported. Chile commercialized in 2019 around 4000 tons of dry *Sphagnum* fiber for USD 15 million (Instituto Forestal 2020). Local families harvest

fibers and sell them to collecting companies. Fiber harvesting has increased since the 1990s without environmental controls and with serious alterations on these ecosystems. The Ministerio de Agricultura, through Decreto 25/2017, enacted a specific regulation for this activity. Regeneration of *Sphagnum* fiber after harvesting is technically feasible under specific conditions and requirements, but the sustainability of this activity is uncertain because of the necessary expenses, care, and control to ensure moss regeneration.

3.1.2 Livestock Support

Fens and peat-wet meadows of Patagonia support diversity of plants and animals. Due to its significant biomass productivity, most of them have been subjected to the grazing of domestic livestock for over one century (Paruelo et al. 2004, Collantes et al. 2013). Cattle raising is the main rural productive activity in extra-Andean Patagonia, which was originally based on sheep and in the last decades combined with cows. Paruelo et al. (2004) report 4000 kg h⁻¹ y⁻¹ of aerial net primary production (ANPP) in meadows of the western portion of the extra-Andean Patagonian steppe (Argentina). In contrast, they specify 500 kg h⁻¹ y⁻¹ of ANPP in the surrounding semi-desert lands. Covering only 3.3% of the area, meadows contributed more than 12% of the total ANPP in this study area. Considering the traditional extensive farming practice, with rotational grazing in fenced paddocks, the stocking rate in each farm depends on the proportion of wet meadows that each one has.

Fens and meadows are natural habitats of guanaco (*Lama guanicoe*) which is the unique large native ungulate. Before sheep introduction, guanaco was the integral sustenance for indigenous communities that inhabited Patagonia, since they got from it food, coating, and materials to build hunting artefacts and basic housing.

3.1.3 Water Supply

Like other kinds of wetlands, mires present available surface water for wild animals and cattle. Peatland outflow contributes to maintaining runoff during no rain periods. Bog contributions can be effective for the short-term runoff but rarely in the long term (Evans et al. 1999, Holden and Burt 2003). Active bog water reservoirs have a limited capacity. Extended dry periods induce asymptotic WTL drops and near null outflows. Fens and further groundwater-fed peatlands can sustain water outputs in dry periods for the long term, depending on the water source, as it occurs in some fens and wet meadows of extra-Andean Patagonia. No dry season and no extended periods without rain are precipitation features of *Sphagnum* bog environments of Patagonia, such that it occurs in Ushuaia, Punta Arenas, and Coyhaique, where there are and more than 40% of rainy days in the year and moderate seasonality (Sarricolea and Martín-Vide 2012, Iturraspe and Schroder 1999). In this short-term context, bogs can be effective in attenuating runoff reduction.

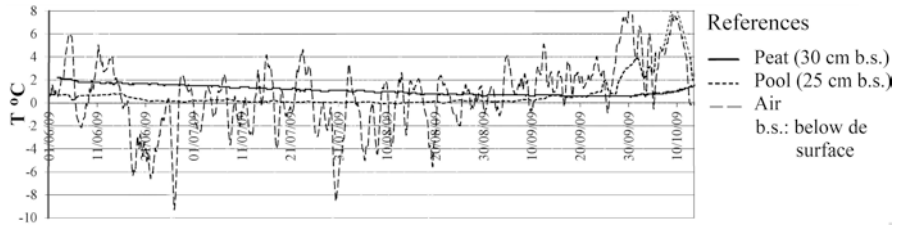


Fig. 8.2 Winter air, peat, and pool water temperature in Rancho Hambre bog, TDF (54°45'S, 67°50'W, 125 m ASL). The pool froze in mid-June, at the same time that neighboring mineral soil (not plotted on the image). The lower acrotelm layer remained unfroze throughout the winter. Maximum depth of peat freezing was 17 cm, in late August. Water bog outflow persisted in winter

Water Provision in Wintertime

No permafrost exists in the region at the latitudinal range in which peatlands develop; instead, seasonal soil freezing occurs in southern Patagonia (e.g., TDF). Consequently, substantial runoff reduction causes difficulties to the water supply for urban and rural populations. Soil and peatland temperature monitoring in *Sphagnum* bogs of TDF shows the acrotelm horizontal flow remaining hydrologically active during most of the winter, while bog, pools, and external mineral soils are frozen (Fig. 8.2). The WTL persists near the surface, feed by meltwater; this way, peat bogs generate winter outflows that mitigate runoff reduction at the time that other water reservoirs are inactive.

Forest-peatland mosaics favor snow accumulation on peatlands by wind effect. Forest and peatlands have their own snowmelt timing, which extends the general melting period.

Peatlands water regulation favors provision for urban and rural populations, notably in Chiloé Island. The intensive *Sphagnum* fiber harvesting in Chiloé threatens the natural hydrological balance and the water availability for human consumption and other uses (Domínguez Díaz 2014). Punta Arenas and Ushuaia are examples of cities using water that peatlands partially provide.

3.2 Regulating and Maintaining Services

3.2.1 Flood Control

Wetlands play a central role in the water cycle, and peatlands are the dominant wetland type in much of Patagonia. Water content in peat is over 90% (Loisel and Yu 2013). However, although water is largely the main peat component, most of it remains immobilized in micro-pores or as a constituent of undecayed plant fibers. Water movement into peatland is restricted to the upper layer and depends on vegetation, decomposition degree, and compression; therefore, water conductivity

decreases as the depth below the ground surface increases. Rainwater infiltrates very fast until it reaches the WTL, but no vertical flux occurs in bog's saturated layers. Horizontal water movement is limited to the upper peat layer, which has low decomposition and compression levels. Ivanov (1981) called diplotelmic to the mires that show two layers that differ in their hydrological properties: the acrotelm, which is the undecomposed and hydrologically active upper layer where the WTL fluctuates, and the catotelm, which is beneath it, always saturated and practically impervious. *Sphagnum*-raised bogs are typical diplotelmic mires in Patagonia. Fens and other kinds of peatland do not have a definite acrotelm layer. Moreover, a more complex vertical variation in peat properties could exist. In addition, natural pipes that allow water flux like underground streams can carry out water excess rapidly.

Peatlands, marshes, lakes, swamp forests, mineral soils, and other hydrological basin components are natural water reservoirs that contribute to the flood control. This reservoir's capacity varies in the time, as a function of their water storage, and their efficiency depends on the flood magnitude:

$$\text{Outflow} = \text{inflow} - \Delta S \quad \Delta S : \text{the storage change in a determined interval time}$$

No full reservoir has flood control aptitude; thus, the efficacy in flood peaks mitigation varies significantly, according to peatland type, peatland cover rate, climatic and hydrological features, geomorphology, and other factors. That should be carefully interpreted, in order to avoid generalizations that have been a matter of the discrepancy between authors who argue that peatlands have high importance in flood mitigation and those who have obtained evidence to the contrary.

Peat bogs may store input water into the unsaturated upper layer and over its surface. Rain infiltration causes rapid WTL raising. The WTL elevation/precipitation rate in *Sphagnum* bogs of TDF is in average 3.3 ± 0.8 , according to measures in several mires (Iturraspe 2010). Normal WTL in most *Sphagnum* bog lawns from TDF is about 17 cm below the surface (with lower values in hollows and higher ones in hummocks). So that signifies a 51 mm rain potential retention, that is right for TDF, where yearly precipitation on *Sphagnum* mires is 500–700 mm and daily rates, over 40 mm in 24 hours, are unusual.

Bog saturated areas produce water excess and surface flux that can keep in hollows and pools. The pool water level is always lower than the marginal WTL, which means a pool receives runoff from its micro water catchment and sub-surface flux from the acrotelm too. In wetter conditions, the output peatland response depends on the micro-hydrological mire systems connectivity. As the linkage is better, the surface water retention capacity decreases and the output flow increases. In the lowlands, the surface storage may be more significant than the inner storage.

For moderate to large storms preceded by relatively wet conditions, headwater bogs may have a little regulatory effect. Blanket peat catchments in the United Kingdom exhibit flashy regimes, and saturation excess overland flow dominates hillslope runoff (Evans et al. 1999, Holden and Burt 2003). The general blanket peat slope does not favor water retention on the surface, so peatland regulation is limited.

There are far fewer references from flood control by peatlands located in middle-low streams in gentle slopes. This is difficult to quantify due to the low rate of the peatland area with respect to the whole water basin area. Hydrological models are useful aids for understanding and quantifying the processes operating in a peatland. Furthermore, they can produce data on WTL and water discharge. However, numerical models are often oversimplified or misrepresent the complex structure of mire systems.

Discharge responses of patterned mires in Canadian subarctic regions are distinctive from those of other peatland types because the large capacity of the wetland pools delays the runoff (Quinton and Roulet 1998). Water movement in patterned peatlands is controlled by the nature and position of pools and ridges within the basin, and water volume retained in microrelief can be significant. These systems often have an endorheic behavior, except in special wet conditions. Peatlands in bottom valleys normally have a poor drainage capacity, so when it is exceeded by flow inputs, a part of the input volume keeps on flooded areas.

Iturraspe (2010) evaluated the water storage capability in Carbajal wetland, which occupies the middle-lower valley (150 m ASL) of Olivia River, near Ushuaia, TDF. It is a mire complex composed of patterned ombrotrophic raised bogs, mesotrophic fens, pools, lagoons, and rivers (Fig. 9.2). The main river runs along the wetland body and receives six tributaries from transversal mountain valleys that cross the mire.

This evaluation supposes a rain event in a standard wet antecedent condition, with a usual former WTL of 17 cm below the surface, 40 mm as the normal maximum daily precipitation in the year, and 24 m³s⁻¹ as the ordinary annual maximum flow of Olivia River. The calculated storage capability in the unsaturated peat layer, microrelief and pools, results able to hold almost all the local rain. Therefore, it is possible to suppose it produces negligible outputs. The main river and tributaries supply the major inputs to the peatland that inundate low wetland areas and temporally connected lagoons. This water mass was calculated using a digital terrain model. The total volume that holds in the wetland equals 35% of the runoff volume in 24 h. Applying the same procedure for an extraordinary rain-flood event, the related ratio is 19%. These results validate the reliable capacity of certain peatlands for flood mitigation, even appreciable in extreme events.

3.2.2 Erosion Control Rates and Sediment Transport

Peatland settings in the water basin determine different ways of sediment control. Typically, water erosion is an active process at the headwaters, given the high runoff energy. Natural peatlands have effective resistance to water erosion, and thus headwater areas covered by mires do not contribute with sediments to the fluvial systems. However, peatland degradation by drainage, intensive grazing, burning, or peat mining might cause peat erosion, with gullies reaching the mineral substrate. This way, water and wind mobilize and transport organic and mineral sediments.

Although these processes are more intense on the slopes, they can also occur on flat lands.

Floods cause high sediment transport, which results in the siltation of detention conveyance capacity. Sediment excess turns more expensive the water treatment for human consume. Lowland peatlands may contribute to sediment retention due to their limited capacity to drain incoming floods (Fig. 8.3).

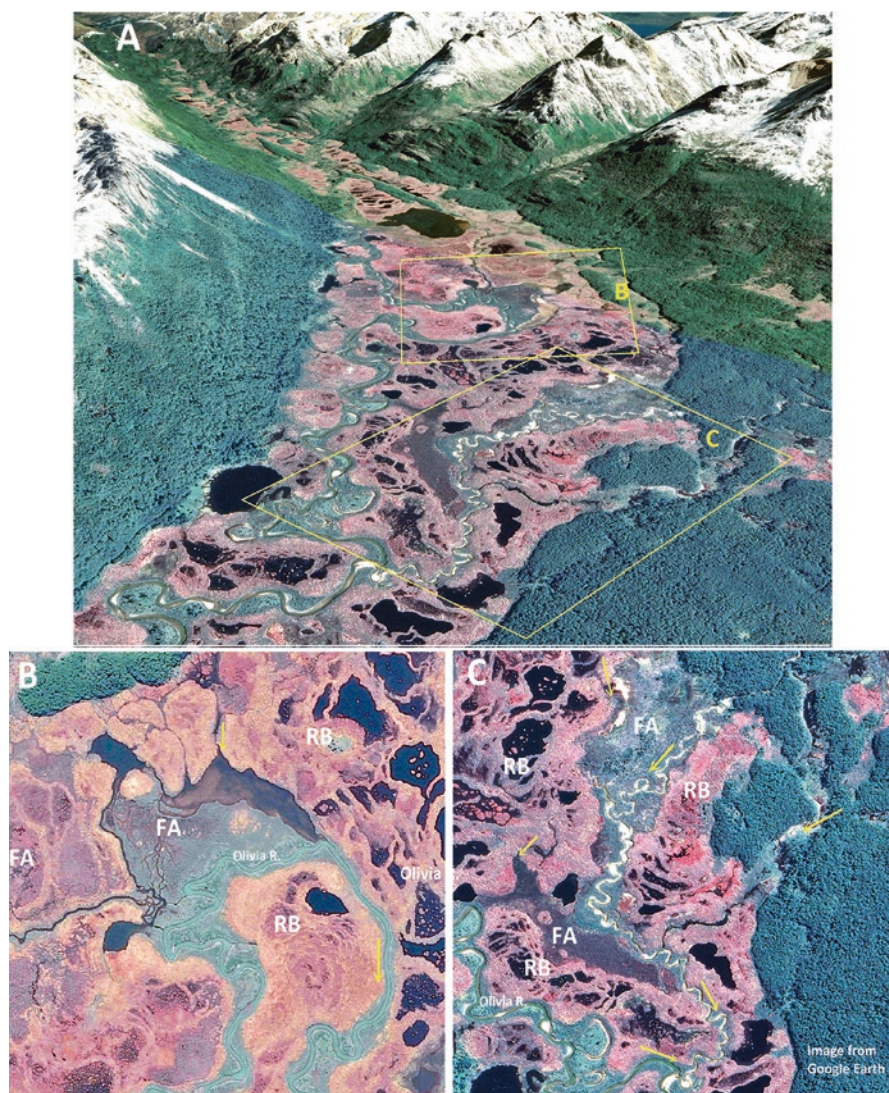


Fig. 8.3 The patterned wetland of the Carbajal Valley, TDF. (a) General view. (b) View of the surface water reservoirs in pools of raised bogs (RB) and floodable areas (FA). (c) A torrential tributary loses energy in the peatland and deposits sandy sediments (in white) in the riverbed and margins. Green areas adjacent to the stream are shrub and moss vegetation over sediments deposited during extraordinary floods

3.2.3 Regulation of Climate Change Through the Control of Carbon Cycle

The increasing concentration of greenhouse gases (GHG) in the atmosphere in the industrial era is the main factor in the radiative forcing of climate (the difference between incoming insolation and energy radiated back to space). The current concentration is the net result of the history of its past emissions and removals from the atmosphere (Solomon et al. 2007). For the 1995–2005 period, the growth rate of carbon dioxide (CO₂) in the atmosphere led to a 20% increase in its radiative forcing. That is indicative of the significance of CO₂ on the greenhouse effect and the meaning of the carbon (C) cycle over the climate change.

Soils are terrestrial C pools; therefore, soil C cycling is a key to develop efficient mitigation strategies of land use-induced C losses. In this context, peatlands are the largest terrestrial organic C store, because of the great quantity of C that they have accumulated since the end of the last glaciation. Mires are sinks for atmospheric C because decomposition is slowed down under anoxic under-logged conditions in prolonged absence of oxygen.

To evaluate the knowledge status of Patagonian peatlands as drivers of the C cycle, it is necessary to know the storage accumulated by them in the past and the rate at which they are accumulating it now (Clymo 1998).

The Peatland Carbon Store. How Much Carbon is Stored in Patagonian Peatlands?

A single peat coring allows measuring bulk density, OM, and C content at different layers to integrating these in the vertical profile. The regional C storage assessment requires these data for distinct kinds of peatlands, a proper estimation of peatlands extension, and the peat thickness-weighted average. This information is still insufficient for Patagonia, but first estimations have been improved through the last decade.

Yu et al. (2010) estimated 15 GtC (1 GtC = 1000 million tons carbon) considering a peatland extension of 45,000 km² in South Patagonia and C storage data from 16 peatlands. Loisel and Yu (2013) improved this result based on information from 24 sites to obtain a rate of 0.168 kg m⁻² C and 7.6 GtC stored in Patagonia.

Finally, Loisel (2015) expanded the database to 52 peat coring in Patagonia and updated the C storage evaluation:

C density (CD): 28 kg/m³

Thickness average (TA): 5.49 m

Mean C rate (CR = CD.TA): 154 kg/m²

Total C = CR: 45,000 km² = 6.9 GtC

So that, C content in Patagonia would represent 1.26% from 547 GtC estimated by Yu et al. (2010) for the global C stored in 4.4 million km² peatland extension in

the world. Loisel (2015) notices the uncertainty of the estimated peatland area as the main error factor.

In this sense, the peatland area south of 45°S (45,000 km²) is overvalued and excludes peatlands of northern Patagonia. However, this error would decrease if this surface amount and the computed C storage were assigned to the entire Patagonian peatland area, that means considering 41°S as the northern limit of the study area.

On the other hand, the thickness average (5.49 m) has been also likely overestimated because it corresponds to a biased sample. Most of the peatlands in the database were selected for paleoclimate studies that required deep peat accumulation; so thin peatlands are not represented. The lowest basal depth data is 1.50 m, while seven sites in the database exceed 8 m thickness. Next, we mention general information related to peatland thickness in Patagonia that supports the idea of a lower peat thickness average.

- *Sphagnum* bogs have basal depths close the applied average value of 5.5 m, but bogs are not the dominant mire type. Vega-Valdés and Domínguez Díaz (2015) computed 2845 km² *Sphagnum* bog extension in the Region of Magallanes that is 13.5% of the peatland area in this region.
- Peat soundings in lowlands of Peninsula Mitre (Eastern TDF) where peatlands extend 2400 km² range from 2.6 to 5.7 m in depth, with around 4 m average (Grootjans et al. 2014). Peat depth at the headwaters of blanket peatlands is around 1.5 m.
- The inventory of a bog-fen-grassland-forest mosaic that extends 355 km² to the east of the Fagnano Lake (TDF) determined 2.6 m as mean thickness and 20% of peatland cover (Roig 2001).
- Rodríguez Martínez (2015) calculates 0.76 m as the basal deep average in Aysén, Chile, for ten representative peatlands in the Baker and Pascua basins. Maximal depth of each one ranges from 0.80 m to 4.17 m.
- Much peatlands corresponds to the Pacific Archipelago. In this area prevails hyperoceanic cushion bogs, which are 25–100 cm deep. Higher accumulations are limited to small level areas, scattered on these rugged and sloping terrains (Pisano 1977, Holdgate 1961, Roig & Faggy 1985, Domínguez Díaz et al. 2015).

These references suggest average peatland thickness in Patagonia would be likely lesser than 2.5 m, which would imply a C amount storage less than a half of what is estimated by Loisel (2015) and 1/5 of what is estimated by Yu et al. (2010).

A more accurate estimate of peatland coverage and peat deep average will improve the important advances reached in the evaluation of the regional C storage.

Peatlands as a Carbon Sink: The Current Carbon Balance

The current C balance in peatlands is the second point denoted by Clymo (1998) to find out the present accumulation C rates of peatlands in Patagonia. Peat accumulation rate is widely driven by the physiological state of the primary producers, and a limitation of photo-assimilation by external conditions can turn it into a source of

CO₂ (Naumov et al. 2020). Decomposition must be less than the net primary productivity (NPP) over time for peat to accumulate.

Peat coring dating at a level not far to the surface allows determining the recent C accumulation rate (RERCA) usually in the order of 100 years. RERCA can be considered as indicative of the current accumulation rate; however, the present productivity of peat bogs may differ due to the climatic instability proper of the last century.

Leon and Olivan (2014) published RERCA data for five sites in Chiloé: two oligotrophic *Sphagnum* bogs and three anthropogenic peatlands. Results range from 9.4 to 15.5 gCm⁻² y⁻¹ for bogs and 32.8 to 58.2 gCm⁻² y⁻¹ for anthropogenic peatlands.

Gas Fluxes Between Peatlands Surface and Atmosphere

Net C flux between ecosystems and atmosphere is a key to understanding the C balance. Photosynthesis is the primary C input way to ecosystems; soil CO₂ efflux is a large respiratory flux and a critical component of the global C cycle (Riveros et al. 2008). Primary productivity is the formation rate of the biomass created by plants through photosynthesis, resulting from the difference between the rates of photosynthesis and autotrophic respiration (Rydin et al. 2006). Respiration produced by roots and soil organisms is the primary pathway for CO₂ fixed by plants to return to the atmosphere (Peri et al. 2015).

Wetlands are likely the main natural source of the CH₄ in the atmosphere. Mires are sources of this GHG. As well as other wetlands, peatlands are good habitats for methanogenic archaea that form CH₄ during the OM decomposition. Methanogens require OM without oxygen, and permanent peatland's saturated layers comply with that.

Dissolved organic carbon (DOC) and particulate organic carbon (POC) are the results of the partial decay of OM in the peat matrix pore. Usually, DOC and POC are outputs of the peatland C balance to the groundwater, or to the surface flow.

Nitrous oxide (N₂O) emissions from soils are the result of the N cycling in the soil. N₂O is a GHG that has a low concentration in the atmosphere, but its influence on the radiative forcing is considerable (Moore 1994).

GHG Flux in Patagonia

A reduced number of studies have generated GHG flux field data from peatlands of Patagonia, and all of them correspond to the last decade. Table 8.2 shows a literature review of GHG emissions for Patagonia published until July 2020. We selected only specific papers that provided new data, acquired by in situ measuring in a closed chamber method (Hutchinson and Livingston 1993). We have homogenized the units of measurement.

Table 8.2. Literature review on GHG emissions in Patagonian peatlands. N₂O, mg N₂O m⁻²d⁻¹; CO₂, g CO₂ m⁻² d⁻¹; CH₄, mg CH₄ m⁻² d⁻¹; GPP, TRE, NEE, g C m⁻²y⁻¹. AP anthropogenic peatland. Negative values indicate ecosystem sink behavior

Region	Site	Lat S Long W	Alt. [masl]	Ecosystem	Period	Dominant veg	N ₂ O	CO ₂	CH ₄			Reference
									Lawn	Pool	Mean	
TDF-Arg	Moat	54°58'	40	Cushion bog	Dec 2008	<i>Astelia pumila</i> , <i>Donatia fascicularis</i>			~0	~0	<1	Fritz et al. (2011)
		66°44'	Nov 2009		2-19							
Magallanes, Chile	Valle Andorra	54° 45'	200	Raised bog	Mar-Apr 2010	<i>Sphagnum magellanicum</i>		2.4	1-11		7.5	Broder et al. (2012)
		68°20'	16						1-14		< 3.2	
	SkyI	52°31'		Cushion bog		<i>Sphagnum</i> , <i>Empetrum</i> , <i>Astelia pumila</i>		1.8	< 3.2	< 3.2		
	SkyII	52°28'		Raised Bog		<i>Sphagnum</i> , <i>Empetrum rubrum</i>		2.2	< 3.2	< 3.2		
TDF-Arg	Valle R. Pipo	53°38'	15	Raised bog	Jan 2015 (4 days)	<i>Sphagnum</i> , <i>Empetrum rubrum</i>						Lehmann et al. (2016)
		70°05'	40						49.0	5.4	13.1 to 21.8	
TDF-Arg	Harowen	54°50'		Raised bog (N)	Nov 2014 (6 days)	<i>Sphagnum magellanicum</i>		2.4	3.4	7.1	7.1	Veber et al. (2018)
		68°27'	150						0.37	2.4	7.1	
TDF-Arg	Laguna Esperanza	54° 44'	60	Managed Fen: moder. grazing		<i>Carex</i> spp., <i>Deschampsia antarctica</i> , <i>Hordeum</i> spp., <i>Alopecurus magellanicus</i>		5.0	22.3		22.3	
		67°55'	60						-1.57			

Fritz et al. (2011) published the first results on gas fluxes in peatlands of Patagonia, reporting close to null CH₄ emissions from *Astelia* cushion bogs (TDF) and comparing them with the flux in a *Sphagnum* bog. The distribution of cushion-forming *A. pumila* root density and associated O₂ supply strongly controlled the CH₄ production and consumption. However, Munchberger et al. (2019) noticed patches of *Donatia fascicularis* with a weak root density that accelerates CH₄ production and increases emissions to intermediate level by aerenchymatic roots.

Broder et al. (2014) reported low CH₄ and CO₂ flux rates in three *Sphagnum* bogs located around 50 km of Punta Arenas city. They suggest sea spray and a lack of essential trace metals, such as nickel, are likely factors that constraint CH₄ and CO₂ emission.

Lehman et al. (2016) analyzed CH₄ spatial variability in a pristine *Sphagnum* bog in TDF, with contrasting results: major emission was from *Sphagnum* lawns, $49.04 \pm 25.7 \text{ mg m}^{-2} \text{ day}^{-1}$, and the lower one from *Empetrum* fluxes, $3.97 \pm 2.99 \text{ mg m}^{-2} \text{ day}^{-1}$. The *Sphagnum* lawn emission is the higher CH₄ flux rate measured in Patagonia.

A transect from Quebec, Canada, to TDF for a comparative study of gas emissions from peatlands in America (Veber et al. 2018) included measures in TDF, Argentina, in a pristine bog and a managed fen. The CO₂ emission rate in the pristine bog of TDF ($26.8 \text{ mg C h}^{-1} \text{ m}^{-2}$) was the lowest one recorded in this transect.

Holl et al. (2019) determined in TDF the annual CO₂ net ecosystem exchange (NEE) in an *Astelia* cushion bog and in a *Sphagnum* bog. The NEE uptake was 4.5 times larger in the *Astelia* bog than in the moss-dominated bog. The balance of the last one was within the typical range of data from similar raised bogs of the Northern Hemisphere. These results would not be applicable to cushion bogs of the hyperoceanic Pacific shore due to differences in depth and peat structure.

In addition to the information corresponding to southern Patagonia, just mentioned, there are also GHG flux data from the north of the region. Urrutia (2017) carried out simultaneous measures in Chiloé, in temperate rain forest soils and anthropogenic peatland (AP), resulting in close to zero N₂O flux rates and weak negative CH₄ values for both, the forest and the peatland. Until now, all measures made in Patagonia demonstrated very low N₂O emission rates.

Valdés-Barrera (2019), also in Chiloé, determined CO₂ NEE, comparing managed with no managed areas of an AP. They found very low CO₂ NEE rates in the managed sector and a more significant CO₂ retention in the no managed one.

In the order of a better understanding of the general terrestrial C cycle, we compiled results of GHG flux measurements in soils of diverse Patagonian ecosystems (Table 8.3) to facilitate the comparison of peatland emissions with these.

Dissolved and Particulate Organic Matter

Water movement through the peat is an exit way of C to pools, surface streams, or groundwater. Holden et al. (2012) remark that pipes (natural tunnels on peat) are important pathways for fluvial C export. The quantification of the dynamic of water

Table 8.3 GHG soil emissions in no peatland ecosystems of Patagonia. Units: N₂O, mg m⁻²d⁻¹; CO₂, g m⁻² d⁻¹; CH₄, mg m⁻² d⁻¹

Region	Site/purpose	Lat S Long W	Alt. [masl]	Ecosystem	Period	Dominant veg	N ₂ O	CO ₂	CH ₄	Reference	
Coyhaique Chile	Comparing ecosystem management	45°25' 72°00'	730	Man.Nat pasture	Nov 2007– Nov 2009	Perennial grasses		5.1		Dube et al. (2013)	
				<i>Pinus Pond. plantation</i>		<i>Pinus Pond.</i>		4.3			
				Silvopastoral		Perennial grasses		4.6			
Santa Cruz Arg	Comparing ecosystems	51°31' 70°04'	300	Grass Steppe (S)	2011–2013, seasonal	<i>Jarava chrysopterylla</i> , <i>Carex</i> spp., <i>Poa</i> spp.		9.6		Peri et al. (2015)	
				Shrub S		<i>J. tridens</i> grasses		8.2			
				Andean S		<i>Festuca palllescens</i> , <i>Carex</i> spp., <i>Poa</i> spp.		14.6			
	Comparing grazing intensity	51°33' 69°17'	150	Dry S moderated grazing		<i>Festuca gracillima</i> grasses		13.9			
				Hum. S High grazing		<i>Festuca gracillima</i> , <i>F. magellanica</i> grasses		9.8			
				Primary forest		<i>Nothofagus antarctica</i> , herbs and shrubs		18			
	Comparing land use	51°13' 72°16'	330	Silvopastoral		<i>Nothofagus antarctica</i> , <i>C. andina</i> , <i>Poa pratensis</i>		18			
				Open grassland		<i>Festuca palllescens</i> , <i>Carex</i> spp., <i>Poa</i> spp.		14.4			
				Vegetated patch Bare soil patch Average steppe	Jun 2015–May 2016	Shrubs and grasses		1.18 0.80 1.06		Carbonell Silletta et al. (2019)	
N Patag. Arg.	Río Mayo	45°24' 70°17'	540								
TDF-Arg	Martial Valley, Ushuaia	54°47' 68°24'	600	Tree line	29 Nov–5 Dec	<i>Nothofagus antarctica</i>		8.4	-1.70	Médice Firme Sá et al. (2019)	
				Lower Andean tundra	2011 and 1–6 Feb 2012	Cushion veg: <i>Bolax gummifera</i> , <i>Empetrum rubrum</i>		0.01	16.7		-0.14
				Upper Andean tundra		<i>Bolax gummifera</i> <i>Empetrum rubrum</i>		0.02	18.0		0.15

AP Anthropogenic peatland, S steppe

discharge from bog complexes is significant for the C balance, because part of the organic C accumulated by primary production is decomposed, released, and dissolved in superficial bog water, to be subsequently exported to fluvial systems (Moore et al. 1998).

There are not focused papers on DOC fluvial outputs from peatlands of Patagonia, neither in bogs lateral flux. However, some references are available: Garcia et al. (2017) determine $15.4 \pm 6 \text{ mg l}^{-1}$ as DOC average concentration in 26 pools of 2 *Sphagnum* bogs in Southern TDF, Argentina. Broder et al. (2012) report DOC concentration in the peat matrix from three *Sphagnum* bogs ranging from $<30 \text{ mg l}^{-1}$ to 160 mg l^{-1} increasing with depth. In eastern TDF, where mires dominate the landscape, dark brown-colored river waters with pH close to 5 indicate high rates of DOC fluvial transport from the peat soils to the sea (Iturraspe et al. 2012).

3.2.4 Maintaining Habitats

Patagonian peatlands maintain habitats of particular biodiversity that includes a range of rare and specialized plants and animals. These habitats present specific features that respond to the different peatland types. Peatlands are barriers to alien species invasions because their acidic and anoxic conditions constitute a strong restriction for not specialized plant development.

Domínguez Díaz et al. (2015) identified 126 species in 50 mires of Magallanes and none exotic, while a similar study found 8 invader aliens, between a total of 24 species, in a drained and abandoned peatland after peat extraction, 20 years ago (Domínguez Díaz et al. 2012). Graminoid fens and cushion bogs have a greater number of species than *Sphagnum* bogs, where mosses and hepatic flora prevail over vascular plants.

The richness of species increased in northern Patagonia. León et al. (2014) reported 129 species in *Sphagnum* bogs and swamp forests of *Tepualia stipularis* in Chiloé, which were distributed in 50 mosses, 52 liverworts, and 27 macrolichens.

Peat bogs are not a preferred habitat of large and medium mammals. However, fens and wet meadows of the extra-Andean region provide water and grazing to guanacos (*Lama guanicoe*) and are eventual hunting areas of pumas (*Puma concolor*), red foxes (*Lycalopex culpaeus*), and introduced grey foxes (*Lycalopex griseus*). These wetlands also support sheep and cow grazing. A particular anthropogenic case is an overpopulation of wild cows and horses in the isolated lands of Península Mitre, eastern TDF. These animals escaped from neighboring farms and bred there.

Bogs and fens could not stop beaver (*Castor canadensis*) spreading throughout TDF and adjacent islands. This introduced species can transform their peatland habitat, building dams that flood them.

Bird's presence in mires depends on habitat factors, such as food availability, wildness, and the structure of dominant vegetation (Riveros et al. 2015). Peatlands of Patagonia are wild environment, without significant human perturbations, with low productivity and very variable vegetation features. No bird species have peatland as unique habitat, but several of them develop the ability to adapt to it. No more

than 25 species nest or remain in peat bogs of TDF (Schlater 2004). Riveros et al. (2015) identified 46 bird species in mires of the Magallanes Region. *Sphagnum* bogs have the lower bird richness, but bird diversity increases in *Sphagnum* bogs with shrubs. Focused studies in peatlands are scarce because bird cadasters are usually made with a regional scope.

Although the entomofauna in mires is less rich than in other ecosystems of the region, it verifies an important function in the transfer of energy, sustaining amphibian and bird populations (Jerez and Muñoz-Escobar 2015). The highest diversity corresponds to the order Coleoptera.

Peatlands include aquatic habitats, such as endorheic pools, lagoons, and streams, with specific biodiversity. Ortiz (2015) denotes four amphibious species in peatlands of southern Aysén and Magallanes regions; they do not show a situation of vulnerability, but peat extraction is not compatible with the preservation of them.

In Tierra del Fuego, García et al. (2017) recorded 29 taxa of aquatic microinvertebrates in two peat bog. The authors denote notably contrasts in the environmental characteristics of pools in the same peatland that explain differences in species richness and diversity among communities of microinvertebrates of these habitats. They highlight the importance of *Sphagnum* moss as a low diversity extreme environment that supports endemic species.

3.3 Cultural Services

Cultural ES emerge out of the relationships between ecosystems and humans (Fish et al. 2016); they have a strong connection with the roots of the population and the links between ecosystems and local traditions. These features assign to the cultural ES an evolutionary character.

3.3.1 Physical and Experiential Interactions with Natural Environments

The scenic value of landscapes, notably in cases of mire landscapes, depends on perception as a subjective social component. Pungas-Kohv et al. (2015) explain mire perception changes in Estonia over the twentieth century; initially, they have been considered useless and sometimes dangerous. Consequently, many peat bogs disappeared because of their land use change. Next, the industrial mentality is dominated that evaluated the natural environment in terms of direct resources exploitable for human purposes. The recognition in the last decades of ecological values, as well as the recreational potential of them, has changed the former perception to appreciate pristine, rare, and contrasting environments. On the other hand, current farmers and naturalists, for example, contrast in the way they view different kinds of landscapes; thus, the perception is cultural, as well. In comparison with Northern Europe, where mires were part of the history and the life of nations, the cultural factor in Patagonia, as a contribution to a positive peatland perception, is weak, in

general terms. The experience seeing a bog from a viewpoint of someone, who has never explored anyone and does not know about its millenary age or its environmental services, is able only to feel aesthetical features of this landscape. Living and interactive experiences on the site signify a more substantial involvement of visitors than the simple contemplation (Pungas-Kohv et al. 2015). A long walk by a bog, with the attention on pools, animals, and vegetation tips (like small flowers, moss fibers, or carnivorous plants), is a way to impact on visitors.

Despite this context, and recognizing that peatlands differ on its aesthetic values, many peatland sites achieve, in Patagonia, objective scenic attributes, in terms of water, colors, singularity, wilderness, loneliness, etc.

Domínguez Díaz and Bahamonde (2012) analyzed methodologies to value the quality of peatland landscapes, through the case study of a bog near Punta Arenas, Chile. They recommend introducing techniques for landscape quality assessment to the planning of peatland management to avoid the scenic environmental degradation.

Peatlands are singular components of the Patagonian landscape, notably in the Andean Patagonian forest ecoregion. Glaciers, lakes, sea, native forest, mountains, and peatlands compose their unique and remarkable landscapes that contribute to the well-being of local inhabitants. Tourist agencies have not yet taken advantage of the wild mire's value as an attraction; meanwhile, mires work as anonymous actors in the landscape concert that nature play in the beautiful tourist places of Patagonia.

In mountain valleys of TDF (Argentina), *Sphagnum* bogs give support to tourist and recreational winter activities like cross-country skiing, snow racket walking, dog sledding, ice skating on natural pools, and, recently, speed riding.

Although the main interest of visitors focuses on the nearby mountain sky center, these winter sports on the bogs represent a great complement and improve the tourist offer. In winter 2017, TDF received 60,000 visitors that contributed to the local economy. That is a case example of the benefits that people may get from bogs, through sustainable use.

Several public or private reserves in Patagonia, with peatlands as a plain attraction, at the time that protect these nature heritages, promote the regional tourism. Some of them are the Tantauco Park (southern Chiloé), the Ramsar site in the Andorra Valley (TDF), and the Omora Ethnobotanical Park (Navarino Island, Chile). The last one offers a tourist circuit through a micro-forest of mosses, lichens, and hepatics, by using a magnifying glass.

3.3.2 Intellectual and Representative Interactions: Peatland as Data Archive for Scientific Investigation

Peatlands accumulate in situ most of the OM they produce and, with it, anything that falls on its surfaces, such as pollen or tephra. This way, they have preserved paleoenvironmental and paleoclimatic data over thousands of years.

This peatland characteristic enabled, one century ago, scientific researches in Patagonia, related to the history of the vegetation and climate evolution in the last 18,000 years.

In the 1920s, pollen preserved in peat bogs became a tool to study the Quaternary vegetation and climate change, leading to the expansion of this research line in Northern Europe. At that time, Carl Caldenius, who was studying glacial deposits in the Argentinean Patagonia, extracted two cores 150 cm long from a peatland located in TDF, at the eastern head of Fagnano Lake. He sent them to the Swedish scientist Von Post to be analyzed. The pollen diagram made by Von Post (Von Post 1929) from these peat samples represents the first vegetation history record from South America (Markgraf 2016).

Väinö Auer developed the first extensive peatland field works on paleoclimatic research, between 1928 and 1952 (Tuhkanen 1997). Auer's work demonstrated that pollen records obtained from bogs of Patagonia contained a sequence of paleoenvironmental changes for which chronological control was critical, in order to establish synchronicity of events during a period of major global paleoclimatic changes (Markgraf 1983).

Radiocarbon-dated basal peat determines a minimum age for previous geological processes, like ice retreating or sea-level drop. Peatlands preserve tephra layer sequences from volcanic eruptions in the Holocene.

Plant macrofossils analysis can be used to reconstruct vegetation development as a paleoclimate proxy. This method was used by the first time in Patagonia in Andorra bog-TDF (Mauquoy et al. 2004). Multiproxy analysis improves and complements paleoclimate data. Van Bellen et al. (2014) used testate amoeba (a globally dispersed unicellular protist, and abundant in *Sphagnum* bogs) as a proxy for reconstructing Holocene water table dynamics in bogs of TDF. New techniques, such as peat humification, biomarkers, stable isotopes, inorganic geochemistry, etc., offer complementary proxies, enhancing the scientific potential of peatlands to understand paleoenvironmental changes.

Peat coring is a tool for archaeology. Charcoal particles preserved in peat, out of reach of volcanic activity (e.g., in TDF), are indicative of anthropological fires, revealing ages of human occupation.

4 Conclusions

We compiled an arranged listing of peatland's ES in Patagonia, following the CICES V 5.1 structure, with the aim to assess the contribution of these ecosystems to human well-being, in order to offer useful information and references for the wise use of peatland in Patagonia.

Peatlands provide peat, moss fibers, and water, as well as the natural products that grow on its surface. Even though the current *Sphagnum* peat extraction has a relatively low rate, it is concentrated in areas near the population settlements,

affecting the ES that they offer. Fiber harvesting is an extractive use that should be carefully planned and controlled. The fast spatial spreading of such interventions is threatening the future of *Sphagnum* ecosystems. Water provision, as well as several regulation services, is not easy to quantify.

The ES respond to complex processes that depend not only on peatland features but also the climate. We indicate effective case examples in Patagonia of water provision as well as flood and sediment control, but we emphasize that different peatlands may contrast in the kind of ES that they provide, as well as in their efficacy and importance. This remark has a special validity for Patagonia, due to the dissimilar peatland environments in this region.

The global meaning of peatlands in the regulation and mitigation of climate change stimulated last years the scientific interest in the C stock and GHG fluxes of these ecosystems in Patagonia. We reviewed the progress in the valuation of C storage, which has been estimated at 6.9 GtC in the last calculation by Loisel (2015). In our opinion, this result should be even improved through a more proper estimation of peatland thickness and extent.

The compiled information regarding GHG fluxes shows this research line is only 10 years old in Patagonia, with very scarce data still on this topic; GHG emissions have a great variability and depend on many variables. Notably, a significant part of the GHG data corresponds to particular peatland types of Patagonia, like the cushion *Astelia* bogs of TDF and the anthropogenic peatlands of Chiloe. Both denote near null CH₄ emissions and a good efficiency as C sinks.

Patagonian peatlands have played a significant role in ratifying the global incidence and synchronicity of climatic instability episodes during the Late Glacial Interstadial and the Holocene, which were initially identified just for the Northern Hemisphere.

Mires also allow the study of contrasts and similarities on carbon accumulation – climate relationships in the past and the present – under unlikely environmental conditions than as that of the northern peatlands. Patagonia expands the context to improve the understanding of potential climate change effects on ES of the world's peatlands relating to the C cycle.

Most of the services and benefits described and analyzed in this chapter correspond exclusively to natural peatlands. Degraded peatlands are not C sinks but sources; its aesthetic value is usually negative; they don't assure protection from erosion, but rather induce ditch's formation, contributing to organic and inorganic sediments; drainage modifies its regulatory capacity and damages the natural biodiversity in favor of invasive species.

The majority of peatlands in Patagonia maintain its original state. That is their main attribute ensuring the efficacy of ES; however, such state has been disturbed in the environs of most populated areas.

Peatland management policies must turn on from debates in cross-sectorial decision-making, with an ecosystem approach, and apply ES concepts and examples of them. This way, it is possible to contrast the continuity of services and goods that these ecosystems provide to the entire society, versus occasional benefits reaching sometimes the community and other times a particular sector. To this end,

scientists and professionals must continue to provide evidence-based references giving proven testimony of derived benefits from ES.

Most peatlands are owned by the state in both countries, usually, and especially in Chile, under a protected status. It should be noted that a majority of these mires are located far away from inhabited areas. Peatland services become effective when local persons are benefited from them. Several ES, like water provision for human use, flow regulation, erosion control, maintaining biodiversity, and aesthetic or cultural benefits, are examples of services that can only be given by peatlands located near inhabited areas, but these nearby wetlands are frequently out the protected areas.

The National System of Wild Protected Areas of Chile includes 71% of the existing peatland area in the Magallanes Region (Vega-Valdés and Domínguez Díaz 2015), 21% in Aysén, and 2% in Los Lagos. The last one, with lesser protection, is the most populated region of the Chilean Patagonia. As expected, as the population increases, the protected peatland area decreases. In Chiloe, many peatlands from private owners are subjected to a productive management with negative environmental consequences.

It is not enough to protect large expanses of peatlands in remote places; supplementary policies and regulations are necessary for a sustainable or at least a rational management of nearby peatlands that provide valuable local services.

In TDF, Argentina, most of the mires are in public lands, at the wild eastern side of the island. Several law projects were presented to the Provincial Parliament in the last 20 years, to protect a 1930 km² mire area, which represents 71% of the total in the Province. However, none of these law projects has had so far a positive treatment.

The National Mining Law was the unique regulation for peatland use in TDF (Argentina) until 2008. That year, the government formulated a participative strategy for the wise use of peatlands that among other actions included a moratorium on new concessions and delimited the zoning plan for peat mining, which remains currently in effect. No granting of new concessions outside this established area is permitted. In addition, applicable conditions in the peat-mining zone were established (Iturraspe and Urciuolo 2014). These measures ended a disordered proliferation of peat concession requests in inappropriate sites. At the time of the moratorium, these demands involved most of the peatlands accessible by road. Likewise, no peat extraction from fens is permitted in TDF, to maintain livestock use of them.

The rest of the Patagonian peatlands of Argentina has no specific regulations, in addition to the mining law, for peatland management. The Argentinean provinces have the competence in planning the use of its natural resources, among which, these ecosystems are not abundant, and even less, *Sphagnum* bogs, which are the most required for peat mining. Therefore, it would be significant to discuss into each provincial ambit about the convenience to avoid extractive activities, before first requests for concessions appear.

Chile is working on policies and measures that lead to better use of peatlands. Stricter requirements for peat mining and environmental impact studies have been established, and since 2014, new regulations for fiber harvesting have been enforced.

Despite these advances, it is still necessary to continue enhancing the peatland management, with proper policies, regulations, knowledge, and education. On this way, we present below some criteria and actions that can be considered.

Concessions for peat extraction should be subject to the opinion of other technical areas of the state, in addition to the mining authority (e.g., water resources, environment, etc.) to avoid possible loss of valuable ES from the competence of such areas.

Peat mining bad practices should be corrected. Drain closures should be progressively established, according to present planning and before the mining company leaves the bog, avoiding the abandonment of peat bogs with open drains.

Environmental impact studies for peat mining projects should consider the ES evaluation and its affectation.

Peatlands that allow a sustainable alternative use (i.e., tourism, education) should be preserved from peat extraction, as well as those with rarity attributes or special aesthetic value. It should be protected, notably peatlands located in water basins that provide water to populations and those which maintain flood or sediment control of rivers that run in the urban areas.

Peat draining should be avoided because it causes wetland degradation. In addition to it, dry peat is a highly combustible material, therefore drained bogs are potential sources of fire that spread to forest. Road's drainages in peatlands degrade extensive mire stretches. It should be avoided through suitable constructive ditch road specifications for peaty terrains.

Specific regulation for urban peatland use and conservation is essential.

Livestock in fens or wet meadows is normally owned by private farmers, who seek to optimize its production through sustainable management. However, they are often unaware of the fragility of these ecosystems. For this reason, training and assistance from the state agencies are important.

On the other hand and considering the concern of people as essential for ecosystem conservation, the government should promote education and dissemination policies on peatland values, particularly where they represent the dominant and distinctive wetland ecosystem.

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