DETERMINING THE SUSTAINABLE HARVEST OF OREGON-GRAPE (*BERBERIS NERVOSA)*

by

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We certify that we have read this study and that it conforms to acceptable standards of scholarly presentation and is fully acceptable, in scope and quality, as a thesis for degree of Master of Science.

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ABSTRACT

Determining the Sustainable Harvest of Oregon-grape (*Berberis nervosa*)

Jolie Lonner

This study tested the Six Rivers National Forest guidelines for harvest of *Berberis nervosa*, which allow removal of 25 percent of the *Berberis nervosa* population every two years. Treatments mimicking harvest activity of 25 percent total rhizome, 25 percent partial rhizome and 100 percent removal were tested in a random block design at two locations, Willow Creek and Jim Jam, in northern California. The hypothesis was that it would take longer then the two-year period suggested by the USDA Forest Service for Oregon-grape to recover. After two years the amount of rhizome regeneration from experimental treatments were compared to pre-harvest and absence of harvest baselines using analysis of variance tests.

Oregon-grape populations at the two sites responded differently to harvest. At both sites, completely harvested plots (100 percent) regenerated significantly slower than plots where one out of four plants (25 percent) were harvested. At both sites completely harvested plots did not regenerate to pre-harvest rhizome biomass levels after two years. The 25 percent harvest treatments at Jim Jam did regenerate to pre-harvest rhizome biomass levels. The 25 percent harvest treatments at Willow Creek did not regenerate to pre-harvest levels. None of the harvested treatments regenerated to biomass levels equal to those found in the absence of harvest baseline. There was no significant difference in regeneration between harvesting the total rhizome or only the top 0.3 meters of it. None of the harvest strategies in this study are restrictive to ensure a sustainable harvest.

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INTRODUCTION

Herbal medicine is gaining popularity rapidly among consumers in North America and Europe. Over 60 million adult Americans have used medicinal herbs, spending an average of $54 per person each year on herbal medicine (Johnston 1997). The phytopharmaceutical market in Europe has expanded with annual sales now at an estimated $6 billion, including at least $2 billion in Germany alone (Blumenthal 1999). Nearly 80 percent of German physicians regularly recommend plant medications (Harrison 1998). The herbal medicine industry has experienced five years of unprecedented growth (Blumenthal 1999) and the US market for medicinal botanicals has reached $3.87 billion dollars (Brevoort 1998).

Many of these medicinal plants are wildcrafted, meaning they are harvested from wild areas rather than cultivated as crops. In the Pacific Northwest, non-timber forest products such as medicinal plants account for over $200 million in revenue per year (Molina et al 1997). As rural forest communities experience drastic declines in revenue due to loss of federal timber dollars, the non-timber forest product industry is becoming increasingly important to rural economic recovery and development (Molina et al. 1997).

While the medical claims of herbal medicines are rapidly being substantiated, the ecological and biological impacts from increased harvest of these special forest products have yet to be explored. Intensive commercial collection of wild medicinal plants may be contributing to the demise of plant populations already under threat from habitat alteration (Robbins 1998).

A medicinal plant currently gaining attention is the forest shrub dwarf Oregon-grape (*Berberis nervosa*, Family Berberidaceae*)*, an evergreen shrub that grows in the understory of conifer forests in the Pacific Northwest and in northern California. It is a commercially valuable forest botanical with a growing market.

The Six Rivers National Forest in coastal northern California, has guidelines for products collected by complete plant removal. These guidelines allow for the harvest of one-quarter of the desired species of plants within the area. Harvested areas must then rest for two years between harvests (United States Department of Agriculture, Forest Service 1995).

This study tested the current Six Rivers National Forest Service harvest guidelines for dwarf Oregon-grape, which are attempting to promote a sustainable level of harvest. This research mimics current regulated and proposed wildcrafting practices for *B. nervosa* rhizome. Experimental treatments of harvest methods are applied at two sites located in the Six Rivers and the Shasta-Trinity National Forests. The objective was to evaluate effects of 100 percent harvest, 25 percent harvest, and partial rhizome harvest on biomass regeneration two years after initial harvest.

The harvesting of non-timber forest products can be detrimental to individual species as well as ecosystems and habitats (Viana 1996). In the northeastern United States, over-harvesting of edible fiddlehead fern (*Matteuccia struthiopteris*) has caused a decline in the number, size, and flavor of ferns from popular collection sites (Viana 1996). In Canada, local extinctions of wild leek (*Allium triococcum*) were reportedly due to harvest at levels as low as 5 to 15 percent of the population (Viana 1996).

Organizations are forming to address the overharvest of wild plants. United Plant Savers, a non-profit grassroots group composed of concerned representatives from the herbal and phytomedicine industry, is dedicated to the conservation and cultivation of at-risk native medicinal plants (Katz 2001). United Plant Savers has prepared a list of at-risk plants, and has initiated programs designed to preserve these important medicinal plants in the wild. Popular botanical medicines such as American ginseng (*Panex quinquefolius*, Family Arailaceae), goldenseal (*Hydrastis canadensis*, Family Ranunculaceae), kava (*Piper methysticum*, Family Piperaceae), peyote (*Lophophora williami*, Family Cactaceae) osha *(Ligusticum spp.*, Family Apiaceae), and black cohosh (*Cimicifuga racemosa,* Family Ranunculaceae) are included in the United Plant Savers at-risk list (Katz 2001). In addition, United Plant Savers publishes a "To-Watch" list that features plants that have the potential to become at-risk within the near future (Gladstar and Hirsch 2000). United Plant Savers features all North American Oregon-grape species on their To-Watch list which contains plants that have the potential to become at-risk within the near future (Gladstar and Hirsch 2000).

Dwarf Oregon-grape (*Berberis nervosa*, Family Berberidaceae) is swiftly becoming popular as an herbal remedy (Drum 2000). The rhizome is harvested for medicinal purposes, while the leaves are in demand for floral greens.

The literature on reproductive biology and population ecology of *Berberis nervosa* is limited. Oregon-grape is a slow-growing erect evergreen clonal shrub about 0.1 to 2 meters tall, and is found at altitudes of less than 2000 meters (Hickman 1993). The plant originates from long rhizomes that send up woody stems bearing pinnately divided evergreen leaves (Hickman 1993). These aerial stems appear to be long-lived. Huffman and Tappeiner (1997) sampled stems that had 20 height growth increments, and the oldest living stem was estimated at 30 years. Drum (2000) estimated that plants live for up to 150 years.

Each holly-like leaf is made up of 7 to 23 lanceolate to ovate palmately veined leaflets that are 2.5 to 9 cm long and 1.5 to 2.3 cm wide, with 1 to 2 mm spines along the edges (Hickman 1993, Tilford 1993). Bud bracts are leathery and persist among upper leaf bases (Hickman 1993). Figure 1 is an illustration of *Berberis nervosa* showing a compound leaf made up of palmately veined leaflets, which is subtended by persistent bracts.

The flowers of Oregon-grape are yellow, and grow in terminate racemes containing over 20 flowers separated by internodes of 2 to 8 mm (Hickman 1993). There are nine sepals in three whorls of three, and six petals in two whorls of three (Hitchcock et al. 1994). Each flower has six stamens and one spherical stigma. The blue or purple berries are 8 to 12 mm in diameter, containing seeds measuring 4 to 6 mm in diameter (Hitchcock et al. 1994). *Berberis nervosa* can be found west of the Cascades from southern British Columbia south to central California (Hitchcock et al. 1994). Within the California

Figure 1. Dwarf Oregon-grape (*Berberis nervosa*). The distinguishing taxonomic features of *B. nervosa* are palmately veined leaflets and persistent bracts that subtend compound leaves.

Floristic Province, *Berberis nervosa* is found in northwestern California, Sierra County, the San Francisco Bay area, and the south Coast Range (Hickman 1993).

Berberis nervosa flowers from March through June (Hitchcock et al. 1994). The rhizomatious nature of this plant makes it an effective soil aerator and erosion control agent. The berries are produced late in the summer and fall, and along with the leaves, are browsed upon by deer, elk, moose, bears, rodents, and birds (Tilford 1993). For many animals, Oregon-grape produces one of the last berries available before winter (Everett 1997).

In the Pacific Northwest, *Berberis nervosa* is a common understory species which occurs in all stages of forest stand development, from the stem initiation stage (following fire or timber harvest) through old-growth stages (Huffman and Tappeiner 1997). In early seral stages (shade-thinned stands at the stem exclusion stage) these shrubs occur as small (1.0 x 1.0 meter), sparse ($\leq$ 20 percent cover) single-species patches. However, in thinned pole or mature stage stands they may become dense (> 70 percent cover) patches from 1 to 1.5 m tall and from 2 to more than 10 m across (Huffman and Tappeiner 1997). Because of its frequency, extent, and cover, Oregon-grape is likely to exert a major influence on understory development. It inhibits the establishment of such shade-tolerant trees as western hemlock (*Tsuga hetrophylla* Family Pinaceae), bigleaf maple (*Acer macrophyllum,* Family Aceraceae), and probably shrubs and herbs as well (Huffman and Tappeiner 1997).

Oregon-grape understory establishment is accomplished by recruitment of seedlings and new genets. Seedling recruitment enables Oregon-grape to expand to the perimeter of established patches, as well as to establish new patches. Huffman and Tappeiner (1997) examined the clonal expansion and seedling recruitment of Oregon-grape and indicated that seedling establishment is the principle means of colonization. However, once Oregon-grape becomes established in a dense patch, it is then maintained by vegetative recruitment via aerial stems and ramets (Huffman and Tappeiner 1997).

Auge and Brandl (1997) found sexual reproduction to be important for dispersal to new sites in *Berberis aquifolium*. Seedling densities were found to be higher beneath the canopy of adults than outside adult patches or neighborhoods. Seedling density increased with increasing cover of adult ramets. The spatially clumped pattern of seedling emergence results in density-dependent mortality, especially in the most crowded seedling clusters. The adult neighborhood imposes a high mortality on seedlings (Auge and Brandl 1997)

The importance of *Berberis aquifolium* seedling recruitment on population dynamics declines as the invasion process continues (Auge and Brandl 1997). In situations where competition from other species is increased, the number of successful recruits is reduced and clonal growth is the predominant mode of reproduction (Auge and Brandl 1997).

While the information on the biology and ecology of Oregon-grape is scarce, the ethnobotanical information is prolific. Oregon-grape has rich cultural history and wide range of traditional usage. Some tribes dried the fruits of Oregon-grape for winter food (Balls 1962). Another important use for these plants was to make a yellow dye for baskets, buckskins, and fabrics (Clarke 1977). The bark was used as a laxative and to make a lotion to treat various skin diseases (Balls 1962). The Karok used it as a medicine for all kinds of sickness (Moerman 1986,). Yet according to Balls (1962), the Karok Indians considered the berries to be poisonous but pounded them with the flowers of Larkspur for decorating bows and arrows. The Kwakiutls of Oregon used Oregon-grape to aid digestion (Clarke 1977). Many Indian groups boiled the rhizome to drink as treatment for venereal disease or fever (Clarke 1977).

Today, the medicinal value of Oregon-grape is gaining attention. In western herbalism the rhizome is commonly used as a bitter tonic for impaired salivary and gastric secretions, a stimulant to liver and skin protein metabolism, and an anti-microbial for the intestinal tract and mucous membranes (Moore 1993). *Berberis spp.* can be used for gallstones (Hoffman 1990). It is a useful treatment for chronic and scaly skin conditions, such as eczema, associated with liver dysfunction (Moore 1993). Oregon-grape can treat low stomach acid conditions, constipation, nausea or vomiting (Hoffman 1990). *Berberis spp.* soothes irritations of the intestines and can be employed to kill intestinal bacteria or parasites (Hobbs 1992). The leaves can be powdered or used in a salve to combat external infection (Moore 1993).

One of the active constituents in Oregon-grape rhizome is the yellow alkaloid berberine. Berberine's most common clinical uses include treatment of bacterial diarrhea and intestinal parasites. Evidence also suggests intravenous berberine administration can also prevent the onset of rapid rate irregularities of ventricular heartbeat and sudden coronary death following insufficient supply of blood to the heart muscle (Birdsall 1997).

Berberine is also found in the highly valued goldenseal (*Hydrastis canadensis*), which grows primarily in the eastern United States (Drum 2000). Goldenseal is the second most important North American native medicinal plant trade, second only to wild American ginseng (Blumenthal 2000). Goldenseal is major product in the US herbal market. In 1997, goldenseal sales accounted for 4 percent of the $3.6 billion herbal market (Brevoort 1998). Goldenseal is a slow-growing perennial native to hardwood forests of the northeast United States (Blumenthal 2000). In response to concerns of diminishing wild populations, the American Herbal Products Association sponsored a tonnage survey to quantify the 1998 harvest of the root from all wild and cultivated sources (Blumenthal 2000). Annual usage for 1998 was reported to be 265,000 pounds of dried root. Of this amount, only 2.4 percent of the tonnage was from cultivated sources (Blumenthal 2000). The largest producers of goldenseal have been investing in the transition to agricultural sources, and the establishment of cultivated acreage has increased significantly in the last several years. The American Herbal Products Association projects that in the next several years cultivated goldenseal will increase to 15 to 30 percent of total demand (Blumenthal 2000). Regretfully, these efforts may not be sufficient to protect wild populations of goldenseal (McGuffin 1999). In June 1997, the Commission on International Trade in Endangered Species listed goldenseal in Appendix II, prohibiting international trade of whole or powdered goldenseal root (Gladstar and Hirsch 2000). Because goldenseal is so scarce, some authors and herbal industry leaders recommend using Oregon-grape as an alternative source of berberine, and to fulfill a role similar to that of goldenseal (Blumenthal 2000).

The entire portion of the Oregon-grape plant that grows beneath the ground is used for medicine (Moore 1993). However, Tilford (1993) recommended harvesting only the top one foot of the rhizome and leaving the rest in the ground to reduce ecological impact. Tilford (1993) also recommended that wildcrafters wait to harvest rhizomes until the plant has set seed. Moore (1993) recommended harvesting rhizomes from mid-summer to fall as the medicinal qualities of the rhizomes will be more potent later in the season.

The plant is usually harvested by grasping the main stem just above ground level and pulling the rhizome out of the earth. If the rhizome does not pull out easily, clipping it with sharp clippers is recommended (Tilford 1993). Everett (1997) recommends harvesting from the edges of stands to avoid compacting and trampling soil.

Many land managers, herbalists, and community members are concerned that the growing demand for Oregon-grape will lead to over-harvesting and the decrease or loss of this native plant (Drum 2000). Everett (1997) classified *Berberis* as sensitive to harvest because management information is limited and harvest of this slow-growing native species kills the entire plant.

Some National Forests regulate the harvest of special forest products like Oregon-grape, by issuing permits for specified quantities (United States Department of Agriculture and United Stated Department of the Interior 1994). The Six Rivers National Forest located in northern California has developed guidelines for products collected by complete plant removal (United States Department of Agriculture, Forest Service 1995). These guidelines allow the harvest of one out every four plants of each desired species at each site. The Forest Service guidelines state that harvesting one out of every four plants “can be interpreted to mean the harvest of 25 percent of the population of each harvestable species in each permitted area.” Areas in which permits are issued are supposed to be rested for two years between harvests (United States Department of Agriculture, Forest Service 1995). These regulations attempt a conservative definition of the best management practices given a distinct lack of study and management information.

Due to the lack of data on the reproductive biology and population ecology of *Berberis nervosa* and the growing demand for this plant, *B. nervosa* warrants increased scientific attention. Until now, no studies pertaining to the harvest of rhizomes of *B. nervosa* or related species have been reported. My study tests the current Six Rivers National Forest harvest guidelines for dwarf Oregon-grape attempting to determine guidelines for sustainable harvest. My research focuses on patches of *B. nervosa* growing on two different locations in the Six Rivers and Shasta-Trinity National Forests. In 1998, plots containing Oregon grape were subjected to one of four treatments. These treatments were: the current Six Rivers National Forest guidelines of harvesting one out of four plants; a proposed wildcrafting method of harvesting only the top 0.3 meters (one foot) of rhizome from one out of every four plants; complete removal of all plants in the plots; and control (no harvest). All excised biomass was dried and weighed. In the summer of 2000, after two years of resting the plots, I harvested the remaining plants within all the plots in order to determine the amount of biomass regeneration.

The objectives of this study were:

1. To determine whether there is a difference in rhizome biomass at the two research sites.

2. To determine whether harvest impacts vary across the environmental gradient of the sites.

3. To determine whether the rhizome biomass of each treatment regenerates to levels statistically similar to pre-harvest levels within two years of initial harvest.

4. To determine whether the rhizome biomass of each treatment regenerates to levels statistically similar to control plots that represent biomass levels in absence of harvest within two years.

5. To determine whether harvesting the total versus partial rhizome from one out of every four *Berberis* plants results in a difference in biomass regeneration two years after initial treatment.

STUDY SITES

Three study areas located within the Six Rivers and Shasta-Trinity National Forests along a moisture and elevational gradient were selected in 1998. The use of multiple study sites increased the ability to interpret the effects of location and differing environmental factors on regeneration of Oregon-grape in response to harvest. Prerequisites for site selection were a minimum of 25 percent Oregon-grape ground cover and a Forest Service management strategy that excluded timber harvest for the duration of this study. The three sites were Jim Jam, East Fork Willow Creek (Willow Creek), and Waterman Ridge. Study areas were located in the southern-most quarter of the range for *Berberis nervosa* (Hitchcock et al. 1994). All three research sites were in the northwestern region of the California Floristic Province and were located within Klamath Range subregion (Hickman 1993).

In summer of 1999, lightning strikes ignited several fires, collectively called the Big Bar fires, in the western Trinity Alps mountains of northern California. The Megram fire, a major component of the Big Bar fires, burned through the Waterman Ridge site. The Forest Service constructed a fireline directly through this study site. The Oregon-grape plots were not recoverable, and the Waterman Ridge site was removed from this study.

Figure 2 shows the study sites in northern California. Willow Creek was the western-most site while Jim Jam was the easternmost. Willow Creek had an elevation

Figure 2

of 600 meters with a northeastern aspect and average annual precipitation of 190 cm (California Department of Water Resources 2001). Jim Jam had the highest elevation (approximately 1300 meters) with a northwestern aspect and a mean annual precipitation of 165 cm (California Department of Water Resources 2001). At each site, 0.040 hectare (one-tenth acre) plots were placed in areas representative of the site that contained *B. nervosa* plots. These characterization plots were used to determine slope, aspect, canopy closure.

The overstory at each site was characterized for a 0.008 hectare (one-fiftieth of an acre) circular plot with a radius of 4.9 meters. All trees within this circular plot were recorded by species and diameter at breast height (dbh). Dbh classes were defined as: less then 15 cm; 15 to 25 cm; 26 to 45 cm; 46-60 cm; and greater than 60 cm (Avery and Burkhart 1994).

Understory characteristics were assessed in 0.00040 hectare plots (one-thousanth of an acre) containing a radius of 0.95 meters. Each plant species and its percentage cover were recorded. *Berberis* cover within the plots was recorded and averaged to achieve the mean *Berberis* cover for the study area. Plant associations were determined using in Jimmerson et al. (1996). This guide describes an ecological classification for plant associations of the tanoak (*Lithocarpus densiflorus*) and Douglas fir (*Pseudotsuga menziesii*) vegetation series.

Jim Jam was located in the Shasta Trinity National Forest and borders the Trinity Alps Wilderness Area (T7N R8E Section 30, Mount Diablo Meridian). The elevation was approximately 1300 meters. This area included a recreational trail to Jim Jam Ridge. All 40 Oregon-grape harvest plots were located near this trail. The slope on site averaged 20 percent. The Jim Jam site had a northwest aspect of 314 degrees.

This late mature mixed conifer forest had a mean canopy cover of 82.5 percent. It was structurally diverse with numerous down trees and snags. It did not appear to have been logged. The overstory canopy was composed of about 25 large Douglas fir (*Pseudotsuga menziesii)* trees per hectare with and average dbh of 127 cm. White fir (*Abies concolor)* dominated the mid-canopy layers. There were approximately 50 white fir trees per hectare ranging from 25 to 90 dbh. Scars on the white fir indicated a low intensity fire. Also in the middle canopy were small numbers of big leaf maple *(Acer macrophyllum),* and Pacific dogwood *(Cornus nuttallii*). The regeneration layer consisted of tanoak (*Lithocarpus densiflorus).* Tanoak canopy cover ranged between 10 and 100 percent.

The shrub layer consisted of dwarf Oregon-grape, holly-leaved Oregon-grape (*Berberis aquifolium*), California hazelnut *(Corylus cornuta* var. *californica*), snowberry *(Symphoricarpos alba*), oceanspray (*Holodiscus discolor),* and black-cap raspberry (*Rubus leucodermis).*

Berberis nervosa cover within the 40 harvest plots averaged 68 percent. *Berberis aquifolium* was present in small numbers throughout the plots. While a few plots had 30 percent *B. aquifolium* cover, the majority had less then 1 percent cover. The herb layer was made up of a variety of species, none of which alone exceed an average ground cover of 3 percent. Plant species included: The inside-out flower (*Vancouveria hexandra),* fairy bells (*Diasporum hookeri),* rattlesnake plantain *(Goodyera oblongifolia),* cleavers (*Galium sp.),* rose *(Rosa sp.),* false Solomon seal *(Smilacina racemosa),* trail plant *(Adenocaulon bicolor),* thimbleberry *(Rubus parviflorus),* cinquefoil *(Potentilla sp.),* and sweet root *(Ozmorhiza sp.).*

The Jim Jam site was in the tanoak/dwarf Oregon-grape association. This forest type is commonly found in middle elevation inland sites in northern California with steep cool slopes (Jimmerson et al. 1996).

The Willow Creek Site was located in the Six Rivers National Forest. This site was at the East Fork campground on the east fork of Willow Creek, and was found in T6N R4E Section 15, Mount Diablo Meridian. The elevation was approximately 600 meters. This site had a slope of 25 percent, and a northeast aspect of 50 degrees.

This mature forest had a mean canopy cover of 88 percent. It also had a high degree of structural diversity, down trees, and snags. There is some evidence of selective logging. The overstory canopy was composed of about 60 large Douglas fir (*Pseudotsuga menziesii*) trees per hectare, averaging 85 cm dbh. Also scattered in the overstory were large Pacific madrone (*Arbutus menziesii)* trees with an average dbh over 80 cm. Chinquapin *(Chrysolepis chrysophylla)* was present in the overstory and middle canopy, making up less then 5 percent cover. Tanoak (*Lithocarpus densiflorus)* dominated the lower regeneration layer. My survey recorded 100 tanoak trees per hectare with a dbh of 25 cm or less. Tanoak canopy cover ranged from 10 to 100 percent.

The shrub layer consisted of dwarf Oregon-grape and salal (*Gaultheria shallon).* On average, 37 percent of the ground in the research plots was covered with Oregon-grape, while 10 percent of the ground was covered with salal.

The herb layer was made up of a variety of species, none of which alone had an average ground cover greater than 3 percent. The herb layer was composed of bracken fern (*Pteridium aquilimun),* oxalis (*Oxalis oregana),* white veined shin-leaf (*Pyrola picta),* and little prince's pine (*Chimaphila umbellatum).*

This site was in the tanoak/dwarf Oregon-grape-salal association. This forest type is found in middle elevation sites with steep, cool, north-facing slopes. This association is characterized by the presence of Salal and Dwarf Oregon-grape (Jimmerson et al. 1996). Table 1 compares environmental variables for Jim Jam and Willow Creek sites.

Table 1. Environmental variables at Willow Creek and Jim Jam research sites

Site	Willow Creek	Jim Jim
Elevation	600 meters	1300 meters
Aspect	50°	314°
Slope	25%	20%
Mean Canopy % Cover	88%	82.5%
Mean *Berberis* % Cover	37%	68%
Mean Annual Precipitation	190 cm	165 cm
Plant Association	Tanoak/dwarf Oregon-grape-salal	Tanoak/dwarf Oregon-grape

MATERIALS AND METHODS

The research design was modified from Everett and Beyers (1997).Within each study area, I identified 40 permanent four square meter plots. I subjectively placed plots in areas with greater than 25 percent *B. nervosa* cover. At each plot two pieces of rebar, approximately one meter long, were set half-way in the ground, marking diagonal plot corners. Plots were assigned a number, identified by a survey tag, and mapped.

One of four treatments was randomly assigned to each plot. Ten plots per site were assigned each treatment. I used four light-weight wooden plot boundary markers measuring two meters each to delineate the plots during the harvest. At each plot, I recorded the percentage cover for all plant species including *B. nervosa*. The number of *B. nervosa* stems were counted. The number of fruiting Oregon-grape plants within the plot was recorded. During all stages of the fieldwork, special care was taken to avoid trampling or stepping within treatment areas.

In 1998, the initial harvest treatments were completed. The harvest treatments were no harvest (control), 25 percent total rhizome harvest, 25 percent partial rhizome harvest, and 100 percent harvest. No Oregon-grape removal occurred in the control plots. Often control treatments are used to represent the normal condition such as the current United States Department of Agriculture Forest Service guidelines, however in this study control plots were used to assess normal Oregon-grape growth (in absence of harvest) over two years of study.

The 25 percent total rhizome harvest meant that the complete rhizome was removed from one out of every four Oregon-grape plants in the plot. Aerial parts were pulled up until the rhizome was accessible. The whole rhizome was then pulled out of the ground. If necessary, clippers were used to cut rhizomes that were too difficult to pull completely out of the ground. This treatment mimics current Six Rivers National Forest harvest guidelines.

The 25 percent partial rhizome harvest consisted of removing the top 0.3 meters (one-foot) of rhizome from one out of every four Oregon-grape plants while leaving the remainder of the rhizome in the ground. Aerial parts were pulled up until the rhizome became accessible and the top 0.3 meters of rhizome was clipped off. This treatment tests the wildcrafting methods proposed by Tilford (1993).

The 100 percent harvest consisted of complete rhizome removal of all the Oregon grape plants in the plot. When necessary, clippers were used to cut rhizomes that were too difficult to pull completely out of the ground. This treatment mimicked intensive commercial wildcrafting. The initial treatment is referred to as “100 percent in 1998” and the next harvest, which consisted of only the two-year regeneration in the plot, is referred to as “100 percent in 2000”.

All harvest plant material was placed in brown paper grocery bags at the site and labeled with the site and plot number. I separated the above-ground leaf biomass from the below ground-rhizomes. Rhizomes and vegetation were placed in separate grocery bags and labeled. All of the bags were dried in large ovens, provided by the Pacific Southwest Research Station at Redwood Science Laboratories, at 66°C for at least 24 hours. Because ambient moisture can add weight, bags were weighed promptly after removal from oven. The weight of the empty bag was subtracted to arrive at the net biomass.

In the summer of 2000, two years after initial harvest, all remaining biomass was removed from all plots. The processing methods outlined above were repeated to determine above- and below-ground biomass in the plots two years after harvest.

I analyzed changes in biomass following my treatments using statistical analyses. All analyses were performed in Number Crunchers Statistical Software (NCSS) 2000 or Microsoft Excel 5.0.

ANOVA was used to assess differences between treatments (Zar 1999). I addressed the differences in harvest impacts between sites and then looked at whether the differences or similarities in treatments were constant across both sites. In addition, I analyzed whether the treatments differed from pre-harvest and control baselines. In order to test proposed harvest methods, I looked at the difference between 25 percent partial and total rhizome harvest treatments.

In order to use ANOVA to test whether treatments regenerated to pre-harvest biomass levels or to biomass levels in absence of harvest, it was necessary to determine these baselines for each site. The rhizome biomass from the 100 percent harvest treatments in 1998 serves as the baseline for average pre-harvest biomass for each site individually. The rhizome biomass recorded from control plots at each site in 2000 is used as the baseline of biomass levels in absence of harvest.

In order to assess the effects of both treatment and site on population means, I used a two-factor analysis of variance (Norman 1999). This two-factor ANOVA compared 100 percent 1998 (pre-harvest baseline), 100 percent 2000, 25 percent total, 25 percent partial, and control (absence of harvest baseline), treatments blocked by site. The two factor ANOVA showed a significant interaction between treatment and site meaning that Oregon grape regeneration varied due to treatment but the variation among treatments was not the same at each site. Because of this interaction it became difficult to interpret the effects due to the individual factors of site and treatment (Zar 1999). Because of this difficulty in interpretation, I used two separate single factor ANOVAs to test for differences between treatments at each site. While I used the analysis of variance tests to determine if there is a difference between effects, these tests do not indicate where that difference is. I used Fisher's LSD multiple comparison procedure to assess which of the treatments differed (Ott 1993).

Two years after initial harvest, the 100 percent harvested plots contained only re-growth, and this re-growth was used to determine the mean amount of rhizome biomass regeneration two years after a complete harvest. The amount of rhizome regeneration after complete harvest was compared by site.

The average number of fruiting *B. nervosa* plants per plot was determined for each site. The mean number of fruiting plants per plot was compared by site for 1998 and 2000.

RESULTS

As indicated by the relatively high standard deviations and errors in Table 2, there was a high amount of variation within each treatment at both sites. This variation was in large part due to the natural variation within the population.

Data were analyzed in NCSS 2000. A two-factor analysis of variance was used in order to examine potential differences, P Value =0.05. N=10, (Table 3). As indicated by very low probability levels (less than 0.0000001) for the site, further, there was a significant difference in rhizome biomass at the two research sites. Jim Jam clearly had more Oregon-grape rhizome biomass than Willow Creek (Table 2). Oregon-grape ground cover was also greater at Jim Jam than at Willow Creek. Prior to the initial treatments, mean Oregon-grape ground covers at Jim Jam and Willow Creek were 68 percent and 37 percent respectively. Jim Jam continued to have significantly higher Oregon-grape ground cover in all the treatments two years after the initial harvests.

ANOVA results (Figure 3) show the interaction of site and treatment. This interaction occurred because the difference in mean responses between treatments was not constant at both sites (Ott 1993). Willow Creek 25 percent partial rhizome harvest plots regenerated slower than the 25 percent total rhizome harvest plots (Figure 4). The opposite was true at Jim Jam. From Figures 3 and 4, it is clear that each site responded differently to harvest treatments and that harvest impacts vary between the two sites.

Table 2. Mean rhizome biomass (grams), standard deviations, and standard error by treatment and site.

Jim Jam

Treatment	Control	100% in 98	25 % total	25% partial	100% in 2000
Mean	365.9	253.1	224.4	328.6	18.6
SD	126.1	131.2	86.4	161.1	17.0
SE	39.9	41.5	27.3	56.9	5.4

Willow Creek

Treatment	Control	100% in 98	25 % total	25% partial	100% in 2000
Mean	208.7	135.9	103.85	80.75	13.15
SD	68.5	61.7	35.8	56.0	8.3
SE	21.7	19.5	11.3	17.7	2.6

Table 3. Two-way analysis of variance table for differences among treatments and sites.

Source term	df	Sum of Squares	Mean Square	F-Ratio	Prob. Level	Power (alpha=.05)
Site	1	404164.4	404164.4	52.79	0.000000*	1.000000
Treatment	4	753872.9	188468.2	24.61	0.000000*	1.00000
Site and treatment interaction	4	141567.8	35391.96	4.62	0.001973*	0.936508
Error	87	666133.9	7656.711			
Total (adjusted)	96	1946786				
Total	97					

*Term significant at alpha = 0.05

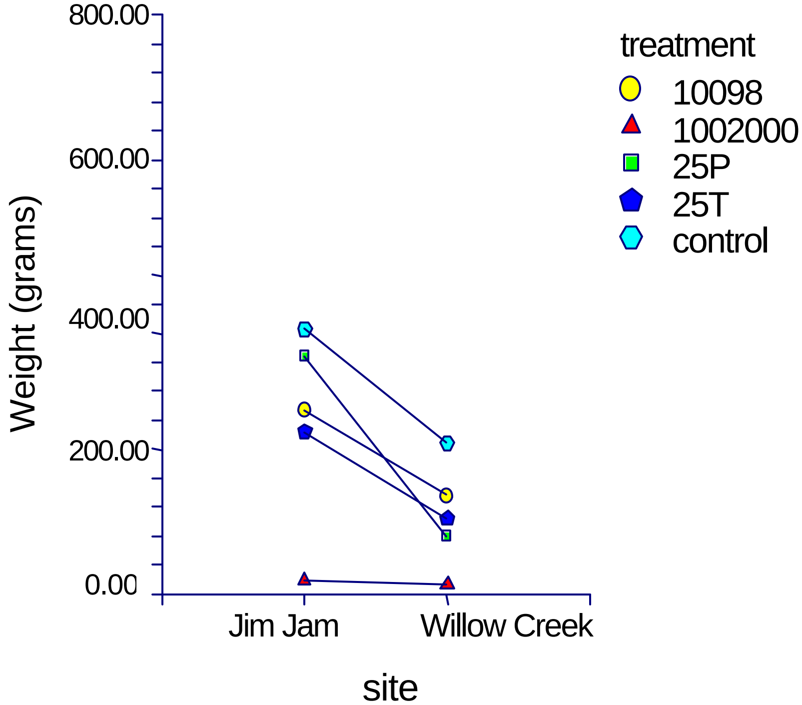

Figure 3. An ANOVA graph showing the interaction between site and treatment. The mean rhizome biomass in grams is given for each treatment at each site.

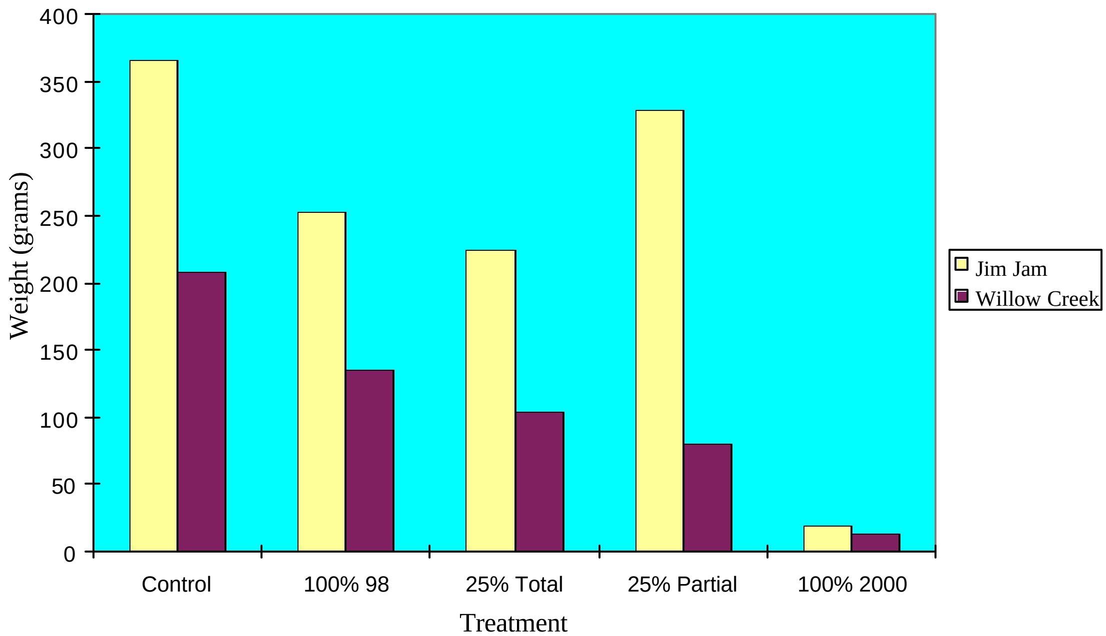

Figure 4. Rhizome biomass by treatment and site.

Because the harvest impacts vary between the two sites it was difficult to interpret the ANOVA results regarding differences in treatments. In order to assess treatment differences, I performed a one-way ANOVA for each site using a P=0.025 to avoid experimental error.

A one-way analysis of variance was performed on the Jim Jam data (Table 4). The low probability value indicated that there was a difference between the harvest treatments at Jim Jam. Fisher's LSD multiple comparison test was used to distinguish which treatments differed (Table 5). For example, in the first row of Table 5, the 100 percent harvest in 2000 treatment differed from the 25 percent total, 100 percent harvest in 1998, 25 percent partial, and control treatments.

Figure 5 illustrates the results of Fisher's LSD multiple comparison test for Jim Jam. Treatments not underlined by a common line are considered to be different from one another. Biomass levels in plots containing only re-growth (100 percent in 2000) were significantly different from the 25 percent total treatment, the 25 percent partial treatment and biomass levels in absence of harvest (control). There was a difference between 25 total and control treatments. I could not conclude how the 100 percent in 1998 and 25 percent partial treatments are related to the other means. Repeating the analysis with a larger number of data points would allow for more decisive conclusions. In addition, reducing the initial Oregon-grape cover variation among all the initial plots would most likely aid in accurately determining differences between treatments.

Table 4. One-way analysis of variance table for Jim Jam rhizome biomass.

	df	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (alpha=.025)
Treatment	4	714161.3	178540.3	13.97	0.000000*	0.999962
Error	43	549417.1	12777.14			
Total (Adjusted)	47	1263578				
Total	48					

*Term significant at alpha = 0.025

Table 5. Fisher's LSD multiple comparison procedure results for Jim Jam rhizome biomass.

Group	Count	Mean	Different from groups
100% in 2000	10	18.6	25% total,100% in 1998, 25% partial, control
25% total	10	224.4	100% in 2000, control
100% in 1998	10	253.2	100% in 2000
25% partial	8	328.6	100% in 2000
control	10	365.9	100% in 2000, 25% total

Alpha=0.025 Error Term=S(A) DF=43 MSE=12777.14 CriticalValue=2.322618

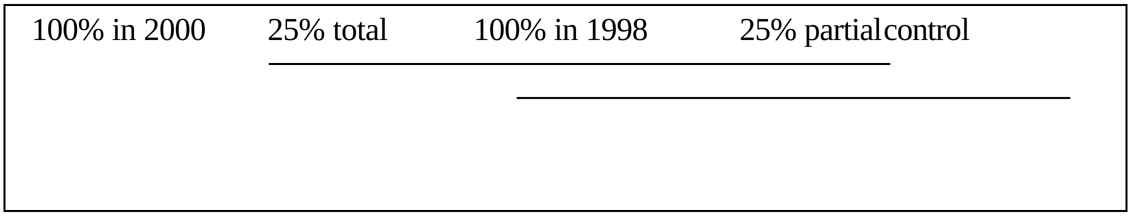

Figure 5. Sketch of Fisher's LSD multiple comparison test results from Jim Jam. Populations not underlined by a common line are declared to have means that are significantly different according to the least significant difference criterion.

By results from the one way ANOVA for Willow Creek (Table 6), I determined that there was a significant effect due to treatment. In other words, there was a statistical difference between treatments at the Willow Creek site. The low probability level (<0.000001) indicates that it is highly unlikely that the treatments originate from the same population. At least one treatment differed from the other treatments at Willow Creek. Fisher's LSD multiple comparison test was used to distinguish the source of the differences (Table 7). This table shows which treatments differed from one another on a treatment-by-treatment basis.

Figure 6 illustrates the results of Fisher's LSD multiple comparison test. Treatments not underlined by a common line are considered to belong to different populations. The 100 percent in 2000 plots (representing re-growth only) were significantly different than all the other treatments. Plots harvested completely were slow to regenerate when compared to 25 percent total and 25 percent partial harvested plots. These post 100 percent harvest plots were significantly different from pre-harvest levels (100 percent in 98) and the control plots (absence of harvest).

There was a statistical difference between the control group and all other treatments. None of the treatments regenerated to biomass levels that existed in the absence of harvest. There was a statistical difference between control and 100 percent in 1998. This difference represented the two-year average growth that occurred in the absence of harvest.

Table 6. Analysis of variance table for Willow Creek rhizome.

	df	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (alpha=0.25)
Treatment	4	195296.8	48824.2	18.41	0.000000*	1.000000
Error	44	116716.8	2652.65			
Total (Adjusted)	48	312013.6				
Total	48					
	49					

*Term significant at alpha = 0.025

Table 7. Fisher's LSD multiple comparison procedure results for Willow Creek.

Group	Count	Mean	Different From Groups
100 % in 2000	9	14.38	25% partial, 25% total, 100% in 1998, control
25% partial	10	80.75	100% in 2000, 100% in 1998, control
25% total	10	103.85	100% in 2000, control
100% in 1998	10	135.87	100% in 2000, 25% partial, control
control	10	208.7	100% in 2000, 25% partial, 25% total, 100% in 1998

Alpha=0.025 Error Term=S(A) DF=43 MSE=12777.14 CriticalValue=2.322618

100% 2000	25% Partial	25% Total	100% 1998	Control

Figure 6. Fisher's LSD multiple comparison test results for Willow Creek. Populations not underlined by a common line are declared to have means that are significantly different according to the least significant difference criterion.

Plots in the 25 percent partial harvest treatment were significantly different than the plots in the 100 percent in 1998 treatment, which indicated that the 25 percent partial harvest plots did not regenerate to biomass levels prior to harvest. Fisher's Multiple Comparison test was not able to determine accurately whether the 25 percent total harvest plots came from the 25 percent partial or the 100 percent in 1998 population. Repeating the analysis with a larger number of data points would allow for more decisive conclusions. In addition, reducing the variation among all the initial plots would most likely aid in accurate determination of differences.

Two-year rhizome regeneration was determined by measuring the rhizome biomass two years after the initial 100 percent harvest. In these plots, all of the possible biomass was removed in 1998, and plants were allowed to re-grow for two years. This two-year growth was used to determine mean rhizome biomass regeneration for completely (100 percent in 1998) harvested plots. Two-year rhizome biomass regeneration was compared by site (Table 8). Two years after harvest, the mean rhizome biomass regeneration of Oregon-grape for Jim Jam and Willow Creek amounted to 5.4 and 18.6 grams, respectively. A correlation was performed comparing initial rhizome biomass in 1998 with the re-growth in the same plots at both sites. The correlation coefficient was 0.20, showing that plots containing high amounts of Oregon-grape in 1998 did not necessarily regenerate faster than plots with smaller amounts of Oregon-grape. The relatively high standard deviation and errors indicated a high degree of variability among plots used to determine regeneration.

Table 8. Two-year rhizome biomass regeneration rates (in grams) for in 100% harvested plots by site.

Site	Mean	Range	SD	SE
Willow Creek	5.4	2 - 22	8.3	2.6
Jim Jam	18.6	6 - 59	16.9	5.4

The 100 percent in 1998 harvest plots at Jim Jam are growing three times as fast as similar plots at Willow Creek. Most likely, regeneration came from underground rhizomes that harvesters were unable to pullout during the initial harvest. If this were the case, there would be more of these residual rhizomes at Jim Jam than at Willow Creek because, on average, population density of Oregon-grape was higher at Jim Jam during initial harvest. Regeneration by residual rhizome could explain the difference in regeneration rates.

It is also possible that regeneration by seedlings occurred. Jim Jam had more fruiting plants per plot than did Willow Creek. Mean numbers of fruiting plants per plot for Jim Jam and Willow Creek in 1998 were 1.8 and 0.1, respectively. The faster regeneration measured at Jim Jam could be attributed to the greater amount of fruiting plants at time of harvest.

DISCUSSION

The Six Rivers National Forest guidelines for products collected by complete plant removal specify a harvest rate of "...every 4th plant/species/site (or can be interpreted as 25 percent of each species/permitted area). Areas in which permits are issued should be rested for two years between harvest" (United States Department of Agriculture, Forest Service 1995). My research indicated that application of this guideline to the harvest of Oregon-grape could have severe management implications.

Wildcrafters interested in the most amount of rhizome for the least amount of effort would chose an intensive harvest of a small area rather than harvesting one out of every four plants. When harvesters focus on a smaller area, the soil becomes loosened and rhizome linkages between plants are broken. The decreased effort required to pull plants and easier access to underground rhizomes, along with less ground to cover make this method more attractive. While the wildcrafter may very well prefer to harvest 100 percent of the plants in a smaller area rather than harvest one out of every four plants over a larger area, it is evident that these two methods produce different results.

In the case of Oregon-grape, harvesting every fourth *B. nervosa* plant throughout the site (25 percent harvest) should definitely not be interpreted to be the same as an intensive harvest of 25 percent of all *B. nervosa* on site. If we have 100 acres of Oregon-grape and want to harvest 25 percent of this population. Our results will differ drastically depending on which harvest method we choose. Gathering one out of every four plants throughout the 100 acres will result in less overall impact than intensively harvesting 25 acres and leaving 75 acres untouched. It is clear from this study that plants will not regenerate as fast in larger harvest patches. At both sites, completely harvested plots regenerated significantly slower than did plots in which only out of every four plants was harvested.

In regard to proposed harvesting methods, I was unable to determine if there is a difference between harvesting the total rhizome and harvesting only a part of it. The Jim Jam 25 percent partial plots recovered better than the 25 percent total plots, yet the opposite was true for Willow Creek site. While some might say it is more conservative to instruct wildcrafters to harvest only partial roots, this may not prove to be the most ecologically sound. For example, if a wildcrafter needed to fill an Oregon-grape order for twenty pounds from the Willow Creek site, the method of partial root harvest would result in the net harvest and mortality of more plants.

The policy of the Six Rivers National Forest's for special forest products is to:

> ...ensure sustainability and the conservation of plant diversity. The policy calls for the use of management measures which "shall perpetuate or increase the production of special forest products. ...At the core of the SFPs issue is the need to manage in a sustainable manner concurrent with the maintenance of plant diversity indigenous to the area (United States Department of Agriculture, Forest Service, 1995)

There is heated debate as to the definition of sustainable. The International Union for Conservation of Nature and Natural Resources, the United Nations Environmental Programme and the World Wide Fund for Nature states that:

> ...an activity is sustainable, for all practical purposes if it can continue forever. ... When people define an activity as sustainable, however, it is on the basis of what they know at the time. There can be no long-term guarantee of sustainability, because many factors remain unknown or unpredictable (Anonymous 1991)

The statements above indicate that sustainable harvest of non-timber forest products is defined as one where the level of harvest does not impair the ability of the harvested population to replace itself. Shankar et al. (1996) suggested that the sustainable harvest of non-timber forest products requires a harvest limited to only a small fraction of the total productivity. Productivity is defined as the rate at which the biomass is produced per unit area by any organism (Begon et al. 1996). Hence, Oregon-grape productivity is the rate at which Oregon-grape biomass is produced per unit area.

According to these definitions of sustainability, harvesting at levels allowed in the current guidelines would not produce a sustainable harvest at Willow Creek, and would not perpetuate or increase the production of Oregon-grape. I could not conclude that the Willow Creek plots in which one out of four plants were harvested (25 percent partial and total) regenerated to pre-harvest (100 percent in 1998) levels within two years. Harvesting at rates specified by current guidelines would most definitely cause a decline in the Willow Creek dwarf Oregon-grape populations, and would fail to meet stated USFS management goals.

While Jim Jam was more productive for Oregon-grape than Willow Creek, I do not believe that the current guidelines will provide adequate long-term protection for Oregon-grape populations at Jim Jam either. These Oregon-grape populations may not retain their capacity for renewal if allowed only to regenerate to pre-harvest levels represented by the 100 percent in 1998 treatment. In the year 2000, two years after the initial harvest, the Jim Jam 25 percent partial and total plots regenerated to only 1998 levels. If we were to harvest again in the year 2000 and wait two years until 2002, it is likely that the best regeneration we would see is re-growth only to 1998 levels. In this example, the best-case scenario would maintain dwarf Oregon-grape at 1998 levels.

Removing such a large percentage of the productivity could have drastic effects on populations. If these regeneration results are even slightly overestimated, the harvest rate will always exceed the recruitment rate. Population declines will follow (Begon et al. 1996). In addition, when populations become stressed, they are increasingly vulnerable to unfavorable environmental conditions and a population decline may occur. Harvesting such a high proportion of total plants would most likely impair the ability of the remaining population to replace itself.

In addition, the above management scheme does not allow for natural succession of dwarf Oregon-grape. Because the best outcome of this scheme would result in holding populations levels steady at 1998 pre-harvest levels, increase in harvestable Oregon-grape would not occur. This could affect forest succession and cause a decline in overall forest health, which would not ensure the mandated maintenance of indigenous plant diversity.

Given that we have little knowledge of Oregon-grape and its role in the forest environment, it would be prudent to error on the side of conservation and develop management plans limiting *Berberis* removal to only a small portion of the productivity or recruitment (Shankar et al. 1996). This scheme would ensure that Oregon-grape recruitment remains greater than harvest quantities. Willow Creek is an example that illustrates the differences in the two strategies.

Biomass in the control plots exceeded biomass from plots fully harvested in 1998 (100 percent in 1998) by an average of 72.8 grams. This amount represented average productivity per plot over two years in absence of harvest. If we were to harvest only a small fraction (5 percent) of that growth, then we would yield 3.6 grams of rhizome per plot every two years. In comparison, an average of 30.3 and 54.2 grams of rhizome were harvested in Willow Creek in the 25 percent partial and 25 percent total rhizome harvest treatments, respectively. Following the current guidelines at Willow Creek resulted in harvesting 42 percent to 74 percent of the two-year productivity per plot. Current USFS harvest guidelines allow too great a portion of productivity to be removed, and therefore do not meet the goals of sustainable harvest.

Finally, the concept of a sustainable harvest is quite different from the concept of a sustainable ecosystem. If we are to have a sustainable forest ecosystem, attention must be given to the impact of so-called sustainable harvest on other, non-marketable species that are part of the ecosystem being exploited. It may be possible to develop harvest systems that yield Oregon-grape over repeated rotations, however, will these prove to conserve the full complement of forest species? If our objective is to continually produce only Oregon-grape, then studies and management plans need be concerned only with those species relevant to the regeneration and growth of Oregon-grape. However, if our objective is to maintain a sustainable forest environment, then attention must be focused on the whole forest. One of the short-comings of this research is its lack of attention to the role of Oregon-grape in the forest system as a whole. Further studies are needed which evaluate the effects of harvesting Oregon-grape on the entire forest ecosystem.

Another crucial question concerns the affect of subsequent harvests on the long-term recovery and sustainability of Oregon-grape populations. Forest Service guidelines permit re-harvest every two years. Even if regeneration proved successful after the first harvest, this experiment gives no evidence that trends of re-growth will continue after a second or third harvest. Harvesting of Oregon-grape populations may increase susceptibility of the remaining plants to climatic fluctuations, pests, diseases, and competition from other species. Resiliency to impacts of harvest could decrease in subsequent harvests. Removal of biomass and nutrients, and possible decrease of sexual reproduction may have cumulative effects on populations. Population crashes can result. It is impossible to know how Oregon-grape will respond to repeated harvest. Further study should address the impacts of subsequent harvest of dwarf Oregon-grape.

This experiment could have been improved with an increased number of plots per treatment. The number of data points was too small to reach decisive conclusions. A greater sample size would increase the power of the analysis of variance to detect differences.

Additionally, the high initial variation within treatments also diminished the ability of ANOVA to detect differences among treatments. The high variation within treatments was due to patchy distribution within natural populations of dwarf Oregon-grape. The Oregon-grape ground cover in plots varied from 25 percent to 98 percent. Plots should have been limited to a smaller range of Oregon-grape cover. However, for the purposes of this study, it was important to keep as many environmental variables constant as is possible in a field situation. Sites that were selected had similar slopes, aspects, and vegetation types. Because of these restrictions and the fact that Oregon-grape grows in a patchy distribution, it is doubtful that an adequate number of plots would have been located if strict limitations required areas with exactly the same percentage of *Berberi*s cover. I suggest that future studies limit plot selection to a small range of Oregon-grape cover such as 30 to 50 percent.

Wildcrafters seek out harvest areas with high Oregon-grape cover to maximize yields. By placing study plots in areas with a minimum of 25 percent *Berberis nervosa*, I attempted to mimic the process by which wildcrafters choose their harvest locations. Areas with a high dwarf Oregon-grape concentration are located in prime conditions for Oregon-grape regeneration. Oregon-grape will likely regenerate more rapidly in high-density areas than in places less suitable for growing Oregon-grape. This study only addresses the regeneration of *Berberis nervosa* in areas of high cover and should not be extrapolated to areas with sparser populations of Oregon-grape.

It turns out the distinction between the 25 percent partial and 25 percent total harvest treatments are not exact. Only the top 0.3 meters (one-foot) of the rhizome was removed in the 25 percent partial treatments while all possible rhizome was removed in the 25 percent total harvest treatments. Breakage often occurred in attempts to harvest the total rhizome, resulting in a de-facto partial harvest of the rhizome. In many of the 25 percent total harvest plots it was difficult to get more than 0.3 meters of rhizome before it broke off and became impossible to pull further. While this was the case in only the minority of instances, it could have diminished the ability of statistical tests to find differences between the two treatments.

RECOMMENDATIONS

Because sites can vary greatly in productivity, harvest regulation should be site-specific. The allowable harvest at each site should be based on site productivity. Harvest allowances should only equal a small fraction of site productivity.

Oregon-grape should not be harvested intensively in a small area. Plants should be conservatively harvested from a large area leaving many neighboring plants on-site to re-colonize. I recommend deleting from the Six Rivers National Forest guidelines that "harvesting every 4th plant/species/site *can be interpreted* as 25 percent of each species/permitted". The Six Rivers National Forest guidelines should be revised to include a longer rotation and (or) a harvest of less than one out of four plants.

This study should be repeated with a greater number of plots per treatments and smaller variations of Oregon-grape cover within plots. This change should increase the power of statistical tests needed to detect true differences.

The overall management scheme should include an ecological monitoring component designed to monitor productivity and harvest levels. The effects of varying levels of harvest on regeneration and population growth rate of Oregon-grape should be evaluated. In order to address sustainability issues properly, it is of utmost importance that we study the impact of subsequent harvests on Oregon-grape.

The forest community of species at the site must be evaluated to better understand the role of Oregon-grape in this ecosystem and how harvesting could impact the sustainability of the entire system. Implementation of current Six Rivers National Forest guidelines could impact forest systems negatively and run counter to the Six Rivers National Forest policy of sustainable ecosystem management. Our ignorance of the role that dwarf Oregon-grape plays within its ecosystem is great, so we must tailor management to error on the side of conservation.

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