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Recovery of Black Cohosh (*Actaea racemosa* L.) Following Experimental Harvests

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ABSTRACT.—Since European colonization and subsequent commercialization of Appalachian medicinal and edible plants, millions of kilograms of plant material have been extracted from our forests, with little effort to manage these species as natural resources. Roots and rhizomes of black cohosh, a native Appalachian forest herb, are extensively harvested for treatment of menopausal symptoms. As nearly all cohosh sold commercially is collected from natural populations, the potential for harvest impacts is considerable. To better understand wild-harvest impacts and the likelihood of post-harvest recovery, we studied the effects of 2 to 4 y of experimental harvest on natural black cohosh populations in the George Washington-Jefferson National Forest in southwest Virginia. After 2 to 3 y of intense harvest (66% plant removal), we found significant reductions in foliage area, stem production, and mean and maximum plant height. The effects of moderately intense harvest (33%) were less clear, producing growth measures between, yet not significantly different from, control (non-harvest) and intensively harvested plots. After three successive years of experimental harvest, harvest treatments were terminated to assess population regrowth. Populations experiencing intensive harvest showed no evidence of recovery after 1 y. Results suggest that black cohosh is highly responsive to harvest intensity and that low to moderate harvest intensities and/or longer recovery periods will be necessary for prolonged and sustainable harvests at our study site. While this study has increased our understanding of harvest impacts on black cohosh, continued assessment is needed to determine the sustainability of low to moderate harvest levels and minimum recovery periods necessary for population reestablishment.

INTRODUCTION

Harvesting of Appalachian medicinal plants began well-before Europeans settled the region in the early 1700s (Foster, 1995; Chamberlain *et al.*, 2002; Sanders and McGraw, 2005). With colonization and subsequent population increases, market demand and harvest pressures increased dramatically on medicinal plant resources. Since colonization and subsequent commercialization of these resources, millions of kilograms of plant material have been extracted from Appalachian forests, with little effort to manage the plant species as natural resources (Chamberlain *et al.*, 2002; Ticktin, 2004). Concern for the conservation and sustainability of these natural resources over the last 20 y has led to increased efforts to understand the ecological impacts of harvesting on natural populations (van der Voort *et al.*, 2003; Sanders and McGraw, 2005; van Manen *et al.*, 2005; Albrecht and McCarthy, 2007).

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As many as 500 plant species from the Eastern Deciduous Forest region have reported medicinal properties (Krochmal *et al.*, 1969; Foster, 1995), with more than two dozen commonly collected for sale in the herbal and dietary supplements industry (Robbins, 1999; Greenfield and Davis, 2003). Central and southern Appalachian forests are particularly noteworthy sources of medicinal and edible plants, including such prominent species as *Panax quinquefolius* L. (American ginseng), *Hydrastis canadensis* L. (goldenseal) and *Allium tricoccum* Aiton (ramps) (Foster, 1995; Chamberlain *et al.*, 2002). Despite this diversity of medicinal plants, relatively few studies have examined harvest impacts on native Appalachian forest herbs, and most suggest pronounced impacts on natural populations (Rock *et al.*, 2004; Sanders and McGraw, 2005; Albrecht and McCarthy, 2007).

Black cohosh (*Actaea racemosa* L.; Ranunculaceae), a native Appalachian forest herb, also has been extensively harvested for its commercial value (Foster, 1999; Predny *et al.*, 2006). Widely distributed across deciduous forests of eastern North America, black cohosh reaches peak abundance in mesic cove forests of the southern Appalachians (Fleming *et al.*, 2010; NatureServe, 2009). Today, the roots and rhizomes of this forest herb are sold widely in U.S. and European herbal and dietary supplement markets for treatment of menopausal symptoms. The American Herbal Products Association (2007) estimates that between 1997 and 2005, more than 1 million kg of black cohosh roots and rhizomes were harvested from these forests.

In 1996, an estimated 10 million retail units (a container of tablets or other forms in which black cohosh is sold) of black cohosh were sold in Germany, the U.S. and Australia (Blumenthal, 2003b). In 1998, commercial demand for black cohosh was cited as one of the fastest growing southern Appalachian non-timber forest products (Blumenthal, 2003a; Predny *et al.*, 2006). Black cohosh has been listed as one of the top 10 selling herbal supplements each year since 2002.

Despite widespread use and commercial sales of black cohosh, the impact of harvesting is unclear. Plant reproduction and population expansion occur primarily through regrowth of buds from below-ground rhizomes, thus fragments remaining in the soil are the primary means of regeneration after wild-harvest (Predny *et al.*, 2006). As nearly all black cohosh sold commercially is collected from natural forest populations, the potential for harvesting impacts is considerable (Chamberlain *et al.*, 2002; Greenfield and Davis, 2003; Predny *et al.*, 2006). Despite a national conservation status of “apparently secure” (N4) (NatureServe, 2009), global projections suggest 10–30% declines in black cohosh populations over the next decade, unless sources of cultivated plant material are established (NatureServe, 2009).

Few studies have examined the impacts of harvesting on natural populations of black cohosh, and little effort has been made to manage this species as a natural resource. Mitigating potential harvest impacts requires determining harvest intensities that have minimal impact and allow for post-harvest recovery and long-term population maintenance. To better understand the impacts of wild-harvesting and the potential for population recovery, we examined the effects of 2 to 4 y of experimental harvest on natural black cohosh populations and monitored population regrowth after harvest. Regeneration and growth were investigated at different harvest intensities to simulate the range of current wild-harvesting practices and to examine the viability of native populations under these experimental harvest regimes. Our results will aid in efforts to determine sustainable harvesting intensities and development of improved management plans for this native Appalachian medicinal plant.

METHODS

Field methods.—In 2000, the U.S. Fish and Wildlife Service, Garden Club of America and U.S. Forest Service created an informal partnership to monitor and examine impacts of wild-harvesting on naturally-occurring black cohosh populations in national forests of North Carolina. Harvest intensities for that study were selected based on discussions with industry representatives and experience with regional harvesters. In 2004, the U.S. Forest Service Southern Research Station adopted a similar design to study the distribution and abundance of black cohosh populations and the impacts of experimental harvest treatments in national forests of Virginia. Long-term study plots were established in the George Washington-Jefferson National Forest, Augusta County, Virginia (38°26′33.52″N/79°15′51.80″W). Elevation of the study area was ~1190 m, on a moderately steep (26 to 32%) southeast-facing (~130°) slope. The site is located within the Appalachian Oak Forest Region (Stephenson *et al.*, 1993), dominated by *Quercus rubra* L., *Acer rubrum* L., *Robinia pseudoacacia* L., *Betula lenta* L., *Prunus serotina* Ehrh. and scattered *Tsuga canadensis* (L.) Carrière in the canopy, and *Hamamelis virginiana* L. and various ericaceous species (*Kalmia latifolia* L., *Vaccinium* spp. and *Pieris floribunda* (Pursh) Benth. & Hook. f.) in the shrub layer.

In Jun. 2005, a 100 m transect was established along the upper contour of the study area, parallel to Forest Road 85 (~3 m from the nearest road edge), and designated as “Site 1.” Twelve subtransects were initiated at random locations along this transect. Each subtransect was 45 m long and oriented perpendicular to the main transect (130° SE). Subtransects were assigned to one of three experimental harvest treatments: 0% (control), 33% or 66% (following harvest regimes of the NC study above). Thus, four replicate subtransects were assigned to each harvest treatment. In Jun. 2007, a second 100 m transect (“Site 2”) was established as a continuation of the 100 m transect in Site 1. The same data collection procedures were followed at each site, as described below.

Three 2 × 5 m sample plots were located randomly along each 45 m subtransect. Thus, 12 sample plots were assigned to each harvest treatment at each study site. Within each plot, the location of each black cohosh stem was mapped and the number of black cohosh stems, foliage height and foliage area were measured. Foliage height was measured from the ground surface to the top of the main canopy of leaves, excluding flowering or fruiting peduncles. Because the vegetative canopy of a typical black cohosh plant is roughly circular, foliage area was calculated as the area of a circle, based on two perpendicular measurements of the canopy. (Foliage area = $(PI \times D_1 \times D_2)/4$, where D_i = one of two foliage diameter measures across the canopy.) Stems originating from discrete locations along underground rhizomes were treated as separate plants. Branching stems originating from the same location along a rhizome were measured as single plants.

Data in Site 1 were collected annually in Jun. 2005–2009. In 2005, 2006 and 2007, experimental harvest treatments were applied immediately following plant measurements. Harvests followed the designated treatment for each subtransect (0, 33% or 66%), with harvested plants selected at random from all plants in the plot. All above-ground and below-ground plant materials (foliage, rhizomes and roots) were removed for harvested plants. After 3 y of experimental harvesting on Site 1, harvest treatments were terminated to assess post-harvest recovery of black cohosh populations. Annual measurements of foliage height, stem counts and foliage area continued, without harvesting, in Jun. 2008 and 2009. On Site 2, experimental harvest treatments and plant measures were conducted in Jun. 2007–2009, following the same procedure.

Data analysis.—Field data were used to calculate mean and maximum plant height, total foliage area and total number of stems per plot. Plots having no black cohosh before initial

harvest treatments (Site 1: 2005, Site 2: 2007) were excluded from our analysis, because our primary objective was to assess population recovery after experimental harvest. After exclusion of empty plots, our analysis included 25 plots for Site 1 (0% = 8 plots, 33% = 9 plots, 66% = 8 plots) and 26 plots for Site 2 (8, 9 and 9 plots, respectively). Statistical analyses were conducted using NCSS 2000 (Hintze, 2000) and JMP software (SAS, 2006).

Measures of plant size and abundance were compared between harvest treatments (0%, 33%, 66%; fixed treatment effect) using one-way multivariate analysis of variance (MANOVA). MANOVA tests were performed on pre-harvest data (Site 1: 2005; Site 2: 2007), 1 y after final harvest (Site 1: 2008; Site 2: 2009) and 1 y of recovery (Site 1: 2009). Dependent variables were log-transformed as necessary to meet MANOVA normality and variance assumptions and checked for significant intercorrelation ($P < 0.05$). If MANOVA results were significant (F statistic calculated from Roy's greatest root), separate univariate ANOVA tests were conducted, followed by Bonferroni *a posteriori* multiple comparisons. Holme's Sequential Bonferroni correction was used to adjust for experiment-wise error in individual ANOVAs (Roback and Askins, 2005).

Multivariate repeated measures ANOVA and Profile Analysis were used to examine changes in growth parameters over time relative to harvest treatments. Following the recommendations of O'Brien and Kaiser (1985) and von Ende (2001), response curves were evaluated for parallelism (time $\times$ harvest interaction), flatness (within-subjects time effect) and elevation (between-subjects main treatment effect). Repeated measures were analyzed from pre-harvest through 1 y after final harvest (Site 1: 2005–2008; Site 2: 2007–2009). Changes with 1 y of recovery also were examined (Site 1: 2008–2009). Variables were log transformed as necessary to meet normality and variance assumptions.

RESULTS

Prior to initial harvests, black cohosh growth measures did not differ significantly between treatment groups (Site 1 - 2005: Roy's greatest root = 0.227, $F_{4,20} = 1.13$, $P = 0.369$; Site 2 - 2007: Roy's greatest root = 0.602, $F_{4,21} = 3.16$, $P = 0.035$. ANOVAs for all individual response variables $P > 0.05$; Fig. 1). However, 3 y of intensive harvesting (66%) on Site 1 significantly reduced foliage area ($F_{2,22} = 5.72$, $P = 0.010$) and stem production ($F_{2,22} = 4.41$, $P = 0.025$) relative to control plots (MANOVA 2008: Roy's greatest root = 0.799, $F_{4,20} = 3.99$, $P = 0.015$; Fig. 1). Similarly, after 2 y of intensive harvesting on Site 2, we found lower foliage area ($F_{2,23} = 3.74$, $P = 0.039$), mean height ($F_{2,23} = 7.29$, $P = 0.004$) and maximum height ($F_{2,23} = 4.91$, $P = 0.017$) relative to control plots (MANOVA 2009: Roy's greatest root = 0.705, $F_{4,21} = 3.70$, $P = 0.020$; Fig. 1). Growth following low intensity harvest (33%) did not differ significantly from control or 66% harvest treatments on either site.

Evaluating changes in black cohosh relative to repeated harvesting treatments revealed no harvest $\times$ time interactions on either site. Average change over time did not differ significantly between treatment groups and the hypothesis of parallelism could not be rejected. Since no interactions were found, response curves were examined for significant deviations from flatness (within-subjects time effect) and elevation (between-subjects main treatment effect). In Site 1, all black cohosh measures showed significant reductions from 2005 to 2008 (time effect only, all $P < 0.01$; Table 1). In a comparison of treatment effects across all years, foliage area was significantly larger in control plots relative to 66% harvest plots (Table 1; Fig. 1). In Site 2, mean and maximum plant height again declined from 2007 to 2009 ($P < 0.01$; Table 1). In evaluating Site 2 treatment effects across all years, populations subjected to both low (33%) and high (66%) harvest intensities were

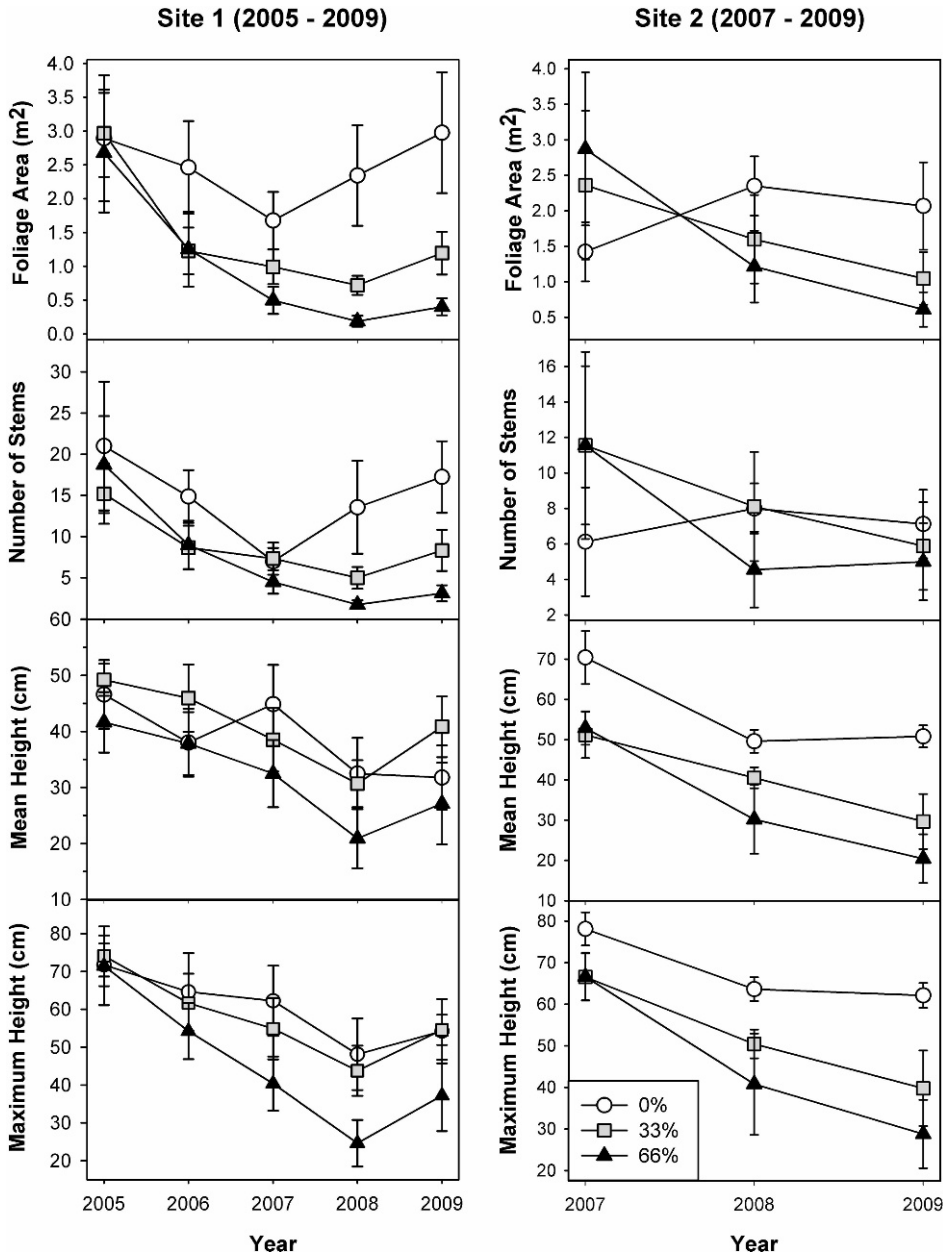


FIG. 1.—Annual changes in black cohosh growth and abundance parameters (mean and maximum plant height, total number of stems and total foliage area per plot) with experimental harvesting. Data are means $\pm$ SE. Harvest treatments were carried out at Site 1 in 2005, 2006 and 2007 and at Site 2 in 2007, 2008 and 2009. Plant measurement data were collected before harvest each sample year.

TABLE 1.—Effects of harvesting on black cohosh (*Actaea racemosa*) growth and abundance parameters during the study period. Values are F ratios, P-values and degrees of freedom (df) from multivariate repeated measures ANOVA tests

Dependent variable	Harvest	P	Year	P	H × Y	P
Site 1: Pre-harvest through Final Harvest (2005–2008)						
Foliage area	6.79	0.002	6.80	<0.001	0.96	0
Number of stems	3.03	0.053	7.02	<0.001	0.75	0.609
Plant height (mean)	2.42	0.095	5.34	0.002	0.38	0.887
Plant height (max)	3.33	0.040	9.44	<0.001	0.48	0.820
df (each test)	2, 88		3, 88		6, 88	
Site 2: Pre-harvest through Final Harvest (2007–2009)						
Foliage area	3.65	0.031	2.09	0.132	1.93	0.115
Number of stems	1.23	0.298	0.85	0.433	1.94	0.114
Plant height (mean)	12.51	<0.001	15.47	<0.001	0.72	0.582
Plant height (max)	8.01	<0.001	11.78	<0.001	0.64	0.633
df (each test)	2, 69		2, 69		4, 69	
Site 1: Final Harvest through Recovery Year (2008–2009)						
Foliage area	14.58	<0.001	1.88	0.178	0.01	0.987
Number of stems	11.13	<0.001	2.20	0.145	0.08	0.927
Plant height (mean)	2.20	0.1225	1.24	0.271	0.46	0.632
Plant height (max)	4.34	0.0191	2.60	0.114	0.10	0.908
df (each test)	2, 44		1, 44		2, 44	

Significant values for Holme’s Sequential Bonferroni correction: $P < 0.0125$, $P < 0.0167$, $P < 0.0250$, $P < 0.0500$

significantly shorter (mean and maximum height) than control plants ($P < 0.01$; Table 1; Fig. 1).

All harvest treatments on Site 1 were terminated in 2008. The following year (2009), populations were examined for evidence of recovery (increased plant size or reestablishment). Plants subjected to intensive harvest (66%) from 2005–2007 showed no improvement. Instead, most growth measures continued to diverge relative to control plots (Fig. 1). Analysis of 2009 data showed increased disparity between control and 66% harvest in foliage area ($F_{2,22} = 6.86$, $P = 0.004$), stem production ($F_{2,22} = 6.07$, $P = 0.008$) and maximum plant height ($F_{2,22} = 3.51$, $P = 0.047$) relative to the previous sample year (MANOVA 2009: Roy’s greatest root = 1.60, $F_{4,20} = 8.00$, $P < 0.001$; Fig. 1). Repeated measures analyses supported these findings, showing no improvement from 2008 to 2009. Instead, all growth measures remained significantly lower during the “recovery” year for the intensive harvest treatment relative to the control [0 and 33% vs. 66% foliage area ($P < 0.01$), 0 vs. 66% stem production ($P < 0.01$), 0 vs. 66% max height ($P < 0.01$)] (Table 1).

DISCUSSION

A primary objective of our study was to establish recommendations for sustainable harvest intensities of black cohosh. Two to 3 y of intensive experimental harvest (66%) led to declines in foliage area at both study sites (Fig. 1). Stem density and height each declined on one of our two sites. Thus, harvest of two-thirds of the population appears unsustainable, based on our particular methods and site conditions. The effects of moderate harvests

(33%) were less clear. Removal of one-third of the population resulted in foliage and stem production intermediate between our control and intensively harvested populations. Only plant height declined in response to our less intensive harvest.

Comparable studies examining experimental or wild-harvest effects on black cohosh are lacking, making it difficult to extrapolate our results across differing harvest methods and site conditions. However, black cohosh, like other Appalachian forest herbs, appears highly sensitive to harvest intensity. Slow-growing perennials that require extended periods to reach reproductive maturity (*i.e.*, most deciduous forest herbs) seem particularly vulnerable to over-harvesting (Freese, 1997; Van der Voort *et al.*, 2003; Ticktin, 2004). Increased harvest intensity removes a greater proportion of belowground biomass, leaving fewer or smaller roots and rhizomes to support population reestablishment. Regrowth of goldenseal (*Hydrastis canadensis*) and ginseng (*Panax quinquefolius*), for example, is dependent on the size and type of vegetative propagules remaining in the soil (*e.g.*, rootlets and intact, distal, mid- or proximal rhizome fragments; Van der Voort *et al.*, 2003). Smaller pre-harvest goldenseal plants (or those experiencing repeated harvest) showed little to no stem recovery in the year following harvest, and those plants that did emerge tended to remain smaller (relative to pre-harvest plants; Sanders and McGraw, 2005) and have lower survival rates (Sinclair *et al.*, 2005) in subsequent years. Rock *et al.* (2004) suggest that the consequences of over-harvesting may persist for extended periods of time. They estimate a recovery period of about 2.5 y for populations of ramps (*Allium tricoccum*) subjected to 5% harvest but nearly 150 y for populations at 95% harvest.

A second objective of our study was to assess the potential of black cohosh populations to recover to pre-harvest vigor and abundance. After 3 y of experimental harvest, we allowed 1 y for population regrowth. Following intensive (66%) harvest, we saw no evidence of "recovery." Instead, control and intensive harvest treatments continued to diverge (2008 vs. 2009; Table 1; Fig. 1). Thus, 1 y clearly was not sufficient for population recovery. Our results agree with others suggesting that population regrowth may require several years (Van der Voort *et al.*, 2003; Sanders and McGraw, 2005; Albrecht and McCarthy, 2006). For goldenseal and ginseng, Van der Voort *et al.* (2003) found that plants were small 1 y after harvest but continued to increase in size in subsequent years. Albrecht and McCarthy (2007) also report significant increases in goldenseal height, leaf size and reproduction with longer recovery periods (2 vs. 4 y), although their results were not consistent across their two study sites. Sanders and McGraw (2005) similarly report significant increases in goldenseal leaf area from 1 to 2 y after harvest. However, these and other authors note that populations often do not recover to pre-harvest levels. Rock *et al.* (2004) followed ramp populations 4 y after experimental harvests and found only limited recovery. To determine the extent and time necessary for black cohosh reestablishment, we will continue to monitor populations at our study site over the next several years.

In considering the implications of our results, it is important to note that harvest method (frequency, intensity, technique), site disturbance (Sanders and McGraw, 2005) and harvest history, and differences in site conditions (especially light availability; Sanders and McGraw, 2005; Van der Voort *et al.*, 2003; Ticktin, 2004) are likely to affect harvest impacts and recovery potential. In our study, we examined only mid- to late-summer harvests. It has been suggested that harvest season may affect population recovery capacity, with greater recovery of leaf biomass reported for fall- (vs. mid-summer) harvested goldenseal populations (Sanders and McGraw, 2005; Albrecht and McCarthy, 2007). These trends have been attributed to increased allocation to below ground storage structures just prior to winter dormancy (Albrecht and McCarthy, 2007).

In addition to harvest effects, both of our study sites showed significant declines in black cohosh over time (within-subjects time effect; Table 1). Such changes may have resulted, at least in part, from repeated foot traffic and plant handling during 3 to 5 y of sampling. The sensitivity of mesic forest herbs to disturbance and microenvironmental change is well recognized (Small and McCarthy, 2002b; McCarthy, 2003; Small and McCarthy, 2005). Experimental studies repeatedly have demonstrated impacts of short-term, low-intensity trampling, showing reduced understory cover and increased bulk density of the soil after as few as 25 walking passes (*e.g.*, Marion and Cole, 1996; Roovers *et al.*, 2004; Kissling *et al.*, 2009). Such effects have been shown to persist at least 1 y (Cole, 1995) and have been associated with reduced site productivity and growth and fecundity of forest herbs (Mou *et al.*, 1993; Roberts and Gilliam, 1995; Small and McCarthy, 2002a). At our study sites, increases in control population from 2007–2009 (foliage area and stem production, both sites; Fig. 1) suggest that overall declines also are likely to reflect natural year-to-year variations (*e.g.*, local climate conditions) and the pronounced influence of intense harvest treatments on overall trends over time.

CONCLUSIONS

There is general concern among natural resource managers that wild-harvested medicinal plants are at-risk due to over-harvesting. The conservation status of many plants with medicinal value is unclear, and little effort has been made to determine their sustainable harvest levels. Black cohosh is a prime example of a medicinal plant that has significant demand to warrant examination of the impact and recovery from harvesting. Without basic information on the capacity for medicinal plants such as black cohosh to recover from harvesting, sustainable harvest levels will remain enigmatic. We have limited knowledge of how much black cohosh root is harvested from a typical population. Our study demonstrated negative effects of harvesting, although we cannot be certain if our treatments represent typical harvest levels. While this study has improved our understanding of the impact of harvesting, additional work is needed to determine the threshold level above which harvest is not sustainable.

With rising demand for southern Appalachian medicinal plants such as black cohosh, assessing the sustainability of wild-harvesting practices and establishing viable management plans is increasingly important. Claims of sustainable harvesting should be examined with great suspect, unless such claims are supported by empirical evidence. Continued study will help us to assess impacts of low to moderate harvesting levels, identify sustainable harvesting intensities, and determine minimum recovery periods necessary to prevent long-term damage to natural populations.

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