Moss Harvest Recovery Report:
Cover, Biomass, and Species Composition Eleven Years After Harvest

Salem District, Bureau of Land Management
August 2005
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Abstract. Recovery of epiphyte biomass and species composition following commercial moss harvest is extremely slow. Vine maple (*Acer circinatum*) shrub stems harvested in 1994 showed an average increase in percent cover of epiphytic bryophytes of 34% (std 3) over 11 years of recovery. No harvestable moss mats were present in 2005, mat depth did not exceed 4 mm, and biomass was only half that of the moss mats originally harvested in 1994. Species were both gained and lost from 1994 to 2005 and species richness is higher now than before harvest. Assuming constant cover growth, it will take nearly three decades before harvested stems regain total cover and 25-40 years before biomass is completely regained. Based on these and previous findings, which suggest a minimum rotation period of 30 years and low biomass inventory, commercial moss harvest on this district is unlikely to be sustainable.

Overview

In 1994, in fulfillment of a Master's degree from the Department of Botany and Plant Pathology under Dr. Bruce McCune at Oregon State University (Peck 1996), eighteen different sites on the Salem District BLM were inventoried for harvestable quantities of moss (actually a mixture of mosses and liverworts; Peck 1997a). Sites were not chosen based on the presence of harvestable moss; sites in the former Clackamas Resource Area were chosen to represent epiphyte "hotspots," areas of high epiphyte diversity, while sites in the former Santiam Resource Area were chosen to represent matrix and younger forests (see Peck & McCune 1995 for details). Each site was surveyed for epiphytic lichens and, when present, for harvestable quantities of moss. Of the 18 sites originally surveyed, 9 had some harvestable moss present and 7 had harvestable quantities of moss (>50 kg/ha). Five sites had at least 5 vine maple (*Acer circinatum*) stems in the sampling, which were permanently tagged following harvest to enable future regrowth measurements. A total of nine stems in two of these sites were successfully relocated in 2005.

In the decade since the initiation of this project, valuable information has been gained on the species of mosses, liverworts, lichens, and vascular plants impacted by commercial moss harvest in the western foothills of the Cascade Range (Peck 1997a, Peck & Muir 2001a), the host trees and shrubs upon which harvestable mosses are found (Peck 1997b), the macroinvertebrates utilizing large moss mats (Peck & Moldenke 1999), and the biomass inventory and retrospective growth rates of sites considered capable of harboring harvestable moss (Peck & Muir 2001a,b). In response to these projects, and budgetary cutbacks in personnel, the Salem and Eugene Districts of the Bureau of Land Management no longer sell commercial moss permits.

Meanwhile, a shift has occurred in the community of commercial moss harvesters away from locals using patchy methods of harvest to supplement their income to migrants using strip harvest methods in full-time black market employment. The resulting increase in pressure on areas still open for moss harvest has led to a reduction in permits issued by other agencies, a reduction in available inventory, and a substantial increase in illegal moss harvest. Concerns about the impacts and recovery rate of commercial moss harvest thus continue to be raised.

The completion of this project provides the first hard data on the rate and dynamics of long-term recovery following commercial moss harvest on the western slope of the Cascades of central and northern Oregon.

Methods

In the summer of 1994, epiphytic bryophytes on nine individual stems of vine maple (*Acer circinatum*), the dominant shrub harboring harvestable moss, were harvested (stripped clean) from one-meter segments and the stems were permanently tagged. Stems were selected using the point-centered quarter method (Cottam et al. 1953), with an unequal number of stems among the sites due to the patchy distribution of vine maple. In the laboratory, the epiphytes were sorted by species, their abundance estimated visually as a percentage of the total volume of material on a given stripped segment (after McCune 1990), and oven dried (60°C for 24 hr) and weighed. Stem density estimates were obtained based on the point-centered quarter method and used to extrapolate stem-level moss mat biomass to the stand-level (see Peck & McCune 1995 for details).

Each of these vine maple stems was also cored to determine age, which was then used to calculate a retrospective minimum periodic net accumulation rate (Table 1) by dividing the mass of an individual mass mat by the age of the host stem (minus 5 years to account for no epiphytes during early shrub establishment). The estimates were *net* in that they represented gains (from growth and litterfall) minus losses (from mortality and litterfall) and were *periodic* because they represented net growth over an extended period, incorporating periods of mat growth as well as periods of no growth such as post-disturbance conditions. They are *minimum* accumulation rates, underestimating actual annual growth, because they incorporate these periods of no growth; this, however, makes them realistic for purposes of estimating sustainable yield. The minimum accumulation rates obtained for these two sites are comparable to the mean of 1.1 g/m/yr across all sites for which retrospective rates were calculated (Peck & McCune 1995). The rotation periods for these two sites, calculated as the mass of the originally harvested moss mat divided by the estimated rate, were somewhat less than the estimated minimum required rotation period across all sites of 40 years (Peck & McCune 1995).

Table 1. Site characteristics and retrospective growth rates estimated in 1994.

Site	Stand Age	Elevation (m)	BA of hardwoods (m^2/ha)	Biomass kg/ha	Retrospective growth rate g/m-stem/yr	Rotation Period yr/m-stem
Church Creek (G)	100	366	4.6	94	1.1	29 (15-33)
Table Rock (T)	114	777	12.9	133	1.6	20 (13-27)

In July, 2005 these two sites were relocated and the nine stems re-examined to determine the percent cover of each species in the one-meter segment that had been harvested in 1994. Cover was estimated separately for the upper and lower surfaces of all stems. A record was kept of whether or not the remaining epiphytes on the stem encroached into the stripped segment and measurements were made of the height of the stem from the ground at the segment center, the average mat depth, mat volume, and the number of harvestable mats (12”x6”x1” minimum). All epiphytes were then removed from the stem, oven dried at 60°C for 24 hours, and weighed to obtain biomass. Cover estimates were made by Peck in both 1994 and 2005. Nomenclature follows Anderson et al. (1990) for mosses, Stotler & Crandall-Stotler (1977) for hepatics, Esslinger & Egan (1995) for lichens, and Hitchcock & Cronquist (1973) for vascular plants.

Species richness is defined as the number of species found in a given sample and was calculated for each site. Mean alpha diversity is the average number of species *per* segment for a given site (stem-level). Percent cover is the percent of the surface area of the one-meter long stem segments (of varying diameter) covered by epiphytes (averaging upper and lower surfaces). Average cover is calculated across stems for each site. The rate of increase in percent cover from year to year is calculated as the total increase in cover (total cover in 2005) divided by time (11 years).

Due to the small sample size, species richness and cover were not tested for differences between upper and lower surfaces or among sites. Differences in relative abundances and species composition were determined using multi-response permutation procedures (MRPP, McCune &

Mefford 1999). MRPP is a nonparametric test used here to evaluate differences among groups, on the basis of frequency and abundance of species.

Results

Species composition

A total of 16 taxa of mosses, liverworts, and one vascular plant (licorice fern) were found growing in the harvested segments of the stems eleven years after harvest (Table 2). Several species gained in relative abundance over the pre-harvest mat composition, including *Claopodium*, *Eurhynchium*, and *Homalothecium fulgescens*, while a few were slightly reduced (*Neckera*, *Orthotrichum*, *Porella*).

The regrowth on the stems at these sites had greater species richness and mean alpha diversity

Table 2. Taxa found in harvestable epiphyte mats (1994) and on post-harvest stems (2005). Values are average proportion of total abundance.

M = Moss, L = Liverwort, V = Vascular plant	**Pre-Harvest 1994**	**Recovery 2005**
Antitrichia curtipendula		
Claopodium crispifolium		
Dendroalsia abietina		
Eurhynchium oreganum		
Frullania tamariscii subsp. *nisquallensi*		
Homalothecium fulgescens		
Homalothecium nutallii		
Isothecium myosuroides		
Metzgeria conjugata		
Neckera douglasii		
Orthotrichum lyellii		
Polypodium glycyrrhiza		
Porella navicularis		
Porella roellii		
Radula bolanderi		

Table 3. Site averages for 1994 and 2005. SpR = species richness. Mean alpha is the average number of species per sample. # taxa gained/lost is from 2005 back to 1994.

		Church Creek (G)	**Table Rock (T)**
	# stems	4	5
1994	SpR	8	6
	Mean alpha	4	3
2005	SpR	9	11
	Mean alpha	4	5
	% Cover	35.9	31.9
	(std)	(1.9)	(2.5)
	% original species	78	100
	% original SpR	112	183
	# taxa gained	4	5
	# taxa lost	3	0

compared to the originally harvested mats (Table 3). This increase is in part due to taxa truly new to these regrowth stems (e.g., licorice fern, *Homalothecium fulgescens*) but also reflects the fact that the species identified in the 1994 sampling only included those present in the harvestable mat and may have overlooked appressed species that remained on the stem after harvest (e.g., *Metzgeria*, *Radula*). Interestingly, three taxa at the Church Creek site present in the original mat had not returned to these stems in the past 11 years: *Antitrichia curtipendula*, *Dendroalsia abietina* and *Porella navicularis*.

After analyzing each site separately because of significant differences in species composition between sites ($p=0.02$), no difference in species composition between the originally harvested mats and the 11-year regrowth were found for either site (MRPP, $p>0.8$).

Abundance Regrowth

The overall average accumulation of vegetative cover over the 11 year period since harvest was 34% (s.d. 3), which converts to a constant average annual rate of increase of 3%/year. Upper surfaces of stems averaged 40.5% (11.7) cover, while lower surfaces averaged only 26.8% (11.7). Regrowth occurred from both propagules or residuals in the center of the stripped segment and from encroachment from residual populations at the edges of the segment. On average, 12% (std 9) cover (38% of total cover) was attributed to encroachment from adjacent populations of *Claopodium*, *Eurhynchium*, *Homalothecium*, *Isothecium*, and *Neckera*. No incidence of obvious reestablishment by litterfall was observed.

No stem had even a single harvestable mat, and in fact total volume estimates averaged only 2 in^3 on both upper and lower surfaces, for a total of 4 in^3 per m-stem (in contrast to the minimum of 72 in^3 for a "harvestable" moss mat; Peck 1997a). Mean mat depth on both upper and lower surfaces was <1.5 mm (std 1.2), in contrast to the estimated 2-3 cm depth of the originally harvested mats.

Biomass Regrowth

Eleven years after harvest, the nine stems at Church Creek and Table rock averaged 11.3 g/m-stem (std 4.7) of moss at 0% moisture content (mc), which corresponds to a simple constant growth rate of 1.0 g/m-stem/year or 8.0 $g/m^2/yr$ (std 3.2) taking surface area into account. The average upper surface mat depth of 1.5 mm (s.d. 1.3) remained notably lower than at the time of initial harvest in 1994 (estimated to be 2-3 cm). On average, these stems had recovered 49% (s.d. 25) of their original biomass over the past eleven years and would take, on average, about 16 (95th percentile from 8 to 25) more years to reaccumulate that mass assuming a constant growth rate. Thus the total time required to acquire a harvestable biomass at these sites would be on the order of 24-41 years.

Discussion

Species composition

The increase in diversity over that found in the originally harvested mats is similar to that found in post-harvest recovery on the Hebo Ranger District, Siuslaw National Forest in on the western slope of the Oregon Coast Range. In both studies, the originally harvested mats were generally dominated by *Isothecium* and had relatively few small, appressed species. With the removal of the large mats and a large surface area opened for colonization, a long period of establishment provided ample opportunity for greater diversity to develop in the absence of direct competition. The relatively large harvested area provided several niches with high small-scale habitat heterogeneity (rough vs. smooth bark, upper vs. lower surfaces, bud scars, etc.). The boost to diversity will likely continue until cover reaches 100% and competition increases again.

In contrast to comparable stems on the Hebo District, natural disturbance rates appear to have been relatively high. On Hebo, losses to natural disturbance were less than 20% over a decade, while in this study numerous stems were unable to be relocated and presumed to have died or been crushed under falling trees. In both studies, disturbance was complete: the entire host was killed as well as the epiphyte mat disturbed. In contrast, no evidence was seen of patchy epiphyte mat disturbance comparable to the partial removal of moss mats typical of commercial moss harvest, supporting the hypothesis that human harvest is a unique form of disturbance for understory moss mats.

Abundance Regrowth

The rate of recovery was remarkably similar among all nine stems, providing us with confidence in the observed estimates of regrowth. Only one other regrowth study exists for comparison, although that work reports on 10-year regrowth on the Hebo Ranger District in the moist western slope of the Coast Range of northern Oregon (Peck 2004). As expected, all parameters indicate slower recovery in the Cascades than the Coast Range. Percent cover on the upper surfaces of stems averaged 40.5% in the current study vs. 65.6% at Hebo; cover on lower surfaces averaged 26.8% and 34.9%, respectively. These values translate into differential annual growth rates of 3%/year vs. 5%/year, which suggest that 100% cover can be attained in the Cascades in roughly 30 years as opposed to 21 years at Hebo. These differences continue with mat volume as well, with regrowth averaging <1.5 mm in depth here vs. 3 mm at Hebo and total volume averaging 4 in^3 in the current study vs. 11 in^3 at Hebo. One interesting point is that encroachment from adjacent stem sections makes a roughly comparable contribution to total cover in both Ranges, with 38% of total cover in the current study attributable to encroachment vs. 41% at Hebo. At the very least, these differences suggest that low

rates of recovery and impacts of commercial moss harvest are likely to be more extreme in the Cascades than those reported for the Hebo Ranger District.

The slow growth of mat thickness has important implications for invertebrate habitat and potential hydrological and nutrient cycling functions. If invertebrates require thick mats with accumulations of epiphytic soil, stems with high cover but low mat thickness may be poor habitat for invertebrate communities. The absence of large moss mats may also have implications for fire susceptibility (wet moss smolders but does not burn) and flooding as the pattern of rapid retention and slow release of rainfall/stemflow/throughflow by large mats is interrupted. With fewer and fewer large mats around, these ecosystem functions would be reduced.

Biomass Regrowth

In eleven years of regrowth, only 11.3 g of moss reaccumulated on each stem, which is nearly 1/3 that found after 10 years on Hebo. Just under half of the original biomass harvested in 1994 had returned to these stems, compared to just over half (56%) at Hebo in 10 years. This translates into an annual accumulation rate of 1.0 g/m-stem/year (vs. 3 g/m-stem/yr at Hebo), which is remarkably similar to the 1.1 g/m-stem/yr estimate obtained from the original retrospective method used in 1994. These regrowth rates suggest that 27 years will be required, on average, to reaccumulate the moss mass harvested from the stems in 1994, which is toward the upper end of the estimates obtained from the original retrospective technique (Table 1) and almost identical to the 28 years necessary at Hebo. An equivalently long period of time is required to reaccumulate the moss mats at Hebo compared to these sites despite higher growth rates because of the larger mass of the mats originally harvested at those sites.

A potentially important aspect of regrowth is that the biomass that is returning appears to be spread out more evenly on the stem segment, such that although 50% of biomass has returned, mat depths are significantly lower than in the originally harvested material. This suggests that even though total biomass may recover within 30 years, it may take even longer for mat depths to become harvestable and to provide the ecosystem services unique to large moss mats.

Finally, these data indicate that both vegetative cover and biomass appear to require at least 30 years to recover following commercial harvest. Such slow rates of recovery, combined with relatively low biomass inventory (Peck & Muir 2001a), suggest that commercial moss harvest is unlikely to be sustainable on the Salem District of the Bureau of Land Management.

Acknowledgments

My grateful appreciation is owed to B. Becker, T. Fennel, C. Hibbler, W.S. Hong, J. Knurowski-Thiel, and B. McCune.

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