

# Harvest Recovery of Goldenseal, *Hydrastis canadensis* L.

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**ABSTRACT.**—Goldenseal, *Hydrastis canadensis* L., is a herbaceous understory plant of the eastern deciduous forest that is harvested from natural populations due to its medicinal value. The objectives of this study were to determine if regrowth from harvest varies between patches and also to relate regrowth to pre-harvest leaf and patch size. We used data from three experimentally harvested natural patches and data on recovery of an illegally harvested patch harvested at the end of the growing season. We found variation in patch regrowth which suggests harvest technique and timing may be important. Experimental rhizome removal during mid-summer resulted in slower recovery of leaf size relative to the patch that was illegally harvested. We found a trend for reduced leaf area 2 y post-harvest relative to that pre-harvest. We also found variation in stem count between patches in response to harvest, which may be due to the pre-harvest size of ramets. The patch with larger pre-harvest ramets showed compensatory growth in the year immediately after harvest while the patches comprised of smaller ramets did not. Our results indicate that response to, and recovery from, harvest varies between patches and that individual ramet leaf size may be a better predictor of patch recovery than stem count. Because regrowth may be affected by harvest timing, an established harvest season may alleviate some harvest pressure on *H. canadensis*.

## INTRODUCTION

Harvest of native understory species in the eastern deciduous forest is a time-honored tradition ingrained in both the cultural and economic fabric of some regions. Harvested items, and their derivatives, are used locally as food, food additives and medicines. They are sold on the herbal market (Bailey, 1999). Harvested understory species include the herbaceous plants, ginseng, *Panax quinquefolius* L., black cohosh, *Actaea racemosa* L. (Nutt.), and ramps, *Allium tricoccum* Ait. (Rock *et al.*, 2004), as well as various mushroom and moss (Peck and McCune, 1998) species. Increases in demand from the herbal market, as well as increasing human population size, have put additional pressures on these species. One species for which harvest pressure may be detrimental is goldenseal, *Hydrastis canadensis* L. (Ranunculaceae).

*Hydrastis canadensis* is an herbaceous plant native to the eastern deciduous forest of North America. This species exhibits clonal growth via an extensive network of rhizomes and lateral roots, resulting in dense patches of *H. canadensis* ramets. Although the amount of genetic diversity within patches has not been documented, the high degree of clonal reproduction suggests that only a few genotypes may be present within any given patch. Populations comprised of multiple patches typically number from between a few to several hundred ramets (Suzanne Sanders, pers. obs.; Sinclair and Catling, 2000a, b; Mulligan and Gorchoy, 2003). Recent evidence suggests that *H. canadensis* is experiencing population decline. There are fewer populations present (Sinclair and Catling, 2000b; Mulligan and Gorchoy, 2003), fewer patches per population (Sanders and McGraw, 2002) and fewer ramets per patch (Sanders and McGraw, 2002). Stem count in some patches may be increasing ( and Catling, 2002). Currently, it is unclear what role harvest plays in *H. canadensis* patch dynamics.

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Observations of a patch near Morgantown, West Virginia, that was recently harvested illegally (*i.e.*, “poached”) suggested that harvest may initially stimulate the production of above-ground stems (Van der Voort *et al.*, 2003). This can occur because lateral roots are broken and left in the soil when the large storage rhizome is removed from the ground. These lateral roots contain adventitious buds that can develop into new aerial shoots (Bowers, 1891). The pre-harvest stem count, size and stage structures of the Morgantown patch were unknown. However, four ramets were observed during summer 1995 immediately following harvest. Van der Voort *et al.* (2003) monitored regrowth over the next four growing seasons (1996–1999). The trends they reported were an increase in leaf size over the 4 y monitored, but a decrease in stem number. Unfortunately, this study provided us with recovery information from only one patch, of which pre-harvest size was not known. It is also not known how generalizable these results are across variable environments.

Christensen and Gorchov (2002; David Gorchov, pers. comm.) have examined the effect of harvests by using transition matrix modeling to simulate annual harvest of 10% of a population while accounting for “normal” demography in the remaining 90%. This is analogous to thorough harvest occurring in 10% of a population’s patches each year. The authors projected that this management scenario would lead to population decline ( $\lambda$  for Y 1 = 0.98,  $\lambda$  for Y 2 = 0.62). While this addressed population viability in theory, it does not substitute for empirical studies of harvest effects.

This study focused on regrowth of three experimentally harvested patches and a comparison with data from the poached natural patch (Van der Voort *et al.*, 2003). Our first objective was to determine if trends in regrowth were consistent across multiple harvested patches. We wanted to know how generalizable previous results were to other patches and other environments. We compared all four patches and asked whether the effect of the length of time since harvest on ramet leaf area, a measure of recovery rate, varied between patches. The null hypothesis was that leaf area recovery would not differ among patches. Our second objective was to determine the degree to which ramet leaf size had recovered 2 y after harvest. We, therefore, compared ramet leaf area of the three experimentally harvested patches at two times: immediately prior to harvest and 2 y post-harvest.

#### METHODS

Three patches were selected to be experimentally harvested. These sites are referred to as Cheat Canyon 1, Cheat Canyon 2 and Kingwood. Because we were interested in quantifying recovery within densely clumped patches, and because a population may contain one or multiple patches, we refer to a harvested unit as a “patch.” These patches were selected because, based on pre-harvest leaf size, they appeared to be older established populations and showed no evidence of recent harvest. The Kingwood site is located on land that had been selectively logged 2 y prior to harvest while the Cheat Canyon sites are located in older second growth forests dominated by red oak (*Quercus rubra* L.) and tulip poplar (*Liriodendron tulipifera* L.).

The experimental harvests were carried out on 24 July (Cheat Canyon 1 and 2) and 25 July 2001 (Kingwood). Prior to digging, stems were counted and the number that were reproductive was noted. Ramets were dug using a hand trowel with an effort made to remove all rhizomes attached to the visible aboveground stems. The harvest was conducted in a manner designed to simulate actual harvest; an effort was made to remove all rhizomes, although extra effort was not extended to dig and sift further in the soil for more possible rhizomes, allowing the harvest to be conducted efficiently. All plant material was returned to

the laboratory where stem height and leaf length were measured on all single-leaved ramets. On two-leaved ramets, the length of each leaf was measured and the area of the two leaves was summed to obtain the total leaf area of the ramet. The rhizomes were cleaned and used for other studies.

Estimates of leaf area were obtained using leaves of 100 additional ramets not included in these studies and regressing the natural log of leaf area on the natural log of leaf length. From the allometric relationship determined by this regression [leaf area =  $C$  (leaf length) <sup>$a$</sup> , where  $C = e^{0.6068}$  and  $a = 1.82848$  ( $r^2 = 0.96$ )], we determined leaf area of all harvested ramets. Measurements of regrowth of the experimentally harvested patches were taken during the last week of June 2002 and 2003. We counted stem number and measured stem height and leaf length of all ramets. We also measured length of the second leaf on reproductive ramets. For the Morgantown patch, we obtained the original data on leaf length from the authors (van der Voort *et al.*, 2003). For this patch, the authors randomly selected 100 leaves for measurement each year. Using this original data, we calculated leaf area for these 100 ramets as described above.

To determine if trends in regrowth were consistent across multiple harvested patches (our first objective) we compared the three experimental patches and the illegally harvested patch and asked whether the effect of the length of time post-harvest on ramet leaf area varied between patches. We used two-way ANOVA to test the main effects of time post-harvest (1 y or 2 y) and patch and to determine if there was a differential response among the four patches. The patch effect and the patch  $\times$  year interaction term were treated as random effects while time post-harvest was treated as a fixed effect in the model. For the Morgantown patch, we used the data from the 100 measured leaves. Because we also wanted to compare the three experimental patches (with common harvest methods and timing), we performed the same analysis described above, omitting the Morgantown patch.

Because changes in leaf area might be offset by inverse changes in the total number of ramets present, we felt that total patch leaf area may be a better measure for assessing year to year harvest recovery. For the three experimentally harvested patches, total patch leaf area was calculated by adding the leaf area of all individual ramets. For the Morgantown patch, the authors measured 100 randomly selected leaves. Because this patch contained 943 leaves 1 y post-harvest (921 single-leaved ramets and 11 two-leaved reproductive ramets) and 860 leaves 2 y post-harvest (820 + 20), we calculated the total summed leaf area of the 100 measured ramets each year and multiplied these values by 9.43 and 8.60, to obtain total patch leaf area 1 y and 2 y post-harvest, respectively. We used one-way ANOVA to test the effect of time since harvest on total patch leaf area and patch stem count across all four populations. We did not test the patch effect since the total patch leaf area and patch stem count will vary between patches due to inherently different sizes of the patches. Tests for differential responses of patches to the length of time since harvest are not possible due to lack of replication, although summarized data of yearly patch leaf area and stem count are presented and addressed for explanatory purposes.

To address the second objective, relating pre-harvest leaf size to regrowth, we used two-way ANOVA to test for differences in ramet leaf area of the experimentally harvested patches at two time periods: pre-harvest and 2 y post-harvest. The main effects were time period relative to harvest (treated as a fixed effect) and patch (treated as a random effect). We examined the significance of the time period  $\times$  patch effect to determine if there was patch dependent recovery of ramet leaf area after harvest. We used a power transformation, optimized to improve normality of the residuals.

We also used one-way ANOVA to test the effect of time period on the dependent variables of patch stem count and patch leaf area.

TABLE 1.—ANOVA of ramet leaf area of four patches: the three experimentally harvested patches and the illegally harvested patch. Time post-harvest is 1 y and 2 y

| Effects                   | df | F     | P > F   |
|---------------------------|----|-------|---------|
| Time post-harvest         | 1  | 11.72 | 0.0365  |
| Patch                     | 3  | 11.01 | 0.0397  |
| Time post-harvest × patch | 3  | 10.07 | <0.0001 |

### RESULTS

Our first objective was to determine if trends in regrowth were consistent across multiple harvested patches. Across all four harvested patches, post-harvest ramet leaf area differed between years (Table 1) and was greater 2 y post-harvest ( $27.5 \pm 3.0 \text{ cm}^2$ ) than 1 y post-harvest ( $17.0 \pm 2.6 \text{ cm}^2$ ). Harvest recovery depended on the patch (Table 1); the increase in ramet leaf area of the Morgantown patch between 1 and 2 y post-harvest was greater than that of the three experimentally harvested patches (Fig. 1). When we excluded the Morgantown patch from the analysis to account for possible differences in harvest practices, we found that ramet leaf area was, again, affected by the time since harvest (Table 2), although it was not patch-dependent (Table 2).

On a whole-patch basis, recovery from harvest was not evident beyond the initial flush of regrowth in year 1 after harvest. Neither whole-patch stem count ( $F = 0.22$ ,  $P = 0.6528$ ) nor whole-patch leaf area ( $F = 0.12$ ,  $P = 0.7401$ ) differed between the two time periods post-harvest.

The second objective was to relate pre-harvest ramet leaf area of the three experimentally harvested patches to ramet leaf area following 2 y of regrowth. There was a trend for ramet leaf area to differ between the two time periods (Table 3), with mean ramet leaf area reduced 66.7% following 2 y of regrowth compared with the size pre-harvest. Change in ramet leaf area during the two time periods was patch-dependent (Table 3). Ramet leaf area of the Kingwood site decreased more than that of either Cheat Canyon site (Fig. 2).

On a whole-patch basis, stem count did not differ between the pre-harvest and 2 y post-harvest time frame ( $F = 0.26$ ,  $P = 0.64$ ). However, changes in stem count between the pre-harvest and 1 y post-harvest time periods varied considerably between the three patches.

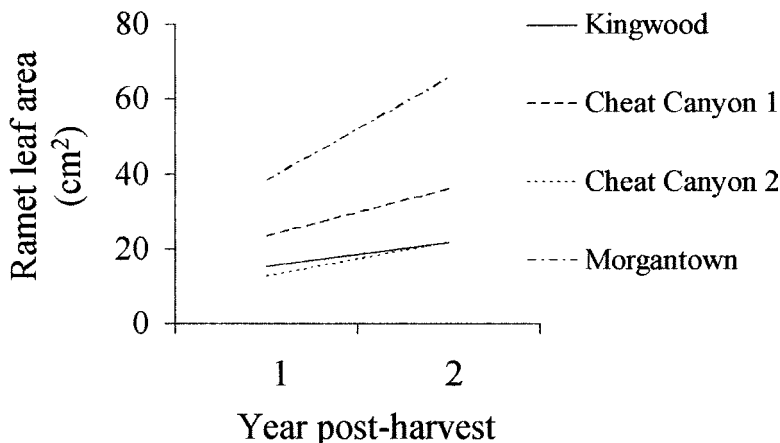


FIG. 1.—Differential response of ramet leaf area to harvest in four populations of *Hydrastis canadensis*

TABLE 2.—ANOVA of ramet leaf area of the three experimentally harvested patches. Time post-harvest is 1 y and 2 y

| Effects                   | df | F     | P > F  |
|---------------------------|----|-------|--------|
| Time post-harvest         | 1  | 26.92 | 0.0140 |
| Patch                     | 2  | 10.69 | 0.0856 |
| Time post-harvest × patch | 2  | 2.05  | 0.1285 |

Stem count of the Kingwood patch increased over 300% between the two time periods (Table 4) while stem count of Cheat Canyon 1 and Cheat Canyon 2 patches decreased 63% and 36%, respectively. Total patch leaf area was affected by the time relative to harvest ( $F = 16.08$ ,  $P = 0.0160$ ) and was greater pre-harvest ( $2.479 \text{ m}^2$ ) than 2 y ( $0.593 \text{ m}^2$ ) post-harvest (Fig. 3).

#### DISCUSSION

Our null hypothesis that leaf size would increase in a uniform manner across multiple harvested populations was not supported. Leaf size of the illicitly harvested Morgantown patch increased more between 1 and 2 y post-harvest than did the other patches. This could have been due to differences in harvest technique, although we attempted to experimentally harvest our patches in a manner simulating actual harvest. Variation in digging and collecting methods by harvesters could influence how thoroughly a patch is harvested, as could the degree of isolation of the patch and the consequences of a harvester being discovered. Because the Morgantown patch was poached from private land in late August and the experimental harvests were conducted in late July, timing of the harvest may also influence our results. Seasonal patterns of carbohydrate flux in perennial species generally show a decline in storage reserves during the period of greatest growth (Chapin *et al.*, 1990; Jonsdottir and Watson, 1997; Price *et al.*, 2002) followed by a reallocation of resources prior to senescence. If *Hydrastis canadensis* rhizomes and lateral roots are a strong carbohydrate and nutrient sink during the month of August, removal of rhizomes in July could reduce regrowth of lateral roots relative to removal later in the season. This, in turn, could reduce the resources available to the adventitious root buds and could account for the differential regrowth response between the experimentally harvested patches and the poached patch.

Our second objective concerned the degree to which three experimentally harvested patches recovered following 2 y of regrowth. Across all three populations, mean ramet leaf area after 2 y of regrowth was only 34% of the pre-harvest size.

Although there was no difference in stem count between years for the three experimentally harvested patches, there was considerable variation between patches in pre-harvest stem count relative to that 1 y post-harvest. Stem count of the Kingwood patch tripled while stem counts of Cheat Canyon sites were reduced roughly by half. The variation

TABLE 3.—ANOVA table of ramet leaf area of the three experimentally harvested patches. Time relative to harvest is pre-harvest and 2 y post-harvest

| Effects                          | df | F     | P > F   |
|----------------------------------|----|-------|---------|
| Time relative to harvest         | 1  | 5.46  | 0.0577  |
| Patch                            | 2  | 0.83  | 0.4090  |
| Time relative to harvest × patch | 2  | 79.97 | <0.0001 |

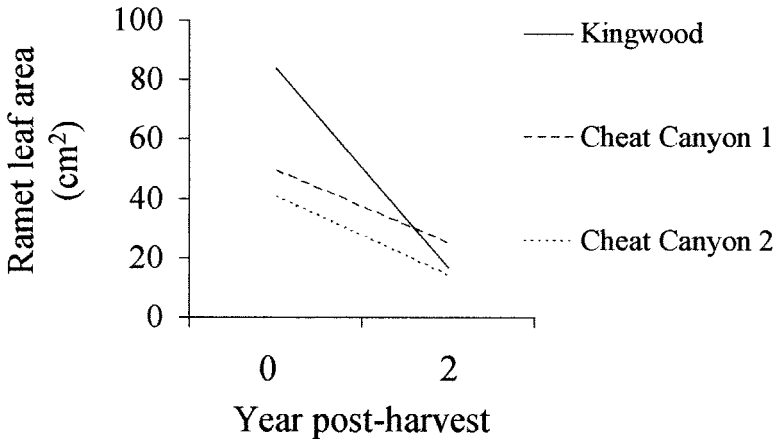


FIG. 2.—Differential response of ramet leaf area to harvest in three populations of *Hydrastis canadensis*. Data presented are back transformed means

in stem count during regrowth may be due to different degrees of control of the shoot apex over the adventitious root buds, possibly due to nutrient partitioning. The apical meristem can be a strong metabolic sink, depriving nutrients from other stems or buds (McIntyre, 1977; Cline, 1991; Cline, 1994). Larger stems are likely to be stronger sinks than smaller stems and, consequently, exert stronger suppression of the adventitious buds. This could explain the response of the Kingwood site, where 25% of the ramets pre-harvest were reproductive, a high percentage not commonly observed in natural *Hydrastis canadensis* patches. At Cheat Canyon 1 and Cheat Canyon 2, only 5.6% and 0.3% of ramets, respectively, were reproductive. Suppression of adventitious buds at the Kingwood site may have been far greater than at the Cheat Canyon sites. Any decreases in stem counts between 1 and 2 y post-harvest could be due to reestablishment of one or a few strong nutrient sinks by the new shoot apices in the remaining clones (Cline, 1997).

A second possible explanation for the overcompensatory response at the Kingwood site may be related to previous browsing history of the patch. Plants exposed to a history of repeated, low levels of browsing can have greater restraint in bud activation (Tuomi *et al.*, 1994), an insurance against complete destruction by herbivores. In contrast, high levels of browse (or harvest in our case) often result in a compensatory response of the plant whereby latent meristems and buds are activated (Paige and Whitham, 1987). A history of deer browse at the Kingwood site may have promoted activation of a large number of dormant buds and latent meristems, resulting in overcompensatory growth upon harvest.

TABLE 4.—Whole-patch stem count and leaf area for all patches included in this study

| Patch          | Patch stem count |                  |                  | Patch leaf area (m <sup>2</sup> ) |                  |                  |
|----------------|------------------|------------------|------------------|-----------------------------------|------------------|------------------|
|                | pre-harvest      | 1 y post-harvest | 2 y post-harvest | pre-harvest                       | 1 y post-harvest | 2 y post-harvest |
| Kingwood       | 163              | 657              | 474              | 2.313                             | 1.014            | 1.009            |
| Cheat Canyon 1 | 285              | 107              | 67               | 1.861                             | 0.248            | 0.241            |
| Cheat Canyon 2 | 610              | 392              | 247              | 3.264                             | 0.448            | 0.531            |
| Morgantown     | NA               | 932              | 840              | NA                                | 3.640            | 5.691            |

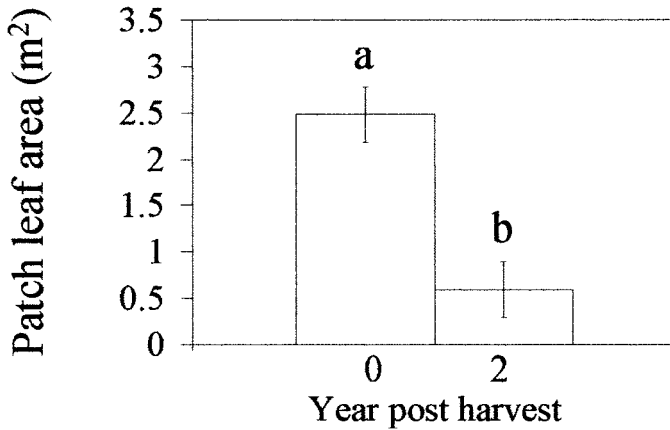


FIG. 3.—Whole-patch leaf area of the three experimentally harvested patches pre-harvest (year 0), and 2 y post-harvest

Our results show that the stem count of a patch following harvest varies between patches and does not clearly relate to the pre-harvest stem number. Therefore, stem counts may not be the most effective measure of patch size (*i.e.*, total belowground resources available to the plant) and harvest recovery. In contrast, we found that ramet leaf area appears to be directly, negatively affected immediately following harvest. Because of the variation in stem count between patches following harvest, measures of changes in leaf size over time may be an effective method to monitor long-term recovery of *Hydrastis canadensis* patches following harvest.

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