Growth and Biomass of Water Hyacinth in a Tidal Blackwater River System, South Carolina

By

Amanda Rae Rotella

Submitted in Partial Fulfillment of the

Requirements for the Degree of Master of Science in

Coastal Marine and Wetland Studies in the

College of Natural and Applied Sciences

Coastal Carolina University

2010

____
Dr. James O. Luken
Major Professor

____
Dr. Keith Walters
Committee Member

____
Dr. Doug Van Hoewyk
Committee Member

____
Dr. Michael H. Roberts
Dean

____
Dr. Deborah Vrooman
Interim, Graduate Director

Dedication

I dedicate this publication to my Granny Peacock who gave me my inspiration and love for the environmental field. I also dedicate this work to my parents, Peggy and Raymond Rotella, who have shown me continuous love, support, and guidance. You guys always kept me motivated by reminding me that this is one of the many stepping-stones in life.

Acknowledgements

My endeavors at Coastal Carolina University afforded me many wonderful and life changing opportunities. I am grateful to the South Carolina Aquatic Plant Management Society (SCAPMS) and the University Research Council (URC) for providing me with the funding to complete this project.

I would like to thank all those who participated in my journey. Without them I could not have completed this thesis. Dr. Jim Luken, I especially thank, for his guidance as my advisor. He has been my stand in Dad, constantly advising me in my academic and personal decisions over the past two years. I also thank my committee, Dr. Keith Walters and Dr. Doug Van Hoewyk, for their suggestions and guidance. Finally, thank you to Nyoka Hucks and Michelle Marken for their help and comedic relief during my many office visits.

A special thanks to my assistants David Young and Dara-Lynn Baker for entertaining me with stories and for the strenuous physical backbreaking work they endured. David always kept chugging away, dissecting plants, and shoveling them into bags, even when I wanted to quit for the day. Thank you to all of the graduate students who helped me. These included: Morgan Marsh, Whitney Ruppel, Rachel Connelly, Adam Fox, Laura Canton, Sam Gary, Grant Lockeridge, Julie Murphy, Julie Barker, Karen Heeley, Nick Henke, Katie Eyring, Sarah Gardner, and Jackie Foote. This project definitely required an army of people to complete because of its numerous components.

Abstract

Water hyacinth is considered to be a problematic invasive species worldwide. The plant currently is managed as a nuisance to navigation in the Waccamaw River, SC. Although actively managed, the natural survival and growth of water hyacinths under conditions experienced within the Waccamaw, a tidal blackwater river, have not been examined. Water hyacinth biomass was determined by sequential harvest within three river locations. In addition a field experiment was conducted in which plants were placed within cages made out of nylon netting and PVC and anchored within three river zones. Cages were deployed for one month after which plants were removed and growth measured. Salinity tolerance of individual plants also was investigated in a controlled mesocosm experiments. Mid- and lower-river sites had greater growth and extension in root length, longest leaf length, widest leaf width, and stem base diameter. Most biomass was in the leaves. Biomass was greater in the back of the water hyacinth mat during the fall season, than in the spring. Salt levels ≥ 4.5 ppt resulted in no plant production. Results suggest the plant responds to an increase in nutrients with greater growth. However, results also suggest standing crop and growth are reduced in this aquatic system when compared to other studies and plant growth will be reduced as individuals are transported naturally down the river towards estuarine regions of increased salinity.

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ICW –Intercoastal Waterway

DO- dissolved oxygen

PPT- parts per thousand

INTRODUCTION

Invasive Species

Human perceptions and biases about invasive species can influence management practices. Biases often are expressed through sensationalized and inconsistent use of terminology (Davis and Thompson 2000). For example, invasive plants commonly are called introduced species, non-indigenous species, exotic plants, weeds, noxious plants, or non-native species (Davis and Thompson 2000). Sensationalized accounts result in people thinking invasive species, such as water hyacinth, grow faster and in greater numbers in introduced compared to native habitats (Crawley 1987, Hierro *et al.* 2005). Invasive species often occur at only moderate densities in introduced habitats (Hierro *et al*. 2005), but frequently data are lacking to compare the performance of invasive species in native versus introduced habitats.

Nearly 5,000 introduced plant species brought in for food, fiber, or ornamental reasons have ‘escaped’ and now are establishing in the United States (Morse *et al.* 1995, Pimental *et al*. 2000). Invasive plants are distributed around the world by various means. People typically introduce plants unintentionally as attached seeds when agricultural experiments are not properly controlled, as a souvenir, to resolve an existing environmental problem, or to examine the species in detail (Carlton and Ruiz 2000). In the U.S. each of the aforementioned reasons and others have led to the introduction of invasive plants.

Invasive plants are successful in occupying new areas rapidly through both vegetative propagation and sexual reproduction. The growth of invasive plants often exceeds the surrounding native plants and leads to an alteration of the community

(Penfound and Earle 1948, Luken 1997, Pimentel *et al*. 2000, Cronk and Fennessy 2001). Environmental alterations by invasives can have negative effects on both the local ecology and human populations. In aquatic systems, invasive plants directly affect humans by obstructing navigation and recreation within waterways, decreasing fish production, clogging boat motors, and increasing the prevalence of parasitic diseases (Gopal 1987, Luken 1997, Pimentel *et al.* 2000, Cronk and Fennessy 2001). Economic costs associated with invasive species are not trivial and are estimated to exceed $137 billion per year (Pimentel *et al.* 2000).

Aquatic Invasive Species in River Systems

The production and growth of aquatic invasive species are different depending on the aquatic system. River systems of the U.S. coastal plains are divided into redwater and blackwater systems (Hopkinson 1992). Redwater rivers tend to originate in the Piedmont region and carry red clay sediment deposits which make the rivers more nutrient rich and more alkaline (Hupp 2000, Laurie and Chamberlain 2003). Blackwater rivers arise in the coastal plain and typically have a low slope which affects sediment characteristics, water velocity, and chemistry (Smock and Gilinsky 1992). As these rivers flow through the coastal region natural erosion and sediment deposition may cause the river to meander and change course cutting new channels and forming oxbow lakes (Laurie and Chamberlain 2003). A blackwater river is characterized by a high dissolved organic carbon concentration that results in the dark color of the water and an increase in acidity (Smock and Gilinsky 1992). The Waccamaw River, a blackwater river, and the Pee Dee River, a redwater river, are linked through Bull Creek.

The Waccamaw River also experiences seasonal variations in flow. High-flow occurs in the winter, while low-flow occurs in the summer and autumn. Lower flow rates are more a product of increased rates of evapotranspiration than low precipitation (Smock and Gilinsky 1992). The Waccamaw River experiences semidiurnal tides near the mouth in Georgetown, SC (Doyle *et al*. 2007). The boundary between fresh and brackish water depends on precipitation, river flow, and tidal stage (Laurie and Chamberlain 2003).

Water hyacinth (*Eichhornia crassipes* (Mart.) Solms) is established and currently managed in the Waccamaw River, but limited data exists to predict growth patterns and effects on the blackwater river system. The following section is a detailed account of the species and should be useful to individuals needing more background on either the plant or on the management practices.

The Species

Invasive species, like water hyacinth, often have complex invasion histories. One anecdote concerning the introduction of water hyacinth into the U.S. can be traced back to an expedition along the Orinoco River of Venezuela, where Japanese exhibitors collected water hyacinth because of plant's beautiful lavender flowers (Wolverton and McDonald 1979). The exhibitors transported the plant all the way to New Orleans, Louisiana and gave away water hyacinth as a souvenir at the 1884 Cotton Centennial Exposition (Penfound and Earle 1948). Guests of the exhibition took the plant home to admire, introducing water hyacinth to ponds and rivers throughout the Southeast. Without the insects, viruses, and other natural enemies which presumably kept the plant in homeostasis in a tropical environment, water hyacinth grew rapidly (Wolverton and McDonald 1979).

The literature suggests that water hyacinth was introduced into Florida after a visitor to the exposition brought some back for a lawn fountain. The plant grew excessively and cuttings were thrown into the St. Johns River near Palatka, Florida (Tabita and Woods 1962, Zeiger 1962). By 1900 water hyacinth had spread so extensively that steamboats had difficulty navigating the river (Zeiger 1962).

Water hyacinth was first recognized as an issue by the federal government in 1897 when Congress paid for an investigation of how the plant was obstructing navigable waters of Florida and other southeastern territories (Tabita and Woods 1962). The goal was to experiment with removal and find the most feasible method. In 1899, the 55th Congress authorized a program for the Removal of Aquatic Growths under the Rivers and Harbors Act (Schmitz *et al.* 1993, Cronk and Fennessy 2001). The Act allowed for the destruction of water hyacinth throughout the southeast in order to clear obstructions from navigable waterways. The Act permitted mechanical and chemical removal (Tabita and Woods 1962). Soon after, the Army Corps of Engineers was given command to control water hyacinth populations.

The Clean Water Act was later adapted from the Rivers and Harbors Act to regulate water pollution. Other laws created to control invasive plants and water hyacinth in particular included the Federal Noxious Weed Act of 1974, the Water Resources Development Act of 1986, the Non-Indigenous Aquatic Nuisance Prevention and Control Act of 1990 and the National Invasive Species Council established in 1999 (Schmitz *et al*. 1993).

Water hyacinth is a floating, fleshy aquatic plant. Currently, water hyacinth exists in almost all regions of the world, including Africa, Australia, China, India, and Japan.

The range is limited primarily by temperature. The species presently is distributed between 38° N and 38° S (Gopal 1987). Water hyacinth can be found in freshwater habitats including shallow temporary ponds, marshes, large lakes, reservoirs, and rivers (Gopal 1987). The plant also can be found in slightly brackish environments as well as tidal fresh waters (Tiner 1993).

Water hyacinth belongs to the Pickerelweed family, Pontederiaceae, which consists of mostly tropical species. The thick, leathery, egg-shaped leaves can range from 1.25 cm to 14.00 cm in length (Tiner 1993, Aulbach-Smith and de Kozlowski 1996). A flowering stalk develops that consists of five to twenty six-petaled, violet flowers with the upper middle petal having a yellow dot in the center (Tiner 1993, Aulbach-Smith and de Kozlowski 1996). Plant fruits are a three-celled seed capsule (Muenscher 1944).

The plants also can reproduce by vegetative runners or stolons (Aulbach-Smith and de Kozlowski 1996). Vegetative growth is rapid except in winter (Penfound and Earle 1948). With continued propagation, plants form a dense mat connected through the stolon offshoots. Initially plants grow horizontally along the water surface increasing in numbers and only later in the season change to vertical growth (Tucker 1981, Gopal 1987). The edge of a water hyacinth mat can extend 60 cm/month (Penfound and Earle 1948). In Louisiana, two parent plants produced 300 offspring in 23 days and 1,200 within four months (Vietmeyer 1975). Mats have been reported to be so thick that ships had difficulty breaking through (Gopal and Sharma 1981).

Vegetative reproduction contributes most to mat growth, but water hyacinths have the potential to reproduce sexually. The seeds germinate in the water hyacinth mat or on moist sediment (Hitchcock *et al.* 1949). Seedlings are better able to grow on a less crowded mat with greater access to sunlight (Penfound and Earle 1948). Flowering takes place ten to fifteen weeks after seed germination, a short time span for most perennial species (Barrett 1980a). The flowering season lasts five to nine months in many parts of North America (Barrett 1980a).

The fourteen day flowering cycle concludes when the apical flowers open and the stalk bends towards the water (Penfound and Earle 1948, Gopal 1981). The flowering stalk will bend at three sections: the rhizome crown, midway up the stem, and in the rachis (Penfound and Earle 1948). In warm weather the bending process can take 23 to 33 hrs, while in cooler temperatures the process takes up to 4 d (Penfound and Earle 1948). Once bending is complete and the flowers are submerged, the fruit grows and ripens (Penfound and Earle 1948). The capsule then disperses the seeds into the water where the seeds either sink to the bottom or are entangled in the water hyacinth mat (Penfound and Earle 1948). A single plant produced > 240,000 seeds in a twenty-one day period (Barrett 1980a). Submergence is not necessary for seed production (Das 1969, Gopal and Sharma 1981). On average, submerged fruits contain 15 seeds/plant, while non-submerged fruits contain 41 seeds/plant (Das 1969). Seed numbers range from 9 to 242 in submerged and 2 to 160 in non-submerged fruit capsules (Gopal and Sharma 1981). Once dispersed, seeds remain dormant and viable in sediments from fifteen to twenty years, germinating when conditions are appropriate (Gopal 1987).

Controversy surrounds whether pollination by insects occurs in water hyacinth. Honeybees and other insects were found to visit flowers, but the number of visitors observed, did not account for the high number of capsules (Penfound and Earle 1948).

Other studies observed insects visiting the flowers; however, pollen was not transferred to the stigma (Penfound and Earle 1948, Seed and Obeid 1974, Barrett 1980b). Pollination also may be influenced by the length of the style (Barrett 1980b, Penfound and Earle 1948). Penfound and Earle (1948) observed that pollination from insects rarely occurred because the mid-styled form of water hyacinth was predominant in Louisiana. Barrett (1980a) found that prolonged periods of vegetative reproduction lead to mutations that altered fertility and prevented sexual reproduction.

Barrett (1980b) compared clones of water hyacinth from diverse regions and found that, although the plant demonstrated vegetative propagation as a major form of reproduction, water hyacinth was still capable of sexual reproduction in many regions. Environmental factors played a larger role in the plants sexual reproductive success rather than genetic factors and seed production, which was twice as great in tropical environments as it was in temperate environments (Barrett 1980b). Factors limiting sexual reproduction were pollinator visits and necessary conditions for seed germination and establishment (Barrett 1980b).

Water hyacinth growth is influenced by nutrient levels, salinity, and water temperature. The main nutrients contributing to growth are nitrogen and phosphorous. Reddy *et al*. (1989) found that the level of nitrogen in the plant tissue directly was related to the concentration of nitrogen added to the water and maximum biomass yield was obtained at a nitrogen concentration of 5.5 ppm. Knipling *et al*. (1970) found that plants in a low-phosphorous environment of 0.05 ppm had larger root-to-shoot ratios than plants in high phosphorous water of 0.50 ppm. Haller and Sutton (1973) reported an optimal phosphorous concentration to be 20 ppm, which is 20 times the amount of Reddy *et al.*

(1990), who found plant growth to respond at only 1.06 ppm. Increased phosphorous supply did not further amplify yield. Water hyacinth is also dependent on plant density (Reddy *et al*. 1990).

While some aquatic plants are adapted to higher salinities, water hyacinth is intolerant of salinity at increased levels. Plants experience physiological stresses to an increase in salinity through a reduction of water potential in the salt water (Epstein and Bloom 2005). These stresses result in decreased productivity of the plant (Penfound and Earle 1948, Epstein and Bloom 2005). Penfound and Earle (1948) claimed lethal toxicity to the plant to be at 2.19 ppt. Other studies reported the lethal level to fall between 3.29-3.41 ppt (Haller *et al*. 1974, Zhenbin *et al*. 1990, and Olivares and Colonnello 2000). Muramoto *et al*. (1991) found the lethal level to be at 6.30 ppt and De Casabianca and Laugier (1995) recorded it at 8.76 ppt. Similarly, Water lettuce (*Pistia stratoites*) growth severely decreased at salinity levels above 1.66 ppt, resulting in mortality at levels ≤ 2.50 ppt (Haller *et al*. 1974). Duckweed (*Lemna minor*) maintained consistent growth even at salinity levels of 5.0 ppt (Haller *et al*. 1974).

Different plant species are adapted to different temperature zones and for each species there is an optimum temperature at which it functions best (Mitchell 1974, Epstein and Bloom 2005). When temperatures drop below the optimum, biochemical and physical processes continue at less than their maximum rate, resulting in decreased productivity of the plant (Epstein and Bloom 2005). Temperatures below 0° C are lethal, but water hyacinth can survive subfreezing temperatures for short durations of time (Penfound and Earle 1948). Penfound and Earle (1948) established that the most vulnerable part of the plant to freezing temperatures was the rhizome tip. Knipling *et al*. (1970) found that optimum growth for water hyacinth occurred between 22-35°C.

Few previous studies in South Carolina examined growth and biomass of water hyacinth in a tidal blackwater river. The Waccamaw River is a tidally influenced, low nutrient, low oxygen system at the northern range of water hyacinth distribution, and questions remain about how plant production is affected by these conditions. The objectives of this study were to assess the growth of water hyacinth, to measure growth in response to variation in water quality, and to determine how salinity may affect water hyacinth growth. The ability to predict water hyacinth growth and biomass is important for expanding integrated management approaches in South Carolina.

METHODS

Study Sites

The study was conducted in the Waccamaw River, SC (33°38'12.41" N, 79°05'37.22"W) a freshwater, low oxygen, low nutrient system, the lower reaches of which are estuarine. Tidal fluctuations and seasonal drought affect the extent of saltwater intrusion, modifying the hypothetical salinity gradient (Fig. 1) proposed for the Waccamaw River (Conner *et al*. 2007). According to Conner *et al*. (2007), the location of this study would fall between the tidal freshwater forest/marsh and the oligohaline system (Fig. 1). The Atlantic Intracoastal Waterway joins the Waccamaw near Enterprise Landing and shares the channel until emptying into Winyah Bay, Georgetown, SC. The Pee Dee River also enters the Waccamaw River via Bull Creek near Longwood Island. The joining of Bull Creek with the Wacammaw presumably allows for an alteration in nutrient availability.

Water Quality

Specific conductance and dissolved oxygen (DO) were measured to compare with published USGS data, not for a comprehensive assessment of water quality. Specific conductance and DO were measured using a YSI 30 or 55 multiprobe meter. Specific conductance was recorded for the upper river sites on June 17, 2009 at 10:30 AM for the inside of the mat, the outside of the mat, and in the channel where the cages were located (Fig. 3). Middle and lower river specific conductances were recorded around the cages on July 1, 2009 at 10:30 AM. Dissolved oxygen was recorded for the upper river sites on June 17, 2009 at 10:30 AM for the inside of the mat, the outside of the mat, and in the channel where the cage was located. Middle and lower river DO was recorded around the cages on July 1, 2009 at 10:30 AM. Water quality data were presented simply as means and standard errors as a method of relative comparison to data collected by USGS.

Biomass

Surveys of the Waccamaw River in April 2009 indicated three persistent populations that survived the winter (Fig. 2). The three populations were located at upper river sites and were used for the biomass study (Fig. 3). In the spring (June 10, 2009) and fall (October 14, 2009) harvests were performed to assess biomass allocation (% biomass in leaves, roots, stem bases, and stolons). Water hyacinths were collected from within four 0.25 m^2 frames haphazardly placed either at the front and/or the back of each mat (n=3). Application of herbicide by DNR in September killed plants within the front of mats and samples only were collected from the back of the mats in October. Whole plants and loose parts were collected within each frame by using extendable forged steel hedging sheers. Plants were rinsed with water to remove periphyton, macroinvertebrates and attached organic and inorganic matter before separating into leaves, roots, stem bases, and stolons.

Plant dry mass was measured after tissue was dried at 70° C for 48h. Samples from the four frames collected in the front and back of each mat were combined to obtain a single estimate of biomass. From each combined sample, 20 random subsamples were selected to determine ash-free dry mass (AFDM). Small sections of leaves (0.56 g), roots (0.60 g), and stem bases (0.60 g) were taken from subsamples. Subsample sections were then combusted at 500° C for 10 hrs and the AFDM determined by subtraction (Mean % ash contents ± SE, leaves 16.50 ± 2.50, roots 23.00 ± 4.93, and stem bases 24.33 ± 11.85).

Water hyacinth biomass from the front and back of mats in the spring was compared with a paired samples t-test. Biomass from the back of mats in spring and fall was compared using a t-test. In addition correlations between the various plant components were calculated. The goal was to determine the degree of association between total plant biomass and various plant components. Correlations were run for the fall data and the spring data. $P<0.05$ was chosen as a level of significance for all analyses. SPSS version 17.0 was used for all statistical tests.

Field Growth Caging Experiment

Sites for the field experiment were selected from within the three large populations of water hyacinth or within nearby smaller sub-populations. Middle and lower river sites were selected based on depth of water and presence of spatterdock (*Nuphar luteum var. sagittifolium).* Eighteen sites were established in total, six in the upper Waccamaw near Peach Tree Landing, six in the mid-Waccamaw between Enterprise Landing and Bucksport Marina, and six in the lower river near Longwood Island (Fig. 3).

Cages constructed from ¾" PVC piping and nylon netting based on the methods described by Grecco and de Freitas (2002) were placed at upper (n=12), middle (n=6), and lower river sites (n=6). Each cage was 1.0 m^2 and was fixed to the river bottom using nylon rope tied to a brick. Enough slack was left on the rope to account for the change in tides, as well as storms. Upper-river cages were deployed on May 19, 2009 while mid- and lower-river cages were deployed on June 1, 2009. Each cage was stocked with six young water hyacinth ramets of equal size, the longest leaf length between 7 to 25 cm with new offshoots removed, in (Greco and Freitas 2002). Individual plants were numbered with stainless steel tags affixed to the root base with zip ties. All green leaves were counted and root length, longest leaf length, widest leaf length, and stem base diameter initially measured on each caged plant. The experiment was completed at the end of one month and the number of leaves were recounted and root length, longest leaf length, widest leaf length, and stem base diameter re-measured for each plant. Duplicate cages in the upper river were combined and averages were calculated to yield 6 samples. The absolute growth rate of each original plant and new plants were calculated as the difference between the final and initial values. The original plants and new plants were combined to account for the cumulative growth of each cage. ANOVA was used to determine significant growth differences among the three different river zones. A Tukey HSD test was used to compare each group mean with every other group mean in a pair-wise manner. Data were square root transformed to meet ANOVA assumptions. P<0.05 was chosen as a level of significance for all analyses. SPSS version 17.0 was used for all statistical tests.

Caging Experiment Plant Tissue Analysis

Ten plants were randomly selected from cages in each river zone. Plants were separated into leaves and roots and the leaves and roots from two plants combined to produce a total of five samples of each plant part for each zone of the river. The samples were sent to Clemson University's Agricultural Lab for analysis. Nitrogen, phosphorous, potassium, calcium, magnesium, zinc, copper, manganese, iron, sulfur, sodium, boron, and aluminum levels were measured to look for variations in nutrient absorption of the plant in the different zones of the river. Two root samples were insufficient for total plant tissue analysis and only Nitrogen content was obtained. Statistical analysis used was a one-way ANOVA to test for significant differences in nutrient and element content among river zones. $P<0.05$ was chosen as a level of significance for all analyses. SPSS version 17.0 was used for all statistical tests.

Mesocosm Salinity Experiment

The tolerance of local water hyacinth plants to different salinity levels was tested in two mesocosm experiments. Experiments initially were designed to block for local gradients in shade and sprinkler effects. Individual ramets were rinsed and new growth removed before placing one each into 22 L orange paint buckets (n=40). Each bucket was labeled and filled with 15 L of tap water. Instant Ocean® was used to vary salinities among treatment levels and 30 mL of Miracle-Gro® Liquid Plant Food was added to each treatment to stimulate growth. Salinity treatment levels were 0, 0.5, 5, and 18 ppt in the June experiment and 0, 1.5, 3, and 4.5 ppt in the September experiment. Both experiments lasted for one month and were conducted at the CCU greenhouse site.

The four treatment blocks were established with 4 rows of 10 buckets, each with a different salinity treatment and were randomized to account for any changes, which could result in an alteration of growth (light availability, sprinklers, etc). Leaf number was counted and root length, longest leaf length, widest leaf length, and stem base diameter were measured for each plant. Dissolved oxygen was recorded using a YSI 55 DO meter. Temperature and conductivity were recorded using a YSI 30 Conductivity meter. Absolute growth change in new leaves, new offshoots, root length, longest leaf length, widest leaf width, and stem base diameter were analyzed in the salinity experiment. Salinities $\geq$ 5.0 ppt resulted in total plant mortality so a t-test was used to test for differences between 0.0 and 0.5 ppt in the first experiment. A Levine's Test for Equality was used to check that data met assumptions of the t-test. In the second experiment a one-way ANOVA was used to test differences among salinity treatment levels. One sample from 4.5 ppt was removed because it died. A Tukey HSD test was used for pairwise comparisons among treatment levels if a significant salinity effect was identified. $P<0.05$ was chosen as a level of significance for all analyses. SPSS version 17.0 was used for all statistical tests.

RESULTS

Variation in Water Quality Among Research Sites

The results for specific conductance of our sites closely resembled the data collected by the USGS (Fig. 5). There was a slight increase in specific conductance at Longwood Island, where the lower river sites were located (Figs. 3, 5). Specific conductance ranged from 85 uS/cm in Conway to 100 uS/cm in Pawleys Island.

Our DO data were similar to daily means for USGS data (Fig. 6). Dissolved oxygen ranged from a low of 2.0 mg/L in Bucksport to a high of 4.1 mg/L in Conway.

Biomass

Spring biomass ranged from 157.3 g/m^2 in the front of the mat to 202.9 g/m^2 in the back of the mat (Fig. 7). Total spring plant biomass was significantly different between the front and back of the mat ($t_2 = -9.125$, $P < 0.05$, df= 2). In the spring biomass sample, leaves made up 58% of total biomass, while roots made up 36% of total biomass. Majority of biomass was found in the roots and leaves (Fig. 7). There was a 39% increase in leaves and a 10% increase in the roots in the back of the mat compared to the front of the mat. Biomass nearly doubled from 202.9 g/m^2 in the spring to 380.13 g/m^2 by the fall (Fig. 8). Stem base biomass was significantly different between spring and fall ($t_2 = -4.554$, $P < 0.05$, df= 2). Leaves exhibited the highest percentage of total biomass, as well as the most seasonal change, increasing by 116% (Fig. 8). Roots increased in length from spring to fall by 24%.

Dry weight of roots and leaves were correlated with total biomass (Fig. 9). Correlation r values for the spring ranged from 0.41 to 0.91 with leaves and roots exhibiting majority of total biomass. The correlation for stolons was weak when compared with total biomass of the plant (Fig. 9). The fall harvest revealed r values ranging from 0.45 to 0.93 with higher correlations between total biomass and dry weight of leaves and roots (Fig. 10). The correlation for stolons remained low in the fall (Fig. 10).

Growth Experiment

Water hyacinths grew best when plants were placed in lower river sites (Fig. 11). The growth of all plant parts was significantly different (Tukey HSD, $P < 0.05$) in the lower river compared to the upper river and middle river sites with the exception of the roots (ANOVA, $F_{2, 15} = 2.176$, $P > 0.05$). The longest leaf length was the one component of growth which responded greatest to river zones (Fig. 11). Cumulative longest leaf length range increased from 10.16 cm/day in the upper river zone to 42.98 cm/day in lower river zone. Number of cumulative leaves produced per frame increased from an average of 5 per day in the upper river zone to 11 per day in the lower river zone.

Nutrient Accumulation

Percent nutrients (N, P, K, Ca) found in leaves and roots of water hyacinth plants in the lower river zones differed significantly between the upper and middle river zones (Fig. 12). Only Ca exhibited a negative change in content of plants when grown in the lower river zone. Leaves in the upper and lower river zones differed in percent content of N by 1%, K by 3%, P by 0.24%, and Ca by 0.58%. Higher percentages of nutrient content were found in the leaves as compared to the roots (Fig. 12). Roots only showed significance between the lower river zone and the middle river zone in the percent content of P (Fig. 12B) (ANOVA, $F_{2, 10} = 4.971$, $P < 0.05$). Roots in the upper and lower river zones differed in percent content of N by 0.33%, K by 0.49%, P by 0.004%, and Ca by 0.10%. In general, water hyacinth plants contained greater levels of nutrients in the leaves compared to other plant parts.

Elements (Cu, B, Zn, Al, Fe, Mn, Na) showed greater variation among river zones when compared to nutrients (Fig. 13, 14, 15, 16). Element content was generally higher in the roots than in the leaves. Al and Fe levels showed greater differences in content in the roots than in the leaves (Fig. 14, 16). There was no clear trend among element levels and river zones.

Salinity Experiment

The first salinity experiment resulted in strong effects on the water hyacinth plants. In the first salinity experiment all water hyacinth plants were green and noticeably healthy at the start of the experiment. By 1500 h leaves on the plants in the 18 ppt treatment were curled at the edges and by the third day wilting was noticeable in majority of plants in salinity treatments. Plants in 5 and 18 ppt treatments became yellow and soft after one week and appeared dead by the fourth week. When transferred into buckets with water at 0.0 ppt dead appearing plants did not improve; the water hyacinths were irreversibly affected.

Water hyacinth plants showed a general decline in relative production as salinity was increased (Fig. 17, 18). Plants at 0.5 ppt had more offshoot production than plants at 0.0 ppt (Fig. 17). The saline solution did not appear to benefit any other production of the plant at 0.5 ppt, except in offshoot production (Fig 17). Treatment of 0.5 ppt resulted in a negative growth of roots, leaves, and stem bases. Difference among treatments was only found in stem bases ($t_2 = 2.722$, $P < 0.05$, df= 18). In experiment one, salinity treatments represented a mean conductance of 354.90 µS/cm for 0.0 ppt, 1564.18 µS/cm for 0.5 ppt, 7974.00 µS/cm for 5 ppt, and 26724.00 µS/cm for 18 ppt. High conductance levels were a result of using tap water, as well as adding fertilizers and salt to the water used in the experiment. Mean DO ranged from 6.60 mg/L to 9.90 mg/L across treatments.

In the second experiment salt strongly affected the growth of water hyacinth plants as well. The plants used in the second experiment were gathered toward the end of the season in September, therefore causing the plants to be larger in comparison to the ones used in the first experiment.

The second experiment revealed a general decrease in plant productivity as salinity increased (Fig. 19, 20). Plants in 0.0 ppt grew better than in other treatments. All growth components at 0.0 ppt showed a significant decrease in growth from those at 4.5 ppt (Tukey HSD, $P < 0.05$). There was significant difference among treatments in growth of offshoots (ANOVA, $F_{3,36}= 28.80$, $P < 0.05$) and new leaves produced on those offshoots (ANOVA, $F_{3, 36} = 25.13$, $P < 0.05$). Between 1.5 ppt and 4.5 ppt offshoot production was relatively low (Fig. 19). There was generally less offshoot production than in the first experiment carried out in July. The appearance of offshoots ranged from 1 to 5 per plant at 1.5 ppt. At 4.5 ppt there was no production. For salinity levels over 1.5 ppt there was a decrease in growth (Fig. 19).

Experiment two salinity treatments represented a mean conductance of 568.70 µS/cm for 0.0 ppt, 2852.68 µS/cm for 1.5 ppt, 7884.00 µS/cm for 3.0 ppt, and 9522.00 µS/cm for 4.5 ppt. High conductance levels were a result using tap water , as well as adding fertilizers and salt to the water used in the experiment. Mean DO ranged from 10.12 mg/L to 12.15 mg/L across treatments.

DISCUSSION

Biomass

Biomass levels reached a maximum of 375 g/m^2, in the Waccamaw River, SC in fall. Water hyacinth biomass in the Waccamaw River was much lower than in other climatic zones where values ranged from 1500 to nearly 3000 g/m^2 (Table 1). Studies which reported higher biomass levels were also effluent studies and likely had high levels of nutrients. The Waccamaw River is a naturally low nutrient system when compared to aquatic systems used in other water hyacinth studies (Smock and Gilinsky 1992, Laurie and Chamberlain 2003). Water quality measurements showed low conductance levels and low DO, which is not unusual for the Waccamaw River, a low nutrient, low oxygen system (Smock and Gilinsky 1992, Laurie and Chamberlain 2003). Dissolved oxygen levels were less than the Clean Water Act suggested level of 4 mg/L or greater. Our levels fell short of the CWA suggested level, however there were no extreme variations when compared with the daily means from USGS data (Fig. 6). Dissolved oxygen levels follow a seasonal pattern in blackwater rivers. Low concentrations are common in the summer and fall due to low flow conditions (Smock and Gilinsky 1992).

Although conductivity was low for the 2009 season, it is possible that levels could rise in future seasons. Smock and Gilinsky (1992) reported that conductivity for streams in the upper and lower South Carolina Coastal Plain increased from a mean of 21 uS/cm to 64 uS/cm. Severity of seasonal droughts and hurricanes could allow for salt intrusion beyond what would be found with normal tidal patterns. Penfound and Earle (1948) found that salinity levels of 2.19 ppt resulted in negative effects on water hyacinth growth. Doyle *et al*. (2007), reported salinity levels reaching 1.1 ppt south of Longwood Island and 6.0 ppt at Sandy Island during a drought in November of 2001. Severe droughts such as these could reduce numbers of water hyacinth during peak growing seasons.

At the start of the season the water hyacinth biomass was low. Plants started out short with small leaves, growing horizontally to increase in density and cover. The first signs of growth occurred when shoots emerged from the wintered stem bases. This could explain why the relationship between biomass and stem base was strong, if it plays such a role in the plants regrowth.

By fall, as the water surface was fully covered, the plants started vertical growth, appearing lengthy, agreeing with previous results (Gopal 1987, Tucker 1981). The senescence of older, lengthy leaves in the fall gave space for new leaves to shoot up, as well as new plants to access. Since only one harvest was done in the fall it is difficult to tell when plant biomass starts to decline. Luu and Getsinger (1990) reported that biomass declines in November and December in Vicksburg, MS.

Growth Experiment

The proliferation of water hyacinth plants in the lower river zone was likely due to more nutrient availability. Aquatic free-floating plants, like water hyacinth, absorb all their nutrients from the water (Haslam 1978). Plants in the middle and lower river zones showed higher levels of N and P uptake, which contribute to greater vegetative growth. Water quality analyses of surface water from the Pee Dee River and Waccamaw River obtained from data collected by the U.S. Geological Survey (USGS), exhibit the contrasts in constituent concentrations of redwater and blackwater rivers (Table 3). The Pee Dee River expresses higher conductivity, turbidity, pH, and nitrate concentrations when compared with the levels obtained from the Waccamaw River (Table 3). Thus, the higher accumulation of nutrients by plants in the lower river zones, than in the upper and middle river zones, likely resulted from an influx of nutrients from Bull Creek.

Another factor which possibly affected the growth of water hyacinth in the upper river zones was that cages in the upper river were anchored inside established mats, where plants possibly competed for resources and were overcrowded. The experiment was designed to reduce competition of plants however water hyacinth in the upper river sites grew up around a number of the cages by the end of the experiment. In the middle and lower sites, cages were removed from these large populations. Center and Spencer (1981) stated that increases in biomass and size directly related to intraspecific competition. Overcrowding of plants reduced leaf production and longevity of the leaves (Center and Van 1989, Greco and de Freitas 2002). Less crowding in the middle river and lower river zones resulted in the longest leaf length showing the greatest change in growth. Leaves were able to gain height at a quicker rate without having to wait for older plants to die.

Nutrient Accumulation

Average uptake of nutrients and elements by water hyacinth plants in the Waccamaw River appeared to be higher than what other studies found. Total N varied from lower values of 1.81% in the roots to higher values of 3.89% in the leaves. These values were higher than those reported by other studies. Other studies found N levels to be 2.64% to 2.82%, K to be 2.88% to 4.25%, and P to be 0.40% to 0.53% (Boyd 1970, Knipling *et al*. 1970, and Center *et al.* 1999). Note that Boyd (1970) reported percentages for the entire plant. These levels recorded from previous studies were less than what was found in this study.

Water hyacinth has been evaluated as an absorbent for many wastewater purification studies (Boyd 1970, Rogers and Davis 1972, Wooten and Dodd 1976, Wolverton and McDonald 1979). Boyd (1970) hypothesized that water hyacinth plants grown in nutrient rich effluents would contain twice the level of nutrients than those found growing in natural areas. Rogers and Davis (1972) showed that nitrogen concentrations were reduced from 22.00 to 12.0 mg/L and phosphorous levels from 3.7 to 0.1 mg/L over a four day period. Wooten and Dodd (1976) showed a reduction of nitrogen from 1.48 to 0.11ppm and phosphorus from 23.66 to 14.24 ppm. These studies show the plant's ability to absorb high amounts of nutrient from nutrient rich systems. This study revealed similar results wherein plants in the lower river exhibited greater nutrient accumulation than in the upper or middle river zones. The lower river zone exhibited greater nutrient levels as a result of a connection to Pee Dee River via Bull Creek.

Even more, Greco and de Freitas (2002) explained that water hyacinth plants conserve limited nutrients from senescent leaves through translocation. As the plant grows vertically, the new mass pushes the spreading lower leaves under water, where they die (Center and Van 1989). The remaining layer of leaves above the water assumes the role of the support function for the plant (Center and Van 1989). The continuous replacement of the outer leaves allows for the plant to maintain its buoyancy (Center and Van 1989). The nutrients liberated near the roots during leaf decomposition are reabsorbed for new growth (Center and Van 1989). Therefore, the water hyacinth plants in the lower river sites were receiving high nutrients via Bull Creek and as they died, possibly recycling those nutrients back into the system for reabsorption by new plants.

Salt Tolerance

This study showed that salinities ≥ 4.5 ppt are lethal (Table 2). While there was a reduction in the growth of plants at 3.0 ppt, 30% of plants receiving this treatment level showed the ability to produce one new offshoot. These results were considerably different than those presented by DeCasabianca and Laugier (1995) who measured a lethal level of salinity of 8.76 ppt and Muramato *et al*. (1991) who reported a lethal level of 6.30 ppt. The results of this study more closely resembled results obtained by Haller *et al*. (1974), Zhenbin *et al*. (1990), and Olivares and Colonnello (2000), who found the lethal level of salinity to be 3.29-3.41 ppt (Table 2).

Our first experiment produced a greater increase in offshoot production when plants were added to treatments receiving 0.5 ppt, than in the control. In general tap water contains an assortment of nutrients and trace elements in low concentrations. Given the fact that tap water was used in addition to fertilizer, plants at such low levels of salinity stress were not affected. The 0.5 ppt treatment did not appear to benefit any other production of the plant except in offshoot production (Fig. 15).

The increase in offshoot production of the first experiment could be a result of the plant's reaction to stress and limited resources. Center and Spencer (1989) found that insect damage caused by weevils increased leaf production in water hyacinth. It would appear that plants under herbivory stress react by accelerating their growth rates to replace leaves lost. It may also be the case that any stress caused to the plant results in increased leaf or offshoot production (Watson 1984, Lehtila and Larsson 2005). Meristem or offshoot production is dependent on resource levels (Lehtila and Larsson 2005). Therefore, limited resources result in the plant allocating energy into offshoot production rather than growth of existing tissue (Lehtila and Larsson 2005). Watson (1984) found that the induction of flowering caused by concentrations of gibberellic acid during the early expansion of population growth significantly slowed ramet population growth. The plants used in the first experiment were at early stages of development when resources are being allocated for growth, causing them to overcome these low levels of stress with more growth. Hence, water hyacinth plants may have a slight increase in growth at low levels of salinity, but as the plant moves farther down the river higher levels of salinity would result in irreversible damage.

Management Suggestions

Water hyacinth is currently being managed chemically with diquat, imazamox, triclopyr, and penoxsulam periodically from May through November (Michael Hook, personal communication, November 18, 2008, SCDNR 2008). There are three implications to managing water hyacinth in the Waccamaw River that should be addressed before any further chemical applications are applied. First, does this plant pose a problem to this system? Have there been any noted complaints of how water hyacinth is damaging or disrupting this system? Second, have the involved groups looked at how to target management of this species to be most time and cost effective? Third, has there been any follow up to look at the success of the management techniques being used? Is the goal to eradicate the species or keep it in check?

According to the South Carolina Aquatic Plant Management Plan, estimated cost to control the growth of water hyacinth and phragmites in the Waccamaw River for 2008, was $9,150 and $9,131 in 2009 (SCDNR 2008, 2009). While all these chemicals pose minimal risk to birds, fish, and invertebrates, they do kill vegetation surrounding or growing in the water hyacinth mats (Table 4). Historically, the drifting water hyacinth mats are known to uproot submerged aquatic vegetation and defoliate other floating and marginal plants (Gopal 1987). This would be an example of a loss of habitat because an invasive plant replaces an indigenous plant, and so that invasive species assumes the role of habitat destroyer (Crooks 2002).

It is assumed that invasive species, such as water hyacinth, occur at greater densities and show greater growth in their introduced range than in their native ones (Crawley 1987, Hierro *et al*. 2005). Hierro *et al*. (2005), explains many invasive species only occur at moderate densities in the introduced environment, but this remains unknown because there was usually no direct comparison of how it grew in the native versus the introduced range. Fortunately, there have been hundreds of studies evaluating the growth and biomass of water hyacinth in climatic zones worldwide. When compared to these other climatic zones, this study showed that water hyacinth biomass was lowest in the Waccamaw River.

In fact, water hyacinth proves to be a benefit in some habitats by acting as an ecosystem engineer (Toft *et al*. 2003). Ecosystem engineering uses the innate ability of organisms in order to modify the environment in a specific way (Jones *et al*. 1997). Water hyacinth mats may provide shelter and protection to other plants and organisms, even in places where habitat did not originally exist. The mats have been shown to benefit invertebrates and fish populations by providing a nursery habitat within the roots (Toft *et al.* 2003). The water hyacinth mats in the Waccamaw provide a habitat for many indigenous plants, as well as some invasive ones (Table 4). Species become reliant on the created habitat for population growth, therefore, when mat size decreases, water hyacinth-dependent populations may decrease as well (Jones *et al.* 1997).

In order to preserve this new habitat for indigenous plants, management should be carefully conducted. According to the data from this study the majority of new populations that form in the lower Waccamaw River originate from the three persistent populations used in this study. Penfound and Earle (1948) observed that the edge of a water hyacinth mat can extend 60 cm per month. Chemical applications should be used at the leading edge of the mat, where the new growth occurs. Plants that do break away from the mats, should only be managed from Peach Tree to Long Island, where there are potentially more nutrients available to the plants, which could result in greater growth. Stray populations that form below the entrance of Bull Creek will eventually die off, as river current carries them into higher salinity zones of $\geq$ 4.5 ppt, which this study found to be lethal to the plant.

Presently, DNR applies herbicide periodically from late May through November (SCDNR 2008, 2009). Chemical applications should be made during the month of May when biomass is low and flowering and offshoot production are just beginning. Traditional resource allocation theory proposes that during flower production plants allocate large amounts of energy to the flowering stalk, therefore, halting leaf production (Harper 1977, Watson 1984).

Finally, are the current techniques working? Has there been any follow up? It doesn't appear that much has changed in the management plan from 2008-2009, besides a slight decrease in estimated costs of management (SCDNR 2008, 2009). The long term management strategy listed in the plan proposes three strategies: (1) to manage distribution and abundance of invasive populations, (2) selectively control invasive plant populations where feasible to maintain and enhance native aquatic plant populations, and (3) seek to prevent further introduction and distribution through public education, sign postings at boat ramps, surveys of the water body, and enforcement of existing laws and regulations (SCDNR 2008, 2009). There doesn't appear to be any analysis of the year to year progress of eradication or response to chemical applications.

Conclusions

The biomass levels of water hyacinth in the Waccamaw River were low when compared with other climatic zones. The highest amount of biomass recorded was 375 g/m^2 in the fall. Growth of water hyacinth was greatest in the lower river sites. Nutrient analysis of the plant tissue showed greater concentration of both macro and micro nutrients in the lower river plants. It is likely that greater supply of nutrient in the lower river zones was available because of Bull Creek transferring nutrients from the Pee Dee River into the Waccamaw River just above the study site. This study showed a lethal salinity to be $\geq$ 4.5 ppt. This level was only slightly more than what other studies found (Table 2). Therefore, even though the lower river sites exhibited higher growth rates, elevated salinity levels south of Sandy Island, caused by droughts and tides, will act as a natural control to non-permanent populations and stray plants, which break away from the permanent populations in the upper river sites.

Management of water hyacinth should be carried out during the month of May when biomass is low and flowering and offshoot production are just beginning. Chemical applications should be used at the leading edge of the mat, where the new growth occurs. Plants that do break away from the mat, should only be managed from Peach Tree to Long Island, where there are potentially more nutrients available to the plants, which could result in greater growth. Stray populations that form below the entrance of Bull Creek will eventually die off, as river current carries them into higher salinity zones of ≥ 4.5 ppt, which this study found to be lethal to the plant.

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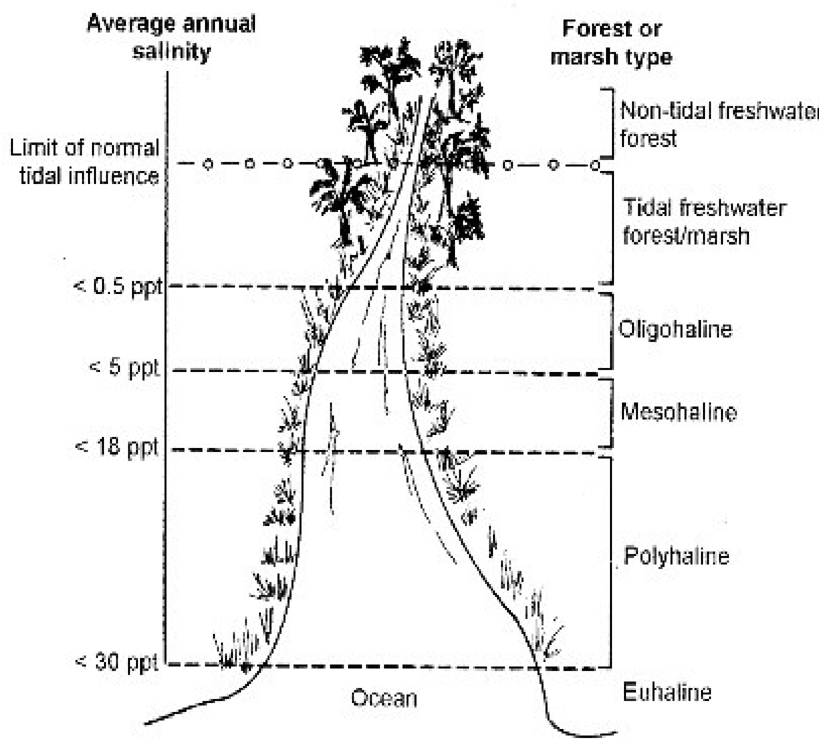

Fig. 1 – Hypothetical salinity gradient of the Waccamaw River. From Conner *et al.* 2007.

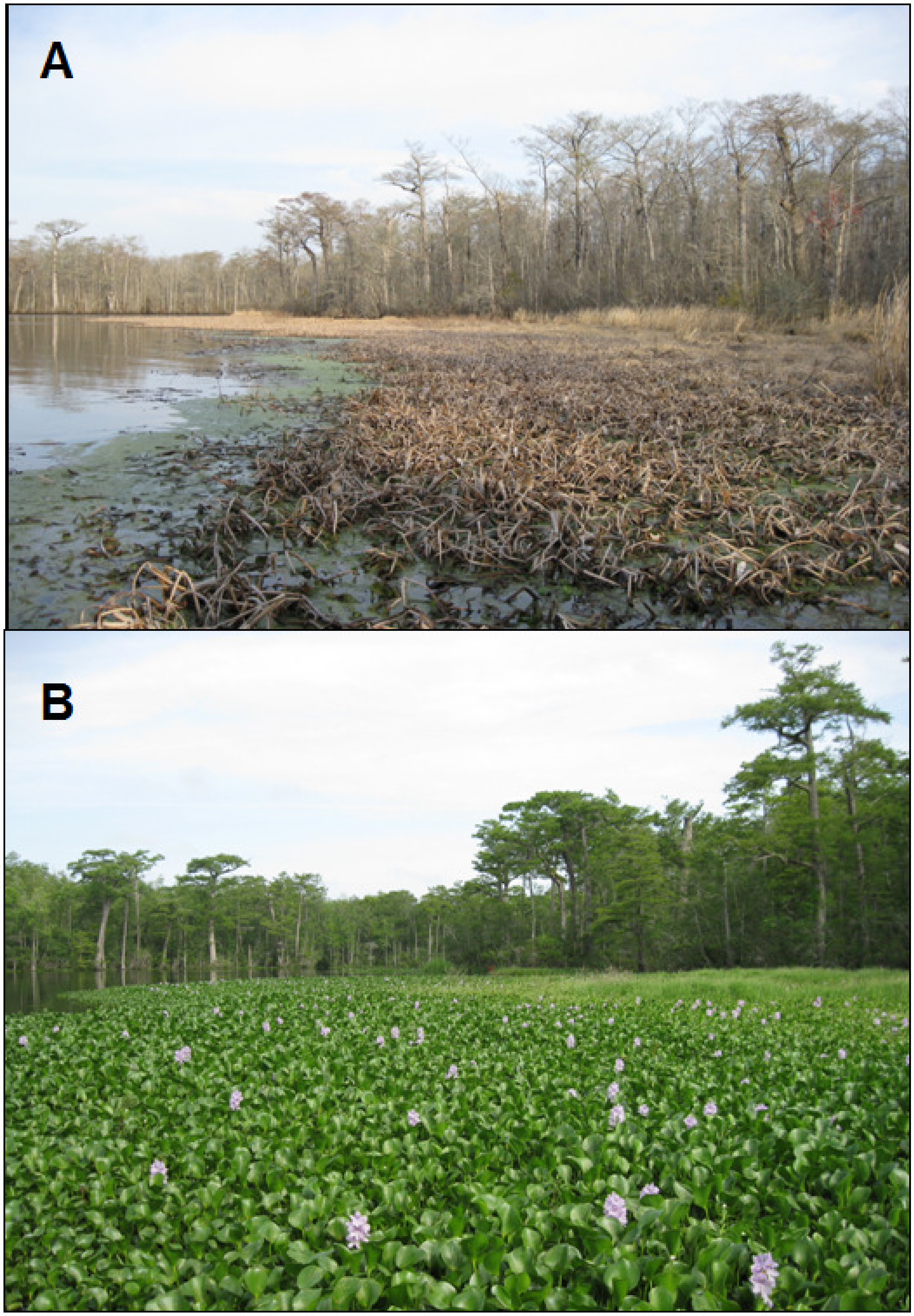

Fig.2 - Seasonal changes in a water hyacinth mat located near Peach Tree Landing (A) March 12, 2009- Plants in senescence; (B) June 17, 2009- Plants growing.

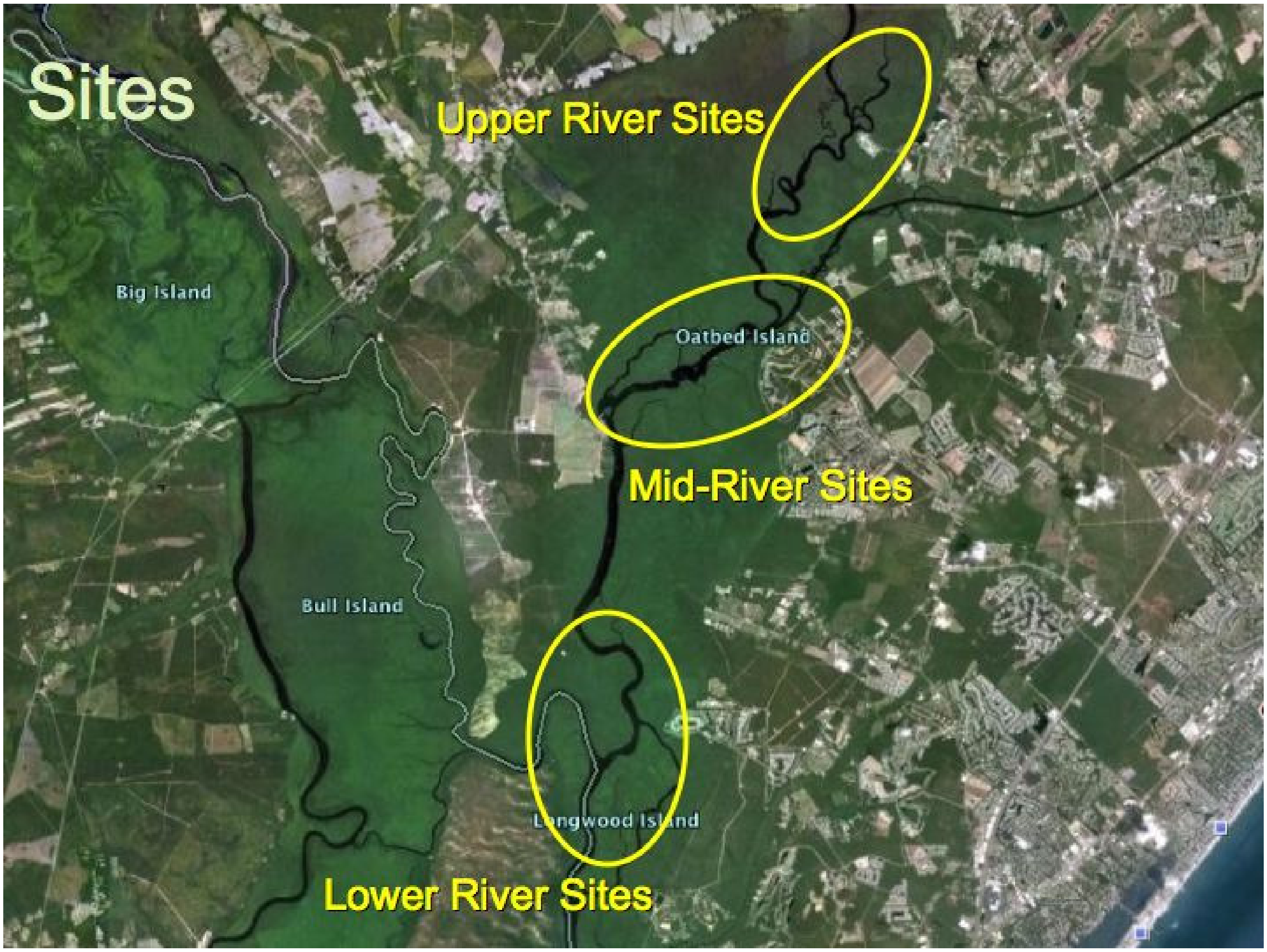

Fig.3 – Location of study sites in the Waccamaw River, South Carolina.

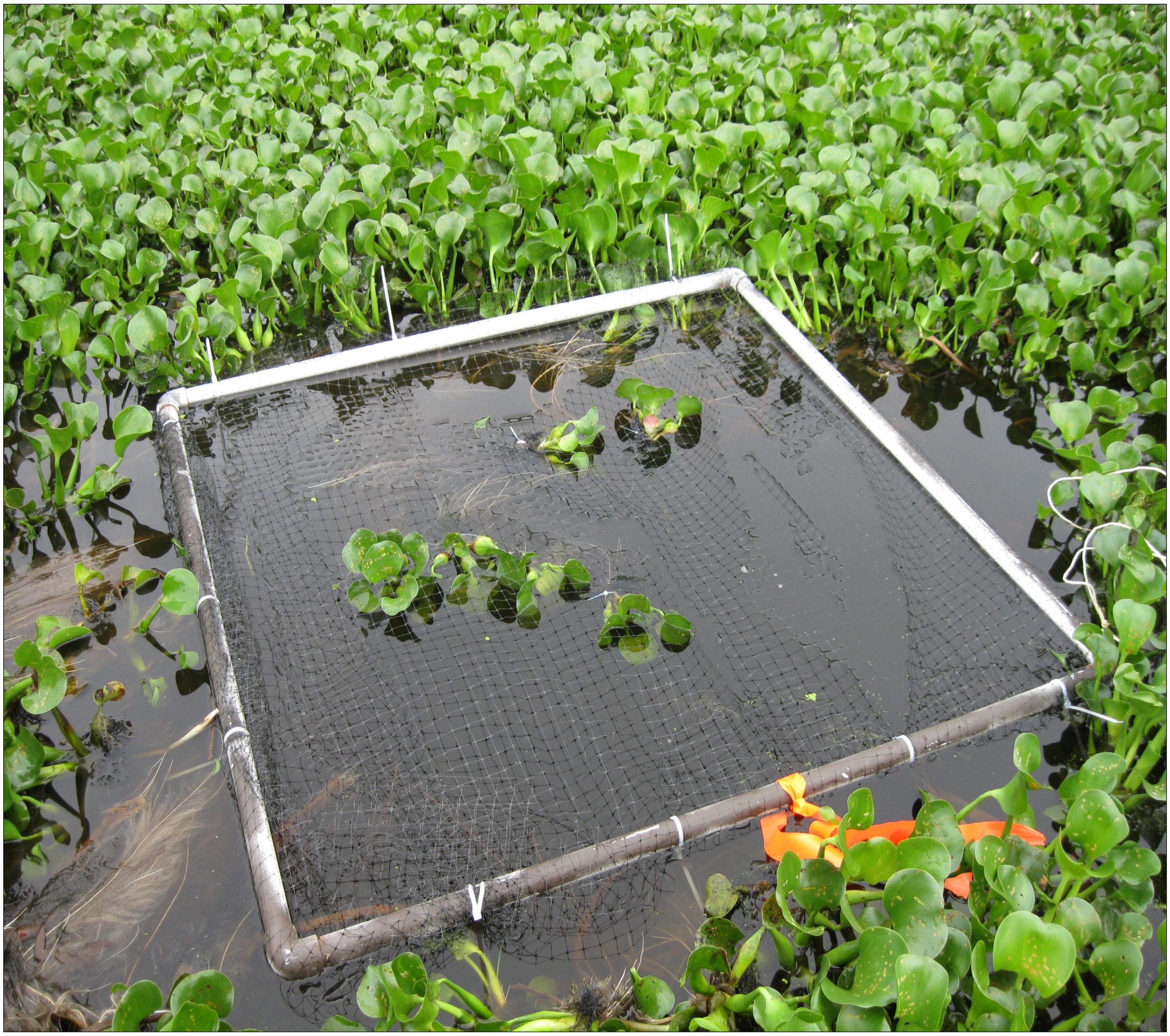

Fig. 4 – Floating, tethered cage used for measurement of water hyacinth relative growth.

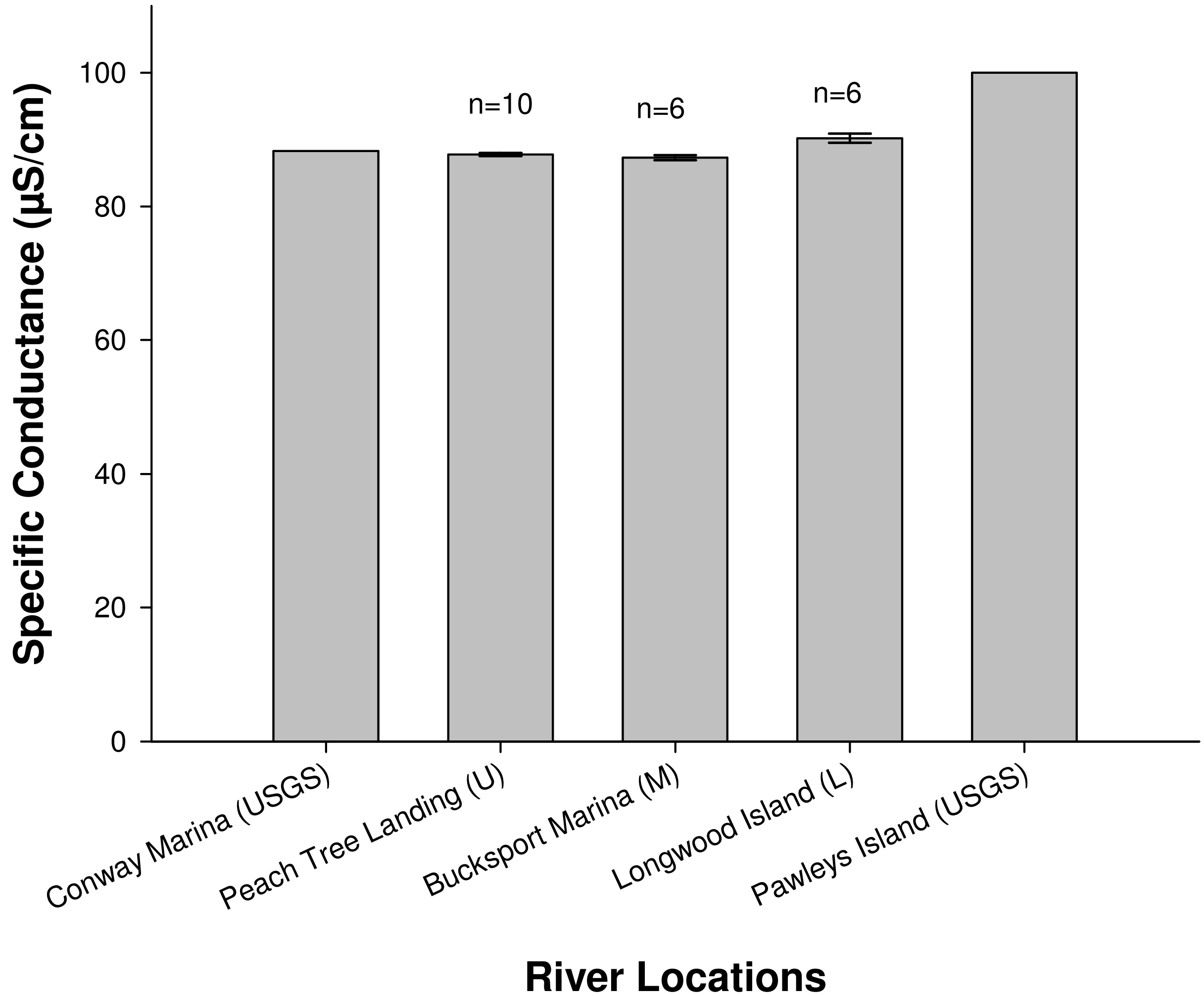

Fig. 5– Specific conductance (mean ± SE) of the Waccamaw River on June 17, 2009 for upper river locations and July 1, 2009 for mid and lower river locations. Data for Conway Marina (June 17, 2009) and Pawleys Island (July 1, 2009) from USGS (2009).

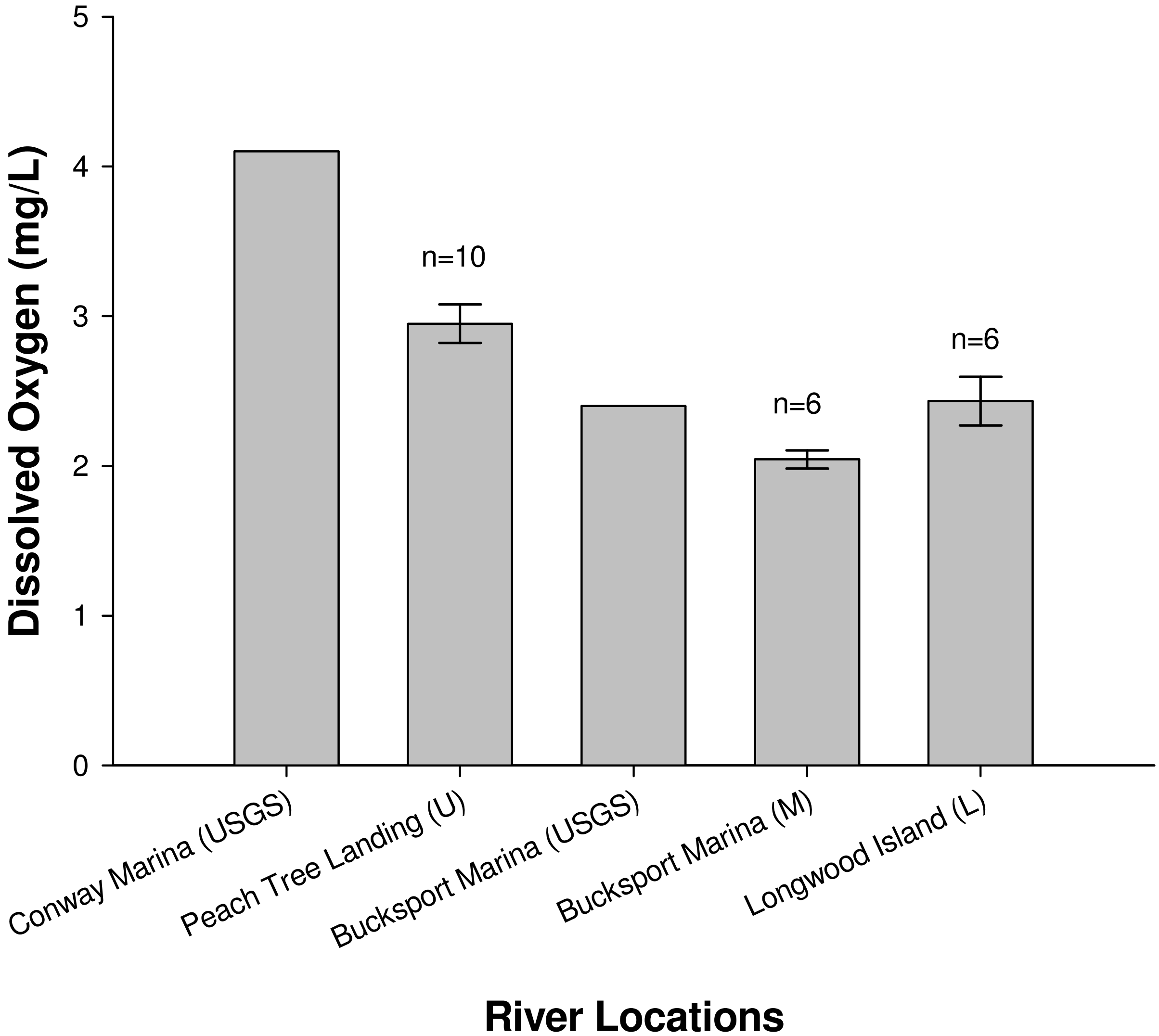

Fig. 6 - Dissolved oxygen content (mean ± SE) of the Waccamaw River on June 17, 2009 for upper river locations and July 1, 2009 for mid and lower river locations. Data for Conway Marina (June 17, 2009) and Bucksport Marina (July 1, 2009) from USGS (2009).

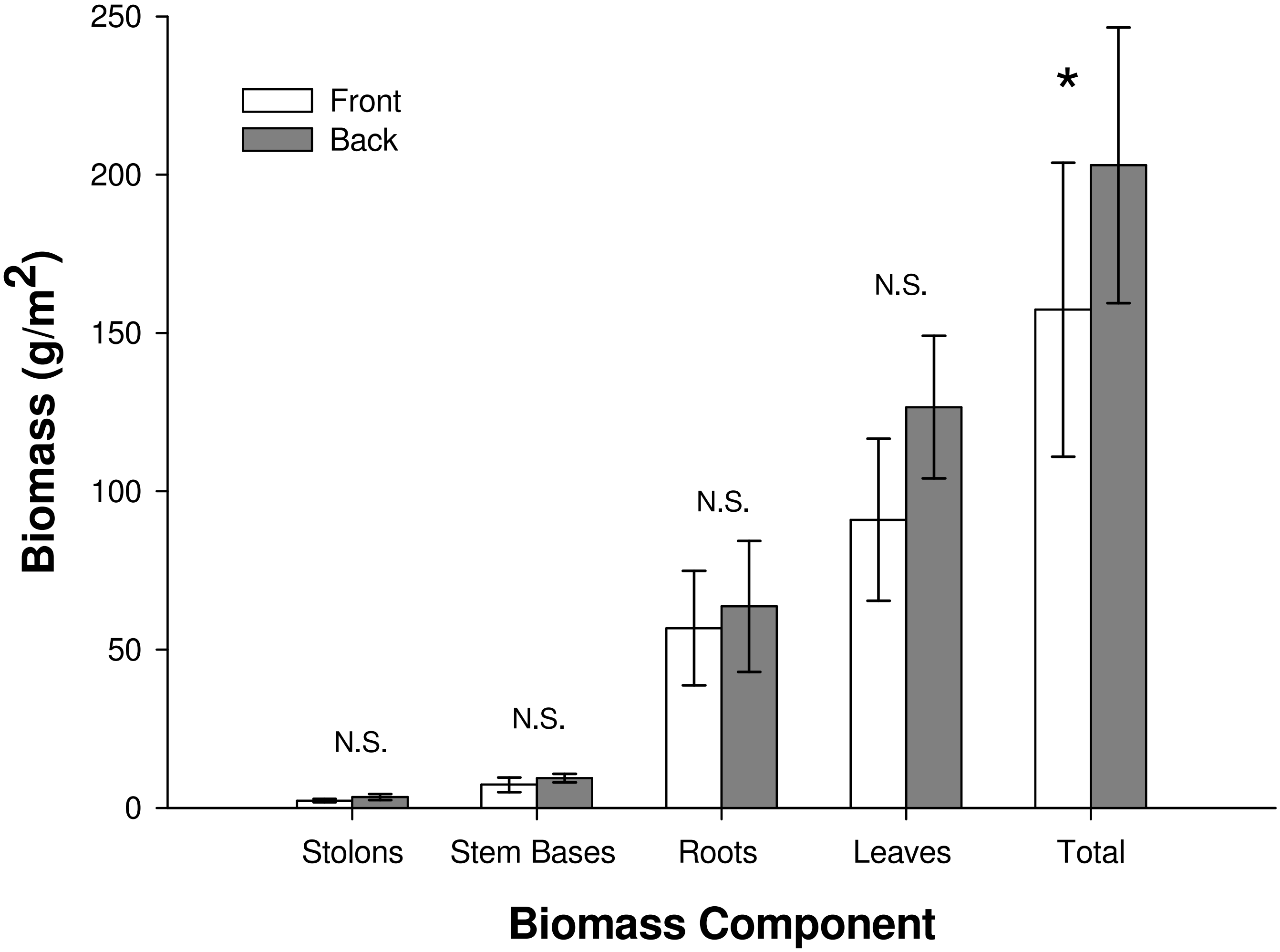

Fig. 7 – Mean total biomass (±SE) of water hyacinth floating mats sampled on June 9, 2009. Biomass differences between the front and back of the mats are compared. (*= $P < 0.05$; N.S.= $P > 0.05$)

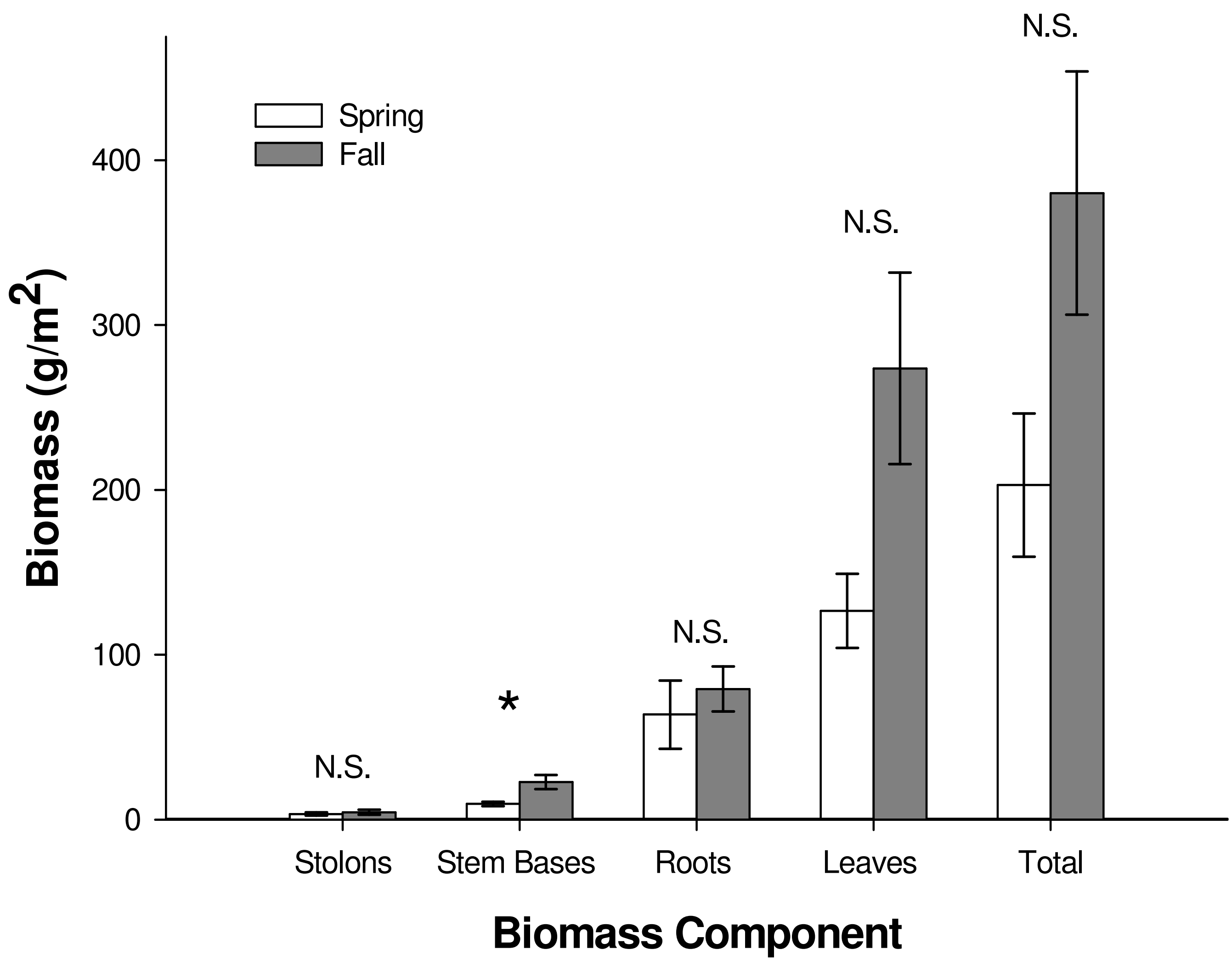

Fig. 8 – Mean total biomass (±SE) of water hyacinth floating mats sampled on June 9, 2009 (spring) and October 14, 2009 (fall). Biomass differences between spring and fall are compared for the backs of the mats. (*=$P < 0.05$; N.S.= $P > 0.05$).

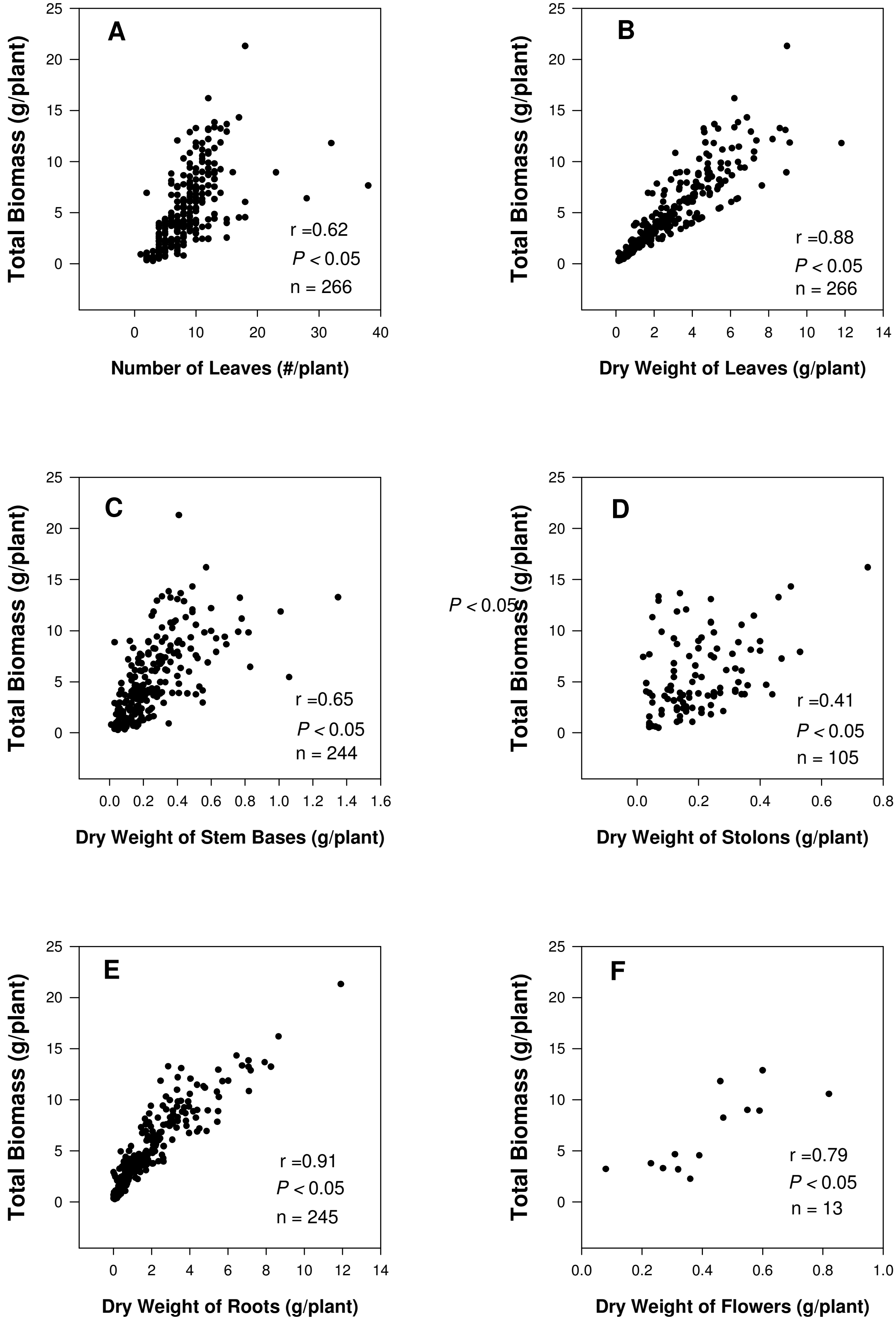

Fig. 9 - Relationships between total biomass of plant and various biomass components for the spring harvest. Between total biomass and (A) number of leaves, (B) dry weight of leaves, (C) dry weight of stem bases, (D) dry weight of stolons, (E) dry weight of roots, and (F) dry weight of flowers.

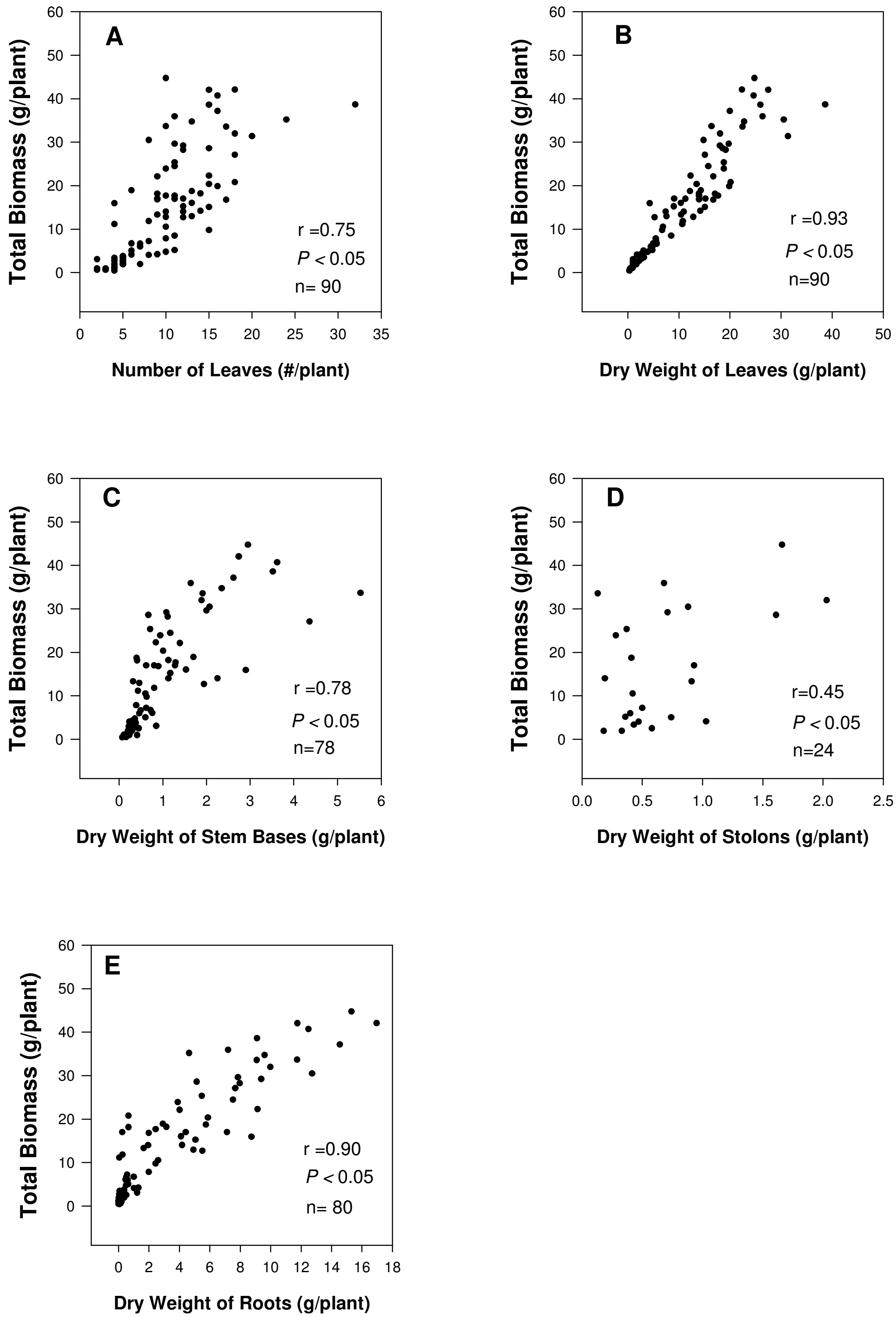

Fig.10 – Relationships between total biomass of plant and various biomass components for the fall harvest. Between total biomass and (A) number of leaves, (B) dry weight of leaves, (C) dry weight of stem bases, (D) dry weight of stolons, (E) dry weight of roots. Flower data were limited and not used.

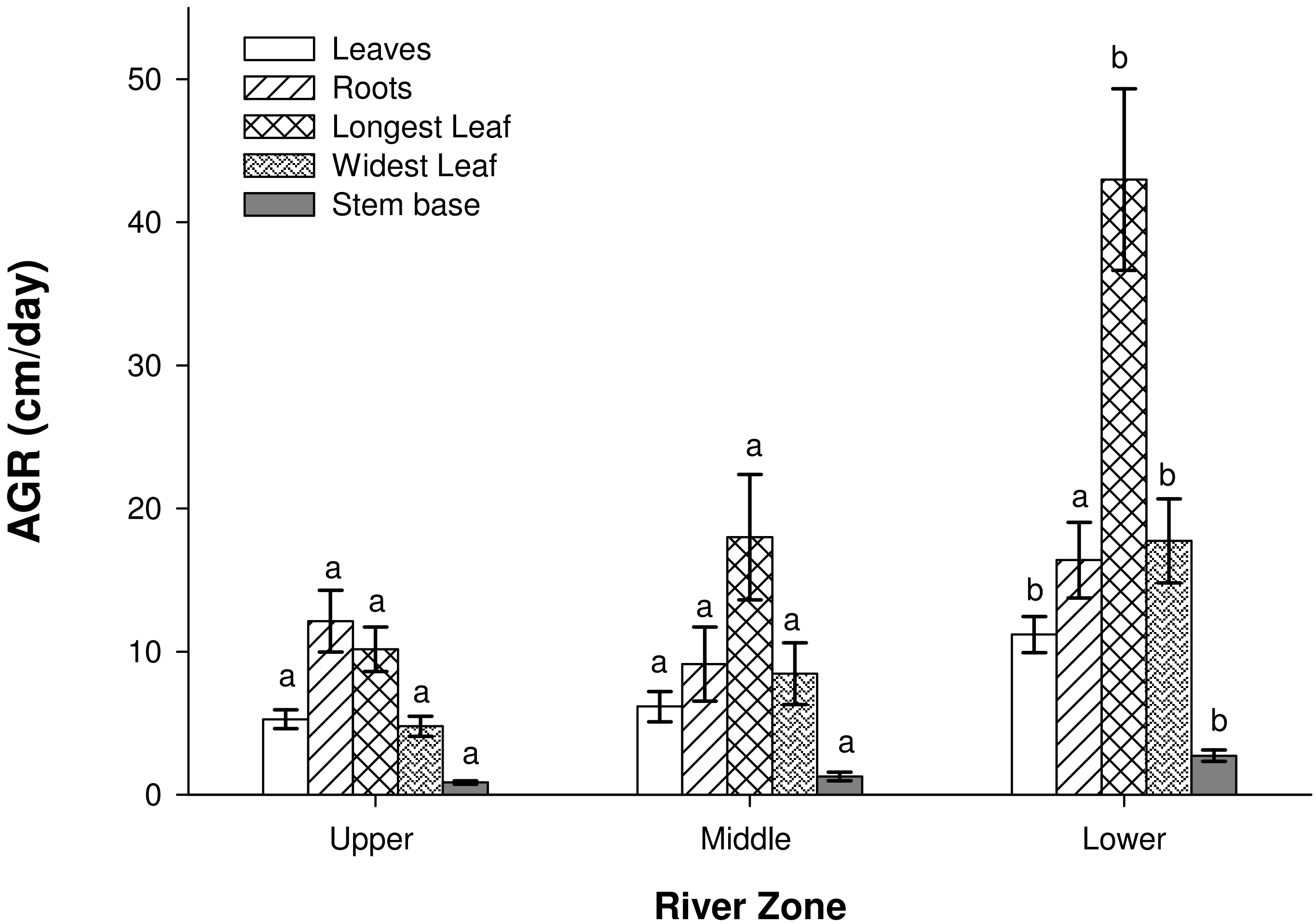

Fig. 11 – Absolute growth of water hyacinth in three different river zones (means ± SE). Letters indicate significant differences among river zones for a growth component. Bars with different letters are significantly different. Data for leaves (units = #/day, $P \leq 0.05$, n=6).

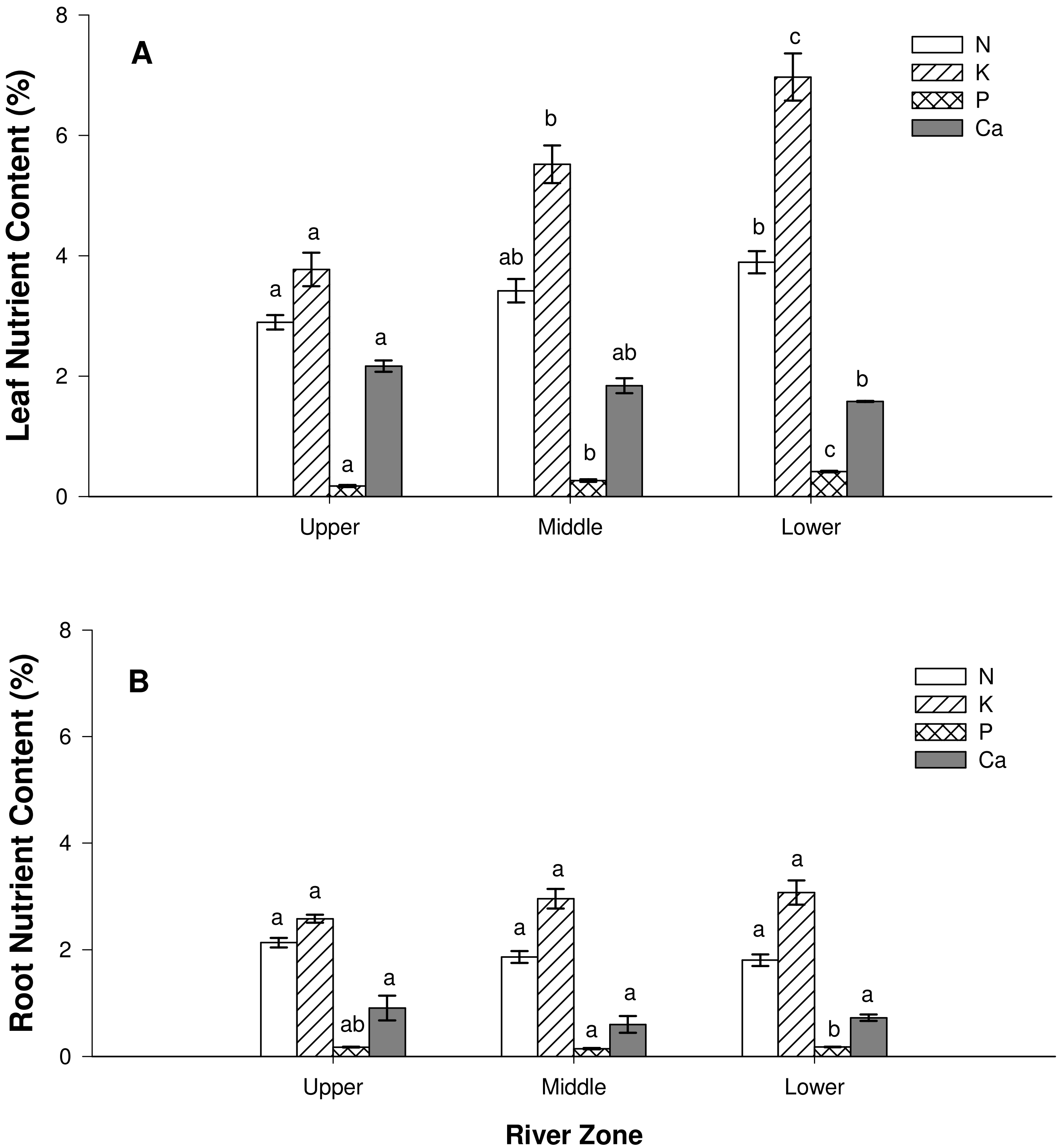

Fig.12 - Percentage of nutrient found in (A) leaves and (B) roots of water hyacinth plants from three different zones of the Waccamaw River. Plants were chosen at random from each zone. Letters indicate significant differences among river zones for a nutrient component. Bars with different letters are significantly different (means ± SE, n=5).

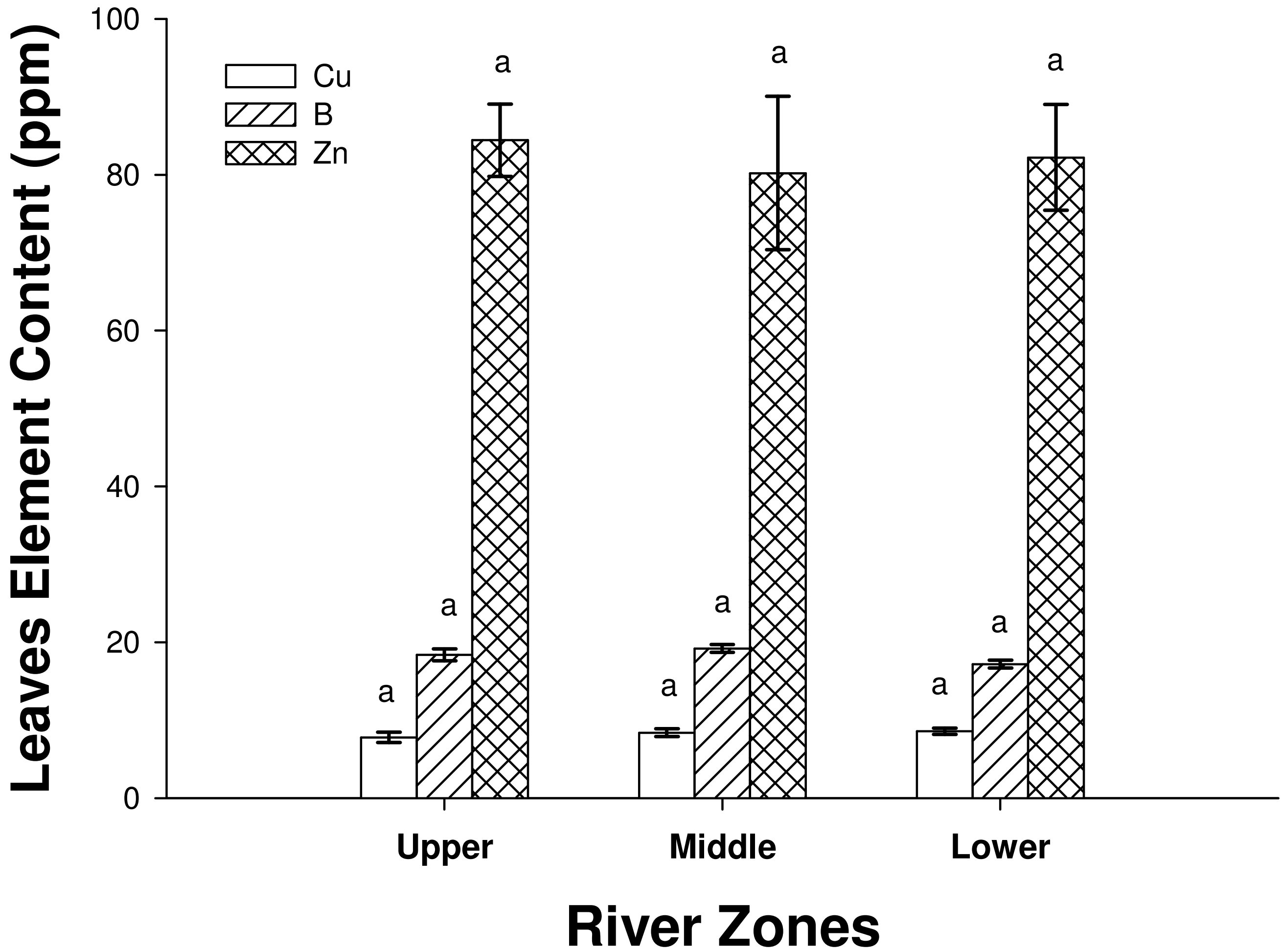

Fig.13 - Element content found in roots of water hyacinth from three different river zones after one month of growth for copper, boron, and zinc. Bars with different letters are significantly different (means ± SE, n=5).

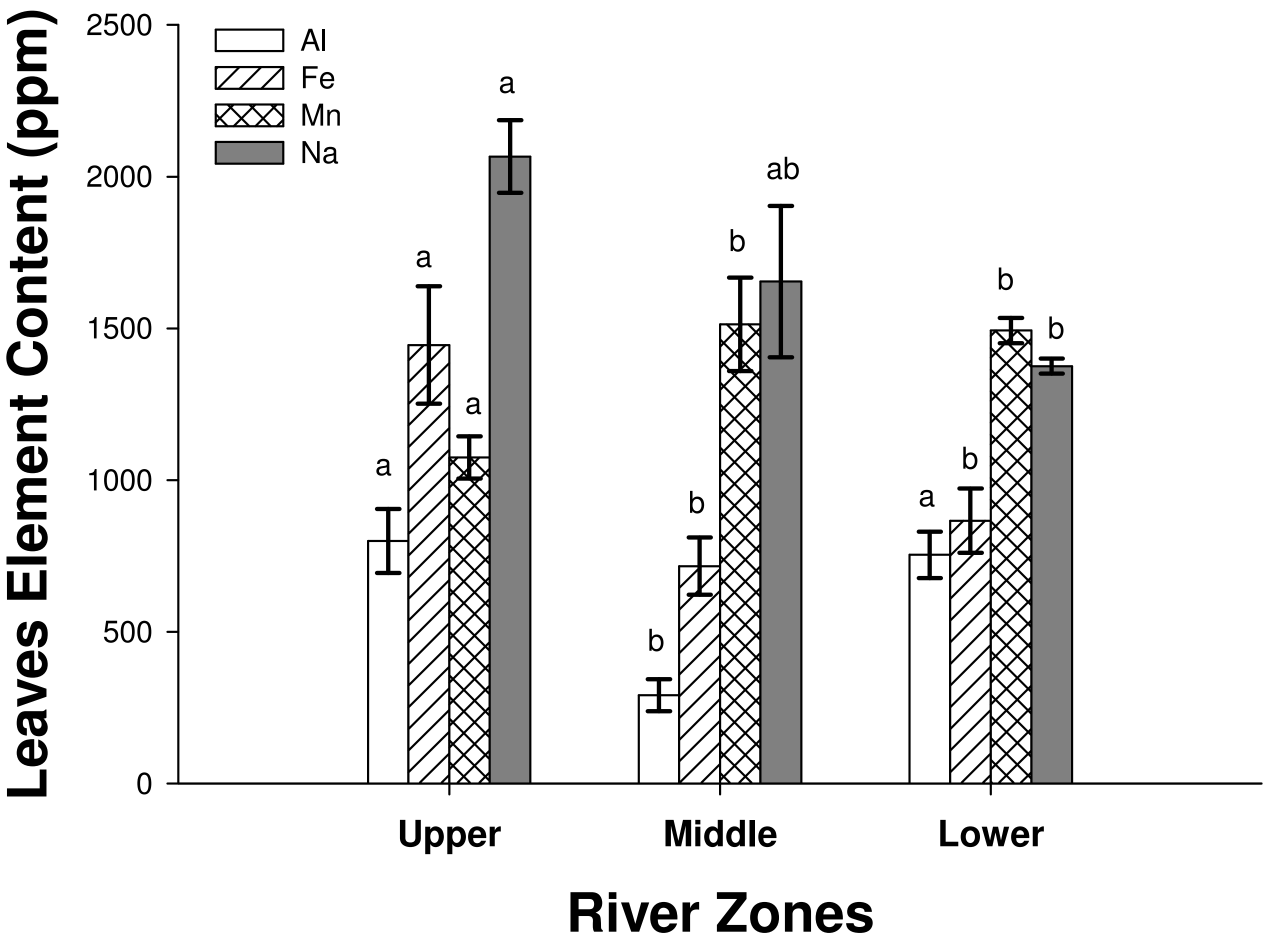

Fig.14 - Element content found in leaves of water hyacinth from three different river zones after one month of growth aluminum, iron, manganese, and sodium. Bars with different letters are significantly different (means ± SE, n=5).

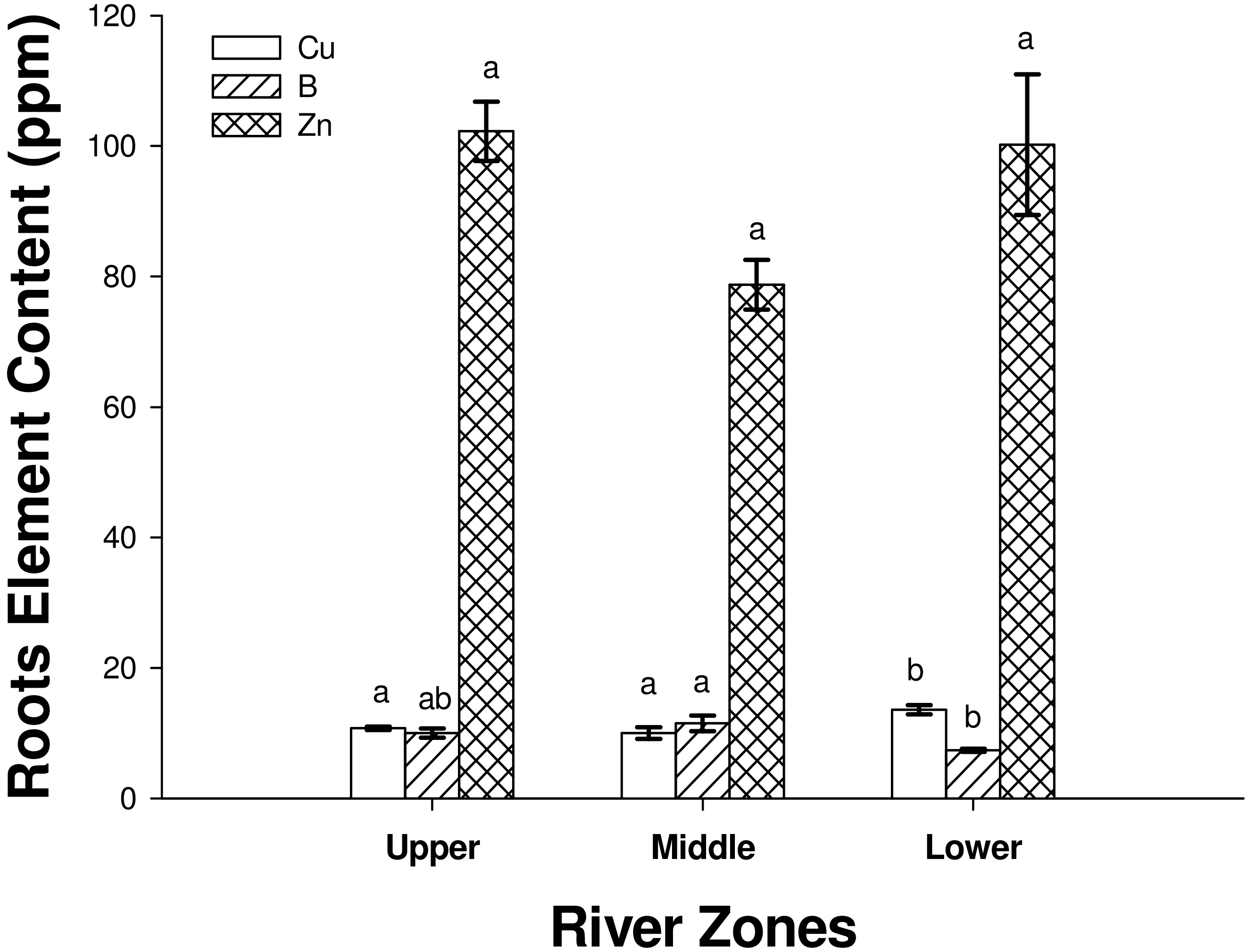

Fig.15 - Element content found in roots of water hyacinth from three different river zones after one month of growth for copper, boron, and zinc. Bars with different letters are significantly different (means ± SE, n=5).

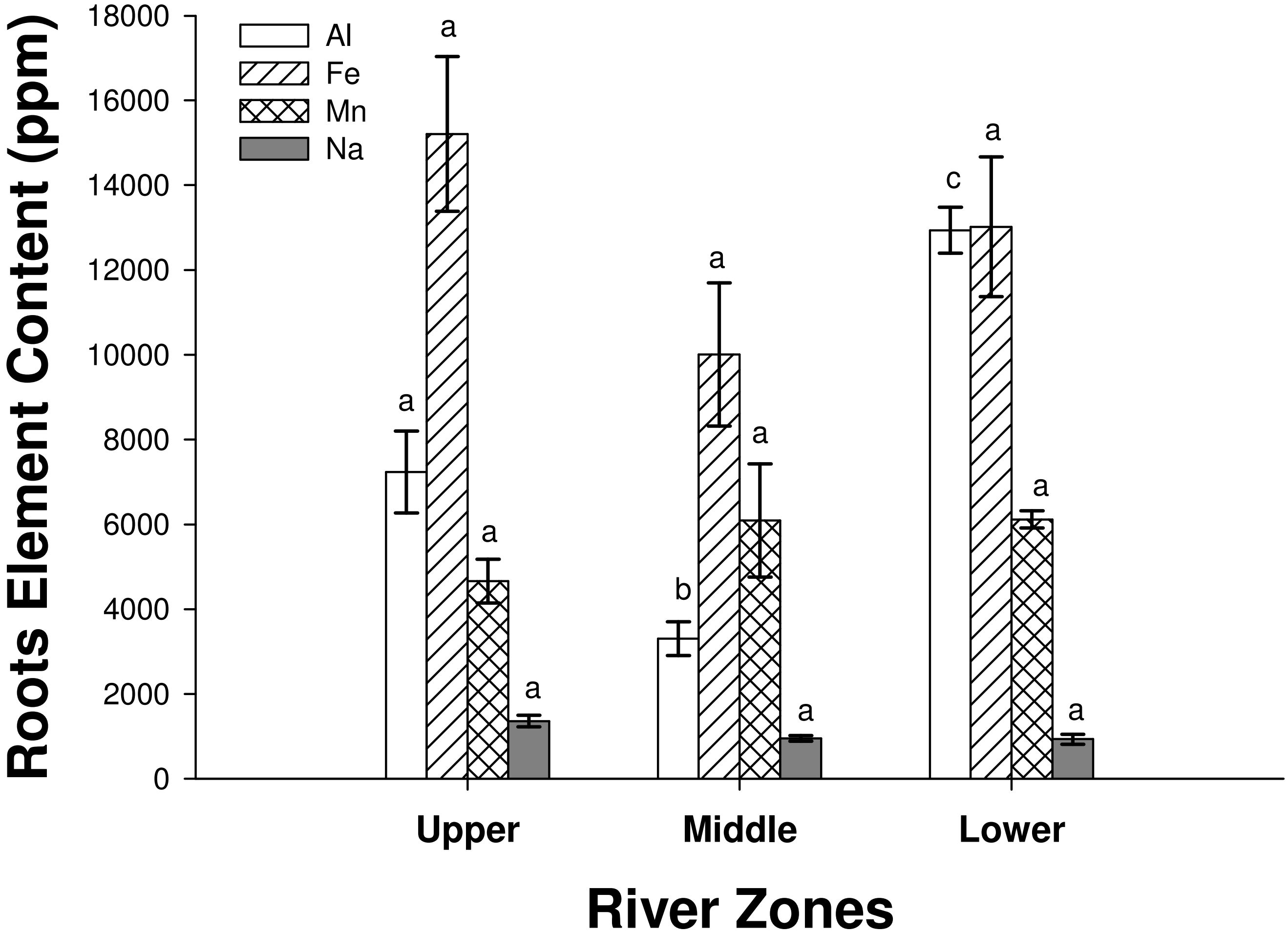

Fig.16 - Element content found in roots of water hyacinth from three different river zones after one month of growth for aluminum, iron, manganese, and sodium. Bars with different letters are significantly different (means ± SE, n=5).

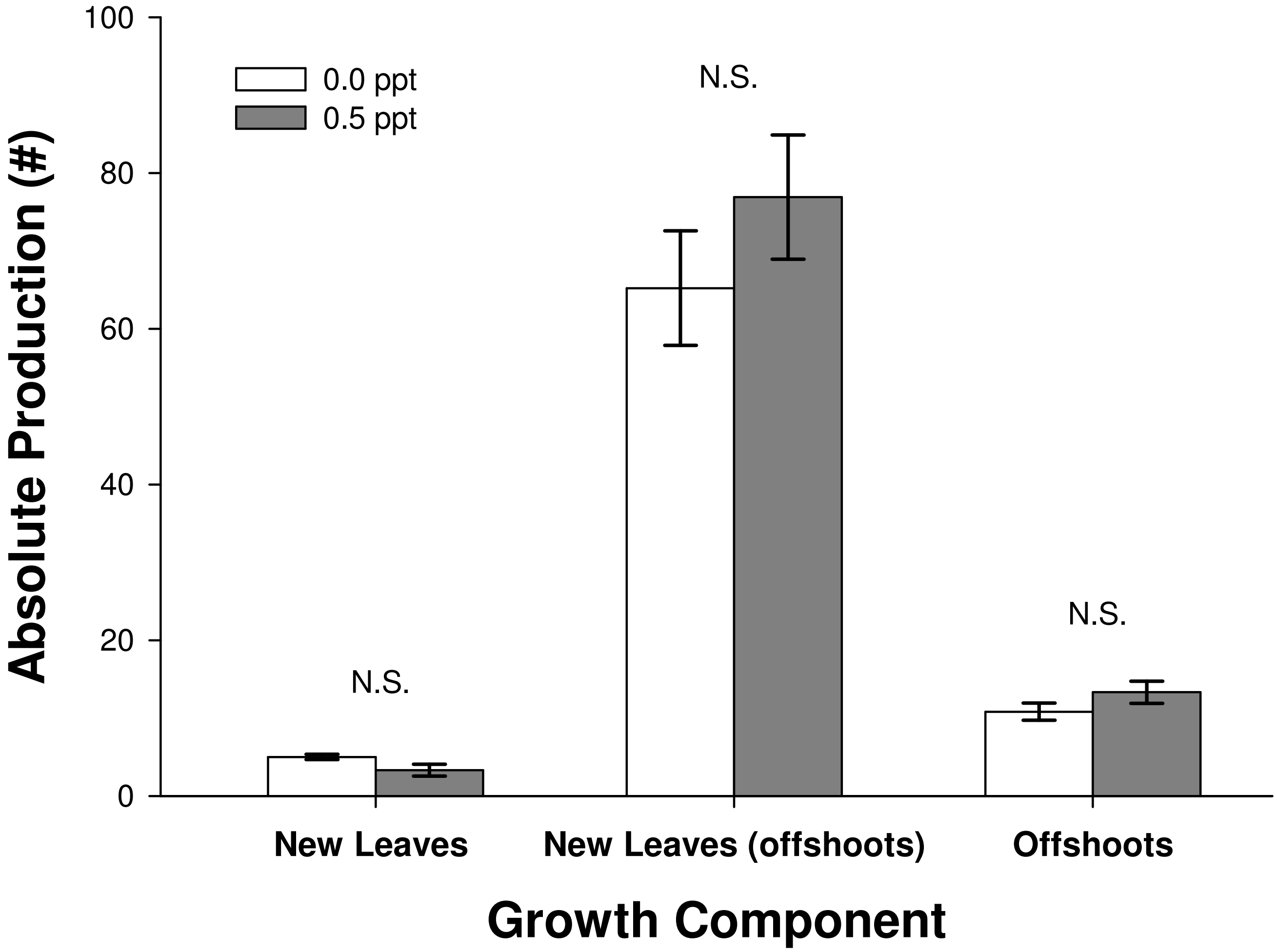

Fig. 17 – Effect of various salinities on number of new leaves produced on the original plant, total new leaves produced from offshoots, and the number of new offshoots from June 24, 2009 to July 17, 2009. Plants at salinities greater than 5 ppt died and so only 0 and 0.5 ppt are shown (* $=P <$ 0.05; N.S.= $P > 0.05$, n=10).

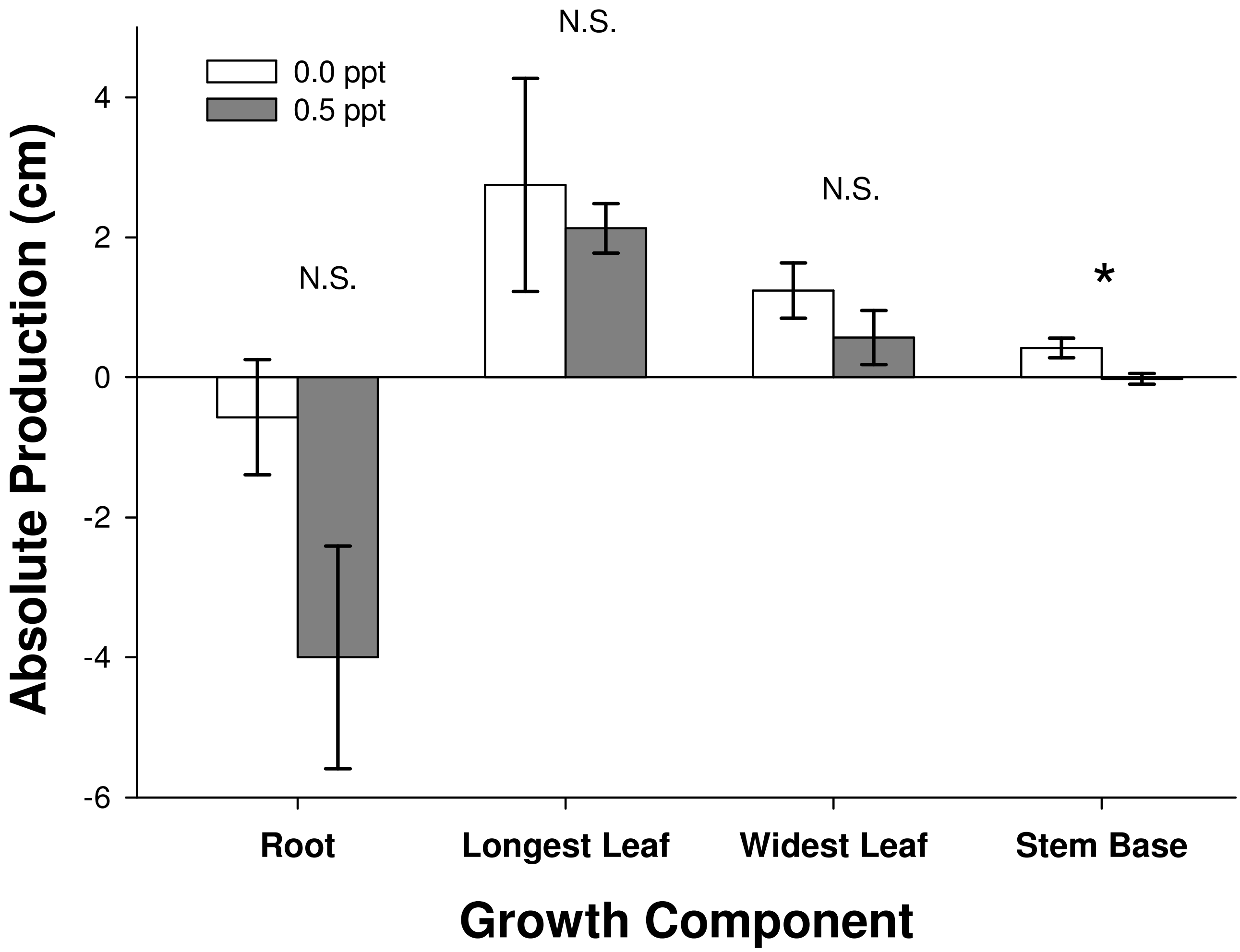

Fig. 18 – Effect of various salinities on the relative production of plant parts from June 24, 2009 to July 17, 2009. Plants at salinities greater than 5 ppt died and so only 0 and 0.5 ppt are shown (* =$P <$ 0.05; N.S.= $P >$ 0.05, n=10).

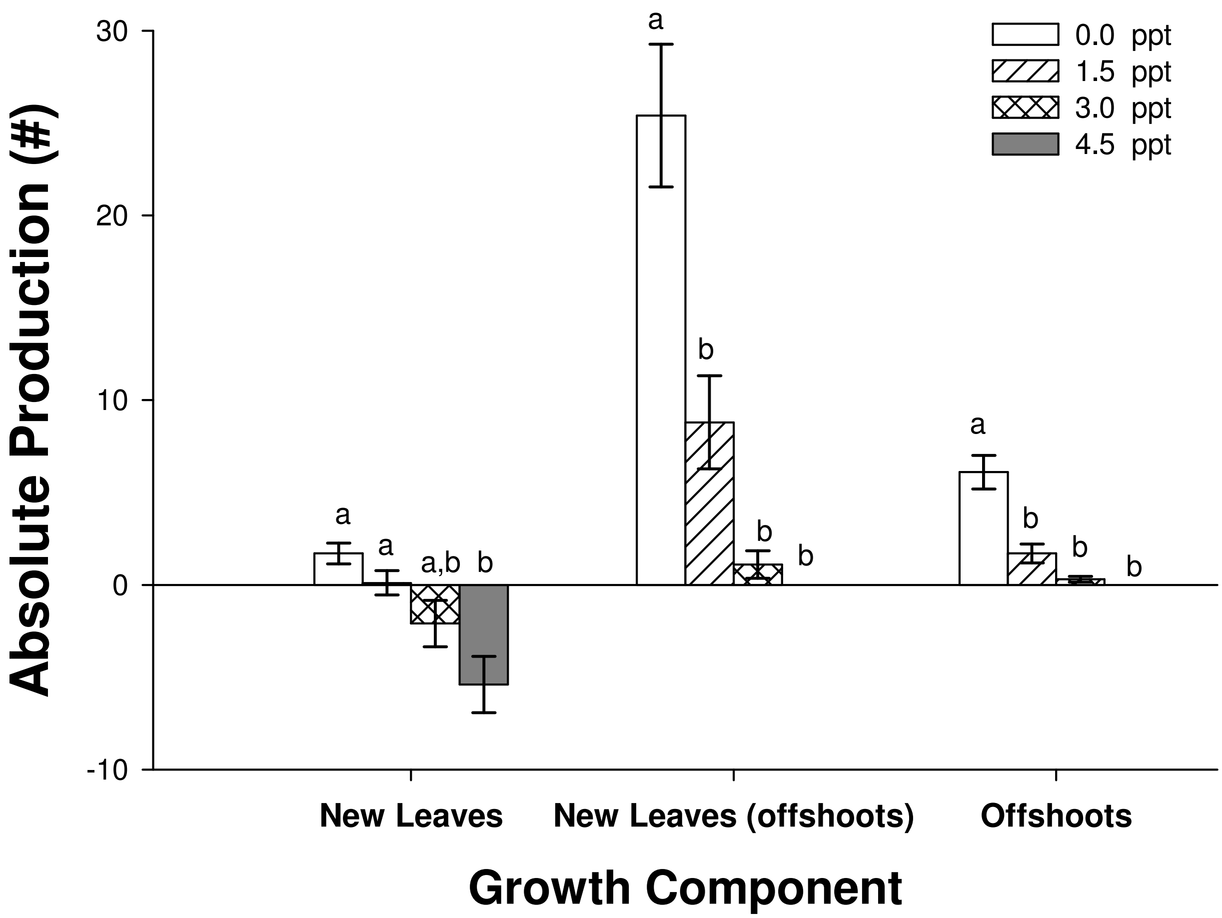

Fig. 19 – Effect of various salinities on number of new leaves produced on the original, total new leaves produced from offshoots, and the number of new offshoots from September 11, 2009 to October 1, 2009. Bars with different letters are significantly different ($P \leq 0.05$, n=10).

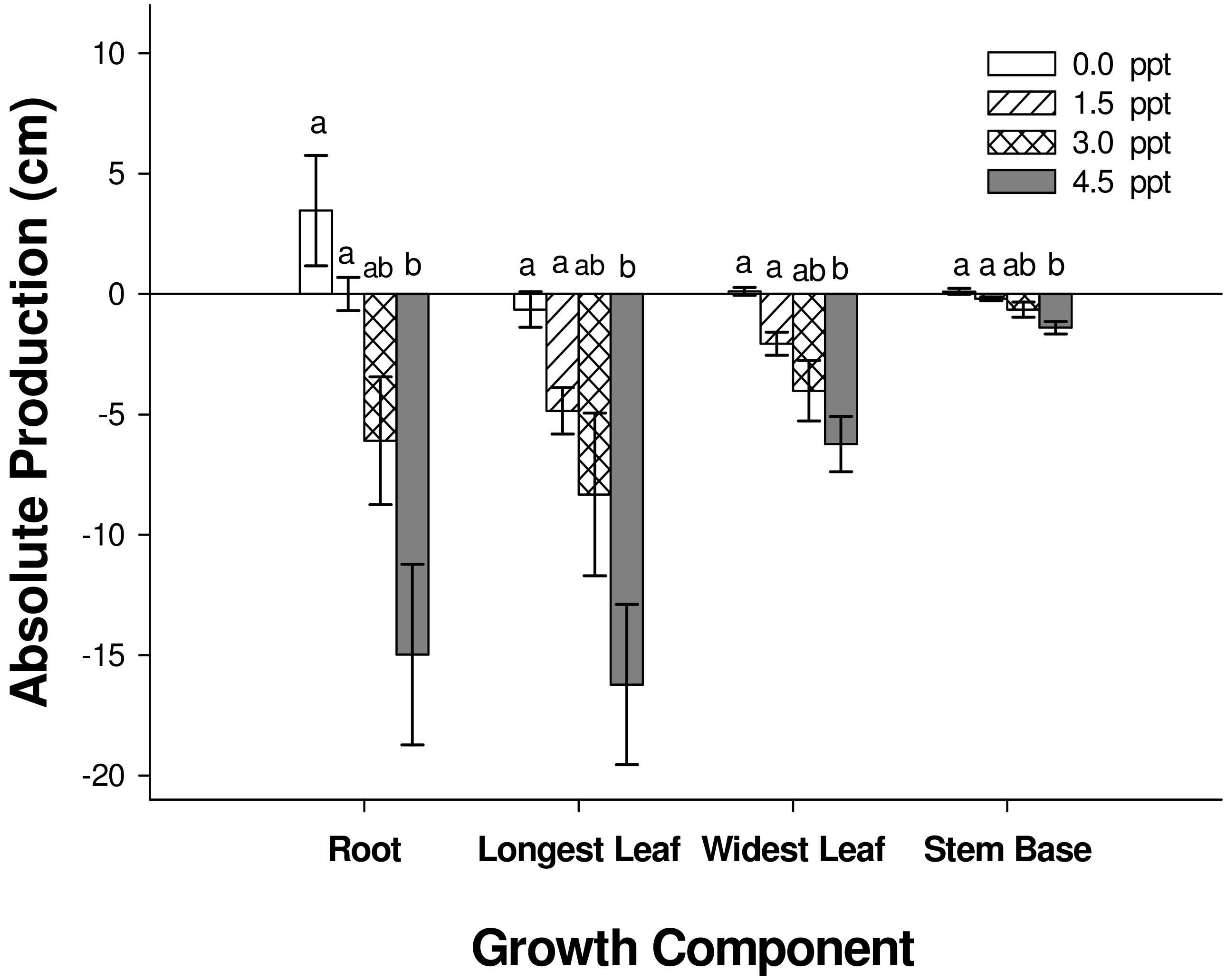

Fig. 20 – Effect of various salinities on the absolute production of plant parts from September 11, 2009 to October 1, 2009. Bars with different letters are significantly different ($P \leq 0.05$, n=10).

Table 1 Maximum biomass (g/m^2) of water hyacinth in different climate zones

Author (Year)	Biomass	Location	Remarks
Wooten and Dodd (1976)	2970	Louisiana, USA	
Knipling *et al*. (1970)	2500	Paines prarie, FL	Collected July
Center and Spencer (1981)	2300	Lake Alice, FL	Max mid June
Boyd and Scarsbrook (1975)	2130	Auburn, AL	(max in August, received nutrient)
Grecco and de Freitas (2002)	2027	Pampulha Reservoir, Brazil	Max in January
Penfound and Earle (1948)	1500	Louisiana, USA	
Luu and Getsinger (1990)	800	Vickburg, MS	Max in September
Sahai and Sinha (1970)	723	Gorakhpur, India	Max in January
Singh and Sahai (1979)	630	Gorakhpur, India	Max in June
Rotella (2010)	375	Waccamaw River, SC	Collected October

Table 2 Lethal levels of salinity (ppt) for water hyacinth

Salinity (ppt)	Author (Year)
2.19	Penfound and Earle (1948)
3.29	Zhenbin *et al*. (1990)
3.33	Haller *et al.* (1974)
3.41	Olivares and Colonnello (2000)
≥ 4.50	Rotella (2010)
6.30	Muramoto *et al.* (1991)
8.76	De Casabianca and Laugier (1995)

Table 3. Comparison of water quality measures between sample sets taken from the Pee Dee and Waccamaw Rivers respectively contrasting redwater and blackwater constituent concentrations. Data were extracted from U.S. Geological Survey surface water studies conducted from 1951-2000 (Doyle *et al.* 2007).

Constituent	Pee Dee River	Waccamaw River
River size	Redwater	Blackwater
Sample size	n=15	n= 12
Conductivity (ms)	75.2	43.7
Turbidity	3	0
pH, field	6.64	6.03
pH, lab	6.36	5.87
Nitrate, filtered (mg/ml)	1.078	0.011
Organic carbon, H_2O (mg/)	0.052	0.035
DOC, suspended (mg/l)	0.470	0.021

Table 4 Plants found growing in or around the water hyacinth mats

Common Name	Scientific Name	Status
Alligatorweed	*Alternanthera philoxeroides*	S.C. invasive
American water horehound	*Lycopus americanus*	
Arrowhead, Duck potato	*Sagittaria*	Federally invasive
Asian spiderwort, Asian dayflower	*Murdannia keisak*	
Baggy-knees grass	*Sacciolepis striata*	
Beggar-ticks, Stick-tights	*Bidens laevis*	
Bladderworts	*Utricularia*	
Climbing hempweed	*Mikania scandens*	
Common duckweed	*Lemna*	
Frog's Bit	*Limnobium spongia*	
Giant cutgrass, Southern wild rice	*Zizaniopsis miliacea*	
Giant Duckweed	*Spirodela*	
Lemon bacopa, Blue-hyssop	*Bacopa caroliniana*	
Lizard's tail	*Saururus cernuus*	
Marsh eryngo	*Eryngium aquaticum*	
Parrot-feather	*Myriophyllum aquaticum*	
Pennywort	*Hydrocotyle ranunculoides*	
Pickerelweed	*Pontederia cordata*	
Sensitive joint-vetch	*Aeschynomene virginica*	
Spider-lilies	*Hymenocallis*	
Swamp mallow, Rose mallow	*Hibiscus Moscheutos*	
Swamp smartweed	*Polygonum hydropiperoides*	
Virginia marsh St. Johnswort	*Triadenum virginicum*	
Water fern	*Salvinia minima*	
Water hemlock	*Cicuta maculata*	