

Commercial Moss Harvest in Northwestern Oregon: Describing the Epiphyte Communities

Abstract

This paper describes the epiphytes impacted by commercial moss harvest in northwestern Oregon. Commercially harvestable epiphytes were sampled on hardwood tree trunks and shrub stems from 10 sites in each of the Cascade and Coast Ranges. Fifty species of mosses, hepatics, lichens, and vascular plants were found in over 500 epiphyte mats. Seven taxa were defined as "target" species, due to high frequency of occurrence and abundance. Six species were defined as "incidental" due to lower frequency and biomass but a high association with target species. The remaining 37 species were defined as "nontarget" species that would generally be avoided by commercial harvesters, but are often accidentally harvested. In the Cascade Range, *Neckera douglasii* was the most abundant harvestable epiphyte, with an average of 170 kg/ha of dry-weight harvestable material across ten sites. In the Coast Range, *Isoetecium myosuroides* was most abundant, with an average of 530 kg/ha of dry-weight harvestable material. All harvestable epiphytes were less abundant in stands with high conifer basal area. Target species were most abundant in stands with relatively high hardwood basal area, except *Antitrichia curtipendula* which was most abundant in younger stands. Some nontarget and incidental species were also most abundant on tree trunks. To protect rare species and epiphyte diversity, moss harvest should be directed away from older forests with mature hardwoods and toward younger, mixed forests. Moss harvest should be prohibited in areas being managed toward "old growth" conditions to facilitate the development of complex epiphyte communities requiring substrate continuity.

Introduction

Epiphytes are a significant and diverse component of forests in the Pacific Northwest. Many species are old growth associates and are sparse to absent in young and mature forests (Lesica et al. 1991, Neillich 1993). Epiphytes play a variety of roles in forest ecosystems, from nesting material for birds (FEMAT 1993) and habitat for invertebrates (Peck and Moldenke in prep.) to nutrient sinks (Brown and Bates 1990). Epiphytes are increasingly being removed from the forest to feed a growing floral and craft trade (Howell 1991, Johnson 1992, Peck 1990), yet little is known about the ecological impact of this harvest. Estimates based on permits for moss harvest on publicly owned lands put the total legal moss harvest in northwest Oregon at more than 226,800 kg/year (500,000 lb/year; moisture content between 10 and 18%). The illegal harvest is thought to be at least twice the legal harvest.

The current study comes at a time when forest managers are required to protect rare epiphytes (ROD 1994) and manage moss harvest for

sustainability (USDA Forest Service 1995). Baseline data for management have been lacking, prompting the current study to address these basic questions about commercial moss harvest:

- (1) What do commercial harvesters consider to be a "commercially harvestable moss mat"?
- (2) What species of epiphytes compose these mats?
 - (a) How many species are affected by harvest?
 - (b) Are species targeted for harvest quantitatively distinct from species that are not targeted?
- (3) Do target and nontarget species differ in their patterns of abundance on the landscape?

This kind of basic information about commercially harvestable moss will enable managers to begin to assess the probable impacts of commercial moss harvest on sustainability and species of concern (e.g., species listed under the "Record of Decision for Amendments to Forest Service and Bureau of Land Management Planning Documents Within the Range of the Northern Spotted Owl" (ROD 1994). This information will also provide a starting point for future investigations of harvestable moss inventories, regrowth rates, and the impacts of harvest on the communities and ecosystem functions of epiphytic bryophytes.

¹Current Address: JeriLynn E. Peck, 3930 NW Witham Hill Dr. #51, Corvallis, Oregon 97330

Methods

Sites

Ten sites were sampled in each of the Cascade (44°30' - 45°20' N, 122°12' - 122°35' W) and Coast (45°2' - 45°13' N, 123°5' - 123°55' W) Ranges of northwestern Oregon. In the Cascade Range, sites were chosen to represent lichen "hotspots" (as part of a larger study); areas presumed to have high lichen diversity based on forest composition (e.g., Neitlich and McCune 1997). The ten Coast Range sites were chosen to represent areas likely to be targeted for commercial moss harvest. These were stands with some hardwood component to the overstory (red alder, *Alnus rubra* Bong.) and tall shrubs in the understory (e.g., vine maple, *Acer circinatum* Pursh, and *Vaccinium parvifolium* Smith). All stands had vine maple in the understory; a favorite host among commercial moss harvesters in this area. Host species will be described elsewhere (Peck 1997). At each site, approximately 1.5 ha was sampled in July 1994. Characteristics recorded at each site included: percent slope, aspect, dominant vascular plant species, and basal area (BA) of conifers and hardwoods (Table 1). Aspect was adjusted to a 0-180° scale, with north and south at the poles (0 = north; 90 = east and west). Basal area estimates were determined using wedge prism data (BAF = 2.3 m³/ha = 10 ft²/acre) at five points. Estimates of elevation and the horizontal and vertical distance to the nearest perennial stream or body of water were taken from topographic maps. Estimates of stand age were taken from timber

TABLE 1. Ranges in site characteristics for Cascade Range and Coast Range sites, northwestern Oregon. Moss mat mass values are oven-dry weight. Stem density refers to the density of hosts harboring harvestable epiphyte mats.

	Cascade Range Sites	Coast Range Sites
Stand Age (years)	50 - 290	65 - 110
Elevation (m)	75 - 780	120 - 410
Conifer BA (m ² /ha)	12.5 - 40.0	3.0 - 46.5
Hardwood BA (m ² /ha)	1.0 - 21.0	0.0 - 28.5
Stem Density (stems/ha)	340 - 6090	1260 - 7450
Mean Harvestable Moss Mat Mass (g)	19 - 81	23 - 78

records (Salem District, BLM; Santiam State Forest; Hebo District, Siuslaw National Forest).

Mat Sampling

To approximate the majority of commercial moss harvest in this region, only understory trees and shrubs with commercially harvestable epiphyte mats were sampled. First, "harvestable" mats had to be defined. Based on numerous conversations with commercial moss harvesters between 1991 and 1994, "harvestable" mats were defined as (1) loose mats of nonadherent species (i.e. no appressed or embedded species), which (2) can be harvested from the host in a single, continuous mass, that (3) a commercial harvester in our area would consider "worth removing at this time." The key elements of harvestability appear to be (a) ease of removal, and (b) high volume per mat. Harvestable mats were generally at least 200 cm³ in volume.

Twenty or twenty-eight tree trunks or shrub stems with harvestable quantities of epiphytes were selected at each site using the point-centered quarter method (Cottam et al. 1953), which was originally developed for sampling tree densities based on tree-to-point distances from systematically located points on a transect. The first point in each transect was at least 50 m from the nearest edge (e.g. road) and points were placed at 50 m intervals. At each point, four quadrants were established. Within each quadrant, the tree trunk or shrub stem with harvestable quantities of epiphytes (hereafter the "stem") nearest the point was chosen for sampling.

Epiphytes were sampled below 2 m in height to approximate current regulations on commercial moss harvest on public lands, which prohibit harvest above 3 m (10'; USDI Bureau of Land Management) or 6.1 m (20'; USFS Siuslaw National Forest), and to reduce measurement error for epiphytes difficult to see from the ground. On each stem, a randomly placed one-meter microplot was stripped of all harvestable epiphytes (the "epiphyte mat"). In the laboratory the epiphytes were sorted by species, their abundance estimated visually as a percentage of the total volume of material from a given stem (after McCune 1990), then oven dried (60°C for 24 hr) and weighed. Nomenclature follows Anderson et al. (1990) for mosses, Stotler and Crandall-Stotler (1977) for hepatics, Esslinger and Egan (1995) for lichens,

and Hitchcock and Cronquist (1973) for vascular plants. Voucher specimens are in the OSU Herbarium, Corvallis, OR.

Calculations

Biomass was estimated for each species by extrapolating from the one meter segment to the entire stem (based on the total length of the stem) and from there to the stand level (based on stem density estimates from the point-centered quarter method; Cottam et al. 1953, Peck and McCune sub.). Gamma, mean alpha, and beta diversity indices were calculated for each of the 20 sites, for all 10 sites in each of the Cascade and Coast Ranges combined, and for all 20 sites combined. Gamma (γ) diversity was measured as the total number of species in all microplots combined. Mean alpha (α) diversity was calculated as the average number of species per microplot across all microplots. Beta (β) diversity, a measure of the amount of community change, was calculated as the ratio of gamma to mean alpha (γ/α).

Pearson correlations were used to evaluate relationships of environmental characteristics to gamma diversity measures. As the primary assumption of ANOVA, independence of samples, was met, ANOVA was used to compare group means between tree trunks and shrub stems for biomass data and for the diversity measures. Because the Cascade and Coast Range sites did not differ significantly for any diversity measure for all cryptogams or for any component group (i.e., mosses, hepatics, or lichens; ANOVA $p < 0.5$), correlations with stand and site characteristics are based on the Cascade and Coast Range data combined.

Indirect Gradient Analysis

To elucidate patterns of abundance among harvestable epiphyte species, I chose to ordinate these data using global nonmetric multidimensional scaling (NMS, McCune and Mefford 1995) with the quantitative version of the Sørensen (1948) similarity index as a distance measure. The data were divided into two matrices (target and non-target/incidental) based on the frequency and abundance of each species. No outliers were identified in the analyses. Ordinations were interpreted on the basis of Pearson correlations and Kendall's tau (a measure of rank correlation useful for categorical data) between ordination axes and species and stand level characteristics.

Differences in species composition among tree trunks and shrub stems were tested with multi-response permutation procedures (MRPP, McCune and Mefford 1995; Zimmerman et al. 1985). MRPP is a nonparametric method that tests for multivariate differences among groups (p-values based on a t-statistic). Species indicative of tree trunks or shrub stems were discerned using indicator species analysis (Dufrière and Legendre in press; program INDICATE, B. McCune unpubl.), which takes both relative abundance and relative frequency into account when assigning indicator values (IV). IV's range from zero (i.e., the species has no value as an indicator of that group) to 100 (i.e., the species perfectly indicate that group). Significance of the IV is evaluated by a Monte Carlo procedure that randomly reassigns sample units to different groups. The resulting p-value is based on the proportion of 1000 random reassignments that result in an IV greater than the observed IV. Species with p-values less than 0.05 and differences in IV values of at least 5 points were considered indicative of the group with the higher IV value.

Results and Discussion

Harvestable Moss Mat Composition

Based on numerous conversations with commercial moss harvesters, I had defined a "harvestable" mat as a loose mat of nonadherent species that could be harvested, with virtually no effort, from the host in a single, continuous mass of at least 200 cm³ in volume. These mats ranged from 20 to 80 g (oven dry weight; Table 1) and were composed of a variety of mosses, hepatics, lichens, and an occasional vascular plant (Table 2). Clearly, commercial "moss" harvest impacts a larger community than simply epiphytic mosses; a community about which ecological interactions are not well understood. The resistance of this community to disturbance, and thus the sustainability of the community under continued commercial harvest, is equally unknown. For instance, the dispersal capabilities and growth rates of the species in this community may differ substantially, contributing to the return of a very different community than the one that was originally harvested (see Vance and Kirkland 1997).

To aid in the management of sustainability for these communities, the species found in this study

TABLE 2. Epiphytes found in harvestable moss mats, Cascade and Coast Ranges, northwestern Oregon. ⁴ Denotes ROD Category 4 (ROD 1994) species. I = incidental species, N = nontarget species, T = target species. Data are frequency of occurrence and mean biomass across all microplots for each Range.

Species	Cascade Range			Coast Range			Utility
	% Frequency (n=224)	Biomass kg/ha	SE	% Frequency (n=280)	Biomass kg/ha	SE	
MOSSES							
⁴ <i>Antitrichia curtipendula</i>	45	13.1	0.6	16	16.9	0.5	T
<i>Claopodium crispifolium</i>	8	4.7	0.2	9	3.9	<0.1	I
<i>Dendroalsia abietina</i>	4	0.3	<0.1	0			N
<i>Dicranum fuscescens</i>	0			1	<0.1	<0.1	N
<i>Dicranum scoparium</i>	<1	<0.1	<0.1	5	17.3	1.0	N
<i>Dicranum tauricum</i>	0			<1	0.1	<0.1	N
<i>Eurhynchium oregonum</i>	14	4.1	0.1	17	10.4	0.2	T
<i>Homalothecium fulgescens</i>	2	0.9	<0.1	0			N
<i>Homalothecium nuttallii</i>	6	1.4	0.1	2	2.6	0.1	I
<i>Hypnum circinale</i>	<1	0.5	<0.1	0			N
<i>Hypnum subimponens</i>	1	0.1	<0.1	<1	<0.1	<0.1	I
<i>Isothecium myosuroides</i>	78	110.0	2.5	97	526.8	10.1	T
<i>Leucolepis acanthoneuron</i>	2	0.8	<0.1	0			N
<i>Metaneckera menziesii</i>	7	16.7	0.6	1	0.1	<0.1	I
<i>Neckera douglasii</i>	79	168.2	4.6	73	238.0	4.8	T
<i>Orthotrichum affine</i>	<1	<0.1	<0.1	0			N
<i>Orthotrichum lyellii</i>	8	0.5	<0.1	20	6.7	0.3	N
<i>Orthotrichum obtusifolium</i>	<1	0.1	<0.1	0			N
<i>Orthotrichum pulchellum</i>	0			1	<0.1	<0.1	N
<i>Plagiomnium insigne</i>	3	0.1	<0.1	1	<0.1	<0.1	N
<i>Plagiomnium venustum</i>	<1	0.2	<0.1	0			N
<i>Plagiothecium undulatum</i>	0			3	4.1	0.2	N
<i>Rhizomnium glabrescens</i>	0			4	2.3	0.1	N
<i>Rhytidiadelphus loreus</i>	8	8.1	0.4	10	42.1	1.9	T
<i>Ulota crispa</i>	0			3	0.3	<0.1	N
HEPATICES							
<i>Frullania bolanderi</i>	5	0.2	<0.1	2	0.6	0.0	I
<i>Frullania tamarisci</i> subsp. <i>nisquallensis</i>	18	8.9	0.4	42	31.8	0.8	T
<i>Lophocolea bidentata</i>	0			<1	<0.1	<0.1	N
<i>Metzgeria conjugata</i>	2	<0.1	<0.1	4	2.0	0.1	N
<i>Porella cordeana</i>	2	<0.1	<0.1	1	0.1	<0.1	I
<i>Porella navicularis</i>	58	19.2	0.3	35	44.7	1.7	T
LICHENS							
<i>Cladonia</i>	1	<0.1	<0.1	7	0.6	<0.1	N
<i>Cladonia ochrochlora</i>	<1	<0.1	<0.1	0			N
<i>Leptogium corniculatum</i>	<1	<0.1	<0.1	0			N
<i>Leptogium polycarpum</i>	1	<0.1	<0.1	0			N
⁴ <i>Lobaria oregana</i>	1	0.2	<0.1	0			N
⁴ <i>Lobaria pulmonaria</i>	2	0.2	<0.1	0			N
<i>Menegazzia terebrata</i>	0			<1	<0.1	<0.1	N
⁴ <i>Nephroma laevigatum</i>	1	<0.1	<0.1	0			N
⁴ <i>Nephroma resupinatum</i>	0			<1	<0.1	<0.1	N
<i>Parmelia sulcata</i>	4	0.3	<0.1	0			N
⁴ <i>Peltigera collina</i>	2	0.1	<0.1	1	<0.1	<0.1	N
<i>Peltigera membranacea</i>	0			<1	<0.1	<0.1	N

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Table 2. Continued

Species	Cascade Range			Coast Range			Utility
	% Frequency (n=224)	Biomass kg/ha	SE	% Frequency (n=280)	Biomass kg/ha	SE	
<i>Pseudocyphellaria anomala</i>	1	<0.1	<0.1	1	0.5	<0.1	N
<i>Ramalina farinacea</i>	2	<0.1	<0.1	0			N
<i>Sphaerophorus globosus</i>	<1	<0.1	<0.1	1	<0.1	<0.1	N
<i>Stictia limbata</i>	0			<1	<0.1	<0.1	N
<i>Usnea filipendula</i> group	4	0.2	<0.1	0			N
VASCULAR PLANTS							
<i>Montia sibirica</i>	<1	<0.1	<0.1	<1	<0.1	<0.1	N
<i>Polypodiumglycyrrhiza</i>	<1	<0.1	<0.1	5	2.2	0.1	N

were separated into three qualitative and quantitative categories on the basis of (1) *a priori* knowledge of the species found in commercially sold moss, and (2) the relative frequency and abundance of species found in this study. Seven species were defined as "target" species based on their predominance in commercially sold "moss" (unpubl. data) and their high frequency and abundance in the current study (>10% frequency and > 10 kg/ha of harvestable biomass); *Antitrichia curtispindula*, *Eurhynchium oregonum*, *Frullania tamarisci* subsp. *nisquallensis*, *Isothecium myosuroides*, *Neckera douglasii*, *Porella navicularis*, and *Rhytidiadelphus loreus*. Together, these species composed more than 90% of the total biomass of harvestable epiphytes in these sites.

Among the remaining 43 species, two categories of species were quantitatively discerned. Six species, considered "incidental" species (Table 2), are not generally targeted for commercial harvest because of their low frequency of occurrence but are nonetheless not discriminated against by commercial harvesters (pers. obs.). These incidental species typically had a frequency of >5 but < 10% and had >5 but < 10 kg/ha of harvestable biomass, except for *Metaneckera menziesii*. While locally abundant, *M. menziesii*, which typically occurs on big leaf maple, *Acer macrophyllum* Pursh, is generally unacceptable for harvest because older portions of the plant turn bright yellow-orange. True "nontarget" species (Table 2) consisted of most hepatics, and all lichens and vascular plants. These 37 species are not generally acceptable for harvest due to poor color or texture. Nontarget species typically occurred in < 5% of samples and had an estimated biomass of < 5 kg/ha. The nontarget species *Dicranum scoparium* and *Orthotrichum lyellii* were excep-

tions. Although common, these species exhibit growth forms (individual tufts) generally undesirable for moss harvest. Collection of nontarget species by commercial harvesters should, at this time, be considered accidental. While some harvest of lichens does occur, none of the species found in this study occurred in large enough abundance to be targeted for harvest in this area.

It is important to note that the assignment of categories such as "target," "incidental," and "nontarget" derives from its usefulness to managers. Harvesters rarely recognize differences among individual species of bryophytes, with the exception of *Rhytidiadelphus loreus* (called "big red stem" by harvesters). Rather, they seek large quantities of abundant mosses of the right color and texture and thus, functionally, target moss mats to a greater extent than individual species. However, these moss mats are often composed of a consistent flora—the target species.

Although no rare, threatened, or endangered species were found, one target and seven nontarget species are listed as Category 4 (ROD 1994) species, requiring general regional surveys (Table 2). Their presence in these stands, and stands included in other epiphyte studies (A. Rosso pers. comm. 1996), suggests that some of these species may be more common than previously believed. However, given that the rate and the impacts of commercial moss harvest are unknown, permitting harvest of species that may become classified for active management is somewhat of a gamble.

Harvestable Moss Mat Diversity

In both mountain ranges, a typical harvestable mat had three to four species, most of which were

target mosses or hepatics (mean alpha diversity, Table 3). Harvest in a typical stand would reduce the populations of 6-7 target species, 2-3 incidental species, and 5-6 nontarget species, and an occasional ROD (ROD 1994) listed Category 4 lichen. Total cryptogamic gamma diversity across mountain ranges was 48; mean alpha diversity was 3.6 and beta diversity was 13.3. The large range in gamma diversity among sites, and subsequently the high beta diversity, is primarily a function of variability in the presence of nontarget species in these mats. Although the same target species occurred in most mats, nontarget species differed from site to site and even from mat to mat within sites. This is because (a) harvesters consistently seek out target species and generally ignore nontarget and incidental species, and (b) nontarget and incidental species tend to be either rare on the landscape in general or most common on other substrates, such as the forest floor (*Leucolepis acanthoneuron*, *Plagiomnium venustum*), logs (*Hypnum circinale*, *Plagiothecium undulatum*, *Rhizomnium glabrescens*), or the canopy (*Pseudocypbellaria anomala*, *Sticta limbata*), and occur only occasionally as understory epiphytes.

Lichen gamma diversity showed no pattern in relation to any stand characteristics. Moss gamma diversity increased when a higher proportion of sampled stems were tree trunks ($r = 0.49$), particularly red alder (*Alnus rubra*; $r = 0.59$), but decreased when conifer basal area was higher ($r = -0.72$). Gamma diversity for hepatics increased only when host surface area was higher (i.e., larger trees; $r = 0.49$). These results indicate that the harvestable epiphyte communities on hardwood tree trunks are distinct from those on shrub stems. Host surface area, epiphyte mat mass, and overall species richness were all substantially higher

TABLE 3. Totals (ranges among sites in parentheses) in cryptogamic diversity of epiphytes found in harvestable moss mats in the Cascade and Coast Ranges, northwestern Oregon. Alpha diversity, α , is the average number of species per mat. Gamma diversity, γ , is the total number of species accumulated from all mats per site and per range. Beta diversity, β , is a measure of community change, calculated is γ/α . ROD = Category 4 (ROD 1994) survey and manage species.

	Cascade Range Sites	Coast Range Sites
α	3.5 (2.5-4.0)	3.7 (1.5-5.8)
γ	37 (8-18)	32 (6-21)
β	10.6 (2.9-5.3)	8.6 (2.9-4.6)
Species Richness		
Mosses	19 (5-13)	18 (3-12)
Hepatics	5 (2-5)	6 (2-4)
Lichens	13 (0-9)	8 (0-3)
No. Target Species	7 (5-7)	7 (5-7)
No. Incidental Species	6 (1-4)	6 (0-4)
No. Nontarget Species	26 (1-11)	21 (1-14)
No. ROD listed lichens	5 (0-5)	4 (0-2)

on tree trunks than shrub stems (ANOVA, $p < 0.001$) and species composition was significantly different between tree trunks and shrub stems for both mountain ranges (MRPP, $p < 0.001$). While only the target species *Isothecium myosuroides* strongly indicated shrub stems, several nontarget and incidental species indicated tree trunks (Table 4).

Although epiphytic bryophyte diversity has been studied in the Pacific Northwest by a number of researchers (Coleman et al. 1956; Hoffman and Kazmierski 1969; Hoffman 1971; Kenkel and Bradfield 1981, 1986; Peck et al. 1995; A. Rosso pers. comm. 1996), direct diversity comparisons between these studies and the current study are

TABLE 4. Indicator values for epiphytes found in harvestable moss mats on shrub stems and tree trunks, northwestern Oregon. IV = indicator values. Species with large IV's for a group are strong indicators for that group. Only species with p values < 0.05 and differences in IV's of 5 points are listed.

Species	IV		Species	IV	
	Shrubs	Trees		Shrubs	Trees
<i>Claopodium crispifolium</i>	1	20	<i>Metzgeria conjugata</i>	0	9
<i>Dicranum scoparium</i>	0	10	<i>Plagiothecium undulatum</i>	0	9
<i>Eurhynchium oreganum</i>	3	25	<i>Polypodium glycyrrhiza</i>	0	8
<i>Isothecium myosuroides</i>	58	26	<i>Porella navicularis</i>	17	37
<i>Leucolepis acanthoneuron</i>	0	6	<i>Rhytidadelphus loreus</i>	2	14
<i>Metaneckera menziesii</i>	0	20			

not possible as these studies involved collections of all epiphytes present, whereas the current study only included species found in harvestable epiphyte mats. By definition, therefore, the current study does not include many appressed species (e.g. *Radula*). However, diversity values in the current study were not outside the range of those found in these studies.

The species list overlaps considerably with other epiphyte studies in the Pacific Northwest. Nineteen out of 29 epiphytes found on *Acer macrophyllum* over five sites in British Columbia (Kenkel and Bradfield 1986) were also found in the current study. In a study of conifers in British Columbia, Peck et al. (1995) found 33 species of epiphytes, 10 of which were also found in the current study. Of 44 bryophytes found in an extensive study of epiphytes on shrubs in the Oregon Coast Range (A. Rosso pers. comm. 1996), 24 were also found in harvestable epiphyte mats. Although the relative overlap among these studies may appear low, these studies included a broader range of bryophytes than only those occurring in harvestable quantities. In that light, the degree of overlap indicates that harvestable epiphyte mats are composed of several species, particularly target species, that are common and abundant throughout the Pacific Northwest.

Variation in Harvestable Moss Mat Communities

Ordinations were performed on two subsets of the combined Cascade and Coast Range data matrix; the "target species" dataset (seven species) and the "nontarget and incidental species" dataset (18 species), which included only species with a frequency of occurrence of >5% in at least one mountain range. Both ordinations were rotated such the basal area of conifers was aligned with axis one to facilitate interpretation.

Ordination of the target species dataset produced a two dimensional solution accounting for 82% of the variability in the data (Figure 1a). The first axis, which explained 57% of the variation, was positively correlated with all target species ($r > 0.5$) except *Antitrichia curtispindula* ($r = 0.1$), and contrasted stands with high hardwood basal area ($r = 0.51$) and stands with high conifer basal area ($r = -0.67$). Target species, except *Antitrichia*, were most abundant in stands with high hardwood basal area. The second axis, which explained 25%

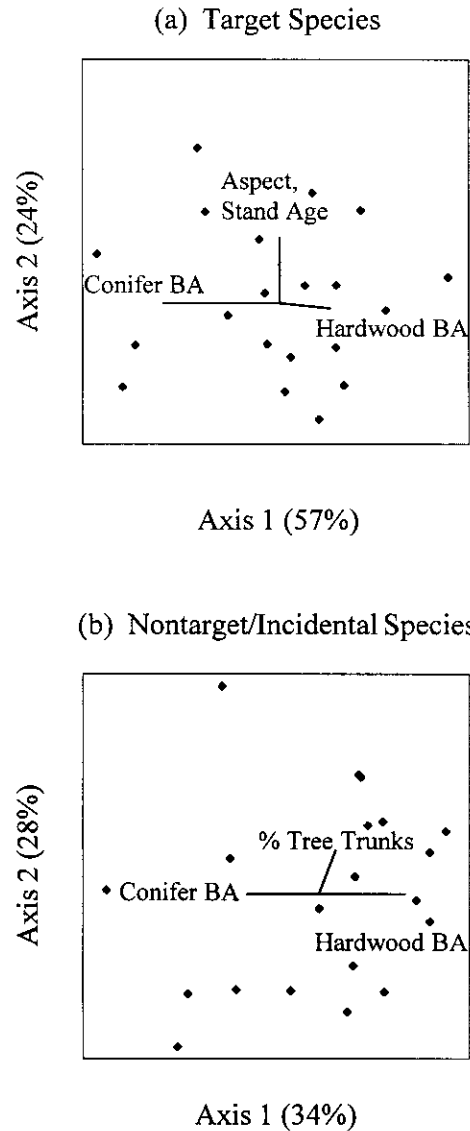


Figure 1. NMS ordinations based on target species (a: seven most common and abundant species), and nontarget/incidental species (b: 18 less common and abundant species), Cascade and Coast Ranges, northwestern Oregon. Diamonds are sites. Line lengths represent the strength and direction of correlations of site characteristics with axes. Both ordinations indicate that epiphytes found in harvestable moss mats are least abundant in stands with high conifer basal area and most abundant in stands with high hardwood basal area. The target species *Antitrichia curtispindula* was less abundant in older, drier stands, while the greater abundance of several nontarget/incidental species on tree trunk hosts transcended other environmental factors.

of the variability in the data, was strongly correlated with *Antitrichia curtispindula* ($r = -0.76$), and contrasted older (stand age $r = 0.47$), drier (aspect $r = 0.57$) stands with younger, wetter stands. *Antitrichia curtispindula* was less abundant in the older, drier stands, despite being typically considered an old-growth associate (ROD 1994). Its presence in these younger stands suggests that its association with old-growth may be a function of general environmental conditions not necessarily specific to old-growth.

The nontarget/incidental species dataset had a two dimensional solution accounting for 62% of the variability in the dataset (Figure 1b). The first axis explained 34% of the variability and was positively correlated with the abundance of the mosses *Claopodium crispifolium* ($r = 0.62$), *Dicranum scoparium* ($r = 0.43$), *Homalothecium nuttalli* ($r = 0.43$), *Orthotrichum lyellii* ($r = 0.49$), *Plagiothecium undulatum* ($r = 0.41$) and *Rhizomnium glabrescens* ($r = 0.43$) and the vascular plant *Polypodium glycyrrhiza* ($r = 0.45$), and negatively correlated with the lichen *Lobaria pulmonaria* ($r = -0.53$). This axis also contrasted stands with high hardwood basal area ($r = 0.59$) and those with high conifer basal area ($r = -0.61$). These nontarget and incidental species were most abundant in stands with high hardwood basal area, except the canopy lichen *Lobaria*, which was most abundant in stands with high conifer basal area. Greater harvestable epiphyte abundance in areas with high hardwood basal area (and lower abundance in conifer dominated sites) supports previous indications that hardwoods are important for epiphyte communities (Neillich and McCune 1997, Rambo and Muir 1995). The second axis, which explained 28% of the variability, was positively correlated with the proportion of tree trunks sampled ($r = 0.44$). This axis was positively correlated with *Claopodium crispifolium* ($r = 0.52$) and *Metaneckera menziesii* ($r = 0.45$), both predominantly tree trunk epiphytes. Again, nontarget/incidental species appear to be associated with hardwood tree trunks to a greater extent than understory shrubs.

Cascade Range and Coast Range sites did not separate in the ordinations when analyzed together and separate analyses of the target species for each range revealed essentially identical patterns. The primary difference between ranges was the complexity of the gradients influencing harvestable epiphyte abundance, with epiphyte abundance in

the Cascade Range related to aspect, slope, hardwood basal area, and the linear distance to water, which were not important in the Coast Range. This complexity, however, may simply reflect the wider geographic range, and larger spread of stand ages (from 50 to 290) of the Cascade Range sites relative to the Coast Range sites. In addition, the Cascade Range sites were chosen as areas of high lichen diversity. Although average moss and hepatic species richness did not differ between the two ranges, it is impossible to quantify what effect this difference in site selection had on the comparison of the two mountain ranges. Of all 50 species, twenty-three species were common to both mountain ranges (Table 2), including all target and incidental species. In the Cascade Range, *Isothecium myosuroides* contributed 31%, and *Neckera douglasii* 47%, to total harvestable biomass. Their roles were reversed in the Coast Range, where *I. myosuroides* and *N. douglasii* contributed 55% and 25% of the harvestable biomass, respectively.

Management Implications

It is important to note that the definition of what is considered harvestable by commercial moss harvesters will depend on demand; as restrictions on moss harvest increase on some public lands, moss mats previously considered marginal will begin to be harvested simply because they are still available on other private and public lands. A shift in this direction would likely lead to increased harvest of incidental species, and of the nontarget species associated with those communities. One of the most important findings of this study is the discovery that commercial moss harvest impacts a significantly larger community than the handful of most abundant mosses, including ROD (1994) listed lichens. The inadvertent harvest of species that may someday require active management suggests that restrictions discouraging the harvest of these species may be appropriate.

Identifying and quantitatively distinguishing categories of target, incidental, and nontarget species will enable managers to direct harvest away from areas with more sensitive species. Managers should protect some areas from harvest (e.g., Late Successional Reserves to be managed toward "old growth" conditions) to facilitate the continuity that may be required to develop complex, mature epiphyte mats. The actual impact

of moss harvest on nontarget and incidental species can only be evaluated by examining the abundance of these species on other substrates, particularly in cases where these species occur primarily as non-epiphytes. The general surveys required for many lichen and bryophyte species listed in the ROD (1994) should provide an opportunity to survey for other species that are impacted by commercial moss harvest. The broad geographic distribution of common epiphytic bryophyte species suggests that some level of commercial moss harvest may be acceptable over the landscape if pockets of target species can be identified for harvest, or conversely, if pockets of nontarget/incidental species can be identified for protection.

There are several obstacles to determining what level of commercial moss harvest is acceptable on the landscape. First, basic inventory information is lacking about the landscape level distribution and abundance of harvestable mosses. Case studies such as the current study aid local managers, but ultimately widescale inventories will be required in order to determine the magnitude of the resource base and to evaluate patterns of abundance in relation to stand characteristics such as the presence of a hardwood component in the overstory. Second, the ecological roles of harvestable mosses are virtually unknown. Landscape level inventories should incorporate sampling designed to evaluate the role of harvestable mosses as food and habitat for invertebrates, as regulators of nutrient and water cycling in the forest ecosystem, and as sources of diversity in the epiphytic and cryptogamic communities.

The most pressing need, however, is for public land managers to come to a consensus on which aspects of "sustainability" need to be managed. Harvestable epiphytes are a multifaceted resource. In addition to their ecological roles, they provide income for local residents with a long tradition

of supplemental income derived from public lands and they provide a level of aesthetics to which residents of the Pacific Northwest are accustomed. Sustainability must be defined, whether it be as sustainability of harvest volumes, of continuity for old-growth moss mat development, or of a rich mantle of green adorning our forests.

Summary

In twenty sites in northwestern Oregon, harvestable moss mats ranged from 20 to 80 g (dry weight) and were composed of 50 species of mosses, hepatics, lichens, and an occasional vascular plant. The most common and abundant species, which are targeted for commercial harvest, are most abundant in stands with high hardwood basal area. These species are common and abundant throughout the Pacific Northwest. Less common and abundant species, which are often incidentally harvested, are also more abundant on large surface-area hosts (i.e., mature hardwoods). These nontarget and incidental species contribute a large proportion of the diversity of the harvestable epiphyte community and can be protected if harvest is directed away from mature hardwood dominated forests.

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