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Recovery of Populations of Goldenseal (Hydrastis canadensis L.) and American Ginseng (Panax quinquefolius L.) Following Harvest

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ABSTRACT.—Goldenseal (*Hydrastis canadensis* L.) and American ginseng(*Panax quinquefolius* L.) have been harvested commercially for the past few centuries. Harvested populations can recover if vegetative propagules remain in the soil. Experiment I tested the efficacy of vegetative reproduction in goldenseal and ginseng. Partial and intact rhizomes and roots were planted in garden experiments in West Virginia and monitored for 1 y (goldenseal), and for 4 y (ginseng). During the experiment more than 40% of the propagule types of goldenseal (n = 5) and ginseng (n = 7) sprouted. Sprouting varied from year to year in ginseng, and dormancy and/or death occurred in both species. Of the ginseng propagules that sprouted, 77% were dormant for at least 1 y and half of those were not present in the final year of the experiment. Sprouting and reproductive status were dependent on propagule type for both species. In Experiment II we monitored recovery of wild populations of goldenseal and ginseng following natural and simulated harvests. After a harvest event leaving only 4 visible plants at the site, a goldenseal population recovered to 932 stems in the first growing season. In the subsequent 3 y, the population declined numerically, but the size of individuals increased significantly. In a harvested ginseng population, less than half the original number of ginseng plants were present 1 y after harvest. By the second year, stem number exceeded the preharvest count, but the demographic structure of the population had changed dramatically: 78% of the population was reproductive before harvest, while 0%, 4%, 7%, 18% and 26%, respectively, were reproductive in the 5 y following harvest. Both rhizomes and roots of goldenseal and ginseng are capable of regenerating plants, conferring a degree of short term resiliency following harvest.

INTRODUCTION

Conservation of wild animal and plant species consumed by humans presents difficult management challenges (Freese, 1997). Harvest by humans decreases populations of wild species, which, unless counteracted by equal or greater recruitment, can drive populations to commercial and biological extinction. Many wild herbaceous perennials are being harvested to supply an increasing global demand for herbal products (Robbins, 1998). Two examples in the eastern deciduous forest of North America are goldenseal (*Hydrastis canadensis* L.) and American ginseng (*Panax quinquefolius* L.). The June 1997 listing of goldenseal in CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) Appendix II (export of any species in Appendix II requires a federal permit) reflected the concern on the part of the US government that increased goldenseal exports merit monitoring and regulatory intervention (Robbins, 2000). Ginseng was placed

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on the same list in 1973, prompting the US Fish and Wildlife Service to determine annually states which may continue to export wild harvested ginseng.

Goldenseal and ginseng are economically valuable, generating millions of dollars annually for harvesters who dig and sell them (Robbins, 2000). The rhizomes of goldenseal and taproot with attached rhizome of ginseng are the harvested structures. Intense harvesting may reduce the abundance of both species in some areas (Millspaugh, 1892; Strausbaugh and Core, 1953; Foster and Duke, 1990; Davis, 1994; Bannerman, 1998; Robbins, 2000), though rigorous quantitative information on population status and recovery remains scarce. The status of goldenseal and ginseng throughout their ranges is unknown because there are insufficient biological data to judge the extinction risk (Nantel *et al.*, 1996; Bannerman, 1998). Six states (North Carolina, Vermont, Connecticut, Georgia, Massachusetts and Minnesota) list goldenseal as endangered (Bannerman, 1998) and ginseng appears on one state (Rhode Island) endangered list (Robbins, 1998).

Life history characteristics of long-lived perennial plants may vary greatly, making harvest impacts variable within this class of plants. Goldenseal commonly occurs in patches of dozens to hundreds of interconnected ramets (defined here as a rhizome plus connected leaf petioles and blades; Eichenberger and Parker, 1976; Sinclair and Catling, 2000a). The clonal growth form and rarity of seedlings in the field (Harding, 1936; pers. obs. 1998, 1999; Sinclair and Catling, 2000a) suggests dependence on vegetative propagation. Recovery of goldenseal from harvest by vegetative means has not been documented, however. By contrast, ginseng normally occurs as distinct individuals (*i.e.*, genets) and splitting of rhizomes is rare (Lewis, 1988; Charron and Gagnon, 1991). This pattern suggests reliance of ginseng on sexual reproduction.

The objectives of the present study were twofold. First, we evaluated the ability of intact and fractional goldenseal and ginseng rhizomes and roots to regenerate plants. Understanding rates of success of such propagules is an important component of predicting recovery after harvest. The second goal was to document recovery of natural populations of goldenseal and ginseng after harvest and to relate the patterns of recovery to the life history differences between the species.

STUDY SPECIES AND METHODS

Study species.—Goldenseal and American ginseng are native to eastern North America and are found in rich, moist, deciduous woods in well-drained soils. Both species emerge in early spring before full canopy closure. A ginseng population consists of a group of individual plants, most of which are distinct genets (Lewis, 1988; Charron and Gagnon, 1991). We use the word "patch" to describe a cluster of goldenseal plants rather than "population" because the plants may not consist of more than one genet (Sinclair and Catling, 2000a).

The erect stems of goldenseal are attached to irregularly knotty bright yellow rhizomes (Sinclair and Catling, 2000a). Many adventitious roots emerge from the rhizome (Fig. 1). Goldenseal plants with a single leaf are sterile, whereas two-leaved plants bear flowers. An inconspicuous, greenish-white flower, consisting of three petal-like sepals and numerous stamens and carpels (Strausbaugh and Core, 1953; Sinclair and Catling, 2000a) emerges briefly in April or May. The fruit ripens in mid- to late-July or August. Seeds are dispersed shortly thereafter (Harding, 1936; Baskin and Baskin, 1998; Sinclair and Catling, 2000a), with birds as the likely primary dispersers (Harding, 1936; Eichenberger and Parker, 1976; Sinclair *et al.*, 2000).

Ginseng leaves are arranged in a whorl on top of a single aerial "stem" consisting of fused leaf petioles (the sympodium) attached to an underground rhizome. The rhizome is attached to a primary taproot which serves as a fleshy storage organ (Fig. 1). Adventitious

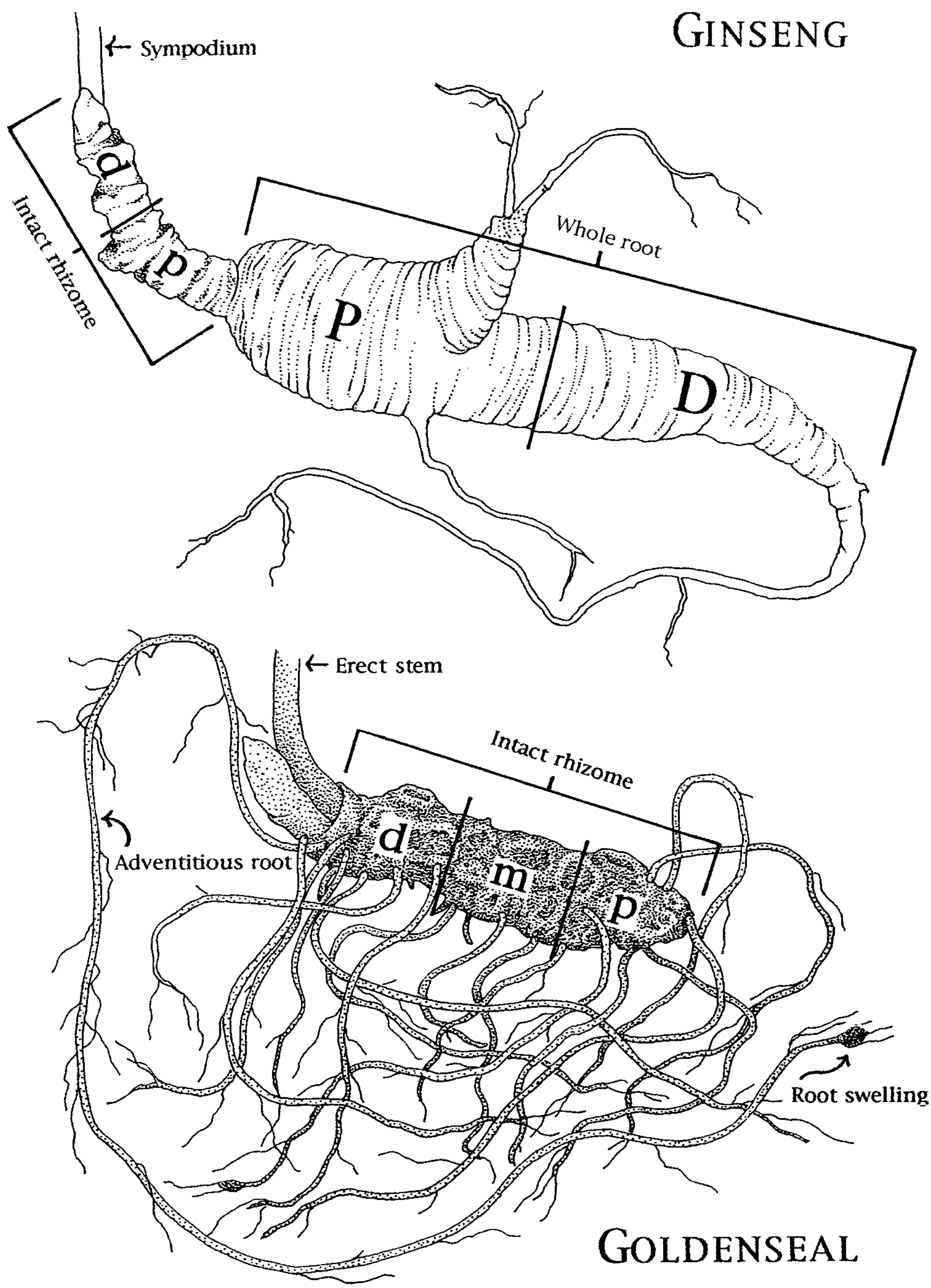

FIG. 1.—Diagrammatic key to treatments for goldenseal and American ginseng used in propagule experiment. P = proximal root propagule, D = distal root propagule, p = proximal rhizome propagule, m = middle rhizome propagule and d = distal rhizome propagule

roots can form from several nodes on the rhizome (Anderson *et al.*, 1984) as the plant ages. Scars form on the rhizome each year as a result of annual abscission of the sympodium (Charron and Gagnon, 1991). Annual bud scars allow the plants to be aged. A juvenile period during which plants may have 2 or 3 leaves (also referred to as "prongs"), each with 3–5 leaflets is followed by a reproductive period which begins around age seven or eight (Carpenter and Cottam, 1982; Charron and Gagnon, 1991; Anderson *et al.*, 1993). Reproductive plants typically have 3–4 leaves, with 3–7 leaflets each (Carpenter and Cottam, 1982).

Ginseng is typically found in scattered populations (Lewis and Zenger, 1982; Charron and Gagnon, 1991). Population size ranged from 1–348 individuals (mean = 21.5, SE = 8.45) in 43 populations located in West Virginia during two summer field seasons (Van der Voort, 1998). The majority of populations had fewer than 10 individuals (65%), 21% had 10–25 individuals and 14% had over 25 individuals. Only two populations had more than 100 individuals. Population size data for other locations are limited. Single populations studied in Wisconsin and Missouri in 1982 and 1985 respectively, were 95 and 98 (Carpenter and Cottam, 1982; Lewis, 1988). Two populations studied in New York in 1984 and 1985 were 211 and 220 individuals, respectively (Lewis, 1984; Schlessman, 1985). Four populations studied in Quebec from 1986–1988, ranged in size from 60–128 genets (mean = 86; Charron and Gagnon, 1991). A population located in North Carolina in the late 1980s numbered over 1000 (R. Sutter, pers. comm.)

Small, greenish white perfect flowers on a solitary umbel appear from May to August (Strausbaugh and Core, 1953; Lewis and Zenger, 1982). Flowers mature centripetally over a period of 1–3 wk (Schlessman, 1985). One to three seeded berries ripen from August–September. Berries are dispersed beneath the plant (Lewis and Zenger, 1982; Anderson *et al.*, 1993) or may be dispersed by rodents and other animals (Lewis and Zenger, 1982; pers. obs.).

PROPAGULE EXPERIMENT

EXPERIMENT I

Goldenseal.—Live plant material was collected in Wirt County, West Virginia, on 30 September 1995 in a mixed hardwood forest. Only plants with aboveground vegetation and attached rhizomes were collected. All plants were placed in containers with several centimeters of water and stored for 4 d at ca. 24 C. On 4 October the rhizomes were washed to remove excess soil, then randomly assigned to 1 of 5 treatment groups: intact plants, distal, middle and proximal rhizome propagules and root buds (small swellings on the adventitious roots branching off the main goldenseal rhizome; Fig. 1). Rhizome propagules were prepared by severing 25 intact rhizomes into roughly equal pieces. Adventitious roots were present on all propagules. Propagule sizes varied from very small root swellings (mean fresh biomass = 0.2 g, SE = 0.03) to larger rhizome fragments (mean fresh biomass of distal fragments = 1.1 g, SE = 0.13) to whole rhizomes (mean fresh biomass = 3.9 g, SE = 0.40).

American ginseng.—Eighteen plants, ranging in age from ca. 5–21-y old were collected from a natural population in Monongalia County, West Virginia on 30 August 1996 from a sugar maple (*Acer saccharum* Marsh.) dominated forest. The elevation of the site was 294 m and had a southwestern aspect (240°). To our knowledge, harvest had not occurred at the site. Roots were stored individually for 6 d at ca. 24 C in plastic bags containing soil from the point of harvest. Roots/rhizomes were washed, then randomly assigned to 1 of 7 treatment groups: intact plants (rhizome with attached taproot and adventitious roots, n = 6), intact rhizomes (n = 6), distal and proximal rhizomes (n = 6 for both groups), whole roots (n =

17), proximal and distal roots (n = 14 for both groups; Fig. 1). Sixteen of the harvested plants had a taproot and varying numbers of adventitious roots. The "whole root" class was composed of single, adventitious roots created by severing plants with multiple roots. Middle rhizome propagules were not used as a treatment because ginseng rhizomes were too small to be cut into three pieces. Propagules for the distal and proximal root and rhizome classes were prepared by severing whole roots and intact rhizomes roughly in half. Propagule sizes varied from small rhizome (mean fresh biomass of distal fragments = 0.4 g, SE = 0.06) and root fragments (mean fresh biomass of distal fragments = 1.5 g, SE = 0.22) to larger intact rhizomes (mean fresh biomass = 4.8 g, SE = 2.14) and whole roots (mean fresh biomass = 4.1 g, SE = 0.99) to intact plants (mean fresh biomass = 13.7 g, SE = 2.65). The six propagules used to create the distal and proximal rhizome pieces ranged in age from 5 to 16 y. The n for all treatment classes was not equal because individual ginseng plants varied in the number of adventitious roots present.

All material was planted in a completely random design in a 1 × 5 m plot. Goldenseal was planted in the West Virginia University Core Arboretum on 4 October 1995 in forest with a dominant red oak (*Quercus rubra* L.) canopy and well developed sugar maple/hickory (*Carya* sp.) subcanopy. The elevation of the site was 250 m and the aspect was west-southwest (275°). Ginseng was planted in a nature preserve 8 km northeast of Morgantown, West Virginia, on 6 September 1996 in a tulip poplar (*Liriodendron tulipifera* L.)/sugar maple dominated forest. The elevation of the site was 290 m and had a southwestern aspect (200°). Both plots were established at approximately the same aspect and elevation as natural wild populations located nearby (an elevation of 250 m and aspect of 285° for goldenseal; an elevation of 290 m and aspect of 190° for ginseng). The garden plots were not prepared for planting *i.e.*, all vegetation and other material remained in situ. Each propagule was assigned a unique number and marked either with a wooden stake (for goldenseal, N = 125) or underground numbered metal band (for ginseng, N = 69). The propagules were planted with 20 cm spacing, at a depth of 3 cm. To facilitate census, x, y coordinates for each propagule were recorded. All propagules were lightly watered following planting. Goldenseal stems first emerged on 28 April 1996. The plot was censused every 10 d beginning 7 May through 25 August 1996, and sprouting status, stem height, leaf width and length and reproductive status were recorded. The ginseng plot was censused in 1997, 1998, 1999 and 2000 between 22 May and 3 July, and sprouting and reproductive status were recorded. Stems of both species were considered reproductive if flowers or fruiting structures were present. We monitored ginseng longer than goldenseal (*i.e.*, for 3 additional years) because of its reported propensity to remain dormant through entire growing seasons (Carpenter and Cottam, 1982).

We observed whether goldenseal and ginseng propagules sprouted in the different propagule classes, then tested the null hypotheses that different propagules were equally able to sprout, and that different classes of propagule were equally able to produce reproductive stems (G-test, Sokal and Rohlf, 1995).

RECOVERY FOLLOWING HARVEST IN WILD POPULATIONS

EXPERIMENT II

Goldenseal.—Following notification from a local landowner that a wild goldenseal patch he had been observing for 7 y had been harvested in late August 1995, a complete census of the area was conducted on 12 September 1995. The patch was located in a mature red oak forest with a well developed sugar maple/hickory subcanopy. The elevation of the site was 390 m and had a northwestern aspect (310°). Only four plants were located in a 5 m × 5 m area where leaf litter and soil were disturbed from the harvest. Some portion of the population may have senesced before the harvest, so our estimate of the remaining population may be low. We established an 8 m × 8 m grid which included the original patch, to track growth of the population should recovery occur. Permanent markers were buried at the four corners of the grid. The plot was censused monthly the following growing season beginning 25 May 1996 and ending in September.

Since recovery did occur, complete censuses were made during the fourth week of June (when leaf expansion was complete) in the summers of 1996, 1997, 1998 and 1999. The total number of stems in the recovering population and their stage class (1 leaf, non reproductive, or 2 leaved, reproductive) were recorded. A random subsample of 100 individuals was taken each year and stem height, leaf width and length were recorded for all plants in the subsample. The numerical dynamics and size structure of the goldenseal population were compared among years using an ANOVA (SAS JMP, V.3.0.2, SAS, Inc., 1989). When the results were statistically significant, multiple comparisons tests using Tukey-Kramer's HSD were performed to determine which years differed.

American ginseng.—Collection of live plant material on 30 August 1996 for the garden experiment served as a simulated "complete" harvest. It is likely that some plants had senesced by this date, however, the harvest was conducted carefully and included plants without aboveground vegetation. The outside perimeters of the population were permanently marked (the harvest area was approximately 1 m × 2.5 m). The plot was censused the following spring (1997). Ginseng plants were discovered in ensuing years. Complete censuses were made in the summers of 1997, 1998, 1999, 2000 and 2001 between 30 May and 4 July, noting the size class and reproductive status of each stem. Ginseng population recovery was monitored for 5 y to provide comparison data to similar research conducted in the mid 1980s (Lewis, 1988).

RESULTS

PROPAGULE EXPERIMENTS

EXPERIMENT I

Goldenseal.—Nearly half of the vegetative propagules sprouted and all five propagule types produced stems (Table 1, n = 25 for all 5 classes). Contingency analysis revealed that sprouting status of goldenseal varied with propagule type ($G = 18.206$, $P = 0.0011$). Intact rhizome and distal rhizome propagules had the highest rate of sprouting. Root swellings had the lowest rate (Table 1). Reproductive status also depended on propagule type ($G = 17.431$, $P = 0.0016$). Intact rhizome propagules produced the most reproductive stems, followed by distal and proximal propagules. Of the propagules which sprouted, slightly more than one fourth (28%) produced reproductive plants.

Plants emerging from different propagule classes grew to different sizes as measured by mean stem height (ANOVA, $F = 10.9254$, $P < 0.0001$. Table 1). Intact rhizomes produced plants with significantly greater mean stem height than the other propagule classes (Tukey-Kramer HSD).

American ginseng.—Sprouting status of ginseng propagules varied over 4 y. Thirty of 69 propagules (44%) sprouted during the experiment, and new plants sprouted in all 4 y. Although the sample size for the rhizome treatments was small, all seven propagule types produced stems in at least 1 y. Only intact plants and whole roots sprouted in all 4 y. Patterns of sprouting across years showed that rhizome and root propagules were capable of remaining dormant for up to three seasons after planting before emergence. Some propagules were dormant in years 1 and 3 and present in years 2 and 4. Dormancy occurred

TABLE 1.—Experiment I. Rate of production of viable aboveground sprouts, reproductive status and final stem height (with SE in parentheses) one year following planting for goldenseal. Data reported here are from the 26 June 1996 census. Means in a column with different letters are significantly different

Propagule type	Sprouted (%)	Reproductive (%)	Stem height (cm)
Total (n = 125)	46	28	—
Intact rhizomes (n = 25)	64	63	13.7a (1.08)
Distal rhizome propagules (n = 25)	64	31	7.5b (0.72)
Middle rhizome propagules (n = 25)	44	0	8.2b (0.91)
Proximal rhizome propagules (n = 25)	48	8	7.6b (0.91)
Root swellings (n = 25)	12	0	5.1b (0.93)

in 77% of the propagules. Contingency analysis revealed that sprouting status of ginseng depended on propagule type in 3 of 4 y (G = 27.377, P = 0.0001; G = 18.764, P = 0.0046; G = 14.887, P = 0.0212; and G = 9.119, P = 0.1670 in 1997, 1998, 1999 and 2000 respectively). Six of the seven propagule types produced reproductive stems (only distal rhizome propagules did not produce a reproductive stem). Reproductive status depended on propagule type in all 4 y (G = 25.682, P = 0.0003; G = 23.021, P = 0.0008; G = 13.202, P = 0.0399; and = 13.202, P = 0.0399 for 1997, 1998, 1999 and 2000, respectively).

Survival of propagules from year to year varied. Of the 30 propagules that sprouted, 50% survived all 4 y (n = 15; 3 intact plants, 1 intact rhizome, 1 distal rhizome propagule, 4 whole roots, 5 proximal root propagules and 1 distal root propagule), 17% survived 3 y (n = 5; 1 intact plant, 2 whole roots and 2 proximal root propagules), 27% survived 2 y (n = 8; 1 intact plant, 2 intact rhizomes, 4 whole roots and 1 distal root propagule) and 7% survived only 1 y (n = 2; 2 proximal rhizome propagules).

In general, more ginseng stems were produced by whole root and root propagules than intact rhizome and rhizome propagules (18% vs. 11% averaged over 4 y). Whole root and root propagules produced reproductive plants with almost 4 times the frequency of intact rhizome and rhizome propagules (49% vs. 13% averaged over 4 y). The root is larger than the rhizome and presumably is capable of storing larger carbohydrate reserves.

RECOVERY FROM HARVEST

EXPERIMENT II

Goldenseal.—The "naturally harvested" goldenseal patch had only 4 plants remaining immediately following harvest. The following spring a total of 932 stems sprouted in the same area. In the three subsequent years, the total population declined slightly in numbers. However, mean stem height, leaf width and length were all significantly greater in 1997, 1998 and 1999 than in 1996 following harvest (ANOVA, P < 0.001 in all cases; Table 2).

American ginseng.—We were not aware of any aboveground plants at the site following the simulated harvest of the ginseng population in 1996. However, one 2-leaved plant was located the first year after harvest. In 1997 less than half the number of plants present before harvest were found. By 1998 there were more plants present than before harvest, but the stage structure of the population was very different. Before harvest, reproductive plants

TABLE 2.—Experiment II. Numerical and morphological traits of goldenseal following a natural harvest event. Means in a column with different letters are significantly different. SES are in parentheses

Year	Population number following harvest	Population number, 1st growing season	Number of flowering plants	Mean stem height (cm)	Mean leaf width (cm)	Mean leaf length (cm)
1995	4		—	—	—	—
1996	—	932	11	8.5a (0.49)	7.8a (0.51)	4.6a (0.29)
1997	—	840	20	13.0bc (0.63)	11.6bc (0.58)	6.5bc (0.30)
1998	—	849	20	11.7b (0.54)	9.6b (0.39)	5.5b (0.22)
1999	—	819	5	14.1c (0.44)	11.5c (0.41)	6.6c (0.23)

accounted for 78% of the population. There were no reproductive plants in the year immediately following harvest. In years 2, 3, 4 and 5 postharvest, 4%, 7%, 18% and 26% of the genets were reproductive, respectively. In the first 4 y following harvest, well over 60% of all genets were 1 leaved, 3 leaflet plants (Table 3). These stems were never excavated to determine seedling status because we did not want to disturb the site further. Based on seed counts made in August 1996 one month before harvest, as many as 89 seeds may have been left at the site before harvest. We do not know the fate of the 89 seeds missing in September but we assume some fraction remained in the soil and germinated in 1998 and 1999. Typically, seeds must remain dormant for at least two winters before germination. This is due to incomplete embryo development by the first spring, followed by the need for cold stratification after completed embryo development before germination (Baskin and Baskin, 1998).

DISCUSSION

Underground parts of both goldenseal and ginseng are capable of regenerating plants. Vegetative reproduction has been observed in ginseng only rarely before our experiment in which we planted root and rhizome fragments (Lewis, 1988). All propagule types of both species produced aerial stems.

The methods harvesters use to remove goldenseal and ginseng are quite different, leading to different probabilities that the various propagule types will be left behind. Because the most valuable ginseng roots are large, slow-growing and intact, ginseng diggers are careful to remove as much of the plant as possible (Bailey, 1999). Our study suggests that vegetative growth from severed parts is possible. However, due to such thorough excavation by harvesters, this is unlikely to account for much population recovery of ginseng.

With goldenseal, in contrast to ginseng, there is no economic premium on keeping roots intact (Bailey, 1999). In addition, the tight interwoven clonal growth form makes it difficult to excavate individual plants with a high degree of care or precision. Thus, in digging a patch of goldenseal, it is highly likely that portions of rhizomes and adventitious roots will be left at the site. Thus, *a priori*, one should expect that vegetative recovery from harvest of goldenseal should be possible. Further, Sinclair and Catling (2000a, b) conducted ecological research on goldenseal in southwestern Ontario (the northern extension of its range), and found that goldenseal may benefit from disturbance. Although they did not address disturbance

TABLE 3.—Experiment II. Changes in size structure and reproductive plant number in a harvested ginseng population

Stage	1996 (Preharvest)	1997	1998	1999	2000	2001
1 leaf	4	10	25	20	14	7
2 leaves	1	1	1	7	7	9
3 leaves	18	0	1	1	1	2
4 leaves	0	0	0	0	0	1
TOTAL	23	11	27	28	22	19
(No. reproductive	18	0	1	2	4	5)

resulting from harvest, they cited soil disturbance as a factor that may be beneficial to goldenseal growth and spread.

The patterns of recovery from harvests in natural populations suggest a greater reliance on sexual reproduction in ginseng than in goldenseal. No goldenseal seedlings were located in the monitored patch. No evidence of seedling development was found by Sinclair and Catling (2000a) in Ontario. Conversely, 91% of the plants present the year following harvest of the ginseng population had 1 leaf (with 3 leaflets). Because we did not wish to disturb the small ginseng plants we could not determine their age; however, the original harvest was conducted thoroughly. It is unlikely that many vegetative fragments were left in the soil. In addition, we know from the propagule experiment that sprouts from fragments usually (>85%) produce 2 and 3 leaved phenotypes. Therefore, we inferred that most small ginseng plants after the harvest event were seedlings.

Lewis (1988) monitored a naturally harvested ginseng population in southwestern Missouri. The one remaining genet following harvest in 1979 was aged by counting bud scars on the rhizome (age = 1). Lewis returned after a 5 y hiatus and aged all plants in the recovered population. He did not cite any signs of disturbance to the population. Seventy nine percent of the original population was present in 1984 (25% of which were reproductive, compared to 66% before harvest). Five years following harvest of the West Virginia ginseng population, 83% of the original number of plants were present, 26% of which were reproductive. We did not observe any signs of disturbance during the study period. Lewis concluded that the Missouri ginseng population was restored because of the viable propagules that had previously accumulated in a seed bank. Our results support his conclusion, though probably a decade or more of observation will be required before we could conclude that the reproductive potential has returned to its preharvest condition.

Despite contrasting patterns of harvest, we observed similarities between goldenseal and ginseng in recovery of natural harvested populations. We did not have a preharvest ramet count for goldenseal, but numerical recovery following harvest was rapid for both species. The stage structures of goldenseal and ginseng recovered more slowly than their numbers. Both goldenseal and ginseng plants were small in the first growing season immediately following harvest. Plants of both species grew larger but fewer in number as they aged.

We do not know if the apparent resilience we observed in one wild goldenseal patch and one wild ginseng population is typical. In addition, we cannot predict whether recovery is sufficient for complete population regeneration or if populations would decline with repeated harvest. Our study has shown that populations of both species are not necessarily eliminated by a single harvest.

The viability of ginseng rhizomes demonstrated in this study (albeit with a limited sample size) suggests an additional opportunity for harvesters to maintain natural populations. Indeed, interviews with harvesters have revealed that some of them purposely plant rhizomes in order to improve the likelihood of future harvests (Bailey, 1999; Hufford, 1999). Recent federal regulations now prevent this practice by requiring that rhizomes remain attached to roots as proof of sufficient age (plants must be ⩾5 years to be considered harvestable). Regulations such as these could change if future research indicates that wild populations are declining. Most states require (and all at least encourage) harvesters to leave ginseng seeds at the harvest site. Removal and planting of the rhizome may be a logical additional step harvesters could take to encourage population growth. While rhizomes had a relatively low long term success rate in our study, this site is known to be heavily browsed by deer which could be influencing that result.

Differences in life history can have a large impact on the suitability of a given species for collection for commercial markets. In general, long-lived species that reach reproductive age after a lengthy juvenile period may be more vulnerable to overharvesting than species that reach reproductive maturity quickly (Bodmer, 1995; Freese, 1997). Long-lived perennials such as goldenseal and ginseng may therefore be vulnerable to harvest effects.

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