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RESEARCH ARTICLE

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Harvesting and Recolonization of Wild Populations of Oshá (*Ligusticum porteri*) in Southern Colorado

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ABSTRACT: Land managers face the challenge of conserving medicinal plants that may be threatened by harvest pressure, often with limited biological information available to inform management decisions. Oshá (*Ligusticum porteri*) is an important medicinal plant whose roots are harvested as an herbal remedy for flu, sore throat, and other illnesses. However, little is known about population structure, root production, or the capacity of oshá to recover from harvest in different environmental contexts. We compared oshá population structure and root production within a gradient of canopy cover from meadow to forested habitat. We experimentally harvested roots of mature oshá plants and recorded oshá recolonization of pits created by root harvest. Prior to harvest, the number and percent cover of reproductive plants and the number of flowering stems per plot were higher in the meadow than in forested habitat. Canopy cover had a significant negative relationship to these variables, suggesting that oshá populations benefit from increased light availability. Average root weight per plant in meadow plots was three times higher than in forested plots. One year after harvest, the majority of all harvest pits across the canopy cover gradient were recolonized by oshá. Our results suggest that oshá population structure and root production are significantly influenced by canopy cover, but that plants have a high capacity for post-harvest recolonization under variable light conditions. These results demonstrate the need to account for environmental factors that influence population structure when addressing concerns about the overharvest of wild medicinal plants.

Index terms: Colorado, ethnobotany, medicinal plant, roots, wild-harvest

INTRODUCTION

Land managers are often tasked with conserving species at risk of becoming rare, endangered, or extinct. Species may be threatened by a multitude of factors, such as small population sizes, anthropogenic alteration and destruction of habitat, invasive species, overexploitation, climate change, or a combination of those or other factors (Wilcove et al. 1998; Hulme 2005). Direct anthropogenic changes to habitat may include fragmentation, logging, or development, among other things (Fahrig 2003).

Land managers must often prioritize the conservation of plant species at risk of overexploitation. Medicinal plants are frequently harvested from natural areas, both in small quantities for personal use and in large quantities sold to companies that market herbal products to the public (American Herbal Products Association 2012). When harvest of medicinal plants occurs within the jurisdiction of the US Forest Service, these plants are considered non-timber forest products (Ticktin and Schackleton 2011; Kauffman et al. 2015). Well-known examples include ginseng (*Panax quinquefolius* L.), black cohosh (*Actaea racemosa* L.), and goldenseal (*Hydrastis canadensis* L.) in Southeastern national forests (Albrecht and McCarthy 2006; Small et al. 2011; Souther and McGraw 2014), and echinacea (*Echinacea angustifolia* DC) in national grasslands of the Great Plains (Kindscher 2016). Managers of federal and other protected lands are often responsible for conserving populations of medicinally important plants.

The variable environmental conditions in which medicinal plant populations grow may influence their response to harvest and thus, the relative threat posed by harvest, making it difficult for land managers to develop generalized conservation strategies. Conservation planning for medicinal plant species therefore, requires an understanding of basic population structure under different environmental conditions, and the impacts of harvesting on species viability.

Oshá (*Ligusticum porteri* J.M. Coult. & Rose) is one such medicinal plant species facing harvest pressure, and it grows in a variety of habitats under variable light conditions (Mooney et al. 2015). Land managers, particularly from the US Forest Service, have been recently tasked with "determining the best method of conservation and of sustainable levels of harvest for this species" (Fitzgerald 2014; Krall 2014). Oshá is an ethnobotanically important medicinal plant with large, pungent, and distinctively spicy roots that are used in tea or tincture to treat influenza, bronchitis, and sore throat. Oshá roots are wild harvested by Native Americans, Hispanics, herbalists, and other individuals for personal use and commercial sale by herbal product companies (Kindscher et al. 2013).

Based on data from the American Herbal Products Association (2012) and our personal interviews with three commercial harvesters (two small-scale and one large-scale) in 2014, we believe that 1000–2000 kg of dried oshá roots are harvested each year from across the species' range. At present, the price of oshá roots has been increasing substantially due to abnormal weather and the lack of federal permits, which is limiting the supply. Commercial brokers were paying \$70–\$90/kg in 2015, with small quantities going as high as \$121/kg, and oshá is currently selling for as high as \$419/kg on the Internet (Sharaf 2016). Commercial harvesters often sell dried roots in bulk at wholesale to brokers or herbal product companies. The roots have been used in the US and Mexico, are exported to Japan, Germany, and elsewhere, and have been included in more than a dozen patented medicines (Felger and Wilson 1995). The majority of oshá on the market is wild harvested because commercial production has not been economically viable; it is difficult to cultivate and requires the climatic regimen of high-elevation habitats (Guernsey 2005).

Given the difficulties of cultivating oshá and the considerable consumer demand for its medicinal properties, the wildcrafting of oshá roots has raised concerns about potential threats from overharvesting (McKeon 1999; Scientific Authority of the United States of America 2000; West and Jackson 2004). Wildcrafting is the harvest of medicinal and edible plants from wild populations (Letchworth 2001), and concerns about the overharvest of natural populations of medicinal plants are widespread (Castle et al. 2014). While oshá was proposed for inclusion in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Scientific Authority of the United States of America 2000; Cech 2002), it has not been listed. However, oshá is listed as an at-risk species by the United Plant Savers, the only US nonprofit organization focused on medicinal plant conservation (United Plant Savers 2012; Castle et al. 2014). The concern about declining oshá populations is difficult to substantiate as oshá populations currently are not tracked by any state or federal conservation agencies. Additionally, there are no comprehensive management strategies in place for the conservation of this species.

The recent concern over conservation of this species, along with growing market demand and potentially declining natural supply, all underscore the need for research that enhances our understanding of oshá population structure, root production, and the ability of plants to recover from harvest. Currently, there is little information regarding how oshá populations and root production respond to environmental variation in the wild. The only study addressing this question to date, Mooney et al. (2005), found that oshá grows under a variety of light conditions However, the influence of canopy cover on population structure and root production is not well known. Furthermore, there is no information regarding whether individual pits created by harvesting oshá roots are recolonized and, if they are, what factors might influence oshá recolonization. Oshá wildcrafters we interviewed reported that plants regenerate after harvest. Mooney et al. (2015) found that oshá plants recovered after moderate levels of root harvest based on data collected from individual leaf and flowering stalks in 1 m^2 plots. However, root yields and recolonization have not been assessed with larger plots or after realistic simulation of wild-harvesting, in which all roots of marketable size are harvested from pits dug around the base of mature plants. Roots of marketable size are at least pencil-sized in diameter (1 cm) and 7–10 cm long; most are much bigger. Recolonization of oshá could occur from root fragments remaining after harvest (Figure 1), or from rhizomes originating outside of the harvested pit. High recolonization rates would indicate that oshá may be resilient to harvest, at least at the scale of individual plants. If recolonization does occur, what factors might be related to recolonization rates? Answering these questions would be an important step toward providing sound management recommendations for the sustainable harvest of oshá.

The objectives of this study were to:

1. Determine whether canopy cover affects stage class (seedlings, juveniles, vegetative, and reproductive plants) distributions (and number of flowering stems) of oshá populations.
2. Determine whether canopy cover affects root weights of vegetative and reproductive oshá plants.
3. Determine the rate of recolonization into harvested pits one year after harvest, and whether the rate was affected by canopy cover, total plant density, or reproductive plant density in the preceding year.

METHODS

Study Species

Oshá is a slow-growing, perennial member of the parsley family (Apiaceae) and its range encompasses the Rocky Mountains, from southern Montana and Wyoming in the north, through Colorado, Nevada, and Utah to New Mexico and Arizona, and significantly south into the Sierra Madre of Mexico (Scientific Authority of the United States of America 2000; Terrell and Fennell 2009; Turi and Murch 2010). According to herbarium specimen data that we acquired from regional herbaria (Kindscher et al. 2013), in Colorado it occurs in high-elevation sites ranging from 1829 to 3567 m (6000 to 11,700 feet) (Kindscher et al. 2013). Roots are branched taproots that produce multiple stems with fibrous collars, and large plants are rhizomatous (Applequist 2005). It thrives in diverse soil types, and is often found in open meadows or within groves of aspen, conifers, fir, and oak (Scientific Authority of the United States of America 2000; Turi and Murch 2010). It can be found in markets across its range, and is commonly known as oshá and bear root in English, and *chuchupate* in Spanish.

Field Methods

Given the extensive range of oshá throughout much of the southern Rocky Mountains, we focused our work in southern Colorado in the Cumbres Pass area of the San Juan National Forest, west of Antonito, Colorado. Substantial wild harvest has been observed by the authors and US Forest Service personnel in this vicinity.

Figure 1. An oshá root that was cut below the soil surface with a shovel during harvesting and resprouted the following year.

Our study site was exposed to seasonal open range grazing by cattle with low to moderate stocking rates, though there was limited browsing observed on oshá plants. We collected oshá population data along a canopy-cover gradient on two sides of a US Forest Service road transecting a north-facing slope. The downhill side of the road had significant mixed spruce–fir tree canopy cover that was never logged (hereafter "forested habitat"). The uphill side of the road was an anthropogenic meadow (hereafter "meadow") with greatly reduced canopy cover from contracted logging of a mixed spruce–fir tree community in 1991. Rather than uniform differences in canopy cover among habitats, logging and the subsequent 21 years of spruce and fir growth resulted in a gradient of canopy cover within and between habitat types. Soils in both the meadow and forested habitats are classified as a Leighcan-Frisco association, which are moist soils that occur on 5%–60% slopes (Soil Survey 2015). The continuity of slope, aspect, and soils between these habitats allowed for a more controlled test of canopy cover effects on oshá populations.

In August of 2012 we established two parallel transects spaced 10 m apart on each side of the road. Each transect consisted of 10 m × 3 m plots (n = 20) with a minimum buffer of 2 m between plots, thus establishing 40 plots on each side of the road for a total of 80 plots. All plots were located between 3100- and 3200-m elevation.

Within each plot we recorded counts and percent cover for specific stage classes of oshá: seedling, juvenile, vegetative, and reproductive. The total number of flowering stalks in each plot was also recorded. Seedlings were designated as plants with cotyledons and plants of comparable size, given that cotyledons senesce. Juveniles were single- or double-stemmed plants that were distinctly larger than seedlings. Vegetative plants had three or more stems and obtained a size equivalent to reproductive plants, but were not flowering in 2012. Reproductive plants displayed inflorescences or evidence that a flowering stalk had formed during the 2012 growing season. An individual oshá plant can be challenging to discern due to its rhizomatous root system. Therefore, we assigned the criteria that one individual plant is 50 cm or less in diameter, and that a plant is treated as a separate individual if it is greater than 20 cm from the edge of another individual. If a plant was greater than 50 cm in diameter, it was considered to be two plants. Although these criteria may be subjective, they were used consistently across plots, and imposing them was necessary in order to quantify both root production and aboveground variables in a standardized manner that realistically mimics wild harvest (i.e., a 50-cm radius seemed consistent with the size of pits observed in areas where wildcrafters had harvested oshá roots).

Harvest intensity treatments were imposed to study long-term effects of harvest on oshá populations. Here we describe these treatments because they affected root weight estimates. Assessment of the long-term resilience of oshá populations to different harvest intensities is ongoing and will be evaluated in the future. The harvest percentages of mature plants (both vegetative and reproductive) were 0%, 33%, 66%, and 100%, with 20 replicate plots of each harvest intensity across the canopy-cover gradient. One of every three mature plants was harvested in the 33% treatment, two of every three mature plants were harvested in the 66% treatment, all mature plants were harvested in the 100% treatment, and no plants were harvested in the 0% control. Because a minimum of six mature oshá plants was required to differentiate between these treatments, prospective plot locations along each transect with fewer than six mature plants were omitted from the study and included in the buffer between plots.

Our harvest methods mimicked those of wildcrafters. To ensure that our methods were realistic, we met with many people who were knowledgeable about the methods of oshá wildcrafters. First, we met with US Forest Service personnel in both the San Juan and Rio Grande National Forests in southern Colorado, who showed us areas where wildcrafters had harvested oshá. In addition, we visited with herbal product companies who buy oshá roots. Finally, we visited with three wildcrafters who shared their techniques with us. One of the wildcrafters, with whom we spent time in the field, had fulfilled significant contracts with several herbal product companies. The other two wildcrafters were smaller scale and used the roots for their own work or for herbal classes. All wild harvesters with whom we interacted made efficient use of their time in the field by harvesting only the largest mature plants. However, they generally refilled their harvest pits, which were sometimes 40-cm deep. They also deliberately left smaller plants because they planned to harvest in the same location in the future, or they simply felt that this was the right thing to do for ensuring the persistence of populations. Wildcrafters selected oshá plants based on large size and ease of access (i.e., in open areas, not next to large rocks, logs, or fallen trees where it is difficult to dig). We simulated those methods in our 33% and 66% harvest treatments. However, all mature plants were harvested in the 100% harvest treatment regardless of size and ease of access.

Harvesting entailed digging as much root as possible from mature plants using standard shovels as the wildcrafters used. Every effort was exerted to harvest all roots of marketable size from mature plants. Roots were harvested such that the main roots underneath the plant were dug as completely as possible, and roots that spread laterally were collected if they were easily retrieved. Harvest of a plant ceased when diminishing returns of roots were reached. Size of the pits, thus, varied depending on quantity of roots associated with a particular plant, up to a maximum of a 50-cm radius. Although the pits were not of systematic size, our methods were necessary due to differences in the quantity of roots per plant, and because we were trying to mimic wild harvesting. Soil removed during harvest was replaced in pits to simulate the practices of more conscientious wildcrafters, such as those we interviewed.

Root Production Estimates

We measured and recorded the combined fresh weight of harvested roots at the plot level for two reasons. First, we wanted to estimate root production, for which we calculated the average root weight per harvested plant (total root weight per plot divided by the number of mature plants harvested). Second, to obtain estimates relevant to consumer markets in which oshá is sold as dried root, we determined dry root weights from fresh root weights that we harvested. We present estimates for the meadow and forest habitat separately for descriptive purposes, because the habitats serve as a proxy for canopy cover (average (± 1 SE) canopy cover was 16.8% (± 1.9%) in meadow plots, and 52.1% (± 2.0%) in forested plots). However, we were unable to test differences statistically as habitat is not replicated. To measure the ratio of fresh to dry root weight, we weighed 10 individual, randomly chosen, fresh roots of variable sizes and allowed them to dry before reweighing them. Dry root weight averaged 37% of fresh weight for the roots we harvested at the Cumbres site, which is consistent with previous findings that roots dried to approximately one-third of their fresh weights (Guernsey 2005). We then multiplied fresh root weights by 0.37 to estimate the cumulative dry root weight for each habitat. Next, to calculate the average dry root weight per harvested plant for each habitat, we divided the cumulative dry root weight by the total number of mature plants harvested. To estimate the dry root weight that could potentially be harvested from each habitat type (if all mature plants had been harvested from every plot), we multiplied the average dry root weight per harvested plant by the total number of mature plants counted. Since each habitat contained 40 plots (3 m × 10 m; 30 m^2), our estimates for each habitat are based on a cumulative area of 800 m^2. We divided this number by the number of plots (40) to generate an average estimate of dry oshá roots per 30-m^2 area, and we estimated dry root mass per 1 m^2 as well. This information at different scales could be very useful for determining the economic potential of oshá stands growing in different environments, which will help us better understand the economic underpinnings of harvest pressure.

Individually Tagged Pits

We estimated initial recolonization rates in the meadow and forest habitats at Cumbres Pass to determine whether pits where plants had been dug in 2012 were recolonized by oshá in 2013. For this purpose, we marked the center of harvested pits with a metal tag and recorded the *x* and *y* coordinates of each tag within a plot. The pits from 125 harvested plants were tagged within each habitat. This data on 250 individual oshá plants allowed us to assess the extent of recolonization and whether factors such as canopy cover, total plant density, or reproductive plant density in the preceding year were related to recolonization. Reproductive plant density in the preceding year could be important if soil disturbance facilitated germination and establishment in harvest pits.

Aboveground recolonization data was collected for all tagged pits in August 2013, the year following harvest. For each tagged pit we recorded a binary (yes or no) response to whether or not recolonization of juveniles and vegetative plants occurred, whether recolonizing plants flowered, and whether any seedlings were present. Recolonization by vegetative or reproductive plants could occur if any root fragment remaining from the harvested plant reestablished, or from rhizomes originating outside of the harvested pit, though these two sources of recolonization could not be differentiated without further digging. Plants were considered to be recolonizing if they were inside the pit or within 2 cm of the pit edge. If we were unable to see the pit, but the tag was visible, we assessed plants rooted within a 30-cm radius of the tag. Seedlings could also cause recolonization, but they were so infrequent that they are discussed separately below. We were unable to locate five tags and pits, so we collected data on 245 pits.

Canopy Cover

To examine the effect of light availability on oshá population density, flowering stem density, and average root weight, we measured canopy cover in each plot with a convex spherical densiometer. Canopy cover was calculated as the average of readings taken from the plot center facing in each of the four cardinal directions (Lemmon 1956).

Slope Position

We calculated slope position for all plots across the canopy cover gradient because it could be a potentially confounding factor affecting oshá population structure at our site. To do this, elevation data from a 1/3 arc-second DEM (USGS NED n38w107 1/3 arc-second 2013 1 × 1 degree ArcGrid) was overlaid in a GIS by GPS coordinates taken at the southwest corner of each plot (US Geological Survey 2015). The elevation of each point for each plot was then extracted from the DEM using the "Extract Values to Points" tool in the Spatial Analyst toolbox in ArcGIS 10.2.

Analyses

To understand the relationships between canopy cover and oshá populations, we performed univariate linear regressions on all response variables at the plot level. We used the 'lm' function in R version 3.0.2, with slope position as a covariate, canopy cover for each plot as the predictor variable, and count and cover for each stage class (adding juvenile and seedlings together because there were too few plots with seedlings; only 16 of 80 total plots had seedlings, and there were no seedlings in any forest plots), as well as number of flowering stems, and average fresh root weight per plant in each plot, as response variables (R Core Team 2013). We transformed all count response variables and average root weight per plot using ln+1, and logit-transformed all percent cover response variables prior to analyses (Warton 2011).

To examine the probability that recolonization of pits (a binary, yes or no response for each of the stage classes of seedling, juvenile/vegetative combined, and reproductive) was influenced by canopy cover, total plant density, or reproductive plant density in the preceding year, we used logistic regression. We combined all data to indicate one yes or no response per pit because there were few seedlings and flowering plants overall. We used the 'glm' function in R version 3.0.2 (R Core Team 2013).

RESULTS

Oshá population structure was related to canopy cover. The number of reproductive plants (slope = –0.01; adjusted r^2 = 0.33), percent cover of reproductive plants (slope = –0.01; adjusted r^2 = 0.24), and number of flowering stems (slope = –0.02; adjusted r^2 = 0.36) had a strong negative relationship to canopy cover (Table 1, Figure 2). The number of vegetative plants (slope = –0.00; adjusted r^2 = 0.00) and cover of vegetative plants (slope = –0.00; adjusted r^2 = –0.01) were not related to canopy cover (Table 1, Figure 2). The number of seedling and juvenile plants was negatively related to canopy cover (slope = –0.01; adjusted r^2 = 0.28), but seedling and juvenile cover had no relationship to canopy cover (slope = –0.00; adjusted r^2 = 0.05) (Table 1, Figure 2).

Root Weights in Harvested Plots

Average root weight per plant per plot was negatively related to canopy cover ($F_{1,57}$ = 4.1, P = 0.05, adjusted r^2 = 0.37) (Figure 2). In total, there were 1225 mature plants (both vegetative and reproductive) present across all plots in the study area (Table 2). Of those, we harvested 593 mature plants total, which equated to 43.66 kg of dried root (Table 2). We harvested three times more dried root mass in the meadow habitat than in the forest habitat (Table 2).

Recolonization

Juvenile and vegetative plants recolonized over 65% of the pits in both meadow and forest habitats (Table 3, Figure 1). However, the probability of pit recolonization overall (i.e., of all stage classes combined) was not significantly related to any of the variables (canopy cover, total plant density, or flowering plant density in the preceding year) that we tested (all $P \geq 0.44$).

DISCUSSION

Our results illustrate oshá's affinity for open environments with lower canopy cover. In particular, oshá appeared to allocate more energy to aboveground reproduction and root biomass in open environments. Oshá is remarkably productive as compared to other medicinal plant roots, such as *Echinacea angustifolia* (Price and Kindscher 2007). Our forest populations averaged 20 g dried root per 1-m^2 area, while meadow

Table 1. Statistics (*F, P*) for regressions of oshá variables on canopy cover. Slope position was included as a covariate in the model.

Source	df	Number of juvenile + seedling	Number of vegetative	Number of reproductive	Number of flowering stalks	df
Slope position	1,77	25.8; <0.01	1.0; 0.33	20.8; <0.01	24.6; <0.01	1,57
Canopy cover	1,77	7.1; 0.01	0.6; 0.43	19.4; <0.01	21.8; <0.01	1,57
Source	**df**	**Juvenile + seedling percent cover**	**Vegetative percent cover**	**Reproductive percent cover**		
Slope position	1,77	5.0; 0.03	0.9; 0.34	6.2; 0.01		
Canopy cover	1,77	1.1; 0.30	0.3; 0.59	20.3; <0.01		

populations had an average of 60 g dried root weight per 1-m^2 area. Given that substantial differences in aboveground cover can be assessed visually, this suggests that harvesters can visually assess prior to digging, which habitats and plants will yield the most root mass.

Lower canopy cover, and thus, increased light availability, led to an increase in the count and cover of reproductive plants, the number of flowering stems, and the average root weight per plant. The abundance of vegetative plants, however, did not respond to canopy cover, indicating that light is most strongly influencing reproduction. Specifically, 72% of mature plants flowered in our meadow plots, while only 60% flowered in the forest.

Mooney et al. (2015) found results similar to ours when they measured oshá at smaller scales (1-m^2 plots), although they did not find an effect of light on root biomass. However, Mooney et al. (2015) harvested roots in aspen stands only to a depth of 25 cm and recorded data from individual leaves or flowering stalks, whereas our study removed all roots of marketable size from mature plants. These differences in scale of measurement and harvest likely explain our finding of a strong negative effect of canopy cover on root biomass, though it is possible that oshá responds differently to seasonal availability in the deciduous canopy of aspen.

Factors Affecting Oshá Populations

Although canopy cover is clearly an important factor in this study, other factors may also influence oshá populations. Grazing intensity can impact oshá populations, with significant declines in cover when over 50% of the population experienced grazing in other studies (Julander 1968). Although we did not quantify the effects of grazing in our study, the vegetation under open canopy cover appeared to be more impacted by cattle (dung piles and browsing) than the vegetation in more closed canopy cover. The differences in land-use history, such as disturbance from logging and long-term impacts of burning, could also result in changes in oshá populations. Therefore, experiments manipulating multiple abiotic and biotic factors should be conducted before we can fully understand the mechanisms driving oshá population dynamics. However, Mooney et al. (2015), who studied oshá in meadows and aspen stands, found that a greater proportion of individuals flowered in high light environments. Our results from different habitat types also suggest that canopy cover had a strong influence on oshá populations, and these findings are consistent with our personal observations and data collection at additional oshá populations in various habitat types throughout its range.

Although the number of seedlings and juveniles declined with increasing canopy cover, it is difficult to draw conclusions relating seedling recruitment to canopy cover in this study given that the median seedling count was zero. This suggests that germination and recruitment in oshá populations may be episodic and dependent upon specific climatic and microsite conditions. We did not find any seedlings under higher canopy cover, which is somewhat surprising given that germination studies have shown that oshá seeds prefer moist soil conditions (Panter et al. 2004; Terrell and Fennell 2009), which are promoted by increased canopy cover. However, lower abundance of reproductive plants and flowering stems suggests a tendency for lower overall seed production with increasing canopy cover, thus decreasing the likelihood of seedling recruitment relative to the more open habitats. Better understanding factors that influence seedling recruitment, and ultimately development into mature plants, is an important focus for future studies of oshá population dynamics.

Harvest pits from plants dug in the previous year were frequently (>65%) recolonized, presumably either by roots that were inadvertently missed during harvest or from rhizomes originating outside of the harvested pit. However, both Terry et al. (2011) and Mooney et al. (2015) found that harvesting of medicinal plants can result in smaller plants, which could impact populations in the long term. Therefore, it will be important to continue monitoring to assess whether plants that initially recolonize following harvest survive to maturity and contribute to the recovery and persistence of harvested oshá populations. Although we recorded some seedlings in pits, there were very few compared to recolonizing juveniles and vegetative plants, and the seedling life history stage is highly vulnerable to environmental stress and mortality (Leck et al. 2008). Clonal root growth, therefore, appears to be the major source of oshá recolonization following harvest. Since the average root weight per plant within plots declined linearly with increased canopy cover, it is possible that the influence of canopy cover on root

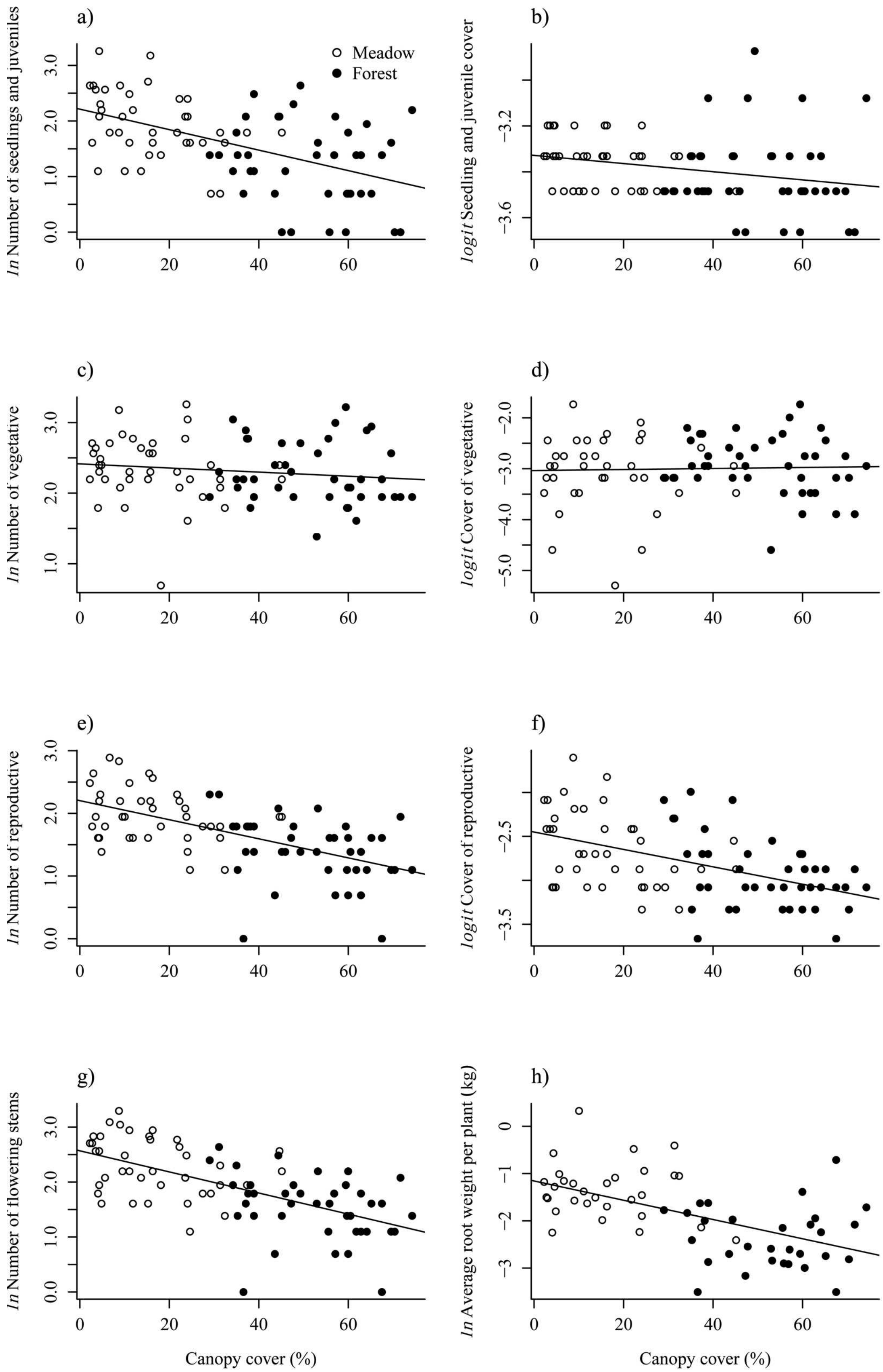

Figure 2. Plot-level relationships between canopy cover and juveniles counts (a), juvenile cover (b), vegetative counts (c), vegetative cover (d), reproductive counts (e), reproductive cover (f), flowering stem counts (g), and average root weight per plant in each plot (h) across the three habitat types.

Table 2. Oshá root production based on estimated dry weights. Summaries are presented separately for meadow and forest habitats for descriptive purposes only.

Weights summary	Meadow	Forest
Total # of plants dug	338	255
Total dry weight of roots dug (kg)	32.92	10.74
Average dry weight of root per harvested plant (kg)	0.1	0.04
Total # of mature plants present	697	528
Estimated dry weight of all roots present (kg)	67.89	22.23
Estimated avg. dry weight of roots present in 30m^2 area (kg)	1.7	0.56
Estimated avg. dry weight of roots present in 1m^2 area (kg)	0.06	0.02

recolonization may require more time to become apparent. Additionally, it is possible that early lateral root recolonization is occurring, but aboveground biomass was not yet associated with those roots.

Management Implications for Oshá and other Medicinal Plant Harvest

At least within our study area, open habitats with more sunlight benefited oshá stands and root production. Management activities such as timber thinning and wild fires could increase light and positively benefit oshá populations within their core range, where moisture and soil conditions are appropriate. Since oshá populations recolonize from resprouts and adjacent plants, it appears that other factors, rather than just harvest, must be considered in studying oshá populations that experience harvest pressure. Other species, for example *Echinacea angustifolia*, are also capable of regenerating after harvest, yet other factors, such as grazing and herbicide, also influence populations and harvest sustainability (Kindscher et al. 2008). Many medicinal plant species, such as ginseng, have no ability to resprout or recolonize after harvest, but depend upon seed production (Hackney and McGraw 2001). Multiple factors, ranging from species life-history traits to environmental context, must be considered when managing lands with populations of species that may be threatened by harvest pressure.

CONCLUSIONS

Environmental influences on population structure, combined with harvest pressures, present unique challenges to land managers tasked with the conservation of medicinal plant species. Our results indicate that changes in canopy cover have considerable effects on oshá populations. Open habitats with low canopy cover appear to promote reproduction and higher root biomass in oshá plants. However, other factors related to changes in canopy cover, such as land-use history, could also be important. Initial results, one year post-harvest, indicate that many harvest pits were recolonized by oshá. The scarcity of seedlings observed across the canopy cover gradient suggests that recruitment is episodic, and that population recovery following harvest is mostly dependent upon vegetative recolonization. Land managers should consider environmental variation in conjunction with harvest pressure when determining whether, how, and where oshá populations should be permitted for harvest, and also where conservation should take priority. When concerns are raised about the impact of harvest pressure on medicinal plant populations, a range of anthropogenic factors, environmental context, and life-history traits must be considered.

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Table 3. Summary of pit recolonization rates for juvenile and vegetative plants combined, as well as seedlings and flowering plants for the meadow and forest habitats one year after harvest. Summaries are presented separately for meadow and forest habitats for descriptive purposes only.

Recolonization type	Meadow (%)	Forest (%)
Juvenile and vegetative	79	66
Seedlings	13	9
Flowering plants	8	3

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