REVISTA CHILENA DE HISTORIA NATURAL

Revista Chilena de Historia Natural 85: 513-518, 2012

SHORT COMMUNICATION

Sphagnum magellanicum growth and productivity in Chilean anthropogenic peatlands

Crecimiento y productividad de *Sphagnum magellanicum* en turberas antropogénicas de Chile

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ABSTRACT

Sphagnum peatlands are threatened at a global scale, not only by peat extraction, but also by *Sphagnum* harvesting. In Chile, dry *Sphagnum* moss is mainly exported for use as substrate for horticulture and orchids. Although the use of *Sphagnum* within Chile is limited, there are no data about its productivity and growth. These peatlands have a special microtopography with hummocks, hollows and lawns, which vary the distance of moss to the water table level. In these ecosystems, the water table is almost all year near the surface. We measured cumulative and relative growth rates and productivity during approximately one annual cycle in private *Sphagnum* peatlands that are being yearly harvested for commercial purposes. We evaluated the relationship between *Sphagnum magellanicum* growth and productivity with microtopography and water table depth. Productivity, cumulative and relative growths were higher in lawns than in hummocks. Overall and relative growth of *S. magellanicum* showed a negative relationship with depth of the water table. There were also differences between sites, some of them showed high growth rates, but low productivity. *Sphagnum* extraction in Chile, is now at low scale, but the growing international market demands constitute a real threat to the resource.

Key words: Chile, growth rate, peatland, *Sphagnum* moss.

RESUMEN

Las turberas de *Sphagnum* están amenazadas a escala global, no solo por la extracción de turba, sino también por la cosecha de *Sphagnum*. En Chile, el musgo seco es importado principalemente para su uso como sustrato para la horticultura y cultivo de orquídeas. Aunque el uso del musgo en Chile es limitado, no existen datos sobre su productividad y crecimiento. Las turberas de *Sphagnum* tienen una microtopografía especial con cojines, zonas planas y zonas bajas o depresiones en el terreno, las que varían en la distancia del musgo a la napa freática. En estos ecosistemas, el nivel freático se encuentra gran parte del año muy cercano a la superficie. Se midieron las tasas de crecimiento acumulado y relativo por aproximadamente un ciclo anual en turberas de *Sphagnum* que se cosechan periódicamente para fines comerciales. Se evaluó la relación entre el crecimiento de *Sphagnum magellanicum* y la productividad con la microtopografía y la profundidad de la napa freática. La productividad, el crecimiento acumulado y relativo fueron mayores en zonas bajas que en cojines. El crecimiento total y relativo de *S. magellanicum* mostró una relación negativa con la profundidad de la napa freática. También se encontraron diferencias entre sitios, algunos mostraron mayores tasas de crecimiento en altura, pero menor productividad. La extracción de *Sphagnum* en Chile aún se realiza a baja escala, pero la creciente demanda del mercado internacional constituye una real amenaza para el musgo.

Palabras clave: Chile, musgo *Sphagnum,* tasa de crecimiento, turberas.

INTRODUCTION

Peatlands are extensive types of wetlands characterized by the accumulation of dead plant matter (peat) that may form layers up to 20 m thick. This ecosystem has important consequences for climate change, human welfare and biodiversity conservation (Parish et al. 2007). In particular, peatlands play a critical role in water storage, regulation and filtration, thus protecting the environment against floods and providing clean water; they are able to sequester even higher volumes of carbon dioxide than the world forests, which might potentially transform them in important sources of CO_2 if destroyed, and finally they harbor a unique biodiversity, which includes many endangered species. In spite of these, peatlands are being degraded and threatened in many regions as a result of plantations, land use change, drainage, fire and its use as energy fuel (Sala et al. 2000, Parish et al. 2007). In southern Chile, the use of fire and clearcutting since the middle of the 19th century in places with low drainage has created areas of wetlands dominated by species of the genus *Sphagnum* (i.e. anthropogenic peatlands, Díaz et al. 2008). A similar situation has happened in New Zealand (Whinam & Buxton 1997) and now peatlands in both countries are one of the major sites for commercial harvesting of *Sphagnum*.

Sphagnum peatlands are characterized by a continuous layer of moss with sparse shrub or tree cover, and whose main water source is rainfall or snowmelt. They have a special microtopography with hummocks, hollows and lawns that vary the distance of moss to the water table (Van Breemen 1995). In Chile, *Sphagnum* peatlands are located in the south of the country (from 39º S to 55º S) and not only are threatened by peat extraction, but also by *Sphagnum* harvesting (i.e. the extraction of the first -active- layer, the acrotelm), mainly for its use as a substrate in horticulture. Once harvested, *Sphagnum* re-growth depends on different factors such as water and light availability, distance to water table and air temperature, among others (Gerdol 1995, Buxton et al. 1996, Gunnarsson et al. 2004). Although the use of *Sphagnum magellanicum* within Chile seems limited and there are no statistics about its production, the exported volumes have increased exponentially in just 10 years: from 360 tons in 1997 to 2675 tons in 2007. This situation coupled to the lack of research, slow regeneration, absence of management plans, and little or no enforcement of harvesting regulations, seriously threat the persistence of this unique and limited resource. Here, we measured growth rates and productivity during approximately one annual cycle in nine private *Sphagnum* peatlands that are being yearly harvested for commercial purposes. Thus, the overall aim of this study was to evaluate the relationship between *Sphagnum magellanicum*'s growth and productivity with microtopography and water table depth.

METHODS

Study area

Nine study sites (below 100 mas l) were chosen in private peatlands in the vicinity of Puerto Montt (41° S 72° W). With the exception of one site, which has not been harvested for at least 30 years (H. Aburto C), all peatlands are harvested yearly (i.e. first layer of moss) for commercial purposes. *Sphagnum magellanicum* is the dominant species in all sites and the one that farmers export. Measurements of growth and productivity were done on this specie. Annual mean precipitation is 2110 mm with a dry period during summer months (January and February) and annual mean relative humidity is 85 %. Annual mean air temperature is 10 °C ranging from 4 to 19 °C (annual mean minimum and maximum temperatures, respectively) (Carmona et al. 2010).

Growth rates and productivity measurements

We have experimentally measured growth rates and productivity and recorded the depth of the water table (hereafter DWT) over approximately one annual cycle (August 2006 to July 2007). At each site, we installed three plots (2 x 1 m), each one with a hummock and lawn area (hummocks with at least 10 cm of difference in height of lawns). Within each plot we measured growth rates and productivity in at least five individual plants. We measured growth every two months with the cranked wire method propose by Clymo (1970). It basically consists in a wire (shaped like a car starling handle) placed over the *Sphagnum* carpet with the horizontal section leveled with the capitula. The growth is measured from the amount of free wire above the surface. We estimated overall cumulative growth over the entire year, and relative growth as the growth rate per month. Productivity was estimated using 10 stems of each treatment in each plot. We cut the first cm under the capitulum, dried and weighed (B_{stem}). We used the equation proposed by Gehrke (1998) as $\Delta h * B_{stem} * \rho cap$ where Δh is the increase in shoot length measured with the cranked wire method propose by Clymo, B_{stem} is biomass for unit length of the shoot and ρcap is the spatial density of capitulum, measured counting the number of capitulum 10 times per treatment in each plot with a square of 4 cm^2.

Statistical Analyses

We used a linear mixed modeling approach to evaluate the effect of the microtopography (hummock and lawn) and DWT on our variables, while taking into account the spatial pseudoreplication of our design and the variance heterogeneity across sites. Productivity was analyzed using microtopography as a fixed effect. Growth-related variables were analyzed using DWT and microtopography as fixed effects. Hypothesis testing for fixed and random effects was carried out using Likelihood Ratio Tests of nested models based on Maximum Likelihood (ML) and Restricted ML estimation, respectively (West et al. 2007). The asymptotic null distribution of the test is a χ^2 with degrees of freedom equal to the difference in the number of parameters between the two models (West et al. 2007). All variables were $\log_{10}$ transformed to meet normality assumptions. We performed all the statistical analyses using R (R Development Core Team 2009). Results are presented as mean ± 1 SD.

RESULTS

Productivity was almost 70 % higher in lawns than in hummocks (χ^2_1 = 10.83, P = 0.001), with a mean of 573.10 ± 303.33 g m^{-2} year^{-1} and 342.83 ± 217.30 g m^{-2} year^{-1}, respectively (Fig. 1A). Also, the effect of microtopography on productivity varied with site (χ^2_1 = 3.92, P = 0.048) (Fig. 1B). Cumulative growth was 92 % higher in lawns (4.42 ± 3.28 cm) than in hummocks (2.31 ± 1.85 cm) (χ^2_1 = 5.01, P = 0.025, Fig. 2A) and was negatively affected by DWT (on a log-scale, b = -0.0063 ± 0.0026 SE; χ^2_1 = 5.17, P = 0.023). There was no interaction between DWT and microtopography (χ^2_1 = 1.13, P = 0.289). Also, the effect of microtopography on cumulative growth varied with site (χ^2_1 = 11.17, P < 0.001) (Fig. 2B).

Although cumulative growth was measured over a different number of days in the different sites (range 226-354, see Fig. 2 for details), number of days did not have an influence on cumulative growth (χ^2_1 = 0.02, P = 0.888).

Relative growth showed a similar pattern that cumulative growth. It was almost 90 % higher in lawns (0.433 ± 0.32 cm month^{-1}) than in hummocks (0.229 ± 0.20 cm month^{-1}) (χ^2_1 = 4.55, P = 0.033, Fig. 3A) and was negatively affected by DWT (on a log-scale, b = - 0.0069 ± 0.0026 SE; χ^2_1 = 6.0, P = 0.014). Also, there was no interaction between DWT and microtopography (χ^2_1 = 1.16, P = 0.282). Furthermore, the effect of microtopography on relative growth varied with site (χ^2_1 = 10.92, P < 0.001) (Fig. 3B).

DISCUSSION

Water availability, one of the factors that determine growth of *Sphagnum* species,

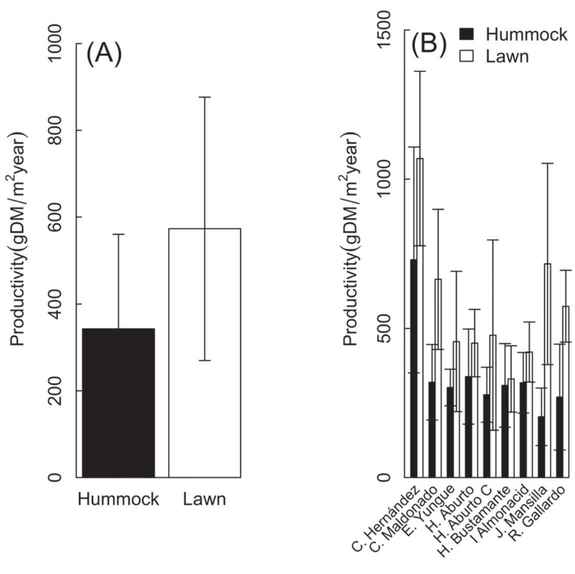

Fig. 1: Overall productivity of *Sphagnum magellanicum* according to microtopography (hummocks and lawns) (A), and in each study site (B). Data are presented as mean ± 1 SD.

Productividad total de *Sphagnum magellanicum* según microtopografía (cojines y zonas bajas) (A), y según sitio de estudio (B). Los datos se presentan como media ± 1 SD.

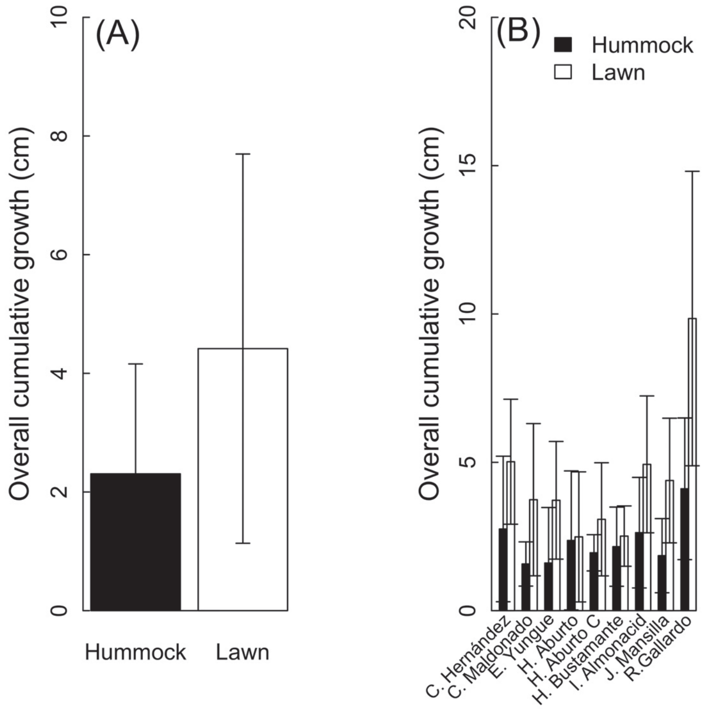

Fig. 2: Overall cumulative growth of *Sphagnum magellanicum* according to microtopography (A), and in each study site (B). C. Hernández 226 days, C. Maldonado 354 days, E. Yungue 320 days, H. Bustamante 272 days, J. Mansilla 338 days, H. Aburto, H. Aburto C, I. Almonacid and R. Gallardo, 322 days of measurement. Data are presented as mean ± 1 SD.

Crecimiento acumulado de *Sphagnum magellanicum* según microtopografía (cojines y zonas bajas) (A), y según sitio de estudio (B). C. Hernández 226 días, C. Maldonado 354 días, E. Yungue 320 días, H. Bustamante 272 días, J. Mansilla 338 días, H. Aburto, H. Aburto C, I. Almonacid y R. Gallardo, 322 días de medición. Los datos se presentan como media ± 1 SD.

depends on the distribution of rainfalls, evaporation and the mean annual water table level (Gignac & Vitt 1990, Grosvernier et al. 1997). As expected, overall and relative growth of *S. magellanicum* showed a negative relationship with DWT. Weltzin et al. (2001) suggested that DWT influences the growth of *S. magellanicum* only when it is between 20 and 25 cm under the moss surface. On the other hand, Grosvernier et al. (1997) proposed that when water table is below 40 cm under the surface (drainage conditions), physicochemical properties of peat change and these in turn affect negatively *Sphagnum*'s growth. It has been suggested that *Sphagnum* species tend to built tight hummocks in extremely dry conditions in order to improve the capillary network and thus water transport (Rydin 1985, Li et al. 1992). This phenomenon could explain *Sphagnum*'s growth with little or no water availability, even in summer when water table is lower than in other seasons. *Sphagnum*'s growth rate fluctuated extensively (range: 0.1-17.3 cm year^{-1}), with a mean cumulative growth of 3.38 ± 2.87 cm year^{-1} (mean ± SD). This is similar to reported values for temperate alpine ecosystems (i.e. Italy, Gerdol, 1995) and higher than the mean growth for higher latitudes (e.g., Sweden, Aerts et al., 1992, Wallen et al. 1988), probably because of climatic conditions (high temperatures, water availability and light intensity) during the growing season in Southern Chile. *Sphagnum*'s productivity also showed a wide range, from 67 to 1590 g m^{-2} year^{-1}, with an overall mean of 458 ± 287 g m^{-2} year^{-1}. This is twice the value recorded for *S. magellanicum* in Tierra del Fuego National Park, Chile (54°51' S) (Robson et al. 2003). A likely explanation for such difference might be related to mean annual temperatures at both

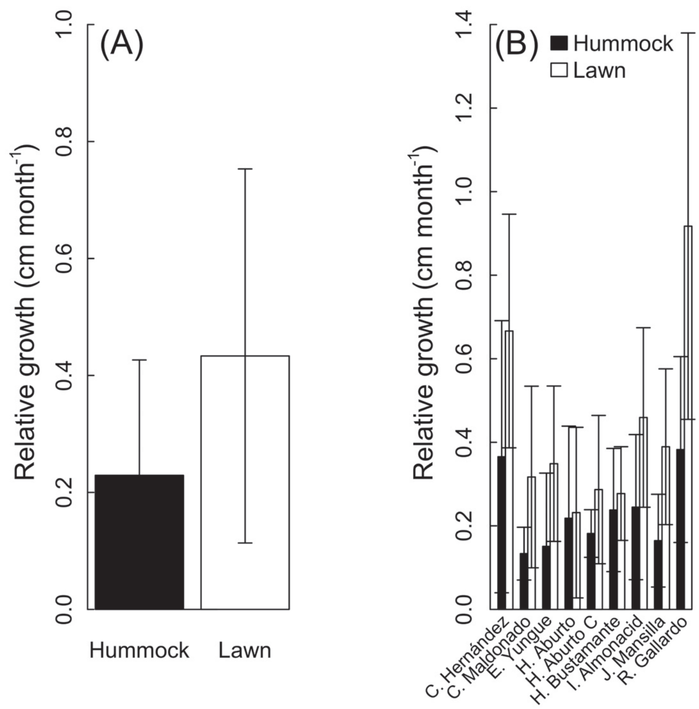

Fig. 3: Overall relative growth rate of *Sphagnum magellanicum* according to microtopography (A), and in each study site (B). Data are presented as mean ± 1 SD.

Tasa de crecimiento relativo de *Sphagnum magellanicum* según microtopografía (A), y según sitio de estudio (B). Los datos se presentan como media ± 1 SD.

sites: 11.2 °C in Chiloé and 5.8 ºC in Tierra del Fuego. Thus, our results are in agreement to what was proposed by Gunnarsson (2005), that mean annual temperature was the most important factor explaining global productivity in *Sphagnum* dominated wetlands.

As expected, growth (overall and relative) and productivity were higher in lawns than in hummocks (see panel (A) in Figs. 1-3). However, this trend was not (statistically) consistent across sites, as we detected an interaction between sites and microtopography. That is, the incidence of microtopography on growth and productivity was more evident in some sites. More importantly, sites with the highest productivity were not necessarily the sites with the highest growth in length (see panel (B) in Figs. 1-3), and vice versa. Our results suggest that it is extremely important to include biomass production and not only height increment or growth when considering the right time to harvest. If only growth in length is used as a proxy for the decision to harvest or not, overexploitation of the resource will be imminent. Moss need to growth not only in length but also in biomass, because when farmers sell it, they sell it by weight. Furthermore, some sites are even harvested on a yearly basis.

In the past decades the increase of moss extraction and export in Chile has generated the need to analyze the current state of conservation of the resource. In 2010 Chile exported 4214 tons of *Sphagnum*. Our results indicate an average annual productivity for *Sphagnum* as 4.6 tons ha^{-1} year^{-1}, then our productivity estimates suggest that every year 920 ha are needed to keep those export volumes. Furthermore, most of *Sphagnum* moss in the Chilean Lake District is located in private properties of small landowners (ca. 11500 ha) (ODEPA, 2007) and its exploitation has provided a significant income to thousands of families in the Region. However, moss extraction at the current rate and without a proper management, would mean the extinction of the resource in less than 12 years. In fact, we are already witnessing the evident symptoms of overexploitation and deterioration because low tender prices (US$ 0.3 to 1.3 per Kg) restrict the revenues to moss collectors stimulating the extraction of increased volumes to increase revenues. This situation imposes the urgent need to promote sustainable management practices for the resource, and ensure the economic viability of the product in the long term.

ACKNOWLEDGMENTS: We thank all the farmers involved in the project: C. Hernández, C. Maldonado, H. Bustamante, H. Aburto, R. Gallardo, I. Almonacid, J. Mansilla, E. Yungue, for facilitating their wetlands and for collaborating with the research. We also thank Erla Silva and Matías Doggenweiler for field assistance. Financial support was provided by Fundacion Copec-UC Project TC026, Iniciativa Científica Milenio P05-002, and grant PFB 23 (CONICYT) to the Instituto de Ecología y Biodiversidad (Chile). Final manuscript preparation was supported by a Fondecyt grant 11085007. This is a contribution to the Research Program of LTSER-Chile network at Estación Biológica Senda Darwin, Chiloé.

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Editorial responsibility: Luis J. Corcuera
Received April 17, 2012; accepted December 10, 2012