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SEED DISPERSAL AND FUTURE MANAGEMENT
OF
GARLIC MUSTARD

by

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ABSTRACT

Garlic mustard (Alliaria petiolata) is an invasive, exotic herbaceous plant, which was introduced in the visitor center area of Mammoth Cave National Park, (MCNP) some time in the last few years. The goals of this study were to monitor the spread of garlic mustard by mapping affected areas and to investigate methods for controlling of garlic mustard, and gathering data for future reference. I agree that garlic mustard is a biannual plant that spreads through a variety of agents, the most common being water. Recommended methods of removal are cutting stems, pulling plants, and herbicide application.

INTRODUCTION

Garlic mustard is presently invading Mammoth Cave National Park. My responsibility is to monitor five plots established last year and one additional plot added this year. Garlic mustard has been identified as an exotic species invading MCNP. The area affected by this plant is at least 15 ha of the 52,830 acres of MCNP. Garlic mustard is presently found growing near the visitor center, in the campground and the picnic area.

Results from last years studies show that "Garlic mustard does better in areas with less shade, but it is not restricted to it" (Brown 1993:7). Other results from last year show that "Length of native plants stems decreases as the length of garlic mustard increase" (Brown 1993:32).

Garlic mustard is a highly competitive noxious plant, that was introduced from Europe into North America in 1868 (Nuzzo 1993). Garlic mustard has become established in many different types of terrains. It occurs most commonly in wooded communities under a partial canopy, but plants frequently grow in sites ranging from full sun to full shade (Nuzzo 1991). Garlic mustard occupies widely varying soils, and moisture levels, from communities flooded four months a year to dry sand forest (Caver 1979). Garlic mustard is also common in oak and savanna forest (Bryers and Quinn 1987). Disturbed areas such trail edges are frequent habitats, thus making MCNP an easy area for the plant to invade.

Garlic mustard is cool-season monocarpic biennial herb with an effective three year generation time (Nuzzo 1991). Seeds germinate in the early spring of year one following the first or second warm rain, approximately in early April in Illinois (Nuzzo 1991). Garlic mustard is a strict biennial; all surviving plants, regardless of size, produce flowers in the spring of year two and subsequently die (Cavers et al. 1979; Bryers and Quinn 1988; Bloom et al. 1990). The flowers are crossed shape with four sepals, four petals, and six stamens. The seedpod (silique) contains a false partition which divides the seed alternately (Wharton and Barbour 1983). Our field counts show that plants can have as few as one and as many as 800 seeds (see also Hoong 1994). Seed germination occurs within two, but seeds remain viable for up to five years (Lhotska 1975, Roberts and Boddrell

1983). Population levels may vary widely from year to year reflecting the biennial nature and delayed seed germination of this plant (Nuzzo 1992).

Leaves on rosettes are circular with lobed serration and leaves on a maturing adult are triangular with a serrated leaf structure and palmate venation. (Note leaves have distinct acrid odor when crushed). The definition of a biennial is a plant that has life cycles that take two years to complete (Raven & Johnson 1992). During the first year, biennials generally form a tuft of leaves, or rosettes (Raven & Johnson 1992). In the second year of these plants' growth, when they flower, the energy is stored in the rosettes and in the underground parts of the plant is used to produce flowering stems (Raven & Johnson 1992).

Among plants generally, competition between root systems for the nutrients that the plants require, and which they obtain from soil, is of central importance (Raven 1992). The roots of one species not only may deplete essential minerals and thus out compete another, but may also excrete toxic substances that depress the growth of other species (Raven and Johnson 1992). Such interactions are poorly understood, but experimental studies are beginning to resolve this complexity (Raven and Johnson 1992). It is not known if garlic mustard excretes toxic substances that may inhibit competition from native species. If garlic mustard was to demonstrate this biology, I would expect to see native species decrease in large quantities.

METHODS

The study area consisted of six permanent plots. Each of these plots are located in the visitor center area (Figure 1). Each plots was given a number x1, X2, X3, X4, X5, and X6 (Figure 2). sal Hollow trail and Buffalo trail were checked, but there was no sign of garlic mustard present (Figure 3). The campground (Figure 4) and the Sunset Lodges (Figure 5) were also included and garlic mustard was present in these areas. The areas with the main focus were Cave Island Nature Trail (Figure 6), and trails leading in and out of Dixon Cave (Figure 6).

Garlic mustard has been removed from six plots. Five permanent plots were selected for random samples. Two random 1m² quadrants were selected around the edges of the permanent plots. These plots were chosen to estimate a time length on approximately how many garlic mustard plants can be pulled in a one meter square quadrant. The plants were collected and counted, and the times taken to pull the plants were all recorded. These samples are also being used to help estimate how many labor hours will be needed to remove garlic mustard crop for a given year. Random quadrants were individually located with two random numbers given for each sample. One number selected a side of a permanent plot, and the other designated where along that side the quadrant should be sighted. Plot x1 (Figure 7) percent coverage for this years rosettes was 61-100%. The proportion of adults to rosettes was 0 to 2000 per 6m². Elapsed time to pull garlic mustard was six and three quarter hours. Time to pull two 1m² random plots, sample one #(1,2) 6 plants

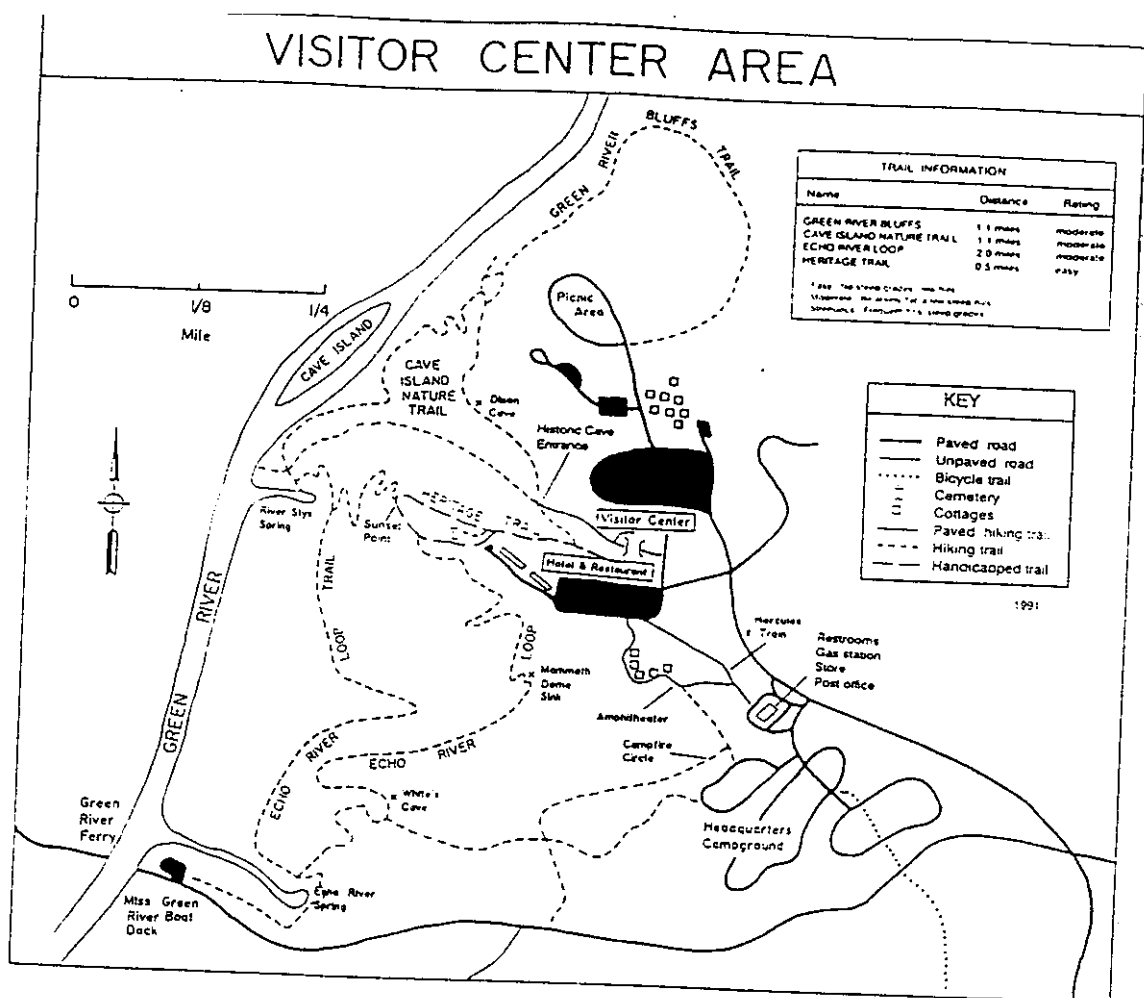


Figure 1. Visitor Center Area.

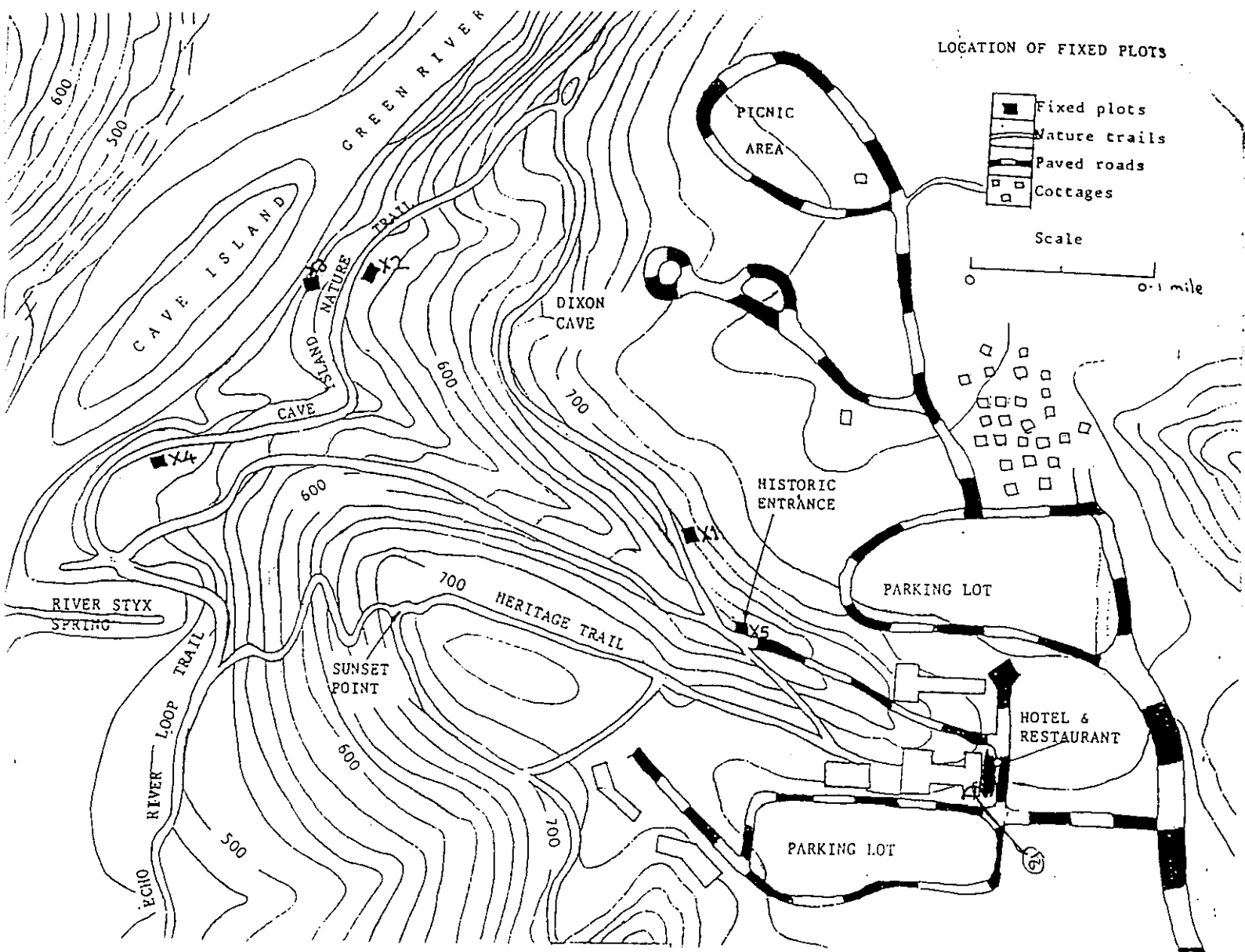


Figure 2. Permanent Plots.

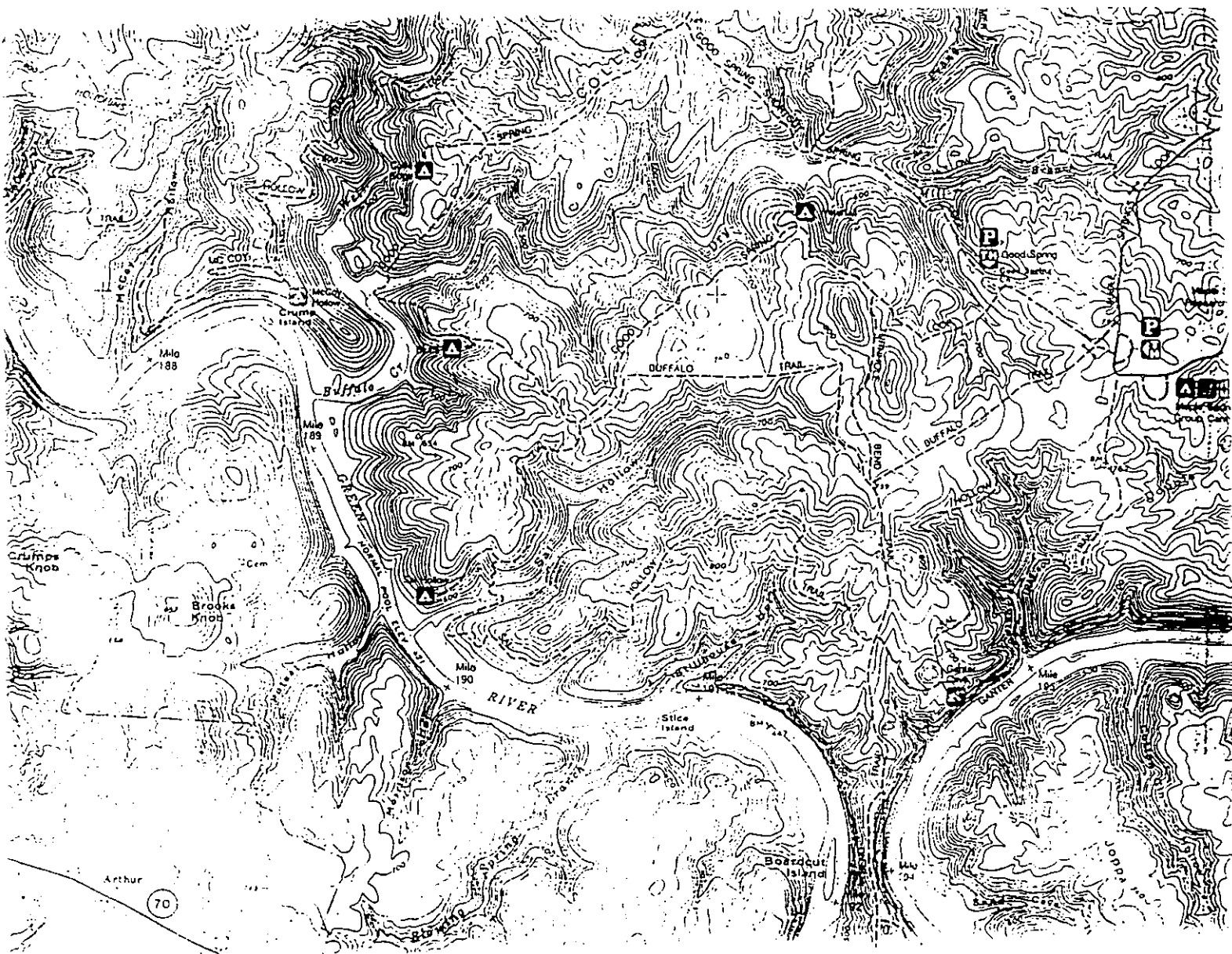


Figure 3. Sal Hollow and Buffalo Trails.

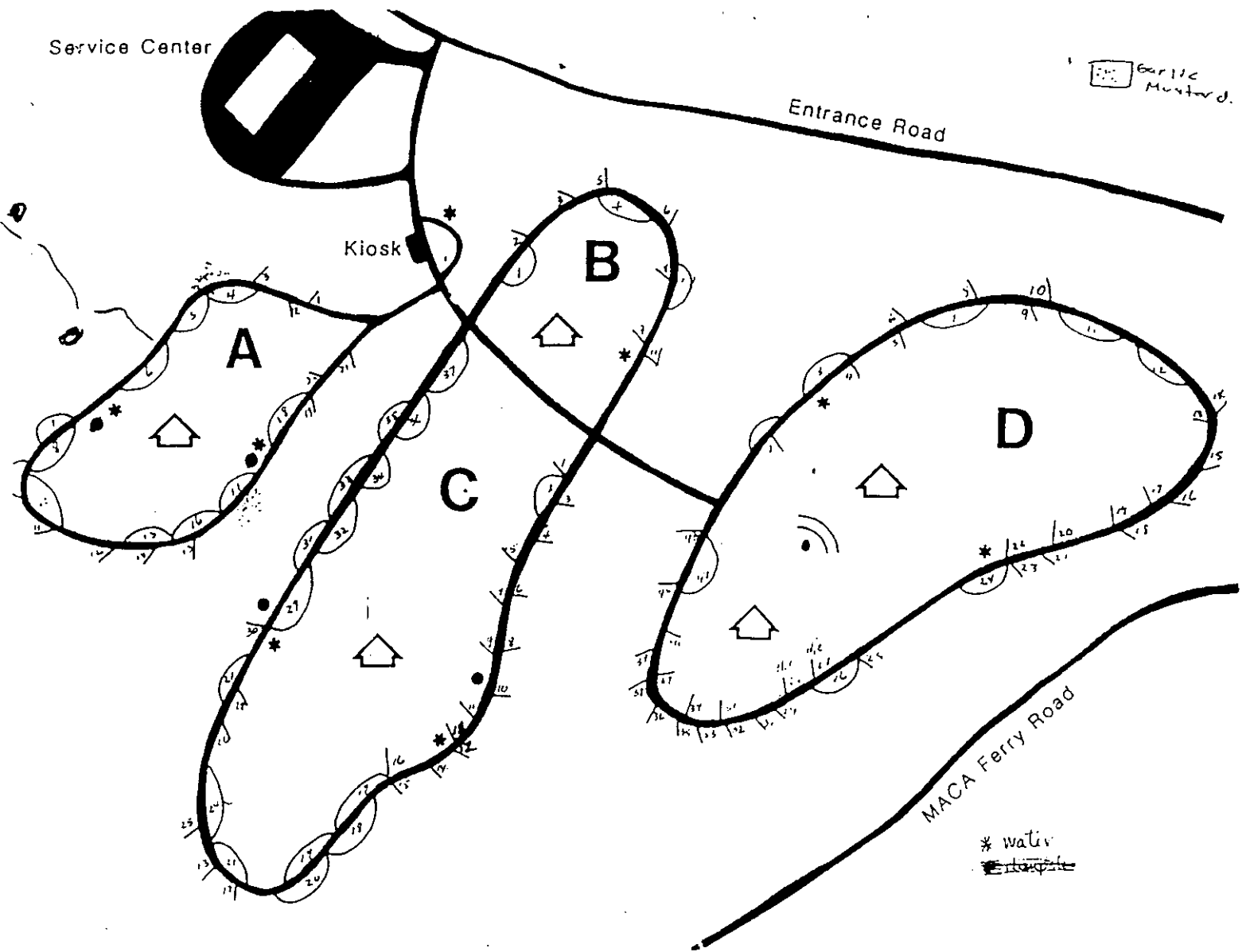
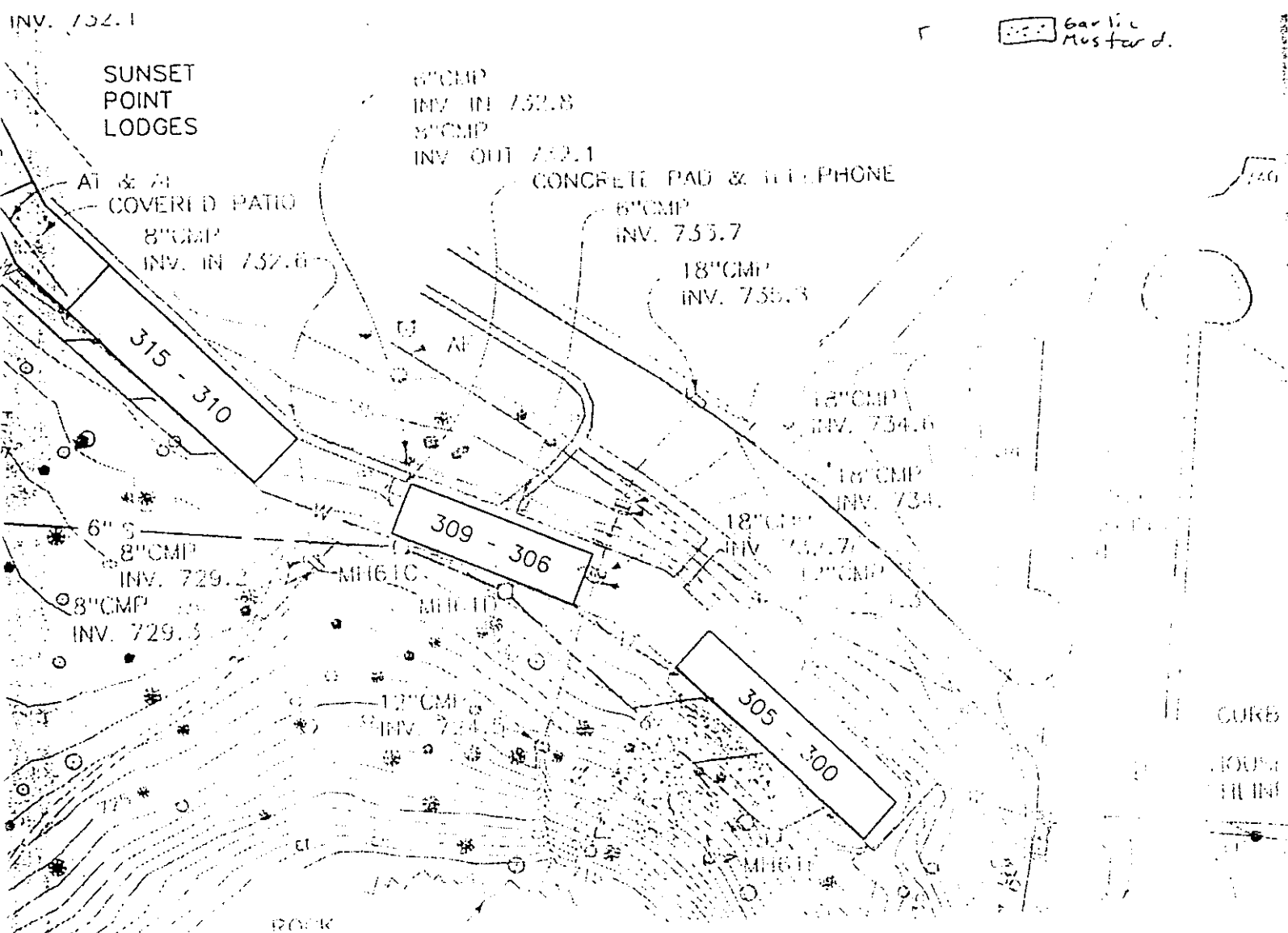


Figure 4. Campground.



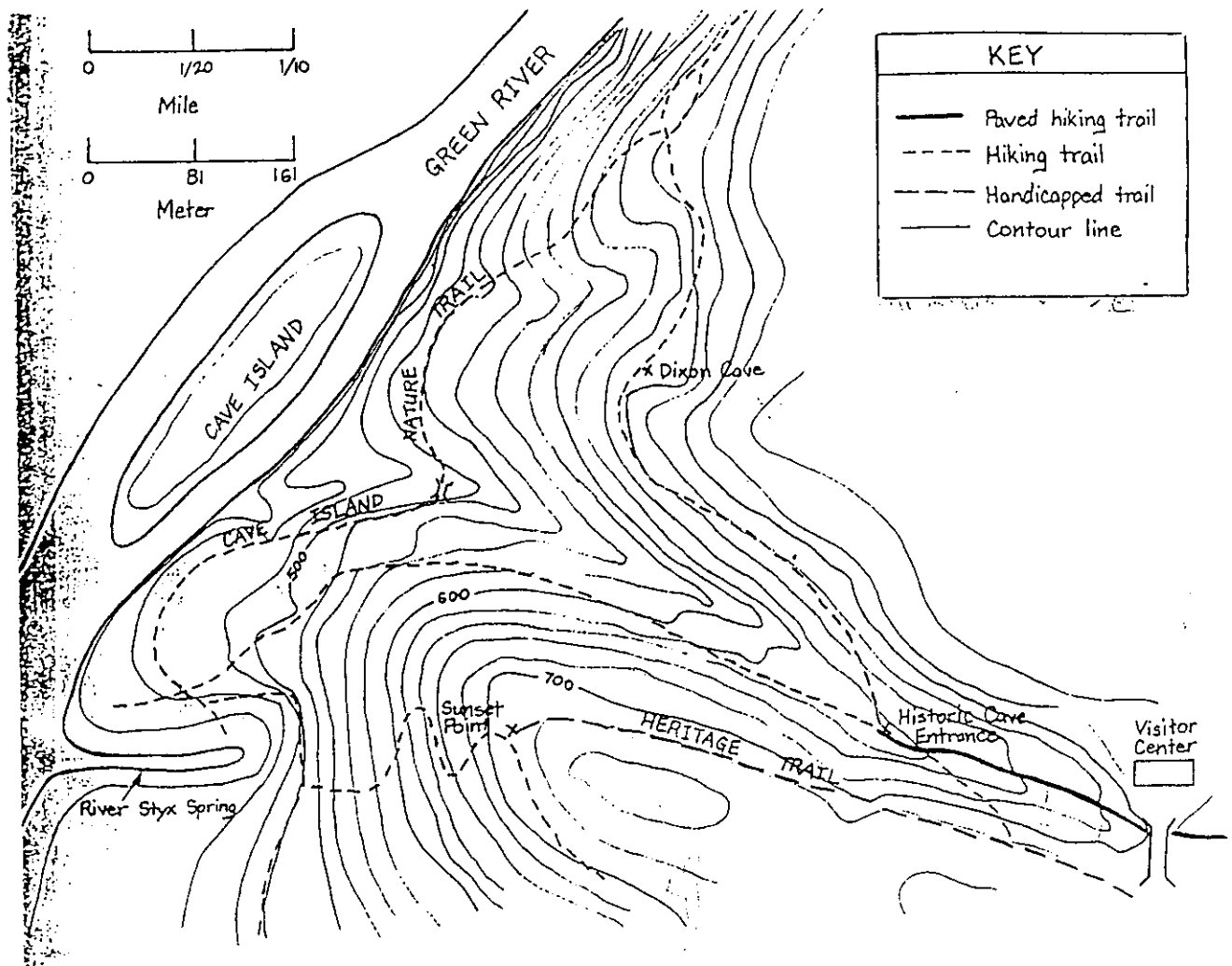


Figure 6. Cave Island Nature Trail and Dixon Cave Trail.

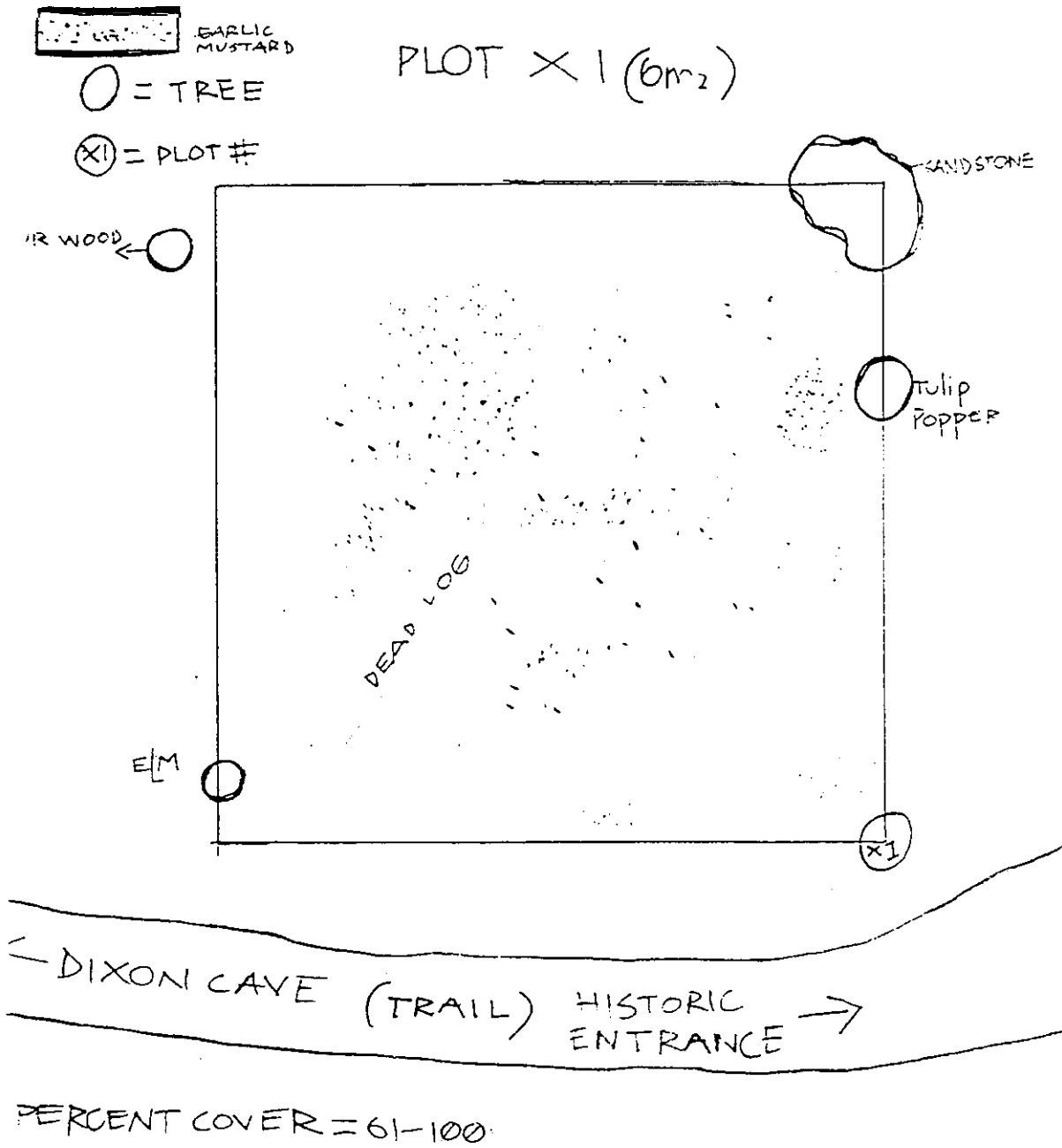


Figure 7. Permanent Plot X1.

pulled time 30 sec. Random sample two #(3,1) 0 plants pulled time 0 sec.

In plot X2 (Figure 8), there was a high percentage of garlic mustard and thus there was a visible impact on other native vegetation. The percent coverage was 61-100%, elapsed time to pull was five hours, and the ratio of adults to rosettes is 0:500-3000 per 5m². Time taken to pull random samples, sample one #(3,2) no plants present, and sample two #(4,4) 25 plants time to pull min 30 seconds.

Plot X3 (Figure 9), had a high percentage of garlic mustard. This impact is clearly visible few garlic mustard adults were present with, an infestation of rosettes a couple of bushes and two beech trees. Percent coverage was 61-100%, the ratio of adults to rosettes 0:500-3000 per 5m². Numbers and times for random plot samples, sample one #(1,2) 37 plants time to pull 5 min, sample two #(4,2) 392 plants time to pull 8 min.

Plot X4 (Figure 10), the percent coverage was 61-100%, and ratio of adults to rosettes 0:500-1000 per 5m². Random plot samples # (1,2) 11 rosettes time taken to pull them 25 sec, sample # (4,2) 40 rosettes time to taken to pull them 3 min 20 sec.

Plot X5 (Figure 11) was a large plot located around a gate to the side of the Historic Entrance stairs. The percent cover was 16-30% ratio of adults to rosettes was 1-700. Elapsed time to pull this plot was four hours.

☐: GARLIC MUSTARD

PERCENT COVER
61-100%

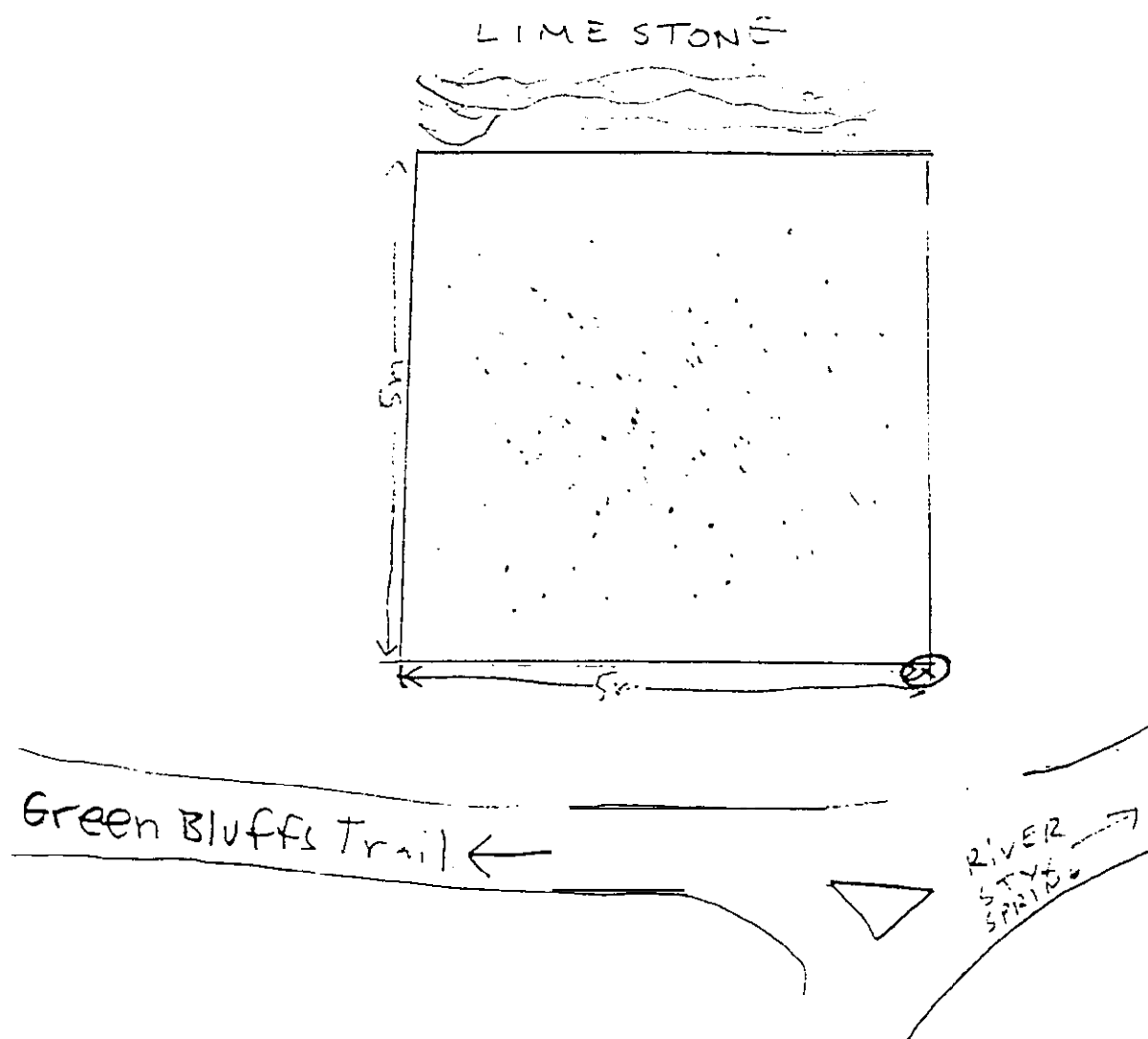
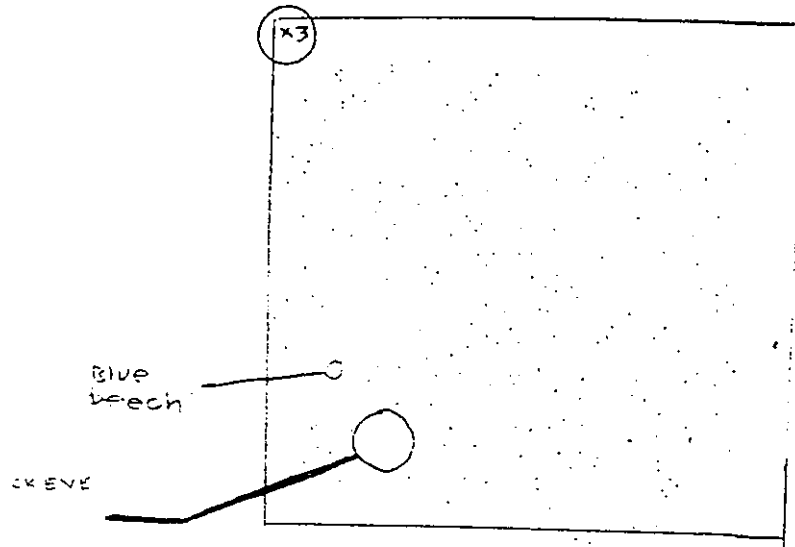


FIGURE 8

Figure 8. Permanent Plot X2.

Garlic Mustards
 % COVER = 61-100
 ratio .05 - .10

TRAIL



PLOT
 X3
 (5m²)

○ blue
 object

Figure 9. Permanent Plot X3.

PLOT, X4
(5m²)

PERCENT COVER = 31.6
24.105 0.4610

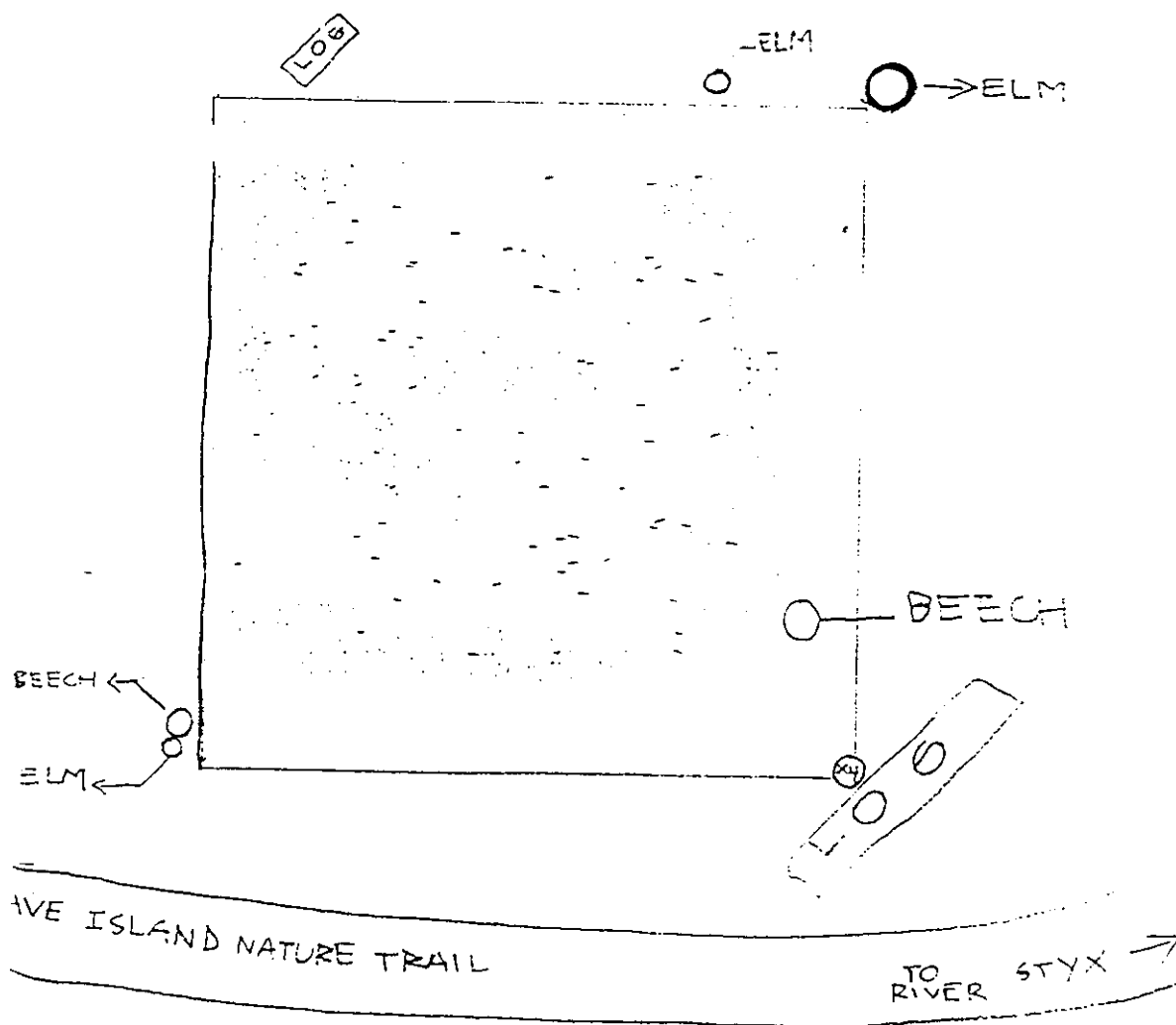


Figure 10. Permanent Plot X4.

- = TREE
- ▨ = FENCE
- ▧ = STAIRS
- = GARDEN
- = MUSTARD
- ✕ = MOUNTAIN GORILLA

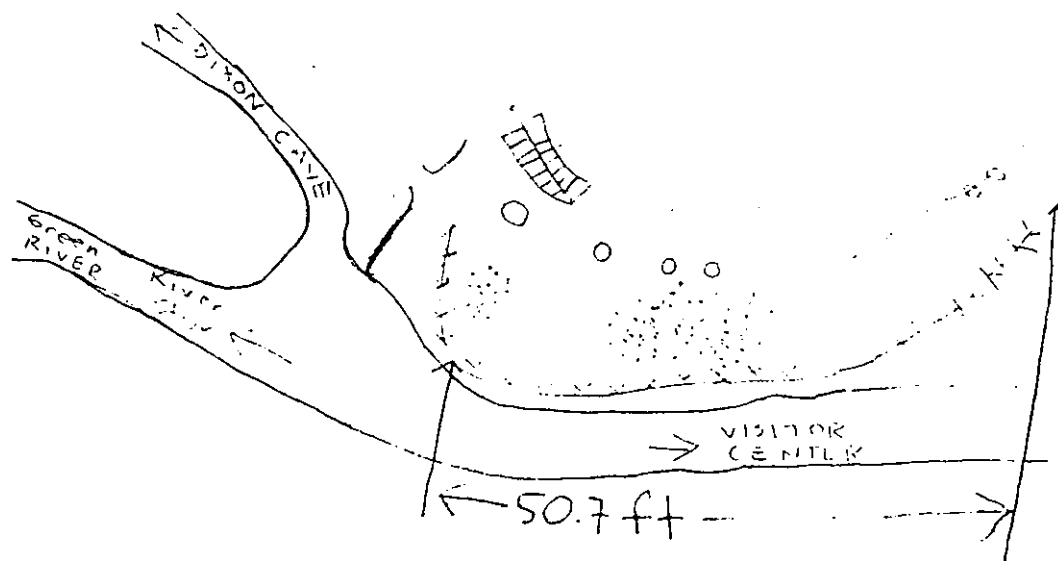


Figure 11. Permanent Plot X5.

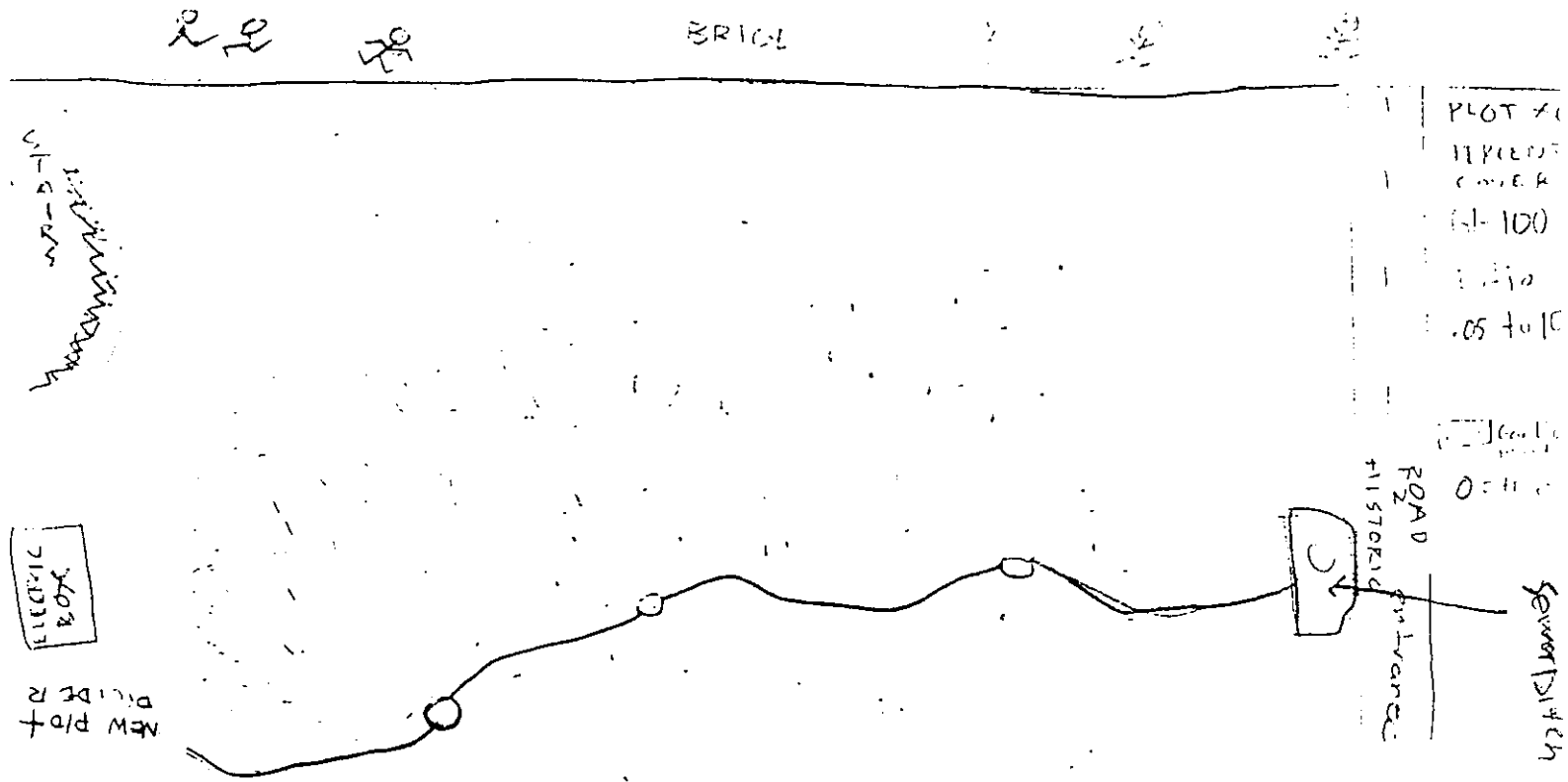


Figure 12. Permanent Plot X6.

leading in to the visitor center and into the hotel. The percent coverage for this plot was 16-30% and ratio of adults to rosettes was 1:1000. Numbers of rosettes pulled 5640 and time taken to pull the rosettes was five hours and twenty five minutes. This plot was reduced in size due to the size of the area and large quantity of rosettes. The second pulling numbers are 843 rosettes and time taken to pull the rosettes was two hours.

Random samples had to be retaken, the reason being that sample plots had previously been disturbed. Plot P1, time taken to remove rosettes was 9 min, number of rosettes pulled 581, the ratio of adults to rosettes 0:581, the percent cover was 61-100% and 74 plants growing in the 1m² quadrant.

Plot P2, the number of garlic mustard pulled, 204, percent coverage was 31-60%, the ratio of adults to rosettes was 0:204, time taken to pull was 9 min, and number of other species was 31 per 1m².

Plot P3, percent coverage was 61-100%, number of rosettes pulled 273, ratio of adults to rosettes was 0:273, time taken to pull was 7 min and number of other species was 66 per 1m².

Plot P4, number of rosettes pulled 203, the percent coverage was 31-60%, ratio of adults to rosettes was 0:203, time taken to pull garlic mustard was 6 min and number of other species was 117 per 1m².

Plot P5, 274 rosettes pulled, the percent coverage was 61-100%, the ratio of adults to rosettes was 0:274, time taken to

the plants was 5 min, and the number of other species present was 39 per 1m².

Plot P6, the percent coverage for this plot was 61-100%, number of plants pulled was 384, ratio of adults to rosettes was 0:384, time taken to pull the plants was 7 min, and number of other species present was 41 per 1m².

Plot P7, percent coverage for this plot 61-100%, number of rosettes pulled was 305, ratio of adults to rosettes was 0:305, time taken to pull was 5 min, and number of other species present was 49 per 1m².

DISCUSSION

The estimated results for the amount of labor needed to control garlic mustard in one growing season. The infestation of garlic at the present time is an average 150,000 m² and the average time to pull a 1m² is 8 min. Next step was to figure out the number of laborers needed to clear garlic mustard. Following step was multiply 8 min the average time to pull a 1m² times the estimated number of garlic mustard present 150,000 m² and ended up with a total of 1,200,000 minutes to pull a 150,000 m² infested area. Then the average time in minutes to remove garlic mustard was then converted into seven working hours. There are 470 minutes in seven hours and there are 525,600 min in a year. Thus times estimates in to 7.83 years for one person to pull a one 150,000 m². This number was then average out to eight people pulling garlic mustard 365 days a year. The estimate was then

converted to a three month period with thirty eight people working five days a week, with two fifteen min breaks, one half hour break each day, and two sick days leave. (Note this is an under estimate but this can help one provide information on how long it to take to control garlic mustard).

A small area of MCNP has been invaded by garlic mustard. Within the 30ha invaded, garlic mustard appears in very dense patches. This plant has a potential to overtake and modify existing native plant communities.

One possible method for controlling garlic mustard is herbicide application. This must be a process that is reapplied until the seed bank of garlic mustard is exhausted. This process can average any where from 5 to 9 years. Previous data indicates that "Herbicides may have a negative effect on native species since garlic mustard at M.C.N.P never occurs alone (Brown 1993:40). My observations show that this plant can occur alone in dense areas in the park, and also note that this plant grows well with this species of exotic grass "Africa". I observed garlic mustard camouflaged in between this exotic grass "Africa". This observation I feel is extremely helpful because in areas like this herbicide application will help clear two types of exotic species. Herbicide application can be efficient way of removing garlic mustard the problems that may arise are long term effects on native species and effects on water qualities.

Other methods of removal to be considered are hand pulling, cutting, and insect control. Hand pulling can an effective

removal method. Problems that may occur are the amounts of laborers needed can be excessive. Cutting the plant helps but the problem is getting people to manicure these plants year in and year out. Laborers should wear long sleeve shirt, jeans, or work pants, and something to sit on.

Another method of removal to be considered is insect control. "After an initial period in which prickly pear cacti (Opuntia), introduced from Latin America choked many of the pasture of Australia with their rampant growth, they were controlled by the introduction of a cactus feeding moth, Cactoblastis, from the areas where the cacti were native" (Raven and Johnson 1992). Knowing the plant biology in its native habitat can be useful information on how this plant can be controlled (Raven and Johnson 1992). Questions such as, do populations have a constant mortality rate throughout their life span, or do populations have high populations in early stages of growth and as stages progress do they decrease, increase, or reach equilibrium.

Long term control requires depleting existing seed bank reserves and preventing further seed production. The easiest most apparent way is to prevent the plant from seeding whether it is through the application of herbicide, pulling, cutting, etc. The choice of management tool is influenced by the size of the infestation and the type and quality of the natural community (Nuzzo 1991). Additional research needs to be done regarding the seed bank longevity. Previous literature states "Implementation

of active control should be delayed until late fall" (Nuzzo 1991).

Other recommendations for next year are to increase the size of the permanent plots. I feel that in order to increase data accuracy these plots need to be doubled in size. The permanent plots this year do not provide accurate information on how garlic mustard spreads. It is difficult to observe in what direction garlic mustard invades. The implement of bigger plots would in turn give a better understanding on how the plant spreads, also numbers of plants pulled need to be recorded. These numbers would assist future data collectors notice variations in the permanent plots.

There are signs of multiple invasion in some areas that could be a combination of highs in seed bank or seeds may not always germinate in the first year. My observations from this year would agree with last years data that "Garlic mustard does better in areas with less shade but is not restricted to it" (Brown 1993).

The present area invaded by garlic mustard I feel is small, yet the potential for impact is immense. The reason is that garlic mustard out competes native plants where it is established. The park is 52,830 acres in size and the present impact is 30ha. This would be an appropriate reason to start making management decisions and start controlling the spread of this pestilence species. The longer it takes to begin management, the greater the chance there is of spread.

Consequently it would in turn cost the park more money to control the plant with more time and labor. Garlic mustard must be taken with a serious approach, the plant will not linger for the park service to make management decisions.

I feel convinced that herbicide application would be the best method to control garlic mustard, yet I also feel that permanent plots should be implemented using the other methods of control (i.e. cutting/pulling). The reason for having the plots are to observe the various methods of removal, then deciding what method is best suited for controlling garlic mustard. These methods of removal all have there strong and weak points. The main focus would be their effect on native species, time, money, labor, and accuracy. That is why these methods first need to be tested in a controlled experiment. The data on effect to native species, accuracy, money, time, etc has to be the main focus of these controlled experiments. Experimentation should begin as soon as possible under the supervision of trained professionals.

Development of Hypotheses

The first step was to make observations, then form a hypotheses, predictions, and test for further observations, or from experiments (e.g permanent plots, random samples). The question under consideration is, how do garlic mustard seeds disperse?

Garlic mustard was observed growing on hill tops, and along ravines. It was hypothesized that garlic mustard spreads by

means of water wash down on hills or slopes, other alternative hypotheses are as follows.

Alternative Hypotheses

1. Wind, seeds popping out
2. Animals
3. Hikers
4. Water flowing on creek and water was down on hills or slopes.

Methods: visual, manipulative, permanent plots and natural experiments.

Alternate #1

The experiment that was completed to determine if garlic mustard is disperse by means of wind, the experiment was also used to determine seed dispersal through seeds popping out. This experiment was conducted at a randomly located site where garlic mustard was present. First my partner and I laid a piece of plastic beneath an adult garlic mustard plant. The plastic measured 5' by 3' and directly in the center of the plastic was located an adult garlic mustard plant. This experiment was done to help me understand how garlic mustard seeds disperse.

Alternate #1 wind dispersal I feel is not one of the methods of garlic mustard seeds being dispersed. Previous data indicates clearly that the seeds have a low wind dispersal (Cavers et al. 1979). From the results of my natural experiment I would agree with this information. Seeds popping out, seeds do not pop out

they fall down. Once the plant has set seed the plant then dies, when this takes place the plant falls thus dropping the seeds on the ground, the seeds have been dispersed, with no real popping out effect. Experimental results for alternate #1 showed that some garlic mustard seeds fell when the plant was still living others fell when the plant had died. This concluded that garlic mustard seeds do not disperse by wind. The seeds once dispersed covered anywhere from 1" to 5' and thus concluding that seeds don't really pop out they usually fall down. "Seeds are basically dispelled from a linear sileque for a distance of several meters", "Seeds have low wind dispersal" (Cavers et. al). Long Distance dispersal and distribution are unclear (Lhotska 1975).

My predictions for hypotheses #1 are that wind dispersal is not a major means of seed dispersal. I will predict that the wind has a very minimal effect on where the seed is placed. Therefore I feel that seeds will sprout within a few feet from where the plant is located. Results from my experiment showed no sign of wind dispersal, thus agreeing with the previously stated idea that garlic mustard seeds have "low wind dispersal".

Alternate#2

There has not been adequate experimentation done to determine if garlic mustard seeds are dispersed by animals. One could suspect animals such as deer could kick the seeds or tilt

the plant causing dispersal. Not much is known about animals dietary habits concerning the spread of garlic mustard seeds, but if ingestion and excretion of feces were an important dispersal mechanism, then I would expect to see garlic mustard appearing in more remote areas.

Alternate #2 I feel is in the small percentage category of seed dispersal. Not much research has been done to actually understand what impact animals have on spreading garlic mustard seeds. One could only suspect the seeds might be dispersed by animals.

Alternate #3

One dominant question about alternate #3 is, do humans transport garlic mustard seeds via mud on shoes or stuck anywhere on clothing. One observation that might help in answering this complexity, was when I noticed a rosette growing along a trash can at seasonal housing. This is an area not known to have garlic mustard, I can only suspect that this seed was dispersed by a human. If garlic mustard seeds are to be dispersed by humans I would expect to see plants growing in new undisturbed areas.

I feel that alternate #3 is in the low risk category of seeds dispersal. The chances of humans spreading the seeds is small, but if humans or animals happen to spread the seeds I feel that undisturbed areas are in danger. Garlic mustard to this date

has only been mapped in the visitor center area. If the seeds are dispersed some where else in the park the possibilities are that it would infest a larger area before actually being identified as an invader. Furthermore I feel this is the least probable means of seed dispersal yet can be the most harmful if the seed is dispersed by this method.

Predictions for alternates hypotheses #2,3 area as follows. I feel that animals and humans may have an important influence in exposing seeds to the soil but not much is know on the effect of exposing seeds to soil surface. Earlier speculations states that this type of soil disturbance may be an important factor in the invasion and spread of garlic mustard (Nuzzo 1991). I would tend to agree with this information but be uncertain on the actual impact that humans or animals actually have. Not much is know about the actual impact humans and animals have, one can only speculate that this is a factor, in the dispersal of garlic mustard seeds. I would agree with previous data that states that garlic mustard can "Get stuck on mud on shoes and also on pant cuffs"(Hoong pers obs. 1993). If this were to be one of the main sources of invasion I would predict that dispersal of garlic mustard seeds will happen in new undisturbed areas.

For alternate \$4, I experimented on how seeds flow in running water. First I placed a garlic mustard seed in a flowing creek and noticed that it floated for a quick second and suddenly just struck the ground. Once the seed had struck the ground if the current was strong enough it would then wash the seed away.

I also placed a silique in flowing water and noticed the same effect. One difference was that the silique has a good chance of getting stuck between a rock. This influenced me to believe that garlic mustard is spread by water from the frequent rain in Kentucky, which receives 50 inches of precipitation annually.

Water wash down from slopes, hills or ravines would be the best means of seed dispersal. If this was to be true I would suspect that garlic mustard seeds would be washed down from rain or water flowing downwards. What I noticed while working on the permanent plots was that garlic mustard germinates in dense patches on top of slopes, hills, etc. As you look down a slope or ridge you can see the plant slowly spreading down hill.

In addition water flowing in a creek can be one of the major means of garlic mustard spreading in new areas, along creeks seeds can be washed away anywhere from a couple of inches to several meters. Personal observations are, garlic mustard can be found growing on rocks along creeks and all along the ravines in the visitor center area at MCNP.

My predictions for alternates #4 are that, if water were to disperse the seeds, then there would be garlic mustard growing along hill tops and expand downwards. I would also predict that garlic mustard will increase to grow along rocks, ravines, creeks, and continue to spread as water flows. I would assume that is the main source for the plants rapid spread.

CONCLUSION

Recent results show that garlic mustard is spreading in new areas in the park. Through personal observations I believe that garlic mustard is a highly invasive plant. The plant produces anywhere from one to eight hundred seeds, easily out competing native species. Furthermore garlic mustard abundance was more dense this year than last year in plotted areas. The dominant conclusion at this point is that, garlic mustard, when measured by the number of rosettes from this year and last year are directly corresponding with biology of a biennial plant. One clear result was the number of adults last year versus the number of rosettes this year. The garlic mustard plants from last year were mostly all adult, thus seeding, and then dying. This year's garlic mustard plants are mainly rosettes showing no signs of shedding seeds.

Garlic mustard needs active management if there is to be any hope of stopping the population from increasing dramatically. The impact of this pest and other factors affecting the population must be analyzed. Native species need protection in areas that remain undisturbed. Immediate plans should be designed and implemented to survey all disturbed areas. Professional biologists and ecologists should be present and involved to assist in gathering information on the status of this ambiguous species. Volunteers, staff, and biologist need to be involved in deciding what method of removal is best suited for the situation!

My recommendation of removal would be herbicide application. The reason being I feel it is less expensive, there is less labor that is needed and it is extremely effective. One would think pulling plants would have less impact on native species, but when you are pulling garlic mustard plants you tend to step on other species consequently killing other plants. In addition chances are that people might fail to remove a few plants and also not remove the entire root system, leaving possibilities for future regrowth. biennial.

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