GOLDENSEAL (*HYDRASTIS CANADENSIS* L.) DISTRIBUTION, PHENOLOGY AND BIOMASS IN AN OAK–HICKORY FOREST[1]

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Abstract. Studies of the distribution, phenology, and biomass of goldenseal (*Hydrastis canadensis* L.), a rare medicinal plant of the northeastern United States, were begun in 1973 in Bryan Nature Preserve, where the species is abundant. Individuals were found in distinct clumps which were aggregated with the greatest concentration occurring in the northwest corner of the forest. Goldenseal matured during canopy closure and remained throughout the growing season. It was found in greater numbers in the interior area of the woods rather than on the edges. Goldenseal emerged in mid- to late April and flowered between April 20 and May 10. Each mature individual flowered, although some flowers never opened. The density of above-ground stems decreased between June and September, with the greatest attrition occurring among immature individuals. Leaf expansion occurred primarily after flowering and during development of the overstory leaf canopy. Fruit enlargement followed the initial rapid development of the leaves. During this time, leaf expansion was depressed. Fruits matured from late June to late July. Above-ground biomass reached a peak by mid-July and then declined with senescence of plants until the first killing frost. Greater than 95% of the above-ground biomass was produced within the first month of the growing season. There was at least a 20% sloughing of roots during the dormant season. Estimates of total biomass per clump show an increase of 24% in both edge and interior clumps between 1973 and 1974. Although the total increase was the same in both areas, the interior clump biomass increased because of an increase in the proportion of larger individuals, while the greater edge clump biomass was due to new individuals.

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Goldenseal (*Hydrastis canadensis* L.) is an uncommon native herb of the eastern deciduous forest; it is found from southern New York to Minnesota and western Ontario, south to Georgia and Missouri. Ohio, Indiana, Kentucky, and West Virginia are listed as the greatest goldenseal producing states (Hardacre, 1962). It has been found in all but the five northwestern counties of Indiana. Goldenseal is found in woodlands with "plenty of leaf mold and usually on hillsides or bluffs affording natural drainage, but is not found in very moist or swampy situations, in prairie lands, or in sterile soil (Hardacre, 1962).

Most information on goldenseal, including that on habitat, range, methods of harvesting and propagating, has been provided by growers and collectors of the plant. The abundance of goldenseal in one of Indiana's state nature preserves provided an opportunity to initiate long-term ecological studies. The objective of the current research was to determine the distribution, phenology, biomass and productivity of goldenseal in Bryan Nature Preserve.

METHODS

Bryan Nature Preserve, located N½ NE¼ Section 13 T22N R2W in Clinton County, Indiana, is a 27 acre old-growth oak-hickory forest. The dominant overstory species are white oak (*Quercus alba*), red oak (*Q. rubra*), and shagbark hickory (*Carya ovata*). The sapling-sized understory is dominated by sugar maple (*Acer saccharum*). Topography of the area is nearly level with less than ten feet elevation change. The two soil types occurring

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on the area are Ragsdale silty clay loam in the wet depressional areas, and Fincastle silt loam on the better drained uplands (Johnson *et al*, 1973).

Permanently marked 0.1 hectare (0.25 acre) quadrats were used for determining distribution of clumps of goldenseal. A clump was defined as a group of individual stems, none of which were more than 0.5 m apart. The entire preserve was canvassed and clumps marked in the field with flagging and recorded on a map of the area. Due to sharp contrast between the forest and the surrounding lands, which are used for row-crop agriculture, differences might be expected between those areas on the edge of the woods and those to the interior. Therefore, the clumps of goldenseal were stratified into edge clumps and interior clumps. From these two stratifications, 25 sample clumps (8 edge and 17 interior) were randomly chosen for intensive study. Each sample clump was gridded into 0.5 m^2 quadrats and permanently marked for continuous study.

Five size classes were defined for counts of the plants:

a. Double stems
b. Large singles (leaf breadth greater than 183 mm)
c. Medium singles (122 to 183 mm)
d. Small singles (46 to 122 mm)
e. Very-small singles (less than 46 mm)

The numbers of viable fruits were also recorded for each subplot. In all, five counts were made: July and September, 1973, and April, June, and July, 1974. During April, 1974, only flowering individuals were counted; in June, 1974, plants were designated only as "doubles" or "singles". The other three counts, however, included and differentiated all size classes.

During the spring of 1974, 60 single stems and 30 double stems were chosen for non-destructive weekly growth measurements. Leaf breadth, stem height, and fruit diameter were measured in the field. Leaf breadth was measured across the widest part of each leaf.

Three harvests of the plant were made: August, 1973 (shortly after fruit maturation); early May, 1974 (during flowering); and late May, 1974 (while fruit was expanding). Plants were harvested from two clumps other than the 25 used for continuous measurement. Harvested plants were taken to the laboratory and separated into component parts: fruits, leaves, stems, tubers, and roots (rhizomes were not separated from roots). Leaf breadth was determined, as previously indicated, for all leaf blades of harvested plants. Plants were then dried at 105° C to constant weight.

RESULTS AND DISCUSSION

PHENOLOGY AND DISTRIBUTION

Goldenseal emerged in mid-April, the flower being fully formed before the leaves unfolded. This was followed by unfolding of the leaves with the flower displayed at the top. Flowering generally occurred between April 20 and May 10. Leaf expansion and fruit growth then followed. Fruit ripened from late June through late July, with each bright red fruit disappearing shortly after ripening. Stems and leaves remain green until frost.

Fruit expansion began after May 18 with the majority of expansion occurring by June 22. During this period of fruit enlargement both leaf and stem growth were depressed (fig. 1). This depression also occurred in single stems. Since single and double stems often occur on the same tuber, it is not surprising that their growth might be coordinated. After June 22 the growth rate of stems and leaves increased slightly as the fruit expansion rate decreased considerably. The stems had generally reached maximum height by the time of flowering.

In the initial survey (1973) 99 clumps were found in the preserve. They were found more commonly on hummocks and well-drained areas and were not found in early spring inundated areas. The majority of clumps were found in the northwestern quadrats. Spring wet areas were obviously limiting to goldenseal, therefore quadrats which were more than half inundated were deleted from consideration, leaving 97 quadrats in which the clumps could have been distributed.

Two statistical tests served as an analysis of the distribution data. A chi-square goodness of fit test found a sinificant departure ($\alpha = .001$) from the Poisson distribution. In a Poisson distribution the variance/mean ratio is equal to 1.0. A value greater than 1 indicates a contagious distribution and less than 1 indicates an even distribution (Greig-Smith, 1957). According to Wadley (1950), a variance/mean ratio of less than 1.5 indicates Poisson would probably give a better fit, whereas a contagious distribution gives a better fit for a population with a variance/mean ratio greater than 1.5. The variance/mean ratio for clumps of goldenseal in this area was 1.52, thus slightly exceeding the 1.5 value set by Wadley for a contagious distribution. For the purposes of this report the data were not fitted to any particular contagious distribution, and it was considered sufficient to have identified the distribution as contagious.

The most likely reason for the contagious

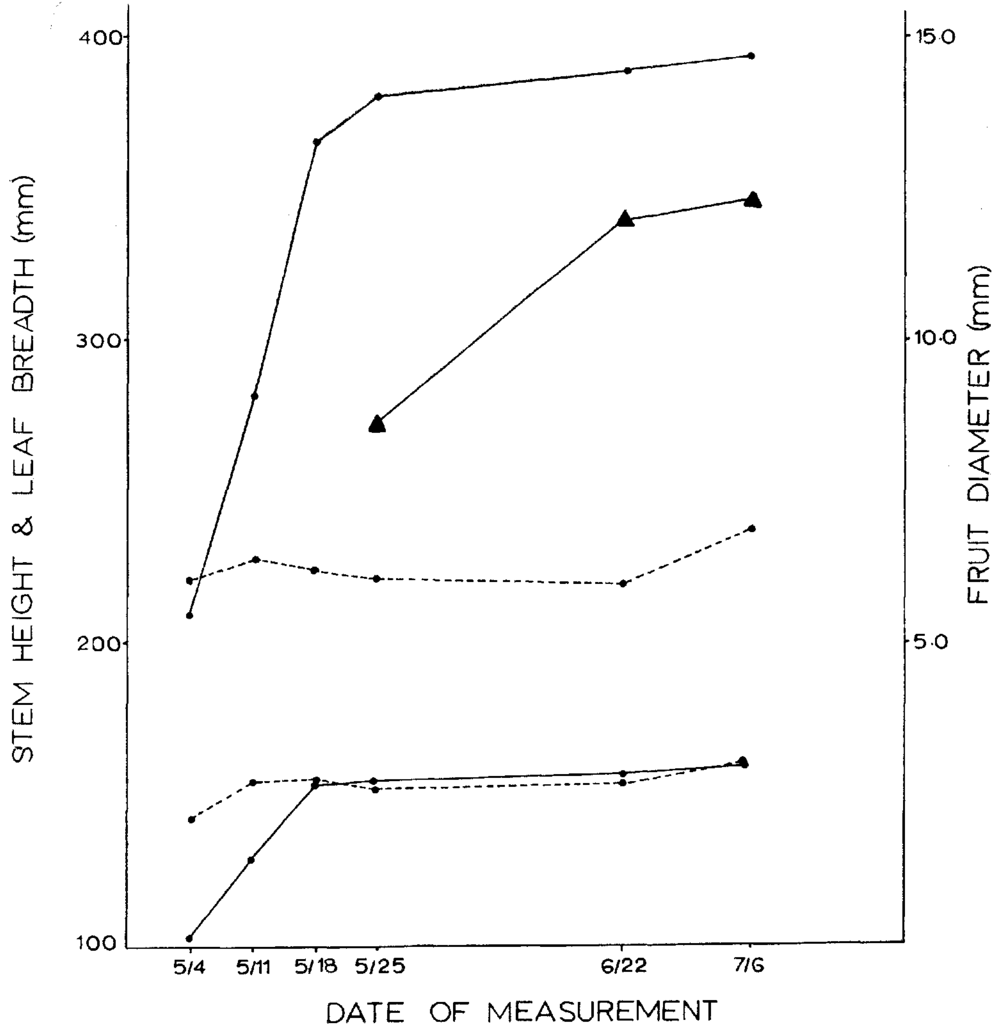

FIGURE 1. Mean leaf breadth (• ——— •), stem height (• — — — •), and fruit diameter (▲——— ▲) for 30 double (upper curves) and 60 single (lower curves) stems of goldenseal (*Hydrastis canadensis*) by date of measurement.

distribution of this species is its reproductive behavior which is accomplished both by seed and by rhizomes. When spread by seed, the distribution depends on the method of dispersal. According to Archibald (1948) it might be expected that random distribution would occur where single seeds are dispersed by wind or water but where seeds are dispersed by animals, particularly where whole fruits containing several seeds are carried away, it is likely that individuals would subsequently occur in clusters. Blackman (1935) indicates that plant species with short rhizomes tend to clump while those species with long rhizomes tend toward a random distribution.

The present clumped distribution of goldenseal may have resulted from either the death of interior plants of large clumps, the dispersal of seed by animals, a lack of sufficient time for the species to completely colonize the suitable habitat, or a combination of the above. There is no evidence that new clumps are being formed from the death of interior individuals. The distribution of clumps and the rapid disappearance of the fruit after ripening suggest animals are the primary dispersal agents. The fruit of goldenseal turns a bright red and is situated at the top of the plant. This evidence suggests that birds are responsible (Welty, 1962).

The distribution pattern for this species may still be changing. The number of plants per clump increased from July, 1973 to June, 1974 (fig. 2). Using a paired analysis t-test, significant increases ($\alpha = .01$) were found for both edge and interior clumps. The edge clumps increased 27.6%, while interior clumps increased only 13.2%. More interesting is the distribution of these increases. In edge clumps doubles and singles increased about equally (25.6% and 28.3%, respectively). Interior clumps, however, experienced a much greater increase in doubles than in singles (doubles 40.4%, singles 7.2%).

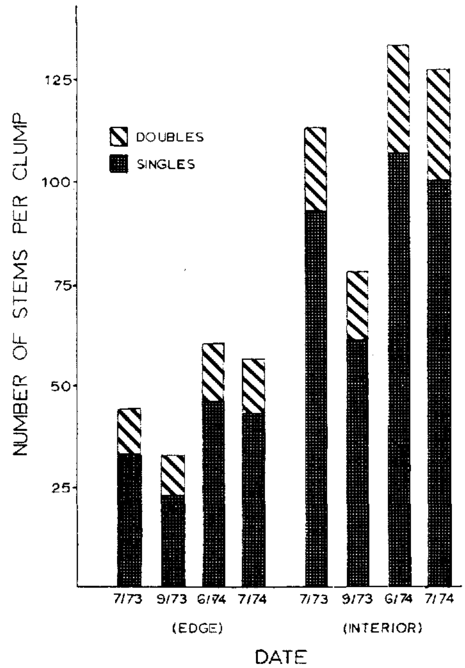

FIGURE 2. Mean number of single and double stems per clump of goldenseal (*Hydrastis canadensis*) by date of measurement.

Biomass

The distribution of biomass among component parts of individual plants is based on tubers which bore at least one mature individual (table 1). Approximately 31% of the biomass is contained in the above-ground components at the time of flowering. Very little root growth occurs during the period of rapid above-ground growth. Root growth occurs after fruit maturation. The increased biomass in stems and leaves after fruit maturation is due to new individuals developing from rhizomes. Struik (1965) found similar below-ground to above-ground distribution for perennials in Wisconsin. The pattern among perennials of suppressed root growth during early growth of above-ground components is well known.

Above-ground productivity of perennials is difficult to determine due to the problem of accounting for that biomass contributed by and taken into storage organs. There is a correlation between biomass and productivity (Lieth, 1973). Collection of individual plants for oven-dry weighing is the common way of determining biomass for individual species. Relating changes in biomass to time, then, can give some indication of productivity. Regression analysis has been

TABLE 1

Biomass, by component part, of all tuber groups of goldenseal (Hydrastis canadensis) *containing at at least one mature stem.*

	Period of Measurement					
	Flowering		Fruit expansion		After fruit drop	
Plant Part	dry wt. (g)	% of plant wt.	dry wt. (g)	% of plant wt.	dry wt. (g)	% of plant wt.
Flowers, fruit	0.011	0.5	0.154	4.4	0.000	0.0
Stems, leaves	0.710	30.7	1.652	47.8	1.928	47.4
Tuber, buds	0.789	34.1	0.790	22.9	0.979	24.1
Rhizome, roots	0.804	34.7	0.859	24.9	1.160	28.5
Total	2.314	100.0	3.455	100.0	4.067	100.0

used with woody plants to determine biomass from measurements which can be taken non-destructively (Madgwick, 1970; Newbould, 1970; Whittaker, 1965). This may also be used in long-term studies of one or several herbaceous species. In a nature preserve, this is a way of deriving information with a minimum of disturbance.

In order to correlate leaf breadth with above-ground biomass, regression analyses were done, first in two groups, the late season (1973) harvests forming the first group with the early season (1974) harvests in the second. Both linear (using leaf breadth as the independent variable) and quadratic (using leaf breadth and the square of the breadth as independent variables) regression models were fit to the data. Although both models resulted in high r^2 values ($>.90$), the y— intercept of the quadratic equation was closer to the origin and therefore gave a better fit in the smaller size classes. The quadratic regression equations for each group and combined groups are:

1973
$$y = -0.08434 + 0.0025921x + 0.000003260x^2$$
1974
$$y = -0.02035 + 0.0017794x + 0.000004950x^2$$
Combined
$$y = -0.04118 + 0.00207x + 0.000004334x^2$$

Since the two regression equations are not significantly different ($\alpha = .05$), the combined formula ($r^2 = .93$) may be used to estimate above-ground biomass per clump from leaf breadth measurements.

The combined regression formula was used to estimate biomass per individual from weekly leaf breadth measurements of the 30 double and 60 single individuals. Single individuals were separated into size classes based on the July 6 measurement. These data combined with distribution of size classes can be used to estimate above-ground, dry-weight biomass for sample clumps.

Determining a relationship between below-ground and above-ground biomass required combining the above-ground weights of all stems on a tuber. A regression analysis of the 1973 (late season) data shows good correlation ($r^2 = .96$) between total above-ground and below-ground biomass. In order to use this formula, however, it would be necessary to know the number of stems on each tuber, which is impossible without excavation of the tubers. The high correlation does, however, suggest that prediction of below-ground biomass from above-ground biomass is applicable here.

A more useable figure would be a root/shoot ratio. A ratio was determined for each tuber group. In order to see if the number of stems per tuber significantly affected the root/shoot ratio, this variable was tested with analysis of variance, groups being determined by the number of stems per tuber. Since there was no significant difference between the groups, the total mean for each sampling period was used as the root/shoot ratio.

A root/shoot ratio (1.6323) for early May was based on 9 plants while the ratio (1.077) for late May was the mean of 12 excavated plants. The July ratio (1.228) was determined from 30 plants. These ratios were used to determine below-ground biomass from estimates of above-ground biomass.

Comparing 1973 with 1974, using a paired t-test, significant increases in biomass per clump were found in both stratifications (edge $\alpha = .05$, interior $\alpha = .01$). Interestingly, this increase was of the same in both interior and edge clumps (24%). This further emphasizes the point made earlier with respect to the number increases. There was a shift to more double individuals in interior clumps compared to an increase in number of individuals for edge clumps. Therefore, the increase in biomass appears to be due to an increase in number of individuals in edge clumps and to a shift to larger-sized individuals in interior clumps.

Above-ground biomass reached a peak by mid-July and then declined with senescence of individual plants until the first killing frost (fig. 3). Greater than 95% of the above-ground biomass had accumulated within the first month of the growing season. Above-ground biomass increased by 30 grams from May 4

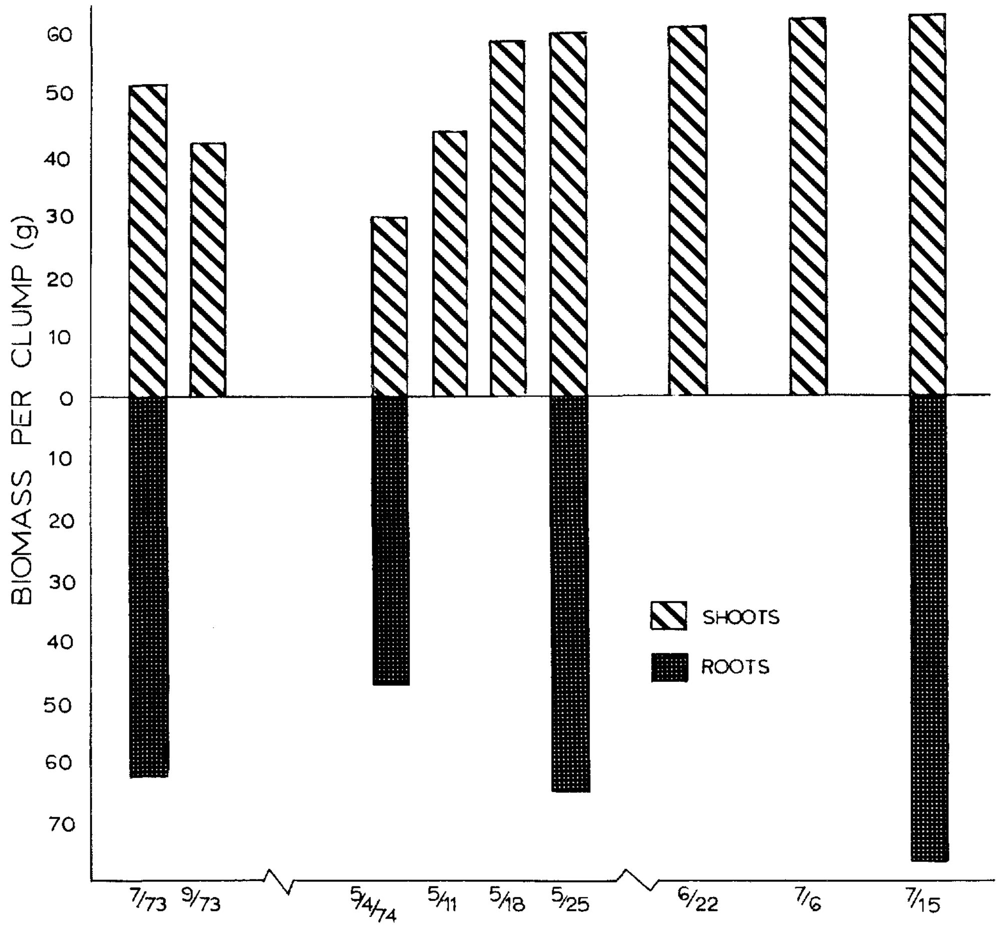

FIGURE 3. Above and below ground dry weight biomass per sample clump of goldenseal (*Hydrastis canadensis*) by date of measurement.

to May 25 while below-ground biomass increased by 17 grams. There was at least a 20% sloughing of roots during the dormant season. This may be an overestimate, however, since no estimate of root biomass was available for late fall, 1974.

Attributing causes for the year to year change involves speculation at this time. Two possible explanations are: (1) differences in climatological conditions, and (2) differences in stage of development. The most noticeable difference in climatological data is in the amount of rainfall (Climatological Data, Frankfort, Indiana, 1973–74). There was significantly more rain during April, May, and June of 1974 and this may have been crucial in the survival of some individuals of goldenseal. Specific studies on moisture relationships for growth of goldenseal are necessary. The second explanation would be that, as might be indicated by the distribution data, goldenseal is still expanding in the woods. In this case, it might be expected to increase in biomass yearly.

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