Sphagnum research programme: the ecological effects of commercial harvesting

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Abstract

Between 1989 and 1993, *Sphagnum* growth rates and woody seedling regeneration was monitored on plots and transects established at several sites in Westland and Nelson to assess the effects of commercial sphagnum harvesting (Buxton *et al.* 1990, 1991 & 1992). In 1993-94 plots at lanthe Forest were reharvested to assess biomass production, and at Skiffington Swamp, Westland National Park, seedling densities were surveyed in temporary non-harvested plots to provide a comparison with harvested lowland sites.

Sphagnum cover and height growth was rapid in heavily harvested plots and was improved by reseeding. In open sites the height growth of *Sphagnum* growing among rushes was significantly greater than that of Sphagnum growing alone or with *Empodisma*. *Sphagnum* yield in reharvested plots was significantly less than initial biomass. Moss regrowth, as a percentage of initial biomass, was less than 50% at both Pell and Ianthe sites, but was improved by reseeding at both sites. Optimal harvesting depth appears to be to or slightly above the normal position of the water table.

Numbers and species of native woody seedlings varied between sites, but there was no significant difference between harvested and related unharvested sites. Seedling numbers were generally negatively correlated with *Sphagnum* cover, especially in beech dominated communities, i.e., as sphagnum cover increased seedling numbers decreased.

Some harvesting guidelines are suggested.

1. Introduction

Globally, *Sphagnum* is the most abundant of all bryophytes, having considerable ecological and economic importance (Clymo & Duckett 1986). 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 favoured by orchid growers and for wrapping rose and fruit tree rootstock for transportation (Denne 1983, Elling and Knighton 1984).

Sphagnum has been harvested in New Zealand for export to Japan since about 1970 (Denne 1983). Although New Zealand sphagnum has always been of high quality, the market was at first almost fully supplied with shipments from U.S.A., Canada, North Korea, the Republic of Korea and Taiwan. In the late 1970s political changes caused the loss of the North Korean supply, and Japanese companies looked to New Zealand to meet domestic needs. Since 1979 several individuals and companies have been attracted to the industry, mostly centred in Westland, but also in Nelson and Southland. By 1990 sphagnum exports reached 1000 tonnes per annum, with several new exporters competing for their market share. At June 1992 this represented $16 m (FOB) annually, with the industry employing up to 1000 people throughout the year, moss processed in 50-70 packhouses and sold by an estimated 27 exporters (Horticultural Export Authority 1993).

At present all *Sphagnum* harvesting in New Zealand is from natural populations, although mostly from highly modified areas such as induced pakihi on logged terrace land. As harvesting activity increased the Department of Conservation (DoC) was placed under greater pressure to allow harvesting in unmodified areas, including the pristine wetlands of South Westland. In 1989 representatives of DoC, Forest Research Institute, and Botany Division, DSIR (the latter two later forming Landcare Research) met to discuss requirements for sphagnum moss research. Important questions to be addressed were seen to be the effects of harvesting in different environments, and particularly on lowland forest regeneration in Westland, and understanding the role of Sphagnum in New Zealand wetland ecosystems.

Sphagnum habitats

Sphagnum peatlands generally form in situations of relatively high precipitation and low evaporation, with little or no threat of drought, and exceedingly low fertility. The low concentration of nitrogen in sphagnum, usually less than 1 (Clymo and Hayward 1982), slows the rate of decay, and the acid environment which sphagnum itself creates, combined with the wet environment, deters bacteria and fungi which would otherwise decompose the dead material, and so peat accumulates. Most New Zealand peat deposits are restionaceous (composed of restionaceous plants), particularly eutrophic lowland swamps, where *Sphagnum* occurs mostly in transitions to shallow, infertile swamps and mires. In southern New Zealand, ombrogenous (rainfall dependent) domed peats are most common, accumulating on poorly drained surfaces, which may be interfluves within swamps, terraces with podzolised soils, or plateaus (Wardle 1991).

There are some 89 000 ha of wetland and 45 000 ha of pakihi heathland in New Zealand (Newsome 1987), but only part of each of these communities contain *Sphagnum*. The highly variable occurrence and extent of *Sphagnum* results from its dependance upon micro-environmental conditions. It may be found from coastal forest to alpine grassland. So far no survey of the sphagnum resource has been attempted and the total resource size remains unknown. Many areas of *Sphagnum* habitat have been drained for farmland or destroyed by mining in the past. Some of the current threats to the long-term survival of *Sphagnum* peatlands include draining for agriculture, frequent burning, peat mining and moss harvesting.

Human activities, particularly logging, can also result in areas of impeded drainage where *Sphagnum* often becomes dominant. On the gley podzols of Westland, drainage of the perched water tables can be further impeded by roads or logs, and where the forest canopy has been removed the additional light has allowed *Sphagnum* to establish. These "cut-over" forests are now some of the major sites of commercial sphagnum harvesting in Westland. It is estimated that ownership of moss producing land in Westland is 50% Timberlands, 20-30% DoC, and 20-30% private, compared with Southland where ownership is 20% Maori, 70% DoC and 10% private.

2. Objectives

The overall aim of this project was to assess the ecological sustainability and long-term impacts of commercial sphagnum harvesting on natural *Sphagnum* communities. Three approaches were used to achieve this:

- To determine the height growth rate of *Sphagnum* under natural and harvested conditions at a range of sites.
- To determine the effects of harvesting techniques and altitude on *Sphagnum* biomass production in experimentally harvested plots at lanthe Forest, South Westland and Pell Stream, near Lewis Pass.
- To determine the effect of *Sphagnum* harvesting on tree and shrub seedling recruitment and sapling survival at nine sites in both lowland and montane areas in Westland and Nelson.

3. Methods

3.1 SITING OF PLOTS

Given that only anecdotal information was available on the growth rate of *Sphagnum* in New Zealand, it was realised that the study would need to be of medium term - at least three years was envisaged. Therefore it was necessary to select sites where there was reasonable certainty that they would remain undisturbed, as poaching was a potential threat. Sites were therefore located on private land, or within licensed harvesting blocks on Timberlands property, or on the Conservation estate.

We considered it important to include as many variations of *Sphagnum* wetland as possible, from alpine to coastal, open to forested situations. However, the need for variation had to be balanced against the logistic constraints of time, money and available personnel. Also, sites with complex vegetation patterns were likely to introduce factors which would make interpretation of results more difficult. Inevitably, we had to compromise, making detailed descriptions of a wide range of sites, but only monitoring *Sphagnum* growth at a subset of these. However, we were able to include more site variation in the investigation of seedling impacts, as it only involved one visit per site.

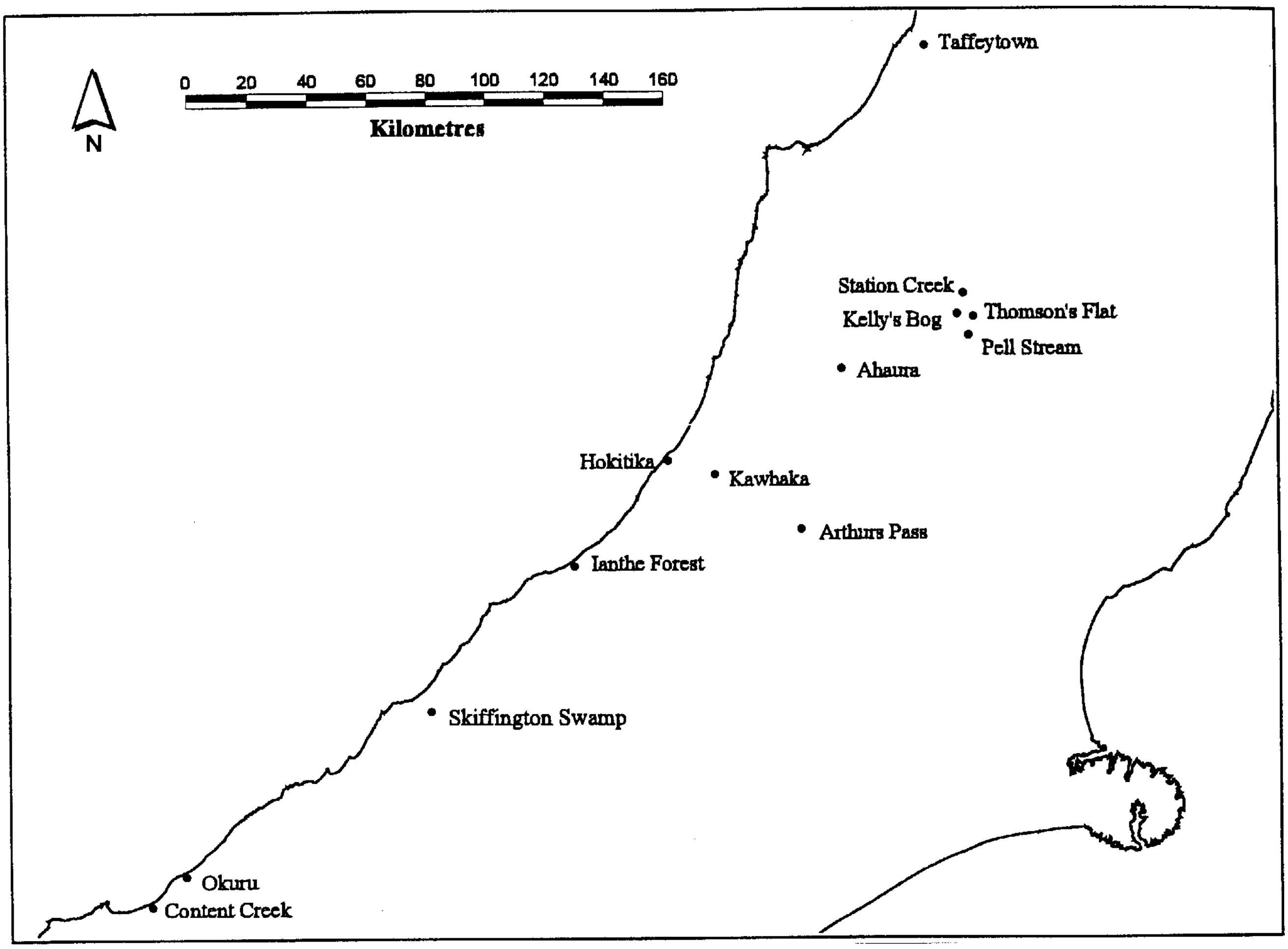
Plots were generally based on 1 m squares, but in some situations (described below) often included short transects.

3.2 HEIGHT GROWTH MEASUREMENTS

Throughout the study various methods were employed to measure growth. The crank wire method of Clymo (1970) was initially misinterpreted, with measurements being made from the buried, horizontal portion of the crank to the moss surface instead of being made from the top of the crank. This caused disruption of the *Sphagnum* carpet at each measurement and the fine wire used may have allowed movement of the cranks. Subsequent measurements were made using 60 cm lengths of 5 mm diameter aluminium rod pushed well into the *Sphagnum* carpet, and placed in short transects of 1 m. A spirit level placed across the tops of the rods was used to check for any movement of rods between measurements, which were made from the top of the rod to the moss surface.

Sphagnum height growth was monitored at six sites: Pell Stream, Kelly's Bog, Station Creek, Hokitika, Ianthe Forest and Arthur's Pass (Fig. 1). Site descriptions are presented in Buxton *et al.* (1990 & 1991). Crank wires were used at Pell Stream and Ianthe Forest, except for control measurements at Pell Stream from October 1991 to December 1992, where 60 cm rods were used. At

FIGURE 1 *SPHAGNUM* STUDY-SITE LOCATIONS



Hokitika, initial plots used crank wires, then 60 cm rods were placed in 14 transects in a range of vegetation types to determine the effect of micro-environment on *Sphagnum* growth rate. Micro-environmental effects were also investigated at Kelly's Bog and Arthur's Pass, where growth rate was recorded in 1 m transects using both methods (plus 30 cm rods) to compare their reliability in relation to frost heave and other movements of the *Sphagnum* carpet. At Station Creek, growth and recovery of *Sphagnum* in forest was monitored initially using cranks and later 60 cm rods. The Arthur's Pass plots were finally re-measured in January 1993, and then removed, as were plots at Hokitika after final re-measurement in September 1993.

3.3 BIOMASS COMPARISONS

Although increase in plant height can be measured relatively quickly, it only provides a linear view of growth. Because *Sphagnum* productivity in a harvesting sense is mostly measured by weight, so recovery after harvesting should also be measured by weight. Therefore we established two sites, one montane and one lowland, to investigate the rate of *Sphagnum* recovery after experimental harvesting (Buxton *et al.* 1990). Treatments involved two harvest depths, reseeding, and variation in canopy cover. The plots were 1 m^2, and centrally within each a subplot 0.5 x 0.5 m was weighed on site and a 1 kg subsample (or total moss if wet weight was less than 1 kg) taken for oven drying (Fig. 2). The subsamples were divided into *Sphagnum* and litter fractions then oven dried at 80°C for 24 hours and weighed.

FIGURE 2 PLOT 52, IANTHE FOREST WITH COVER OF *GLEICHENIA DICARPA, JUNCUS ACUMINATUS* AND BRACKEN, DURING RE-HARVESTING OF SPHAGNUM 1994. THE CENTRAL 0.25 m2 IN EACH PLOT WAS HARVESTED AND WEIGHED FOR BIOMASS CALCULATIONS.

Pell Stream

Plots established in December 1989 were reharvested in December 1992, to the same levels as in the original harvest. To assist any future monitoring of this site, all moss on each plot in excess of the 1 kg subsample taken for oven drying was replaced. Therefore, the weight of moss used for reseeding in 1992 can be derived from the wet weight values held by Landcare, Lincoln. Moss surrounding each subplot was not disturbed.

Ianthe Forest

Plots established in 1990 were located in two areas; plots 41-47 were not previously harvested; 48-56 had been commercially harvested about three years prior to experimental harvest (c.1986/87). Reharvesting in 1994 followed the procedure for Pell Stream; however plot 56 could not be relocated and may have been included in a commercial harvest.

3.4 EFFECTS OF HARVESTING ON WOODY SEEDLINGS

Re-measurement of Taffeytown plots, Karamea

Relocation of plots established at Taffeytown by Jenny Brown (DoC) in 1988, was thwarted by Telecom NZ who, just weeks before our visit, had removed telephone poles used by Jenny as one set of reference markers. However, with assistance from Jason Roxburgh (DoC Westport), plots were surveyed along one transect from the most probable marker, in the hope that some meaningful comparison could be made.

Jenny's methods were duplicated as closely as possible, despite uncertainty over the reference point. Along the transect, which was simply a compass bearing from a power pole, 1 m radius plots were surveyed every 5 m. In each plot the cover of *Sphagnum* and other species was recorded in four height tiers (0-30 cm, 30 cm-1 m, 1-3 m, >3 m), using six abundance classes (present, 1-5, 6-25, 26-50, 51-75, 76-100%). The average length of *Sphagnum* in each plot was also recorded.

Pell Stream and Ianthe Forest

Seedling numbers at Pell Stream were recorded in <10 cm and 10-30 cm tiers from experimentally harvested plots and adjacent 1 m2 controls in April 1991, and again in December 1992. At Ianthe Forest, seedlings on 1 m^2 plots were recorded in March 1991, November 1992 and January 1994. Seedlings were also recorded in December 1991 from 10 x 10 cm subplots and adjacent controls. The November recordings were from the nine previously harvested plots only, as the other plots were inaccessable due to growth of gorse (*Ulex europaeus*) blocking the track. Plot 56 could not be relocated in January 1994.

For the purposes of this analysis only seedlings less than 10 cm were included, as taller seedlings were not affected by the experimental harvesting procedure.

Restricted randomised plots

At each of the six sites, plots were selected randomly using a restricted formula so that two plots were located in each 10 m x 10 m portion within a 50 m x 50 m area, giving a total of 50 plots at each site, excepting 25 plots at Hokitika, 48 at Okuru and 30 at Skiffington Swamp. Each plot consisted of nested quadrats in which information from successive vegetation tiers was recorded.

1. Herbs: species present, height of vegetation and type of cover in 10 cm x 10 cm plots. The percent cover of *Sphagnum,* vascular plants, litter, and other bryophytes were estimated visually.
2. Seedlings up to 10 cm tall: species and numbers in 40 cm x 40 cm plots.
3. Seedlings 10-30 cm tall: species and numbers in 1 m x 1 m plots.
4. Saplings, shrubs and trees >30 cm tall: species and heights/diameters in 1 m x 1 m plots.

Separate analyses were carried out within each of the two seedling tiers (<10 cm and 10-30 cm), and data from Pell Stream and lanthe Forest sites were also included in the analyses. Each plot at a particular time was treated as an entity, and measurements for all entities in each stratum were analysed together. The entities were classified by Cluster Analysis (Canberra Metric similarity measure, Flexible sorting strategy, Beta = -0.25). Eighteen groups were created for each of the two strata. Ordinations were performed using the PATN software package (Belbin 1989).

The ordination generates a two-way table in which plot names form one axis of the table and species form the other, and values expressing species frequency form the matrix. The process groups plots into "associations", and groups species according to the association of their most likely occurrence. From this data the associations numbered AO to A17 in section 5.3 were derived, with AO indicating a plot with no seedlings in the vegetation stratum being considered.

For each site seedling numbers in each stratum and corresponding *Sphagnum* cover were compared using analysis of variance with Minitab.

Site descriptions

Haast Two sites were sampled, one in bog forest north of Content Creek (Buxton *et al.* 1990), and the other in cutover forest near Okuru. Manuka *(Leptospermum scoparium)* to 5 m tall, dominated the Okuru cutover forest, with *Coprosma parviflora, Neomyrtus pedunculata,* and regenerating podocarps over *Gahnia rigida* and *Sphagnum*. *Sphagnum is* harvested commercially at both sites.

Ahaura On an alluvial terrace 150 m above the Ahaura River, near Pattison's Creek, this large pakihi has been logged and burned. Formerly red beech *(Nothofagus fusca)* - rimu *(Dacrydium cupressinum)* forest, now tree skeletons and charred stumps remain among regenerating scrub, fern and moss. The northern end of this pakihi is described in an earlier report (Buxton *et al.* 1991). At its southern end the pakihi has extensive *Coprosma parviflora* shrubs to 2 m tall, over *Sphagnum,* which has been harvested here since 1989-90. Very recent harvesting was evident at the time of sampling.

Thomsons Flat Near Maruia, this montane valley-floor bog is bordered by mountain beech *(Nothofagus solandri* var. *cliffortioides;* Buxton *et al.* 1991), and *Sphagnum* has been commercially harvested here for 7 years. Plots were located in an area which crossed the ecotone from open bog, with scattered small beech saplings, to established forest.

Hokitika At Seth Robinson's moss operation at Kaihinu, *Sphagnum* is harvested from a pakihi on the Arahura River floodplain (Buxton *et al.* 1991). Plot locations in one of the small stands of regenerating podocarps, ranged from open areas to partially closed forest up to 10 m tall.

Skiffmgton Swamp Situated in Westland National Park, this swamp lies at 330 m on a moraine plateau north of the Cook River. Plots were located at the forest margin in scattered manuka with occasional silver pine *(Lagarostrohos colensoi)* and *Phyllocladus alpinus* up to 10 m tall, over *Cyathodes juniperina, C. fasciculata,* and *Gahnia rigida* over *Sphagnum*. There was no evidence of moss harvesting at this site.

4. Results and Discussion

4.1 HEIGHT GROWTH MEASUREMENTS

Results of the Arthur's Pass and Kelly's bog transects confirmed the superior reliability of 60 cm rods over 30 cm rods or our initial crank wires (Buxton *et al.* 1992). The most reliable method for height growth measurement seems to be an adaptation of the crank wire technique. Using 5 mm diameter aluminium rods of 60 cm length and burying the crank section in the moss carpet reduces the possibility of rod movement. Also, placing the rods in short transects with the tops at equal height allows a spirit level to be placed across the tops to measure any movement that may occur. Taking measurements from the top of the rod down to the surface of the moss avoids disturbance of the moss being measured.

Pell Stream

Mean height growth was higher in heavily harvested plots than moderately harvested plots (Fig. 3), and in both cases re-seeded plots attained greater height growth than their not-re-seeded comparisons. In the control mean height growth between October 1991 and December 1992 (12.35 mm) was similar to mean growth in harvested plots (9.75 mm). Height growth increments (Fig. 4) show fluctuations in growth rate according to season, with rapid growth during spring and autumn, but slower rates over summer when dessication may be limiting. In the first 11 months after harvesting, growth increments in re-seeded plots were much greater than their not-re-seeded counterparts, but in subsequent months the effect of re-seeding became less important than that of harvesting depth, with heavily harvested plots generally maintaining greater growth increments than moderately harvested plots.

FIGURE 3 *SPHAGNUM* HEIGHT GROWTH, PELL STREAM, TOTAL GROWTH 12/89 TO 12/92

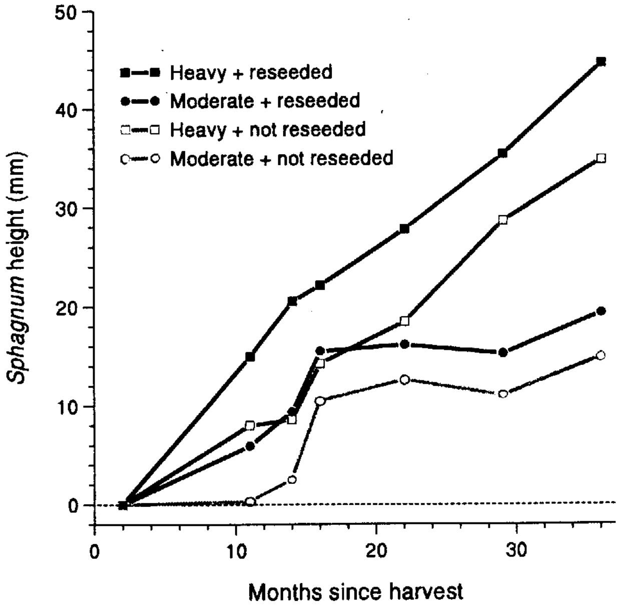


FIGURE 4 INCREMENTAL *SPHAGNUM* HEIGHT GROWTH, PELL STREAM

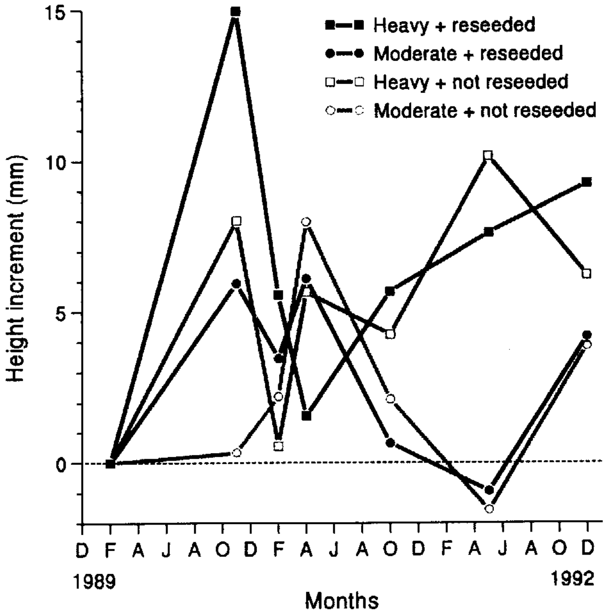


FIGURE 5 PELL STREAM CANOPY COVER AND GROWTH (DECEMBER 1989 - 1992)

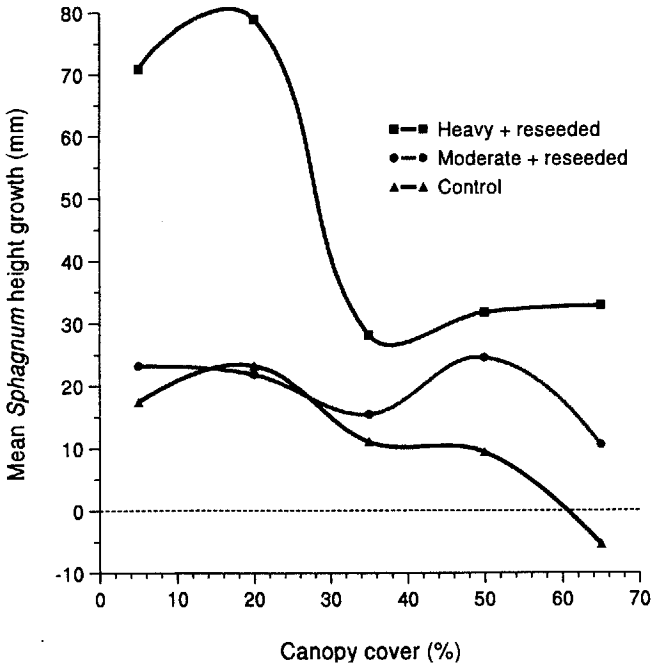
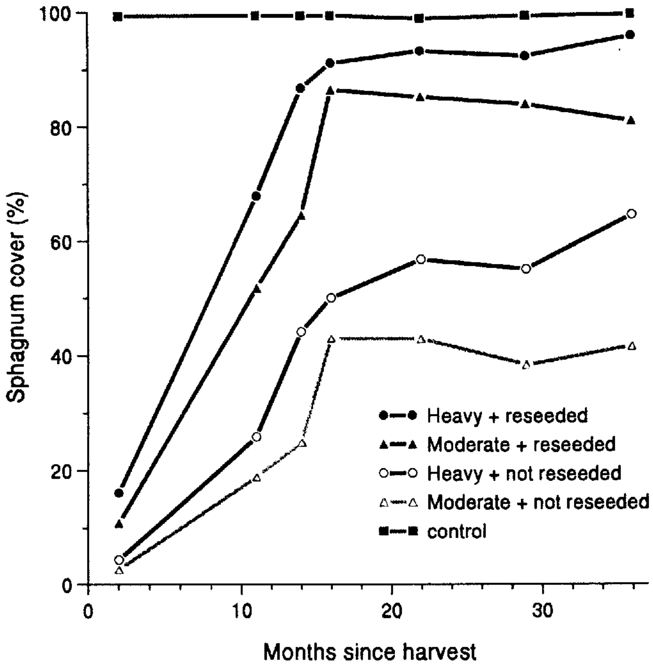


FIGURE 6 CHANGE IN *SPHAGNUM* COVER, PELL STREAM



Sphagnum height growth also varied with % canopy cover (Fig. 5). Growth in Heavy + re-seeded and control plots had a slight positive response to increased shade at 20% compared with open plots, but increased shading generally caused a decrease in height growth, especially in Heavy + re-seeded plots and where canopy cover was greater than 50%.

Mean *Sphagnum* cover in heavily harvested and re-seeded plots after 3 years was approaching 100% (Fig. 6), whereas cover in non-re-seeded plots was about 50%. In all plots, the first 16 months after harvesting appear to be the most crucial in terms of recovery. The rapid improvement in re-seeded plots

FIGURE 7 *SPHAGNUM* HEIGHT GROWTH, IANTHE FOREST

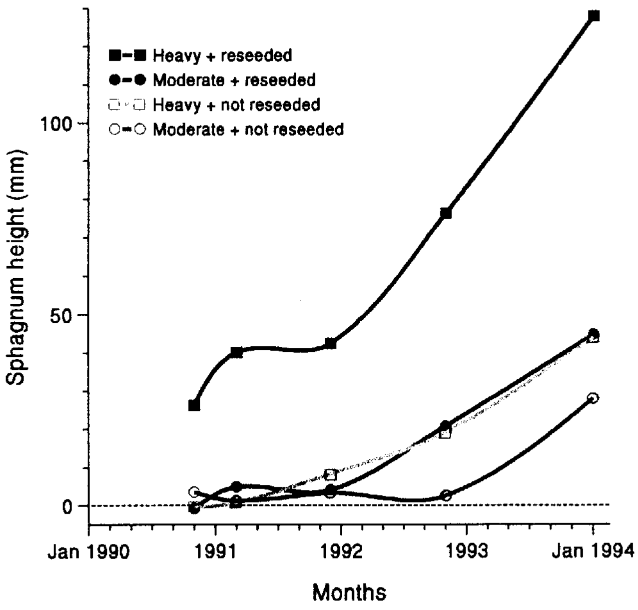


FIGURE 8 *SPHAGNUM AUSTRALE* SEASONAL GROWTH, STATION CREEK, MARUIA

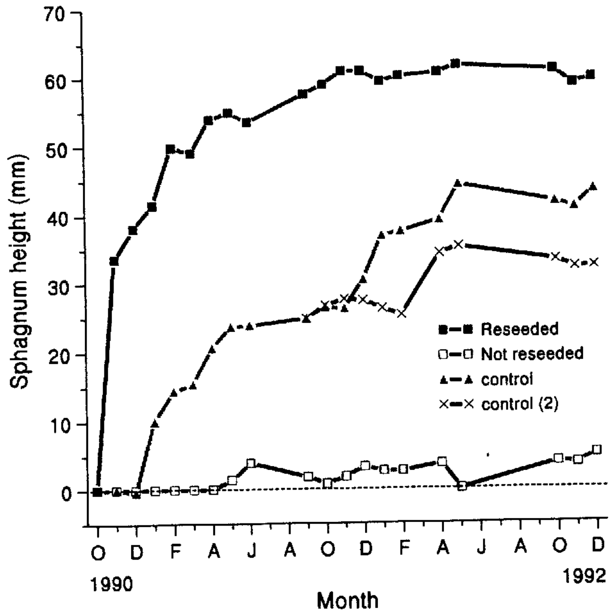


FIGURE 9 *SPHAGNUM* GROWTH AND SPECIES COMPOSITION, KELLY'S BOG, MARUIA

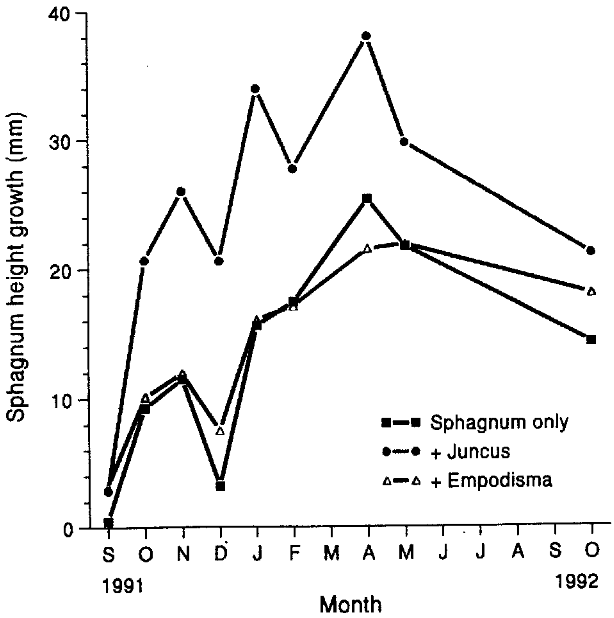
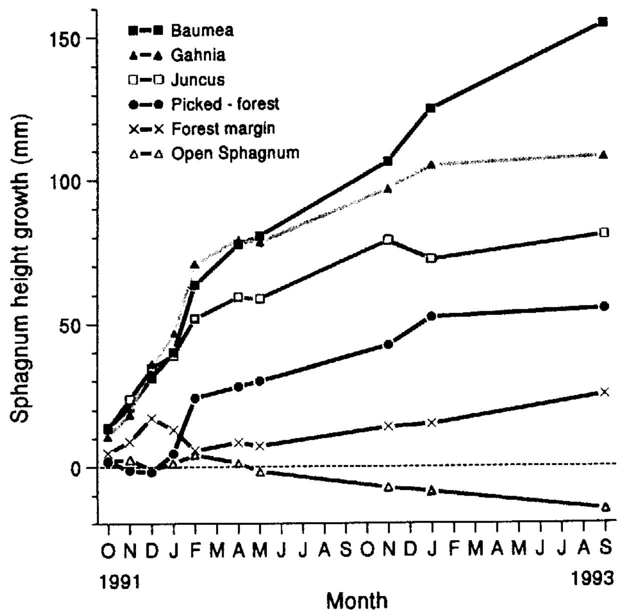


FIGURE 10 *SPHAGNUM* GROWTH AND SPECIES COMPOSITION, HOKITIKA



compared with non-seeded plots, demonstrates the value of retaining a thin layer of *Sphagnum* after harvesting.

At Ianthe Forest, *Sphagnum* height growth was rapid in plots with a treatment combination of heavy harvesting and re-seeding, and by January 1994 it was almost three times that of plots with moderate or not-re-seeded treatments (Fig. 7).

At the FRI ecophysiology site, Station Creek, 65% cover of *Sphagnum* was restored in the re-seeded portion of the plot after 1 year (from an initial 25%), and this levelled off to 70% after 2 years. However, the not-re-seeded portion had only 5% cover after 2 years, and its chances of full recovery seemed unlikely. Height growth in the re-seeded plot exceeded that of the control (Fig. 8), but was virtually nil in the not-re-seeded portion.

Sphagnum height growth and micro-environment

Sphagnum height growth beneath cover of Juncus at Kelly's Bog, Maruia, was greater than that for either *Empodisma* cover or for *Sphagnum* alone (Fig. 9).

A similar pattern emerged from transects at Hokitika (Fig. 10). Height growth of *Sphagnum* in the open was poor, significantly less ($p<0.001$) than in all other vegetation (forest margin $p<0.05$), whereas with light cover of rushes height growth was much greater (up to 75 mm/year in Baumea). Growth in *Baumea* was significantly greater ($p<0.001$) than all other vegetation, even *Gahnia* ($p<0.05$). Within the cutover forest area the recently harvested transects showed slightly (although not significantly) more growth than the unharvested forest margin. It is possible that the rapid growth in the *Baumea* area may be also be related to its relatively recent recovery from harvesting, which was done towards the end of 1989.

4.2 BIOMASS COMPARISONS

Pell Stream 1989-1992

At Pell Stream there was initially no significant difference in *Sphagnum* biomass between Re-seeded (R) and Not-Re-seeded (NR) plot treatments (Table 1), but Heavily harvested (H) plots had significantly greater *Sphagnum* biomass than Moderately harvested (M) plots, due to the extra harvesting depth. Total biomass in 1992 had decreased significantly in all treatments. The decrease in biomass was greater in Heavily harvested plots than Moderately harvested plots ($p<0.05$), but this was an effect of initial biomass differences, rather than a treatment effect, as the regrowth in 1992 (as a percentage of original biomass) was not significantly different between Heavy and Moderate treatments. After three years, regrowth of *Sphagnum* at Pell Stream was significantly greater in plots which had been Re-seeded ($p < 0.05$) than Not-Re-seeded plots, highlighting the benefit of this treatment.

lanthe Forest 1990-1994

Due to the small number of plots relative to treatments at lanthe Forest, statistical analyses were limited to comparisons between the two areas and the two harvest times. Where direct comparisons could be made they showed statistically significant decreases in biomass between 1990 and 1994 for three treatment combinations that were not re-seeded (NR), but there was no significant decrease in the one re-seeded treatment (Picked + Moderately-harvested + Re-seeded), suggesting re-seeding had aided recovery. Three plots which were not re-seeded in 1990 had no *Sphagnum* regrowth at all in 1994. However, despite re-seeding in plots 45 and 46, the final values were mostly derived from moss that had grown in from the edges of the plot and therefore

TABLE 1 OVEN DRY WEIGHTS (kg m -2) FOR PELL STREAM PLOTS, MOSS RE-GROWTH IN 1992 AS A PERCENTAGE OF 1989 VALUES, AND THE CHANGE IN MOSS cnNTF.NT FROM 1989 TO 1992 (H = HEAVILY HARVESTED; M = MODERATELY HARVESTED; R = RE-SEEDED; NR = NOT RE-SEEDED).

PLOT	TREATMENT	1989 MOSS	1992 MOSS	MOSS REGROWTH (%)	1989 LITTER	1992 LITTER	1989 TOTAL	1992 TOTAL	CHANGE IN MOSS CONTENT (%)
1	H+NR	2.82	0.57	20.3	1.02	0.22	3.84	0.79	-1.2
2	M+NR	1.67	0.05	3.1	0.65	0.05	2.33	0.10	-19.7
3	H+NR	3.35	0.06	1.9	0.79	0.04	4.15	0.10	-19.5
4	M+NR	1.64	0.29	26.4	0.44	0.20	2.09	0.50	-19.9
5	H+R	3.62	0.66	0.8	1.14	0.29	4.76	0.95	-6.2
6	M+R	2.61	0.69	1.6	0.62	0.39	3.23	1.08	-16.9
7	H+NR	2.35	0.03	10.4	2.14	0.02	5.94	0.05	-0.8
8	M+NR	1.78	0.04	15.1	1.37	0.03	3.75	0.07	-9.0
9	H+R	4.44	0.23	43.2	1.69	0.15	3.94	0.39	3.6
10	M+R	2.32	0.27	50.8	0.90	0.21	2.71	0.48	-9.8
11	H+R	2.72	1.02	12.5	1.72	0.22	4.06	1.23	24.6
12	M+R	1.65	0.90	10.1	0.60	0.32	2.37	1.22	-1.0
13	H+R	4.51	0.55	12.5	1.32	0.18	5.76	0.73	-1.1
14	M+R	3.32	0.23	10.1	0.48	0.08	2.80	0.31	-7.8
15	H+NR	2.72	0.34	12.5	1.27	0.25	3.99	0.59	-10.2
16	M+NR	1.65	0.53	32.2	0.45	0.22	2.10	0.75	-7.9
17	H+NR	4.51	0.26	5.9	1.13	0.09	5.64	0.35	-5.5
18	M+NR	3.32	0.10	3.1	0.43	0.04	3.75	0.14	-17.7
19	H+R	2.07	1.21	58.3	0.46	0.05	2.53	1.26	13.9
20	M+R	1.08	0.61	56.6	0.40	0.20	1.48	0.69	15.4
21	H+R	4.16	1.14	27.4	1.08	0.16	5.24	1.29	9.4

PLOT	TREATMENT	1989 MOSS	1992 MOSS	MOSS REGROWTH (%)	1989 LITTER	1992 LITTER	1989 TOTAL	1992 TOTAL	CHANGE IN MOSS CONTENT (%)
22	M+R	2.48	0.95	38.2	0.48	0.43	2.96	1.07	4.6
23	H+R	3.66	0.20	5.4	3.27	0.22	6.93	0.42	-5.1
24	M+R	1.65	0.16	9.5	0.88	0.06	2.53	0.22	7.5
25	H+NR	3.09	0.43	13.9	0.70	0.09	3.80	0.52	1.5
26	M+NR	2.39	0.22	9.0	0.39	0.12	2.79	0.33	-20.9
27	H+R	2.78	0.89	32.1	0.59	0.28	3.37	1.17	-6.3
28	M+R	1.97	0.53	26.9	0.79	0.27	2.76	0.80	-4.9
29	H+R	4.53	0.98	21.5	2.42	0.42	6.95	1.39	4.9
30	M+R	2.19	0.47	21.4	1.46	0.38	3.65	0.85	-4.7
Treatment means									
	H+NR	3.27	0.27	9.2	1.16	0.09	4.43	0.36	-5.0
	M+NR	2.43	0.16	7.9	0.66	0.10	3.10	0.26	-16.9
	H+R	3.24	0.78	25.9	1.58	0.21	4.83	0.99	3.4
	M+R	1.64	0.41	29.2	0.91	0.17	2.55	0.59	6.1
Canopy cover (%)									
	5	2.55	0.76	33.9	0.58	0.10	3.13	0.86	4.0
	20	2.93	0.36	14.6	0.69	0.15	3.63	0.51	-12.3
	35	2.60	0.55	22.9	0.93	0.22	3.52	0.77	-4.7
	50	2.70	0.49	17.1	1.62	0.29	4.31	0.78	-1.5
	65	2.87	0.11	4.3	1.92	0.08	4.79	0.19	-1.8

TABLE 2 OVEN DRY WEIGHTS (kg m^{-2}) FOR IANTHE FOREST PLOTS, MOSS RE-GROWTH IN 1994 AS A PERCENTAGE OF 1990 VALUES AND THE CHANGE IN MOSS CONTENT FROM 1990 TO 1992. (P=PREVIOUSLY COMMERCIALLY PICKED 1986/87; NP=NOT PICKED; H=HEAVILY HARVESTED; M=MODERATELY HARVESTED; R= RE-SEEDED; NR=NOT RE-SEEDED; ' = GROWTH FROM PLOT MARGINS).

	TREATMENT	1990 MOSS	1994 MOSS	MOSS REGROWTH (%)	1990 LITTER	1994 LITTER	1990 TOTAL	1994 TOTAL	CHANGE IN MOSS CONTENT (%)
41	NP+H+NR	2.28	0.00	0.0	0.31	0.00	2.59	0.00	-88.0
42	NP+M+NR	1.99	0.02	1.0	0.16	0.00	2.15	0.03	-12.2
43	NP+H+NR	2.93	0.19	6.5	1.72	0.06	4.65	0.25	13.8
44	NP+M+NR	1.71	0.27	16.0	0.52	0.18	2.23	0.45	-15.9
45	NP+H+R	1.50	0.21*	13.7	0.31	0.04	1.80	0.25	-0.1
46	NP+M+R	2.06	0.05*	2.6	0.28	0.01	2.35	0.06	-5.9
47	NP+H+NR	1.87	0.00	0.0	0.20	0.00	2.07	0.00	-90.6
48	P+M+R	1.34	0.29	21.4	0.41	0.04	1.75	0.33	10.6
49	P+M+NR	1.55	0.20	13.2	0.33	0.04	1.88	0.24	1.1
50	P+M+NR	1.77	0.16	9.0	0.22	0.04	1.99	0.20	-10.4
51	P+M+NR	1.00	0.00	0.0	0.30	0.00	1.31	0.00	-76.7
52	P+M+R	0.86	0.37	43.3	0.18	0.08	1.04	0.45	0.0
53	P+M+NR	0.93	0.70	76.0	0.23	0.19	1.16	0.89	-1.1
54	P+H+R	0.95	0.70	73.3	0.52	0.19	1.47	0.89	13.9
55	P+M+R	0.93	1.09	117.1	0.23	0.34	1.16	1.43	-4.0
56	P+M+R	1.01			0.19		1.20		
Treatment means									
	H+NR	2.36	0.06	2.1	0.74	0.02	3.10	0.08	-54.9
	M+NR	1.49	0.23	23.1	0.29	0.08	1.79	0.30	-19.2

PLOT	TREATMENT	1990 MOSS	1994 MOSS	MOSS REGROWTH (%)	1990 LITTER	1994 LOTTER	1990 TOTAL	1994 TOTAL	CHANGE IN MOSS CONTENT (%)
	H+R	1.22	0.45	43.5	0.41	0.12	1.64	0.57	6.9
	H+R	1.24	0.45	46.1	0.26	0.12	1.50	0.57	0.2
	Not Picked	2.05	0.11	8.0	0.50	0.04	2.55	0.15	-28.4
	Picked	1.15	0.44	50.5	0.29	0.12	1.44	0.56	-8.3

probably should be ignored. All other reseeded plots had higher yield than their non-re-seeded counterparts (Table 2).

In 1990, *Sphagnum* biomass in the previously unpicked area was significantly greater than the previously picked area. Sphagnum regrowth in the previously unpicked area was poor compared with the picked area and in 1994 there was no significant difference in biomass between the two areas. There was no significant difference between re-seeded and non-re-seeded plots within each of these areas.

The area without previous commercial moss harvesting (NP) had significantly more *Sphagnum* biomass in 1990 than the previously commercially picked (P) area (p<0.001), but regrowth in NP was poor and in 1994 the difference in biomass between the two areas was less significant (P=0.022; Table 2). Four years after experimental harvesting, there was a significant decrease in sphagnum biomass in both areas, but this was significantly less in P than NP. The initial moss content of NP plots (83%) was similar to that for P plots (80%), but by 1994 these were 55% (31% if plots 45 & 46 are excluded) and 71% respectively, suggesting that sites of continued harvesting are able to recover faster in terms of moss content and repeated harvesting may not be detrimental to moss yield after an initial decline.

However, it is not possible to say whether the difference between P and NP was directly related to harvesting history or to site conditions. Water table depth may be equally important. Peter Veale, who harvests this block, suggests *Sphagnum* is not growing back to the level it was before harvesting. Peter says gorse, and in dry sites bracken (*Pteridium esculentum*), are overtopping the *Sphagnum* and shading it out, and in other areas fast growing rushes are excluding *Sphagnum*. The biomass results (Table 2) show that plots 41,42,45-47, which had 30 percent cover or more of rushes (mainly *Juncus acuminatus*), had very poor regrowth. After initial harvest, plots 45 & 47 were noted as having considerable water at the surface, and at final harvest open water comprised 50 and 25% cover respectively in plots 45 & 46, and 5% in plot 41. It is likely that the position of the water table in relation to the post-harvest sphagnum surface is more limiting to *Sphagnum* regrowth than growth of rushes, and what Peter Veale has observed is probably a secondary effect of high water table in these areas.

Contrary to Peter's observations, plots with moderate cover of gorse or bracken (plots 53-55) appeared to have the best regrowth, but high litter cover does appear to be limiting and it may be this that smothers *Sphagnum* where the former species become more dense. Plot 51, which failed to re-grow, occuppied an old *Sphagnum* hummock with modest cover (15% each) of short *Gleichenia* and bracken, and 65% litter. With the growing points of the *Sphagnum* so far above the water table, it is likely that the mass of *Gleichenia* roots exploited any available water causing the moss to dry and decay, and eventually become overwhelmed by litter.

Comparisons between Pell and Ianthe

Initially the higher altitude Pell Stream plots had significantly greater biomass than their lanthe Forest counterparts (p<0.01). However, at final harvest there was no significant difference in biomass between sites when compared by either harvesting depth or re-seeding treatment, even though lanthe plots grew for an extra 12 months. This suggests that the ecological factors normally associated with increased altitude had not restricted regrowth at Pell Stream.

To enable comparision based on harvesting history, only the Ianthe NP values were compared with the unharvested Pell Stream site. This showed no significant difference between these two sites either initially or at final harvest. However, the possibility that differences in the height of the water table between Ianthe P and NP areas were having a greater effect on recovery than previous harvesting history, led us to compare the drier Ianthe P sites with the similar Pell Stream plots. Again, there was no significant difference between sites except that initially Pell Stream moderately-harvested + re-seeded plots had greater biomass than corresponding Ianthe P plots.

Although higher altitude is generally associated with cooler temperatures, ground surface temperatures can be high, especially in sheltered situations, and there may have been many occasions during the growing season when temperatures on the two bogs were similar. Microsite differences such as the degree of shade, shelter and watertable position can range widely within a bog, and as these factors effect *Sphagnum* growth so its growth rates can also range widely.

Sustainable yield for *Sphagnum* has been estimated at 4 to 5 t ha^{-1} yr^{-1} in optimal conditions, and not more than 1 t ha^{-1} yr^{-1} in natural (unmanaged) conditions (Thompson & Denne 1983). The previously harvested (P) area at Ianthe Forest, representing sustained yield, had a mean biomass of 0.44 kg M^{-2} after four years equating to 1.1 t ha^{-1} yr^{-1}. Although moss regrowth, as a percentage of initial biomass, was less than 50% at both Pell Stream and Ianthe Forest (Tables 1 & 2), re-seeding improved this value at both sites. Initial yield at Pell Stream was 33.4 t ha^{-1} in heavily harvested plots and 20.6 t ha^{-1} in moderately harvested plots, although the number of years of growth this represented is unknown. Mean regrowth in re-seeded plots over three years at Pell Stream equated to 2.17 t ha^{-1} yr^{-1}. This indicates full recovery at this site may take 10 years even with re-seeding.

Bulk density

At Pell Stream, mean *Sphagnum* bulk density in 1992 was slightly greater than initial bulk density in 1989 (Table 3) and recovery from moderate harvesting was more rapid than from heavy harvesting. Re-seeding generally resulted in greater bulk density but comparisons between treatments showed none were significantly different, except that in the H+NR plots bulk density had significantly decreased from 1989 to 1992 ($P<0.05$). This combination of treatments which equates to the poaching or one-off harvest situation is therefore the least desirable for sphagnum recovery.

Bulk density of the initial harvest at Ianthe Forest could not be calculated as initial moss height was not recorded. In 1994, bulk density was higher in picked, moderately harvested, and re-seeded plots than their respective comparisons, and greatest where these three treatments were combined (Table 4).

TABLE 3 CHANGES IN PELL STREAM *SPHAGNUM* BULK DENSITY (kg m'3) FOR EACH TREATMENT (ABBREVIATIONS AS FOR TABLE 1).

TREATMENT	n	1989	1992	CHANGE (% of 1989)
Heavy harvest	15	17.15	16.94	98.8
Mod. harvest	15	14.74	18.39	124.8
Re-seeded	18	15.76	20.56	130.5
Not re-seeded	12	16.22	13.33	82.1
H + R	9	16.96	22.68	133.7
H + NR	6	17.44	8.33	47.8
M + R	9	14.56	18.44	126.7
M + NR	6	15.01	18.32	122.1
mean	30	15.95	17.67	110.8

TABLE 4 IANTHE FOREST *SPHAGNUM* BULK DENSITY (kg m-3) FOR EACH TREATMENT (ABBREVIATIONS AS FOR TABLE 2).

Treatment	n	1994
Picked 1986	8	8.16
Not picked 1986	7	2.33
Heavy harvest	5	2.73
Moderate harvest	10	6.80
Re-seeded	6	7.51
Not re-seeded	9	4.06
P+H+R	1	8.70
P+H+NR	0	-
P+M+R	3	12.12
P+M+NR	4	5.06
NP+H+R	1	0
NP+H+NR	3	1.65
NP+M+R	1	0
NP+M+NR	2	5.69
mean	15	5.44

TABLE 5 EFFECT OF TREATMENT ON *SPHAGNUM* CONTENT IN BIOMASS SAMPLES (MOSS:LITTER) AT PELL STREAM (ABBREVIATIONS AS FOR TABLE 1).

TREATMENT	n	*SPHAGNUM* CONTENT (%) 1989	1992	% CHANGE
Heavy harvest	15	71.9	71.9	0.0
Moderate harvest	15	73.5	66.5	-7.0
Re-seeded	18	68.6	72.8	4.3
Not re-seeded	12	77.1	66.1	-10.9
H+R	9	69.8	73.2	3.4
H+NR	6	75.0	70.0	-5.0
M+R	9	66.0	72.1	6.1
M+NR	6	79.2	62.3	-16.9
MEAN	30	73.5	69.8	-3.7

TABLE 6 EFFECT OF TREATMENT ON *SPHAGNUM* CONTENT IN BIOMASS SAMPLES (MOSS:LITTER) AT IANTHE FOREST (ABBREVIATIONS AS FOR TABLE 2).

TREATMENT	n	*SPHAGNUM* CONTENT (%) 1990	1994	% CHANGE
Picked 1986	8	79.6	70.62	-8.34
Not picked 1986	7	83.1	54.73	-28.41
Heavy harvest	5	77.9	47.66	-30.20
Moderate harvest	10	82.6	70.97	-11.46
Re-seeded	6	79.8	81.53	2.42
Not Re-seeded	9	82.1	50.99	-31.13
P+H+R	1	64.7	78.65	13.90
P+H+NR	0	-	-	-
P+M+R	3	80.8	81.85	2.20
P+M+NR	4	82.0	60.19	-21.81
NP+H+R	1	83.0	82.91	-0.10
NP+H+NR	3	80.5	25.59	-54.94
NP+M+R	1	88.0	82.09	-5.86
NP+M+NR	2	84.7	70.67	-14.04
MEAN	15	81.1	63.20	-17.71

Sphagnum content

The percentage of moss in biomass samples (moss:litter) decreased as a result of harvesting (Table 5) at both sites but was much more apparent at lanthe Forest (Table 6). Factors which may have influenced this are, firstly, that lanthe Forest was re-measured after four years while Pell Stream was re-measured after three, and the extra year may have allowed the downward trend to become more obvious. Secondly, the initial percentage of moss at lanthe Forest was higher than at Pell Stream, where the beech litterfall may have contributed to its relatively high initial litter content. One might have expected this to have caused greater increases in litter content after harvesting than it did, as observations at nearby Station Creek indicated *Sphagnum* beneath the closed beech canopy was barely maintaining itself above the litterfall and was unable to regrow if harvested.

Re-seeding after harvest resulted in a slight increase in moss content at both sites. Heavy harvesting at Pell Stream caused no change, whereas at lanthe Forest it resulted in a 30% decrease in moss content, probably due to this harvest level often being below the water table and therefore limiting regrowth. Moderate harvesting reduced moss content by about 10% at both sites.

4.3 EFFECTS OF HARVESTING ON WOODY SEEDLINGS

Re-measurement of Taffeytown plots, Karamea

Despite being unable to relocate jenny's plots with certainty, the data obtained suggest that the shrubland/Sphagnum community at the Taffeytown site has undergone an increase in species diversity and cover since 1988.

The differences between T1 and T2 (Table 7) are, by and large, much greater than differences between the 1988 measurements and those in 1992. However, assuming the 1992 transect corresponds to a remeasurement of T1, some tentative comparisons can be made. *Sphagnum* frequency (no. of plots with *Sphagnum)* in T1 increased between 1988 and 1992, while moss cover (%) and length remained more or less constant (Table 7). Species diversity also increased slightly in 1992. Fig. 11 illustrates that species diversity in each tier from herbs to shrubs was higher in 1992, but that there was a much greater difference between T1 and T2. The cover (%) of shrubs in 1992 was considerably greater in all but the >3 m tier (Fig. 12).

Although some of this variation may have been due to a difference in transect line location and different recorders, the results overall indicate some possible improvement to the shrub community, and there is no evidence of damage to the site since the baseline data were collected.

Pell Stream and Ianthe Forest

Pell Stream plots

The highest numbers of beech seedlings were, as expected, on plots within the beech canopy. Harvested plots contained on average twice as many seedlings as

FIGURE 11 TAFFEYTOWN SPECIES DIVERSITY

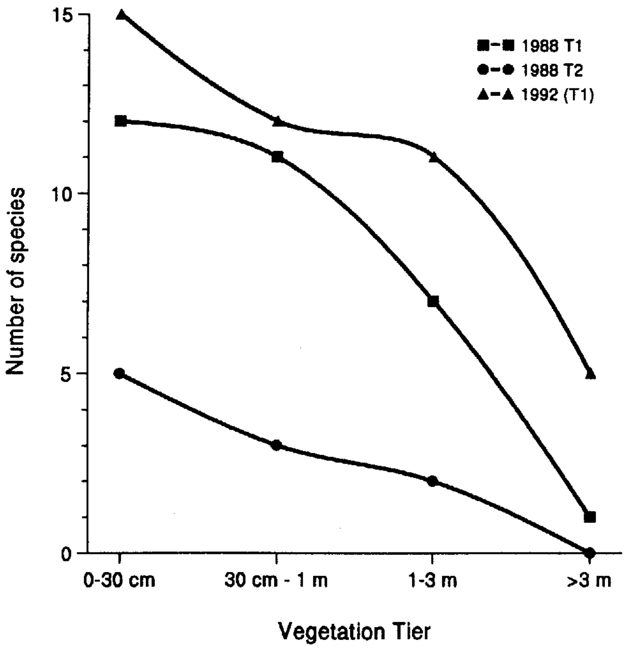


FIGURE 12 TAFFEYTOWN SHRUB COVER

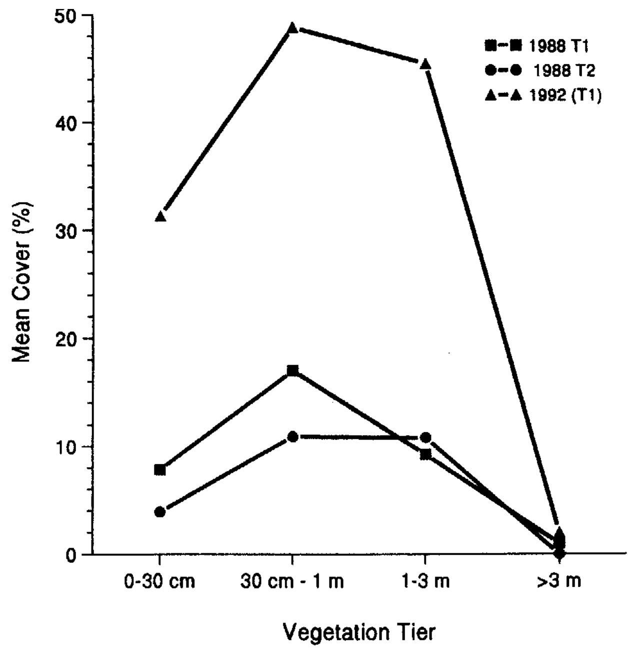


TABLE 7 *SPHAGNUM* ABUNDANCE AND SPECIES DIVERSITY RECORDED IN THREE TRANSECTS AT TAFFEYTOWN, KARAMEA.

	1988 T1 (n=14)	1988 T2 (n=8)	1992 (T1?) (n=14)
Sphagnum cover (%)	19	39	22
Plots with *Sphagnum* (%)	36	50	64
Mean *Sphagnum* length (mm)	170	67	178
Species diversity m^{-2}	3.05	2.59	3.27

TABLE 8 NUMBERS OF BEECH SEEDLINGS <10 CM RECORDED FROM Im2 PLOTS AT PELL STREAM.

	APR 91	DEC 92	MORTALITY	% MORT	NEW SDLGS	% NEW
Heavy sum	1200	823	-399		22	
Moderate sum	1685	1449	-271		35	
Control sum	731	551	-181		1	
Heavy mean	80	54.9	-26.6	-33.3	1.5	2.7
Moderate mean	112.3	96.6	-18.1	-16.1	2.3	2.4
Control mean	48.7	36.7	-12.1	-24.8	0.07	0.01

control plots (Table 8). Seedling mortality was about 25% in both control and harvested (moderate + heavy) plots. However, percentage mortality in heavily harvested plots was two times that of moderately harvested plots. Moderately harvested plots also recruited slighty more seedlings than heavily harvested plots, possibly due to the faster *Sphagnum* height growth in heavily harvested plots excluding seedlings. Only one additional seedling was recorded in control plots in December 1992.

Ianthe plots

The December 1991 results for *Coprosma parviflora* (Table 9) may be somewhat exaggerated by the small plot size used for this measurement, or they may be real, as episodic mass germination of *Coprosma* species has been shown to effect numbers of seedlings under 10 cm in a similar study by Wardle *et al.* (1994). However, in either event there was a trend towards increasing diversity and greater numbers of seedlings by January 1994. Most plots which in 1994 were without seedlings were generally very wet; the water table was at or very close to the surface and rushes (mainly *Juncus acuminatus*) comprised about 50 percent cover.

Restricted randomised plots

Seedling associations (based on percentage occurrence of seedlings <10 cm)

A0 No seedlings.

A1 *Coprosma parviflora* always exclusively dominant.

A2 Coprosma parviflora almost always dominant, but with silver pine, manuka and *Myrsine* divaricata often important. Minor contributions from gorse, *Coprosma tenuicaulis, Pseudopanax crassifolius*, broadleaf (Griselinia littoralis), *Neomyrtus pedunculata, Phyllocladus alpinus,* and others.

A3 *Coprosma parviflora* always abundant with some gorse, and broadleaf occasionally present.

A4 *Neomyrtus pedunculata* frequently common, often with silver pine, *Myrsine divaricata*, and/or silver beech. Yellow-silver pine *(Lepidothamnus intermedius),* gorse and other minor species sometimes common.

A5 Silver pine almost always abundant with either broadleaf *or Phyllocladus alpinus* common. Kamahi (*Weinmannia racemosa*) often common or occasionally southern rata *(Metrosideros umbellata).*

A6 *Dracophyllum palustre* and/or *Pernettya macrostigma* exclusively dominant.

A7 *Phyllocladus alpinus* always exclusively dominant, sometimes with *Halocarpus bidwilfi.*

A8 Broadleaf exclusively dominant.

A9 Kamahi exclusively dominant.

A10 Manuka always abundant to dominant, often with frequent *Coprosma parviflora*. *Neomyrtus pedunculata* and other minor species occasionally present.

A11 *Neomyrtus pedunculata* exclusively dominant.

A12 *Cyathodes fasciculata* exclusively dominant.

A13 *Lagarostrobos colensoi* exclusively dominant.

A14 Red beech almost always abundant to dominant, often with abundant silver beech, and less frequently mountain beech and rare minor species.

A15 Mountain beech always dominant, usually with minor red or occasionally silver beech, or other species.

A16 Exclusive dominance by manuka.

A17 Exclusive dominance by mountain beech.

The associations fell into 4 groups: 1 2 3 4 and 12; 7 8 9 11 and 13; 5 10 and 16; 6 14 15 and 17.

Distribution of the above associations at each location:

The locations fell into 3 groups: lanthe, Ahaura, Okuru, Skiffington; Content Ck, Hokitika; and Thomsons Flat, Pell Stream.

Ianthe Al was abundant with some A2, A3 and minor A4.
Ahaura Al was dominant with some A2 and minor Al l.
Okuru A10 was common with some A2, A5, A16 and minor Al, A4, and A13.

TABLE 9 IANTHE SEEDLINGS < 10 cm m"2. (Cp = *COPROSMA PARVIFLORA*, Ct = *COPROSMA TENUICAULIS*, GI = *GRISELINIA LITTORALIS*; Md = *MYRSINE DIVARICATA*, Ue = *ULEX EUROPAEUS*).

PLOT	NUMBER OF SEEDLINGS										
	MAR 1991			DEC 1991	NOV 1992		JAN 1994				
	Ue	Cp	Gl	Cp	Cp	Ue	Cp	Ue	Md	Ct	Gl
41											
42				600			105	6		11	
43	5	5	1	1000			57	17	3		1
44	8	20		300			67	17	3	1	1
45											
46	2	11					17		1		
47											
48											
49											
50				200	32		70				
51								1			
52					5		3			1	
53					4	2	2	2			
54					4		1				
55		11		100	3		6				
56		5			3						
TOTAL	15	52	1	2200	51	2	328	43	7	13	2
MEAN m^{-2}	0.94	3.25	0.06	137.50	5.6	0.2	21.8	2.87	0.47	0.87	0.13

Skiffington A10 and A16 were common with minor A2, A4, A12, A7 and A13.
Content Ck Mostly A4 with small contributions from A7, A8, A9, All, Al 3 and minor A10.
Hokitika Mostly A4 with Al 2 common and small amounts of A2 and All.
Thomsons Flat Dominant A14 with small amounts of A6 and A17.
Pell Dominant A17 with small amounts of A15 and minor contributions from Al, A2, A4, A8 and A14.

Plots with no seedlings in this tier comprised 12 and 13% of plots respectively at Content Ck and Okuru, 20% of Pell Stream plots, 37% at Skiffington Swamp, 48% at both Thomsons Flat and Ahaura, 60% at Hokitika and 63% at Ianthe.

Seedling associations (percentage occurrence of 10-30 cm seedlings)

A0 No seedlings.
A1 *Coprosma parviflora* exclusively dominant.
A2 *Neomytus pedunculata* and/or *Coprosma parviflora* usually common, with occasional gorse, silver pine, *Cyathodes fasciculata* and 17 minor species.
A3 *Coprosma parviflora* always dominant with abundant *Neomyrtus pedunculata.*
A4 *Myrsine divaricata* always common to dominant, often with abundant *Coprosma parviflora* or *Phyllocladus alpinus* common. Red beech or broadleaf sometimes important.
A5 Exclusive dominance of either broadleaf, gorse or *Coprosma tenuicaulis.*
A6 Mountain beech always common with either abundant *Dracophyllum palustre* or common red beech, *Myrsine divaricata* or *Pernettya macrocarpa.*
A7 Kamahi always common to abundant, almost always with abundant *Neomyrtus pedunculata.* Occasional minor contributions from yellow-silver pine, *Myrsine divaricata* or *Phyllocladus alpinus.*
A8 Manuka always common to abundant. *Coprosma parviflora, Neomyrtus pedunculata* and *Cyathodes juniperina* frequently important and 15 minor species.
A9 *Cyathodes fasciculata* always exclusively dominant.
A10 Red beech always dominant over silver beech, sometimes with mountain beech.
A11 Kamahi and *Phyllocladus alpinus* almost always share dominance. Silver beech frequently occurs. *Coprosma parviflora* and 4 minor species are somtimes present.
A12 *Phyllocladus alpinus* always common to dominant with *Neomyrtus pedunculata, Dracophyllum palustre,* and *Cyathodes fasciculata* occasionally important, and nine minor species.
A13 *Neomyrtus pedunculata* always exclusively dominant.
A14 Kamahi always exclusively dominant.
A15 Red beech always exclusively dominant.
A16 Manuka always exclusively dominant.
A17 Mountain beech always exclusively dominant.

The number of plots without seedlings in this tier at Okuru and Content Ck were low (8 and 12% of plots respectively), moderate at Skiffington Swamp(27%), Hokitika (32%), Ahaura (42%) and Thomsons Flat (48%), but high at Pell Stream (80%) and Ianthe (85%).

Distribution of the above associations at each location:
The locations fell into 3 groups: Ianthe, Content Ck, Ahaura, and Hokitika; Okuru and Skifflngton; Thomsons Flat and Pell Stream.

Ianthe Al, A5, and A2 were equally common.
Content Ck All was dominant, with A2 common and all occurrences of A7, less A12 and A14, and minor contributions from A4, A5 and A13.
Ahaura Al was dominant, with all occurrences of A3, and minor contributions from A2, A4, Al 3, A8 and All.
Hokitika A2 was abundant with minor A13, A14, A9 and A5.
Okuru A8 was dominant with abundant A2, and Al 6, Al and Alt all common.
Skiffington A8 and A16 both common, with less A12 and minor A2 and A9.
Thomsons Flat A15 and A17 common, all occurrences of A10, and minor A6 and A4.
Pell Al 7 abundant with contributions from Al 5, Al, A4 and A6.

Seedling Numbers

The mean number of seedlings m^2 in both <10 cm and 10-30 cm tiers differed significantly between sites (Table 10). In the <10 cm tier Skiffington Swamp had significantly more seedlings than Hokitika ($P<0.01$), Content Ck ($P<0.001$) or Ahaura ($P<0.05$), and numbers at Okuru and Pell Stream were significantly greater than all three ($P<0.01$) as well as Thomsons Flat ($P<0.05$). However, the difference between Pell control plots and Thomsons Flat was not significant, neither was there any significant difference between the harvested plots and respective controls at Pell and Ianthe.

TABLE 10 MEAN AND STANDARD ERROR (S.E.) VALUES FOR SEEDLING NUMBERS IN <10 CM AND 10-30 CM TIERS, AND *SPHAGNUM* COVER AT EACH SITE.
(N = NUMBER OF PLOTS, NI = NUMBER OF PLOTS WITH SEEDLINGS <10 CM, Nz = NUMBER OF PLOTS WITH SEEDLINGS 10-30 CM).

		<10 CM SEEDLINGS			10-30 CM SEEDLINGS			*SPHAGNUM* COVER (%)	
	N	N_1	Mean	S.E.	N_2	Mean	S.E.	Mean	S.E.
Pell Stream	80	64	74.1	14.2	14	0.23	0.06	70.5	3.31
Pell control	34	28	49.9	14.5	8	0.47	0.22	98.5	0.98
Thomsons Flat	50	26	36.9	11.2	26	2.36	0.47	54.8	6.31
Ahaura	50	26	26.5	10.5	29	2.14	0.53	57.1	5.13
Hokitika	25	10	8.8	2.7	17	2.08	0.47	53.7	8.06
Ianthe Forest	58	26	46.4	20.7	11	0.76	0.36	44.2	4.82
Ianthe control	16	11	81.2	81.2	0	0.00	0.00	95.0	0.00
Content Creek	50	44	18.5	2.4	44	5.08	0.55	10.8	3.09
Okuru	48	42	85.3	16.7	44	4.75	0.59	18.3	4.53
Skiffington	30	19	67.3	18.2	22	7.00	1.24	26.4	5.21

In the 10-30 cm tier, Skiffington Swamp plots recorded the greatest number of seedlings which, together with Okuru and Content Ck, were significantly greater than all other sites (P<0.01). In contrast to the <10 cm tier, seedling numbers at Hokitika were significantly greater than at Pell Stream (P<0.05) or Pell control (P<0.001) plots. No seedlings were recorded in the Ianthe control plots in this tier. The number of seedlings in the Skiffington Swamp plots, although high, was not significantly different from similarly vegetated, harvested sites at Okuru and Content Ck.

Sphagnum cover

Seedling suppression and mortality of beech at montane sites is generally high (Wardle 1984). At Thomsons Flat no seedlings were recorded in 30% of plots, and all of these had 95-100% *Sphagnum* cover. *Sphagnum* cover was significantly negatively correlated with seedling numbers in both tiers at Thomsons Flat (<10 cm P=0.001; 10-30 cm P=0.01), but significantly positively correlated with seedling numbers in the <10 cm tier at Content Ck (P<0.05). Although not significant, seedling numbers at all other sites were negatively correlated with *Sphagnum* cover, apart from two positive correlations in the <10 cm tier at Ahaura and the 10-30 cm tier at Skiffington Swamp.

Seedlings at Thomsons Flat and Pell Stream occurring in plots with high *Sphagnum* cover were all mountain beech, which is more tolerant of the wet, infertile conditions of the sphagnum bog than other beech species (Wardle 1984).

Sphagnum was not always present; 33 plots at Content Ck had no *Sphagnum*, and 16 plots at Okuru. In two plot groups at Okuru a significant relationship was found between sapling (10-30 cm) number and *Sphagnum* cover ($p < 0.05$) using Mann-Whitney and PATN. Rimu, silver pine, *Cyathodes, Myrsine,* silver beech, totara *(Podocarpus totara)* and miro *(Prumnopitys ferruginea)* were in the non-Sphagnum plots, but were absent from the plots with significantly more *Sphagnum* where *Lepidothamnus laxifolius* was more common.

Shrubs had been cut and/or trampled in four plots at Ahaura. Trampled shrubs were still growing and most cut stems had regrown, but in one plot all cut shrubs had died. Recent harvesting was obvious in 22% of plots, but the mean number of 10-30 cm seedlings (1.6 xri" 2) was not significantly different to plots without signs of recent harvesting (2.3 in').

5. Conclusions and recommendations

Bulk density values revealed that what is often seen as relatively rapid recovery of *Sphagnum* in terms of height growth betrays the fact this regrowth is often less dense than the initial harvest, and so full recovery in biomass terms may take much longer. If the level of growth measured at Pell Stream was maintained, full recovery in terms of *Sphagnum* biomass could take 11 years in re-seeded plots compared with 32 years in plots without re-seeding. These recovery times may be faster in situations of moderate to high light intensity where *Sphagnum* cover re-establishes quickly, e.g., at 5% canopy cover regrowth was 33.9% in 3 years (Table 1), implying a harvest cycle of 9 years. Elling and Knighton (1984) suggest lineal projection of biomass accumulation rate presents a worst-case recovery estimate, and an S-shaped curve is more realistic, which would improve our estimates of *Sphagnum* recovery time.

Variation in water table, not surprisingly, has revealed itself as a major factor in limiting *Sphagnum* growth. Post-harvest weather patterns may therefore have a strong influence on recovery rate, not only in dry bogs, but also where sites may become too wet, such as Arthur's Pass (Buxton *et al.* 1992) and part of lanthe Forest. Harvesters can therefore optimise *Sphagnum* recovery by harvesting different areas at different times of the year based on water table levels and seasonal rainfall, and to some extent this is probably already being done. Further study is required to determine the precise moisture limits for each species of *Sphagnum*.

Results from the seedling data suggest there has been little impact as a result of harvesting. Overall, the control plots at Pell, lanthe and Skiffington Swamp were not significantly different from their locally harvested equivalents. The greater number of seedlings in the 10-30 cm tier at Okuru, Content Ck and Skiffington Swamp compared with other sites may reflect the greater level of past disturbance (logging, burning etc.) at the latter lowland sites. Also, small seedling numbers are inherently very variable, owing to episodic germination and death. This was particularly evident in *Coprosma parviflora* at lower altitude pakihi sites (Table 9), and beech at the montane sites where greater seedling suppression and mortality is known to occur (Wardle 1984). Natural seedling mortality and self thining may explain most of the decrease in seedling density between the <10 cm and 10-30 cm tiers. However, it is not possible to say from the limited data whether harvesting has enhanced or reduced this decrease, as harvesting in most sites is a fairly recent event.

Harvesting guidelines

The Department of Conservation established guidelines for *Sphagnum* harvesting in May 1991. These guidelines indicated harvesting cycles of eight years. Observations of lowland sites in Westland show harvesting cycles as short as 2-3 years are possible, and five year cycles appear to be achieveable in most situations if certain steps are followed. Factors aiding *Sphagnum* recovery can be summarised as:

1. A suitable site, where the watertable does not fluctuate too widely, and *Sphagnum* growth is vigorous. Growth rates and observations suggest that very wet sites, i.e., where the water table is commonly at or above the post-harvest surface, will not sustain commercial harvesting. *Sphagnum* peatlands near their ecological limits are potentially more vulnerable to damage from harvesting as recovery is likely to be much slower, therefore most sites above 600 m are unlikely to be sustainable ecologically or commercially.

2. Site management. Maintaining some natural shelter to give protection from desiccation and frost appears to be important, as results (Figs. 10 & 11) show that *Sphagnum* in very open sites generally has poor growth, especially when compared to that growing among rushes *(Baumea* and *Juncus).* Harvesters have observed *Sphagnum* growth to be better beneath open shrubland (Yarwood 1990), yet shrubs are often cut to enable easier harvesting. Leaving the harvest site with an even surface so that all remaining *Sphagnum is* in close contact with the water table appears to be preferable to the contrasting situation where portions of hummocks are removed leaving the rest to dry and decay.

3. Re-seeding: *Sphagnum* regeneration on the bare peat surface left after complete harvesting is slow, or sometimes absent, particularly if accompanied by drought. This can lead to dominance by other species or litter. However, by leaving approximately 30% cover of actively growing *Sphagnum* in close contact with the water table, rapid regrowth is encouraged. Re-seeding can reduce the harvest cycle by about one year through promoting rapid restoration of *Sphagnum* cover, giving greater potential for sustainability.

4. Avoiding use of machinery which causes rutting in the bog surface. This can cause small drains to form, resulting in excess desiccation in some parts and localised ponding elsewhere, so that conditions are either too dry or too wet for sphagnum growth.

5. Harvest cycle. Allowing sufficient time for regeneration before reharvesting. This will vary from site to site depending on environmental conditions and moss growth rates. To maintain satisfactory yield it is important to consider biomass production not merely height growth. It would appear that after regrowth in height levels off, biomass will increase proportionally.

Sphagnum harvesting can be managed on a sustainable basis at some sites given these conditions, but whether this is sufficient to maintain the current level of demand for this unquantified resource is unknown.

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8. Appendix

8.1 GLOSSARY OF COMMON AND SCIENTIFIC NAMES

Beech	*Nothofagus* spp.
mountain	*N. solandri* var. *cliffortioides*
red	*N. fusca*
silver	*N. menziesii*
Bracken	*Pteridium esculentum*
Broadleaf	*Grisefnia littoralis*
Gorse	*Ulex europaeus*
Kamahi	*Weinmannia racemosa*
Manuka	*Leptospermum scoparium*
Rimu	*Dacrydium cupressinum*
Silver pine	*Lagarostrobos colensoi*
Yellow-silver pine	*Lepidothamnus intermedius*