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Review

Towards sustainable commercial moss harvest in the Pacific Northwest of North America

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ABSTRACT

The Pacific Northwest is the main source of commercially harvested forest moss in North America, but management guidelines have only included this nontimber forest product for ca. 15 years and research on sustainable harvest practices is barely a decade old. This review summarizes the results of recent research, identifies future research needs, and proposes guidelines for the sustainable management of tree moss (a mixture of mosses and liverworts). The epiphytic species most affected by harvest are *Isothecium myosuroides*, *Neckera douglasii*, and *Porella navicularis*, but dozens of taxa are thought to be impacted. Harvest impacts include reductions in biomass and cover and changes in relative species composition, but it is too early to tell if the species composition will return to pre-harvest conditions. Biomass recovery is slow and estimated rotation periods are 15–25 years. Inventory estimates are still lacking, but harvestable quantities of epiphytic moss are most abundant in low elevation and riparian areas and absent in stands that are very dark and/or lack hardwood tree and shrub species (e.g., <70-year-old Douglas-fir (*Pseudotsuga menziesii*) plantations). Future research should focus on locating unimpacted reference sites and evaluating the ecosystem functions provided by harvestable moss mats, including the provision of habitat and nutrient and water cycling. Management recommendations include prohibiting commercial moss harvest in forests managed toward old-growth condition, obtaining region-specific estimates of resource inventory and recovery rates, and rotating areas open for moss harvest to allow sufficient recovery between harvest entries.

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1. Introduction

1.1. The region

The Pacific Northwest (PNW) of North America may have produced over 23 million kg (air-dried) of commercially sold forest moss in 1999, based on an estimated international export value of ca. 10 million USD (Muir, 2004). In the United States, the PNW is a ca. 250 km wide by 1000 km long strip of land south of Canada and north of California along the coast of the Pacific Ocean that includes the western half of the US states of Washington and Oregon. This region is traversed by the north–south oriented Coast and Cascade Ranges, which are dominated by mixed forests of conifers such as Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), and Douglas-fir (*Pseudotsuga menziesii*) and hardwood trees such as bigleaf maple (*Acer macrophyllum*) and red alder (*Alnus rubra*) (Franklin and Dyrness, 1973). Epiphytic bryophytes (mosses and liverworts) thrive in the Coast Range, which receives >2000 mm of rainfall each year and is subject to frequent coastal fog, but are also abundant in moist pockets in western portions of the drier Cascade Range (Peck and Muir, 2001a; Wiley, 1966). Moss is also commercially harvested in the Appalachian mountains of the eastern US (primarily from logs) and some studies have begun to determine the species impacted by harvest (Studlar, 2003, 2004) and evaluate recovery rates (G. Kauffman, pers. comm.). However, because of substantial differences in ecosystem and habitat, and the fact that only ca. 4% of legally permitted commercial moss originates from the Appalachian region (Muir, 2004), attention is given here only to the predominant source in North America.

1.2. Commercial moss

Commercially harvested 'moss' in the PNW is a mixture of primarily epiphytic mosses and liverworts (Peck, 1997a). Nutrients and water are generally absorbed from rainfall, throughflow, and stemflow, although nutrition may also be obtained from nitrogen-fixing blue-green algae (cyanobacteria) that live among some moss tissues (During and Van Tooren, 1990). The majority of harvestable species lack internal conducting structures and are unable to pierce the tissues of other plants; these rootless nonvascular green plants are neither parasitic nor saprophytic. Epiphytic 'moss' grows primarily on the upper surfaces (66%, Peck, 2004) of understory shrub stems or tree boles and must become deep enough that the rhizoids interweave into a mat above the host bark to become easy to remove and thus harvestable. Harvestable mats are generally at least 100 cm^3 in volume and mature mats average 4000 cm^3 in the primary study area (Peck, 2004).

1.3. Ecosystem functions

Epiphytes play a variety of ecological roles in forest ecosystems. Many are old-growth associates and are sparse or absent in young and mature stands (USDI BLM and USDA FS, 2003). In addition to aquatic rotifers and tartigrades residing in the moist interstitial tissues of mosses, aphids (Thomas, 1993), nematodes (Merrifield and Ingham, 1998), snails, and other invertebrates either feed on or live among moss (Tarter and Nelson, 1995). Many vertebrates use moss as a nesting material (USDI BLM and USDA FS, 2003), including the threatened marbled murrelet (USFWS, 1997). Bryophytes also act as sinks for water and nutrients carried in intercepted stemflow and throughfall (Brown and Bates, 1990; Nadkarni, 1981, 1984). Nutrients are either assimilated and released by decay (Turetsky, 2003) or stored in porous cells and released in pulses during significant rain events (Coxson, 1991; Coxson et al., 1992). Large, wet moss mats may also contribute to the extremely long (400 + year) natural fire cycles (Turetsky, 2003) in the region – lightning strikes on wet moss mats may smolder, but are unlikely to burn.

2. Industry development

Collecting freshly cut wild plant material for the floral industry, the 'brush' or 'greenery picking' industry, originated in the PNW perhaps as early as 1915 and by the 1940s more than 90% of the floral greens used in the US originated in this region (Allen, 1950; Heckman, 1951). In a multi-million dollar industry (Shaw, 1949), mosses such as *Eurhynchium oreganum* and *Antitrichia curtipendula* sold for 0.11 USD/kg ($ 0.05/lb) and were only a small portion of the total non-timber forest product (NTFP) harvest. Green portions were used for funeral decorations and the mat-like rhizoidal backing for orchid potting (Wiley, 1966). Used as a packing material, soil conditioner, and a lining for hanging flower baskets (Cronemiller et al., 1950; USDA FS, 1963, 1969), by the 1960s at least 10,000 kg/year (fresh weight) was harvested in western Oregon and twice as much in Washington (for ca. 0.3 USD/kg ($ 0.13/lb)) (USDA FS, 1969).

Moss is now also used for cultivating mushrooms and shipping live bulbs and substantially as a decorative accessory in domestic and overseas floral industries (Savage, 1995; USDA FS, 1993, 2001; von Hagen and Fight, 1999). Although moss harvest in the PNW is thought by some to have peaked in the early 1990s (Howell, 1991), demand for moss harvest permits and reports by managers and harvesters alike suggest that demand currently exceeds supply (R. Babcock, D. Harrison, pers. comm.). Most moss is now sold at around 0.88 USD/kg ($ 0.40/lb), but reports of higher prices include 1.65 USD/kg ($ 0.75/lb) in 1997 (J. Peck, pers. obs.) and nearly 7.70 USD/kg ($ 3.50/lb) in 1991 (Howell, 1991). Moss can be found for sale in the US at nursery suppliers, craft stores, and on the internet (e.g., www.hohgrown.com, www.hiawathacorp.com, www.moss-tropicare.com).

Harvesters work part- to full-time hiking through the woods to mossy areas, peeling thick pelt-like moss mats off trees and shrubs, packing the fresh material into feed sacks, and hauling it to a staging area to air-dry to ca. 15% moisture content (dry to the touch). The moss is then sold to buying sheds either loose for 0.55–1.10 USD/kg ($ 0.25–0.50/lb) (Peck, 2005) or compressed into 11.3 kg (25 lb) bales and sold for 12–14 USD/bale before being shipped to large national and international floral greens wholesalers, who sell the moss for 4.4–6.6 USD/kg ($ 2–3/lb) (Muir, 2004; Peck, 1990, 2005). Moss is generally considered a disposable product, maintaining demand from year to year.

Moss harvest was an "afterthought" during the peak years of timber extraction in the region (Johnson, 1992), but the search for alternative income sources focused attention on the NTFP industry in the 1980s and 1990s. Public awareness of the industry grew as articles appeared in the popular literature (e.g., Fellows, 1992; Howell, 1991; Johnson, 1992; Savage, 1995). Industry extent and growth potential drew interest by researchers (Freed, 1995; MRI, 1992; Powel, 1981; Schlosser et al., 1991, 1992) and government publications promoted NTFP harvest (USDA FS, 1989, 1993; von Hagen and Fight, 1999). These reports, however, often excluded epiphytes (e.g., USDA FS, 1975) and even detailed studies of NTFPs gave little attention to moss (e.g., Powel, 1981; Schlosser and Blatner, 1993). Interest in industry participants and practices (e.g., Kantor, 1994; Love et al., 1992; Schnepf, 1995) revealed a shift over the past 15 years from patchy harvest by part-time local harvesters to strip harvest by seasonal migrant crews (R. Babcock, D. Harrison, pers. comm.; Peck, 1990; cf. Lynch and McLain, 2003).

In a recent survey of public and private PNW land managers, 37% (57 individuals) of respondents had been asked to allow commercial moss harvest on their land (Muir, 2004). Few private landowners allow NTFP harvest. Small landowners find that efforts to monitor activities on their land outweigh the small income that such a low-value NTFP can generate, while large landowners are concerned with allowing access to harvesters due to concerns about eco-terrorists, squatters, and vandals (D. Baird, D. Harrison, P. Muir, pers. comm.). Most harvest has therefore taken place on federal lands such as the national forests. The harvest of NTFPs such as moss was traditionally viewed by public land managers as more of a "service to local communities than a revenue source" (Chamberlain et al., 2002; Peck, 1990), slowing the regulation of commercial moss harvest. Increased demand, however, spurred concern about sustainability of harvest and impacts on rare species (Liegel, 1992) and the recognition that mandates to protect rare species and species diversity and to maintain ecosystem function also apply to NTFP harvest (Lesher et al., 1994). National forest management plans that include NTFPs, once rare, are now legislatively mandated.

These updated management plans now address these products (e.g., USDI BLM, 1993), but the paucity of available data often results in non-operational guidelines based on general ecological knowledge rather than product or organism-specific data. Previously distributed misinformation, such as that moss regrows in 3–5 years (USDI BLM and USDA FS, 1993), has been replaced by easily subverted guidelines, such as restricting harvest of epiphytic moss to "every other stem" (USDA FS, 1995) – allowing harvesters to remove material from 50% of stems on one day and the remaining 50% the next without violating their permits. Another guideline set an annual limit on commercial moss harvest permits at 50,000 kg/year on the Siuslaw National Forest in northwestern Oregon; after this limit is met (typically at the start of the dry peak harvest season), permits are no longer sold for the remainder of the fiscal year. This shifted harvest (or at least the sale of permits) to adjacent federal Bureau of Land Management (BLM) land, which saw a sudden increase in permit sales from 5000 kg to over 91,000 kg (F. Duran, pers. comm.), prompting reductions in the number of permits sold on BLM land in the following year. Of the seven large public forest landowners in western Oregon, three no longer sell any permits for commercial moss harvest. Recent increases in illegal harvest from protected areas such as the Olympic National Park (Hutten, 1999) may reflect reductions in either the moss resource inventory, access to the resource, or both.

The lack of information on the impacts of commercial harvest on ecosystem functions has led to calls to prohibit moss harvest in old-growth forests (e.g., Muir, 2004), in which it is still allowed (USDI BLM and USDA FS, 1997). Identified research needs for NTFPs include basic biological and ecological information about the products and resource inventories (Wickens, 1991) as well as information on whether or not a lack of active management (or failure to enforce harvest guidelines) causes long-term degradation of the resource (Chamberlain et al., 2002; von Hagen and Fight, 1999). Data on impacts to incidentally harvested or otherwise impacted species are also needed (USDA FS, 2001a), as are data on social and economic aspects. The charge to make NTFPs available within the "limitations of ecosystem sustainability" (USDA FS, 2001b) calls for more information on inventories and the effects of harvest on species and ecosystems. In the case of forest moss, little information is available on actual harvest rates, ecosystem impacts of harvest, or the renewability of the resource (Muir, 2004). Further, due to false impressions, lack of information, and the difficulty of studying the behavior of seasonal and migratory NTFP harvesters (who in northwestern Oregon are often undocumented aliens, D. Harrison, pers. comm.), agencies often do not know how to take the needs of these social groups into account (Love et al., 1992). While modern forest management is able to draw on two centuries of silvicultural research and evolving social structures, the moss harvest industry has been studied for barely a decade.

Even industry representatives recognize the need for change: in 1992 a regional industry organization was founded to promote the NTFP industry for "perpetual and sustainable harvesting" (NWSFPA, 1996). A variety of law enforcement issues have also been identified by industry participants, including unenforceable regulations, overharvest, illegal harvest, low success of shifting the burden of record keeping to buyers, territorial disputes, on-site damage from illegal vehicles, inconsistency in permit systems across landowners, and low penalties for violations (WOSFPC, 1997). Due to the paucity of law enforcement *per* unit area, information on permit-compliance rates is completely lacking (Johnson, 1992), although illegal harvest is suspected to constitute a significant proportion of the harvest (Muir, 2004; Peck, 1990). Of recently surveyed land managers in the PNW, 41% of respondents indicated that illegal harvest occurs on their lands (Muir, 2004). Estimates of the total national moss harvest, in fact, were many times the reported legally permitted harvest on publicly owned lands (Muir, 2004).

3. Moss harvest research

3.1. Biomass distribution

On the publicly owned lands in the northern Coast Range and central and northern Cascade Range of the PNW that have been examined, commercially harvestable quantities of moss (>50 kg/ha) are generally not found at elevations >600 m or >50 m from perennial streams or lakes, in dark stands (e.g., Douglas-fir plantations <70 years in age), or in the absence of overstory hardwood trees such as red alder or understory shrubs such as vine maple (Peck and McCune, 1998; Peck and Muir, 2001a; Peck, 2005). This concurs with reports by harvesters that the best moss grows in low elevation areas and along creek beds (USDA FS, 1969). Harvest in these areas, however, may be incompatible with special riparian forest guidelines to protect rare species and preserve hydrologic function and is often prohibited.

Most research has taken place on the Hebo Ranger District of the Siuslaw National Forest, in the moist coastal fog belt of northwestern Oregon, which is thought to be the largest single source of commercial moss in the PNW. The first estimates of harvestable moss biomass on Hebo were based on extrapolations of moss mat biomass (below 2 m in height) and host density. These mossy sites were estimated to have from 120 to 1479 kg/ha dry weight (134–1650 lb/acre at 26% moisture content, which is the average for fresh weight at the time of harvest) (Peck and McCune, 1998). While variability in inventory is high in these mossy sites, it is extremely patchy in drier areas. In an inventory of 100 sites on the western slope of the Oregon Cascades (Eugene District, BLM and Sweet Home District, Willamette National Forest) stratified to exclude areas thought to lack moss as described above, harvestable mats were found in 29 sites but harvestable quantities (>50 kg/ha) in only six sites (which had 65–217 kg/ha dry weight; 73–244 lb/acre at 26% moisture content) (Peck and Muir, 2001a). The patchy distribution of harvestable moss on the landscape makes extrapolations of stand-level inventories to entire landholdings difficult.

According to reporters (Howell, 1991), agency personnel (Hutten, 1999; USDA FS, 1969), harvesters (D. Harrison, pers. comm.; Wiley, 1966), and researchers (Peck, 1997b; Peck and Muir, 2001a; Vance and Kirkland, 1997; D. Shaw, pers. comm.), this biomass is primarily removed from red alder, big-leaf maple, and vine maple throughout western Oregon and Washington. Mat mass and species richness differ between trees and shrubs primarily as a function of surface area, but some epiphytic species show actual host preferences (Peck, 1997b). Because some hosts (e.g., elderberry (*Sambucus*) or large diameter red alder) always support particularly diverse moss communities, restricting commercial harvest to a single host species (e.g., vine–maple) could reduce the overall impacts of harvest on the epiphytic bryophyte community. Hardwood trees and shrubs, which provide critical habitat for epiphytes such as commercially harvested bryophytes (Hazell and Gustafsson, 1999), have historically been cut and sprayed with herbicides in western forests to favor conifer species. A shift in forest management practices toward promoting hardwood trees and shrubs could enhance diversity while increasing resource inventory through improved habitat (cf. Muir et al., 2002; Peck and McCune, 1998; Vance et al., 2001). The retention of vine maple shrubs from one overstory rotation into the next could also enhance both biomass (by allowing stems to age and become decumbent, enabling the development of large moss mats (see Ruchty et al., 2001)) and diversity (by increasing substrate heterogeneity).

3.2. Species composition

Moss harvest research began in 1994 with the simulated harvest of moss mats from understory shrub stems and hardwood tree boles in 10 sites on Hebo known to have harvestable quantities of moss. This sampling identified 19 mosses, 6 hepatics, 8 lichens, and 2 vascular plants (Peck, 1997a). Both lichens and vascular plants were relatively rare, and the latter only present in mats of sufficient depth to accumulate epiphytic soil. Three groups of species were identified: nontarget species, generally avoided by harvesters because they are not saleable (vascular plants, lichens, and some bryophytes); incidentally harvested species, taken opportunistically or when growing entwined with more desirable species (e.g., species of *Claopodium*, *Frullania*, and *Homalothecium*); and target species, which grow in sufficient abundance to attract harvesters and have desirable commercial properties such as green coloring (*A. curtipendula*, *E. oreganum*, *Isothecium myosuroides*, *Neckera douglasii*, species of *Porella*, and *Rhytidiadelphus loreus*). The abundance of the ubiquitous moss *I. myosuroides* was positively associated with conifer basal area, in contrast to most other species that were most abundant in hardwood stands. Limiting commercial moss harvest to conifer-dominated stands could reduce the landscape level impact on epiphytic bryophyte diversity by focusing harvest on this extremely common species.

Another study on eight publicly owned sites in western Oregon around the same time found many of the same taxa (18 mosses, 6 hepatics, 13 lichens, and 2 vascular plants), including the same target species (Vance and Kirkland, 1997). Fewer species were recorded in a study on 27 sites on the western slope of the Cascades (19 mosses, but only 3 liverwort, 2 lichen, and 1 vascular taxon), presumably due to drier conditions (Peck and Muir, 2001b). Examination of 15 large bags (ca. 3–9 kg at 26% moisture content) of moss illegally harvested from the extremely moist Olympic National Park in western Washington found comparable species (19 mosses, 6 hepatics, and 13 lichens) (Hutten, 1999), but greater abundances of moisture-loving log and ground mosses such as *R. loreus*. A recent study of 34 small bags (58–282 g at 26% moisture content) of commercially sold PNW moss (purchased from wholesalers or retailers) found many of the same taxa (28 species of moss, 6 liverworts, trace amounts of 9 lichens, and two vascular species) (Muir, 2004), but included species harvested from throughout the region and valley species not previously known to be commercially harvested (e.g., *Antitrichia californica*).

Species of concern found in harvested moss mats include several sensitive lichens (Vance and Kirkland, 1997) and one moss (*A. curtipendula*, a common and abundant old-growth associate). This moss species has high transplant survival rates (Hazell and Gustafsson, 1999) and high growth rates in old and young forests and understory and canopy locations alike (Rosso et al., 2001) as well as under a wide range of canopy densities, including small clearcuts (Muir et al., in press), which may explain why fragments of this canopy epiphyte are able to survive and develop into harvestable mats in the understory moss harvest zone. The status of this moss species has subsequently been upgraded and it is not considered at risk (USDI BLM and USDA FS, 2003).

3.3. *Dynamics of recovery*

We generally know which species are impacted by commercial moss harvest, but not how harvest affects stand-and landscape-level species composition and ecosystem function. Data from the tropics suggest that species composition on stems formerly bearing bryophyte mats can remain dramatically altered for several years following disturbance (Nadkarni, 2000). It is possible that *E. oreganum*, which constitutes <4% of currently commercially harvested material (unpub. data), has declined in abundance in the epiphyte community as a result of harvest: although taxonomic accuracy cannot be verified, this typical forest floor species was once listed as a commonly harvested epiphyte (Wiley, 1966). When moss mats were peeled from their substrate in mossy sites on the western slope of the Cascades in western Oregon, they left behind residual quantities of species in different relative abundances than were present in the harvested mat (Peck and Muir, 2001b), suggesting harvest could alter succession. Three years later, species richness, cover, and volume were still lower than before harvest and the surface area of uncolonized branch stems remained higher (R. Kimmerer, pers. comm.). Similarly, three-years after disturbance, alpha and gamma diversity on canopy big-leaf maple (*A. macrophyllum*) tree limbs in western Washington state remained lower than on pre-harvest branches (Cobb et al., 2001). A decade following simulated commercial harvest in the understory on Hebo, species composition has yet to return to pre-harvest conditions (Peck, 2004).

The dynamics of recovery on substrates bared by harvest are poorly understood, but recolonization is thought to arise from residual particles, microscopic propagules, reestablished litterfall, or encroachment (after Frego, 1996). No data exist on recovery from residual particles or microscopic propagules, but regrowth studies have found significant encroachment of species from adjacent, unharvested areas (Cobb et al., 2001; R.W. Kimmerer pers. comm.; Peck, 2004). Observations of re-establishment of canopy epiphyte litterfall in understory mats (Peck, 1997a) and on the forest floor (Peck et al., 1995) indicate that vegetative propagation may be important for recolonization in this region. However, retention of litterfall may be substantially reduced following harvest; when bryophyte fragments were experimentally dropped onto canopy branches in the tropics, only 5% were retained after six months on bare branches compared to 25% for branches with intact epiphyte mats (Nadkarni et al., 2000).

The only assessment of the impacts of commercial moss harvest on vegetative cover, species richness, and species composition has been for historically harvested riparian areas on Hebo. Three treatments were used: no-harvest control; harvest by a commercial moss harvester according to current guidelines, resulting in a removal rate of 33.6 kg/ha (30 lbs/acre; fresh weight); and harvest with no restrictions, resulting in a removal rate of 112.1 kg/ha (100 lbs/acre) (Peck, 2005). Stands were resurveyed immediately following harvest and again one, two, and eight years after harvest. Due to historic harvest on the entire district, including the study sites, harvest was by default restricted to only the occasional stem that bore a harvestable moss mat, such that even in the absence of restrictions most stems in a plot were unimpacted. Harvested stems showed significant reductions in cover and changes in species composition (increased dominance of *N. douglasii* after the removal of most of the *I. myosuroides*) for the first few years, but were undistinguishable in cover, species richness, and species composition from unimpacted stems by the end of the study. Because the unimpacted stems in each treatment showed no change, no treatment effects were ever observed at the stand level. Due to historic harvest, these results can not be considered reflective of impacts in “natural” stands, but they are representative of the condition of harvestable stands on the district. It thus appears that, due to the patchy nature of historic harvest, continued harvest may have only minor stand level impacts. Because of the lack of unharvested sites on the district, moss harvest impacts at the first stand entry remain unknown.

3.4. *Biomass recovery rates*

The factors driving biomass recovery following harvest are also unknown: no significant relationships have been found between harvestable moss regrowth and original mat volume, harvested surface area, stem slope, bark texture, stem density, or distance to perennial water, although bryophytes in riparian areas tend to regrow faster than those in upland areas (R. Kimmerer, pers. comm.; J. Peck, unpub. data). More attention has been paid to estimating recovery rates.

The first approach to estimating biomass accumulation rates assumed that a harvestable moss mat growing on a 20-year-old host stem could not have taken longer than 20 years to develop. Following the simulated harvest of moss mats on Hebo in 1994, a subsample of vine maple were aged (ranging from 7 to 76 years), and net periodic accumulation rates were estimated by dividing the mass of the harvested moss mat by the age of the stem upon which it grew. Despite tremendous variation due to the occasional occurrence of extremely large mats (likely due to reestablished litterfall) and small mats (likely due to disturbance), this accumulation rate averaged 1.6 g/m stem/year (std 1.4; dry weight) for shrub stems bearing harvestable mats. Estimated recovery times based on this rate resulted in recommended rotation periods of 10–15 years for mossy sites on Hebo (Peck and McCune, 1998). Application of a similar methodology on vine maple stems of comparable age on sites in the drier western Cascades resulted in a minimum estimated accumulation rate of 22.4 g/m^2/year (std 15.5; dry weight) for shrub stem segments under harvestable mats, or 1.2 g/m-stem/year when made comparable to the methods of Peck and McCune (1998) (Peck and Muir, 2001b). The resulting recommended rotation period was 21–23 years. Some of the variability observed in these estimates may be explained by the recent observation that larger mats are found on decumbent shrub stems but decumbent shrub stems are not always older than upright stems (Ruchty et al., 2001).

Actual regrowth estimates can be obtained from long-term studies, but few have been conducted. Five years after simulated harvest on Hebo, the average harvested stem had 28% vegetative cover, having gained 3% vegetative cover each year (Peck, 1999). By year 10, cover on these stems averaged 50% (Peck, 2004). Somewhat higher cover regrowth was found on mature big-leaf maple canopy limbs in Washington state, which had 27% cover after only three years (Cobb et al., 2001), but stripped canopy branches in the tropics have been unexpectedly slow to regrow, possibly requiring decades (Nadkarni, 2000).

In year five of the Hebo regrowth study, no mats exceeded 2 mm in depth, and even by year 10 average mat depth remained less than 3 mm (Peck, 2004), a stark reduction in volume from the original moss mats (which were over 3 cm in depth). Biomass regrowth increased at only 0.2–0.8 g/m/year (Peck, 1999; dry weight) in the first 2–4 years, but the average rate of increase was up to 3.0 g/m/year by year 10 (Peck, 2004; dry weight), resulting in recommended rotation periods of 15–25 years. These low biomass recovery rates contrast with growth studies in which harvestable epiphytes suspended in mesh nets with 7 mm^2 openings in the understory of young and old-growth forests (combined) increased in mass over a 13 month period by 11.8% (*A. curtipendula*) and 3.7% (*I. myosuroides*) (Rosso et al., 2001). Average annual growth over a three-year period under variable overstory conditions in a similar transplant study was 29% (*A. curtipendula*) and 17% (*I. myosuroides*) (Muir et al., in press). Slow recovery after harvest likely reflects the slow rate of recolonization as well as the time needed to reach a critical mass before rapid growth can occur (i.e., large enough to retain sufficient water to promote growth, D. Norris pers. comm.). [Future data on recovery may arise from Cobb et al. (2001); D. Shaw (pers. comm.); Peck and Muir (2001b); Vance and Kirkland (1997).]

3.5. *Ecosystem impacts*

No comprehensive investigations of the ecosystem impacts of harvest have been conducted. Projects on Hebo and in the Cascades of western Oregon, however, have determined that mats of commercially harvestable moss host substantial invertebrate communities involving well over 100 taxa, with most mats averaging 5–17 taxa (and dozens of individuals) (Peck and Moldenke, 1999). Although no studies have evaluated the impacts of harvest on these macroinvertebrates, the fact that many of them are cryptobiotic (i.e., able to survive extended drought and darkness) and may be able to survive storage, shipping, and handling has led to a current study investigating invertebrate taxa found in discarded commercially sold moss (Peck and Moldenke, unpub. data). The potential for exotic introductions is noteworthy given that PNW moss is sold throughout the country as well as to over 44 international destinations, such as The Netherlands, Germany, and Japan (Muir, 2004; USDA FS, 2001).

4. Research needs

Despite the progress that has been made in the past decade, further research is required in several areas:

- The natural dynamics of growth and compositional development in “old growth moss” or unimpacted forests must be determined to establish a reference condition for use in impact studies. The paucity of such un-harvested sites currently limits this research, but carefully guarded set-asides could provide future sites for such comparisons.
- The ecosystem impacts of commercial moss harvest must be determined, including impacts on habitat quality and hydrologic and nutrient cycling.
- The potential for exotic species introductions through international distribution of unsterilized epiphytes must be determined and mitigation procedures identified if necessary.
- The potential for commercial production of moss from propagules must be evaluated to determine if cultivation can reduce the impacts of wild harvest. Varying combinations of propagule sources (spores from harvested capsules vs. whole leaves vs. leaf fragments), binding solutions (glue, clay slurry, egg white and water mixtures, buttermilk, etc.), substrates (tree bark, suspended plastic sheeting or burlap, etc.), and light and moisture conditions must be assessed.
- The nature of the social and economic structures of the moss harvest industry must be identified and trends in harvest practices linked to research on harvest impacts.

5. Management recommendations

Although historic data show no clear trend in the demand for commercially harvested forest moss (Muir, 2004), in the absence of alternative products or sources (e.g., farmed moss, Nadkarni, 2004), demand is not expected to decline in the near future. Sustainable strategies for commercial moss harvest will not only reduce pressure on our parks and preserves, promote community-based industries, and ensure long-term economic and ecologic stability, but also serve as examples for other regions facing similar issues (e.g., Mexico, Peralta and Wolf, 2001; Great Britain, Anonymous, 1994). Because of the widespread nature of illegal harvest, and the greater potential for illegal harvest to impact species of concern, strategies to reduce illegal harvest will be required regardless of other management recommendations. Moss ‘poaching’ often affects riparian habitats and logs, which may have a disproportional impact on landscape level diversity because decayed logs are important habitat for a large number of mosses and liverworts (Rambo, 2001), as well as invertebrates and amphibians. Remaining recommendations regarding commercial moss harvest in the PNW include:

- As others have suggested (Peck and McCune, 1998; Vance et al., 2001; Muir et al., 2002), forest management practices should be encouraged that promote the retention, survival, and growth of understory and overstory hardwood species, including legacies over multiple overstory rotations.
- Areas with low natural moss inventories should be open only for personal use harvest, with the exception of commercial harvest in areas scheduled for immediate overstory removal (moss 'salvage,' which currently occurs very infrequently). Commercial moss harvest programs in areas with low moss inventories incur costs that exceed permit revenues and have ecological impacts that outweigh the benefit to a few harvesters.
- Commercial moss harvest should be prohibited in areas designated as Late Successional Reserves (USDI BLM and USDA FS, 1997) or being otherwise managed toward old-growth condition. Harvest impacts on hydrology, nutrient cycling, epiphyte diversity, and invertebrate communities are likely inconsistent with the development of old-growth ecosystem functions, particularly given the slow rate of regrowth. Such areas should also be protected from harvest to provide reference conditions for studies evaluating harvest impacts.
- Forest lands managed primarily for timber production (e.g., matrix, USDI BLM and USDA FS, 1997) and open for commercial moss harvest should be assessed for their moss resource inventory. Without inventory data, it is impossible to evaluate the sustainability of allowable harvest quantities. At the very least, harvest limits should reflect the absence of commercially harvestable quantities of forest moss >600 m in elevation, >50 m from a source of at least seasonal humidity, under young (<70-year-old) conifer overstories, or in stands lacking hardwood trees or shrubs. Moss salvage from harvested overstories should also be encouraged.
- Forest lands managed primarily for timber production and open for commercial moss harvest should be assessed for reaccumulation rates to determine moss harvest rotation periods.
- Due to the prevalence of illegal harvest, it is recommended that districts be divided into moss harvest zones on the basis of road access to facilitate law enforcement patrol. Rotating these zones would allow sufficient time for regrowth. For instance, a district of 100,000 ha could be divided into five harvest zones and each zone rotated every 5 years (thus allowing 20 years of "fallow" time for recovery). Assuming that each zone has about 5000 ha of mossy areas with a known moss inventory of 100 kg/ha, permits could be sold for 100,000 kg/zone/year.
- Periodic monitoring of the species impacted by harvest may require additional impact studies to assess recovery rates and revise harvest guidelines as harvest practices change in the future.

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REFERENCES

Allen, J. W., 1950. Marketing woodlot products in the State of Washington. Bulletin 1. Washington Department of Conservation and Development, Institute of Forest Products. Olympia, WA, USA.

Anonymous, 1994. Missing Moss. New Scientist (11 June), 42.

Brown, D., Bates, J., 1990. Bryophytes and nutrient cycling. Botanical Journal of the Linnean Society 104, 129–147.

Chamberlain, J., Bush, R., Hammett, A., Araman, P., 2002. Eastern national forests: managing for nontimber products. Journal of Forestry (Jan/Feb), 8–14.

Cobb, A.R., Nadkarni, N., Ramsey, G., Svoboda, A., 2001. Recolonization of bigleaf maple branches by epiphytic bryophytes following experimental disturbance. Canadian Journal of Botany 79, 1–8.

Coxson, D., 1991. Nutrient release from epiphytic bryophytes in tropical montane rain forest (Guadeloupe). Canadian Journal of Botany 69, 2122–2129.

Coxson, D, McIntyre, D., Vogel, J., 1992. Pulse release of sugars and polyols from canopy bryophytes in tropical montane rain forest (Guadeloupe, French West Indies). Biotropica 24, 121–133.

Cronemiller, L.F., Woods, Jr., J.B., Ladd, C.H., 1950. Secret treasures in the forest. Bulletin 14, Oregon State Board of Forestry, Salem, OR, USA.

During, H.J., Van Tooren, B.F., 1990. Bryophyte interactions with other plants. Botanical Journal of the Linnean Society 104, 79–98.

Fellows, L., 1992. What are forests worth? Lancet 339, 1330–1333.

Franklin, J.F., Dyrness, C.T., 1973. Natural Vegetation of Oregon and Washington. Oregon State University Press, Corvallis, OR, USA.

Freed, J., 1995. Special forest products: past, present, and future. International Journal of Ecoforestry 11 (2/3), 62–67.

Frego, K.A., 1996. Regeneration of four boreal bryophytes: colonization of experimental gaps by naturally occurring propagules. Canadian Journal of Botany 74, 1937–1942.

Hazell, P., Gustafsson, L., 1999. Retention of trees at final harvest – evaluation of a conservation technique using epiphytic bryophyte and lichen transplants. Biological Conservation 90, 133–142.

Heckman, H., 1951. The happy brush pickers of the high Cascades. Saturday Evening Post 4, 35–40 (October 6, 1951).

Howell, S., 1991. The brush business. Ruralite 38 (4), 6–11.

Hutten, M., 1999. Staircase moss harvest. Unpublished to the Olympic National Park, Port Angeles, WA, USA.

Johnson, J., 1992. The secret harvest. American Forests (March/April), 28–31+.

Kantor, S., 1994. Local knowledge and policy development: special forest products in coastal Washington. M.S. thesis, University of Washington, Seattle, WA, USA.

Lesher, R., Rosentreter, R., Christy, J., 1994. The role of fungi, lichens, and bryophytes in the development of management alternatives for federal lands in the Pacific Northwest. Northwest Science 68 (2), 136 (Abstract).

Liegel, L., 1992. Concerns and issues for special forest products research in the Northwest. Internal report to the Pacific Northwest Research Station, Corvallis, OR, USA.
Love, T., Denison, W., Donoghue, J., Zasada, J., 1992. Nontimber forest products extraction in the Pacific Northwest: who is involved and how widespread is this activity? In: 4th North American Symposium on Society and Resource Management, 17–20 May 1992, Madison, IL, USA.
Lynch, K.A., McLain, R.J., 2003. Access, labor, and wild floral greens management in Western Washington's forests. PNW-GTR-585, USDA Forest Service, Portland, OR, USA.
Merrifield, K., Ingham, R.E., 1998. Nematodes and other aquatic invertebrates in *Eurhynchium oreganum* from Mary's peak, Oregon Coast Range. Bryologist 101, 505–511.
MRI, 1992. Greenery, transplants, and floral products. Midwest Research Institute Technical Paper, Kansas City, MO, USA.
Muir, P.S, 2004. An assessment of commercial "moss" harvesting from forested lands in the Pacific Northwestern and Appalachian regions of the United States: How much moss is harvested and sold domestically and internationally and which species are involved? Report to US Fish and Wildlife Service and US Geological Survey, Forest and Rangeland Ecosystem Science Center, Corvallis, OR, USA.
Muir, P.S, Mattingly, R., Tappeiner, J., Bailey, J., Elliott, W., Hagar, J., Miller, J., Peterson, E., Starkey, E., 2002. Managing for biodiversity in young Douglas–fir forests in western Oregon. Biological Science Report USGS/BRD/BSR–2002–0006, USGS Forest and Rangeland Ecosystem Science Center, Corvallis, OR, USA.
Muir, P.S., Rambo, T.R., Kimmerer, R.W., Keon, D.B., in press . Influence of overstory removal on growth of epiphytic mosses and lichens in western Oregon. Ecological Applications.
Nadkarni, N.M., 1981. Canopy roots: convergent evolution in rainforest nutrient cycles. Science 214, 1023–1024.
Nadkarni, N.M., 1984. Biomass and mineral capital of epiphytes in an *Acer macrophyllum* community of a temperate moist coniferous forest, Olympic Peninsula, Washington State. Canadian Journal of Botany 62, 2223–2228.
Nadkarni, N.M., 2000. Colonization of stripped branch surfaces by epiphytes in a lower montane cloud forest, Monteverde, Costa Rica. Biotropica 32 (2), 358–363.
Nadkarni, N.M., 2004. Not preaching to the choir: communicating the importance of forest conservation to nontraditional audiences. Conservation Biology 18, 602–606.
Nadkarni, N.M, Cobb, A.R., Solano, R., 2000. Interception and retention of macroscopic bryophyte fragments by branch substrates in a tropical cloud forest: an experimental and demographic approach. Oecologia 122, 60–65.
NWSFPA, 1996. Northwest Special Forest Products Association, P.O. Box 30, Brownsville, OR, USA.
Peck, J. E., 1990. The harvest of moss: an industrial perspective. Unpublished report to the Department of Sociology and Anthropology, Linfield College, McMinnville, OR, USA.
Peck, J.E., 1997a. Commercial moss harvest in northwestern Oregon: Describing the epiphyte communities. Northwest Science 71, 186–195.
Peck, J.E., 1997b. The association of commercially-harvestable bryophytes and their host species in Northwestern Oregon. Bryologist 100, 383–393.
Peck, J.E., 1999. Moss recovery report. Unpublished report to the Siuslaw National Forest, Corvallis, OR, USA.
Peck, J.E., 2004. Final moss recovery report: Ten years after harvest. Unpublished report to the Siuslaw National Forest, Corvallis, OR, USA.
Peck, J.E., 2005. Final report the moss harvest monitoring plan: descriptions and results for special forest products stewardship areas SA1 and SA2. Unpublished report to the Siuslaw National Forest, Corvallis, OR, USA.
Peck, J.E., McCune, B., 1998. Commercial moss harvest in Northwestern Oregon: biomass and accumulation. Biological Conservation 86, 299–305.
Peck, J. E., Moldenke, A., 1999. Describing and estimating the abundance of macroinvertebrates in commercially harvestable moss. Unpublished report to the Eugene District of the Bureau of Land Management, Eugene, OR, USA.
Peck, J.E, Muir, P.S., 2001a. Estimating the biomass of harvestable epiphytic bryophytes in Central Western Oregon. Northwest Science 75 (2), 99–106.
Peck, J.E., Muir, P.S., 2001b. Harvestable epiphytic bryophytes and their accumulation in central western Oregon. Bryologist 104 (2), 181–190.
Peck, J.E., Acker, S.A., McKee, W.A., 1995. Autecology of mosses in mature and old-growth forests in the central western Cascades of Oregon. Northwest Science 69 (3), 184–190.
Peralta, M.G., Wolf, J., 2001. Commercial bryophyte harvesting in the monarch butterfly biosphere reserve, Sierra Chincua, Michoacan, Mexico. Bryologist 104 (4), 517–521.
Powel, J., 1981. An Economic Analysis of Nontimber Uses in Forestland in the Pacific Northwest. The Consulting Division, Boeing Computer Services Company, Seattle, WA, USA.
Rambo, T., 2001. Decaying logs and habitat heterogeneity: implications for bryophyte diversity in Western Oregon forests. Northwest Science 75 (3), 270–277.
Rosso, A., Muir, P.S., Rambo, T.R., 2001. Using transplants to measure accumulation rates of epiphytic bryophytes in forests of Western Oregon. Bryologist 104 (3), 430–439.
Ruchty, A., Rosso, A., McCune, B., 2001. Changes in epiphyte communities as the shrub *Acer circinatum* develops and ages. Bryologist 104 (2), 274–281.
Savage, M., 1995. Pacific Northwest special forest products: an industry in transition. Journal of Forestry 93 (3), 6–11.
Schlosser, W., Blatner, K., 1993. Critical aspects of the production and marketing of special forest products. Unpublished report to the Social and Economic Values Research Program, PNW Research Station, Portland, OR, USA.
Schlosser, W., Blatner, K., Chapman, R., 1991. Economic and marketing implications of special forest products harvest in the coastal Pacific Northwest. Western Journal of Applied Forestry 6 (3), 67–72.
Schlosser, W., Blatner, K., Zamora, B., 1992. Pacific Northwest forest lands potential for floral greenery production. Northwest Science 66, 44–55.
Schnepf, C. (Ed.), 1995. Dancing with an elephant. In: Proceedings of the Business and Science of Special Forest Products: A Conference and Exposition; 1994 January 26–27, Hillsboro, OR. Washington State University Cooperative Extension, Pullman, WA, USA.
Shaw, E.W., 1949. Minor forest products of the Pacific Northwest. Research Note 59. USDA FS, PNW Forest and Range Experiment Station. Portland, OR, USA.
Studlar, S., 2003. Moss harvest in West Virginia: target species and incidental take. Report submitted to the Monongahela National Forest, Elkins, WV, USA.
Studlar, S., 2004. Moss harvest in West Virginia: increasing pressure on riparian habitats. Botany 2004 Alpine Diversity: Adapted to the Peaks. July 31–August 5, 2004, Salt Lake City, UT, USA.
Tarter, D., Nelson, D., 1995. Conservation of the spruce fir moss mat spider (*Microhexura montevega*). In: Regional Conference Proceedings – American Zoo and Aquarium Association, Great Lakes Region, March 1995, Louisville, KY, USA.
Thomas, R., 1993. An aphid feeding on moss. Maine Naturalist 1 (1), 37–38.
Turetsky, M.R., 2003. Role of bryophytes in carbon and nitrogen cycling. Bryologist 106 (3), 395–409.

USDA FS, 1963. Special forest products for profit. Agricultural Information Bulletin No. 278, US Government Printing Office, Washington DC.
USDA FS, 1969. Special forest products 1969 harvesting report, Oregon and Washington. US Government Printing Office 998–162, PNW Region, Portland, OR, USA.
USDA FS, 1975. Floral greenery from Pacific Northwest forests. US Government Printing Office 1975–798–323/81, Washington DC.
USDA FS, 1989. Rural development opportunities in special forest products. US Cooperative Forestry, Washington DC.
USDA FS, 1993. The forest beyond the trees: a browser's guide to special forest products. Olympic National Forest, Washington, USA.
USDA FS, 1995. Decision notice and finding of no significant impact, special forest products program environmental assessment, forest plan amendment No. 6. Siuslaw National Forest, Corvallis, OR, USA.
USDA FS, 2001a. Special forest products: species information guide for the Pacific Northwest. In: Vance, N., Borsting, M., Pilz, D., Freed, J. (Eds.), PNW–GTR–513, Corvallis, OR, USA.
USDA FS, 2001b. National strategy for special forest products. US Government Printing Office FS-713, Washington DC.
USDI BLM, 1993. Managing special forest products in Oregon and Washington: a final report. Portland, OR, USA.
USDI BLM, USDA FS, 1993. Special Forest Products (informational brochure). R6-WIL-UP-032-93. Salem, OR, USA.
USDI BLM, USDA FS, 1997. Northern Coast Range adaptive management area guide. BLM/OR/WA/PL–97/008+1792. Tillamook OR, USA.
USDI BLM, USDA FS, 2003. Draft supplemental environmental impact statement to remove or modify the survey and manage mitigation measure standards and guidelines. BLM/OR/WA/PL-03/023+1792. Portland, OR, USA.
USFWS., 1997. Recovery Plan for the Marbled Murrelet (Washington, Oregon, and California Populations). Region 1, US Fish and Wildlife Service, Portland, OR, USA.
Vance, N., Kirkland, M., 1997. Bryophytes associated with *Acer circinatum*: Recovery and growth following harvest. In: Kaye, T., Liston, A., Love, R., Luoma, D., Meineke, R., Wilson, M. (Eds.), Conservation and Management of Native Plants and Fungi. Native Plant Society of Oregon, Corvallis, OR, USA, pp. 267–271.
Vance, N., Borsting, M., Pilz, D., Freed, J., 2001. Special forest products species information guide for the Pacific Northwest. USDA FS PNW-GTR-513. Portland, OR, USA.
von Hagen, B., Fight, R., 1999. Opportunities for conservation-based development of nontimber forest products in the Pacific Northwest. USDA FS PNW–GTR–473. Portland, OR, USA.
Wickens, G., 1991. Management issues for development of nontimber forest products. Unasylva 42 (165), 3–8.
Wiley, L., 1966. Wild Harvest. Self published, Portland, OR, USA.
WOSFPC, 1997. Annual Meeting of Western Oregon Special Forest Products Council. Eugene, OR, USA.