Distribution and Management of Invasive Aquatic Plants in the Ross Barnett Reservoir

M.S. Thesis Research Proposal

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Introduction

Invasive aquatic plant species are an increasing problem to water resources in Mississippi and the United States, due to their increasing populations and spreading habits. Generally introduced from other parts of the world for beneficial or horticultural uses, these plants have taken on negative roles that impede and threaten the use of the water resources by people, native plant species, and wildlife. The natural ecosystem processes and biodiversity that should occur in and around these water resources are also threatened by the existence of these invasive species (Madsen 2004). Creating dense mats that harbor disease-carrying insects and decreasing property value and water quality are some ways that these nuisance weeds affect human societal values as well (Carpenter 1980, James et al. 2001, Rockwell 2003).

The Ross Barnett Reservoir, located just north of Jackson, Mississippi, is a 13,400 hectare (33,000 acre) freshwater impoundment that serves as the primary drinking water supply for the City of Jackson and the Pearl River Valley Water Supply District. Surrounded by over 4,600 residential homes and providing recreation in numerous forms such as fishing, boating, camping, and trail systems, the reservoir is the largest surface water impoundment in Mississippi. Recently, however, invasive plant species have become a problem to the reservoir by hindering navigation in the channels, decreasing available fishing areas, and overall reducing access to the reservoir (Madsen 2004).

Via a survey of the reservoir performed in June of 2005, 19 aquatic and riparian species were found, including alligatorweed [*Alternanthera philoxeroides* (Mart.) Griseb.] and waterhyacinth [*Eichhornia crassipes* (Mart.) Solms.] (Wersal et.al. 2006a). In October of 2006, a littoral zone (water depth of ten feet or less) survey was performed on the reservoir. A total of 21 aquatic or riparian species were found growing in or along the shoreline of the reservoir's littoral zone. Alligatorweed comprised 3.9% of this plant population with an estimated acreage of 444 and waterhyacinth at 2.9% with an estimated acreage of 333 (Wersal et al. 2007).

Alligatorweed [*Alternanthera philoxeroides* (Mart.) Griseb.]

Alligatorweed is an aquatic, mat-forming weed introduced from South America into the United States in 1897, and has rapidly spread across the southern portion of the nation (Kay and Haller 1982). It is a member of the dicotyledon family Amaranthaceae, and has the ability to grow in a variety of conditions including conservation and agricultural systems of tropical, subtropical, and temperate climates (Julien and Stanley 1999). Described by Vogt and others (1979) as an amphibious plant because of its ability to grow in terrestrial or aquatic conditions, alligatorweed can adapt to many different environmental conditions and moisture levels. It is very likely that alligatorweed can grow under a broader spectrum of soil and water conditions than any other aquatic plant species (Wain et al. 1984). A perennial plant that rarely produces viable seed, alligatorweed reproduces by vegetative structures (Julien et al. 1995). It exhibits two distinctive morphological variations, attributed to different environmental conditions (Kay and Haller 1982). Alligatorweed in aquatic habitats has larger hollow stems, which provide buoyancy and gives them a free-floating mat-like habit. Terrestrial-growing alligatorweed has smaller diameter stems lacking aerenchyma (Julien and Chan 1992). A variability in response to herbicides suggests that one alligatorweed biotype may be more tolerant to some herbicides than the others (Kay 1992).

Many techniques and procedures have been and are currently being used for the control of alligatorweed. Chemical control methods, such as applications of 2,4-D and glyphosate, are used on populations of alligatorweed. Tolerances of glyphosate in alligatorweed may be caused by poor translocation to roots and rhizomes, dilution by underground biomass, metabolism to nontoxic metabolites, and exudation from the roots have contributed to the ineffectiveness of alligatorweed control by glyphosate (Eberbach and Bowmer 1995). In addition, high concentrations, multiple applications, and high cost associated with retreatments of herbicides in general for control of alligatorweed have made chemical control methods quite limited (Gangstad et al. 1975).

Biological control of alligatorweed was undertaken in the United States in the 1960s by introduction of a flea beetle, *Agasicles hygrophila* Selman and Vogt, a moth, *Vogtia malloi* Pastrana, and a thrips, *Amynothrips andersoni* O'Neill, from South America (Spencer and Coulson 1976). Control of alligatorweed predominantely from damage done by the flea beetle and sometimes by a combination of the beetle and moth were observed in various locations. However, the flea beetle survives only in aquatic habitats and has no effect on terrestrial alligatorweed (Julien et al. 1995). The flea beetle also has a more limited survival zone than alligatorweed due to climate (temperature and altitude) restrictions (Buckingham et al. 1983). According to Gangstad and others (1975), integrating chemical and biological control methods provides the most effective and cost efficient control of alligatorweed.

Waterhyacinth (*Eichhornia crassipes* (Mart.) Solms)

Waterhyacinth is a mat-forming, floating aquatic plant of the Pontederiaceae family, introduced into the United States before 1890 from South America. It can currently be found in Central America, North America (prominently southern states and California), Africa, India, Asia, and Australia. Waterhyacinth is adapted to a broad range of aquatic environments including lakes, ponds, rivers, ditches, and backwater areas. High nutrient availability in the water provides waterhyacinth with an environment optimal to its spread and growth (Aquatic Ecosystem Restoration Foundation 2005). Waterhyacinth can double its population in under a month's time due to its vigorous vegetative growth and has one of the highest growth rates of any known plant (Madsen et al. 1993). Problems associated with waterhyacinth include: decrease in water quality, mosquito control, and waterflow impediment (Owens and Madsen 1995). Navigation interference, fish and native plant mortality, and water loss from evapotranspiration are also problems attributed to waterhyacinth and its growth intensity (Timmer and Weldon 1967). For energy reserves in times of stress, waterhyacinth stores carbohydrates in the stem base during the fall. However, due to the lack of mechanisms necessary for survival during cold temperatures, air temperatures below 0°C significantly decrease the survival rate of the plant (Owens and Madsen 1995).

Control of waterhyacinth, like alligatorweed, is mainly performed by chemical methods. Small and limited applications of herbicides such as 2,4-D, diquat, and glyphosate have been utilized in previous studies to decrease the surface cover of waterhyacinth. For each herbicide, only multiple applications were successful (Haag 1986, Haag and Habeck 1991, Lopez 1993).

Although chemical control will suppress waterhyacinth distribution and densities, pollution of groundwater and health hazards of humans and wildlife are concerns (Haag 1986). According to Sacher (1978), glyphosate degrades in water and does not limit irrigation timing due to concentration. Bronstad and Friestad (1985) also stated that glyphosate does not normally affect aquatic organisms or fish at the rates applied. The mode of action of glyphosate [N-(phosphonmethyl) glycine] may be ideal for control of waterhyacinth since it is easily absorbed and translocated in broadleaf weeds, and waterhyacinth links itself by way of stolons (Lopez 1993). 2,4-D, however, is a more preferred choice in the U.S. for waterhyacinth control because of its selectivity, effectiveness, and low cost (Madsen 2004, AERF 2005).

Several insects have been introduced into the United States for biological control of waterhyacinth, and some insects are still presently being studied. *Neochetina eichhorniae* Warner and *N. bruchi* Hustache are two host-specific phytophagous weevils that were released in Florida after being imported from Argentina in 1972 and 1974. Other insects, particularly several arthropod species, have been investigated for possible effective control agents of waterhyacinth. Some of these include: an oribatid mite (*Orthogalumna terebrantis* Wallwork), a crambine moth (*Acigona ingusella* Walker), and an acridid grasshopper (*Cornops aquaticum* Bruner)(Coulson 1971). Noted by Madsen (2006), suppression of waterhyacinth by indicated insect predators has predominantly been found only in reduction of flowering and biomass.

Hydrilla (*Hydrilla verticillata* L.F. Royle)

Hydrilla is a submersed aquatic macrophyte that belongs to the family Hydrocharitaceae. It has been referred to as "the perfect aquatic weed" because of its adaptive characteristics that allow it to survive in many aquatic situations (Langeland 1996). A native of warmer areas in Asia, hydrilla was first discovered in the United States in 1958 on the west coast of Florida (Yeo et al. 1984). Over the next 25 years, hydrilla's presence was reported to be found in 13 more states in the United States. Hydrilla populations can impose serious problems on waterflow and recreational activities including: filter clogging in irrigation pumps, boating, water skiing, fishing, swimming, and other water navigation activities (Yeo et al. 1984). Hydrilla also displaces native aquatic plants while becoming established. Because of its adaptive characteristics, hydrilla can outcompete other neighboring aquatic species for sunlight and nutrients, enabling itself to take over the area. A very fast growth rate of up to one inch per day allows hydrilla to reach the water surface very quickly and then profusely branch out and produce a dense mat of stems (Haller and Sutton 1975). It will also tolerate a wide range of pH levels, nutrient levels, low light levels during photosynthesis (Van et al. 1976, Bowes et al. 1977), and can grow in water depths up to 15m (Steward 1991). The very efficient reproductive structures and methods of hydrilla (fragmentation, tubers, turions, and seeds) are conducive for surviving adverse conditions and continual distribution (Langeland 1996).

Management and control of hydrilla can be accomplished in several ways, depending upon the use of the water in which in inhabits. Mechanical control is a very expensive option, only used if immediate results are required, hydrilla is present in rapidly flowing water, or it exists close to water supply intakes (Langeland 1996). Grass carp (*Ctenopharyngodon ideall*a Val.) were introduced in 1970 in Florida for a potential biological control agent of hydrilla (Osborne and Sassic 1979). Although they are an effective control agent of hydrilla, grass carp are non-specific herbivores and are rarely used in multi-purpose water bodies that utilize aquatic vegetation for fishing and waterfowl habitat (Langeland 1996).

Over 40 species of insects in the United States have been studied and found to suppress hydrilla. Some of these include a weevil (*Bagous affinis* Hustache), a leaf mining fly (*Hydrellia pakistanae* Deonier), and an aquatic moth (*Parapoynx diminutalis* Snellen). The most damage of hydrilla observed by an insect was from the larvae of aquatic moths (Lepidoptera: Pyralidae) (Balciunas and Minno 1985). However, factors such as predation, damage vs. hydrilla growth and reproduction ability, and timing of damage have prevented most of these insects from being favorable hydrilla control options (Langeland 1996). Because hydrilla is very resistant to most aquatic herbicides (Blackburn and Weldon 1970), chemical control options are somewhat limited. Copper, diquat, endothall, and fluridone are active ingredients that are effective for controlling hydrilla (Langeland 1996), however, resistance to fluridone has been detected (Michel et al. 2004). Several factors have been accredited to this developed resistance including hydrilla's fast growth and multiple means of propagation, favorable gene expression allowing adaptation in suppressed environments, and the use of a single herbicide (fluridone) which exposes the species to low doses over a long period of time (Arias et al. 2005). Blackburn and Weldon (1970) reported that low concentrations of copper sulfate added to diquat and endothall greatly increased the herbicides' control of hydrilla, with the most effective combination being copper sulfate and diquat. Though normally used for control of phytoplankton and algae, chelated copper compounds such as Komeen have also been found to successfully control hydrilla (Madsen 2000).

Point-intercept survey

The point-intercept method of gathering data is a relatively simple technique that records measurements at strategically spaced, defined locations over a preselected grid system. Having been broadly used in terrestrial plant and animal ecology surveys, it has also been adapted to use in the aquatic plant field, and provides the alternative to randomly selecting research locations in the field (Madsen 1999). Finding these points in the field may be done manually, with a GPS (Global Positioning System), a GIS (geographic information system), or a mapping software package. After determining the distance between the points on the grid, environmental data can be entered into the system to provide additional information about the area (i.e. water depth, bottom type, etc.), with water depth being the most critical in all surveys dealing with aquatic plant occurrence. The presence/absence technique of recording species is used to calculate percent frequency of the species. A “1” indicates species present, and a “0” indicates the absence of a species. Observations of the species can be made from the surface, using a bathyscope, or by the use of a device such as a rake. All observations taken at each point in a relative grid system should done consistently by the same method. Percent frequency is then calculated by dividing the number of present marks by the total number of points on the grid and multiplied time 100. This gives a percentage of how often an aquatic plant species occurs in that area (Madsen 1999). This technique has been previously used in data analyses of invasive species population occurrences in the Ross Barnett Reservoir on a yearly basis since 2005 (Wersal et al. 2007). By using this analysis method in correlation with point intercept surveys, present management practices can be evaluated for efficiency.

Remote Sensing

Defined by Lillesand and others (2004), remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation. This method of gathering data has been utilized in many studies for researching aquatic vegetation, such as the distribution of waterhyacinth in Lake Victoria and the Kagera River Basin in Africa and waterhyacinth and hydrilla in southern Texas (Albright et al. 2004, Everitt et al. 1999). Carter (1982) and Tiner (1997) add that remote sensing has a well-established value to the field of managing wetlands through identification and assessment. This process of gathering data involves sensors that read the reflectivity of light by objects, areas, or phenomenons in different ranges of wavelengths. Different surfaces reflect and absorb light differently, producing images with colors specific to the surfaces reflecting or absorbing the light and reflectivity at different wavelengths of the electromagnetic spectrum (Lillesand et al. 2004). In the study done in southern Texas, waterhyacinth had higher near-infrared (NIR) reflectance than adjacent plant species and water. Hydrilla had lower NIR reflectance than adjacent plant species and higher NIR reflectance than water, with each species showing differentiation by color on the color-infrared (CIR) video imagery (Everitt et al. 1999). Through integration of remote sensing and global positioning systems (GPS), data can be compared from two credible sources to further compare and analyze for future evaluation and assessment (Lillesand et al. 2004).

Site Description and Analysis

Since 2005, the Ross Barnett Reservoir has been undergoing surveys on aquatic plant populations and percent frequencies. The reservoir was divided into four major sections: Upper Reservoir, Middle Reservoir, Lower Reservoir, and Pelahatchie Bay (Wersal et al. 2006a). In June of 2005, these sections were surveyed using a point-intercept method containing a 300 meter grid system (Madsen 1999). Some other sections of the reservoir were not accessible because of increased sedimentation since the opening of the reservoir in 1996. In 2007, the reservoir was further divided into seven sections to aid in sampling and data recording of the littoral zones: Upper Reservoir, Middle Reservoir 5, Middle Reservoir 4, Lower Reservoir 3, Lower Reservoir 2, Lower Reservoir 1, and Pelahatchie Bay. As a result of the 2007 survey, 19 aquatic and riparian plant species were recorded. Only 5% or less non-native species were found, with alligatorweed observed at 4% and waterhyacinth at 1%. From 2005 to 2007, the frequency of occurrence for alligatorweed decreased by 81% and waterhyacinth by 75%. Applications of 2,4-D for waterhyacinth and 2,4-D and imazapyr for alligatorweed may be accredited for these reductions in plant occurrence levels during this time frame (Wersal et.al. 2008).

Objectives

- Estimate the distribution of invasive plants in the Ross Barnett Reservoir using a point intercept method, and evaluate changes over a five year time span (2005-2010).
- Compare estimates of alligatorweed and waterhyacinth distribution from remote sensing to those derived from point intercept surveys and ground-truth.
- Assess the optimal herbicide formulation and rate for management of alligatorweed.

Materials and Methods

Point-intercept survey of invasive plant distribution

A survey estimating the distribution of invasive plants (alligatorweed, waterhyacinth, and hydrilla) will be conducted in June of 2009 and 2010 on the littoral zone of the Ross Barnett Reservoir via the point-intercept method. Navigation to and from the assigned points on the 300 meter grid will be performed with the aid of a hand-held personal digital assistant (PDA) outfitted with a global positioning system (GPS) that provides geographic and attribute data, enabling specific point recognition. A total of 1,400 points were sampled on the Ross Barnett Reservoir in 2005. In subsequent years, the total number of sampled points has been decreased to approximately 677, based on plant species occurrence in the littoral zone (water depth of 10 ft. or less) of the reservoir (Figures 1-3). Samples will be taken at each of the points on the grid to determine presence or absence of aquatic species by casting a rake. Water depth at each point will also be recorded. Spatial data from the surveys will be recorded in the PDA using Farm Works® Farm Site Mate software (Wersal et al. 2006a, Wersal et al. 2007). The data collected from these surveys will be analyzed by the following: change in occurrence of plant species using McNemar's Test to account for repeated sample points in several years in the sampling design, and the Cochran-Mantel-Haenszel for a pairwise comparison of species occurrence between years (Stokes et al. 2000, Wersal et al. 2006b).

Remote-sensing evaluation of invasive plant distribution

Satellite imagery, most likely obtained from LandSat, will be used to gather data on the presence/absence of invasive plant populations in the Ross Barnett Reservoir at a spatial resolution of 30 meters. Unsupervised clustering used by ISODATA (Iterative Self-Organizing Data Analysis Technique) algorithms will be used to group spectrally similar targets together in specific classes (Tou and Gonzalez 1974). These classes can then be labeled by plant species through evaluation and analysis of their light reflectance and compared to the data gathered from the point intercept surveys to inspect for ground-truth. An accuracy assessment of the satellite imagery data gathered can then be evaluated based on the proven data collected from the point intercept surveys. Only data collected from physically accessible areas can be compared due to the ground-truth inspections. Satellite imagery data from physically inaccessible areas is subject to the ISODATA clustering and class organization only.

Herbicide Evaluation

A 12-week study of herbicide applications and analysis of alligatorweed will be performed at the Mississippi State University mesocosm located at the Rodney R. Foil Research center, Starkville, MS. Nine herbicides will be applied to the alligatorweed samples at two application rates, for 4 replications, with three harvests at three pots per harvest. Two, 10 cm plant stem segments will be planted in every 10.2 cm(4 in) tall x 12.7 cm(5 in) wide pot, for a total of 684 pots. The pots will be contained in 1.2 m(4 ft) diameter pools, consistently maintained with an approximate water level of 12.7-15.2 cm(5-6 in). There will be 10 pots in each pool (9 treated pots and 1 pre-treatment reference pot), and one reference pool (10 pots) per replication block (4), for a total of 76 pools with 19 pools per block. The following herbicides will be applied as foliar applications to the alligatorweed samples at the full application rate and half of the application rate (see table 1 for complete rates): 2,4-D (DMA IV) at 1.6821 and 3.3642 kg/ha, diquat (Reward) at 4.1827 and 8.3655 kg/ha, glyphosate (Rodeo) at 1.6821 and 3.3641 kg/ha, glyphosate (Touchdown Pro) at 2.1026 and 4.2052 kg/ha, imazapyr (Habitat) at 0.5607 and 1.1214 kg/ha, imazamox (Clearcast) at 0.2803 and 0.5607 kg/ha, penoxsulam (Galleon SC) at 0.0491 and 0.0982 kg/ha, triclopyr (Renovate) at 3.3641 and 6.7283 kg/ha, and carfentrazone (Stingray) at 0.1123 and 0.2246 kg/ha. Visual ratings to determine biomass percentage controlled will be performed at the following DATs (days after treatment): 3, 5, 7, 14, 21, 28, 35, 42, 49, 56, 63, 70, 77, and 84. Biomass harvests will be conducted on 28, 56, and 84 DAT to determine the percentage of control by weight. On each of these dates, 3 pots will be removed from each pool, dried, and weighed. At the end of the 12 week period, conclusions on the optimum herbicide and rate for control of alligatorweed may be determined. This process will be repeated the following year, and the data will be analyzed using one-way Analysis of Variance with a Fisher's protected LSD test.

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Table 1. Alligatorweed herbicide evaluation treatments indicating the common name, tradename, and rates of application.

Common Name	Trade Name	kg a.i./ha		qts./acre formulation	
		half rate	**full rate**	**half rate**	**full rate**
2-4,D	DMA 4	1.68	3.36	2.0	4.0
diquat	Reward	4.18	8.37	4.0	8.0
glyphosate	Rodeo	1.68	3.36	1.5	3.0
glyphosate	Touchdown Pro	2.1	4.21	2.5	5.0
imazapyr	Habitat	0.56	1.12	1.0	2.0
imazamox	Clearcast	0.28	0.56	1.0	2.0
penoxulum	Galleon SC	0.05	0.10	0.09	0.18
triclopyr	Renovate	*3.36*	*6.73*	4.0	8.0
carfentrazone	Stingray	0.11	0.22	0.21	0.42

* herbicide label gives active chemical in acid equivalent form

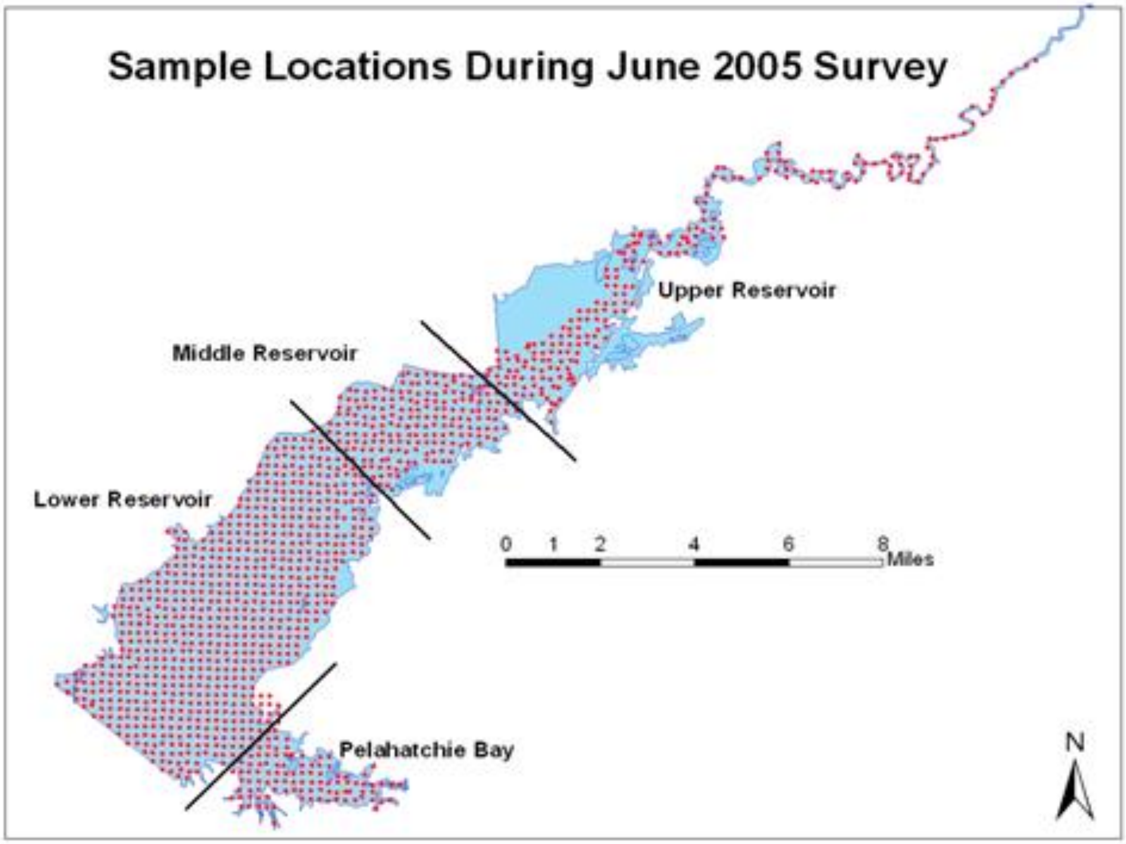

Figure 1. Points sampled on the Ross Barnett Reservoir during the survey conducted in June of 2005 (1,423 total points)(Wersal et al. 2005).

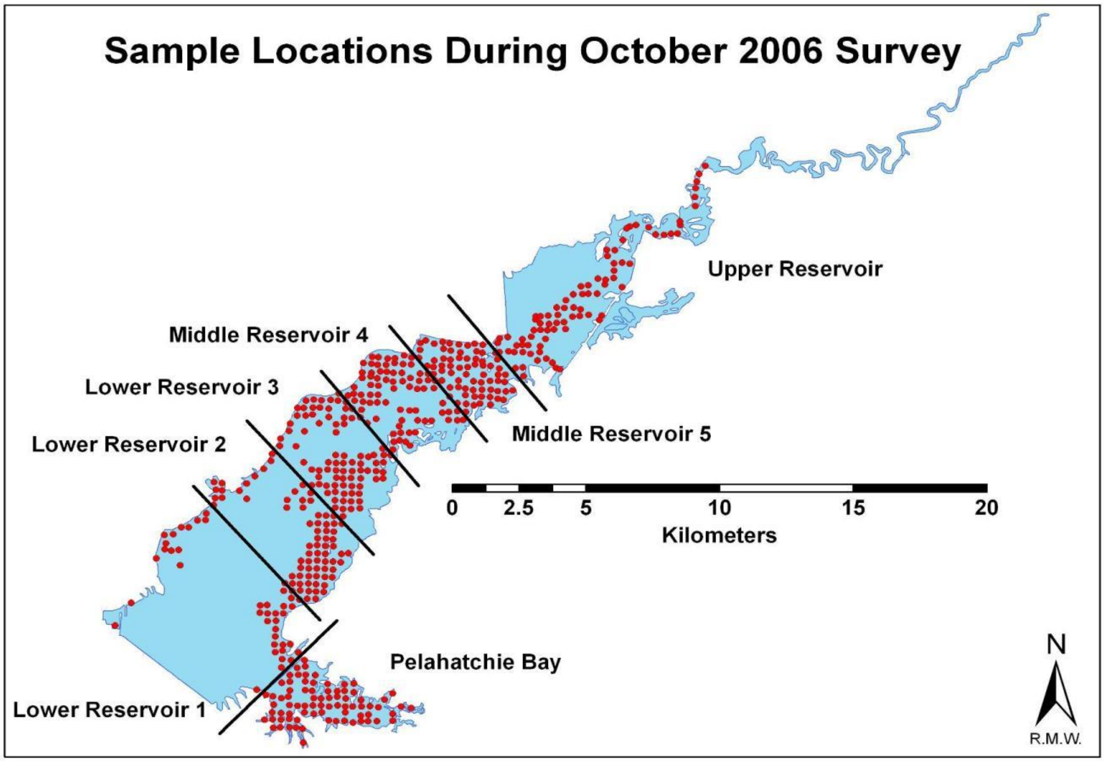

Figure 2. Points sampled in the littoral zone (water depths of 10 ft or less) on the Ross Barnett Reservoir during the survey conducted in October 2006 (508 total points) (Wersal et al. 2006).

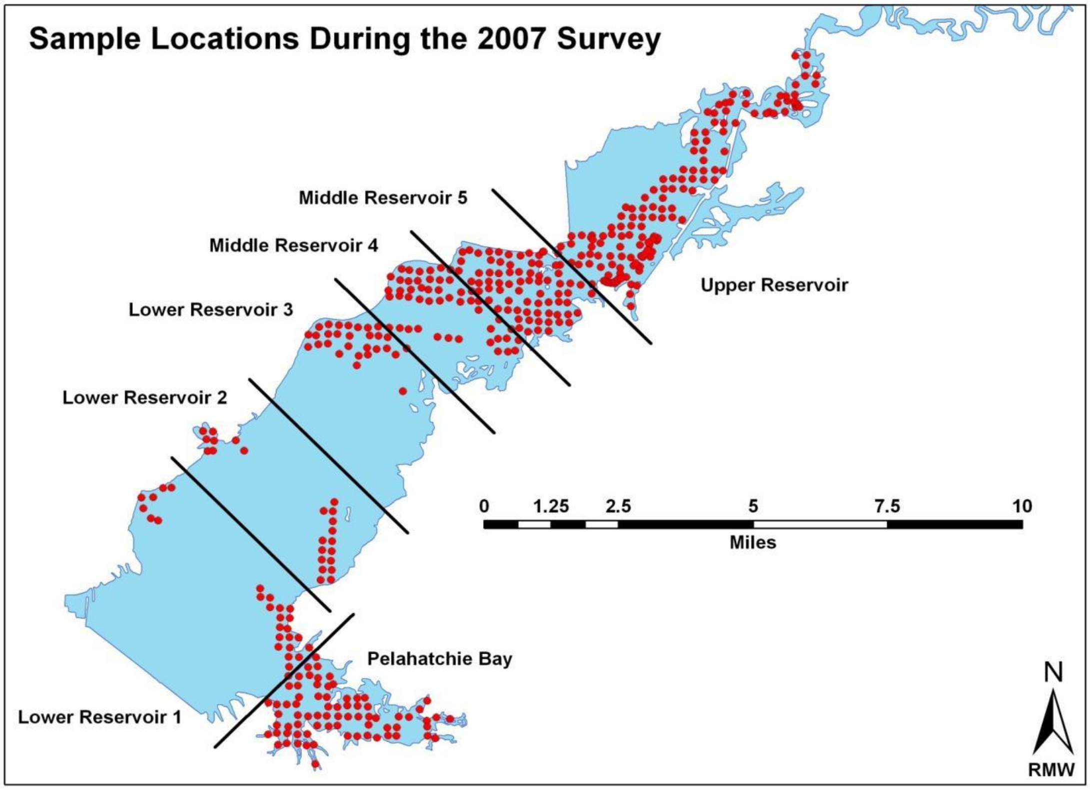

Figure 3. Points sampled in the littoral zone (water depths of 10 ft or less) on the Ross Barnett Reservoir during the survey conducted in July 2007 (423 total points) (Wersal et al. 2007).

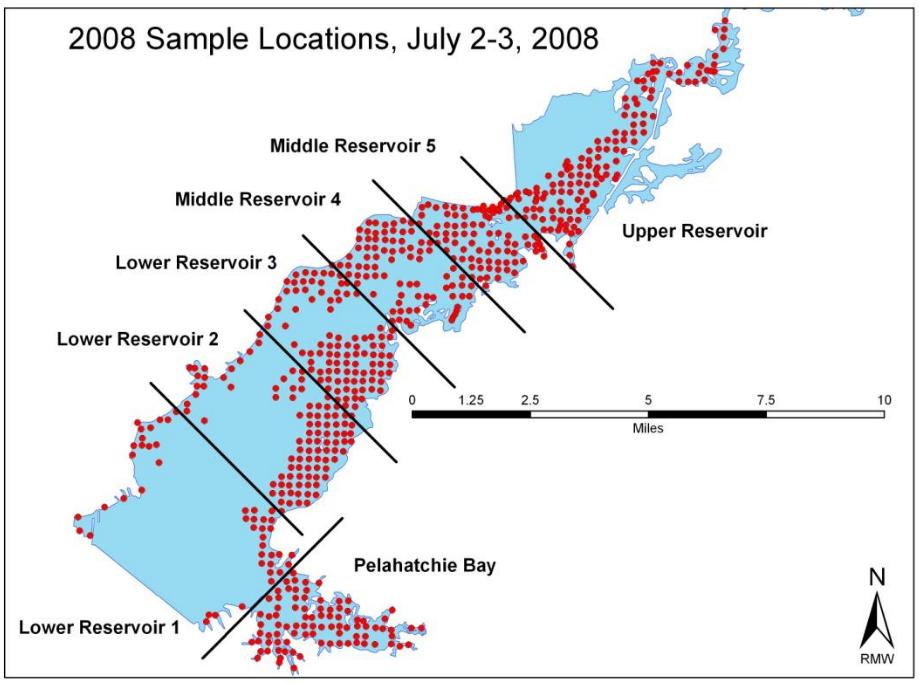

Figure 4. Points sampled in the littoral zone on the Ross Barnett Reservoir during the survey conducted in July 2008 (677 total points) (Wersal et al. 2008).