WATERCHESTNUT (<u>TRAPA NATANS</u> L.) RESEARCH IN WATERVLIET RESERVOIR - 1989 REPORT

prepared for the
City of Watervliet

by

John D. Madsen, Ph.D.
Research Scientist

Rensselaer Fresh Water Institute
Rensselaer Polytechnic Institute
Troy, NY 12180-3590

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INTRODUCTION

Waterchestnut (Trapa natans L.) is an exotic plant first introduced to North America from Asia in the late 1800's. Waterchestnut overwinters completely by seeds, being a true annual. Growth from this seed is rapid, with the plant establishing a floating rosette of leaves by early summer. By mid-summer, the rosettes may form several flowers in succession, with the first fruits ripening by late summer. Flowering and seed production will continue into the fall, until a hard frost kills the floating rosette.

Waterchestnut was first introduced to Collins Lake in Schenectady County in 1884 (Wibbe, 1886; Smith, 1955). It spread from there to nearby Mohawk River, the Hudson River, and Champlain Barge canal. By 1952, it was known to be in Keuka Lake and Lake Champlain. Additional locations with Waterchestnut in North America included Vermont, Maryland, Virginia, and Massachusetts (Steenis and Stotts, 1963; Burk et al., 1976). Problem growths have been predominantly in the Hudson-Mohawk River, Lake Champlain, and the Potomac River (Steenis and Stotts, 1963; Elser, 1966). Vigorous control programs have been largely successful in the Potomac River, but nuisance problems still exist on the Hudson-Mohawk River and Lake Champlain.

New York State had a vigorous eradication program in the Hudson-Mohawk region, heavily dependent on the use of herbicides, during the period (Smith, 1955; Greeley and Steenis, 1959). This program had been almost completely successful in eliminating the plant (Greeley, 1965). However, budget cuts in the 1970's eliminated the program. During the late 1970's and early 1980's, Waterchestnut has become reestablished and grown to nuisance proportions in many localities along the Hudson-Mohawk River system. This cautionary tale points out the necessity of maintaining a long-term management effort, even after it appears that control has been largely successful. A small investment in monitoring and low-technology control of limited numbers of plants will ensure that a costly control program will not need to be reinstated.

As mentioned previously, Waterchestnut is an annual. Therefore, the key point of the life cycle to attack for effective control is prevention of fertile seed formation. In essence, cutting, harvesting, or herbicide use is only useful in relation to preventing or reducing seed production. As might be expected of an annual, Waterchestnut is capable of both cross- and self-pollination, as well as being apomictic. Pollination by insect vectors is only incidental, with most flowers being self-pollinated (Kadono and Schneider, 1986). This ensures that the maximum number of seeds will be pollinated.

Previous studies have indicated that up to twenty seeds may be produced per rosette (Elser, 1965), and that individual seeds may remain viable up to twelve years (Winne, 1935; cited in Winner, 1987). Winner (1987) states that mature seeds are negatively buoyant.

Seasonal growth of Waterchestnut typically begins in late April or early May in temperate Japan, with a peak in growth in late June or early July (Sastroutomo, 1980; Tsuchiya and Iwaki, 1983). Floating rosettes are active until late September or early October, or whenever frost is sufficient to kill the floating rosettes. Although peak biomass was estimated to be 300 g m^{-2}, total production was 1010 g m^{-2} y^{-1}, for a turnover rate (P/B) of 3.4 (Tsuchiya and Iwaki, 1983). This extremely high turnover rate results in increased decomposition and nutrient release to the water column, significantly reducing water quality. In addition, the Waterchestnut creates a stagnant water environment which greatly increases the water temperature within the stand, facilitating further decomposition and oxygen reductions (Juget and Rostan, 1973). Oxygen depletion or even anoxia are not uncommon under dense Waterchestnut stands. These conditions allow phosphorus release from sediments, exacerbating water quality problems and encouraging the growth of dense algae (Seki et al., 1979).

Although Waterchestnut has a decidedly negative impact on native plant populations, and has a generally deleterious effect on water quality, it is not all bad. Studies by Schmidt and Kiviat (1988) indicate that it is an excellent habitat for small fish and insects, which are crucial food items for gamefish.

One final impact to consider is the impact Waterchestnut may have on water quantity. Studies of evapotranspiration in floating-leaved and emergent plants have indicated that high biomass of floating-leaved plants may increase evapotranspiration as compared to open water, while low-growing forms may actually reduce evapotranspirational losses (Idso and Anderson, 1988). Results from a small amount of data indicated that Waterchestnut reduced evapotranspiration as compared to open water, but this reduction may not have been statistically significant (Brezny et al., 1973). The trade-off lies in the difference between not exposing the water's surface directly to wind, versus increasing the surface area for evaporation through the many leaves in the canopy.

Previous control attempts have largely abandoned traditional plant harvesting for Waterchestnut control (Elser, 1965), although New York and Vermont have maintained a harvesting program on Lake Champlain (Countryman, 1977). Recent efforts at the Watervliet Reservoir (or French's Mills Reservoir) show indications of potential success by abandoning the very slow aquatic harvesters in favor of high-speed cutting using an airboat. This project was undertaken to evaluate the effectiveness of cutting efforts, as well as gather basic information on the Waterchestnut population in Watervliet Reservoir.

Fresh Water Institute participation in this study included the following (indicated in the proposal dated April 24, 1989):

Sampling Seeds in the Sediment. One key element in the eventual control of Waterchestnut is to eliminate all of the seeds retained in the seed bank. The "seed bank" is the stored accumulation of dormant, viable seeds in the sediment. Depending on environmental conditions, they may germinate rapidly (the next season), or may remain dormant for several years.

The number of viable seeds in the seed bank was examined using sediment cores.

Seed Fall. In addition to the contribution of the seed bank to Waterchestnut population dynamics, the recruitment of new seeds each year is important. Seed production can be highly variable from one year to the next. A proper assessment of the number of seeds produced by Waterchestnut populations will help to evaluate annual seed production, or recruitment to the seed bank, and help to estimate how long seeds remain in the seed bank. This knowledge will aid in estimating when control can be expected by persistent efforts.

Seed fall was estimated by placing wire-mesh baskets in the reservoir, under stands of Waterchestnut.

Fragment Growth and Propagation. The current cutting operation does not remove cut plant fragments from the lake.

One point of concern is whether or not these fragments can flower and produce seeds, or reestablish elsewhere in the reservoir. If propagation from these fragments were to be significant, then the expense and effort of fragment removal would not only be worthwhile, but necessary for effective management. If propagation from fragments was not significant, then fragment removal (at least relating strictly to plant propagation) would be an unnecessary expense and effort which might directly compete with efforts at cutting.

Fragment propagation, flowering and seed set was examined using both field and laboratory experiments.

Seed Germination. Since Waterchestnut is an annual, the seed stage is critical in terms of initiating annual growth and setting phenological patterns. The initiation of seed germination in essence determines when Waterchestnut will appear in the lake. Environmental factors, such as light, daylength, and temperature, are typically important in determining seed germination of other aquatic species (Hartleb et al., 1990; Madsen and Boylen, 1988). The effect of daylength, light, and temperature will be examined as factors controlling the germination of Waterchestnut seeds. This portion of the project was not accomplished as of the writing of this report, as discussed below.

METHODS

Study Site. All samples and experiments were performed at the Watervliet Reservoir located in the Town of Guilderland, Albany County (Figure 1). Sample sites are indicated for each of the individual studies.

Watervliet Reservoir is a water supply reservoir for the City of Watervliet, and provides drinking water for the cities of Guilderland and Watervliet. Routine monitoring of water quality and quantity is performed as required by NYS DOH standards. The reservoir was formed by a dam across the Normanskill River. Samples taken in December of 1988 indicate a pH of 7.7 and alkalinity of 76 mg/l as $CaCO_3$ (City of Watervliet, unpubl.).

Sediment Seed Bank. The sediment seed bank was sampled using a 7.6 cm i.d. plexiglass tube approximately 60 cm in length which could be closed at both ends using a rubber stopper. In order to obtain a sediment core sample, a diver would insert the unstopped tube (corer) into the sediment until the dense clay layer was encountered, then stopper the upper (exposed) end. This created sufficient "vacuum" to extract the contents of the core without loosing seeds. The bottom of the corer was then stoppered, and the core returned to the boat. All seeds were removed from the cores by washing the contents, and the seeds counted, dried, and weighed. In the first sampling (June), seeds were subsampled for viability. In the second sampling, all seeds were sampled for viability. Seeds were considered viable if they contained an intact endosperm. Nonviable seeds typically were empty.

Cores were taken at two locations in the lake, corresponding to a "control" area in which cutting was not performed, and a "treatment" area in which cutting of Waterchestnut was performed (Figure 1). At each location, twenty cores were sampled during two time periods: the first sampling after seed germination, to sample for dormant seeds (June 27, 1989) and after the senescence of rosettes, to count seed production for that year (November 8, 1989).

Seed Fall. The annual production of seeds was also examined by directly measuring seed fall under the canopy of Waterchestnut rosettes. For this procedure, forty seed fall collectors were constructed out of wire mesh with dimensions of 30 cm by 60 cm. Twenty seed fall collectors were placed in the control area, with surface floats marking their location. Twenty seed fall collectors were also placed in the treatment area, with a subsurface float placed 60 cm under the water's surface, as well as being grouped according to triangulated shoreline references. The seed fall collectors were placed on June 27, 1989.

Seed fall collectors were retrieved on November 8, 1989. Sixteen of the twenty control collectors were successfully retrieved. The other collectors were lost either because the marker broke off of the anchor line, or some markers having lost buoyancy or pulled just under the surface were not seen. Two of the lost marker bottles were retrieved

None of the seed fall collectors were found in the treatment area. Either water levels had risen significantly, making retrieval difficult in the turbid waters, or subsurface floats were lost or knocked off during control efforts. Visits to our triangulated locations did not assist in retrieval.

Fragment Growth and Propagation. Fragment growth and propagation was analyzed using two experiments, one in the laboratory and the other in the field.

Laboratory Fragment Experiment. Fragment growth and propagation was examined in a laboratory setting to provide a secure and controlled environment for fragment growth. Ten fragments made by cutting activities were placed in an aquarium with laboratory tap water, with this design replicated using ten aquaria for a total of one hundred fragments tested. Water levels were checked twice per week, with water replaced weekly to one-half the volume of the tank. Environmental conditions for growth were 20 C, with 400 uE m^{-2} s^{-1} of light provided on a 14 hr light : 10 hr dark cycle, as is typical of daylength during the summer.

The number of fragments with roots, flowers and seeds were counted each week from the beginning of the experiment (June 28, 1989) to the end of the experiment (July 26, 1989), a total of four weeks.

Field Fragment Experiment. The growth and propagation of fragments in the field were studied using fragment enclosures. The enclosures were made with 1 cm mesh netting over a wooden frame, with mesh on all four sides and the bottom. The dimensions of the enclosures were 45 cm wide by 90 cm long, with a height of 60 cm. Posts at the four corners of the enclosure extended 60 cm down, anchoring the enclosure into the sediments. Ten enclosures were paced near the boat launching and storage area on Watervliet Reservoir, beginning on June 26, 1989. The enclosures remained in place until the end of the experiment.

Ten fragments created through the cutting of Waterchestnut rosettes were used in this experiment to populate each of the ten enclosures, for a total number of 100 fragments examined. Fifty fragments were also measured for initial size, to compare before and after characteristics of the fragments. Parameters measured included rosette diameter, number of floating leaves, stem length, number of seeds, number of flowers, dry weight of fragment, and number of roots. These same parameters were also measured on the enclosure fragments after the course of the experiment.

The enclosure experiment was initiated on July 6, 1989 and extended until August 17, 1989, for a total of 42 days. Biweekly during the course of the experiment, the enclosures were visited to examine the health of the fragments and to record the number of fragments in each enclosure possessing roots, leaves, flowers and seeds.

Flowering and Seed Set. Although not a component of the agreed contract, the phenology of flowering and seed set was examined on an approximately monthly basis from June through September. Twenty rosettes were taken from the Highway 20 site, and other sites on an irregular basis, during these times (Figure 1). The number of flowers, flower buds, pollinated flowers, and seeds were counted for each rosette. These data will be helpful in determining the potential number of seeds set per rosette, and in following the course of seed set in Waterchestnut.

Seed Germination. Initial plans for this experiment were to use ungerminated seeds collected from the reservoir or in core samples obtained in the first sampling trip in order to begin the experiment during the summer. However, sampling began too late in the year to gather ungerminated seeds from the lake, seeds collected from the lake surface proved to be largely nonviable, and core samples did not provide viable seeds during the first sample.

Because of this, seeds were collected directly from rosettes in late September to perform this experiment. These seeds, although largely viable, have proven to be difficult to germinate. Techniques to promote germination are still being examined. If these seeds are not germinable, other seeds will be collected soon after ice-out from the reservoir to perform this experiment. Therefore, a report on the results of this experiment are not possible, but the experiment will be pursued until completed. A report on this project alone will be submitted after completion.

RESULTS AND DISCUSSION

Sediment Seed Bank. The results of this project are important both to the effectiveness of treatment by cutting, and to an understanding of the Waterchestnut seed bank.

On June 27, cores were collected from both the treatment and control areas. In addition, a large number of floating seeds were collected that had been dislodged while working, in the hopes that these would be viable and suitable for seed germination studies. Initial counts of seeds indicated astounding total numbers of seeds. Total seed counts for June 27 revealed an average of 289 seeds m^{-2} for the control area, and an average of 166 seeds m^{-2} for the treatment area. However, the bulk of these seeds proved to be empty husks, the remainder of the nut after germination in previous years. Analyses of subsamples from the June 27 sampling showed that only 4% of seeds were viable, yielding estimates of 12 seeds m^{-2} in the control and 7 seeds m^{-2} in the treatment areas (Figure 3). Note that these estimates are after the given years' cohort has germinated, so this represents the number of dormant seeds waiting to germinate in subsequent years.

Samples taken after the growing season ended (November 8) also show high total numbers of seeds present in the sediments. An average total of 253 seeds m^{-2} were observed in the control area, and an average of 189 seeds m^{-2} in the treatment area. Once more, the bulk of these seeds were empty and thus nonviable. Only 12% of the seeds in the control area were viable, while 3% in the treatment area were viable. Therefore, the average total viable seed count in the sediments at the end of the growing season were 19 seeds m^{-2} for the control area, and 0 seeds m^{-2} (in actuality, -1.4 seeds m^{-2}; or loss of 1.4 seeds m^{-2} from the seed bank in the treatment area). The results of this experiment are significant in two ways. First, the coring method predicts that the Waterchestnut population is producing on average 19 seeds m^{-2} directly below the canopy for continued propagation (e.g., recruitment). Second, treatment by cutting proved to be very effective in reducing seed production, with no additional seeds recruited to the seed bank in a given year. In fact, apparently an average of 1.4 seeds per square meter were actually lost. Continued sampling of this type may be adequate to both quantify impacts and effectiveness of cutting, and monitor the seed bank in given areas of the reservoir. Mechanisms for this loss might include transport, or migration, through water movement and seed mortality.

The above experiments also provided information on seed characteristics. First, none of the floating seeds sampled were viable; all were the nut husks of past germinated seeds. Therefore, floating seeds are not a source of concern. Seeds from floating grab samples were significantly lighter than those from core samples (Figure 4) that sank, but were not different in weight from the core sample seeds that floated. Typically, viable seeds weighed more than 1.5 grams, while empty husks weighed less than 1 gram.

A subsample of 100 seeds from sediment cores were examined for buoyancy and dry weight, as well as viability. Of these seeds, 8 percent were viable and 92 % were empty. Of these seeds, nearly seventy percent sank, while slightly more than 20% floated (Figure 5). All of the floating seeds were not viable, and the majority of the sinking seed were also not viable. The nonviable seeds were consistently less than 1 g dry weight, while the viable seeds averaged 2.5 g dry wt. (Figure 6). Therefore, weight rather than buoyancy is a good indicator of viability. Floating seeds are almost certainly nonviable, while sinking seeds might be either nonviable or viable.

Seed Fall. Seed fall data is only available for the control area, as indicated in the Methods section. As with seed core results, the bulk of the average of 227 seeds m^{-2} found in the seed fall collectors were not viable (92%; Figure 2). The bulk of these nonviable seeds undoubtedly drifted and settled into the baskets. The empty husks are readily transported by wave action or other disturbances. The 19.7 viable seeds m^{-2} found for the seed production at the control site from seed fall collectors coincides almost exactly with the amount of seed production in this area as calculated from seed cores (above; Figure 3).

Seed fall collectors are therefore an appropriate method to estimate seed production by Waterchestnut, especially in control or non-treated areas, but are not useful for testing the effectiveness of cutting techniques, as a surface float is necessary to find and retrieve them.

Laboratory Fragment Growth Experiment. The laboratory fragment experiment failed to demonstrate whether or not fragments could flower and set seed, due to an unforeseen but interesting complication. Fragments transplanted to laboratory tanks soon developed their own insect community, dominated by herbivorous chrysomelid beetle larvae and adults, with some predatory small waterstriders. The predatory insects could not maintain any control of the herbivorous beetle populations, which increased dramatically. Within three weeks of the beginning of this experiment, the beetles ate all of the Waterchestnut floating leaves. By four weeks, the survival of fragments was decreasing, and the experiment was discontinued (Figure 7).

Dr. Smith of our Institute has identified these insects as the chrysomelid beetle *Pyrrhalta nymphaea*, the water lily beetle, which feeds on Waterchestnut, Water lily (*Nymphaea* sp.), Purple Loosestrife (*Lythrum salicaria*), and has also been seen on Cattail (*Typha* sp.). This laboratory study supports other observations that this chrysomelid beetle may be a potential biological control for Waterchestnut, a topic on which further work should be done. At least in this laboratory study, complete removal of leaf material must have prevented flower formation and ultimate seed set.

Field Fragment Experiment. The field fragment experiment was a partial success. The fragments placed in enclosures rapidly developed adventitious roots (Figure 8, top). A steady mortality rate was evident among the rosettes placed in the enclosures. Although this may in part be due to mechanical damage and subsequent infection by fungi, the contributing factor to this was that the site selected, next to the boat launch, for placement of the enclosures was shaded from midday sunlight and protected from water movement. The result was an extremely dense growth of water meal (Wolffia sp.), which shaded out many of the smaller Waterchestnut rosettes. Therefore, this experiment should repeated this year, placing the enclosures in a more open area without shade.

A maximum of 4% of the rosettes produced flowers, and only 3 percent produced seeds (Figure 8, bottom). These seeds were not mature before the end of the experiment. These results would tend to indicate that fragments produce few, if any, seeds, and the risk involved of further seed production from unharvested cut fragments is probably not worth the cost of an extensive program of mechanical fragment removal. However, other aesthetic and management reasons might indicate removal. As mentioned above, light deprivation alone accounts for some reduction in flowering and seed set (see below).

Other quantitative parameters from the beginning to the end of the fragment growth experiment can be examined (Figure 9). The average diameter of rosettes dropped dramatically, due largely to the loss of floating leaves. Rosette dry weight increased from an initial average weight of .16 g to .47 g, largely through the increase in the size of the central stem. The central stem elongated slightly, from an initial length of 25 cm to 37 cm. Lastly, only .016 seeds per rosette were formed, or approximately 2 percent of rosettes having seeds at the end of the experiment.

Flowering and Seed Set. Although only three samples were taken to examine the number of flower buds, flowers, pollinated flowers and developed seeds per rosette, some interesting results have already been obtained (Figure 10). Observations in early July did not reveal any flowers, but flower buds may have been present. Averages for the Route 20 site are displayed for the three dates in question, showing that in general a constant number of buds and flowers are present per rosette, namely 2. However, the regular increase in the number of pollinated flowers and seeds indicates that a consistent rate of development in flower and seed production is operating over most of the growing season. Also, the rate of flower development and pollination is more rapid than the maturation of seeds. By the end of October, the average rosette may only produce 6 to 8 seeds, while by mid-September an average of 13 flowers have already been pollinated. However, seeds undoubtedly mature and then fall off before the end of the growing season, so the actual rate of seed production may be larger. At a minimum, the average rosette has the potential to produce almost 18 seeds, with adequate numbers of buds and flowers in place to produce 22.

The implications of this to the management of Waterchestnut is enormous. The common wisdom has been to attempt control until seeds start to appear, and then control efforts should cease. This could not be farther from the truth. Seeds will continually be produced from mid-August until the end of September or later, depending on heavy frost. Continued cutting will prevent additional seeds from being produced. Pollinated flowers must take at least four weeks to produce a mature seed. Cutting of rosette will prevent these seeds from maturing. Reducing the average number of seeds produced per rosette from 10 to even 2, by cutting in mid-August, will reduce the total seed production from 500 seed per square meter to 100 seeds per square meter, given the average rosette density of 50 rosettes per meter (Tsuchiya and Iwaki, 1983).

A second estimate on seed production compared to seed fall and seed core methods can be achieved by measuring rosette density across the growing season, coupled with studies of the number of flowers and seeds per rosette and the turnover of flowers and seeds. I would strongly recommend such a study for the coming year. This study would also indicate how many seeds are being contributed to other areas of the lake, rather than simply falling underneath the rosette canopy.

<u>Characteristics of Seeds Produced</u>. The seeds produced by rosettes in mid-September were examined for size and buoyancy. Eighty percent of the seeds produced by the rosettes sank, and these had an average weight of 2.5 g dw. (Figure 11 top). The remaining 20% of the seeds produced floated, and these had an average weight of 1 g dw. The floating seeds may be a mechanism of readily dispersing this plant to other locations. The discovery of floating seeds from viable rosettes is in direct contradiction to assertions made by other investigators. One potential factor that may resolve this apparent

discrepancy is that as seeds continue to mature, they increase in weight and decrease in buoyancy. Floating viable seeds from sediment core samples were not observed (see above). Seed weight is a critical factor in seed buoyancy (Figure 11 bottom).

Sun versus Shade in Seed Production. Twenty rosettes were taken from the Route 20 site (Site 1) and the Boatlaunch area (Site 2) on July 24, 1989 and analyzed for the number of flower buds, flowers, pollinated flowers and seeds at each location. There was a significant reduction in the average number of flower buds and pollinated flowers of rosettes taken at the Boatlaunch site as compared to those from the Route 20 site. However, the difference in flower number was not significant. The Route 20 site is located in the open, receiving full sunlight, while the Boatlaunch area was shaded by shoreline vegetation, and in a deep embayment. Although other factors might be important to this difference, it is quite likely that the relative reduction in available light is responsible for observed differences in flower bud and pollinated flower abundances.

The implication of this largely relates to the success of the field enclosure experiment, which was performed at the Boatlaunch site. This experiment should be repeated at a location receiving full sunlight, and some water movement or wind action to reduce the growth of watermeal.

FINDINGS

1. Seed production calculations from seed cores, supported by data from seed fall collectors, indicate that cutting treatments are effective in reducing the number of Waterchestnut seeds produced. Also, early summer and post-growing season sediment cores are an effective means of estimating seed production.

2. The vast majority (90% plus) of seeds observed in the sediment, or those floating, are not viable, but rather the undecomposed husks of seeds already germinated.

3. Laboratory experiments in fragment growth were totally disrupted through the feeding of the herbivorous beetle Pyrrhalta nymphaea. This suggests the effectiveness of this insect as a Waterchestnut herbivore and potential biological control.

4. Fragment growth experiments in field enclosures gave preliminary indications that Waterchestnut fragments formed through cutting for the most part will not set seed (4% or less), but other uncontrolled parameters may have effected this experiment.

5. Waterchestnut flowering initiated in late July, with the first seeds observed in mid-August. Flowering and seed development continue until the first frost. By mid-September, 4 seeds and 13 developing seeds were the average for Waterchestnut rosettes, with another 2 flowers and 2 flower buds present. Thus, the average rosette has the potential to produce at least 21 seeds through mid-September.

RECOMMENDATIONS

1. Seed cores should continue to be used to assess the effectiveness of cutting and other treatments, as well as monitoring the seed bank. More intensive studies of seed production dynamics are warranted to better understand seed production in Watervliet Reservoir, and predict the eventual depletion of the seed bank, and thus control (though not necessarily eradication) of Waterchestnut.

2. Cutting of Waterchestnut has been shown to be effective both in reducing the density of growth, and reducing seed production - thus reducing potential nuisance growth in subsequent years. However, cutting should continue later in the year, unless prevented by other environmental or economic conditions. Continued cutting should reduce the total number of mature seeds produced by Waterchestnut within the reservoir.

3. Other control techniques will have to be implemented and evaluated to manage areas inaccessible or impractical for cutting.

4. Further initial or pilot studies of the chrysomelid beetle <u>Pyrrhalta nymphaea</u> should be undertaken to evaluate its potential as a complementary biological control agent in the future.

5. The field exclosure study should be repeated in a more open, sunlit area to better evaluate the potential for fragments to form seeds. Otherwise, studies to date indicate that this possibility is not a major concern.

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Figure 1. Location of Watervliet Reservoir, and sampling locations on the reservoir.

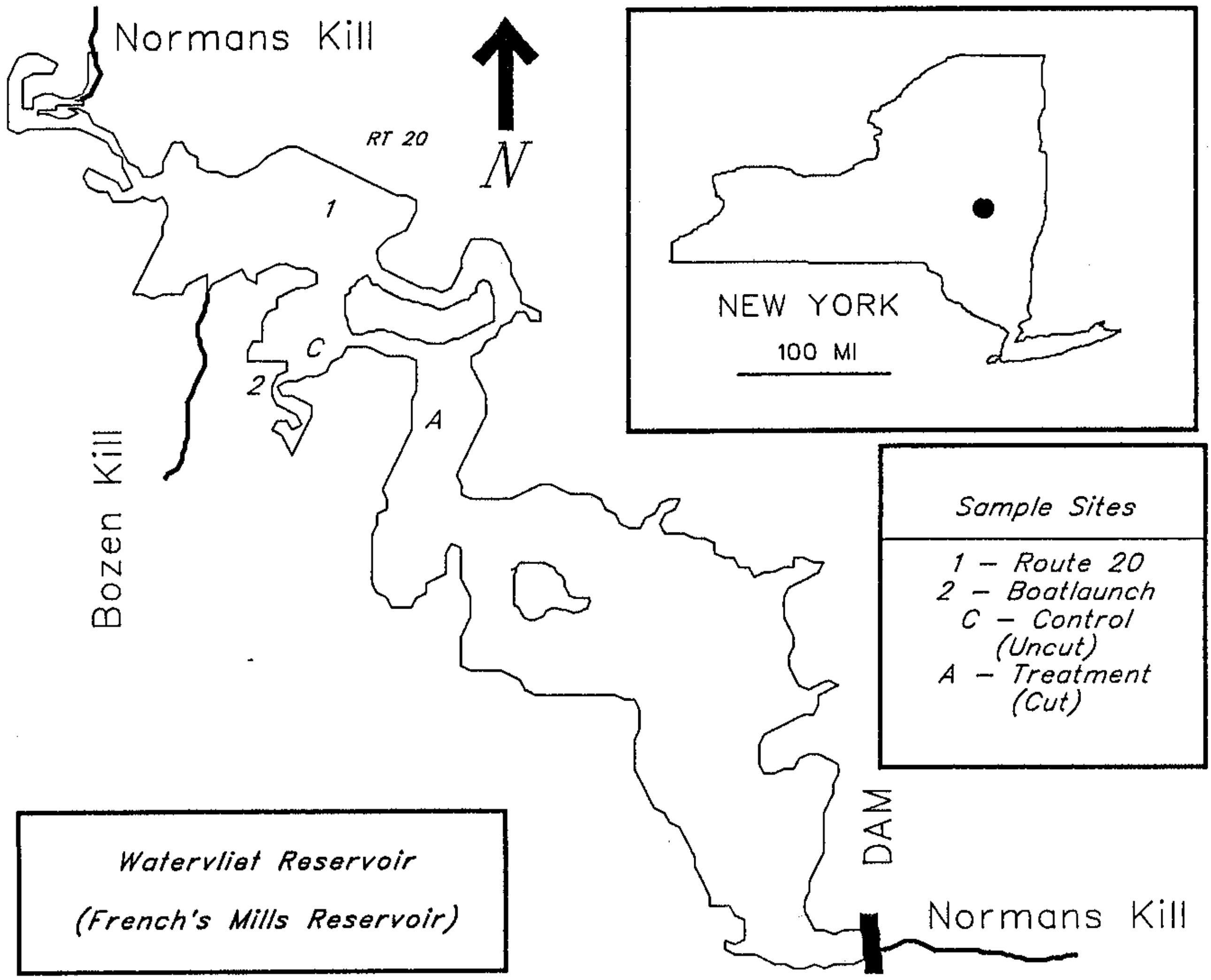


Figure 2. Total number of seeds per square meter from cores and seed fall collectors taken after seed germination in the spring (June 27) and after plant senescence in the fall (November 8).

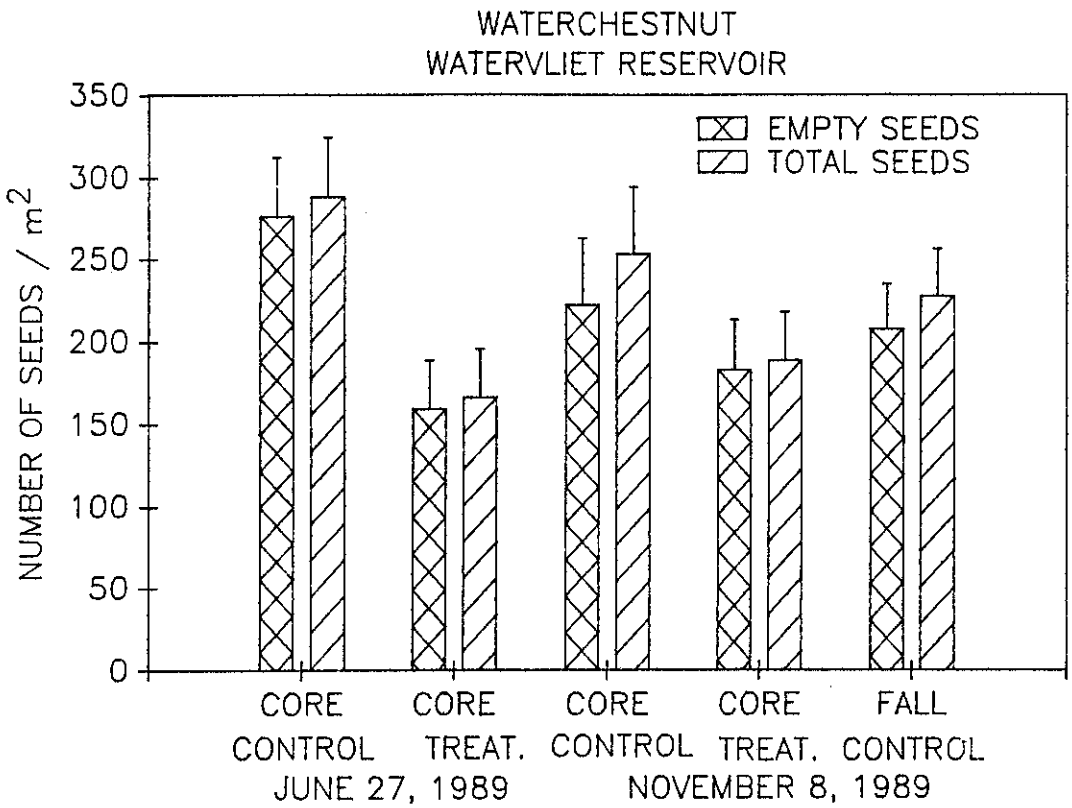


Figure 3. Number of viable seeds per square meter from cores and seed fall collectors taken after seed germination in the spring (June 27) and after plant senescence in the fall (November 8).

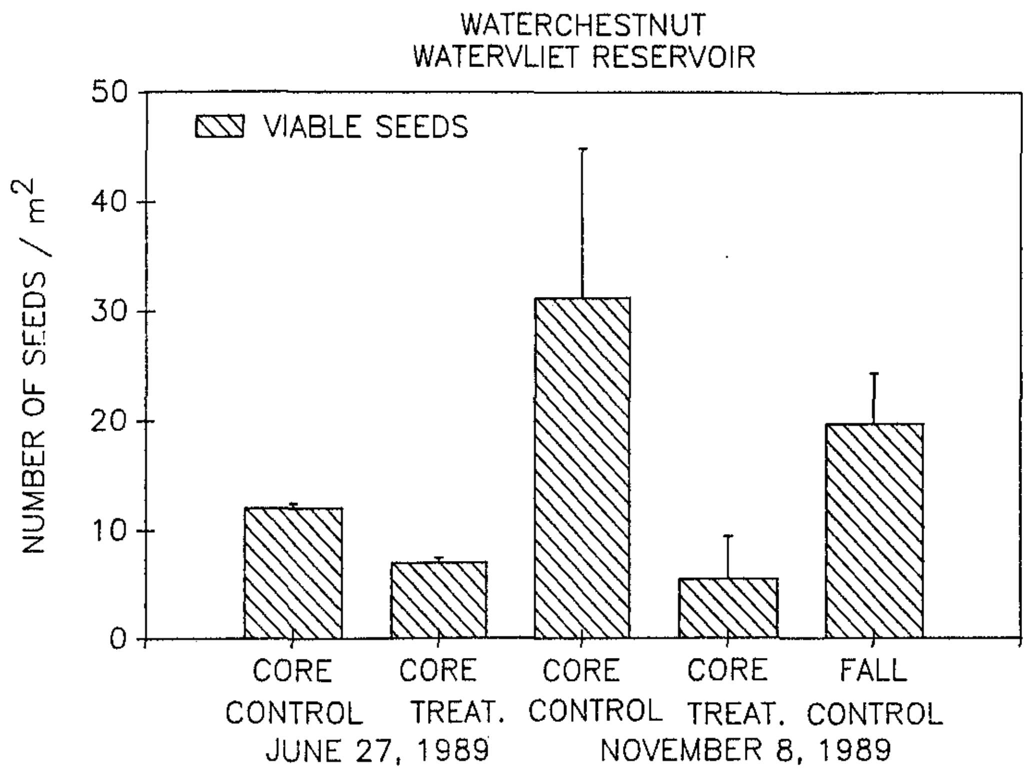


Figure 4. Characteristics of Waterchestnut seeds taken on June 27 as either floating grab samples or seeds from cores.

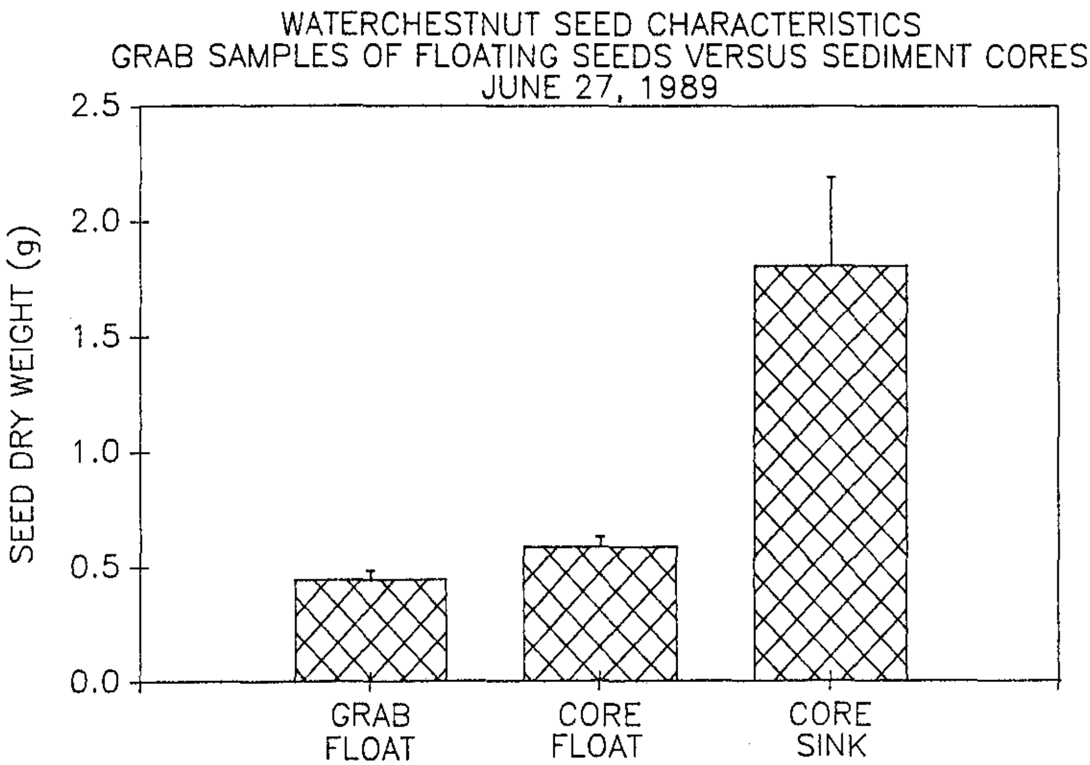


Figure 5. Percent of seeds examined from cores that sank or floated.

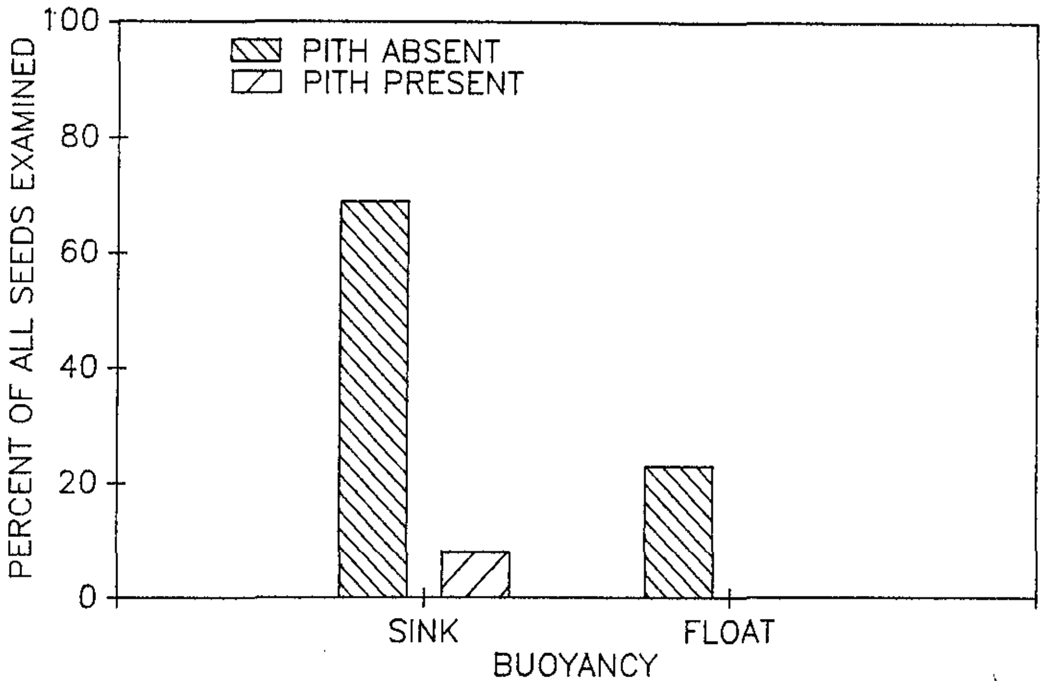


Figure 6. Weight of seeds from cores that sank or floated.

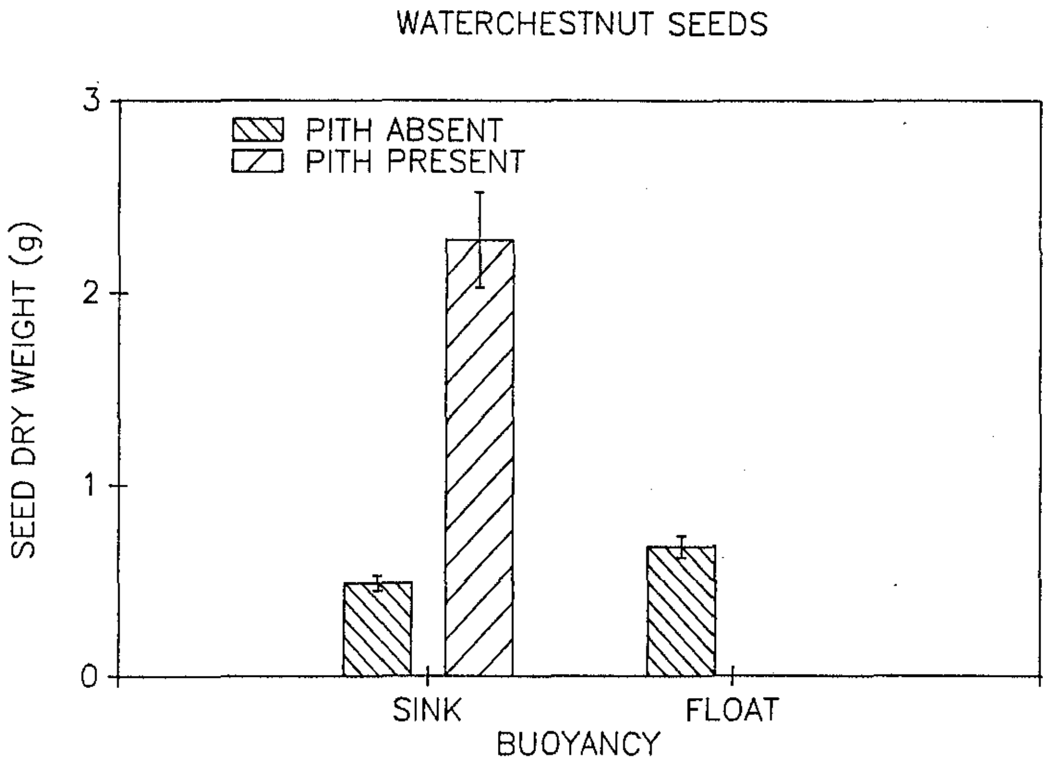


Figure 7. Results of laboratory fragment growth experiment.

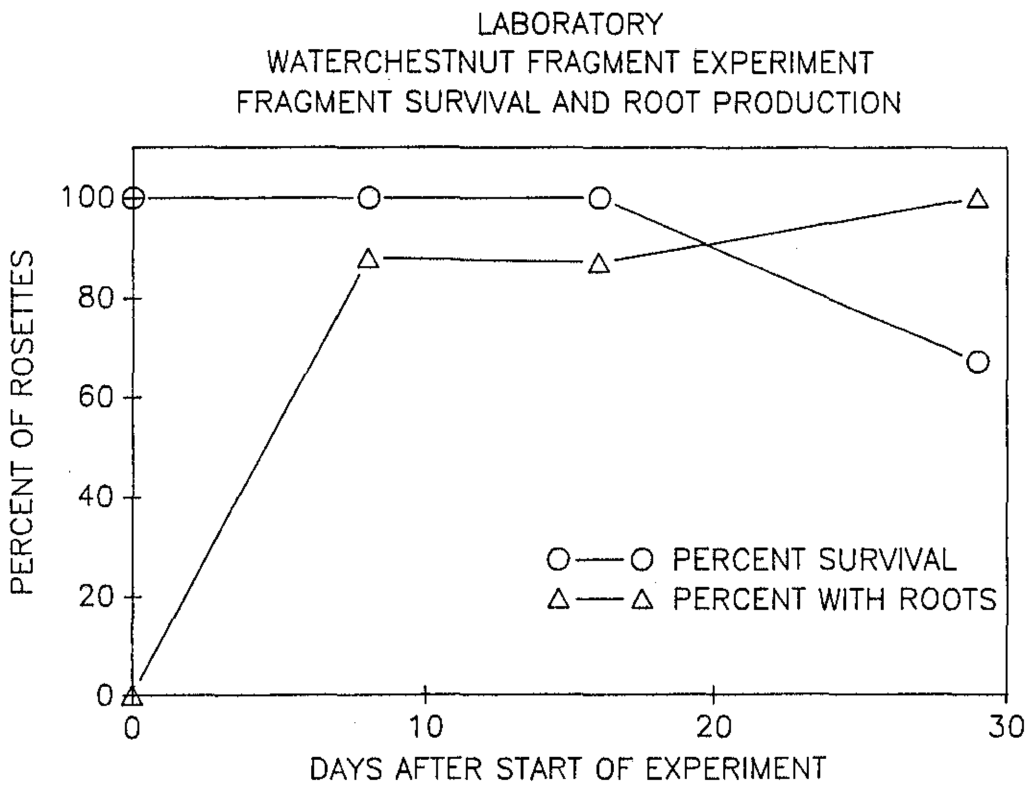
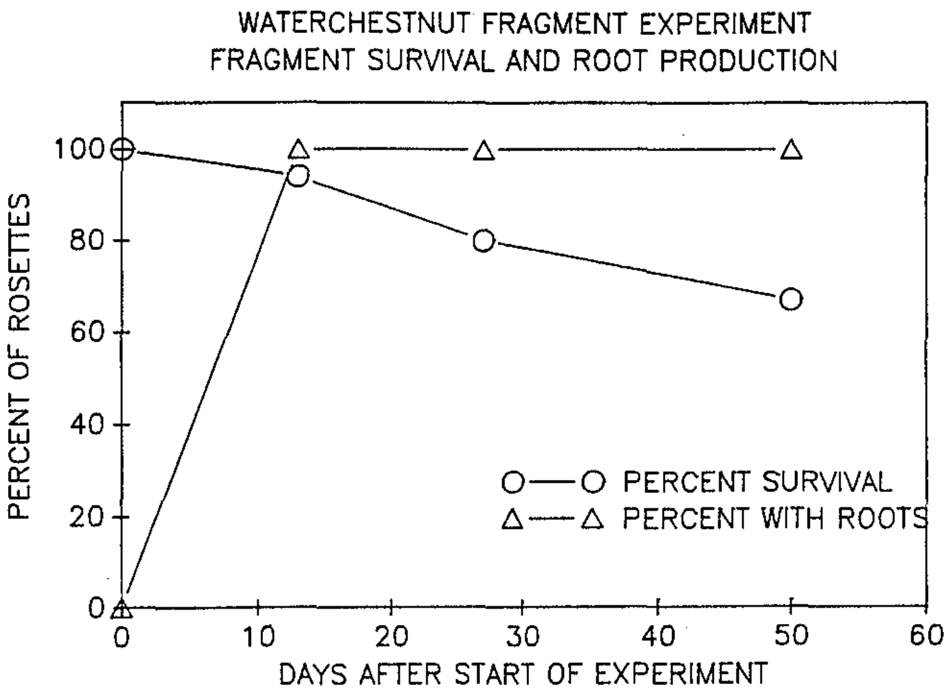


Figure 8. **Biweekly monitoring of field enclosure fragment growth study: Percent survival and root formation for fragments (top) and number of rosettes forming flowers and seeds (bottom).**



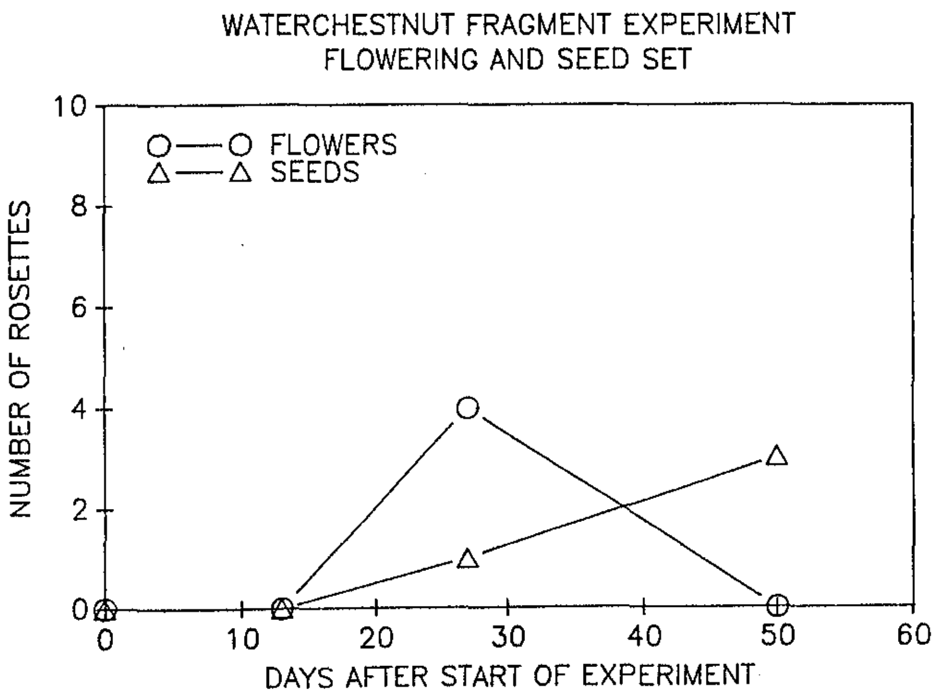


Figure 9. Initial and final quantitative conditions of Watercehstnut fragments from field exclosure experiment.

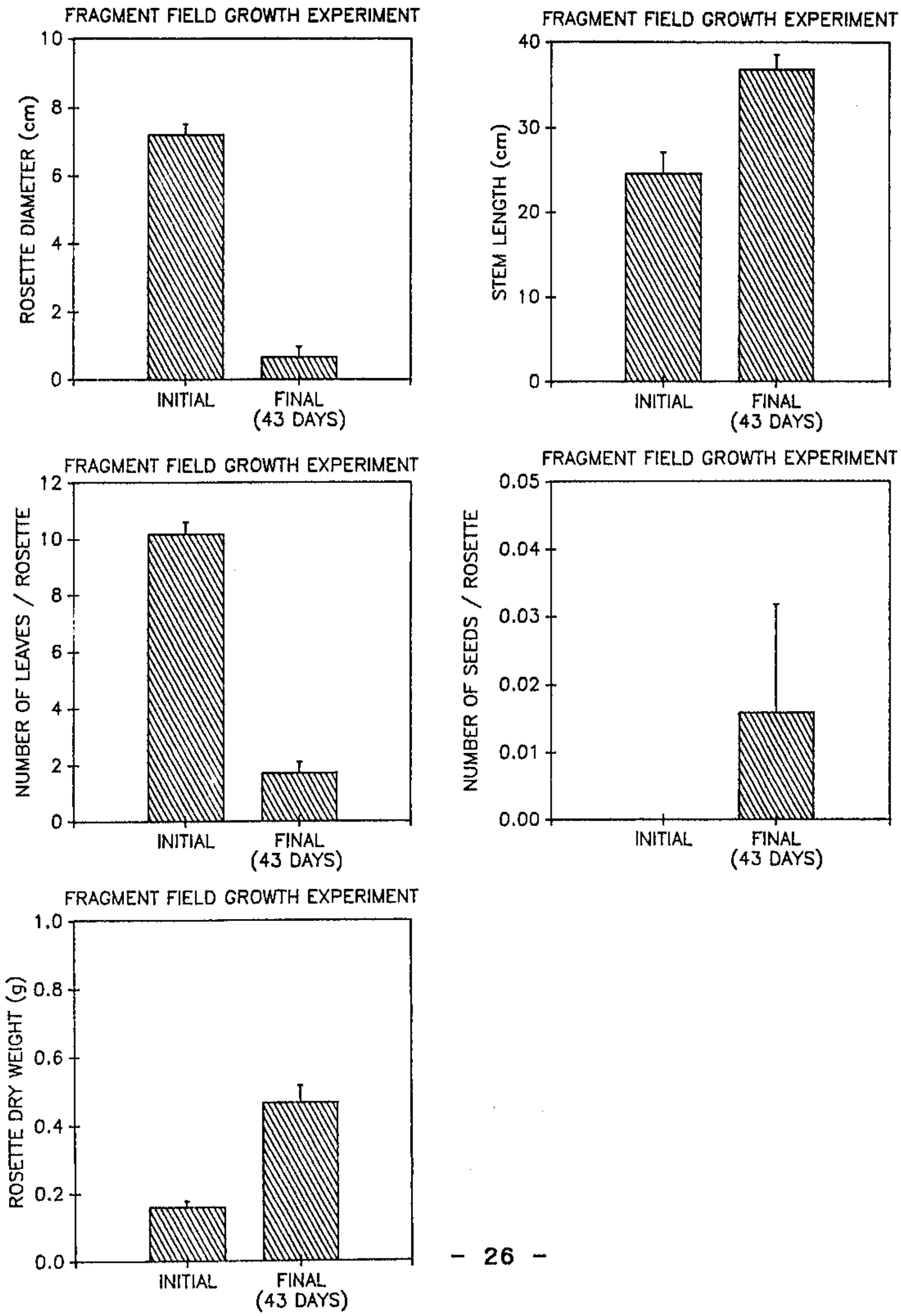


Figure 10. Phenology of flower bud, flower, pollinated flower and seed formation using average number per rosette during the 1989 growing season.

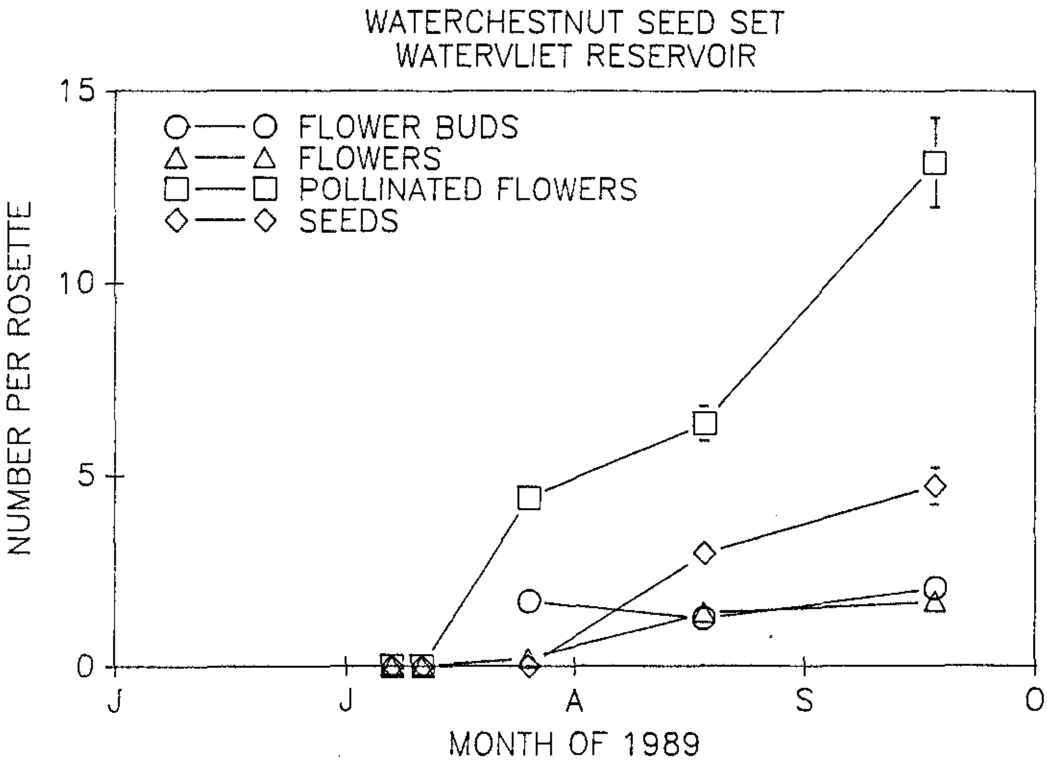
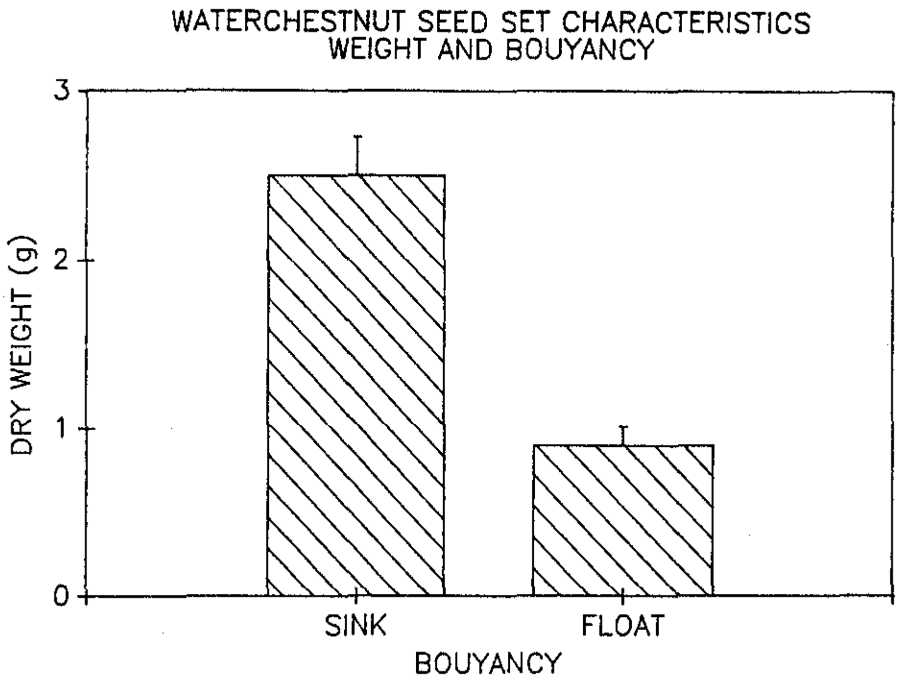


Figure 11. Seed characteristics of Waterchestnut seeds collected from rosettes in September of 1989: Average weight of floating and sinking seeds (top) and weight distribution of floating and sinking seeds (bottom).



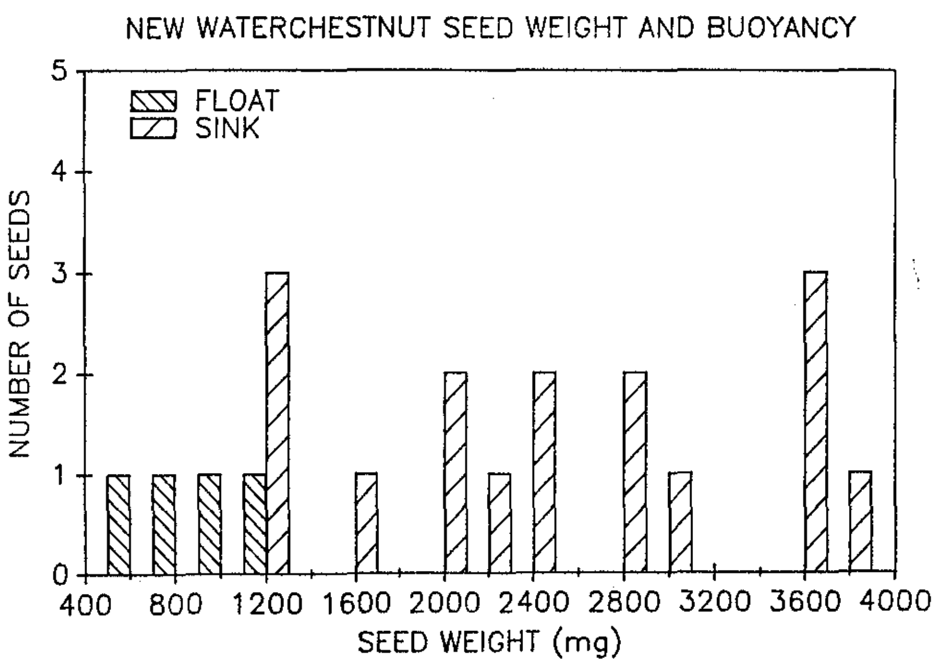


Figure 12. Average number of flower buds, flowers, pollinated flowers and seeds per rosette of Waterchestnut collected from sunny Route 20 (site 1) and shady Boatlaunch (site 2) sites.