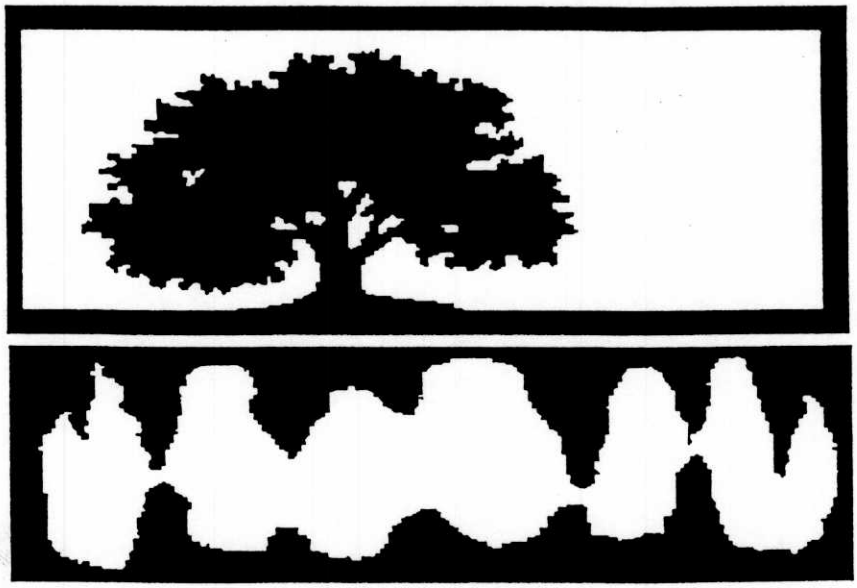
ABIOTIC FACTORS AFFECTING GARLIC MUSTARD AND THE BIOTIC EFFECTS OF GARLIC MUSTARD ON NATIVE SPECIES AT MAMMOTH CAVE NATIONAL PARK.



MAMMOTH CAVE NATIONAL PARK

[redacted]RFIELD "JIMMY" BROWN

AUGUST 20, 1993

STUDENT CONSERVATION ASSOCIATION

MAMMOTH CAVE NATIONAL PARK

SCIENCE AND RESOURCE MANAGEMENT

MAMMOTH CAVE

KENTUCKY 42259

ABSTRACT

This study focuses on an exotic plant, Garlic Mustard, (*Alliaria petiolata*), which has been observed in several areas of Mammoth Cave National Park (M.C.N.P.). Garlic mustard is a monocarpic biennial European herb that is invading natural areas in the eastern United States.

My study concerned the different abiotic factors that affect the growth of garlic mustard and the biotic effect that garlic mustard has on other plants. This was done by hypothesizing about the effects, followed by natural and manipulative experiments in an attempt to falsify our hypotheses.

Results from our natural abiotic experiments showed that the growth of garlic mustard is not restricted by the amount of shade or moisture received and that garlic mustard does grow on different bedrock types and on different slopes. Results for the biotic effects showed that the number of other species remained relatively constant regardless of the percentage cover of garlic mustard. However, the overall growth of other species was suppressed.

Control of the growth and spreading of garlic mustard should be considered, as results obtained show that it is having a negative effect on the growth of native species at M.C.N.P. Recommended methods are hand removal of plants or cutting of stems.

INTRODUCTION

Alien plant species pose a threat to native plant species world wide. This study focuses on one particular exotic, Garlic Mustard, (*Alliaria petiolata*), which has been observed in several areas of the Mammoth Cave National Park (M.C.N.P.). More specifically, garlic mustard is invading a large area between the Visitor Center and the Green River in a northwesterly direction. Small patches have also been observed at Turnhole Bend (Fig. 3), along Loop A (Fig. 4) in the main campground, and at one location in the picnic area.

Garlic mustard was first recorded in North America in 1868 in Long Island, New York in the United States, and in 1879 in Toronto, Canada (Nuzzo 1991). European settlers who may have introduced this garlic-flavored plant as a food or medicinal herb (Nuzzo 1991). A study of the vascular plants of M.C.N.P. by Faller (1975) did not list garlic mustard as being in the park. Therefore it is assumed that garlic mustard was introduced sometime within the last eighteen years.

According to Nuzzo (1993) Garlic mustard is a monocarpic biennial European herb that is invading natural areas in the eastern United States. In Illinois its seeds germinate in the early Spring after an obligate dormancy of $\geq$ 1 year. After germination, seedlings experience >90% mortality so that density

is reduced from an estimated 4000 seedlings to 186.4 rosettes/m^2 in Fall. Continued attrition during the winter reduces rosette density an additional 79% giving a final mean of 39.9 adults/m^2 the following Spring.

Leaves of garlic mustard are triangular or heart shaped, and have the odor of garlic when crushed. Plants grow from 30.5-91.5 cm (1-3 ft.) high and can be found along roads, wood-edges, and rocks (Peterson and McKerry 1968). Flowers are cross-shaped with 4 sepals, 4 petals, and 6 stamens. The seedpod (silique) contains a false portion which divides the seeds alternately (Wharton and Barbour 1979).

My study concerned the different abiotic factors that affect the growth of garlic mustard and the biotic effect that garlic mustard has on other plants. The abiotic factors considered were shade, moisture, slope, aspect, and substrate. The biotic effect of garlic mustard was evaluated by looking at the number of and the total stem heights of native species mixed in with different densities of garlic mustard.

STUDY AREA

The area under observation starts between the Hotel and Visitor Center, continues down to Green River, and then extends approximately a quarter of a mile in both directions along the river. See Fig. 1. There are several short trails within the study area, and they are traveled daily by many visitors. Trails include the Cave Island Nature Trail, Dixon Cave Trail, Historic Trail, and a section of the Heritage Trail. Alongside the trails it is more or less forested, ranging from single to multiple canopy layer forest with some openings.

The study area varies in altitude from 430 ft. to 750 ft. Above the 700 ft. contour, the bedrock is sandstone which is underlain by limestone. As can be seen from Fig. 1, the bedrock for the majority of the study area is limestone. In most areas the bedrocks are close to the surface and are sometimes exposed.

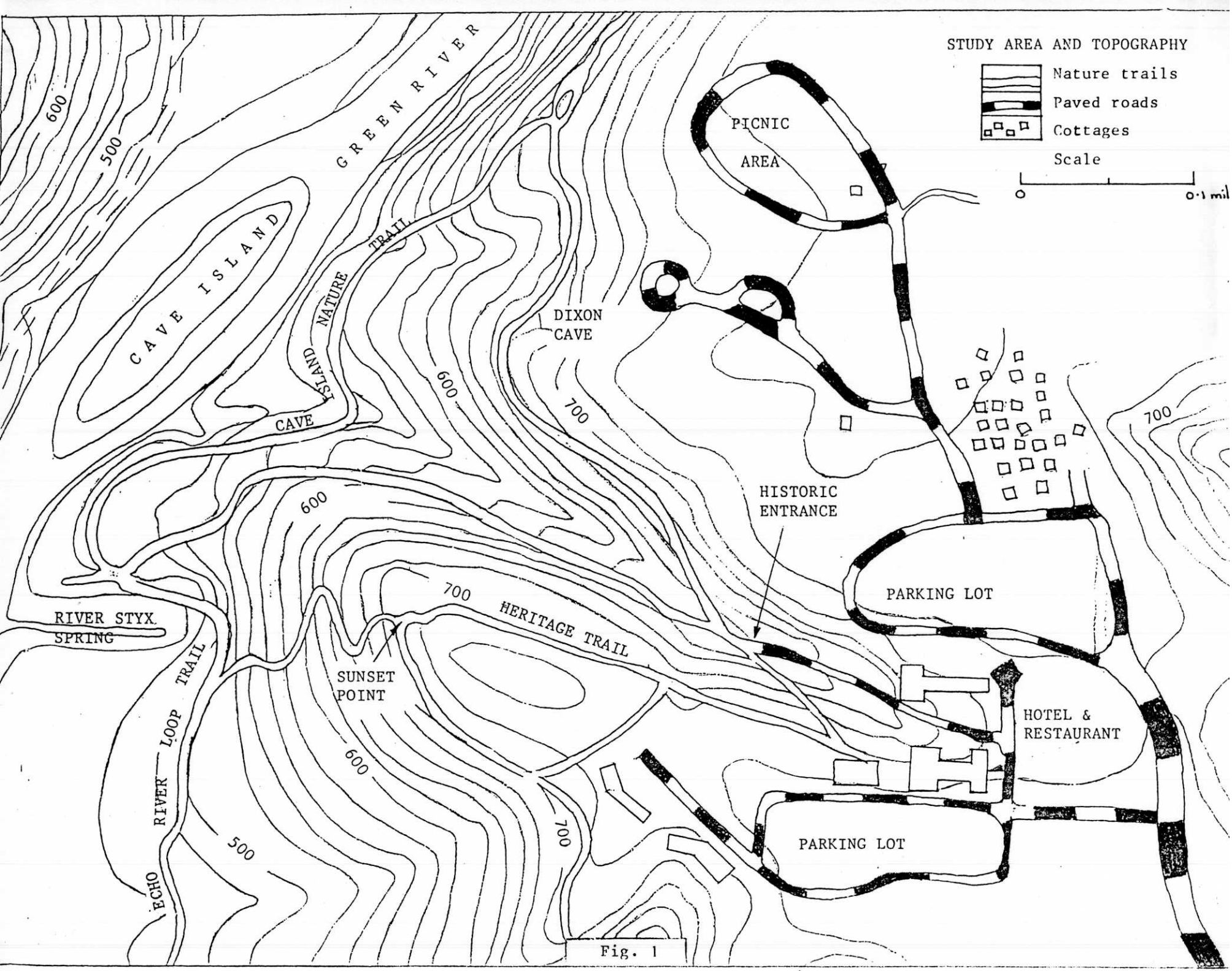

STUDY AREA AND TOPOGRAPHY
Nature trails
Paved roads
Cottages
Scale
0
0·1 mil
GREEN RIVER
CAVE ISLAND
ISLAND NATURE TRAIL
CAVE
DIXON CAVE
PICNIC AREA
HISTORIC ENTRANCE
PARKING LOT
HOTEL & RESTAURANT
PARKING LOT
HERITAGE TRAIL
SUNSET POINT
RIVER STYX SPRING
RIVER LOOP TRAIL
ECHO
600
500
700

Fig. 1

DEVELOPMENT OF HYPOTHESES

The abiotic conditions under which garlic mustard grew in the park were observed while walking the trails to map the relative abundance of garlic mustard (Fig. 3). From the observations, several alternative hypotheses, and associated predictions, were made. Hypotheses and predictions were made about abiotic factors including degree of shading, the amount of moisture, the slope, and the different type of bedrock. Hypotheses were also made about the biotic effects of garlic mustard on other plants. In addition, observations of garlic mustard morphology were used to develop hypotheses and predictions about its life history.

The Scientific Method

Observations --(Inductive Reasoning)--> Alternative Hypotheses --(Deductive Reasoning)--> Predictions ----> Natural &/or Manipulative Experiments

As examples, my application of the scientific method is as follows. Garlic mustard was observed growing thickly in ravines and on the river flood plain. From these observations it was inferred that garlic mustard grows well in moist areas, and the hypothesis that it will grow only in moist areas was developed. From this hypothesis it was reasoned that if garlic mustard will grow only in moist areas, then it will not be found in dry habitats.

Similarly, observations on the texture of garlic mustard seeds, showed that they are relatively soft. It was then hypothesized that garlic mustard does not have a long-lived seed bank, as plants with a long-lived seed bank normally have a hard seed coating (Weaver 1938). A prediction was then made stating that all garlic mustard seeds will germinate within two or three years.

Alternative Hypotheses

Abiotic factors

a) Garlic mustard grows in moist areas only.
b) It will grow on sandstone and limestone.
c) It will grow in shady areas only.
d) It will be found in steep and flat areas.

Biotic effects

e) If the percentage cover of garlic mustard increases, the number of species will decrease.
f) If the sum of stem heights of garlic mustard increases, the sum of stem heights of all other plants will decrease.
g) If the density of garlic mustard increases, the sum of stem heights of all other plants will decrease.

Life History

h) Garlic mustard does not have a long-lived seed bank.
i) Garlic mustard is a biennial plant.

METHODS

In an attempt to falsify the hypotheses about the biotic effect of garlic mustard, the number of species in a $1m^2$, square plot was compared to the percentage cover of garlic mustard in the plot. Percentage cover was obtained by visual inspection of the garlic mustard cover and then an estimated value was given to it. Also compared in the $1m^2$ area was the sum of all the stem heights of garlic mustard to the sum of stem heights of all other plants above 4cm (0.1 ft.). A total of twenty plots were employed. Five plots each were chosen for 0%, 1-30%, 31-60%, and 61-100% cover. The plots of 0% cover were taken as close as possible to a patch of garlic mustard without including them. This was done to give an idea of how well the native plants do without garlic mustard growing among them.

In an attempt to falsify the alternative hypotheses for abiotic factors it was decided to carry out natural experiments at random points within the bounds of the area being invaded by garlic mustard. To derive the random points, random numbers were generated by a calculator and numbers between 100 and 200 were accepted. For these number an equivalent distance in meters were used as the distance between points. All distances were taken along the nature trails beyond the Visitor Center. At each point, a coin was tossed to decide the side of the trail to be sampled.

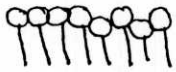
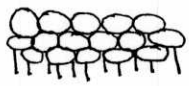
Having decided on the side a marker was thrown over one's shoulder to determine the center of our sample area.

The sample plot at each point encompasses a radius of 15m. Within this area, data on the canopy pattern, shade, moisture, bedrock, aspect, and slope were recorded. Other data included the estimated percent cover of garlic mustard, the sum of stem heights of an individual plant nearest to the plot center, and the number of stems within a 1m radius from the plot center.

Different scales were developed to evaluate the abiotic factors and are given below. The initial shade and moisture value are based on the canopy pattern of the trees above the ground vegetation. A number of IF THEN statements were then used to determine the actual score for shade and moisture. Final scores of shade and moisture are between one and five.

SCALES FOR THE ABIOTIC NATURAL EXPERIMENTAL TEST

CANOPY PATTERN OF TREES:

C1	C2	C3	C4	C5
				
Open and multiple tree fall areas.	Single tree fall or small openings between trees.	Closed canopy of one layer or opening between trees with shorter trees to fill in the openings.	Closed canopy of two layers.	Closed canopy of more than two layers.

SLOPE (in degrees):

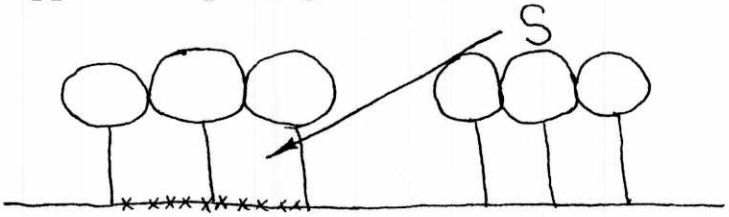
a) level: 0-4
b) somewhat steep: 5-26
c) steep: 27-45
d) very steep: 46-90

SHADE (Scale of 1-5 with 1 = min. and 5 = max.)

Initial values: 1 = C1, 2 = C2, 3 = C3, 4 = C4, 5 = C5.

IF	**THEN**
a) North aspect with steep slope and C2 or C3	+1.0
b) North aspect with somewhat steep slope and C2 or C3	+0.5
c) South aspect with steep slope and C2 or C3	-1.0
d) South aspect with somewhat steep slope and C2 or C3	-0.5
e) Closed canopy with opening to the South	-0.5

i.e.



f) No vegetation	+0.5
g) 1% - 24% vegetation cover	0.0
h) 25% - 49% of vegetation cover	-0.1
i) 50% - 74% of vegetation cover	-0.3
j) >= 75% of vegetation cover	-0.5

MOISTURE: (scale of 1 - 5 with 1=min. and 5= max.)

Initial Values: 1 = C1, 2 = C2, 3 = C3, 4 = C4, 5 = C5

IF	**THEN**
a) sandy soil	-0.5
b) clay soil	+0.5
c) North aspect	+0.5
d) South aspect	-0.5
e) near rock/bedrock	-0.5
f) near permanent river	+1.0
h) near permanent stream	+0.7
i) in dry ravine	+0.5
j) somewhat steep slope	-0.1
k) steep slope	-0.3
l) very steep slope	-0.5

TYPES OF BEDROCK:

1 = sandstone, 2 = intermediate, 3 = limestone

DENSITY OF POPULATION
(% cover in 15m radius)

0: 0
1: 1 - 5
2: 6 - 15
3: 16 - 30
4: 31 - 60
5: 61 - 100

HOW WELL AN INDIVIDUAL IS DOING:
(sum ht. of all stems of an individual closest to center in ft.)

0: 0
1: >0 - 2
2: >2 - 4
3: >4 - 8
4: >8 - 16
5: >16 - 32

NUMBER OF STEMS PER 1m radius:

0: 0
1: 1 - 2
2: 3 - 4
3: 5 - 8
4: 9 - 16
5: 17 - 32
6: 33 - 64
7: 65 - 128
8: 129 -256
9: 257 - 512

SLOPE

0: 0 - 5
1: 6 - 10
2: 11 - 15
3: 16 - 20
4: 21 - 25
5: 26 - 30
6: 31 - 35

SCALES FOR THE BIOTIC IMPACT TEST

NUMBER OF OTHER SPECIES:

0: 0
1: 1 - 2
2: 3 - 4
3: 5 - 8
4: 9 - 16
5: 17 - 32

% COVER OF GARLIC MUSTARD:

0: 0
1: 1 - 30
2: 31 - 60
3: 61 - 100

Permanent Plots

Five permanent plots were established (Fig. 11) to test Hypotheses (h) and (i) by monitoring the regeneration of garlic mustard and any changes in percentage cover during the coming years. Detailed drawings with measurements of distance and bearings are shown in Fig. 12 - 16. Steel rods were used to mark each corner of every plot. On one of the rods in each plot, an aluminum cap was hammered on. The title of the plot was then inscribe on the cap. All permanent plots begin with the label X. Plots were then numbered from one to five, resulting in the names of the plots being X1, X2, X3, X4, and X5.

In all plots the distribution of garlic mustard was mapped. In plot X1 all garlic mustard was then uprooted including the rosettes. Note that only a few rosettes were found in plot X1. In plot X2, X3 and X4 no rosettes were found, and all adult garlic mustard plants was uprooted. In plot X5, only the adult plants were uprooted. All the rosettes observed in this plot were then marked with orange flagging tape.

RESULTS

The distribution of garlic mustard is shown in Figure 2, and it is clear that the majority of individuals are found along the flood plain of the Green River.

Drawings of an adult and an immature plant are shown in Fig. 5 and 6 respectively. Fig. 7 and 8 shows detail drawings of leaves, flower, seed pod, and seed of the garlic mustard.

Sample points were taken within the distribution or along the periphery of the distribution for garlic mustard. Hence, no sample points were taken between Sunset Point and River Styx. A total of 20 random points (Fig. 9) were obtained within the study area. The scores for shade, moisture, bedrock, estimated percentage cover, sum of stem height of an individual garlic mustard, the number of garlic mustard stems per 1m radius, slope, and aspect for all 20 points were recorded and are given in Table 1.

To see how well garlic mustard was doing at locations where it was found, the values of C in Table 1 are considered. These data suggest that where garlic mustard is found, the average percent coverage is 6-15% or 2.1 on our scale (see scale page 10).

To evaluate the effect abiotic factors have on garlic mustard, each factor will be considered separately.

Shade

a) From Table 1 on p. 24 (see p. 9 for scales), the average shade (2.0) at points where garlic mustard is found is lower than the average shade value (2.8) for points where it is not found. This implies that it is sunnier were garlic mustard is found.
b) Graph 1 shows no direct relationship between the estimated percentage cover and shade. However, it does show that more garlic mustard is found in areas with less shade.
c) Graph 2 indicates that the number of stems of garlic mustard in a 1m radius shows no relationship to shade where garlic mustard does occur. Note however that only a few sample points in the heaviest shade categories of 4 and 5 were obtained.

Moisture

a) From Table 1, the average moisture at points where garlic mustard is found is lower than that of the average moisture value for points where it is not found.
b) Graphs 4, 5, and 6 shows no direct relationship between the, percentage cover of garlic mustard, number of garlic mustard stems per one meter radius plot, and the sum of the stem heights of closest garlic mustard respectively to moisture.

Bedrock

a) From Table 1, values obtained shows that garlic mustard grows on both sandstone and limestone.
b) Graphs 7 shows no direct relationship between the percentage cover of garlic mustard and the type of bedrock. However it does indicate that it may do better on limestone.
c) Graph 8 shows no relationship between the number of garlic mustard stems per one meter radius plot and the type of bedrock. On both sandstone and intermediate bedrocks, 3 plots had no garlic mustard compared to 1 with. On limestone, 7 plots had no garlic mustard compared to 5 with. The latter shows a decrease in the ratio of plots with garlic mustard to plots without garlic mustard for limestone substrate. This may indicate that garlic mustard does better on limestone.
d) Graph 9 shows no relationship between the sum of the stem heights of closest garlic mustard to the center of the sample plot with respect to bedrock.

Slope and Aspect

a) Values from Table 1 shows that garlic mustard grew on slopes ranging from 0 - 31°, and with aspects ranging from 0 - 333°.
b) Graphs 10 and 12 shows no direct relationship between the, percentage cover of garlic mustard, and the sum of the stem heights of closest garlic mustard respectively to slope.
c) Graph 11 indicate that the number of stems per one meter radius plot may increase with an increase with slope.

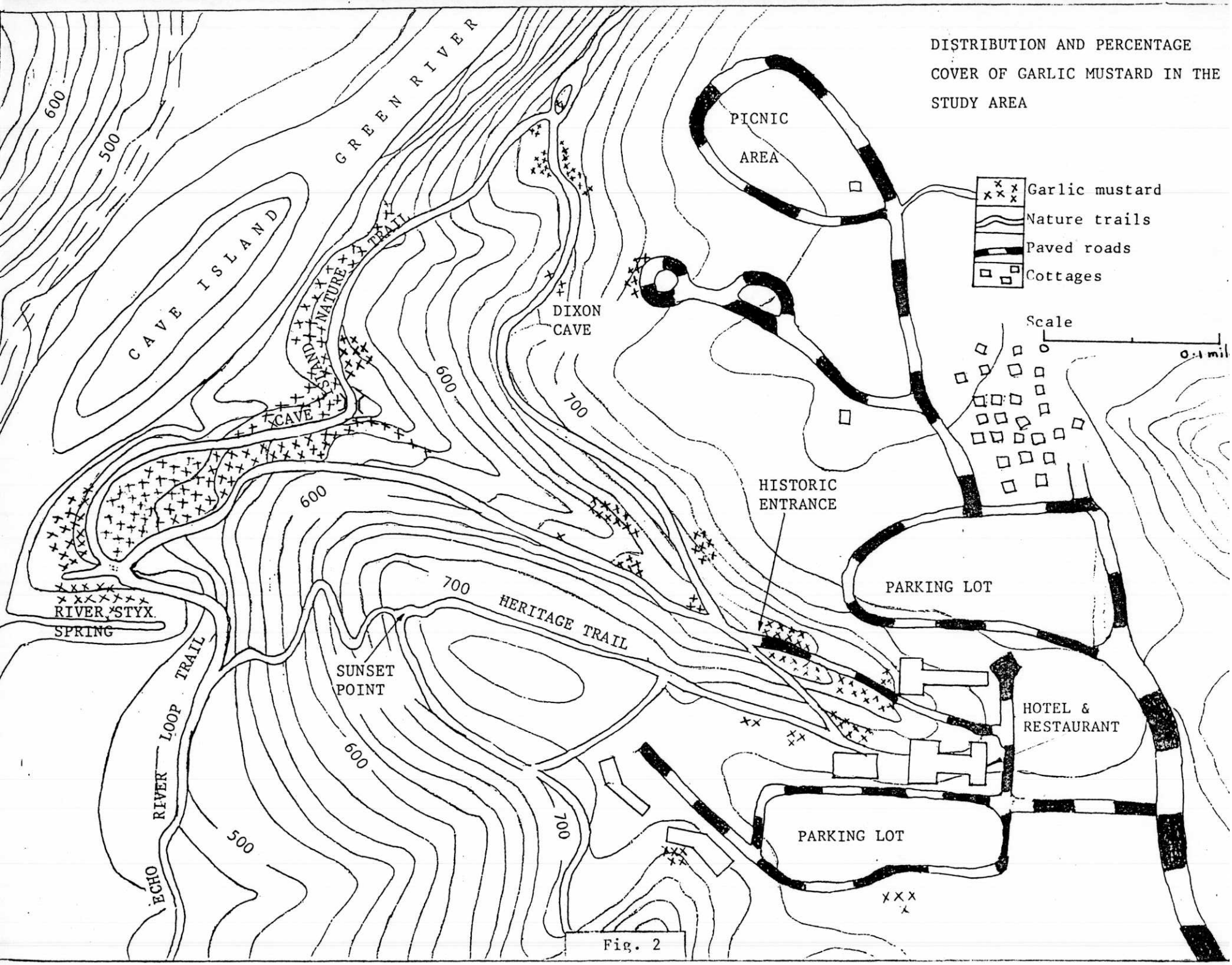
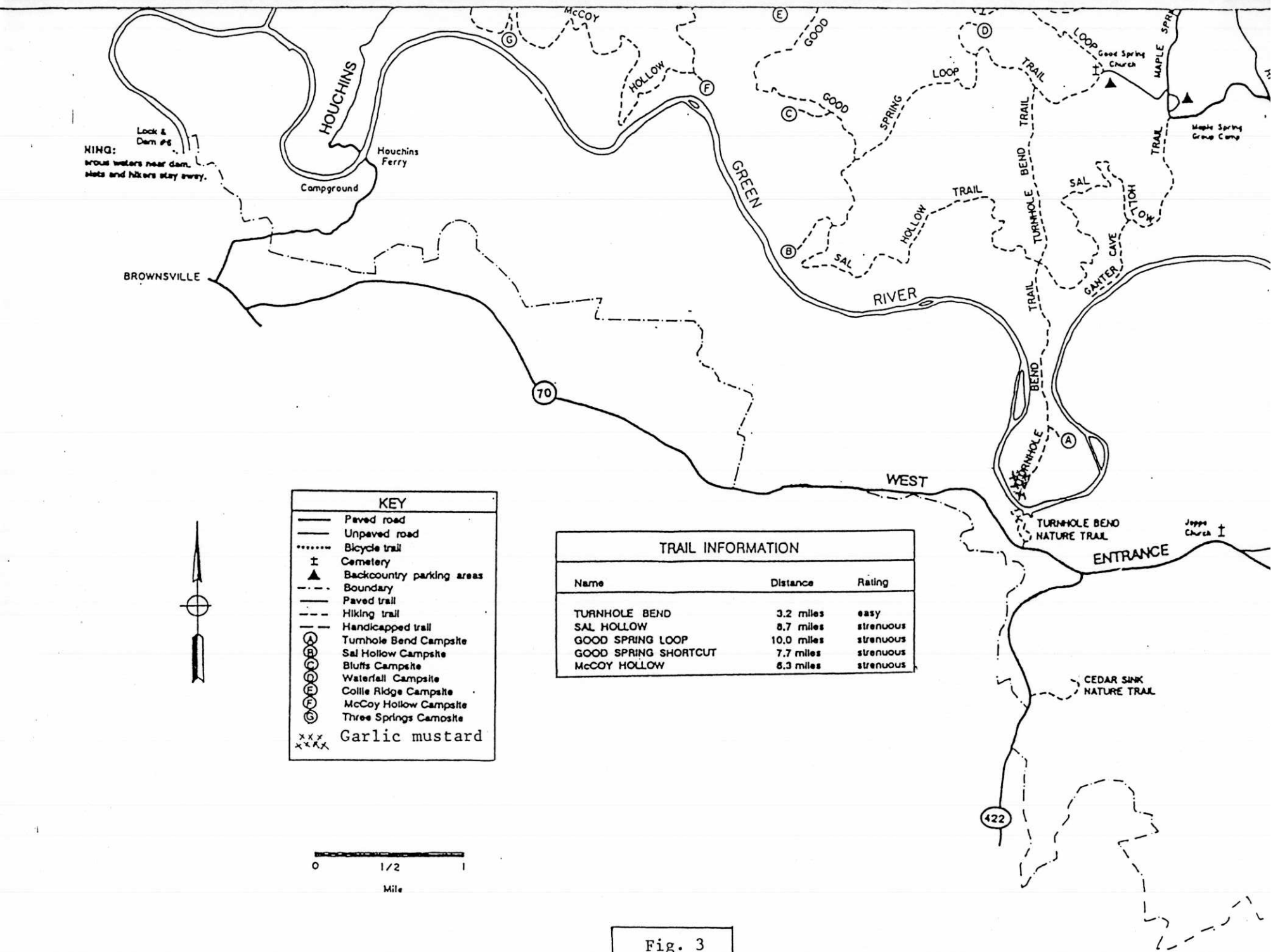

DISTRIBUTION AND PERCENTAGE COVER OF GARLIC MUSTARD IN THE STUDY AREA
GREEN RIVER
CAVE ISLAND
SAND NATURE TRAIL
CAVE
DIXON CAVE
PICNIC AREA
HISTORIC ENTRANCE
PARKING LOT
HOTEL & RESTAURANT
PARKING LOT
HERITAGE TRAIL
SUNSET POINT
RIVER STYX SPRING
RIVER LOOP TRAIL
ECHO
600
500
700
Garlic mustard
Nature trails
Paved roads
Cottages
Scale
0 0.1 mil

Fig. 2



TRAIL INFORMATION

Name	Distance	Rating
TURNHOLE BEND	3.2 miles	easy
SAL HOLLOW	8.7 miles	strenuous
GOOD SPRING LOOP	10.0 miles	strenuous
GOOD SPRING SHORTCUT	7.7 miles	strenuous
McCOY HOLLOW	6.3 miles	strenuous

Fig. 3

VISITOR CENTER AREA

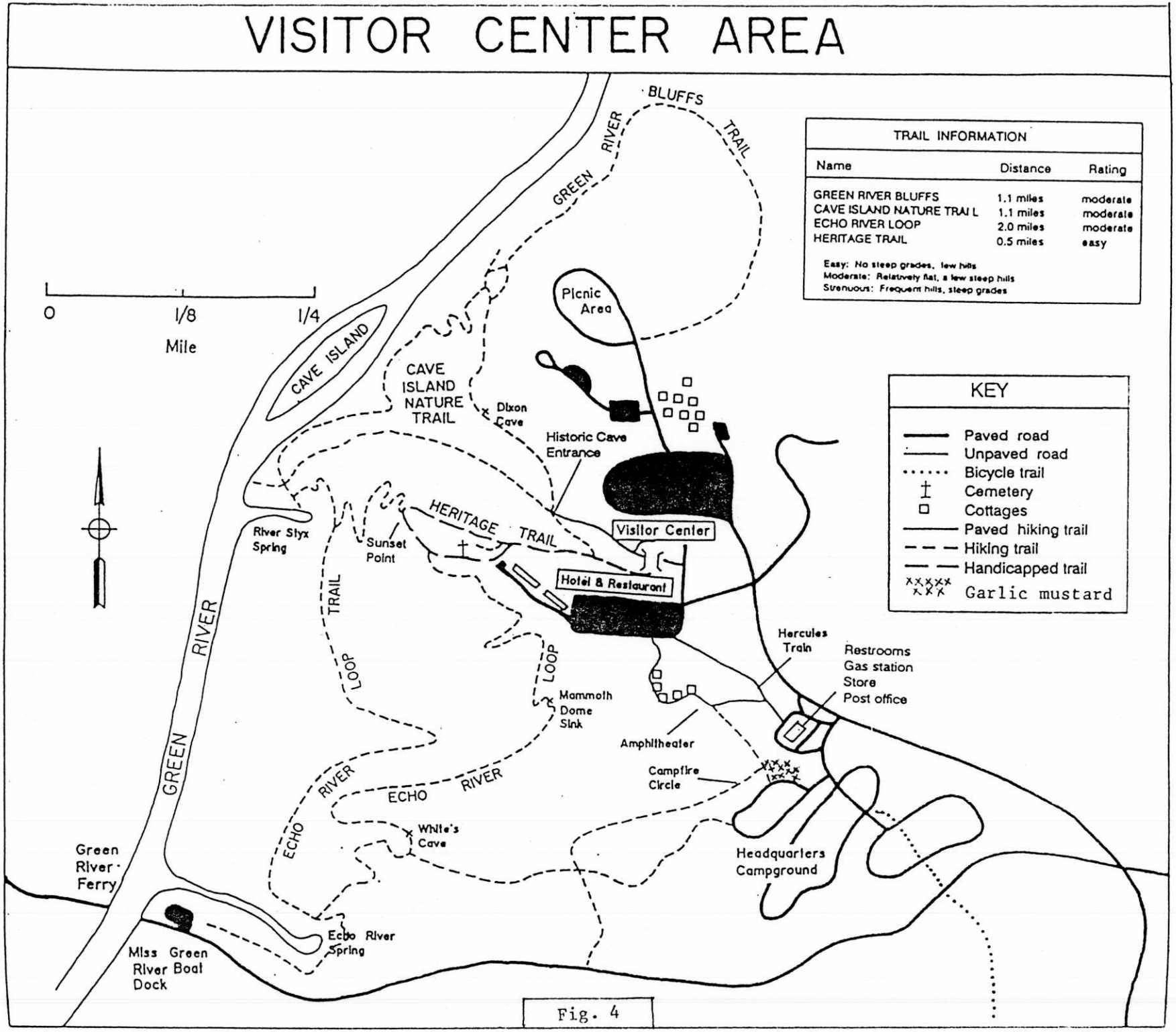
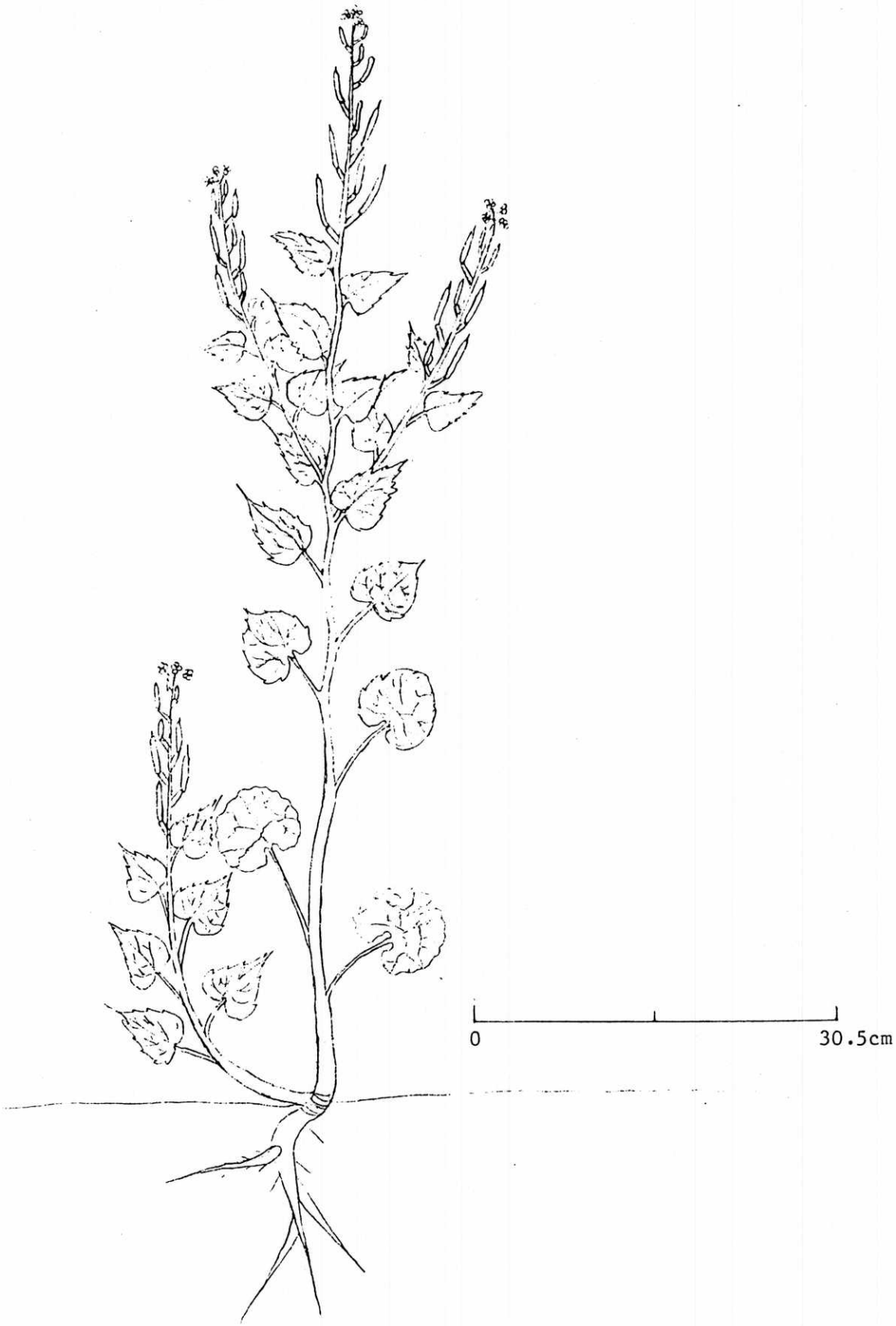
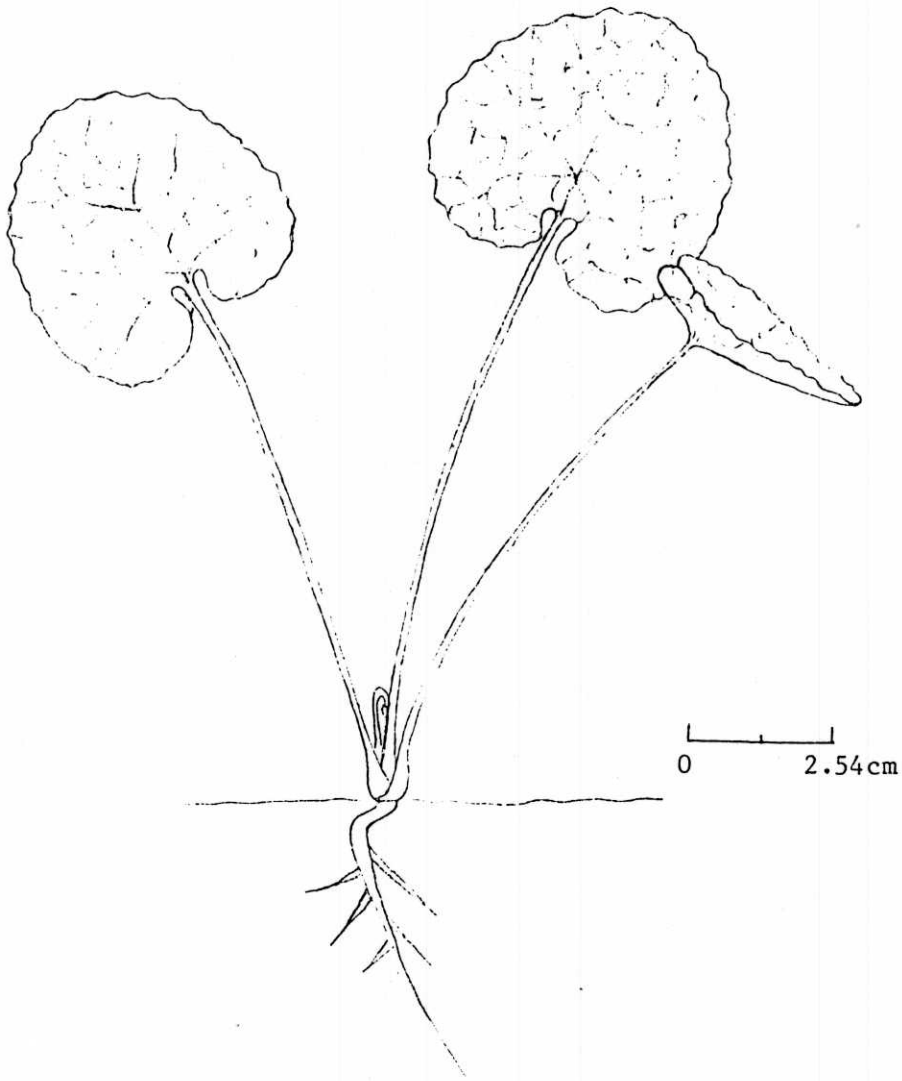


Fig. 4



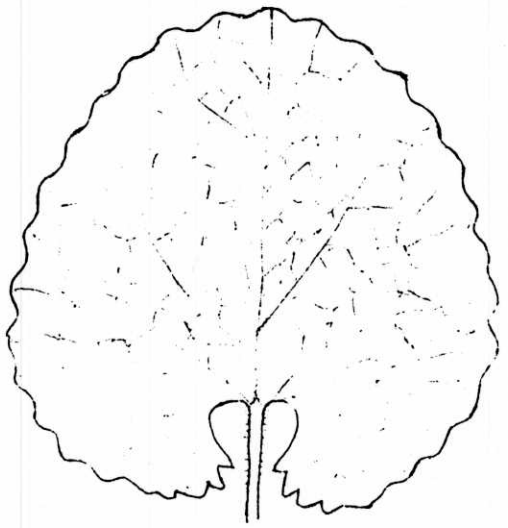
ADULT GARLIC MUSTARD PLANT

Fig. 5



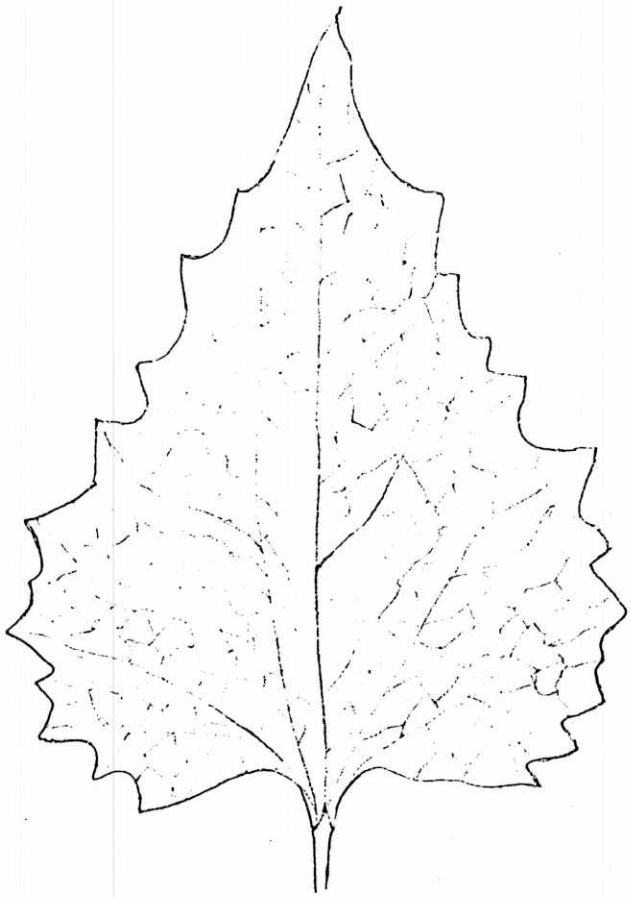
IMMATURE GARLIC MUSTARD PLANT

Fig. 6



LEAF OF AN IMMATURE OR LOWER LEAVES OF AN ADULT GARLIC MUSTARD PLANT

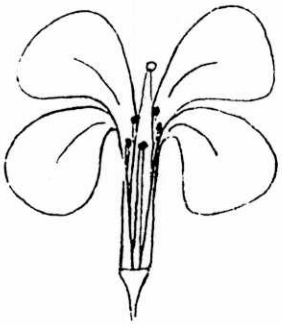
0 2.54 cm



UPPER LEAVES OF ADULT GARLIC MUSTARD PLANT

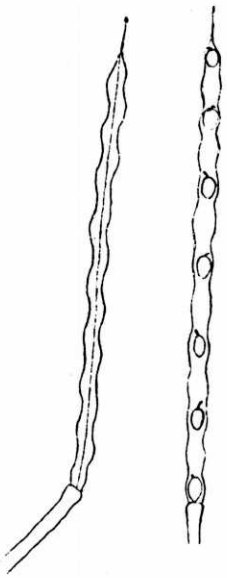
0 2.54 cm

Fig. 7



FLOWER OF GARLIC MUSTARD

0 63mm



SEED PODS SHOWING SEEDS

0 25.4mm

SEED OF GARLIC MUSTARD

0 3.2mm

Fig. 8

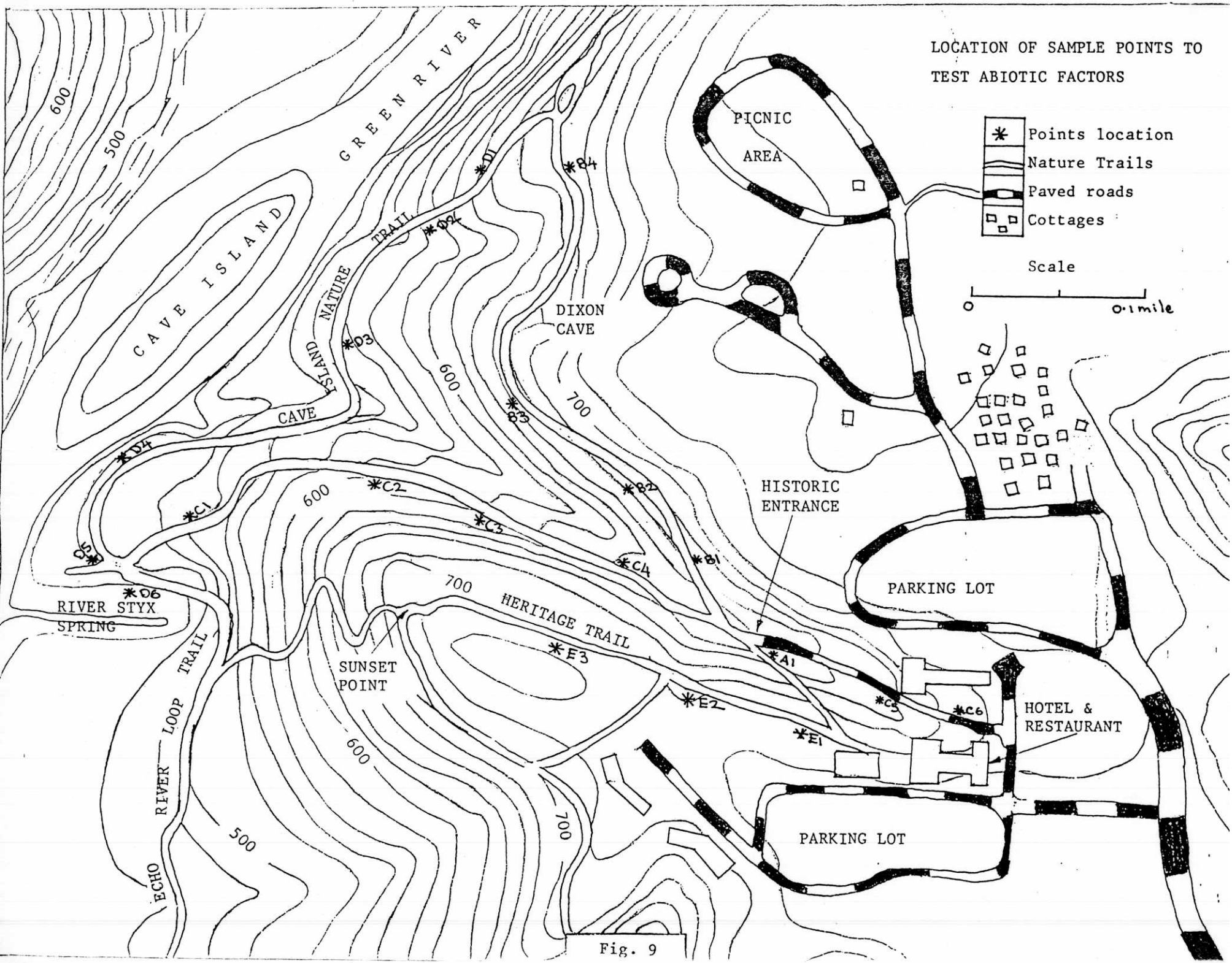

LOCATION OF SAMPLE POINTS TO TEST ABIOTIC FACTORS
Points location
Nature Trails
Paved roads
Cottages
Scale
0 0.1 mile
GREEN RIVER
CAVE ISLAND
ISLAND NATURE TRAIL
CAVE
DIXON CAVE
PICNIC AREA
HISTORIC ENTRANCE
PARKING LOT
HOTEL & RESTAURANT
PARKING LOT
HERITAGE TRAIL
SUNSET POINT
RIVER STYX SPRING
RIVER LOOP TRAIL
ECHO
600
500
700
D1
D2
D3
D4
D5
D6
B1
B2
B3
B4
C1
C2
C3
C4
C5
C6
A1
E1
E2
E3

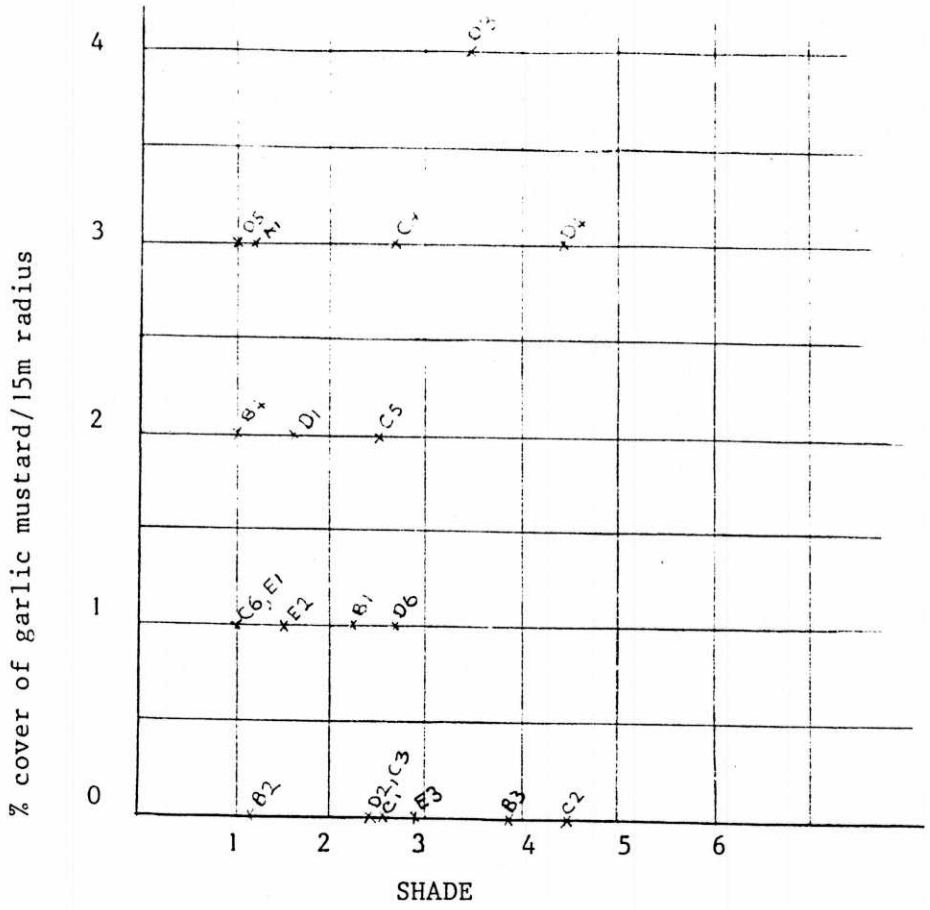
Fig. 9

Table 1: Data for the abiotic natural experimental test on garlic mustard in a 15m radius.

Point	Shade Scale	Moist. Scale	Bedrock	Aspect	Slope	% Cover garlic mustard /15m r.	Sum of ht of an indiv.	# of stems/ 1m radius
C6	1.0	1.0	1	205	-30	1	2	0
D6	2.7	4.4	3	185	-19	1	4	0
D1	1.7	1.9	3	210	-16	2	1	3
D2	2.4	2.9	3	263	-20	0	0	0
D3	3.5	4.4	3	220	-10	4	4	3
D4	4.4	5.0	3	333	-31	3	4	0
D5	1.0	2.5	3	None	0	3	3	2
C1	2.5	3.4	3	0	- 9	0	0	0
C2	4.4	3.7	3	355	-34	0	0	0
C3	2.4	1.9	2	16	- 7	0	0	0
C4	2.7	2.2	2	24	-31	3	5	6
C5	2.5	2.4	1	225	-21	2	3	5
B1	2.2	2.4	1	255	-15	1	1	0
B2	1.2	1.0	2	235	-25	0	0	0
B3	3.9	3.4	3	332	-20	0	0	0
B4	1.0	1.4	3	270	-18	2	2	5
A1	1.2	1.5	3	209	- 3	3	4	7
E1	1.0	1.5	3	None	0	1	5	0
E2	1.5	2.5	2	None	0	1	4	0
E3	2.9	3.4	1	27	-20	0	0	0
A:	2.8	2.8				0	0	0
B:	0.982	0.922						
C:	2.0	2.5				2.1	3.2	2.4
D:	1.047	1.222				0.997	1.310	2.528

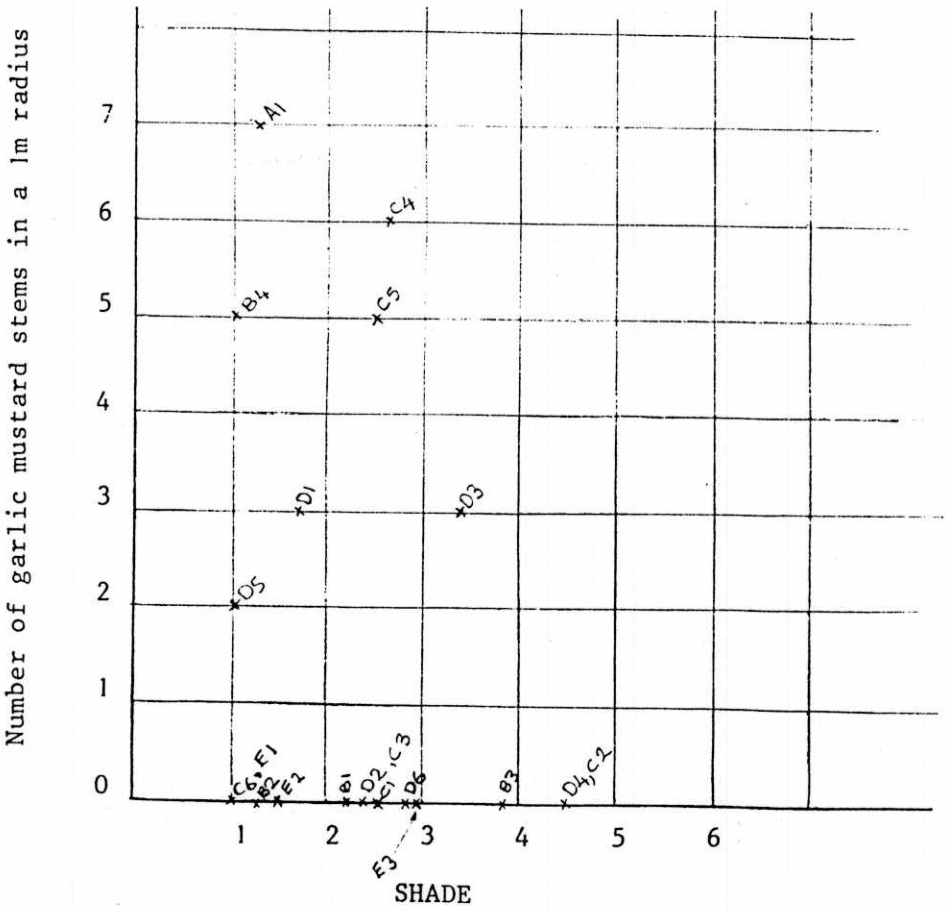
Note: A: The average value for points where garlic mustard does not occur.
B: The standard deviation for points where garlic mustard does not occur.
C: The average value for points where garlic mustard occurs.
D: The standard deviation for points where garlic mustard occurs.

GRAPH 1

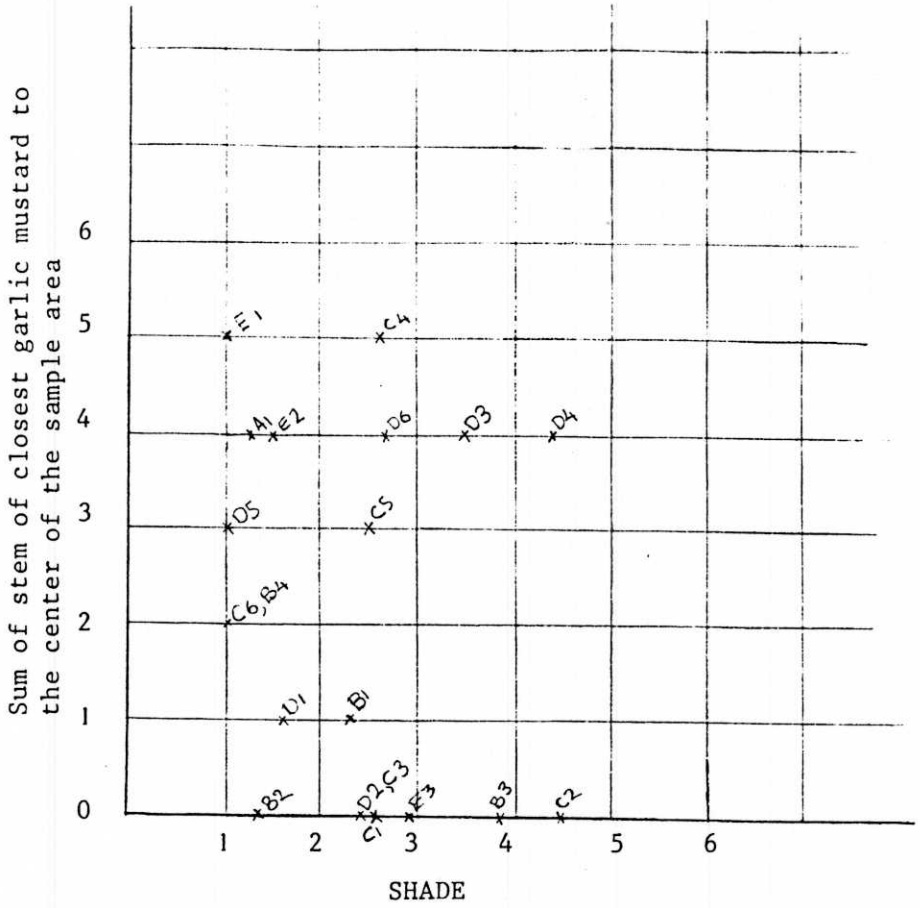


See page 11 for scales

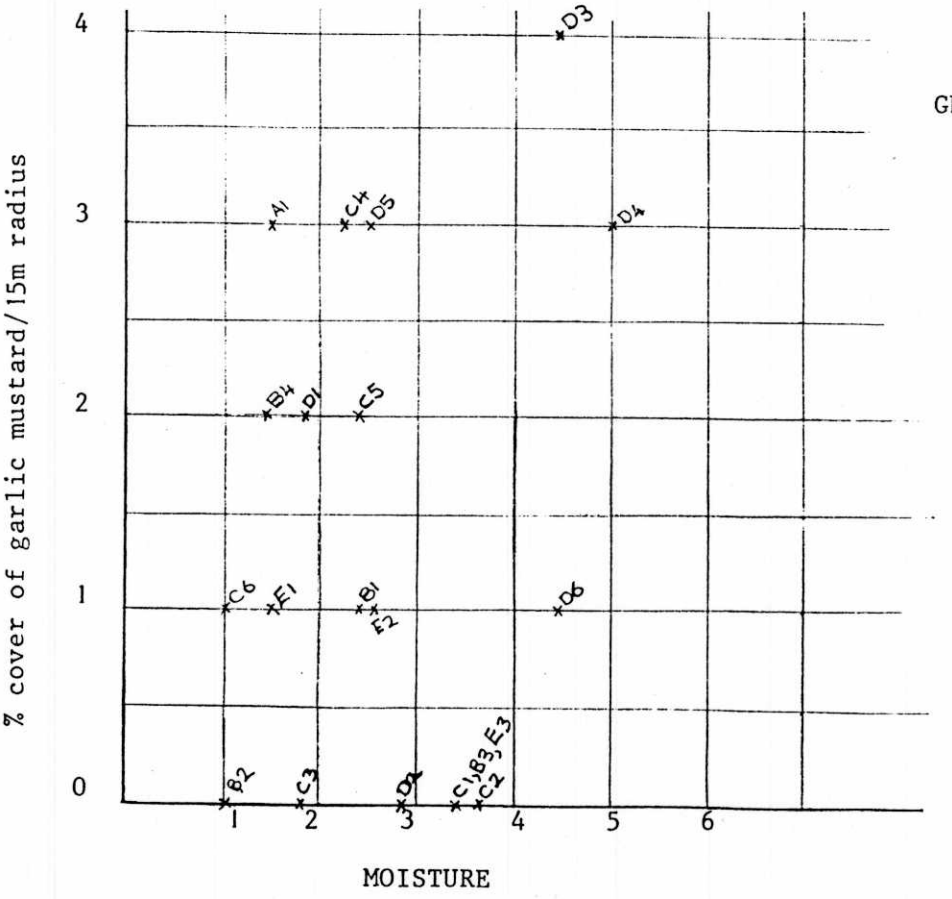
GRAPH 2



GRAPH 3



GRAPH 4



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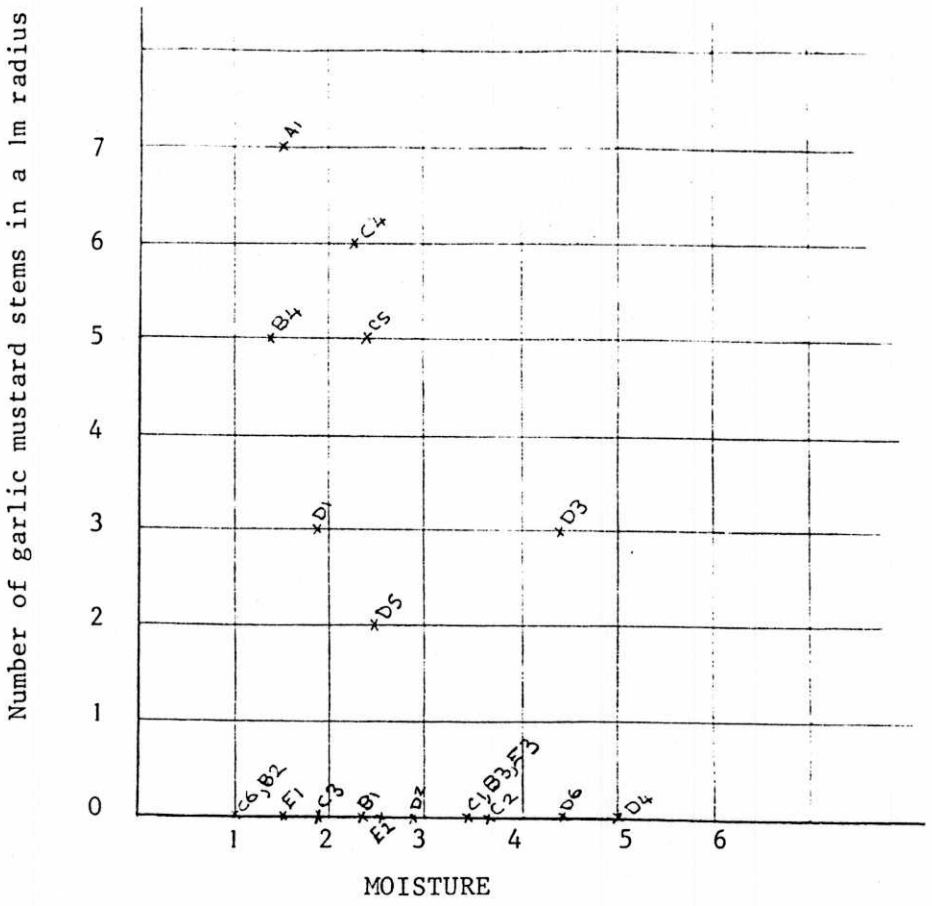

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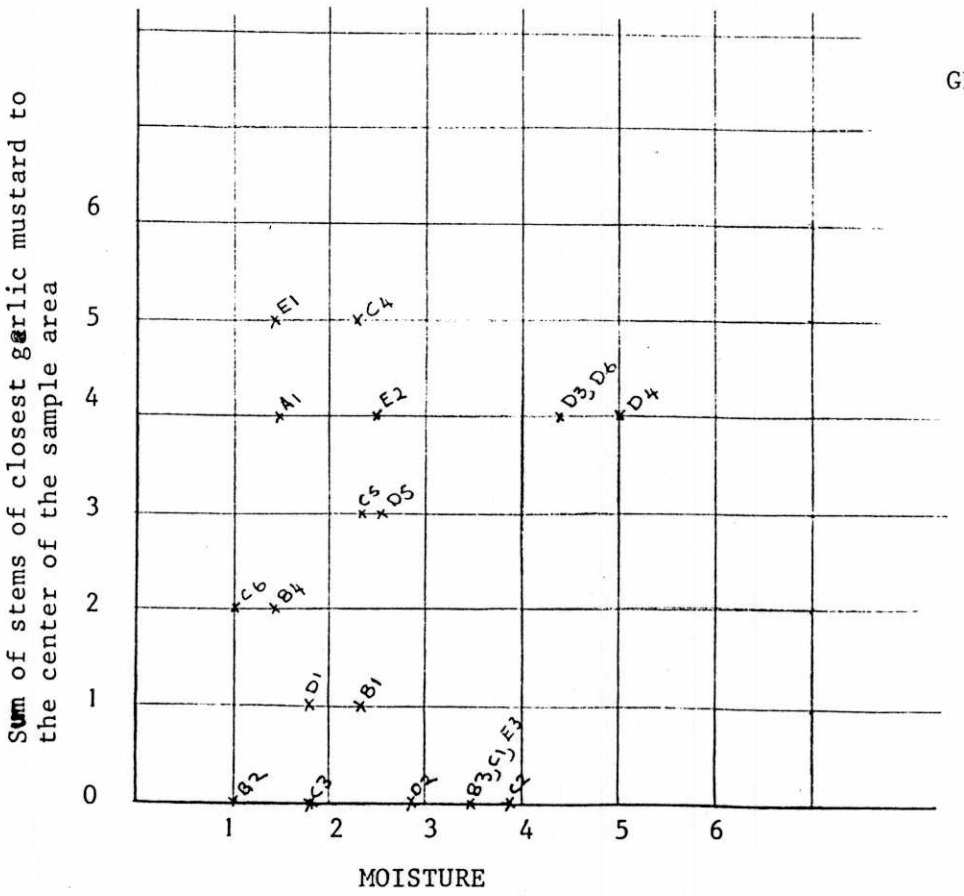
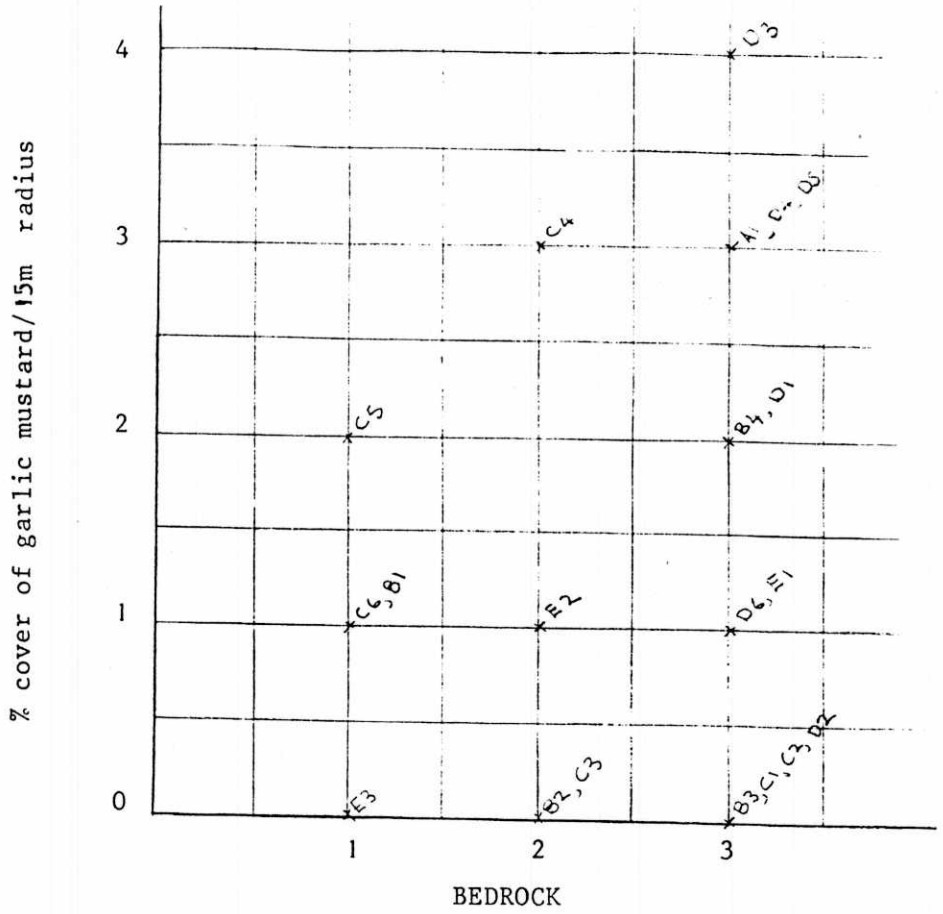


GRAPH 7



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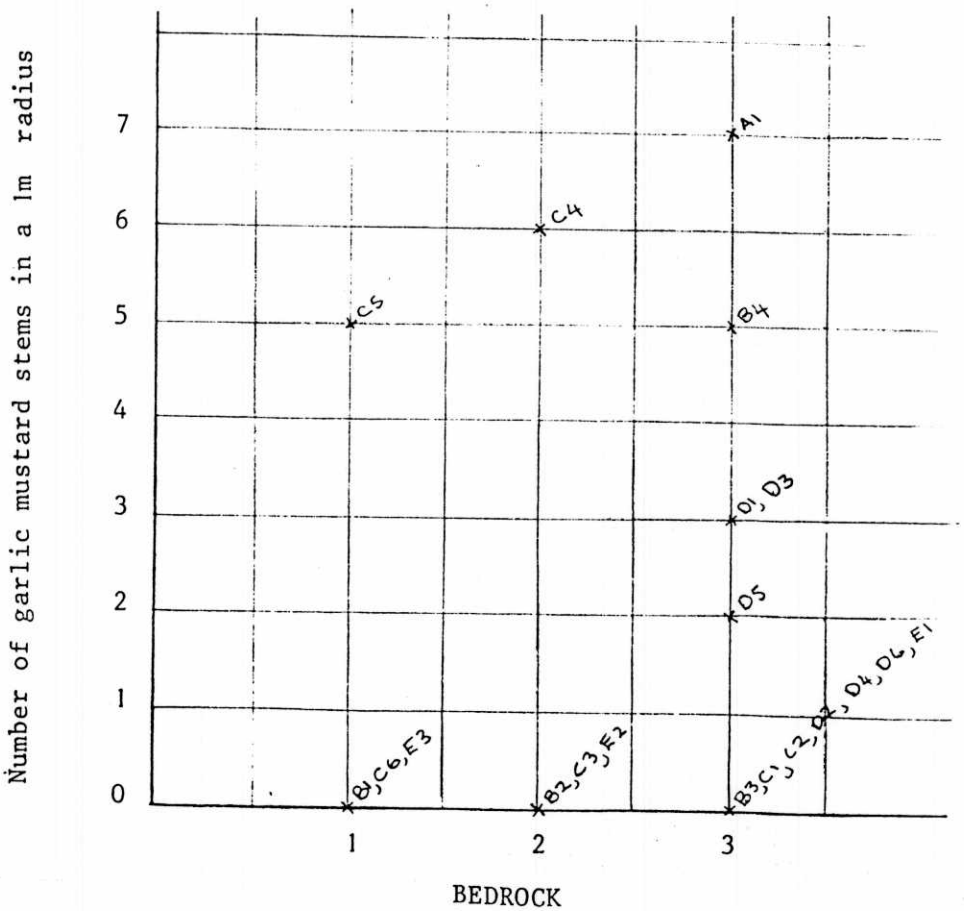

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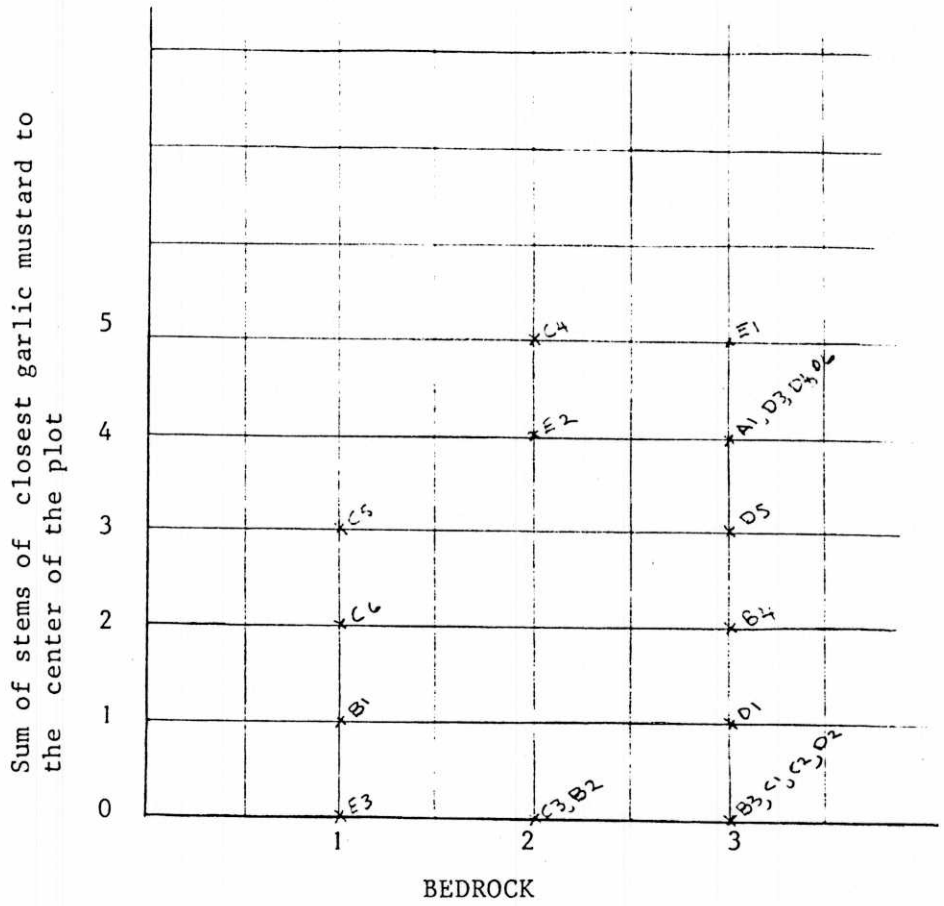
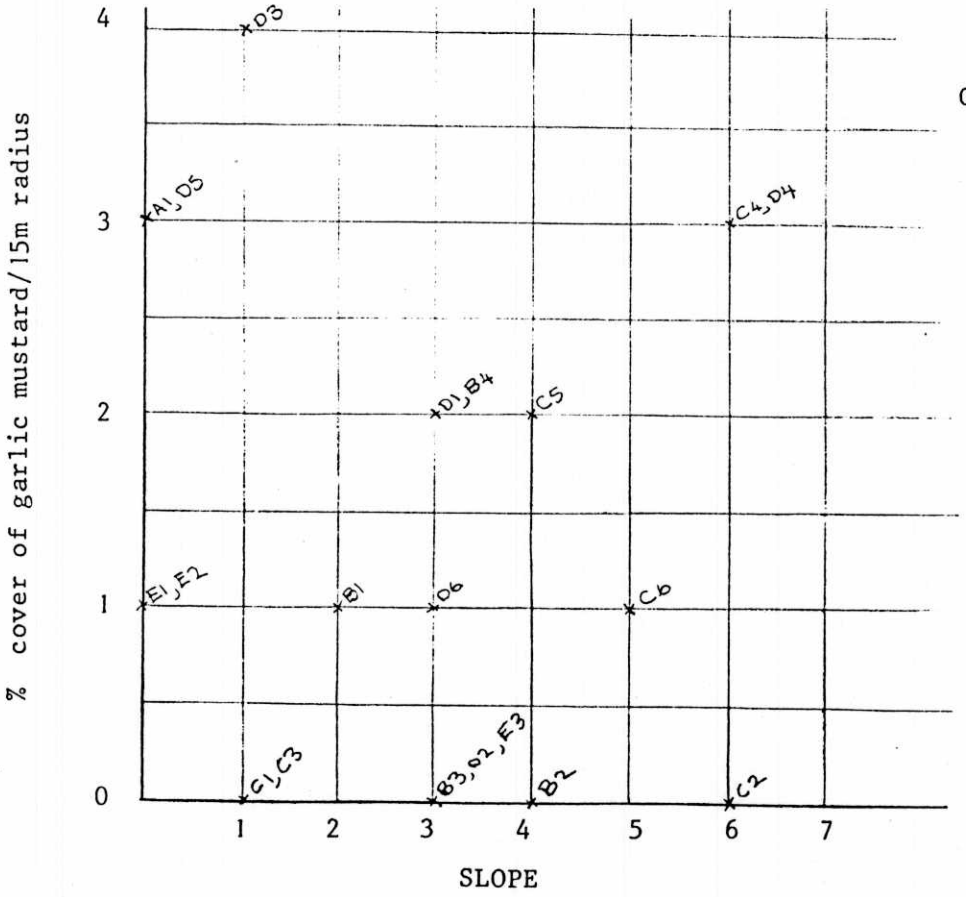
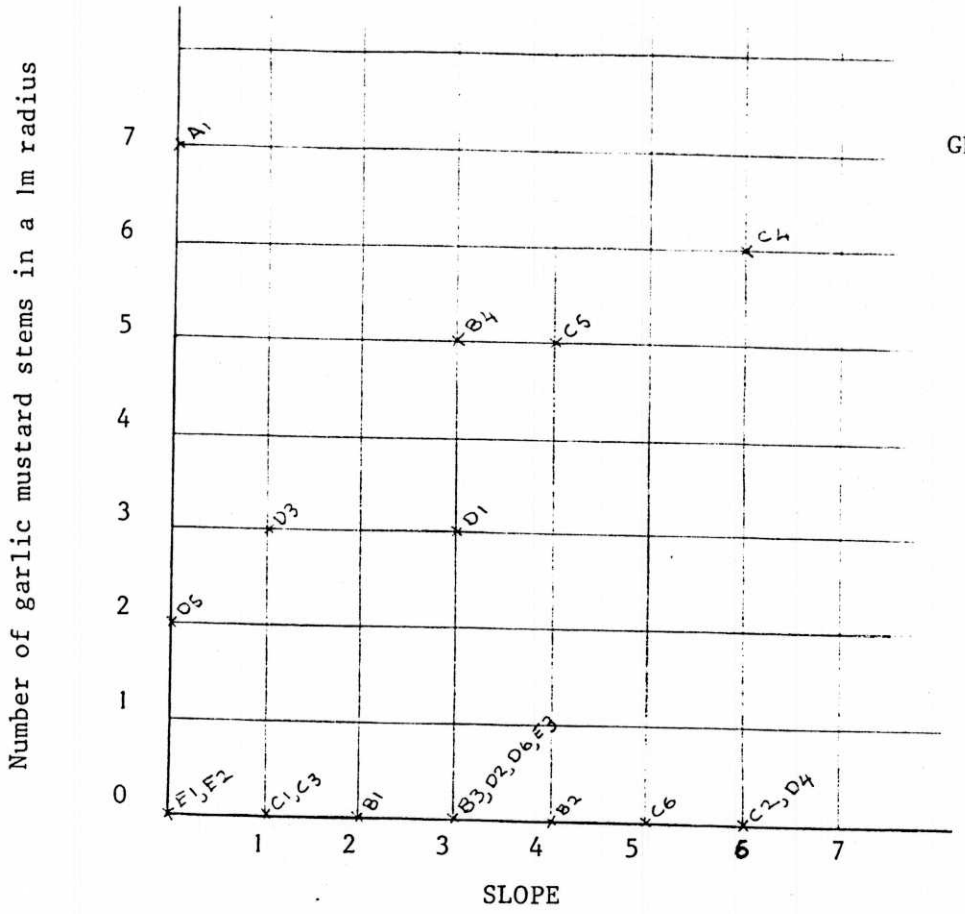


GRAPH 10



GRAPH 11



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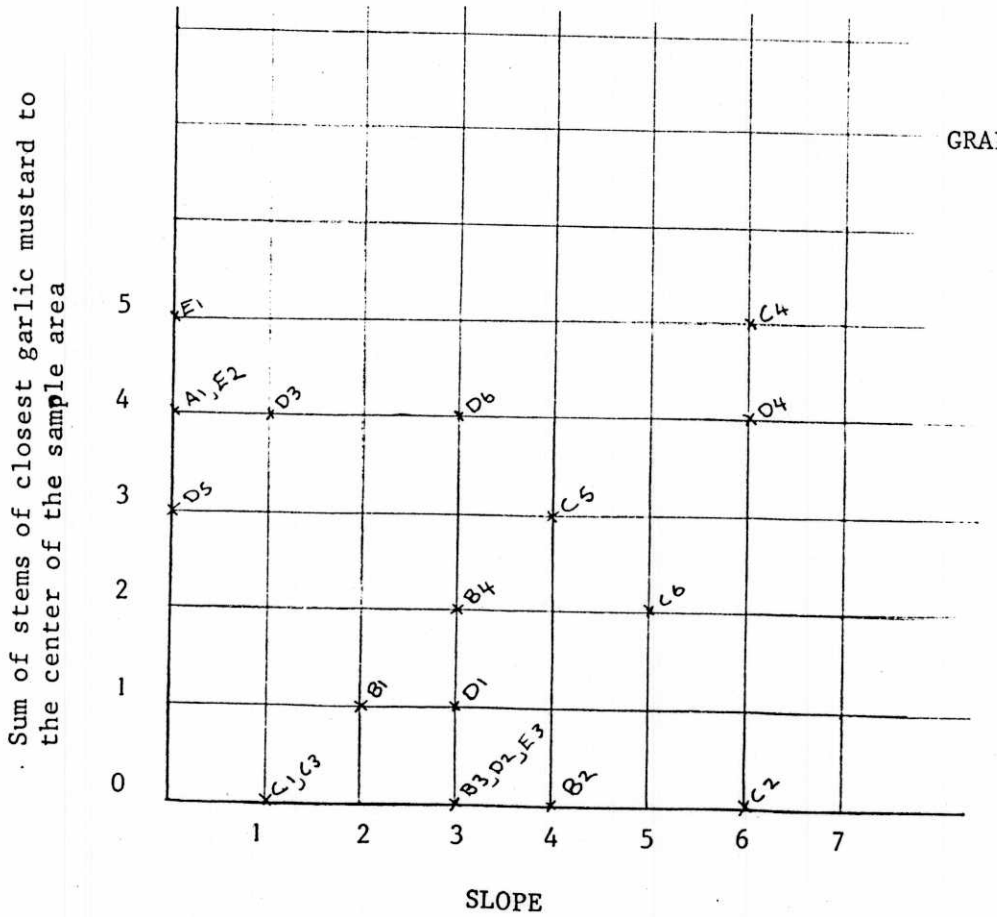
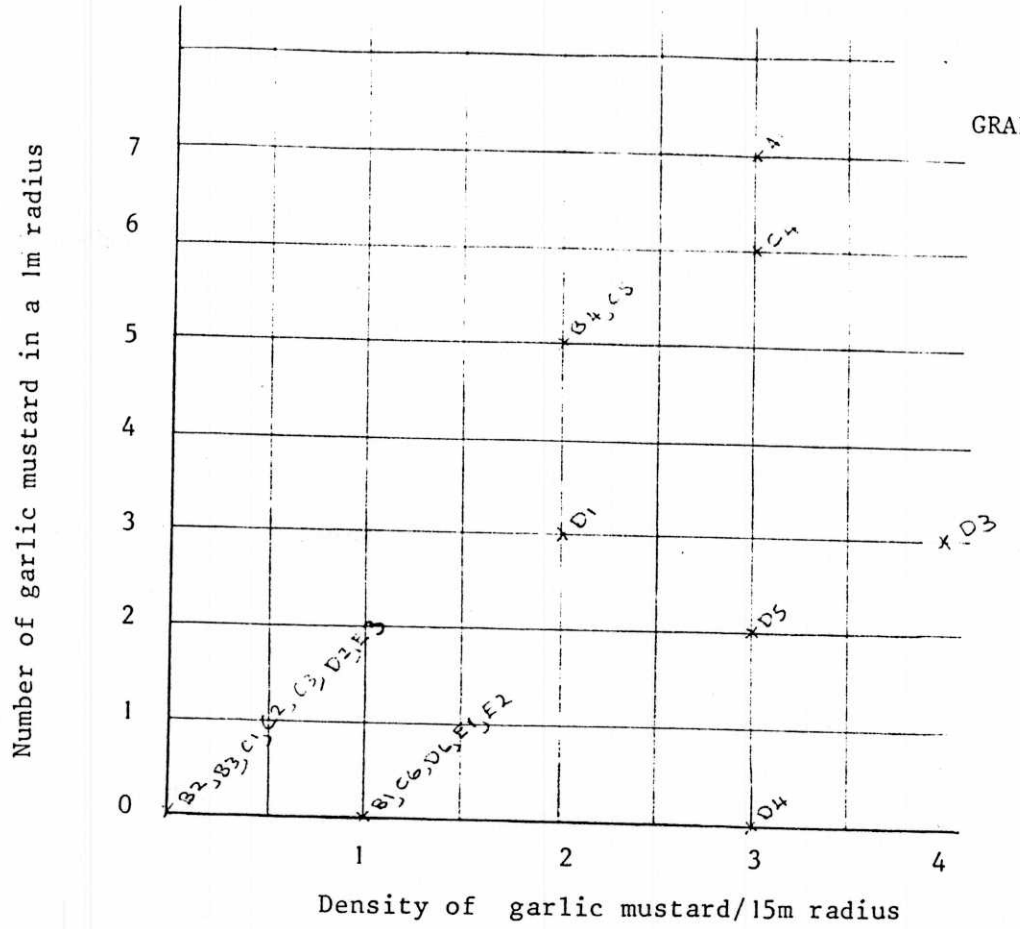
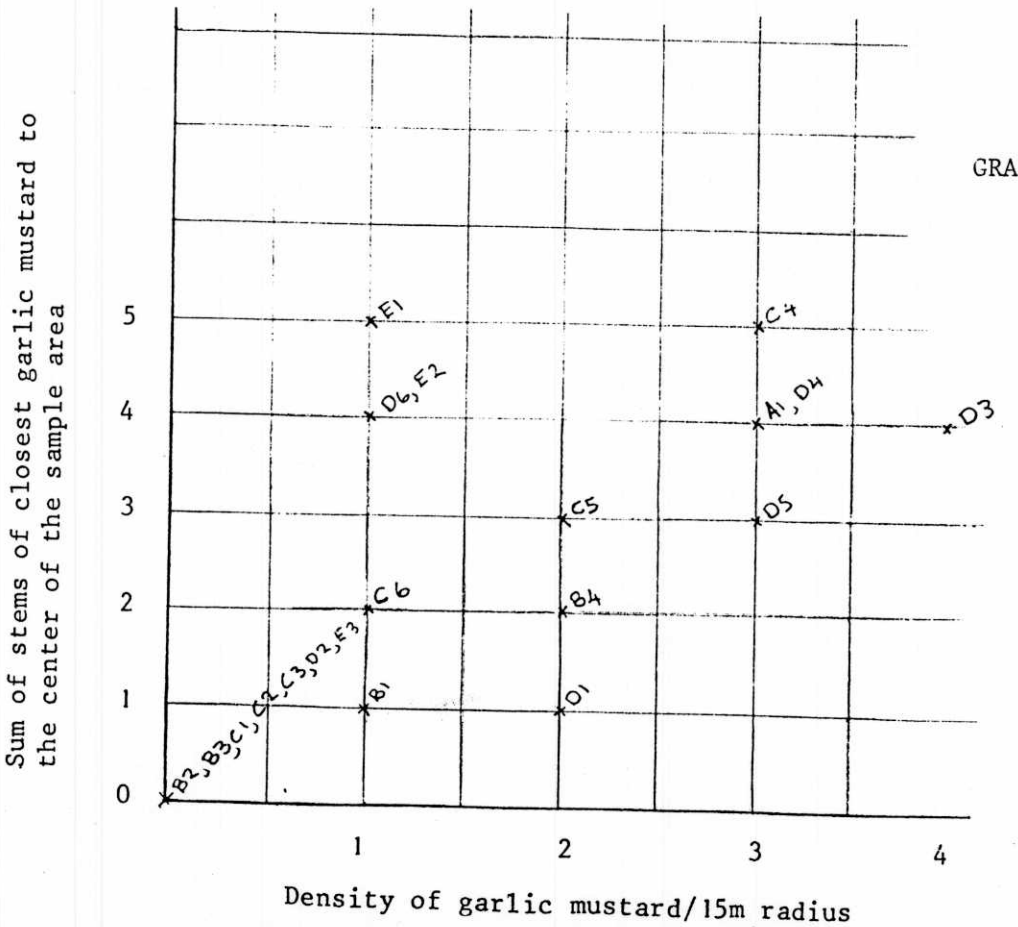


GRAPH 13



GRAPH 14



Twenty points were chosen to determine the biotic effect of garlic mustard on native species (Fig. 10). Five each were chosen for %0, 1-30%, 31-60%, and 61-100% cover. The score for percent cover, number of species, sum of garlic mustard stem heights, and sum of stem heights of other species are given in Table 2. These data (value A) show that the sum height of native species stems increases significantly to 88.1 ft., compared to 40.2 ft. when garlic mustard is growing among them. Surprisingly, the number of species in a $1m^2$ plot remains relatively constant regardless of the percentage cover of garlic mustard (see graph 15). Though the number of other species remains constant, Graph 16 shows that the length of native plants stems decreases as the length of garlic mustard stems increases. This same effect is correlated with an increase in percent cover of garlic mustard (see graph 17).

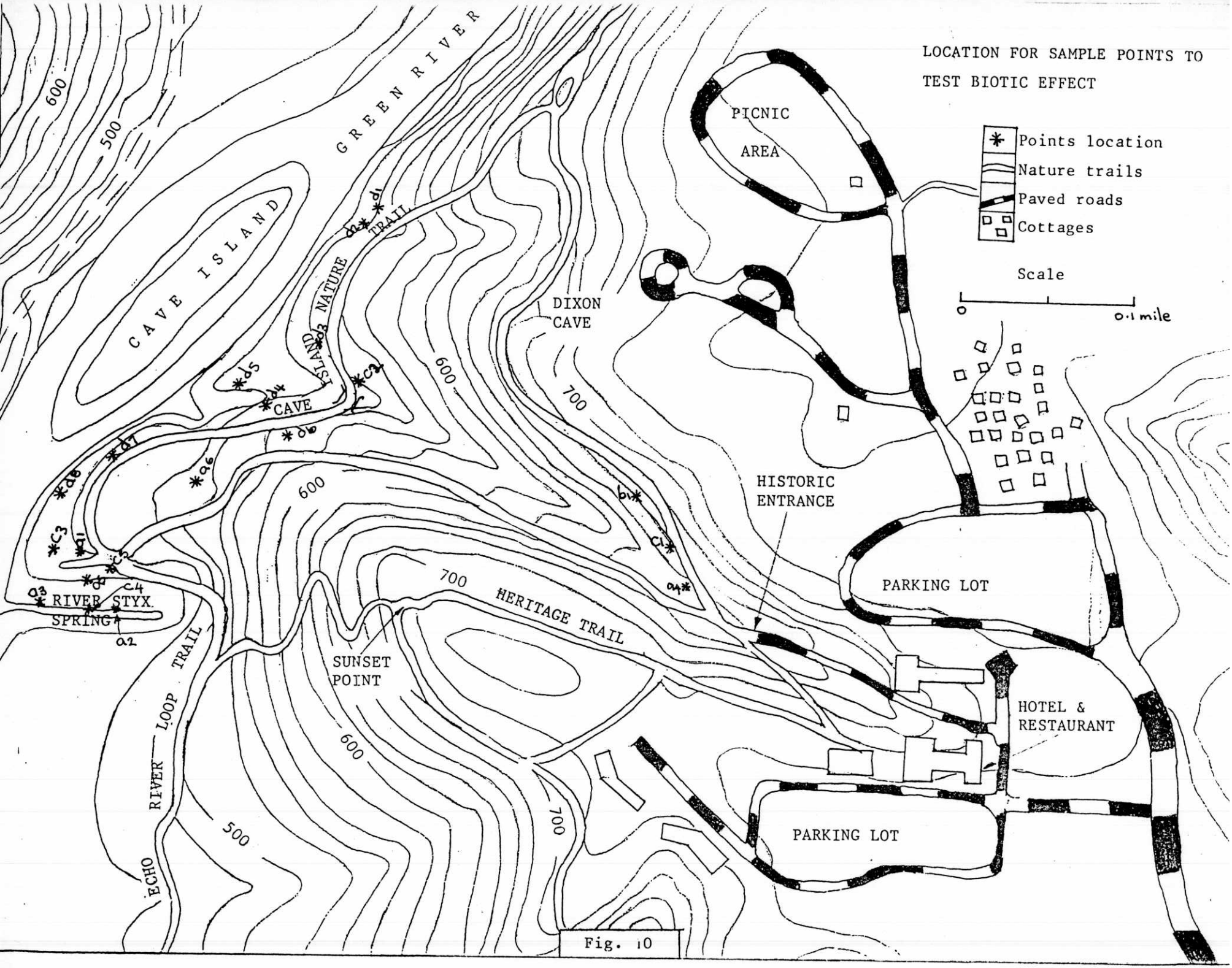
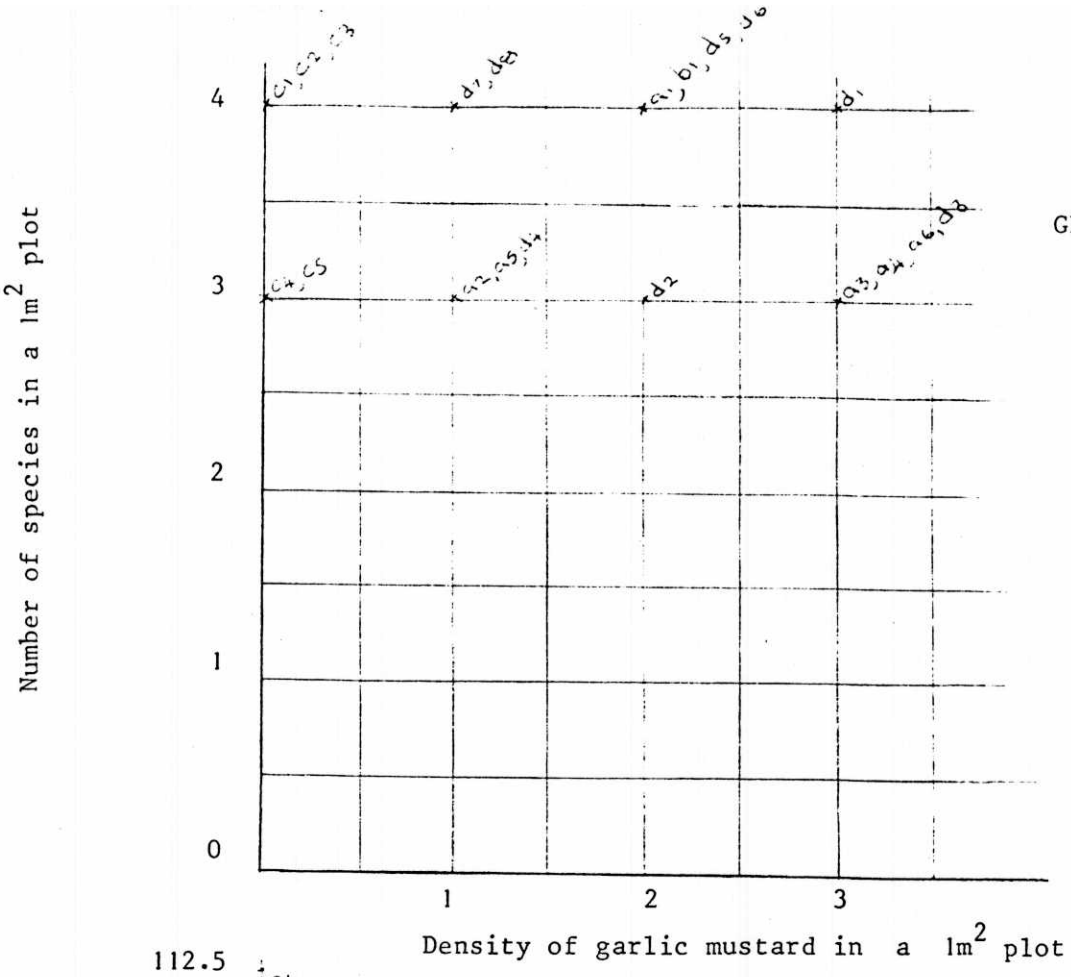

LOCATION FOR SAMPLE POINTS TO TEST BIOTIC EFFECT
Points location
Nature trails
Paved roads
Cottages
Scale
0
0.1 mile
PICNIC AREA
GREEN RIVER
CAVE ISLAND
ISLAND NATURE TRAIL
DIXON CAVE
CAVE
HISTORIC ENTRANCE
PARKING LOT
HOTEL & RESTAURANT
PARKING LOT
HERITAGE TRAIL
SUNSET POINT
RIVER STYX SPRING
RIVER LOOP TRAIL
ECHO
600
500
700

Fig. 10

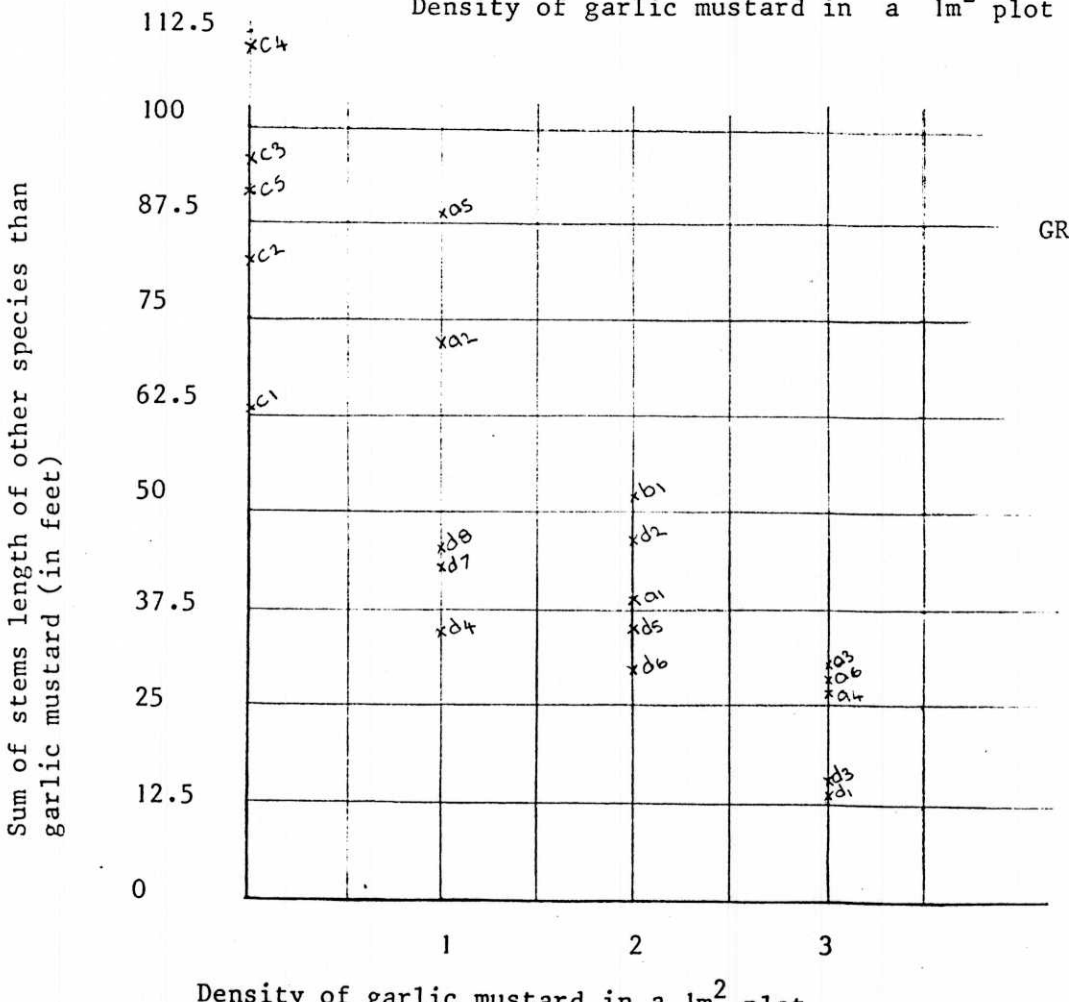
Table 2: Data for the biotic effect of garlic mustard on native species in $1m^2$ plots.

Points	% Cover	Nos. of sp./$1m^2$ plot	Sum of GM stems in ft.	Sum other sp. stems in ft.
c1	0	4	0.0	62.7
c2	0	4	0.0	82.9
c3	0	4	0.0	95.0
c4	0	3	0.0	110.3
c5	0	3	0.0	89.7
a2	1	3	51.8	72.6
a5	1	3	54.4	89.7
d4	1	3	29.3	34.3
d7	1	4	62.2	43.0
d8	1	4	76.8	44.7
a1	2	4	143.3	40.2
b1	2	4	36.7	53.4
d2	2	3	62.6	47.7
d5	2	4	177.3	35.2
d6	2	4	163.1	32.0
a3	3	3	288.1	31.4
a4	3	3	337.0	26.7
a6	3	3	208.7	24.9
d1	3	4	282.1	12.6
d3	3	3	238.7	14.6
A:	2		0.0	88.1
B:	0.82		0	15.59
C:	0		147.5	40.2
D:	0		103.7	19.66

Note:
- A: The average value for points where garlic mustard does not occur.
- B: The standard deviation for points where garlic mustard does not occur.
- C: The average value for points where garlic mustard occurs.
- D: The standard deviation for points where garlic mustard occurs.

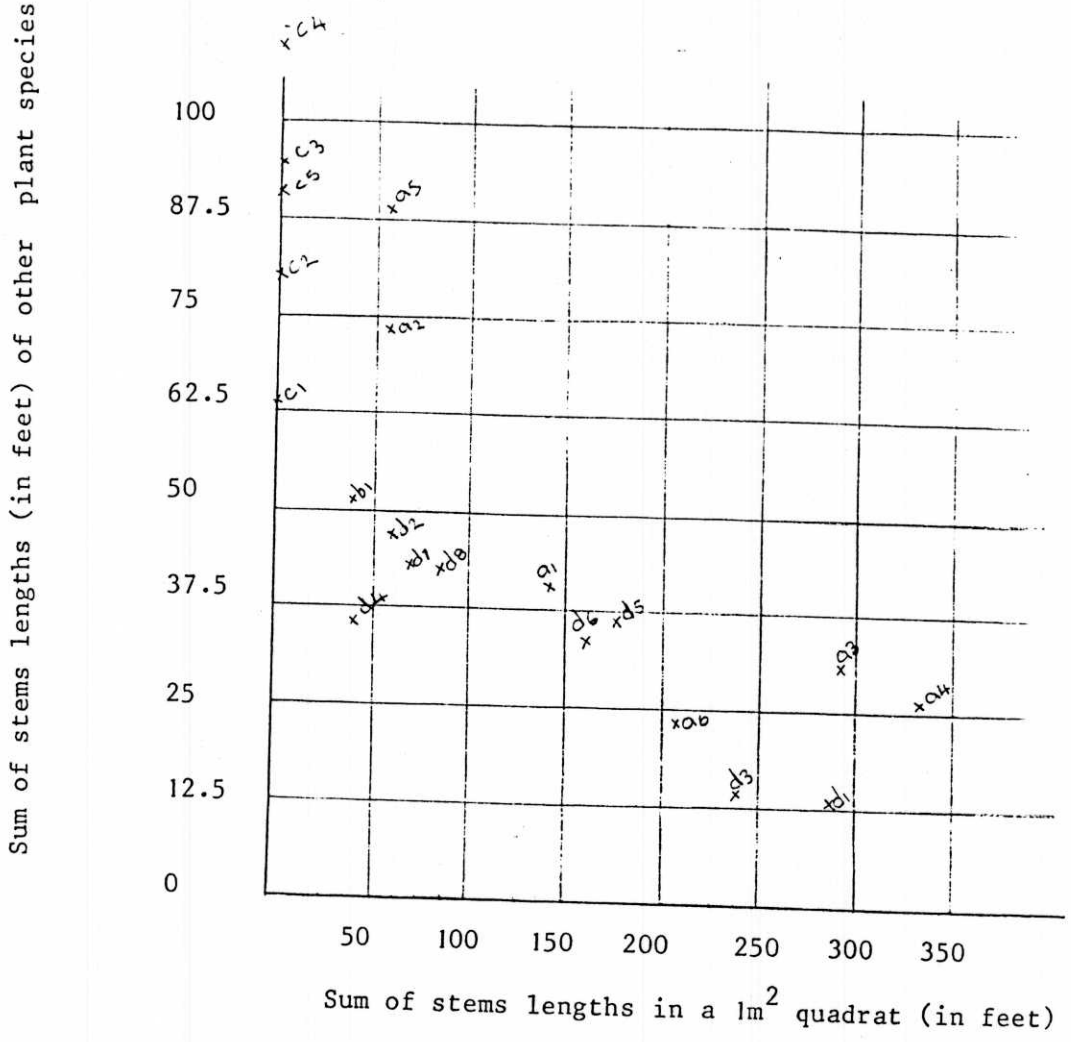


GRAPH 15



GRAPH 16

GRAPH 17


Sum of stems lengths (in feet) of other plant species
100
87.5
75
62.5
50
37.5
25
12.5
0
50
100
150
200
250
300
350
Sum of stems lengths in a 1m² quadrat (in feet)

DISCUSSION

From the results obtained, it appears that garlic mustard does better in areas with less shade, contrary to our third hypothesis which was based on initial observations. Table 1 shows that garlic mustard does grow in shady areas, but is not restricted to it. Similarly, high moisture availability does not necessarily restrict the growth of garlic mustard, and this falsified our first hypothesis. We were not able to falsify our second and fourth hypotheses, and results shows that garlic mustard does grows on sandstone and limestone, and can be found on flat and inclined land. Thus, verifying hypotheses (b) and (d) respectively.

For the biotic effects of garlic mustard on native plants, the results were mixed. Surprisingly, data collected showed that the number of other species remained relatively constant regardless of the percentage cover of garlic mustard. However the overall growth of other species was suppressed by garlic mustard so hypotheses (f) and (g) were supported.

No real experiments were done to determine the seed bank of garlic mustard and its life history as time was too short for these to be done. However, several garlic mustard seeds were examined, they were found to be relatively soft. This may

indicate a short seed bank as plants with long seed bank usually have a very hard shell (Weaver 1938).

Several garlic mustard rosettes were observed growing in the study area. These rosettes showed no sign that they would flower and seed this year. This suggests that garlic mustard is not an annual plant, and may be biennial as stated by Nuzzo (1993). Young plants generally were growing in small patches by themselves with a few among the adult plants. The number of rosettes observed were not equal in number to the number of adults that will die. This could indicate that there may be a smaller population of garlic mustard in the upcoming year.

It is suspected that garlic mustard blooms and produces seeds each year in the park since both adults and immature plants were observed. Being a biennial plant, garlic mustard should flower and seed every two years. Therefore, because both adult and immature plants are observed, this could mean that multiple invasions of this alien species have occurred or that all seeds do not germinate in their first year. If there has been more than one invasion of garlic mustard, then further study should be done on how its seed is dispersed to help in the control of this species. Otherwise one may be correcting a situation that will reoccur.

From Fig. 3 it can be seen that the majority of the garlic mustard population is growing on the flood plain of Green River in ravines. Our data show that the vigor of garlic mustard is not governed by the amount of moisture it receives. If this is so, then maybe the reason garlic mustard is growing along the valley floors and along river banks is that water is the main method of seed dispersal for it. Another method of seed dispersal could be by hikers. After I worked among garlic mustard, and went home, I found many garlic mustard seeds inside my shoes. Wherever these seeds are dumped they could easily grow the following year. This could probably explain the small patches of garlic mustard at the picnic area and at the camp ground.

Recommendations

Control of the growth and spreading of garlic mustard should be considered, as results obtained show that it is having a negative effect on the growth of native species at M.C.N.P. Methods should be by hand removal of plants or cutting of stems. Note however that if plant stems are cut too early they may resprout. We have observed that garlic mustard plants which have flowered and seeded and then fallen, have partly rejuvenated and show a

small amount of flowering and seeding in some instances. Plant removal should be done in early spring when adult populations are at their lowest (Nuzzo 1993).

Chemical control should not be considered, because garlic mustard is growing near river and water ways. Due to these conditions, herbicides could seep down to the water table. Herbicides may also have a negative effect on native species since garlic mustard at M.C.N.P. never occurs alone.

Five permanent plots have been established and should be monitored regularly. This would best be done at least once ever week starting approximately two months before flowering and at least once ever three weeks following flowering and seeding in June. The plots ranges from 25-36m^2. All adult garlic mustard plants have been uprooted in these plots including the rosettes in plot X1.

When collecting data from permanent plots, one should be careful that no damage is done in the plot. Damage can have an effect lasting into future censuses, this is particularly important in the case where the regeneration of seedlings is to be followed. As the seedlings one year may be trampled, which may result in a reduced number of adults the following year.

In plots X1, X2, and X3 most plants have already shed their seeds onto the soil. One can therefore check the number of seedlings next year, and in the following year, the number of adult plants. The percentage cover can then be compared to present data to see if there is any change. If rosettes flower and seed one year after germinating, then there should be no adult plants in plots X1 next year since all rosettes were uprooted. Likewise, no adult garlic mustard should be in plots X2, X3, and X4 since no rosettes were observed. If this is true a repeated uprooting two years from now should eliminate the garlic mustard in these patches.

For plot X5, only adult garlic mustard plants were uprooted. Most of these plants had not seeded as yet, maybe as a result of the cold air coming out of the Historic Entrance. A total of 35 rosettes were observed in this plot and all were marked with orange flagging tape. A count of these next year should indicate the survival rate of rosettes over a one year period. It may also show if other seeds germinated after adult plants were uprooted. Due to the garlic mustard being uprooted before they seeded in plot X5 this year, the percentage cover of garlic mustard may decrease in the next two years.

In the future the number of stems in each plot should be counted and used for references over the following years. Unfortunately, this was not done this year so there is no specific value to compare next year results to.

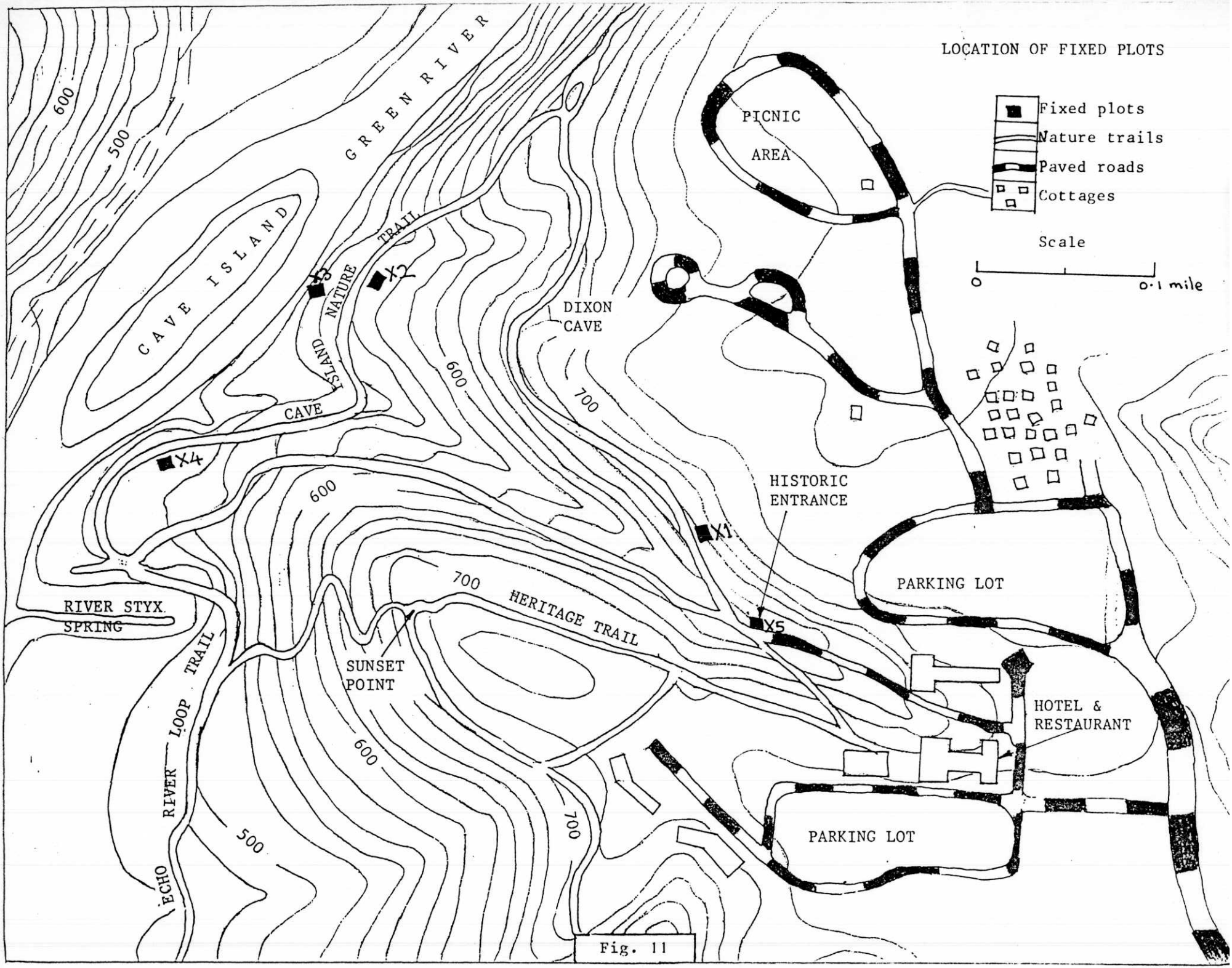

LOCATION OF FIXED PLOTS
Fixed plots
Nature trails
Paved roads
Cottages
Scale
0
0·1 mile
GREEN RIVER
CAVE ISLAND
CAVE
ISLAND NATURE TRAIL
PICNIC AREA
DIXON CAVE
HISTORIC ENTRANCE
PARKING LOT
HOTEL & RESTAURANT
PARKING LOT
HERITAGE TRAIL
SUNSET POINT
RIVER STYX SPRING
RIVER LOOP TRAIL
ECHO
X1
X2
X3
X4
X5
600
500
700

Fig. 11

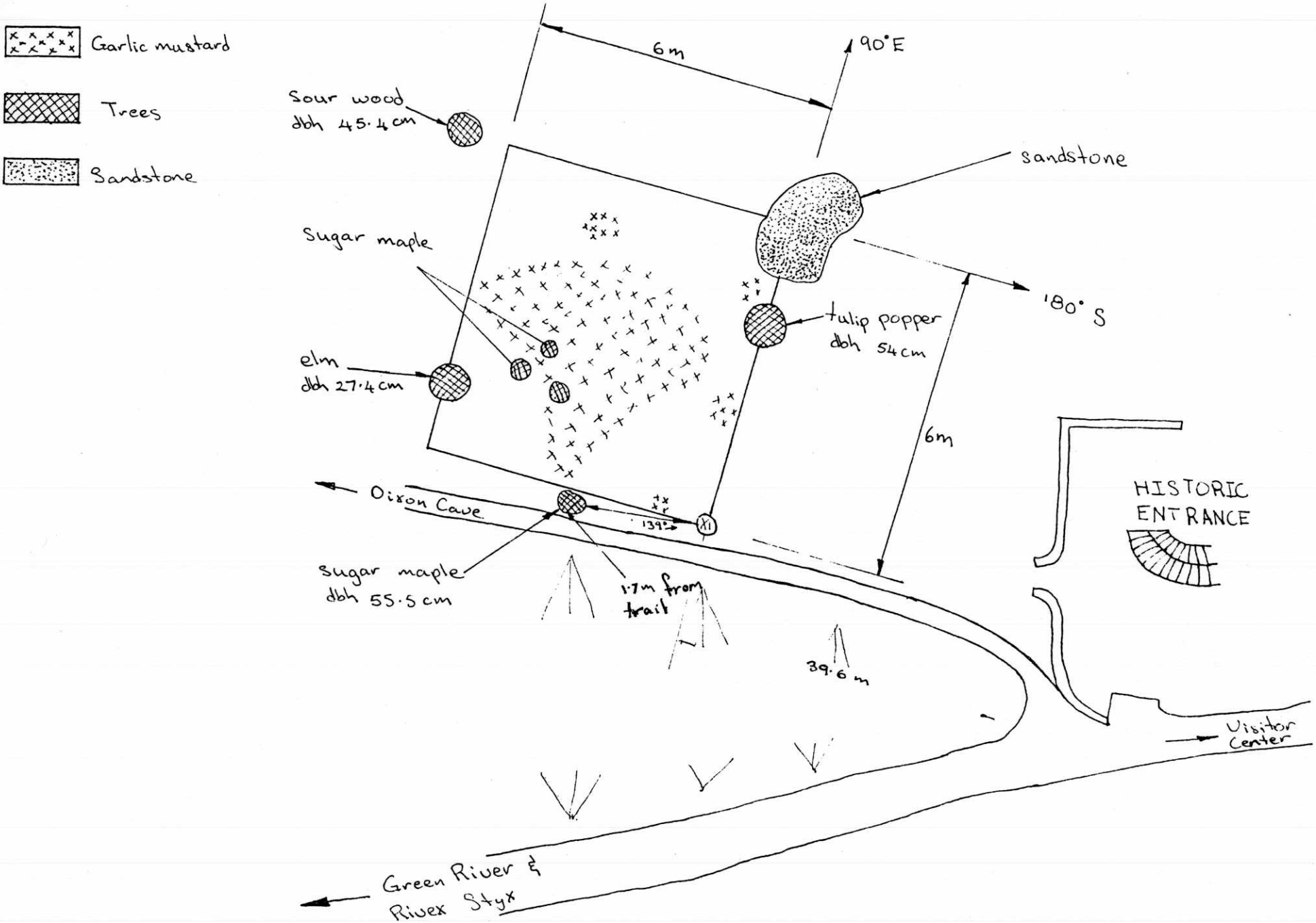

Garlic mustard
Trees
Sandstone
6m
90°E
Sour wood
dbh 45.4cm
sandstone
Sugar maple
tulip popper
dbh 54cm
180° S
elm
dbh 27.4cm
6m
HISTORIC
ENTRANCE
Oiron Cave
139°
XI
sugar maple
dbh 55.5cm
1.7m from
trail
39.6 m
Visitor
Center
Green River &
River Styx

Fig. 12

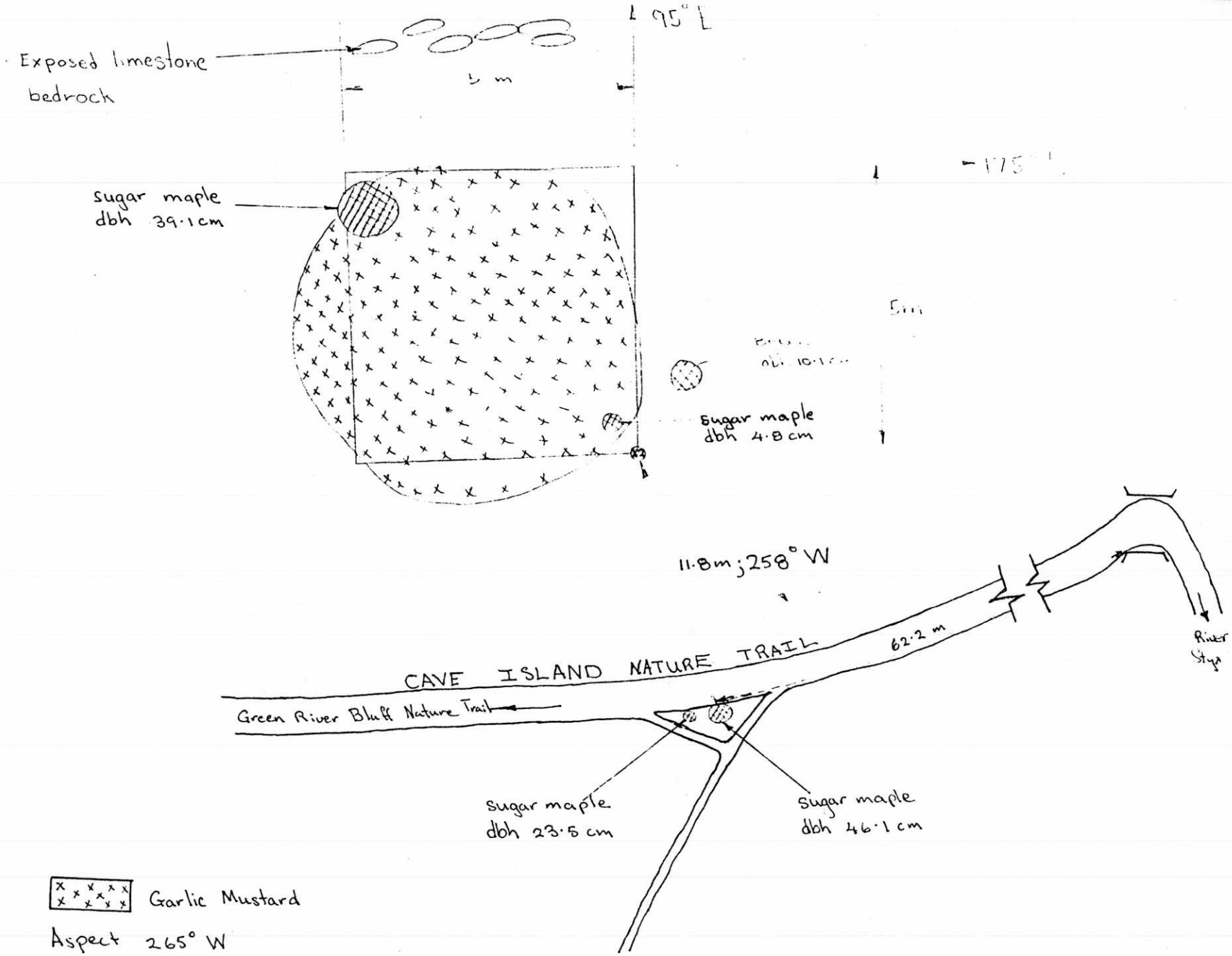

Exposed limestone bedrock
95° L
5 m
sugar maple
dbh 39.1 cm
sugar maple
dbh 4.8 cm
11.8m; 258° W
CAVE ISLAND NATURE TRAIL
62.2 m
Green River Bluff Nature Trail
River Styx
sugar maple
dbh 23.5 cm
sugar maple
dbh 46.1 cm
Garlic Mustard
Aspect 265° W
Slope - 21
Population 31-60% (cover)

Fig. 13

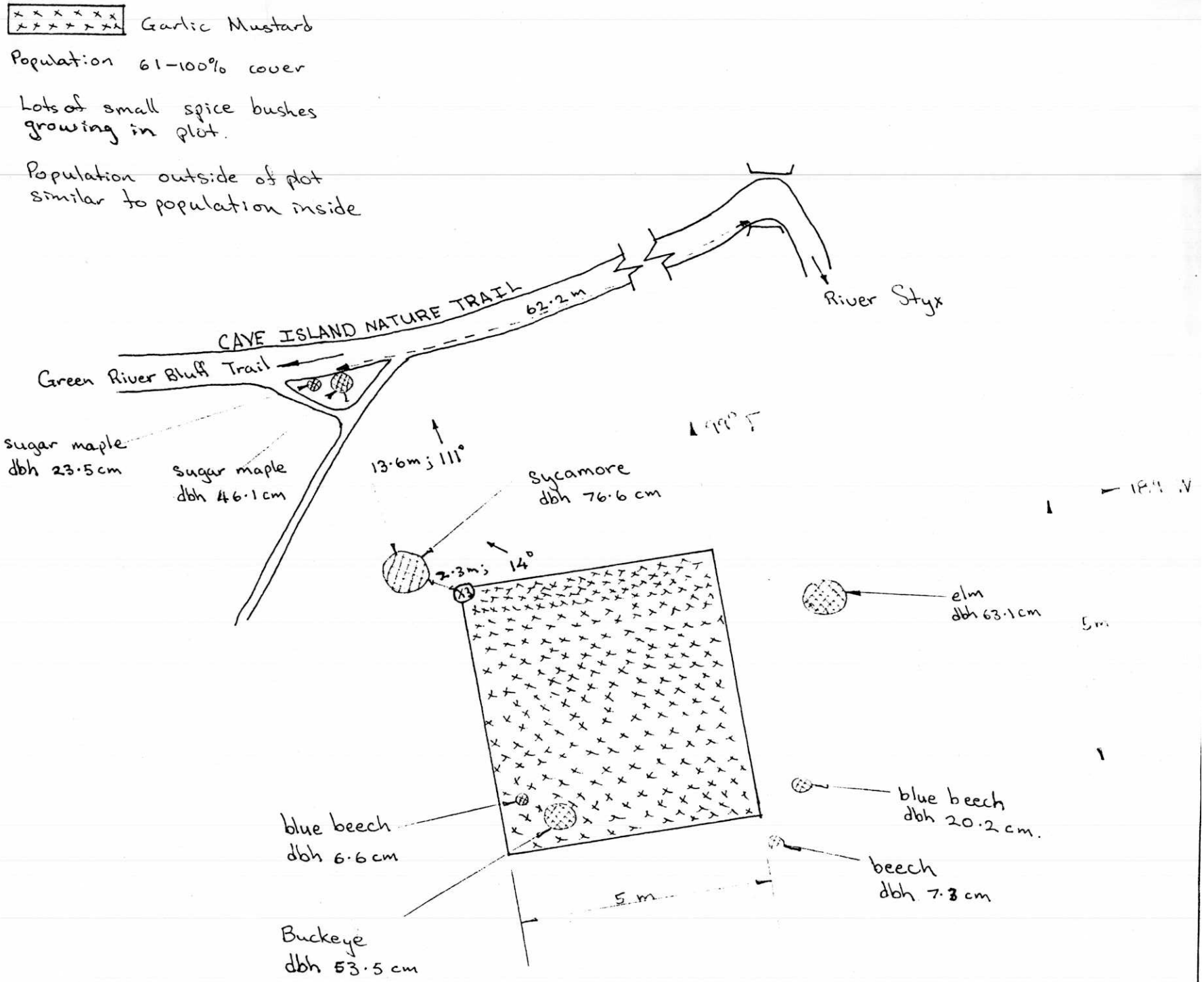

Garlic Mustard
Population 61–100% cover
Lots of small spice bushes growing in plot.
Population outside of plot similar to population inside
CAVE ISLAND NATURE TRAIL
62.2 m
River Styx
Green River Bluff Trail
sugar maple
dbh 23.5 cm
sugar maple
dbh 46.1 cm
13.6 m ; 111°
sycamore
dbh 76.6 cm
2.3 m ; 14°
elm
dbh 63.1 cm
5 m
blue beech
dbh 6.6 cm
blue beech
dbh 20.2 cm.
beech
dbh 7.3 cm
5 m
Buckeye
dbh 53.5 cm

Fig. 14

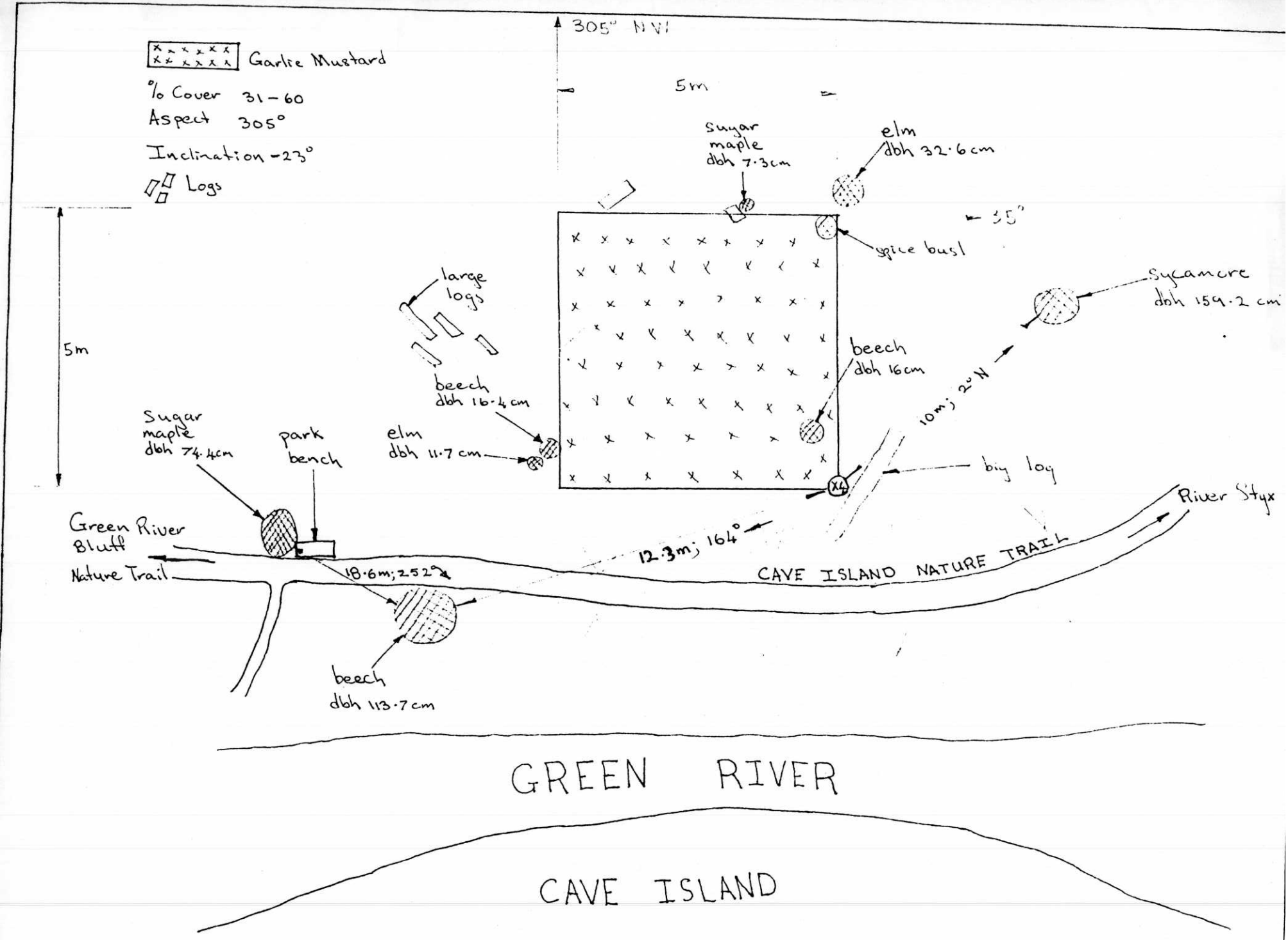
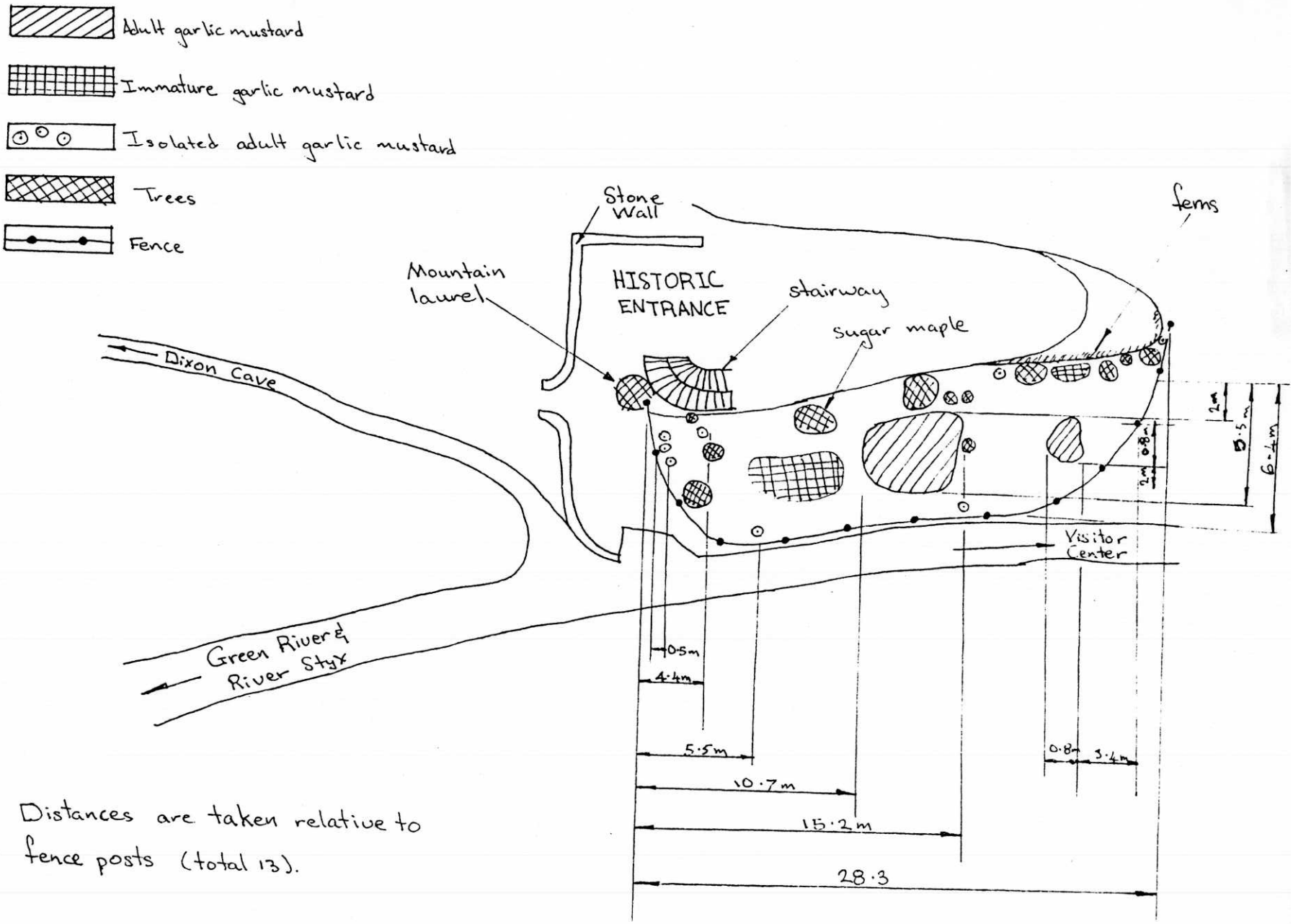

Garlic Mustard
% Cover 31-60
Aspect 305°
Inclination -23°
Logs
305° NW
5m
5m
Sugar maple dbh 7.3cm
elm dbh 32.6 cm
35°
spice bush
large logs
beech dbh 16.4 cm
Sycamore dbh 159.2 cm
beech dbh 16cm
10m; 2° N
Sugar maple dbh 74.4cm
park bench
elm dbh 11.7 cm
X4
big log
Green River Bluff Nature Trail
12.3m; 164°
River Styx
18.6m; 252°
CAVE ISLAND NATURE TRAIL
beech dbh 113.7 cm
GREEN RIVER
CAVE ISLAND

Fig. 15



Note: Distances are taken relative to fence posts (total 13).

Fig. 16

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