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SCINTIFIC NOTE

Improving Harvesting Techniques to Ensure *Sphagnum* Regeneration in Chilean Peatlands

Mejoramiento de Técnicas de Cosecha para asegurar la Regeneración de *Sphagnum* en Turberas de Chile

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Sphagnum species, primarily *Sphagnum magellanicum* Brid., are used internationally as a substrate for horticulture. Market demands have promoted indiscriminate exploitation leading to a number of potentially negative ecological and social consequences, including disruption of *Sphagnum* ecosystems, changes in water storage capacity of moss wetlands affecting water supply to rural communities and reduction of biodiversity. This study proposes improvements in harvesting techniques to ensure moss regeneration and promote sustainability of moss cover in harvested areas. The aim of this study was to determine the maximum harvesting depth for moss regeneration. Samples were taken and divided into sections associated with different depths. We recorded and marked the number of new green shoots of *Sphagnum* monthly. We found a negative relation between regeneration (appearance of new shoots) and depth. Our studies showed that 90% of new shoots recorded in 6-mo of measurements appeared within the first 12 cm depth. This work allowed us to generate some practical recommendations to farmers about maximum harvesting depth. To ensure regeneration, we recommend harvesting up to 12 cm below surface.

Key words: *Sphagnum* moss, sustainable management, wetlands.

Especies de *Sphagnum,* principalmente *Sphagnum magellanicum* Brid., se utilizan internacionalmente como sustrato para horticultura. La creciente demanda del mercado ha promovido una explotación indiscriminada, lo que podría traer consecuencias ecológicas y sociales negativas, producto del deterioro de los ecosistemas de *Sphagnum,* cambios en la capacidad de almacenamiento de agua del humedal, afectando el suministro de agua a comunidades rurales, y pérdida de biodiversidad. Este estudio propone mejorar las técnicas de cosecha para asegurar la regeneración y sustentabilidad del musgo en áreas cosechadas. Específicamente, determinar la máxima profundidad de cosecha que permita la regeneración del musgo. Se tomaron muestras de musgo y se dividieron en secciones asociadas con diferentes profundidades. Se registró mensualmente el número de brotes nuevos. Se encontró una relación negativa entre regeneración (aparición de brotes nuevos) y profundidad. El 90% de los brotes registrados en los 6 meses de medición se observaron en los primeros 12 cm de profundidad. Este trabajo permitió generar recomendaciones prácticas sobre la máxima profundidad de cosecha. Para asegurar la regeneración, recomendamos cosechar hasta 12 cm bajo la superficie.

Palabras clave: musgo *Sphagnum,* manejo sustentable, humedales.

Peatlands are areas with a naturally accumulated layer of organic material on the surface. These ecosystems cover over 400 million hectares in about 180 countries and represent one third of the global wetlands (Parish *et al.,* 2008). Because of their organic matter accumulation and water retention properties, peatlands play an important role in C and water cycling and climate regulation (Moore, 2002). Currently, peatlands are being degraded or threatened in many regions as a result of plantations, land use change, drainage, fire, and climate change (Sala *et al.,* 2000; Parish *et al.,* 2008; Dise, 2009). These processes not only reduce biodiversity and their direct benefits for local people, but also generate additional ecological problems. A major globally recognized threat for peatlands is peat extraction, which started several centuries ago with the use of dry peat as fuel (Gòttlich *et al.,* 1993). While today peat is still an energy source, there is a growing industry that produces substrates for horticultural crops from peat. In Canada, where the history of peatland exploitation is long, a series of investigations have been conducted to restore and manage these ecosystems (Poulin *et al.,* 1999; Rochefort, 2000; Lavoie *et al.,* 2003; Rochefort *et al.,* 2003). The impact of human activities on these ecosystems can hardly be illustrated more dramatically than by looking at the contrast between a pristine peatland and the same ecosystem degraded by exploitation (Chapman *et al.,* 2003).

Forest clearing since mid 19th Century in Los Lagos Region, south of Chile, has created new secondary wetland areas generally dominated by species of the genus *Sphagnum,* locally called "pomponales" because of the common name for *S. magellanicum* "pompon" (Diaz *et al.,* 2008). This has increased the extent of existent *Sphagnum* wetlands especially in some areas of the Region and Chiloé Island. This process of retrogression has reversed the successional postglacial forest expansion into peatlands, through slow colonization of woody species. When the forest on a poorly drained soil (because of the height of the hardpan layer) is burned or cleared, waterlogged conditions impair the recolonization of forest and stimulate *Sphagnum* recolonization (Diaz *et al.,* 2007). Similarly, in New Zealand, anthropogenic disturbances, mainly clear-cutting of poorly drained areas, can favor colonization and dominance of *Sphagnum* species (Whinam and Buxton, 1997). Some of these deforested sites of secondary wetlands have currently become major sites for commercial harvest of *Sphagnum* in both Chile and New Zealand.

Chilean extensive peatlands and Magellanic moorlands are threatened by peat extraction, but also by *Sphagnum* farming (the extraction of the first layer of

Sphagnum moss, the active layer or acrotelm). The water holding capacity of *Sphagnum* has resulted in its use by people for various purposes over hundreds of years (Denne, 1983). In horticulture, *Sphagnum* makes a useful potting medium, particularly favored by orchid growers and for wrapping rose and fruit tree rootstocks for transportation (Denne, 1983; Elting and Knighton, 1984). The use of *Sphagnum* in Chile is limited, although there are no statistics on production and use. However, there is a vast international market for *Sphagnum* moss commercialization since 1998 (Zegers *et al.,* 2006). Currently, *Sphagnum* moss is exported to Taiwan, USA, Japan, South Korea, Holland, China, Vietnam, and France, mainly for its use as substrate for horticulture and orchids. During the last 9 yr, Chile exported an average of 2675 t of *Sphagnum* annually, showing an increasing trend (ODEPA, 2012).

Moss extraction during the last 10 yr from natural and secondary peatlands have caused strong degradation of the ecosystem with a number of potentially negative ecological and social consequences, such as disruption of *Sphagnum* ecosystems, change of water storage capacity of wetlands affecting water supply to rural communities, and reduction of biodiversity (Zegers *et al.,* 2006). Many farmers lease peatlands for peat moss harvesting, causing great ecological impact. This "mining" operation leaves large water holes covered by a dead moss layer with little or no regenerative capacity.

Currently, there is no technical protocol, management plans or harvesting regulations to prevent ecosystem damage or promote long-term sustainability of the resource. Furthermore, no scientific studies in Chile are presently available to contribute to the development of sustainable practices for moss regeneration. This situation, coupled with the recently expanding trends of extraction and slow regeneration, seriously threaten the persistence of this resource.

Sphagnum species have indeterminate apical growth. *Sphagnum* has a peculiar structure with branches produced in fascicles of two or more diverging branches and two or more pendant branches. Near the apex of the plant, these fascicles are compressed together to form a head or *capitulum.* Clymo and Hayward (1982) describe parallel growth of shoots. *Sphagnum* leaves live 1 or 2 yr; subsequent growth of branches above the leaves creates a dense shade before they die. The only parts of the moss that remain alive under the apex seem to be the axillary buds. These buds commonly remain inactive and eventually die, but if the apex is destroyed by artificial means (e.g. by harvest) or accidentally (e.g. by drought), one or more lateral buds can sprout to regenerate the shoot (Clymo and Hayward, 1982).

The overall aim of this study was to improve harvesting techniques to ensure moss regeneration and the sustainability of moss cover in harvested areas. The specific objective was to determine a maximum harvesting depth to ensure *Sphagnum* moss regeneration. If the depth of the moss layer determines its regeneration capacity, it is then expected that with increasing harvesting depth, moss regeneration capacity will decrease.

MATERIALS AND METHODS

The study area was located within Senda Darwin Biological Station (SDBS), ca. 20 km north of Ancud, Chiloé Island (41°50' S, 73°40' W). Climate is wet-temperate with a strong oceanic influence. Meteorological records at Senda Darwin Biological Station (SDBS, 1997 to 2008) indicate a mean annual rainfall of 2110 mm and a mean annual temperature of 10 °C. Mean temperatures fluctuate between 19.1 and 4.0 °C (Carmona *et al.,* 2010). Rainfall occurs throughout the year, but 70% of the precipitation is concentrated between April and September. The predominant soil type is known as "nadis" (Veit and Garleff, 1996), and corresponds to the order Andisol (FAO-UNESCO, 1971). These soils have a long water saturation period and a shallow water table, especially during winter months, due to the presence of an impermeable layer of iron and aluminum oxides, or hardpan, which is found at an average 52 ± 3 cm (mean ± SE, N = 12) below the surface (Diaz *et al.,* 2007). *Sphagnum* peatlands in the Chiloé Island cover 11 225 ha, containing an estimated stock of 3 960 099 t of dry peat moss (superficial moss layer or acrotelm) (SERNAGEOMIN-GORE Los Lagos, 2008).

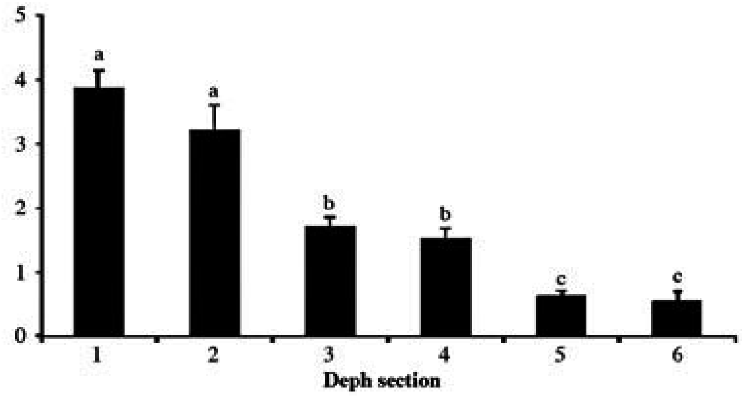
To assess the relation between moss regeneration and depth, *S. magellanicum* stems were collected by hand from an undisturbed secondary peatland in SDBS. The *capitulum* (first centimeter) was cut and removed from each stem, and the remaining stem was divided into six sections of 3 cm length from the apex. Sections were named according to the position of the stem below the surface level: 1 (0-3 cm); 2 (3-6 cm); 3 (6-9 cm); 4 (9-12 cm); 5 (12-15 cm); 6 (15-18 cm). Six stem sections from the same depth level were laid horizontally on commercial peatmoss (as substrate) in a Petri dish, and water from the same peatland in which stems were collected was added. Dishes were then covered and sealed with parafilm to prevent evaporation, and stored in the greenhouse during the study period (mean maximum temperature 20 °C and mean minimum temperature 7.5 °C during November 2009-July 2010). *Sphagnum magellanicum* regeneration measurements were carried out once a month from November 2009 to July 2010 recording the average of new shoots per plate (total number of new shoots found in each dish divided by the number of stems per dish). We replicated each dish 15 times. Dishes were examined with a magnifying glass and the appearance of new green shoots in the stem sections was recorded.

Data were analyzed using a One-Way ANOVA followed by Tukey's HSD post-hoc comparisons to determine whether there were any significant differences in the number of new shoots at different depth levels. Data were square root transformed to meet the assumption of homogeneity of variances. Temporal changes in *S. magellanicum* regeneration were tested by a complex repeated measure ANOVA (Logan, 2010).

RESULTS AND DISCUSSION

Sphagnum magellanicum regeneration showed differences related to stem depth. A significant effect of depth on the number of new shoots was observed (F5.84 = 39.24; P < 0.001, ANOVA), being the number of new shoots significantly greater in upper depth levels (Figure 1). Similarly, we found a significant depth section and time interaction (F_{25420} = 10.47; P < 0.001). New shoots arose in stems from all different depth levels, but the highest rate of new shoots occurred at the beginning of the experiment (after 2-mo) in the upper levels. After 6-mo there was no regeneration response (Figure 2). Ninety percent of the new shoots were recorded in the first 12 cm (Figure 3). In deeper sections (i.e. > 12 cm), the number of new shoots was negligible.

Figure 1. Effect of stem depth on *Sphagnum magellanicum* regeneration. Depth sections: 1 (0-3 cm); 2 (3-6 cm); 3 (6-9 cm); 4 (9-12 cm); 5 (12-15 cm); 6 (15-18 cm) below surface.



Different letters denote significant differences according to Tukey test (P < 0.05).
Data are shown as mean number of new shoots ± 1 SE in each depth section.

Figure 2. Mean number of new *Sphagnum* shoots per plate in different depth sections in 6-mo experiment.

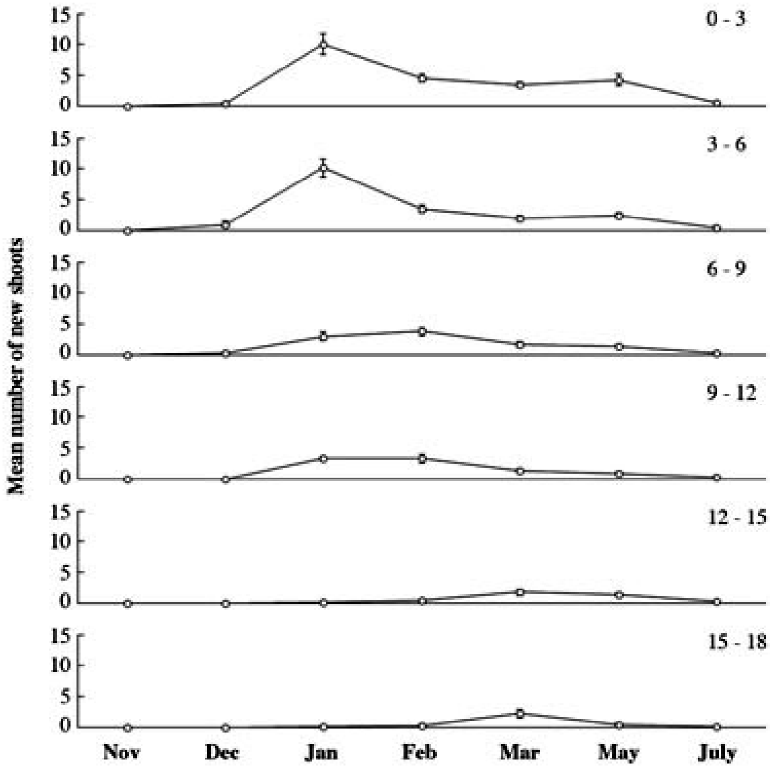
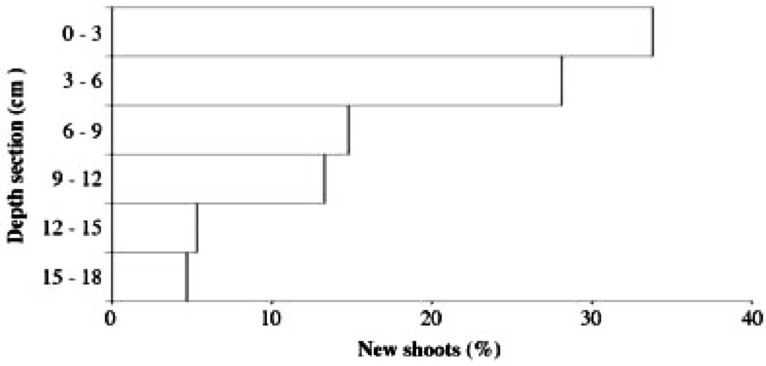


Figure 3. Percentage of the total new shoots appeared in different depth sections.



The results of this study are consistent with the *Sphagnum* regeneration pattern described in the literature (a decline in number of new shoots with depth); nonetheless, some differences can be noted. Clymo and Duckett (1986) assessed the regeneration of three Sphagnum species (S. papillosum, S. recurvum, and S. magellanicum) in slices of peat cores. In particular, for S. magellanicum, they observed that the greatest density of new shoots arose between 3-6 cm below surface, with very few new shoots between 0-3 cm below the surface; however, we observed the major proportion of new shoots in the first depth section level (i.e. the first 3 cm of the stem below the surface). In a similar experiment, Rochefort et al. (2003) observed that the regeneration potential declined for some Sphagnum species fragments 6 cm under the capitula, and that S. magellanicum was viable up to at least 10 cm (their experimental limit). Campeau and Rochefort (1996) found that S. magellanicum capitula produced from material originating from the 0-20 cm layer was greater than the capitula produced from deeper sections.

As mentioned before, the only parts of the moss that stay alive under the apex are the axillary buds, which remain inactive and eventually die, unless the apex is destroyed (by harvest or drought). In that case, one or more lateral buds can sprout regenerating the shoot (Clymo and Hayward, 1982). The appearance of new shoots in *Sphagnum* stems can be regulated by other factors such as water availability, temperature, or light. Rochefort *et al.* (2002) found that, for *S. magellanicum,* the number of new shoots was greater in flooded relative to non-flooded treatments under cold conditions, but no differences were observed under warm conditions. Clymo and Duckett (1986) found that light availability was determinant for the appearance of new shoots. According to the experimental results of this study, after *capitulum* cutting, regeneration capacity of buds decreases with the depth of the moss layer; in other words, regeneration decreases, as moss gets older. However, factors such as water availability or light were not measured in this study.

The results of this work can be useful for *Sphagnum* moss farmers in southern Chile. We suggest harvesting at no more than 12 cm deep to ensure moss regeneration. This is a valuable and practical recommendation that must be communicated to farmers, since it is an easy way to promote the sustainability of the resource. However, this is not the only factor influencing S. *magellanicum* regeneration. More scientific studies and management policies are necessary to improve moss extraction in Chiloé Island. *Sphagnum* extraction in Chile is currently performed at a local scale, but growing international market demand constitutes a real threat to the resource.

Market demands have led to indiscriminate extraction of *Sphagnum* moss from wetlands mainly from Los Ríos to Los Lagos Region. The situation is not economically beneficial to local communities because of low price (ca. $900 kg^{-1} dry moss = US$1.5-2.0), which restricts the revenues for moss collectors, with higher revenues to intermediaries or exporters. The low price paid to producers stimulates the extraction of increased volumes to increase revenues.

Sustainable use is a necessary and urgent need for all our renewable resources. Otherwise, in the long term they will become non-renewable resources, highly increasing the cost and limiting the possibilities to be recovered. This work allowed us to generate some practical recommendations to farmers about maximum harvesting depth. Peatlands are clearly an ecologically and economically valuable resource for many local communities, where the principles of sustainability can be put into practice. If we continue with the current rate of extraction rapid depletion of the resource can be expected. Moss extraction shows evident symptoms of overexploitation and deterioration. This imposes the urgent need to promote sustainable management practices, to ensure the economic viability of the product in the long term.

CONCLUSIONS

To ensure regeneration, we recommend harvesting up to 12 cm below surface. With these data we can improve harvesting techniques as the first step towards a sustainable use of the resource, ensuring moss regeneration of the moss cover.

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