178

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BUTOMUS UMBELLATUS IN BECKER COUNTY MINNESOTA: AN INVESTIGATION INTO THE CONTROL OF AN EXOTIC SPECIES

by

Kirk Alan Johnson

A Thesis Submitted to the Faculty of the
DEPARTMENT OF ENVIRONMENTAL STUDIES
In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE IN ENVIRONMENTAL STUDIES

BEMIDJI STATE UNIVERSITY
Bemidji, Minnesota, USA

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BUTOMUS UMBELLATUS IN BECKER COUNTY, MINNESOTA AN INVESTIGATION INTO THE CONTROL OF AN EXOTIC SPECIES

Kirk Alan Johnson

Abstract

Butomus umbellatus (flowering rush), a native of Europe and Asia, is a rhizomatous aquatic plant that has invaded North American water bodies. The Department of Natural Resources (DNR) of the state of Minnesota (U.S.A.) has declared *B. umbellatus* an ecologically harmful exotic species, and has initiated a strategy for its control. In conjunction with the flowering rush management plan of the DNR's Exotic Species Program, two experiments were performed. Dense populations of *B. umbellatus* were cut repetitively by hand during the summer of 1995 and observed for density of regrowth in order to determine the effectiveness of hand cutting as a control method. Also, in order to determine some of the factors that affect *B. umbellatus* growth, plant biomass was compared, statistically, to sediment particle size, content of nitrate-nitrogen, ortho phosphate, and potassium, and also to population age and location. Hand cutting as a method of control was shown to be effective at one test site. Sediment nutrient content did not contribute strongly to sample biomass variance, while population age and location did.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

INTRODUCTION

TAXONOMY

Butomus umbellatus L. (flowering rush) is a rhizomatous aquatic plant that exists in one of three forms: terrestrial, emergent, or submersed. It possesses the ability to change from one form to either of the other two. The flowering rush is of the family Butomaceae. This family, together with the Hydrocharitaceae, form the first order Butomales. They both immediately precede the Alismataceae in the family sequence adopted by Hutchinson (1959).

There have been many differences concerning the taxonomy of *Butomus umbellatus.* In the past the genera and species which constitute the Butomaceae and Alismataceae, as known today, have been combined under Alismataceae. From time to time *Butomus,* either alone or together with other genera, has been split off from the Alismataceae to form the Butomaceae (Stant, 1967). The family is now considered by many to be monotypic, consisting only of *B. umbellatus.* However, Anderson (1974) sited Fedchenko's treatment of *Butomus* in the Flora of U.S.S.R. listing two species: *B. umbellatus* L. and *B. junceus* Turcz.

Butomus umbellatus was named *Juncus floridus* by botanists in the 16th century, from which the name flowering rush is derived. Today it is commonly called the swan flower in Germany and the water lily in Switzerland (Schneider, 1991).

PHYSICAL CHARACTERISTICS

LEAVES

The leaves of *Butomus* are erect, linear, triquetrous, with sheathing bases (Stant, 1967; Gupta et al., 1975) and are seemingly veinless (Gupta et al., 1975). The tall leaves arising from a basal rosette are almost distichous, the distal tip may be slightly flattened, and it seems reasonable to regard the leaf blade as absent (Stant, 1967). *B. umbellatus* leaves are triangular in cross section, converging at the apex to form a "V" (Lieu, 1979).

Gupta et al. (1975) observed that in a young leaf the protodermis consists of parallel rows of polygonal cells. Some of these differentiate into stomatal apparatuses. Three cycles of mitotic division constitute an integral part of the development of a mature stomatal complex. Stomata of *Butomus* are present on all faces of the leaf but are more frequent in abaxial than adaxial epidermis (Stant, 1967). The subsidiary cells which flank the stomata have been shown to be derived not from the meristemoid, but from the neighboring epidermal cells (Gupta et al., 1975).

RHIZOME

The rhizome is brittle, 1 to 1.5 cm in diameter, and constricted at the junction of the branch and main axis (Lieu, 1979). The dorsoventrally flattened rhizome furrows through the substrate via the fast growth of the plow-like front end of its main axis (Schneider, 1991). As it grows, the older parts die and decay.

The underground rhizome system of *B. umbellatus* shows best the ability of the plants to spread and reproduce vegetatively (Hroudova, 1989). In addition to growth of the main axis, lateral branches and lateral or axillary buds are generated. The lateral buds, also referred to as bulblets (Marie-Victorin, 1938), bulbils (Countryman, 1970; Boutwell, 1990), and corms (Martin and Uhler, 1939), are connected to the rhizome by a very narrow base and tend to break off very easily (Hroudova, 1989). These buds, which are endowed with roots, sprout leaves (Schneider, 1991) and are carried by wave action and currents to be deposited on shorelines and bare sediments.

Hroudova (1989) found that the main axis of the rhizome attained a length of 25-30 cm and some lateral branches were nearly the same length. This allows *B. umbellatus* to spread almost regularly on all sides. Hroudova (1989) also observed that over the course of six growing seasons one plant formed on the average of 195.9 lateral buds, further demonstrating the incredible vegetative reproductive abilities of the species.

The roots of *B. umbellatus* are produced primarily on the underside of the rhizome and grow both laterally and vertically through the substrate. The roots have been described as both adventitious (Schneider, 1991) and contractile (Weber, 1950).

FLOWER

Unlike nonprecocious vegetative buds, inflorescence primordia result from virtually equal divisions of the apical meristem of a rhizome (Wilder, 1974). Two consecutive inflorescences are separated by an odd number of leaves, commonly nine, seven, or five (Wilder, 1974) or eight according to Weber (1950). Given an odd number of leaves between inflorescences, consecutive inflorescences are situated on opposite sides of the median-longitudinal axis of a rhizome (Wilder, 1974).

In Europe *B. umbellatus* blooms from June through August, whereas the North American plants bloom from May through September (Schneider, 1991). The flowers are borne in compound cymose inflorescences. They are bisexual, trimerous (except for the whorl of outer stamens), and very slightly epigynous (Singh, 1974). A series of experiments led Pohl (1936) to conclude that *B. umbellatus* is indeed self sterile. Further research by Krahulcova and Jarolimova (1993) however, has shown only triploid *B. umbellatus* to be self sterile while diploid *B. umbellatus* is self fertile. Ploidy level is discussed in further detail later.

The sepals of *B. umbellatus* are petaloid and therefore might be referred to as tepals, however, they tend to be green at their tips and have a slightly different shape from that of the inner tepals (Sattler and Singh, 1978). Singh and Sattler (1974) described the flower of *B. umbellatus* as follows:

> "There are nine stamens with an outer whorl of six and an inner whorl of three. The filaments are flattened with basifixed dithecous anthers opening by lateral slits. The six pistils (carpels) appear to form a single whorl in a mature flower and have abaxially a common base for a short distance. The ventral margins of each pistil are never fused but are held together in the distal portion by interlocking hairs. The ovary of each pistil is unilocular with numerous anatropous ovules scattered over the inner surface of the ovary wall except for the margins and dorsal suture. There is no distinct style. The margins of the pistil are stigmatic in the upper portion. The fruit consists of six almost free turgid follicles, which dehisce adaxially by the pulling apart of the ventral margins".

Fernando and Cass (1994) reported on the direct relationship between anther tapetum and developing pollen grains in the anthers of *B. umbellatus* where the tapetum becomes plasmodial. They found, among other things, the end products of the dissolution of the tapetum are dispersed as lipid bodies, rectangular or elongate structures, and electron dense debris that accumulate on the interstices of the exine. These products are responsible for the orange coloration of the pollen grains. They also enable pollen grains to stick together, to stigmas, and to the bodies of insect pollinators. The sticky nature of the pollen grains is therefore related to the mode of pollination of *B. umbellatus*.

SEEDS

Cross pollination occurs throughout populations of *B. umbellatus*, forming numerous seeds in both Europe and North America (Stuckey and Schneider, 1990). Ecklund (1928) determined that the *Butomus* plant in south Finland produces on the average 31 seeds per follicle and therefore 186 per flower. A typical inflorescence with 37 flowers produces 6800 seeds (Schneider, 1991). Roper (1952) discussed in detail the embryo sac of *B. umbellatus*, meiosis of the megaspore mother cell, and fertilization.

Krahulcova and Jarolimova (1993) obtained viable seeds after all types of pollination treatment that produced seeds. Seeds collected from wild stands of *B. umbellatus* in Ohio have proven to be viable (Schneider, 1991). Seeds generally float for one day after falling from the plant, however, if they become overgrown with mycelium they may float for two weeks (Stuckey, 1968). The seeds may also drift along the bottom of a river in silt, or the seedlings may float in the spring (Stuckey, 1968). The ability of seeds to remain viable for several years increases the chances for dispersal and germination (Staniforth and Frego, 1980).

CYTOTYPE

The somatic number 2n=26 is reported most frequently for *B. umbellatus*, however, 3n=39 has also been presented. These correspond to diploids and triploids based on the number x=13 (Rao, 1953). Both cytotypes are distinguishable from each other in the field by minute but distinct characteristics in flower morphology (Krahulcova and Jarolimova, 1993). Furthermore, triploids appear to be superior to diploids not only in vegetative reproduction, but also in biomass production of vegetative organs (Hroudova and Zakravsky, 1993a).

Pandita and Mehra (1984) concluded that triploid *B. umbellatus* was derived from the diploid through the sexual function of cytologically reduced and unreduced gametes. Such an origin for polyploids, especially triploids, is considered as the most common way to derive polyploidy (Krahulcova and Jarolimova, 1993).

Hroudova and Zakravsky (1993a) found triploids to have better survival and biomass production in concentrated nutrient solution, indicating their higher tolerance to this kind of stress. This yields an advantage for triploid *B. umbellatus* in human influenced habitats (eutrophic and polluted waters), which may result in a greater ecological distribution when compared to diploids. It was also found that triploids have a wider range of pH tolerance than diploids but are concentrated in habitats with higher pH values and when considering the Ca^{2+} and Na^{+} ion content in soils, triploids inhabit more base rich soils (Hroudova and Zakravsky, 1993b).

Butomus umbellatus IN NORTH AMERICA

The ability of some *B. umbellatus* populations to produce numerous viable seeds coupled with the species' prolific vegetative reproduction raises concerns over invasion of North American lakes, rivers, and wetlands. Also, these reproductive capabilities make possible long distance relocation over short periods of time. Short distance dispersal of vegetative material may be aided by ice movement (Gauthier, 1972; Scotter, 1991) or by the house building activities of muskrats (*Ondatra zibethicus*) (Gaiser, 1949). Furthermore, *B. umbellatus* has the ability to change from one form to another giving it the ability to adapt to changing environments. Because of its ecological plasticity and great reproductive potential, *B. umbellatus* is able to invade natural vegetation (Roberts, 1972). It has been found to be more aggressive, and therefore, able to outcompete native plants (Boutwell, 1990). *B. umbellatus* also appears as a pioneer species, overgrowing shallow sites in reservoirs and new sandy alluvial deposits (Hroudova, 1989).

Butomus umbellatus is actively expanding its range in North America. The plant has spread from a limited area around the Great Lakes and St. Lawrence River to cover, in a sporadic manner, the northern United States and southern Canada (Wetland Species Accounts, 1991).

The first observations of *B. umbellatus* in North America were made in 1897 by Fr. Marie-Victorin at LaPrairie, Quebec on the St. Lawrence River (Core, 1941; Stuckey, 1968; Staniforth and Frego, 1980). The first report of *B. umbellatus* from the United States was made in 1929 (Knowlton, 1929; Muensher, 1929; Countryman, 1970). It was discovered growing abundantly in the southern end of Lake Champlain near Whitehall, New York. A specimen, however, was collected by D. L. Dutton in 1928 from the shores of Lake Champlain at Orwell, Vermont (Countryman, 1970). It has also been reported that *B. umbellatus* populations were well established in Michigan by

1918 (Core, 1941; Stuckey, 1968). Since then, *B. umbellatus* has been identified in Nova Scotia (Hall, 1959), Ontario (Knowlton, 1923; Gaiser, 1949; Montgomery, 1956; Staniforth and Frego, 1980), Alberta (Scotter, 1991), and British Columbia (Wetland Species Accounts, 1991) in Canada. In the United States it has since been identified in Connecticut (Countryman, 1970), Pennsylvania (Gaiser, 1949), Ohio (Schaffner, 1933; Core, 1941; Roberts, 1972), Indiana (Witmer, 1964; Molenbrook, 1970), Wisconsin (Minnesota Department of Natural Resources, 1994), Minnesota (Ownbey and Smith, 1988), North Dakota (Godfread and Barker, 1975), South Dakota (Martin, 1965), and Idaho (Boutwell,1990).

Marie-Victorin (1938) suggested *Butomus umbellatus* was first introduced in the St. Lawrence River and from there spread to Lake Champlain and the Great Lakes. Stuckey (1968) argued that it is more plausible that the River Rouge (Michigan) locality represents a second separate introduction of *B. umbellatus* in North America. In making comparisons between *B. umbellatus* populations from five general regions, Anderson et al. (1974) agreed with Stuckey suggesting the St. Lawrence River populations originated in Asia, whereas the Western America and Great Lakes populations probably originated in Europe. Another argument could be made that there have indeed been multiple introductions of *B. umbellatus* in North

America and that physical differences between these populations are based upon cytotype rather than or in addition to the origin of the introduction.

Butomus umbellatus in Minnesota

B. umbellatus is known from only four localities in Minnesota: historically from near Cannon Lake in Rice County (Ownbey and Smith, 1988) and Anoka County (Minnesota Department of Natural Resources, 1994), and currently in Becker County in Big and Little Detroit Lakes, Lake Sallie, Lake Melissa, as well as in the Pelican River between these lakes (Owneby and Smith, 1988; Minnesota Department of Natural Resources, 1994). More recently it has been identified in Twin Lakes near Marble in Itasca County (Perleberg, 1995).

Due to the potential negative impacts of *B. umbellatus*, both ecological and economic, the state of Minnesota has added the species to its ecologically harmful exotic species list (Minnesota Department of Natural Resources, 1993) making illegal the importation, possession, transport, and sale of *B. umbellatus* within the state.

The management of *B. umbellatus* in Minnesota is coordinated through the Department of Natural Resources Division of Fish and

Wildlife, Section of Ecological Services, Exotic Species Program. The Exotic Species Program coordinates inventory, research, control, and public awareness of undesirable exotic plants and animals (Minnesota Department of Natural Resources, 1994). The Exotic Species Program's current *B. umbellatus* management plan has as its goals to: determine the status of flowering rush in Minnesota; contain flowering rush populations to existing sites in Minnesota; control flowering rush populations in Minnesota in an ecologically sound manner; support and conduct research needed to improve flowering rush management (Minnesota Department of Natural Resources, 1994).

To this point *B. umbellatus* control activities within Minnesota have been confined to the Becker County populations. Several experimental attempts to control *B. umbellatus* with chemicals have been made using the herbicides Rodeo, Sonar, and Arsenal; none of these have been considered effective. Results from 1994 field trials conducted by the Minnesota Department of Natural Resources indicated that Rodeo (glyphosate) is not effective at depths greater than six inches because wave action washes the herbicide from the plants (Minnesota Department of Natural Resources, 1994). Sonar (fluridone) is the only systemic herbicide, currently labeled for aquatic use, that would potentially kill submersed plants. Sonar and most other herbicides that would potentially be effective in killing *B. umbellatus* are also likely to kill many valuable native plants. Specific chemical application rates and techniques for the control of *B. umbellatus* in Minnesota are still in the experimental stage.

The Pelican River Watershed District conducts mechanical harvest of submersed aquatic vegetation including *B. umbellatus* in Becker County. The mechanical harvest of aquatic vegetation in the Pelican River watershed began in 1968 on Lake Sallie and regular harvest began in 1990 on Big and Little Detroit Lakes in order to enhance water quality and to improve recreational opportunities and aesthetics (Pelican River Watershed District, 1995). At the outset aquatic vegetation harvesting was justified by the expectation that significant amounts of nutrients were contained in the tissues of aquatic plants and their removal also would remove these nutrients from the lake systems (Pelican River Watershed District, 1995). It is thought that mechanical harvesting of submersed vegetation does not normally disturb the rhizome system of *B. umbellatus*, however, it should not be entirely ruled out as a facilitator of the vegetative spread of the species.

The control strategies outlined by the Exotic Species Program's flowering rush management plan (1994) include: mechanical harvesting of established submersed stands; manual removal of isolated submersed plants, manual cutting of established emergent stands, and manual removal of isolated emergent plants.

NUTRIENT IMPORTANCE

Nitrogen is essential to plants as a building material of proteins as well as in chlorophyll and alkaloids (Dunn, 1949). Variations in the growth rate of leaves are determined for the most part by variations in the supply of available nitrogen. The size of the plant is thus largely a measure of the rate of nitrogen mineralization. The rate of uptake of nitrogen is determined primarily by the concentration of nitrogen in the soil solution, while the speed of development of the plant is proportional to the inflow of nitrogen (Miller, 1938).

Phosphorus is an important element in the production of nucleic acids and, therefore, is essential for the formation of chromatin of the chromosomes. Phosphorus is necessary in cell division and aids in respiration as well (Dunn, 1949). Another of the important physiological roles of phosphorus is the formation of phospholipids of which lecithin is the most abundant (Miller, 1938).

Potassium is the most abundant cation in higher plants and is crucial for plant nutrition, growth, tropisms, enzyme homeostasis, and osmoregulation (Schachtman and Schreoder, 1994). Potassium acts as a catalyst, promoting the formation of carbohydrates, proteins, and fats (Dunn, 1949) and is found in greatest concentration in meristematic tissue (Miller, 1938) which emphasizes its importance for plant tissue growth.

Interspecific Competition for Available Nutrients

The most basic mechanism of competition for a limiting nutrient is nutrient reduction. As a plant consumes a soil nutrient and reduces its concentration in solution in the soil, its competitors are denied some of that resource, and thus grow more slowly (Tilman and Wedin, 1991). Simple theories of plant competition for a single limiting nutrient predict that if competive interactions go to steady state, the superior competitor will be the species that can reduce the concentration of the limiting nutrient to the lowest level in steady state monocultures (Tilman and Wedin, 1991). Many of the emergent stands of *B. umbellatus* in Becker County, Minnesota appear to be steady state monocultures.

Tilman's theory of resource competition (1987) predicts that there may be no quantitative change in the intensity of competition along a productivity gradient, but that there may be an important qualitative change, with plants mainly competing for soil resources in unproductive habitats and mainly competing for light in more productive areas. This suggests that each species is specialized for a particular ratio of soil resources and light, and that the species that characterize a particular habitat are also the superior competitors for the particular resource ratio of that habitat. Therefore, competition may be important at all points along a productivity gradient but its quality may vary (Tilman, 1988).

Along with Tilman, Newman (1973) proposed that competition should be intense in unproductive habitats. In contrast, Grime (1973) and Huston (1979) have argued that competition increases in intensity with increasing biomass production since higher density and biomass of plants will create greater demand for limiting resources. Extremely unproductive sites are predicted to have a very low intensity of competition (Turkington et al., 1993). Disturbance, or removal of plant biomass, will alter productivity (Wilson and Tilman, 1991a). Chapin (1980) found that species of undisturbed, infertile habitats have lower maximal growth and nutrient uptake rates, greater allocation to roots, and are more likely to be evergreen than species of more fertile, undisturbed habitats. These traits are favored, it is presumed because they confer an advantage, perhaps a competitive advantage, in infertile habitats (Tilman and Wedin, 1991).

In a nitrogen gradient experiment on the nitrogen poor Anoka Sand Plain (Minnesota) Wilson and Tilman (1991b) found that only nitrogen significantly increased community biomass and altered species composition, of all nutrients added to the system (N, P, K, Ca, Mg). Aerts et al. (1992) found both above and below ground biomass of several *Carex* species significantly increased with increasing nitrogen supply. As above ground *Carex* biomass increased more than below ground biomass, the shoot:root ratio of all species increased with increasing nitrogen supply. In further research on species of the Anoka Sand Plain, Tilman and Wedin (1991) concluded that the species with the greatest root biomass and the lowest root and shoot nitrogen concentrations reduced soil ammonium and nitrate to a lower level than other species. Comparably, species with the greatest above ground biomass intercepted the most light. Tilman (1988) also described the possibility that a species could occupy a point on a nitrogen:light gradient at which it is a superior competitor for both nitrogen and light. At this point it would produce more below ground and more above ground biomass than its competitors, but would be displaced from other points along the gradient by species with different allocation patterns. This may be the case with *B. umbellatus* in Becker County, Minnesota as dense stands are nearly pure and areas predominated by *Typha* or *Scirpus* contain few if any *B. umbellatus* individuals, the growth of which tends to appear stunted.

Experimental Design

In conjunction with the Exotic Species Program's *B. umbellatus* management plan, two projects were conducted during 1995. The first was to determine the effects of hand cutting dense emergent stands of *B. umbellatus* and the second was an attempt to determine some of the ecological factors that affect the health of a *B. umbellatus* population.

Among the ecological factors chosen for study were sediment nitrogen, phosphorus, and potassium content. Substrate properties are among the most important factors influencing water environments. Soils in European habitats of *B. umbellatus* are mostly nutrient rich, but variations in soil chemistry may be considerable (Hroudova and Zakravsky, 1994). The bottom of the Ukrainian Kiev Reservoir is mostly sandy. The subhydric soil in which macrophytes are rooted is thus rather poor in mineral nutrients (Husak and Gorbik, 1990). As to the distribution of *B. umbellatus* stands, migration barriers can be as important as differences in substrate chemistry (Hroudova and Zadravsky, 1993). Therefore, the relationship of the community to the nutrient richness of the substrate appears to be an important problem to study (Hroudova and Zakravsky, 1994).

Increases in biomass were expected to be due to increases in sediment nutrient content, especially nitrogen and phosphorus. In aquatic systems, the two nutrients that most commonly act as limiting factors are phosphorus in the form of phosphate (PO_4^{3-}), and nitrogen in the form of either nitrate (NO_3^-) or ammonia (NH_3). However, nitrates are usually regarded as a better source of nitrogen than ammonium compounds.

Since it can be indicated visually that *B. umbellatus* populations in the Pelican River watershed have both high above and below ground biomass the discovery of low sediment nutrient levels, or little variation in nutrient levels would be indicative of the species' ability to outcompete other vegetation for limited resources. This would also indicate that the area's nutrient levels are not as important as other factors for *B. umbellatus* biomass production.

MATERIALS AND METHODS

The original outline of the hand cutting project proposed the delineation and cutting of up to five shallow water emergent *B. umbellatus* sites. Each site was to be cut three times, at the ends of

June, July, and August by crews made up of Becker County sentenced to serve laborers. Due to unusually cool spring temperatures, early *B. umbellatus* growth was hindered so that by late June only one stand had matured to the point of emergence. This site (Deadshot Bay) was surveyed for stem density of *B. umbellatus* . The surveys were conducted in five $1m^2$ plots each divided into $0.25m^2$ quadrants. The sampling apparatus consisted of a square styrofoam form with an inside area of $1m^2$. Each 1m side of the square was bisected, and the quadrants were created by running a string from each side to its opposite. The sampling areas were selected by blindly tossing a wooden dowel rod into the test site. Its resting place determined the center point of the sampling apparatus. The stem density was then determined by counting the number of emergent and submersed stems in each quadrant.

The Deadshot Bay site was treated June 23 by cutting the emergent plants below the water line. The crew accomplished this by throwing a sickle-like cutter well past the mark of three feet of water depth and retrieving it with a tether.

Four new test sites were delineated and described in late July. Vegetation density surveys were conducted in sixteen $0.25m^2$ quadrants. The new sites were designated as Long Bridge Road, Cox's Point, Nodaway Drive, and City Beach-Pavillion (Figure 1). The Long Bridge Road and City Beach-Pavillion sites were treated August 17. The Deadshot Bay site was treated a second time on this day as well. No further treatments were possible prior to the autumn senescence of *B. umbellatus*.

Post treatment *B. umbellatus* stem density data were collected from each test site three weeks after each hand cutting treatment. No post treatment data were available from the City Beach-Pavillion sites as declining water temperature, combined with algal blooms that shaded new shoots, retarded regrowth to the point that very few plants emerged by mid October when growth ultimately ceased for the season.

No post treatment data were available from the Cox's Point or Nodaway Drive sites. Because of heavy wave action on the scheduled cutting date, the crew elected not to cut the *B. umbellatus* plants which exist on either side of a gravel bar extending into the lake from Cox's Point, out of concern for contribution to the vegetative spread of the plant. The conditions of a densely wooded shoreline and soft substrate at the Nodaway Drive site made too difficult, for the crew, the cutting and removal of *B. umbellatus.*

In an effort to characterize the health and possible limiting factors of *B. umbellatus* stands, sediments were sampled and

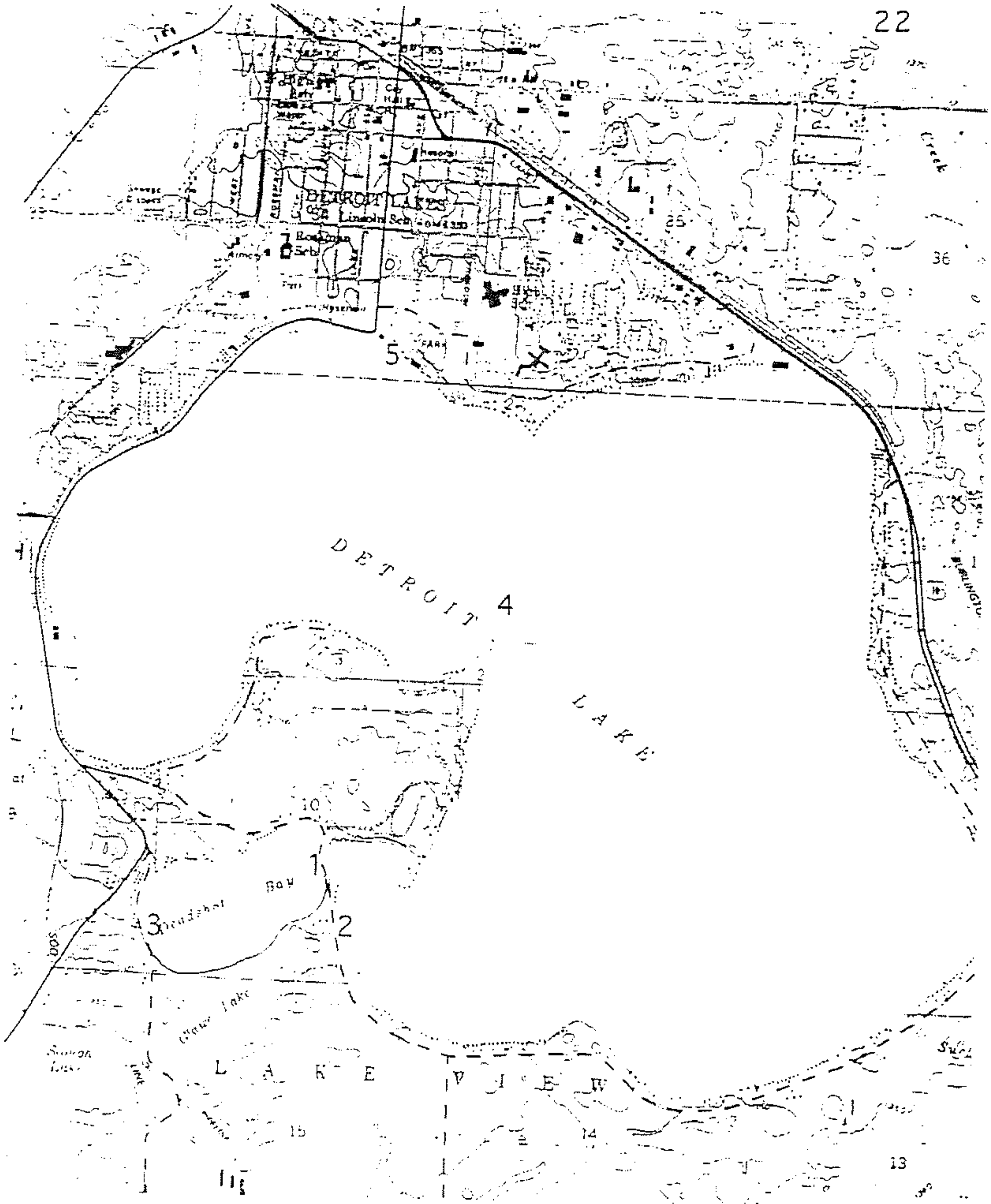

Figure 1: Locations of survey sites from stem cutting project.
1= Deadshot Bay; 2= Long Bridge Road; 3= Nodaway Drive
4= Cox's Point; 5= City Beach-Pavilion. Scale= 1:24,000.

Source: U. S. Geological Survey.

analyzed for nutrient content (nitrate-nitrogen, potassium, ortho phosphate) and plants were removed from mature stands for analysis of biomass. The seven areas sampled (A-F) (Figure 2) were selected based upon apparent differences in above ground biomass and observed differences in stem density. It was thought that differences in available sediment nutrients might account for differences in biomass. Other factors affecting the apparent health of a *B. umbellatus* stand may include: age, water current, wind and wave action, light intensity, and sediment size characteristics.

Five sediment samples were taken from each of seven different areas with dense *B. umbellatus* in Big and Little Detroit Lakes in Becker County, Minnesota. The samples were collected by scooping the top 10 to 15 cm of sediment into a mason jar with a hand held garden shovel. Each sample was mixed in its container then subsampled. The 100 cm^3 subsamples were air dried for 1 week. Soil nitrate and potassium contents were analyzed using the Lomotte Chemical Company soil nutrient test kits.

Nitrate analysis was accomplished by shaking together a 2cm^3 sediment sample and 7 ml of a 3% acetic acid, 9.75% sodium acetate solution for 1 minute. The soil suspension was then filtered through a number 4 Whatman filter paper into a clean tube. One ml

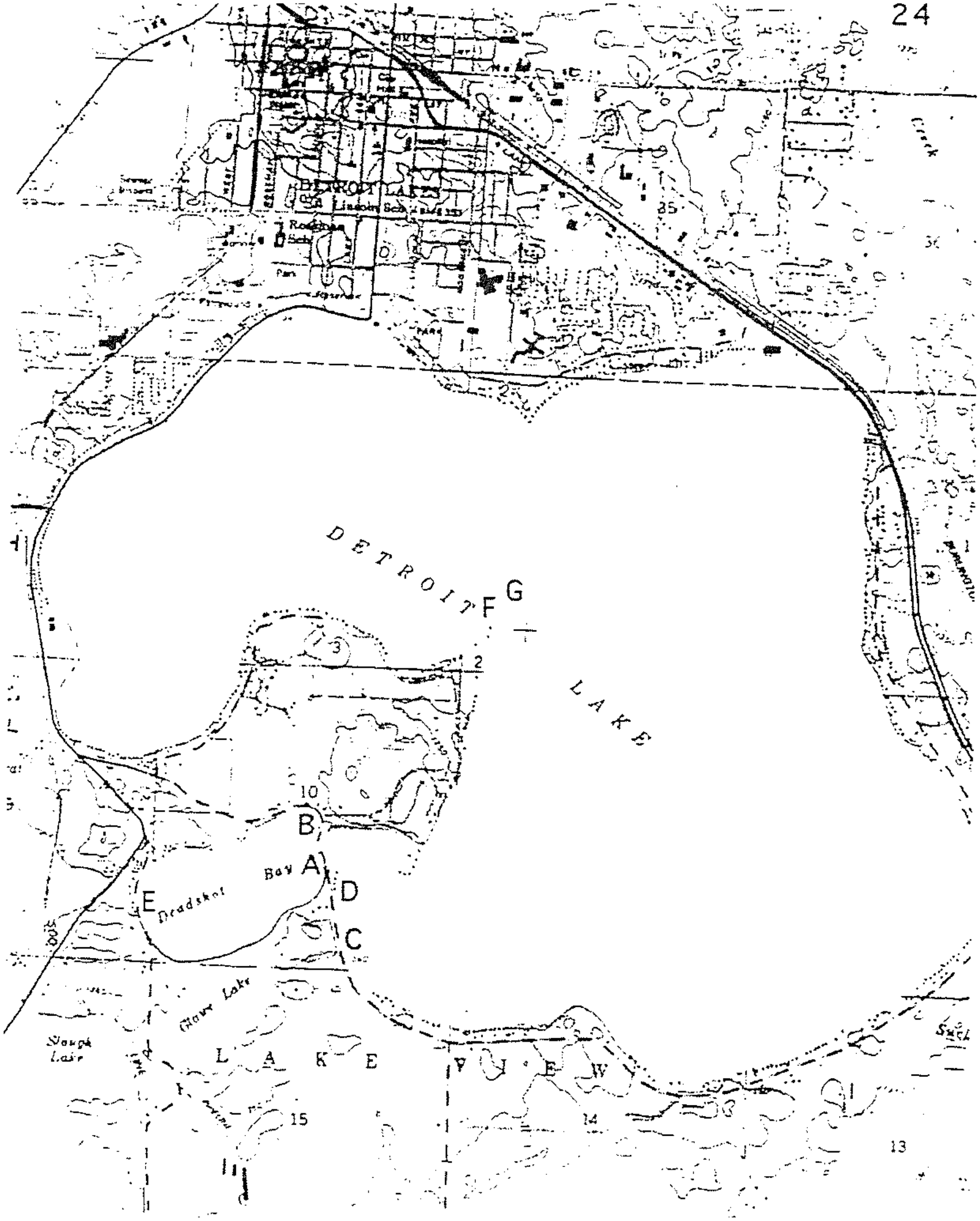

Figure 2: Locations of sediment and biomass samples. Scale= 1:24,000.

Source: U. S. Geological Survey

of the filtrate was transferred to a spot plate and 10 drops of a solution containing 25.4% sodium bisulfate, 7% ammonium sulfate, and less than 1% cresol red along with 0.5 g of a reagent containing 63% barium sulfate, 6.4% zinc dust, 1.4% manganous sulfate monohydrate, 0.6% sulfanilamide, and 0.6% N-1-nathalylethylene-diamine-dihydrochloride were added. After a 5 minute reaction period the nitrate content was determined by color comparison against a card provided by Lomotte Chemical Company. Only 3 values were obtained using this method due to little variance among samples.

In order to determine sediment potassium content a 2 cm^3 sediment sample was added to 7 ml of a 3% acetic acid, 9.75% sodium acetate solution. This was vigorously mixed for 1 minute. The soil suspension was filtered through a number 4 Whatman filter paper into a clean tube. In 3 ml of the filtrate a 60% sodium nitrite, 29% sodium cobalt nitrite, 11% sodium benzoate tablet was dissolved. Four ml of an 80% ethyl alcohol, 4% methyl alcohol, less than 0.01% sodium hydroxide, less than 0.01% methyl red solution was added. A precipitate formed. Potassium content was measured visually by the degree of light penetration against a scale provided by Lomotte Chemical Company.

Phosphorus was analyzed using the Murphy-Riley method for detection of reactive (ortho) phosphate (Adams, 1990). Orthophosphate was extracted from a 3 cm^3 sediment sample using 10 mL of a 3% acetic acid, 9.75% sodium acetate solution by shaking together for 1 minute. This solution was then filtered through a number 4 Whatman filter paper and diluted to 50 mL with distilled water. Added to each 50mL sample were 5mL of Armstrong reagent (Appendix A) and 1mL of a 3g/100mL ascorbic acid solution. After a reaction period of at least 20 minutes the absorbance of the samples was read at 880nm on a Spec 20 spectrophotometer. The reactive (ortho) phosphate in the sample was then calculated using the formula:

$$\text{ug } PO_4^{-3} - P/L = (Abs_2 - Abs_1)(m^{-1})(df)$$

where:

Abs_1 = absorbance of blank sample

Abs_2 = absorbance of sample

m^{-1} = Δ concentration/Δ absorbance

df = dilution factor

Prior to use all plastic and glassware needed in the process of orthophosphate analysis was washed 3 times in 70°-75° C 3M HNO_3, rinsed in distilled water, washed twice in 6M HCl and rinsed in order to remove all traces of phosphorus contamination.

The sediment samples were also analyzed for particle size in order to characterize each sampling area. Each sediment sample was dried and combined with the others from the same sample area. These combined samples were then poured through a series of six U.S.A. standard testing sieves of screen sizes 4.75mm, 2.36mm, 1.70mm, 0.850mm, 0.600mm, and 0.300mm. The material trapped by each sieve was weighed and calculated as a percentage of total sediment in that combined sample.

In order to obtain biomass data, plant samples were taken from the same seven *B. umbellatus* stands as the sediment samples. Each sample consisted of all *B. umbellatus* plant material that originated from a 0.25m^2 area of lake bottom. That is to say, all roots and rhizomes within that area and all stems extending from those rhizomes were removed. Five samples were taken from each of the seven sample areas.

The samples were cleaned of all trapped sediment and non *B. umbellatus* species. The stems were then removed from the rhizomes so as to be treated separately. The samples were air dried for three weeks, weighed, and subsampled before oven drying. Each subsample was weighed, dried at 95° C for 24 hrs., then weighed again. Subsample oven dry weights were extrapolated to calculate dry biomass of the entire sample.

The age of each sample area was determined from records compiled by the Pelican River Watershed District (Figure 3). The age for the oldest known stands was estimated at 20 years, as the exact age is unknown. The geographic location of the sample areas was coded 1 for sites in a small bay with a narrow inlet to the main body of the lake, 2 for sites on the shoreline of the main body of the lake, and 3 for sites extending into the lake along each side of a gravel bar. These were compared to biomass data from each site.

Statistics were calculated using the Statworks program for Macintosh, and graphs were created using Statworks and Cricket Graph. Simple regressions were used to compare each of the three nutrients with stem biomass, underground biomass, and the percent of total biomass found at each site. Multiple regression analyses were used to compare multiple site characterization factors to biomass data. Variance of site characterization factors among sites was determined using one way ANOVA.

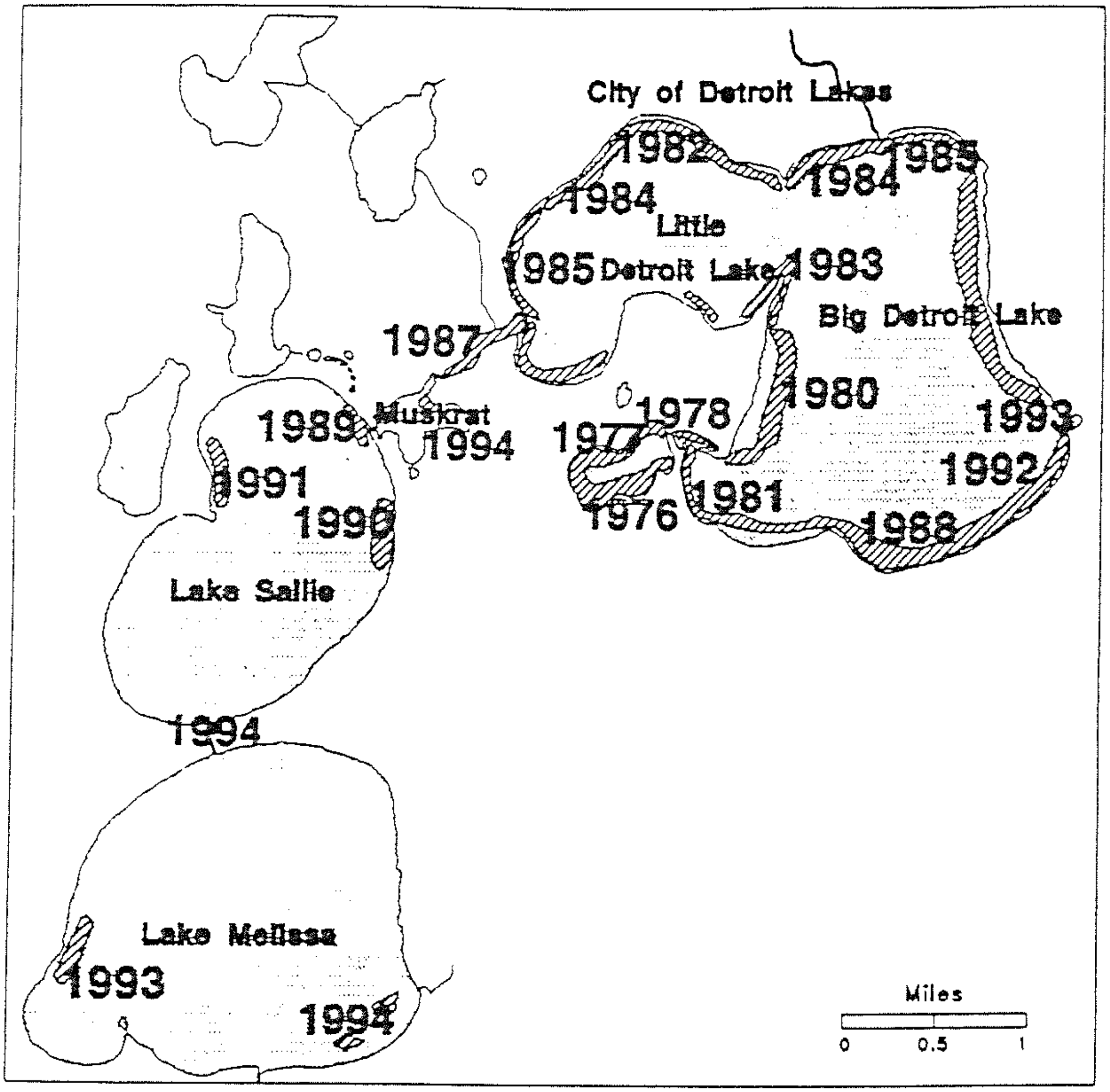

Figure 3: Distribution of *Butomus umbellatus* in the Pelican River Watershed as of 1994. Hashed areas indicate emergent plants of the species; the first year of identification is listed.

Source: Pelican River Watershed District

RESULTS AND DISCUSSION

Stem Cutting as a Control Method

Regardless of the limited number of cutting treatments, some promising results were obtained that may justify further investigation of cutting emergent *B. umbellatus* as a control strategy for mature stands.

The sample plots in which *B. umbellatus* density data were collected were selected randomly each time the test sites were surveyed. Therefore, density data are not paired between pre and post treatment surveys and only mean results can be compared. Nonetheless, the results from the Deadshot Bay site show a significant reduction of density ($p<.05$, $n=3$) following each treatment (Table 1).

TABLE 1: Survey results from the Deadshot Bay site prior to treatment and following each cutting treatment.

survey	min. density $.25m^2$	max. density $.25m^2$	mean density $.25m^2$	total density $5m^2$	% reduction from pretreatment
pretreatment	36	302	159.00	3180	N/A
1st cutting	17	123	71.25	1425	55.19
2nd cutting	7	74	30.55	611	80.79

The effect of a single treatment at the Long Bridge Road site, later in the summer, was an apparent increase in density although not statistically significant (Table 2). As previously mentioned, this site had not emerged at the time the Deadshot Bay site was first treated. One explanation for the increase in stem density is that the site may not have reached its normal maximum stem density prior to pretreatment surveys conducted in late July. Any non-emergent growth at the time of treatment would have escaped being cut and emerged shortly after the treatment, adding to the density when surveyed three weeks after treatment.

TABLE 2: Survey results from the Long Bridge Road site prior to treatment and following the single cutting treatment.

survey	min. density $.25m^2$	max. density $.25m^2$	mean density $.25m^2$	total density $4m^2$	% increase from pretreatment
pretreatment	3	97	36.56	585	N/A
1st cutting	5	90	45.00	720	23.08

Another possible explanation for the increase in stem density may be that at the time of treatment the rhizome system had achieved intense production of lateral branches and of lateral axillary buds, thus allowing for rapid regrowth of the stand. A third possible explanation for the post treatment increase in stem density is the randomness of the sampling procedure. The pretreatment survey mean may have been lower due to sampling of naturally less dense areas than those sampled after treatment or vice-versa (Figures 4 and 5).

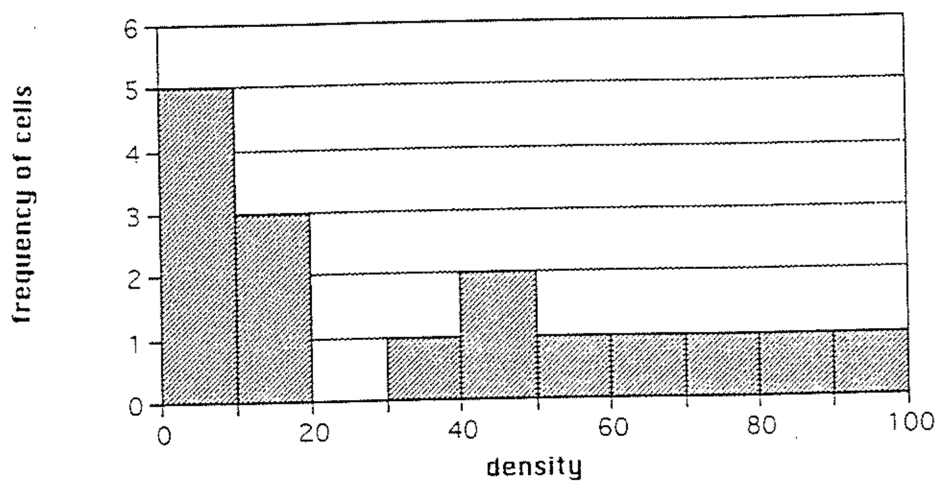

Figure 4: Histogram of pretreatment surveys at the Long Bridge Road site.

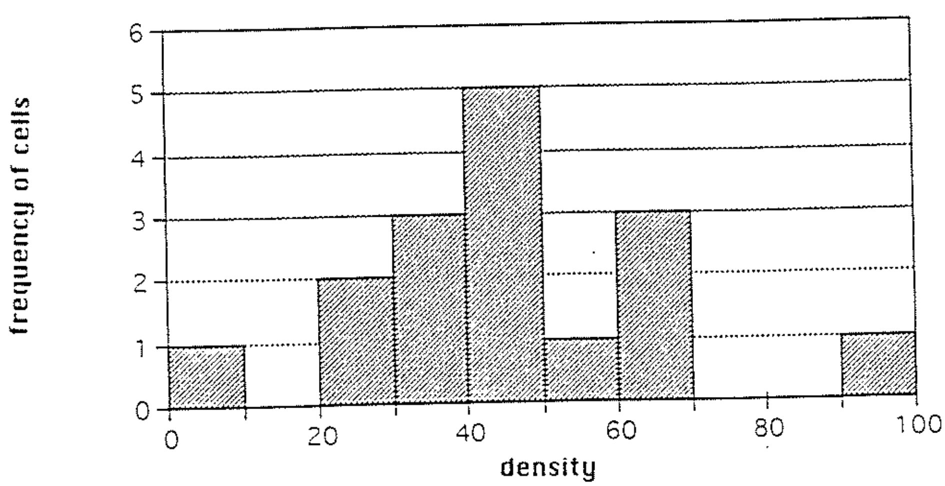

Figure 5: Histogram of post-treatment surveys at the Long Bridge Road site.

The results from the Deadshot Bay site show that repetitive cutting treatments of that *B. umbellatus* stand did reduce its stem density over the course of one growing season. The effect on the following year's growth is as yet unknown, however, and should be investigated. Related to the future density of the stand is the effect of repetitive cutting on the rhizome system. Theoretically the rhizomes should be adversely affected by the sudden interruptions in photosynthesis that result from the cutting of nearly all of the population's stems. Still, the extent of cutting treatments required to permanently reduce or eliminate a stand is unknown and should be explored. Certainly, repetitive cutting over a single growing season will not be effective for elimination of an entire stand. Questions concerning the use of hand cutting as a control strategy include: Of what frequency and for what number of growing seasons should cutting occur before the stem density reduction effect becomes minimal? At what point should alternative control strategies be applied to a stand that has been cut repetitively? What combination of control strategies will have the greatest effect on controlling or even eliminating *B. umbellatus* in the Pelican River watershed.

ANALYSIS OF BIOMASS AND SEDIMENT NUTRIENT CONTENT

In the analysis of the effects of sediment nutrient content on

B. umbellatus biomass several site characterization factors that may contribute to biomass were explored. These were: the age of each sample population, its geographic location, and the sediment particle size. The population age was found to be significantly related ($p<.05$, $n=35$) to stem biomass and rhizome biomass (Figures 6 and 7). Sediment size was not found to be significantly related to *B. umbellatus* biomass, nor was it found to be significantly related to sediment nutrient content (nitrate, potassium, phosphorus) even though sediment size varied significantly ($p<.05$, $n=7$) among sites.

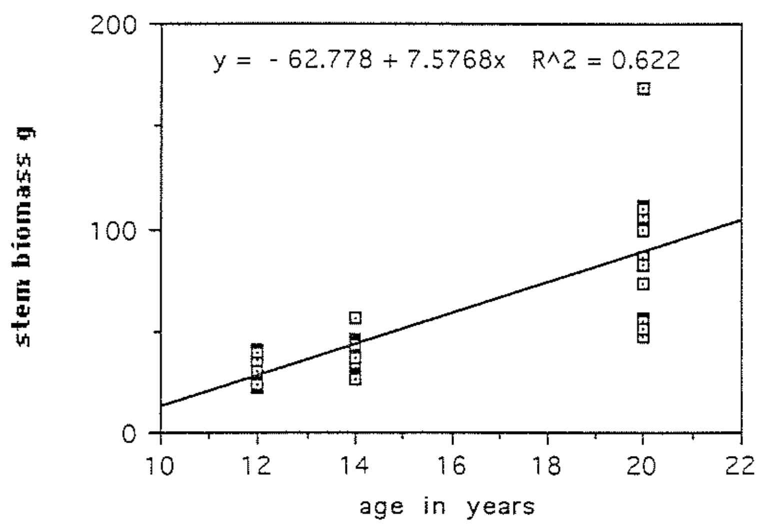

Figure 6: Linear relationship between population age and sample stem biomass.

There is a strong positive relationship between underground biomass and stem biomass (Figure 8). Using a one-way ANOVA both stem biomass and underground biomass varied significantly among sites ($p < .05$, $n=35$). Figure 9 is a representation of mean biomass data collected from each sample area. There was also a significant difference among sites in the percent of total sample biomass found

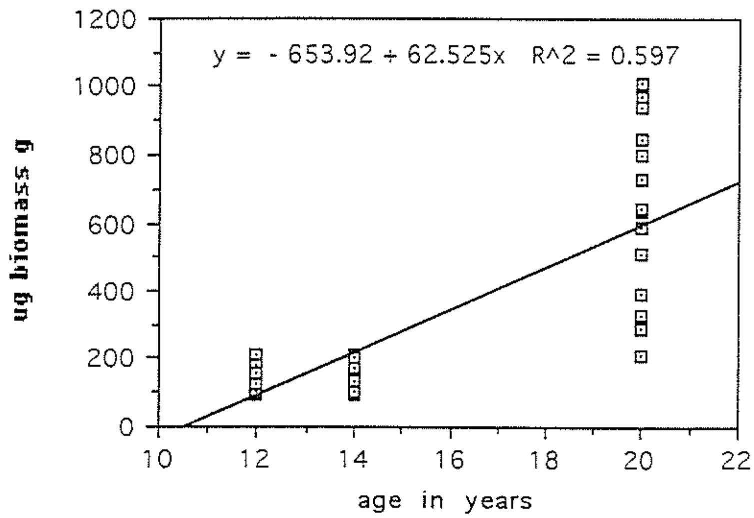

Figure 7: Linear relationship between population age and sample underground biomass

in both stems and underground tissues ($p<.05$, $n=35$) (Figure 10). The use of percentage of total biomass may help offset some variance in actual biomass that could be accounted for by population age or other site differences.

Variations in nitrate content of the sediment samples were not found to explain differences in biomass of stems, underground tissue, or percentages of total sample biomass in either of the two (Figures 11-13). Nor was sediment nitrate content in combination with other site characterization factors, found to explain variations in biomass among samples when multiple regression analyses were

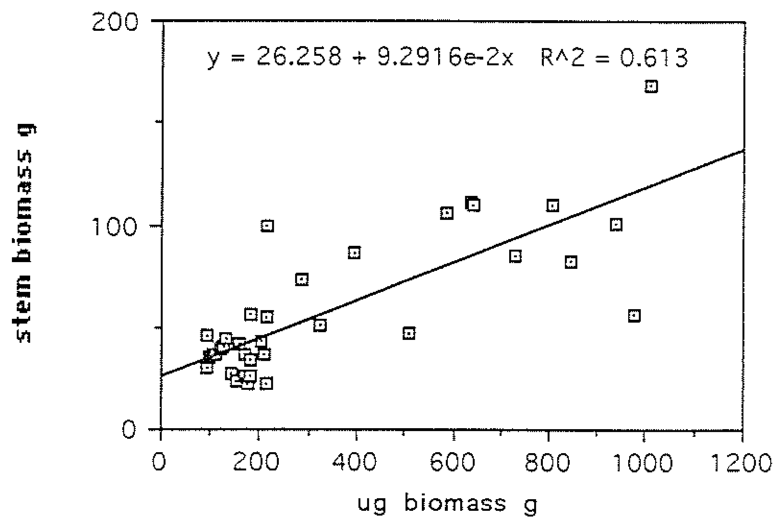

Figure 8:Linear relationship between underground biomass and stem biomass.

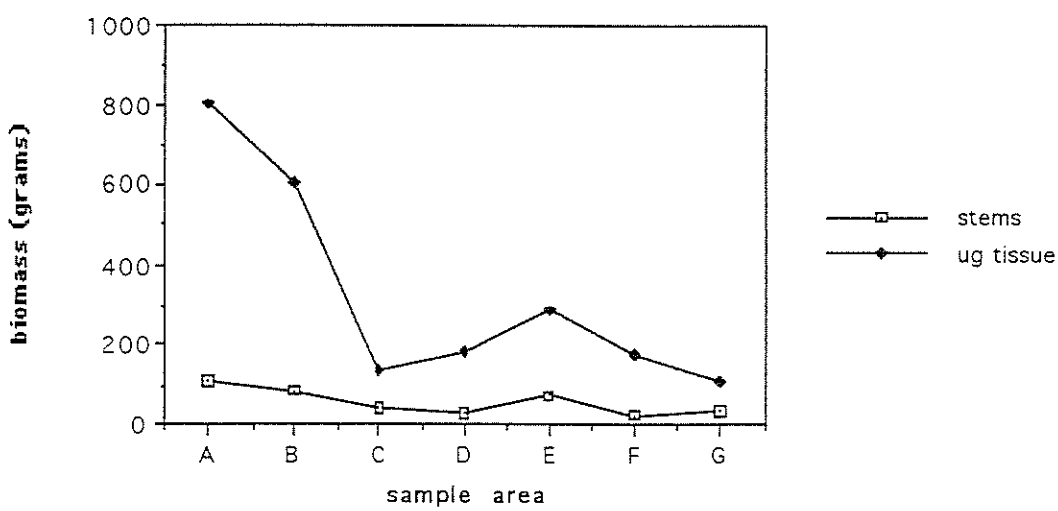

Figure 9: Mean stem and underground (ug) biomass collected from each sample area.

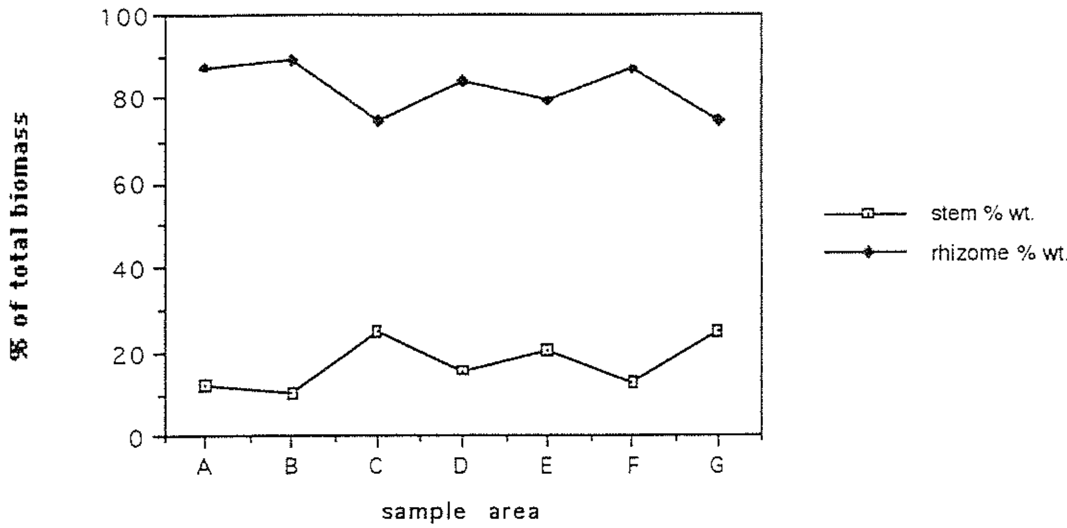

Figure 10: Mean percent of total biomass found in shoots and in underground tissue from each sample area.

performed. This in combination with the relatively low sediment nitrate content from all samples might relate to the possibility that *B. umbellatus* has the ability to utilize nitrate-nitrogen at lower sediment concentrations than other emergent vegetation and thereby has the ability to outcompete other species for the nitrate resource. Furthermore, the relatively large rhizome system allows for nitrogen storage, increasing any competitive advantage based upon nitrate utilization rate. Nitrogen storage may also relate to the ability of *B. umbellatus* to rapidly repopulate an area after being cut below the water level.

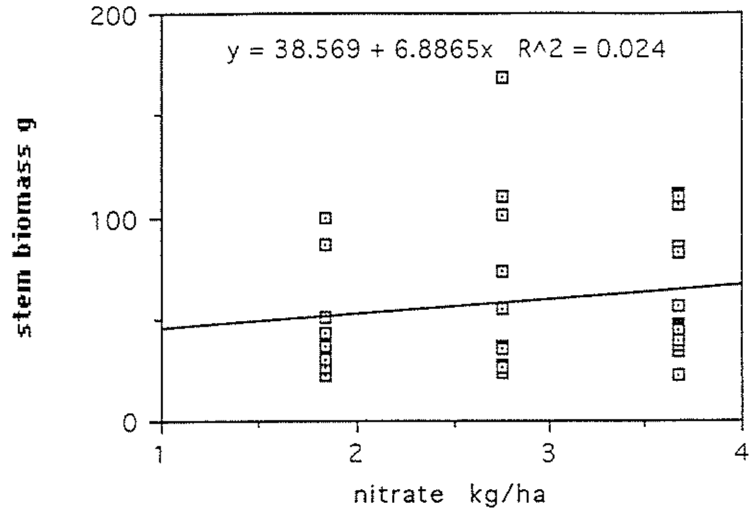

Figure 11: Linear regression showing stem biomass plotted against sediment nitrate content.

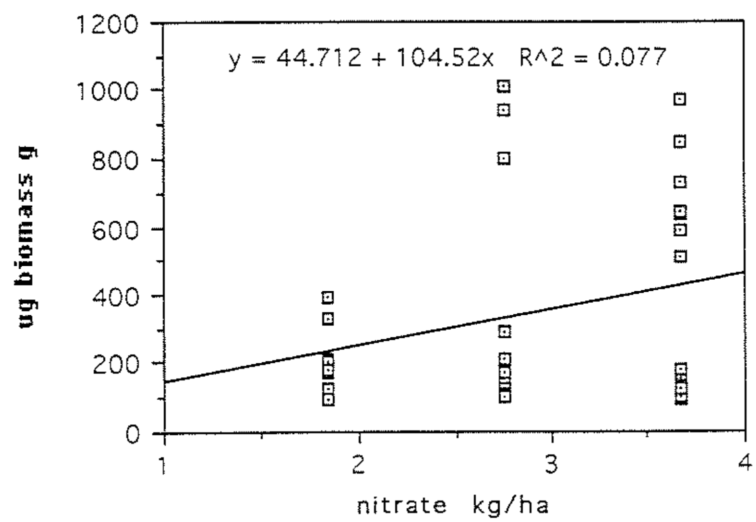

Figure 12: Linear regression showing underground biomass plotted against sediment nitrate content.

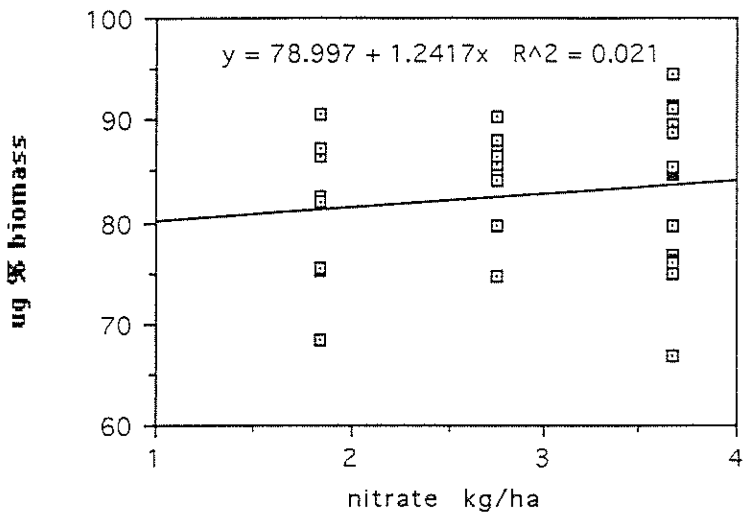

Figure 13: Linear regression showing percent of total sample biomass found in underground tissue plotted against sediment nitrate content.

As with sediment nitrate content, sediment ortho (reactive) phosphate content was not found to be significantly related to variations in stem biomass, underground biomass, or percentages of the total biomass found in either of the two. Figures 14-16 represent linear regressions of these measurements compared to sediment orthophosphate content.

In multiple regression analysis, sediment orthophosphate content in combination with other site factors was not found to significantly affect stem biomass, underground biomass, or percent of total sample biomass of either of the two. However, the two samples with the greatest orthophosphate content had low biomass values. This may be indicative of the species' inability to thrive under these conditions.

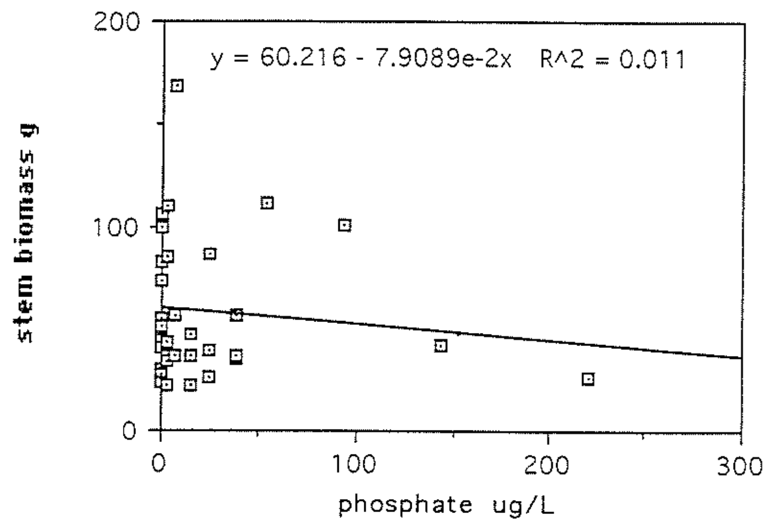

Figure 14: Linear regression showing stem biomass plotted against sediment orthophosphate content.

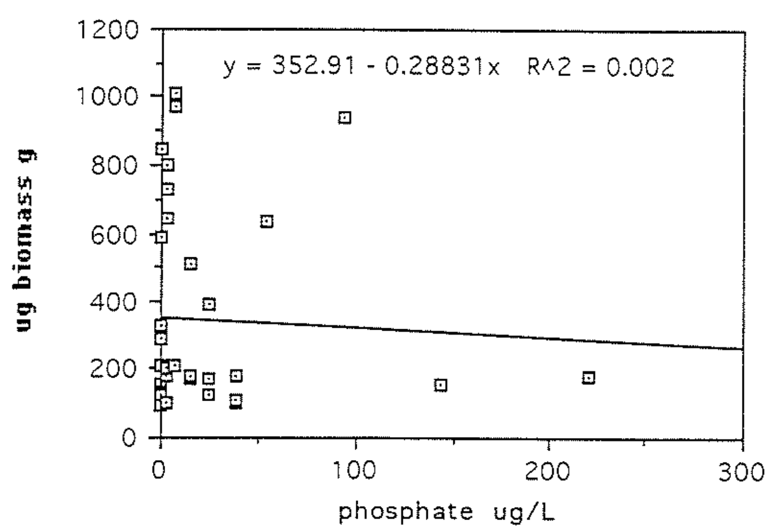

Figure 15: Linear regression showing underground biomass plotted against orthophosphate content.

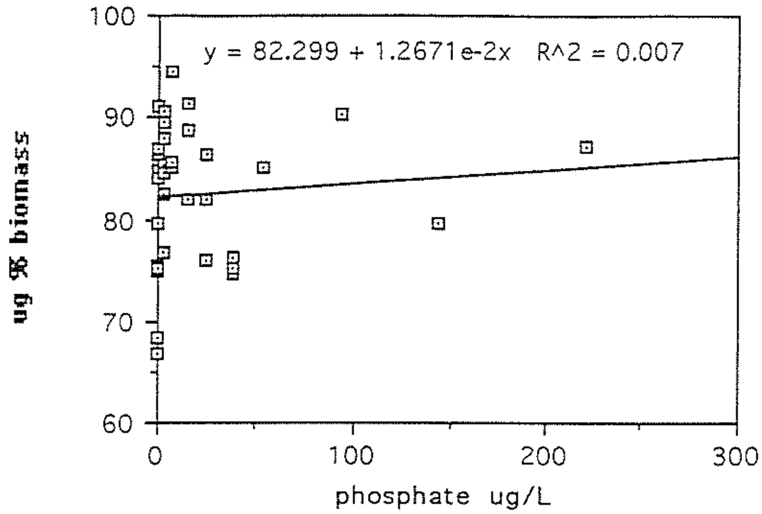

Figure 16: Linear regression showing the percent of total biomass in rhizomes/roots plotted against sediment orthophosphate content.

When sediment sample potassium content is compared with biomass data using simple regression analysis there is a moderate relationship, however its concentration does not account for much variability in biomass among samples. A simple regression comparing stem biomass with sediment potassium content shows that there is a weak relationship although not significant at the .05 level ($p<.13$, $n=35$, $R^2=0.038$) (Figure 17). When comparing sediment potassium content to underground biomass the relationship is similar ($p<.14$, $n=35$, $R^2=0.051$) (Figure 18). There is a slightly stronger relationship, although still not significant at the .05 level, between sediment potassium content and the percent of biomass contained in either the stems or in underground tissue ($p<.08$, $n=35$, $R^2=0.097$) (Figure 19).

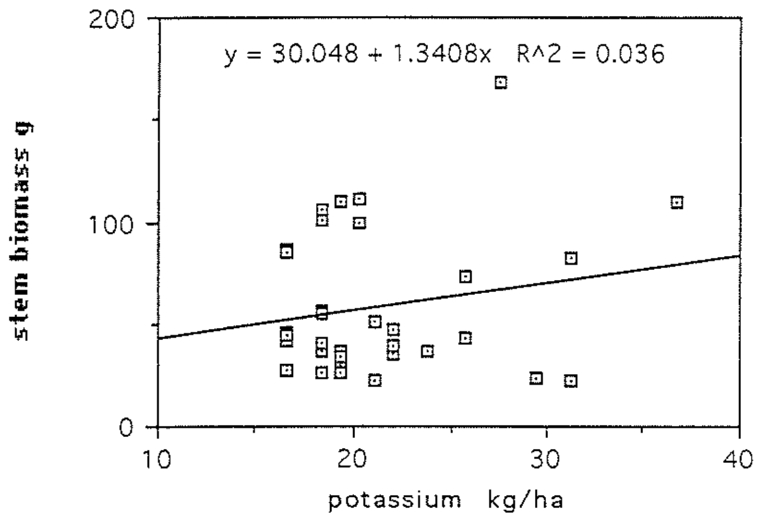

Figure 17: Linear regression showing stem biomass plotted against sediment potassium content.

The relationship between sediment potassium content and *B. umbellatus* biomass increases dramatically when the age of the population and the geographic location of the sample are factored into a multiple regression equation with potassium and biomass. A multiple regression analysis using stem biomass, sediment potassium content, population age, and geographic location of the sample area shows that these site characteristics together are

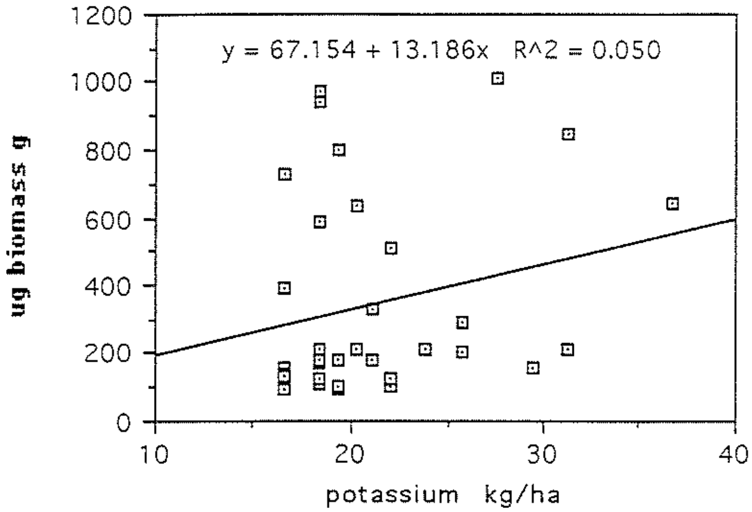

Figure 18: Linear regression showing underground biomass plotted against sediment potassium content.

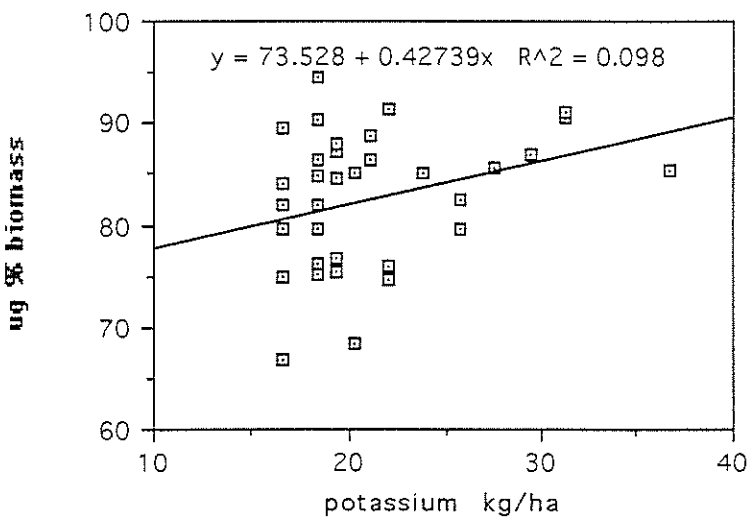

Figure 19: Linear regression showing percent of total sample biomass in underground tissue plotted against sediment potassium content.

significantly related to stem biomass ($p<.01$, $n=35$, $R^2=0.637$). Substituting underground biomass for stem biomass showed a similar relationship ($p<.01$, $n=35$, $R^2=0.631$). Factoring in the sediment size of the sample areas slightly strengthened these relationships, ($p<.01$, $n=35$, $R^2=0.659$) for the effect of these site characterization factors on stem biomass, and for the effect on underground biomass ($p<.01$, $n=35$, $R^2=0.660$).

Using a multiple regression analysis a significant relationship was found between the percent of total biomass in underground tissue and the sediment potassium content, site location, population age, and mean sediment size ($p<.01$, $n=35$, $R^2=0.594$).

The factors that most strongly relate to variations in biomass are the age of the sample stand and its geographic location. There are significant relationships when age is compared, by simple regression, to stem biomass ($p<.01$, $n=35$, $R^2= .622$) and to

underground biomass ($p<.01$, $n=35$, $R^2= .597$). There are also significant relationships when geographic location is compared to stem biomass ($p<.01$, $n=35$, $R^2= .551$) and to underground biomass ($p<.01$, $n=35$, $R^2= .503$)

The sediment potassium content does not strengthen these relationships enough to unequivocally point to it as the most limiting or important nutrient in relation to biomass production of *B. umbellatus*, however of these three nutrients that are most utilized for plant tissue growth, sediment potassium content most strongly accounted for sample biomass variations.

Sediment nutrient levels do not seem to account for much variance in *B. umbellatus* biomass in the Pelican River Watershed. This may be due, in part, to nutrient storage in rhizomes. The lack of variance in biomass due to sediment nutrient content is also in agreement with subject literature that identifies the species as having the ability to flourish in a wide range of nutrient conditions. Further ecological plasticity of the species is evident from the lack of significant variance among sample biomass due to differences in sediment size. In the Pelican River watershed *B. umbellatus* thrives in sediments ranging in size from fine sand to course gravel.

CONCLUSIONS

The results from the hand cutting of the Deadshot Bay site show that this control method can be effective for reduction of the density of an emergent *B. umbellatus* stand over the course of one growing season. However, the effects of repetitive hand cutting during successive growing seasons are yet to be determined. Continued investigation of hand cutting is warranted and necessary in order to answer some of the previously mentioned questions of concern.

Reduction of the density in and possible elimination of the most densely populated *B. umbellatus* stands in the Pelican River watershed will be beneficial for slowing the spread of the species. *B. umbellatus* population reduction should reduce the amount of vegetative material released into the watershed, thereby lowering the chances for long distance dispersal. Also, any success in the elimination of new, sparsely populated emergent stands should slow the downstream spread of the species. Failure at effective control of the species will allow for continued spread in the Pelican River watershed, and could possibly result in the spread of the species to other watersheds in Minnesota.

Results from the comparison of sediment nutrient content to *B. umbellatus* biomass lead to the conclusion that variations in sediment nitrate and orthophosphate content do not explain differences in sample stem or underground biomass, except for an apparent reduction in biomass when sediment orthophosphate concentrations are high. Differences in sediment potassium content are only marginally related to differences in stem and underground biomass. However, differences in sediment potassium content do help strengthen relationships of other site characteristics to biomass. Of the site characteristics explored, population age seems to be the most strongly related to sample biomass. In conversations with property owners on Deadshot Bay it was learned that *B. umbellatus* stands in that area, the most dense in the watershed, have reached their current densities in only the last few years. Several other stands in the watershed may be within a decade of attaining density levels of the Deadshot Bay stands. This further emphasizes the need for an effective control plan, not only for the reduction of density in these areas, but also to eliminate any future increase of viable vegetative material released into the watershed.

The relatively low sediment nutrient content and extremely high above and below ground biomass of emergent *B. umbellatus* suggest that the existing levels of sediment nitrate, orthophosphate, and potassium are not the major factors that limit biomass production of *B. umbellatus*. It seems more plausible that *B. umbellatus* is the superior competitor for limited resources in Big and Little Detroit Lakes. The species may have the ability to reduce concentrations of one or more of these nutrients to levels at which other species cannot exist. Furthermore, the vast amount of emergent stem biomass may be able to reduce available sun light below levels at which native species cannot exist. A further understanding of the possible ability to outcompete native vegetation for available resources combined with proof of the ability of *B. umbellatus* to maintain reserves of limiting nutrients in its rhizomes would help explain its success in certain environments.

Useful future research in this area would include the study of factors of competition between *B. umbellatus*, *Typha*, and *Scirpus* in the Pelican River watershed. It seems as though each has a competitive advantage in different areas of the littoral zones in Big and Little Detroit Lakes, Lake Sallie, and Lake Melissa. Also useful would be the comparison of historic water quality data and historic vegetation surveys of the area. In the past, the Pelican River chain of lakes was highly eutrophic and measures were taken to improve water quality. One of these measures is the mechanical harvest of submersed vegetation. The harvested vegetation is removed from the aquatic environment, thereby removing nutrient reserves from the system. The cross referencing of water quality data with historic vegetation surveys may help uncover factors that have contributed to *B. umbellatus* population increase in the Pelican River watershed.

Another area of interest that may aid in control of the species is investigation of the factors that allow for *B. umbellatus* to form monotypic emergent stands, whereas the submersed and terrestrial forms in Becker County do not form monotypic stands. It may be that certain nutrient or light requirements exist in the emergent zone, allowing for *B. umbellatus* dominance, but these conditions do not prevail in the submersed and terrestrial zones, and *B. umbellatus* does not have a competitive advantage there.

Knowledge of the cytotype of the population in question is important for the control of *B. umbellatus* . This is useful for the reason that cytotype determines the major mode of reproduction of the species. Diploid plants have the ability to produce numerous seeds and reproduce vegetatively, although not as proficiently as triploid plants which have been shown to be sexually sterile. Cytotype also has been shown to determine tolerance ranges for nutrient levels and pH.

For future examination of cutting *B. umbellatus* as a control strategy it is important to ascertain what changes occur within the rhizosphere over the long term. Areas of interest include changes in tissue nutrient levels, changes in sediment nutrient levels, and changes in nutrient mineralization rates. Also of interest is the continuation of data collection concerning the regrowth of stems. The density of regrowth should be closely monitored to determine the limits of any positive effect of a long term cutting project. Also, it may be useful to examine any relationships between the change in biomass of stems removed and changes in rhizome nutrient contents and sediment nutrient contents.

For areas of new *B. umbellatus* colonization, removal of entire individual plants may be the most effective control method. In the soft sandy substrate of the Pelican River chain this is easily accomplished by scooping one's hand or a small tool under the rhizome, which is generally only a couple inches deep, and removing it from the area being careful to avoid breaking the brittle rhizome or separating any lateral buds.

The research conducted in this study dealt only with the emergent form of *B. umbellatus*. Accurate knowledge of aspects concerning the submersed form is equally important for the control of the spread of the species. Especially important is knowledge of this form's ability to reproduce vegetatively and, if needed, what methods of control will be most effective.

In the past there have been conflicting interests concerning the control of *B. umbellatus* in Becker County. The long term effects of cutting the species have yet to be determined, thus the success of the control method can not be assessed after one season. Further research is required in order to develop the most effective long term control plan. Many of the area's property owners have financial interests related to the control of the species and are lobbying for expediency in the development of such a long term plan. It is the author's opinion that continued research toward the development of the most effective *B. umbellatus* management plan is in the best interest of all parties concerned.

APPENDIX A

Process for Mixing Armstrong Reagent

Add 122 mL of concentrated H_2SO_4 to 800 mL of double distilled water. While the solution is still hot, add 10.5 g of ammonium molybdate and 0.3 g antimony potassium tartrate. Heat to dissolve, cool, and dilute to exactly 1 L with distilled water. This will remain stable indefinitely.

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