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CHAROPHYTE MANAGEMENT IN RESERVOIR FISHERIES ON A TEXAS MILITARY INSTALLATION

A Professional Paper

by

VIRGINIA B. SANDERS

Submitted to the Department of Wildlife and Fisheries of Texas A&M University
in partial fulfillment of the requirements for a degree of

MASTERS OF WILDLIFE SCIENCE

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Abstract

In nine central Texas reservoirs, a pond dye treatment was evaluated for its effectiveness in reducing water visibility and ultimately charophyte biomass (CB). Measurements of Secchi disk visibility (SDV) and charophyte biomass were recorded at regular intervals for approximately six months post treatment. The dye treatment applied to reservoirs did reduce the Secchi disk visibility temporarily but did not reduce charophyte biomass. Turbid reservoirs (mean SDV 0.4 m $\pm$ 0.1) contained less charophyte biomass (mean CB 0.26 kg $\pm$ 0.36) than clear reservoirs (mean SDV 1.2 m $\pm$ 0.4; mean CB 21.18 kg $\pm$ 6.01). Overall, Secchi disk visibility was positively correlated to charophyte biomass (tau = 0.68; p = 0.5). Charophyte biomass varied with the season such that the spring peak in biomass steadily declined through the fall measurements. Charophytes comprised 99.91% of the sampled vegetation biomass. The specific mechanisms causing the changes in the observed Secchi disk visibility remain unclear but are likely a complex function of a several factors and feedback loops. Pond dye treatments applied in this manner during the spring season were not effective in reducing the charophyte biomass to the level desired for these recreational reservoirs. Small reservoir managers should consider the relative turbidity or clarity of the water, historic charophyte biomass levels, recreational attitudes toward charophytes and their available charophyte treatment options when creating an adaptive management plan for charophyte growth.

Introduction

Charophytes can grow prolifically in reservoirs in the southern US and these thick charophyte mats are often considered a nuisance to recreational boaters, swimmers and anglers who become entangled or impeded by its presence (Lewis and Miller n.d.; Chilton 2004; Shelton and Murphy 1989). In shallow ponds less than 2.4 meters deep, this aquatic vegetation can become abundant, limiting angler access and reducing oxygen levels (PMC 2005). The positive ecosystem benefits provided by charophytes are often overlooked.

On a military installation in central Texas, the Fort Hood Fisheries Program has included the use of pond dye to treat sport fishing reservoirs for charophyte growth in nine of the thirteen years between 1998 and 2010 (K. Cagle pers. comm.). The intent of the pond dye treatment is to restrict light to submerged macro-algae, therefore limiting photosynthesis and reducing charophyte growth. However, the effectiveness of this installation's charophyte management procedure had not been evaluated, which is an information gap filled by this study.

The term charophyte refers to submerged benthic macroalgae that attaches to substrate by rhizoids. This aquatic, branched algae commonly occurs in lentic fresh and brackish water worldwide. In North America, charophytes include the genus *Chara, Tolypella* and *Nitella* (Wehr and Sheath 2003). According the Integrated Taxonomic Information System on-line database (http://www.itis.gov), these three genera belong to the family Characeae, the order Charales (stonewarts), the class Charophyceae, and the Division Charophyta (green algae, stonewarts) (ITIS 2012). *Chara* species are commonly referred to as muskgrass or skunkweed because they have a strong, foul odor (Wehr and Sheath 2003). Twenty seven species of *Chara* exist in North America (Scribailo and Alix 2010). *Chara* is limited to growing in water depths where light will penetrate (Blindow 2002). *Chara* growth has been documented to depths reaching 65 meters in clear freshwater lakes in North America (Kufel and Kufel 2002). Turbid waters restrict the growth of charophytes to shallower water (Blindlow et al 2002). Charophyte beds anchored to the substrate with rhizoids function to increase turbid water visibility by stabilizing the sediment and reducing its resuspension into the water (Coops 2002). Charophytes may also function to increase visibility in phytoplankton rich waters by acting as a nutrient sink for phosphorous when it is incorporated into the algae structure, thereby limiting the growth of phytoplankton (Fernández-Aláex et al 2002). In a study of shallow lakes, *Chara* vegetation growth corresponded to a decrease in nutrient concentrations (Blindlow et al 2002).

Objectives

This study addressed potential management implications for how, when, and if a pond dye treatment should continue to be used as part of the Fort Hood fisheries management program. The goal of this paper is to summarize the available information on the pond dye treatment effectiveness at controlling charophytes in reservoirs at Fort Hood. Prior to this study, the untested working hypothesis has been that dye is an effective treatment. The objectives for evaluating the dye treatment program included: (a) determining the short-term effects of dye treatment on the charophyte biomass, (b) characterizing the seasonal variation in water clarity and charophyte biomass, and (c) exploring the interactions of biotic and abiotic factors potentially influencing variation in the way reservoirs respond to dye treatments.

Results will be discussed relative to implications for continuing the current dye treatment while considering other potential options for managing charophyte biomass. This information will aid in developing future adaptive management strategies for fine-tuning treatments to specific reservoirs, as needed to improve angler experience while maintaining ecological productivity at Fort Hood.

Study Area

Fort Hood is a U.S. Army installation located in Central Texas, within Coryell and Bell Counties. The installation has approximately 218,823 acres, is located in the Cross Timbers and

Prairies Ecoregion and is within the Leon River Watershed of the Brazos River Basin. This evaluation of the pond dye program is relevant to the reservoirs on Fort Hood with the exception of Belton Lake which is managed by the U.S. Army Corps of Engineers. The streams and rivers are included in the Fort Hood fisheries program, however, flowing waters are not treated with pond dye.

There are over 230 manmade reservoirs on Fort Hood (K. Cagle pers. comm.). The use of terms pond or lake in the proper name for the reservoirs is not an indicator of size or volume (Appendix A). Forty of the reservoirs are five surface acres or larger. The mean reservoir size is 2.6 surface acres and the median size is 0.7 surface acres. Many of the smaller reservoirs dry up during the summer prior to fall rains or during drought years. Permitted anglers are allowed to fish at all of the accessible reservoirs on Fort Hood. The last angler survey conducted in 1998 reported data on angling preferences, including desirable locations (Ditton and Sutton 1998). All of the reservoirs that are most highly preferred by anglers (Ditton and Sutton 1998) are included in the group of reservoirs considered for pond dye treatment (Appendix A) with the exception of Belton Lake and one reservoir which is no longer accessible to anglers due to fence construction. The physical characteristics of the reservoirs selected for treatment varied with their distribution across the landscape (Appendix B).

The installation soils are generally rocky limestone. The average annual rainfall for the last ten years as reported by the NOAA National Weather Service weather forecast office in Waco, Texas is 36.7 inches. May, October, June and April have the highest average monthly rainfalls with 4.5, 3.7, 3.1 and 3.0 inches per month respectively. August and January have the lowest monthly rainfall averages with 1.9 inches each. The U.S. Geological Survey reports water data for the station in Pidcoke, Texas which measures stream discharge for Cowhouse Creek where it enters Fort Hood. The monthly mean water discharge at Cowhouse Creek for the past 50 years is the highest during the months February through June, with the peak of 213 cubic feet per minute occurring in May. The pH ranges for the eight reservoirs sampled during July and August of 2010 are between 7.3 and 9.0. The normal pH range for most unpolluted lakes is between 6.5 and 9.0 (Horne and Goldman1994: 109).

Materials and methods

Historically, thirty-seven reservoirs were on the candidate list for charophyte control Nine of these reservoirs were selected in this study to receive the dye treatment (Table 1; Appendix A) The number of reservoirs treated during a season was limited by funding for the pond dye, time available to treat the reservoirs and the duration and volume of precipitation. The reservoirs were placed into one of two categories, turbid or clear, depending on their alternative stable state (Scheffer et al 1993, De Winton et al 2002). Reservoirs 2, 8 and 9 with low visibility and low charophyte biomass were placed in the turbid stabile state group and reservoirs 1,3,4,5,6 and 7 with high visibility and high charophyte biomass were placed in the clear stabile state group. The dividing point between stabile states was an average Secchi disk visibility of 0.8 meters and 1kg of charophyte biomass per sampling event during pretreatment, six weeks post-treatment and 12 weeks post-treatment.

Prior to treatment with pond dye, the reservoirs had routine water and soil samples collected and analyzed by the Texas A&M Extension Office Laboratory (Appendix E). The routine soil analysis included measurement of pH, nitrate as nitrogen (NO3-N), conductivity and Mehlich III by inductively coupled plasma (ICP) soil phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), and sulfur (S). The routine water analysis included measurements of conductivity, pH, sodium, calcium, magnesium, potassium, carbonate ion

(CO_3^{2-}), bicarbonate (HCO_3^-), sulfate ions (SO_4^{2-}), chlorides (Cl^-), boron (B), nitrate-N, hardness, and sodium absorption ratio (SAR).

Table 1. Reservoir hydrologic data. Maximum depth in meters and surface acres were measured prior to treatment for all reservoirs (n = 9).

Pond Name	Reservoir	Maximum Depth (meters)	Surface Acres	Catch Basin Size (acres)	Stable State
51E	1	3.9	3.8	392	Clear
Airfield Lake	2	2.9	17.4	1333	Turbid
Cantonment A	3	5.3	5.9	225	Clear
Cantonment B Kids	4	2.8	5	225	Clear
Clear Creek Lake	5	5.2	13.1	476	Clear
Engineer Lake	6	5.3	26.5	937	Clear
Heiner	7	5.5	12.1	470	Clear
Larned	8	4.3	24.3	3376	Turbid
Nolan	9	5.0	38.5	8498	Turbid
	Mean	4.4	16.3	1770	
	Standard Deviation	1.2	11.6	2710	

Measurements of the water pH, temperature, conductivity, total dissolved solids, and Secchi disk visibility (SDV) were recorded for each reservoir. As recommended by Lynch (2006), these measurements were taken prior to treatment, the day after treatment and every two to four weeks following treatment until October (n = 8 repeated measures).

The submerged vegetation and the surface vegetation coverage was measured prior to treatment then six, twelve and twenty weeks after treatment. Charophyte Biomass (CB) measurements were based on wet weight of drained samples in kilograms. Submerged vegetation was collected at three points in each reservoir for each sample date (Appendix C). Sample points were chosen randomly for each reservoir without replacement. A location on the shoreline was randomly selected, and then a depth for that site was randomly selected between 0.6 and 1.5

meters deep. Samples were collected by scraping vegetation from the bottom of the reservoir with a garden rake in a square with 0.9 meter sides marked by a polyvinyl chloride (PVC) pipe frame. The three subsamples were combined and submerged vegetation was separated into charophyte and macrophyte groups prior to measuring wet weight. A representative specimen for each macrophyte was transported to the office for identification and a photo record was taken (Appendix D). The reservoir surface vegetation coverage was estimated as light (0-25%), medium (30-80%), or heavy (85-100%) coverage (Ireland 2010). Detailed notes and photographs were taken of the submerged vegetation and the surface plant coverage.

The SDV and maximum depth measurements were used to calculate the estimated amount of pond dye to be applied to each reservoir. The initial pond dye treatment was applied at a rate of one liter of dye per 0.11 hectar meters of water but less dye was applied if the pretreatment Secchi disk visibility less than 0.8 meters and more was added if the depth was greater than 1.5 meters. MARC® Photo Blue and Aquashade® were the brands of pond dye that were used. The material safety data sheets report that these dyes are non-hazardous (AB 1999; MARC 2006). Initial dye treatment was applied over several weeks during the month of April. During each week, at least one small, one medium, and one large reservoir were treated. Size categories were as follows: (a) small (less than 4 surface hectares), (b) medium (4 to 8 surface hectares) and (c) large (greater than 8 surface hectares). The dye was poured onto the reservoir surface from a boat (Appendix C). The dye was added to the reservoir in the area between the upwind shoreline and the center of the lake.

The lasting effects of pond dye can vary due to uncontrollable factors such as precipitation and the ability of the reservoir to retain water. Heavy rainfall shortly after application can wash the pond dye downstream, rendering it ineffective. The protocol was designed to maintain a consistent level of water clarity by re-treating all reservoirs with SDV greater than 0.8 meters. Three weeks after the first treatment, four reservoirs had SDV greater than 0.8 meters and were retreated, exhausting the dye supply. Due to logistical constraints, the water clarity in six reservoirs deviated from what had been specified in the protocol at six and twelve weeks after the start of treatment. When a donation of dye arrived at fourteen weeks, four reservoirs with high SDV were re-treated.

Data analysis

The values of replicate samples at each reservoir location were summed to calculate the CB Index that accounted for variation within each sample location. Microsoft Excel 2007 was used to perform the statistical calculations and produce graphs.

Short-term effects of dye treatment on the CB Index: The Mann-Whitney U statistic (Lehner 1996) was used to test for a difference in mean CB Index between the pre- and post-treatment samples for all reservoirs (n= 9). A non-parametric test of means was chosen due to the small sample size and non-normal distribution of the values. Due to the high variation in the CB Index across reservoirs, the data were also partitioned by the stable state category (clear, turbid). The Mann-Whitney U was recalculated for the ponds categorized as clear (n = 6).

Seasonal variation in SDV and CB Index: To investigate the variation in the CB Index related to seasonal changes, the Kruskal-Wallis one-way analysis of variance (H) was calculated (Lehner 1979:408). Three sampling periods were used as repeated measures (6-week, 12-week, 20-week) of the CB Index for the clear reservoirs (n = 6). Kendall's Tau (Lehner 1996:219) was calculated to determine the correlation between SDV and the CB Index. A non-parametric test of correlation was chosen due to the small sample size and non-normal distribution of the values. The dataset included values from three repeated measures at all nine reservoirs (n = 27).

Interactions of biotic and abiotic factors potentially influencing variation among reservoirs: To characterize variation in SDV across reservoirs and over time, the Friedman's two-way analysis of variance was calculated (Lehner 1996). To examine the effect of location, the variation among reservoirs was examined, while "controlling" for sample date. The data matrix consisted of reservoirs as columns (n = 9) and sample date as rows (n = 8). Ranks were assigned across each row, and summed down each column. To examine the effect of time, the variation across sample dates (columns) was examined (n = 8), while "controlling" for the variation among reservoirs (rows).

Spearman's rho (Lehner 1996) was used to test for correlations between the CB Index and chemical characteristics of the reservoirs. As recommended by Lehner (1996), the Kendall's tau was used for variables with multiple tied rank values. Kendall's tau was used to determine the correlation of pre-treatment CB Index and the catchment basin size. Scattergrams with trendlines of the water and soil chemistry data were plotted against the pre-treatment CB Index for visual interpretation of the variation among reservoirs. Seven variables selected for analysis of correlations included: alkalinity (ppm CaCO3), calcium (ppm), hardness (grains CaCo3/gal), hardness (ppm CaCO3), nitrate-N NO_3-N (ppm), sulfur (ppm) and total dissolved salts (ppm).

Results and discussion

For all of the reservoirs, surface vegetation coverage was within the low to medium range during the first three samplings then at 20 weeks post treatment then declined to low coverage. Charophyte biomass comprised 99.91% of the total biomass, yet macrophytes were a significant factor in the surface vegetation coverage (Table 2). This was especially true in reservoirs eight and nine, which had no charophytes (sampled six and twelve weeks post treatment) but had medium vegetation coverage due largely to American water-willow (*Justicia)* (Appendix D).

Table 2. Surface Vegetation Coverage. The percent of surface vegetation (macrophytes and charophytes) coverage on the reservoirs was categorized as light (L) 0-25%, medium (M) 30-80%, or heavy (H) 85-100%.

Reservoir	Pre-Treatment	6 Weeks Post Treat.	12 Weeks Post Treat.	20 Weeks Post Treat.
1	M	M	M	L
2	L	L	L	L
3	M	M	M	L
4	M	M	M	L
5	M	M	L	L
6	M	M	M	L
7	M	M	M	L
8	L	M	M	L
9	L	M	M	L

The dye treatment applied to reservoirs did reduce the SDV temporarily but did not visibly reduce charophyte biomass within six weeks post treatment (Table 3). Turbid reservoirs (mean SDV 0.4 m $\pm$ 0.1) contained less charophyte biomass (mean CB 0.26 kg $\pm$ 0.36) than clear reservoirs (mean SDV 1.2 m $\pm$ 0.4; mean CB 21.18 kg $\pm$ 6.01).

Other studies have demonstrated that when the SDV is 0.5 meter or less, submerged macrophytes are likely to be absent from shallow reservoirs (Gasith and Hoyer 1998) and that macrophytes are usually found as deep as 2 to 3 times the SDV reading (Canfield et al 1995). Studies in non-peer reviewed literature reported that pond dyes controlled submerged aquatic plant growth such as macrophytes (Lynch 2006; Purdue 1985), others have evaluated it as ineffective in reducing chlorophyll a concentrations or submerged macrophytes (Boyd and Noor 1982).

Table 3. Charophyte biomass and Secchi disk visibility. Changes in mean and standard deviation (SD) of charophyte biomass in kilograms and Secchi disk visibility in meters calculated for all reservoirs (n = 9) combined as well as separated by turbid stabile state (n = 3) and clear stabile state (n = 6) categories.

	Pre-Treatment		6 Weeks Post Treat.		12 Weeks Post Treat.		20 Weeks Post Treat.		All Treatments	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Charophyte Biomass (kg)										
All Reservoirs	5.77	6.87	4.00	3.39	4.10	5.47	0.16	0.37	14.12	11.60
Turbid Reservoirs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Clear Reservoirs	8.66	6.75	6.00	2.00	6.15	5.72	0.23	0.45	21.18	6.01
Secchi Disk Visibility (m)										
All Reservoirs	1.6	1.0	1.2	0.6	0.9	0.5	0.5	0.3	1.0	0.5
Turbid Reservoirs	0.6	0.2	0.5	0.1	0.4	0.0	0.2	0.0	0.4	0.1
Clear Reservoirs	2.1	0.8	1.5	0.4	1.1	0.5	0.7	0.3	1.2	0.4

Short-term effects of dye treatment on the charophyte biomass

Mean CB Index differed significantly between the pre- and post-treatment samples of all reservoirs ($U_S = 110.5$, $U_L = -29.5$, df = 8, $p > 0.05$). Therefore, the dye treatment effect on charophyte biomass was not significant in the first six weeks following the initial treatment (considering all reservoirs). This conclusion remained unchanged when we examined the data partitioned by steady state of the reservoirs. The variation around the mean was high for the data set including all reservoirs (Figure 1) as well as the data for only the clear reservoirs (Figure 2).

Seasonal variation in SDV and CB Index

Looking at the long-term trends in the clear reservoirs, there was a statistically significant difference in the mean CB Index (H= 159.21, df = 17, $p < 0.05$). The median CB declined over the summer, from a high of six kg at 6-weeks post-treatment to less than 1 kg at 20 weeks post treatment (Figure 2). However, due to intervening factors, this trend could not be attributed solely to the dye treatments. Clear reservoirs varied in the degree of flushing after rainfall events and the stability of the SDV after treatment events (Appendix A). Overall, the CB Index was significantly correlated with the SDV (tau = 0.67, n = 27, $p < 0.05$; Figure 3).

Figure 1. Long-term charophyte response to dye treatment. Dye treatments were designed to maintain a constant level of water transparency throughout the growing season in reservoirs (n = 9).

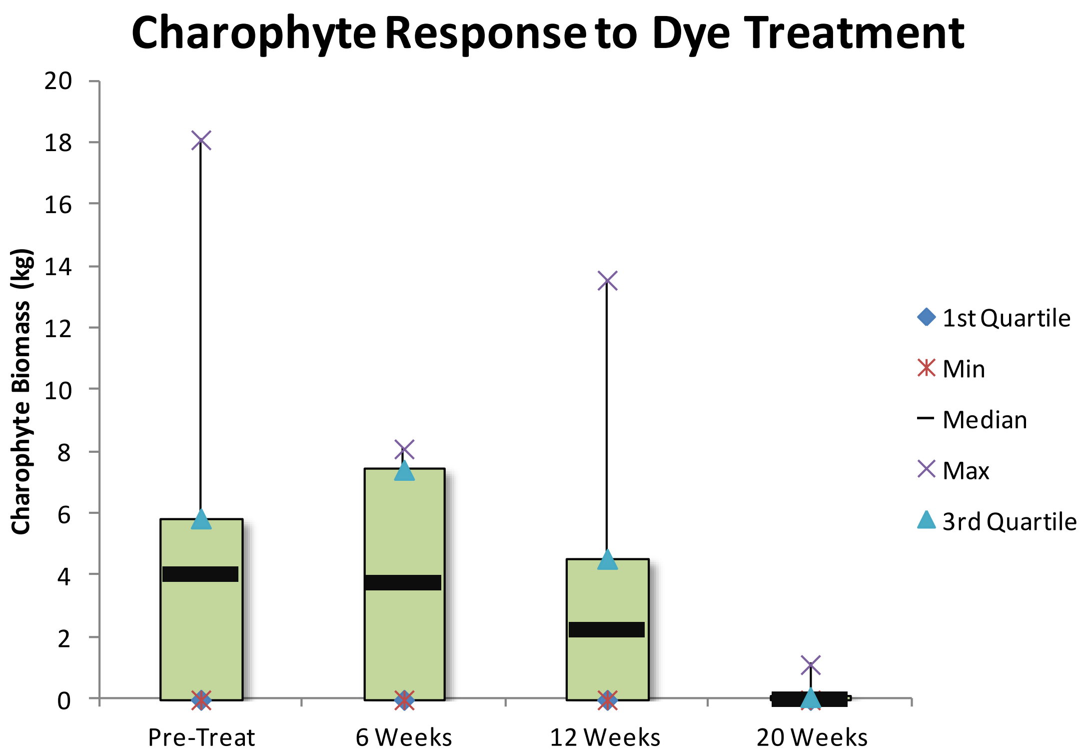


Figure 2. Charophyte biomass in clear reservoirs. Only data from the clear stabile state reservoirs (n = 6) were included in the graph.

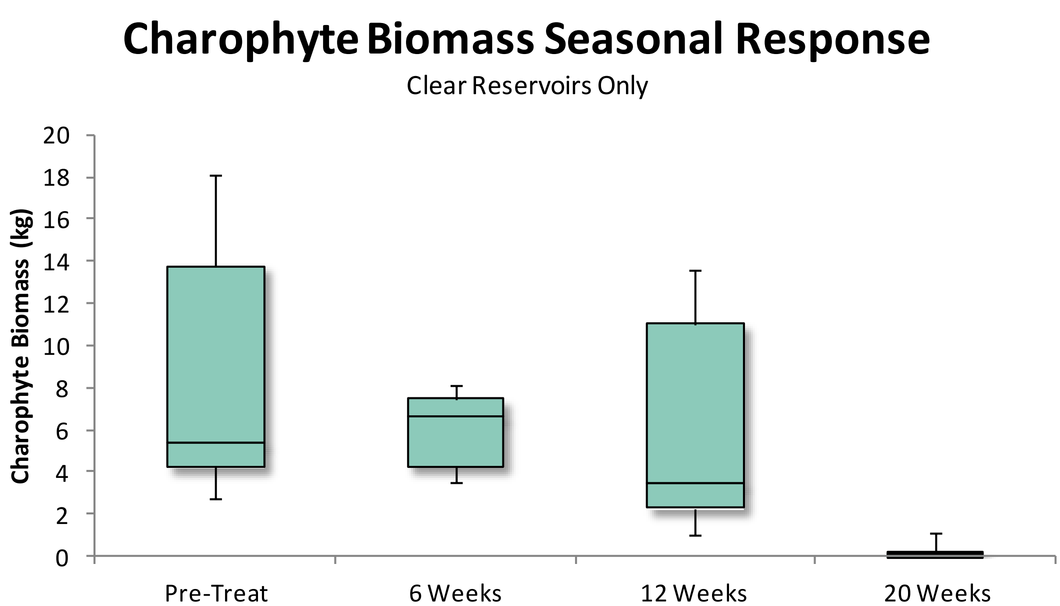
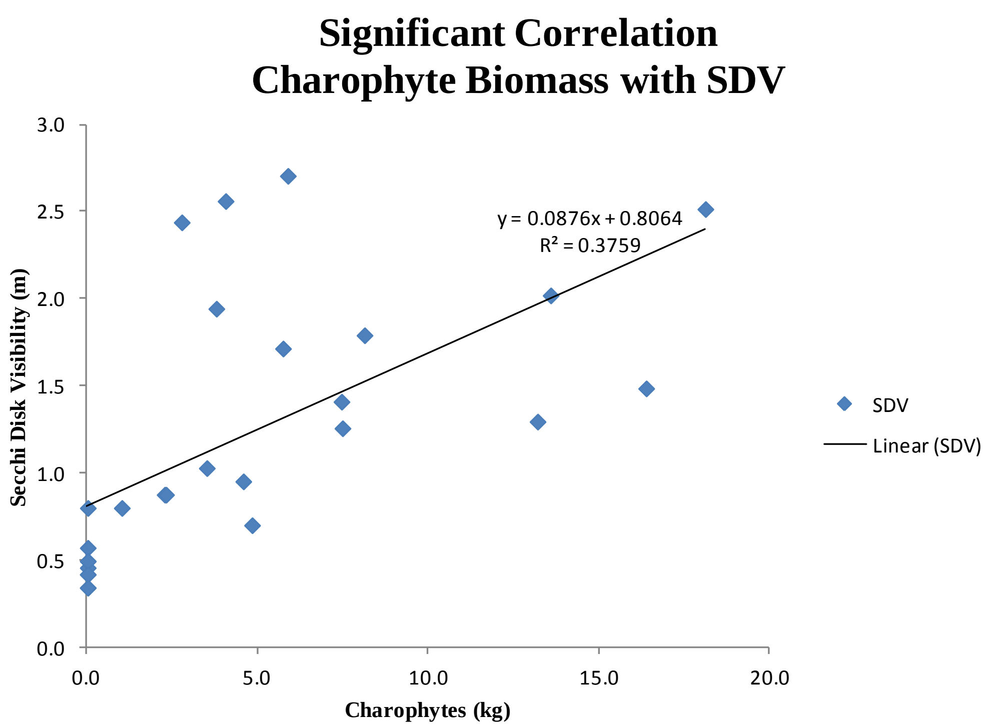


Figure 3. Correlation graph of charophytes with visibility. A scatter plot with a trendline plots the charophyte biomass in kilograms measured at all reservoirs (n = 9) over four repeat samples and the corresponding Secchi disk visibility in meters.



Interactions of biotic and abiotic factors potentially influencing variation among reservoirs

Water clarity varied throughout the summer (Figure 4), and this variation was significant when “controlling” for the variation among all reservoirs (X_r^2 = 23.67, df = 7, p = 0.05). The highest mean SDV occurred prior to dye treatment (1.6 m) and the lowest was at the end of the season (0.5 m). The post-treatment values were followed by a further decline (3-week) and rebound (weeks 6,8). Maintaining a consistent level of turbidity to suppress chara growth was very difficult using only the dye treatment as a management tool.

Reservoirs varied significantly in water clarity (X_r^2 = 50.01, df = 8, p = 0.05). Figure 5 illustrates that the turbid reservoirs (2,8,9) show relatively less variation in SDV compared to the clear reservoirs (1,3,4,5,6,7,8). Factors potentially influencing this variation might include the water flushing rate after rainfall events, the soil type and soil disturbance. More effective and efficient management of pond vegetation may be more possible when each pond is managed according to its unique characteristics.

Figure 4. Secchi disk visibility variation in time. The Secchi disk visibility in meters was repeatedly measured eight times for all reservoirs (n = 9).

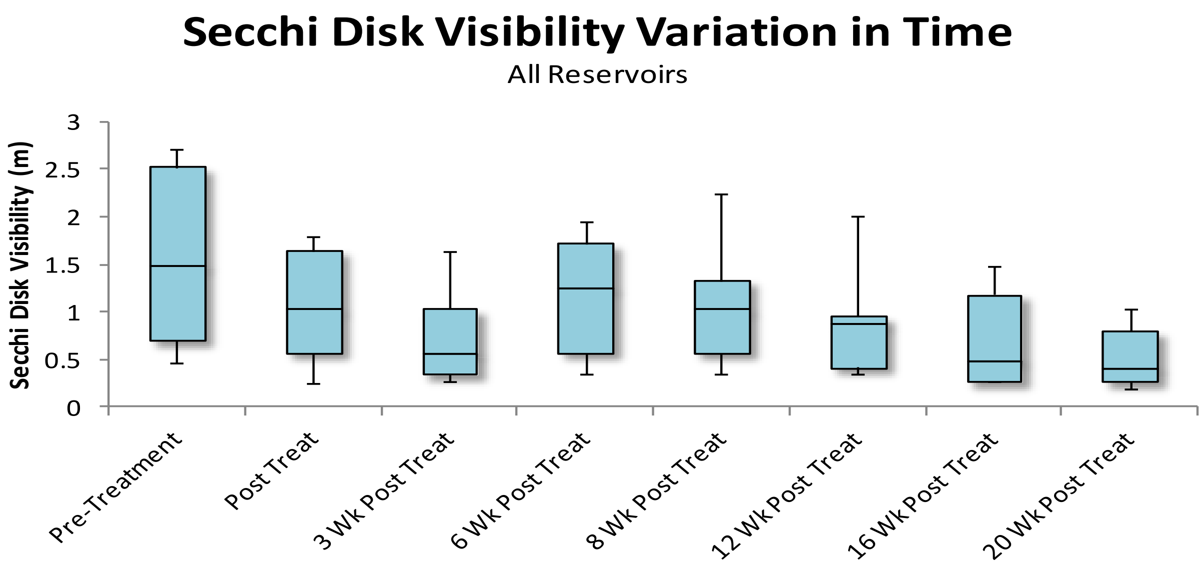
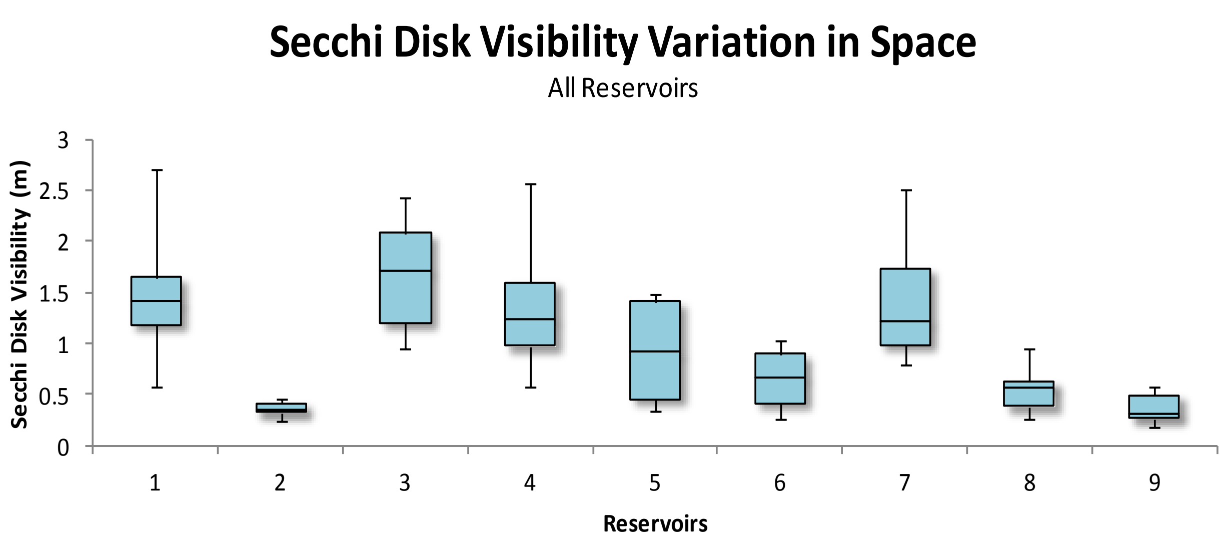


Figure 5. **Secchi disk visibility variation in space**. The Secchi disk visibility in meters was repeatedly measured eight times for all reservoirs (n = 9).



None of the water or soil chemistry variables (Appendix E), nor the catchment basin size (Table 1) were significantly correlated with the pre-treatment charophyte biomass. Nitrogen and phosphorous are nutrients required for the growth of charophytes, although the amounts and ratios required are not yet well understood in the scientific community (Wehr and Sheath 2003).

The results indicate that the application of pond dye in accordance with the methods used in this study are not effective in achieving the reduced level of charophytes desired by the fisheries managers. Further research would be needed to determine whether variations to the methods of dye treatment used in this study such as increasing the dye application rate, or altering the duration, frequency or timing of treatments could produce a greater reduction of charophyte biomass and a reduction earlier in the growing season. The application rate in this study may not have been adequate since it did not maintain the SDV at 0.8 meters or less for all reservoirs and for all repeated samplings. Prior to the dye treatment, SDV in three reservoirs was below this level; after the first treatment, only four reservoirs met this target level. The reduced SDV may not have been sustained for a duration significant enough to cause a change in the charophyte biomass. Six weeks after the initial dye treatment, six reservoirs had a Secchi disk reading higher than was taken the day after the first treatment. Four reservoirs exceeded the SDV treatment target three weeks post treatment and six reservoirs exceeded this target at six weeks post treatment. Treating only reservoirs categorized as clear stabile state is likely to be a more effective use of pond dye than treating all stabile state categories.

The dye treatment may need to be applied earlier in the season because the charophytes were already well established in April when the first dye treatment was applied. In February when these protocols were tested, few charophytes were present in the reservoirs. More basic research is needed to better understand the seasonal growth pattern of charophytes in North

America, the early season interactions between charophytes and phytoplankton and the proper timing of dye treatments.

A consideration for long term management of charophytes is that the seed like oospores can remain dormant for years before germinating (Coops 2002). Therefore, even if the treatment were applied in a manner that made it effective in preventing charophytes growth for a given growing season, the charophytes would return in subsequent years in the absence of a treatment targeted at controlling growth.

Although light maybe the most influential limiting factor for charophyte growth (Fernández-Aláez et al 2002), variables not evaluated by this study (such as rainfall, fish, mussels, slope, erosion and wind) may have also influenced the charophyte growth. Recent models suggest that a complex of variables create a dynamic state in reservoirs which are better at accounting for the level of aquatic vegetation than is a single target SDV (Scheffer and van Nes 2007). Rain events influence the volume of water flow-through the reservoir and may change the water transparency by flushing the dye and the phytoplankton. If the flushing rates among the reservoirs were unequal it could have contributed to the unequal changes in visibility. During the time period between three and six weeks post treatment, one reservoir SDV remained unchanged, SDV decreased in two reservoirs and increased in six reservoirs (min = 0.2 m, max = 1.4 m). Mussels in freshwater can have a clarifying effect by exerting pressure on the nutrients, phosphorus and nitrogen, and ultimately the phytoplankton biomass (Meeuwig et al. 1998). Studies in New Zealand and Europe have shown that herbivorous fish can graze on charophytes, fish can mechanically disturb the macroalgae when building nests, and fish such as common carp (*Cyprinus carpio*) can increase turbidity through sediment disturbance (De Winton et al 2002). Shallow underwater slopes in clear water lakes with a Secchi disk visibility of two meters or more corresponded to greater vegetation than in lakes with steeper underwater slopes (Caffrey et al 2007). If any of these factors were present, they may have contributed to the variation in time and space for SD (Figure 4 and Figure 5) or CB (Figure 1 and Figure 2). Erosion and wind induced waves were directly observed but their effects were not directly measured. The year prior to this study, reservoir number two had *Chara* beds so thick it was difficult to paddle a boat through, yet no *Chara* was sampled the year of this study. Construction upstream of reservoir number two removed several acres of soil stabilizing vegetation and was the likely cause of erosion and sediment runoff into the lake which increased the turbidity over the previous year's level to the degree that it completely restricted *Chara* growth. Both reservoirs number eight and nine have sharply undercut banks which are likely caused by wind induced wave action which can increase turbidity (Hamilton and Mitchell 1996).

Several state extension offices include charophytes in their aquatic weed management literature (Chilton 2004; Lewis and Miller n.d.; Lynch 2006) but commercial pond dye is an uncommon method for controlling charophyte growth and is not thoroughly studied. Suggested charophyte control mechanisms commonly include mechanical, biological, and chemical management means. Mechanical control methods include raking or seining to remove existing charophyte beds, placing bottom barrier mats over the substrate, using a commercial harvester, lowering the water levels to allow the charophytes to dry and freeze, and constructing reservoirs with steep banks. The stocking of a triploid grass carp (*Ctenopharyngodon idella*) has been an effective biological control for both *Chara* and *Nitella* (Wehr and Sheath 2003; Shelton and Murphy 1989). Common herbicides for charophyte control include chelated copper, copper sulfate, and Endothall (Chilton n.d.). Fertilization of ponds to induce a plankton algae bloom can limit light needed for submerged vegetation growth (Shelton and Murphy 1989).

Choosing not to treat charophyte growth and adopting a policy of directing recreation to reservoirs which already have the desired level of charophyte growth may be a practical adaptive management practice. Fisheries managers could play an active role in educating anglers on the benefits of aquatic vegetation. Submerged aquatic macrophytes and benthic macroalgae play an important role as fish habitat, in the predator prey relationship of sport fisheries and in nutrient cycling (Dibble et al 1996; Maceina and Reeves 1996). Submerged vegetation levels that cover up to, but not greater than approximately 20 percent of large Texas impoundments are positively correlated with increased crops of harvestable size largemouth bass (Durocher et al 1984). Fort Hood does not gather data on angler catches or fishing pressure but sells approximately 3,000 Fort Hood fishing permits annually. According to the last survey, Fort Hood anglers prefer to catch, in order of preference, black bass such as the largemouth bass, catfish, crappie and trout (Ditton and Sutton 1998).

The Fort Hood fisheries program could gain insight from studying angling success, sport fish population composition and assemblage (Appendix F) in relation to the level of charophyte and aquatic macrophyte vegetation present. Effective management should include distinguishing between shoreline and boat anglers, directing anglers to reservoirs suited for their mode of recreation, and monitoring the anglers' attitudes to gauge the program's success. Finally, the fisheries program should remain focused on fish population management.

Conclusion

The dye treatment, as applied in this study, does not effectively meet the intent of the fisheries managers to reduce nuisance charophytes in reservoirs used for recreational sport fishing. Further research could address several options for meeting management goals, such as dye applied (a) earlier in the season, (b) at a higher concentration or (c) at more frequent intervals. These options could make the dye treatment program prohibitively expensive to maintain or limit the treatment to a smaller number of reservoirs. Therefore, the recommendation for this fisheries program is to suspend the dye treatments in view of these results and explore alternative control methods. Even in the absence of a sound charophyte control mechanism, this study was effective in establishing proven methods for the fisheries program to monitor and quantify the charophytes and submerged machrophytes of the installation reservoirs.

Acknowledgments

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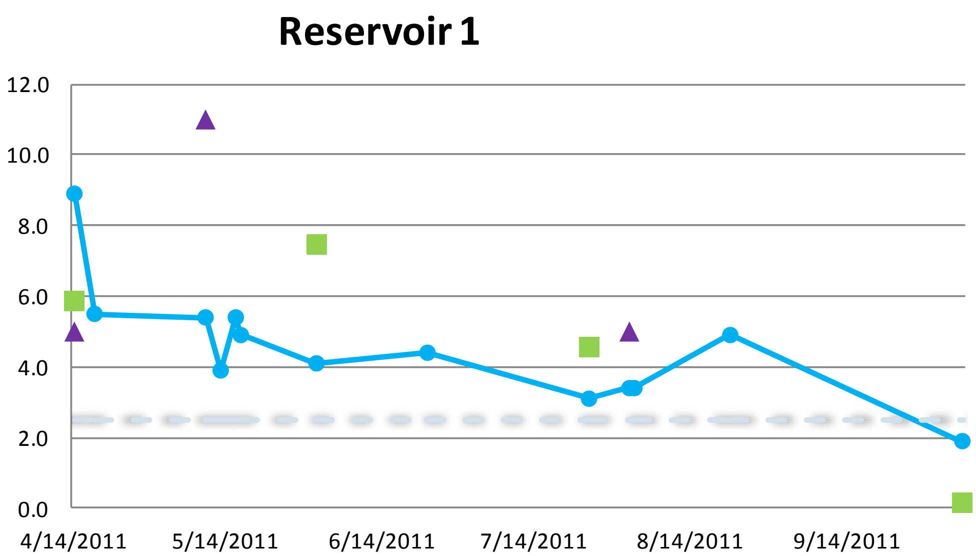
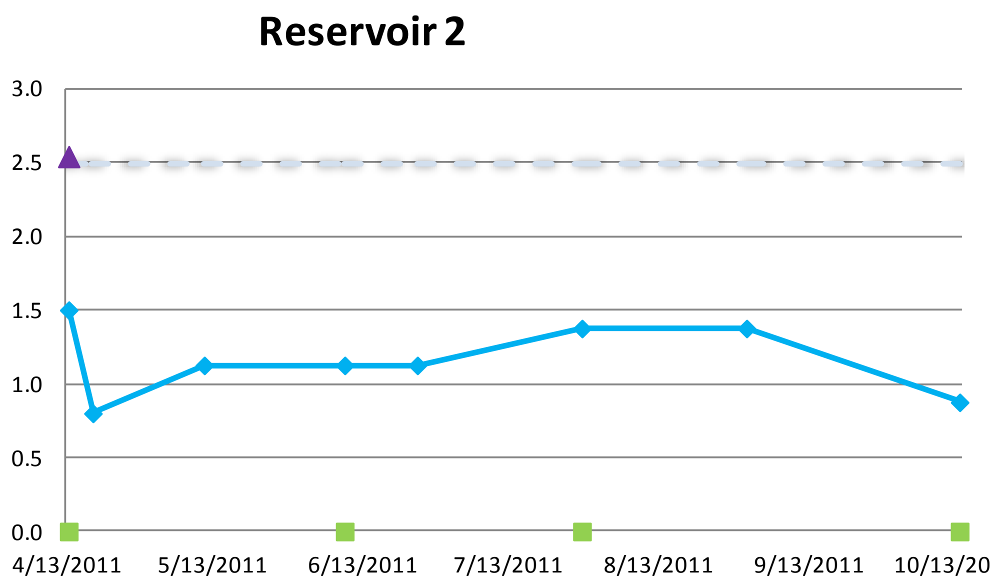
Appendix A. Chronological graphs for each reservoir

Below are line graphs for each of the nine reservoirs displaying relative values chronologically for the quantity of dye treatment, Secchi disk visibility in feet, charophyte biomass in kilograms, and the dye treatment target of 2.5 feet (0.8 meters) or less for the Secchi disk value.

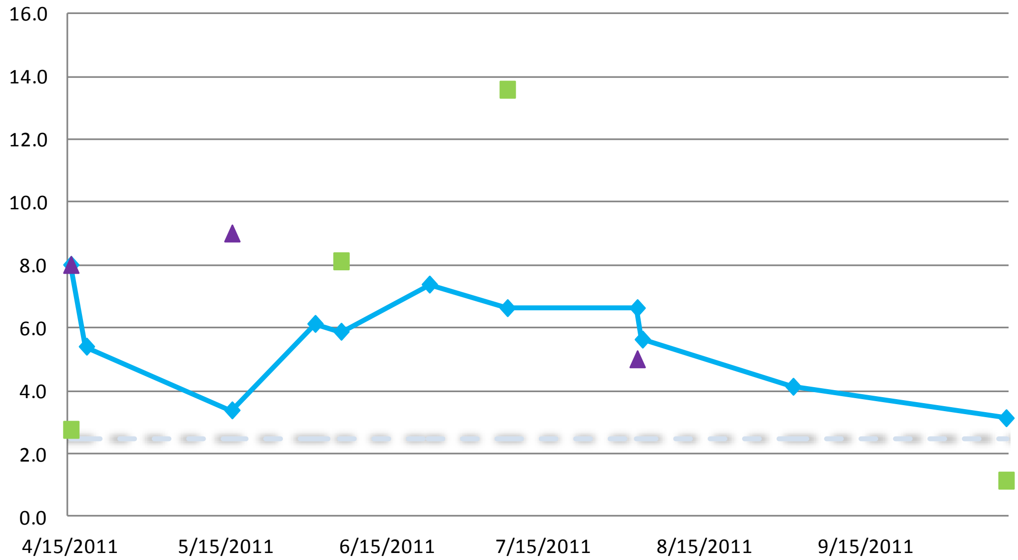


	4/14/2011	4/18/2011	5/10/2011	5/13/2011	5/16/2011	5/17/2011	6/1/2011	6/23/2011	7/25/2011	8/2/2011	8/3/2011	8/22/2011	10/7/2011
Secchi Disk Depth (ft)	8.9	5.5	5.4	3.9	5.4	4.9	4.1	4.4	3.1	3.4	3.4	4.9	1.9
Chara sp. Weight (kg)	5.867						7.468		4.561				0.165
Pond Dye (gallons)	5		11							5			
Target Secchi Disk (ft)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5

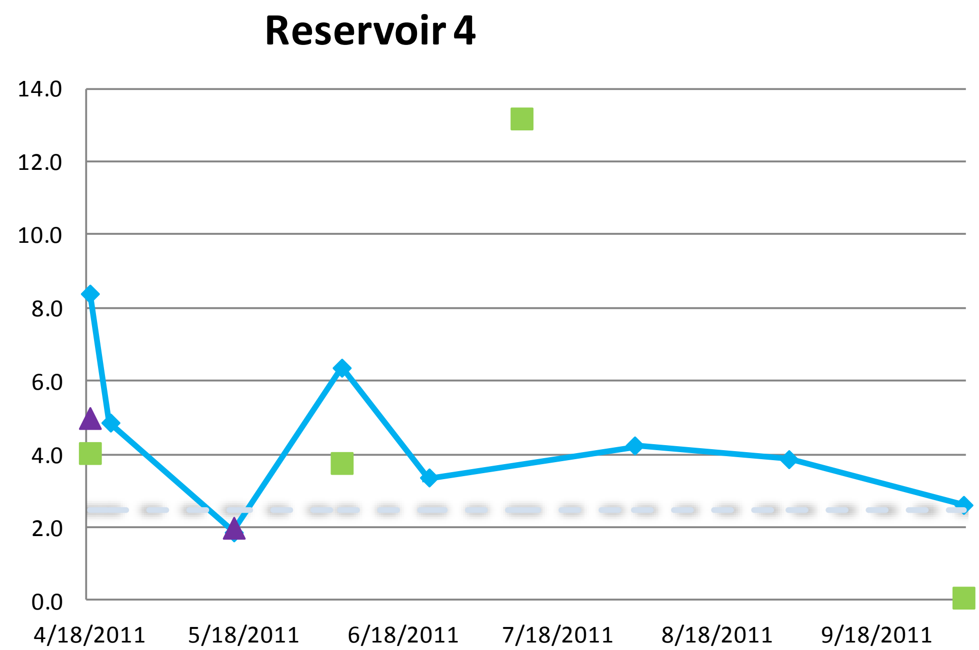


	4/13/2011	4/18/2011	5/11/2011	6/9/2011	6/24/2011	7/28/2011	8/31/2011	10/14/2011
Secchi Disk Depth (ft)	1.5	0.8	1.1	1.1	1.1	1.4	1.4	0.9
Chara sp. Weight (kg)	0			0		0		0
Pond Dye (ft2)	2.5							
Target Secchi Disk (ft)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5

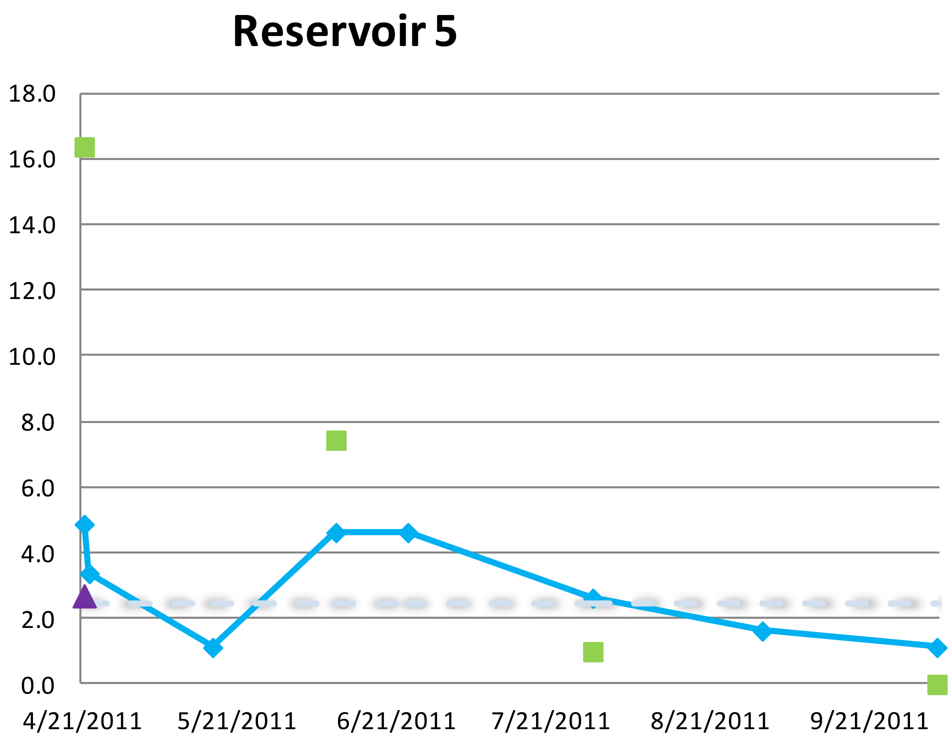
Reservoir 3



	4/15/2011	4/18/2011	5/16/2011	6/1/2011	6/6/2011	6/23/2011	7/8/2011	8/2/2011	8/3/2011	9/1/2011	10/12/2011
Secchi Disk Depth (ft)	8.0	5.4	3.4	6.1	5.9	7.4	6.6	6.6	5.6	4.1	3.1
Chara sp. Weight (kg)	2.756				8.115		13.572				1.140
Pond Dye (gallons)	8		9					5			
Target Secchi Disk (ft)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5

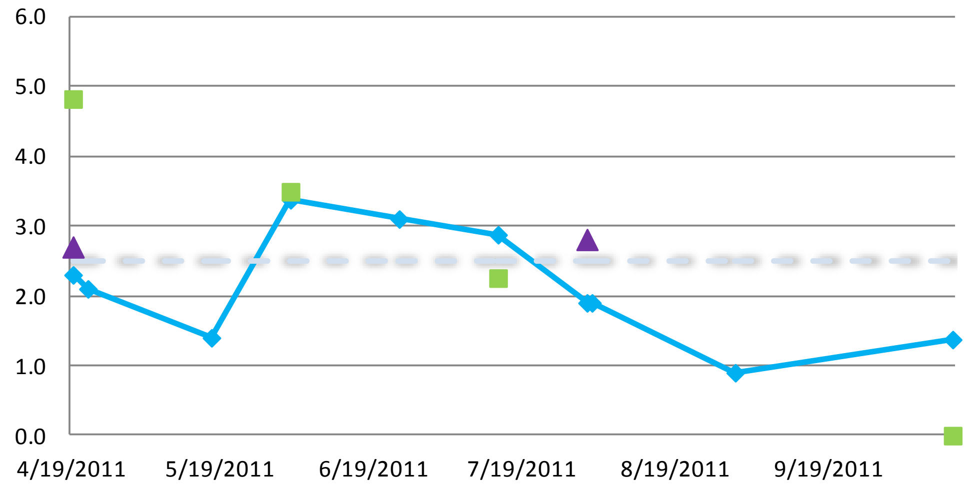


	4/18/2011	4/22/2011	5/16/2011	6/6/2011	6/23/2011	7/11/2011	8/2/2011	9/1/2011	10/5/2011
Secchi Disk Depth (ft)	8.4	4.9	1.9	6.4	3.4		4.3	3.9	2.6
Chara sp. Weight (kg)	4.042			3.770		13.188			0.090
Pond Dye (gallons)	5		2						
Target Secchi Disk (ft)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5



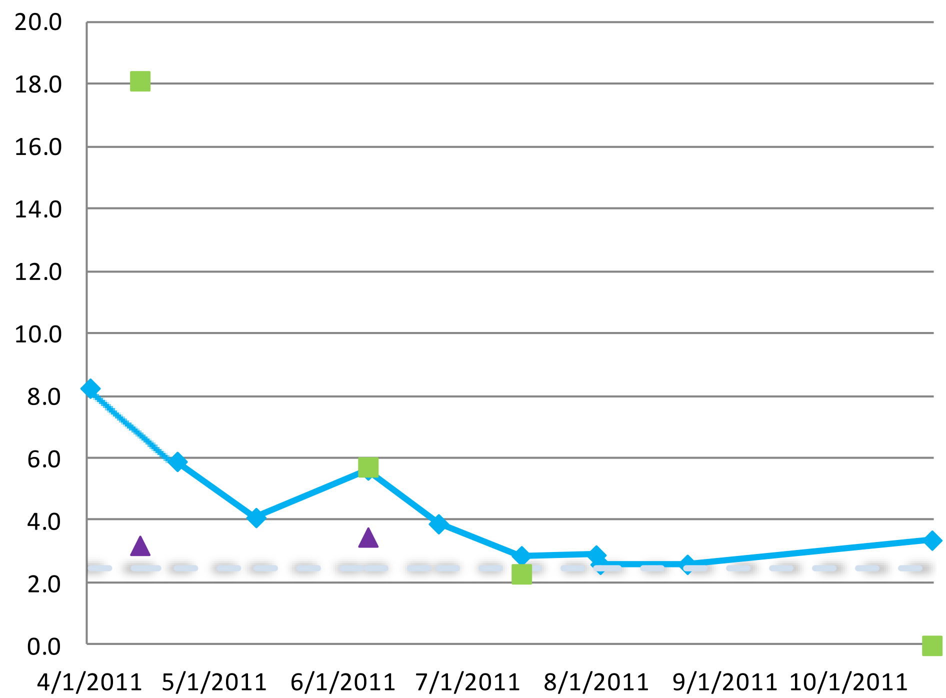
	4/21/2011	4/22/2011	5/16/2011	6/9/2011	6/23/2011	7/29/2011	8/31/2011	10/4/2011
Secchi Disk Depth (ft)	4.9	3.4	1.1	4.6	4.6	2.6	1.6	1.1
Chara sp. Weight (kg)	16.373			7.440		0.999		0
Pond Dye (ft2)	2.7							
Target Secchi Disk (ft)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5

Reservoir 6

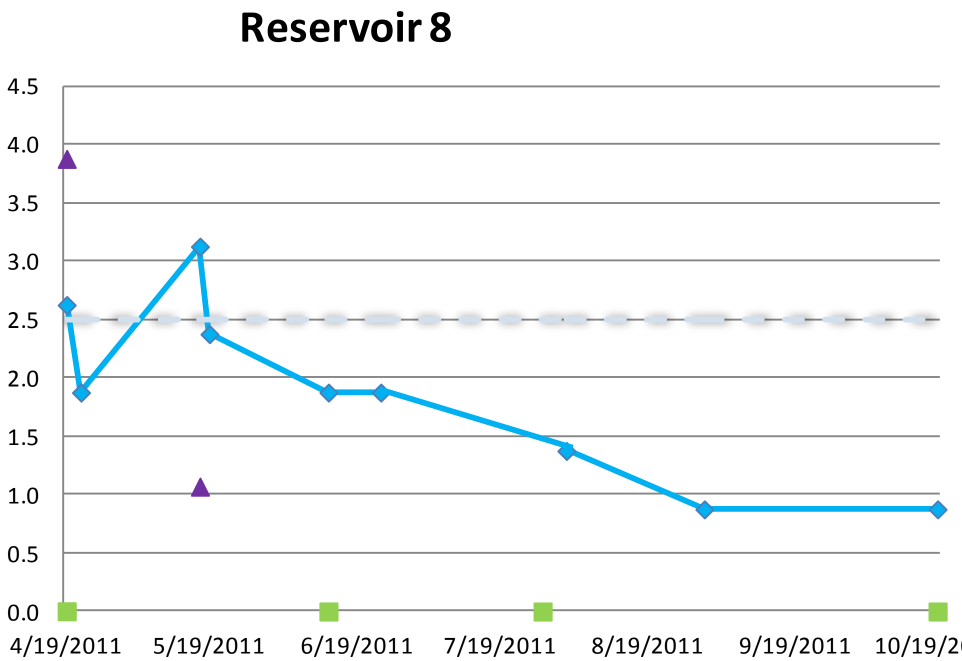


	4/19/2011	4/22/2011	5/17/2011	6/2/2011	6/24/2011	7/14/2011	8/1/2011	8/2/2011	8/31/2011	10/14/2011
Secchi Disk Depth (ft)	2.3	2.1	1.4	3.4	3.1	2.9	1.9	1.9	0.9	1.4
Chara sp. Weight (kg)	4.818			3.491		2.255				0
Pond Dye (ft2)	2.7						2.8			
Target Secchi Disk (ft)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5

Reservoir 7

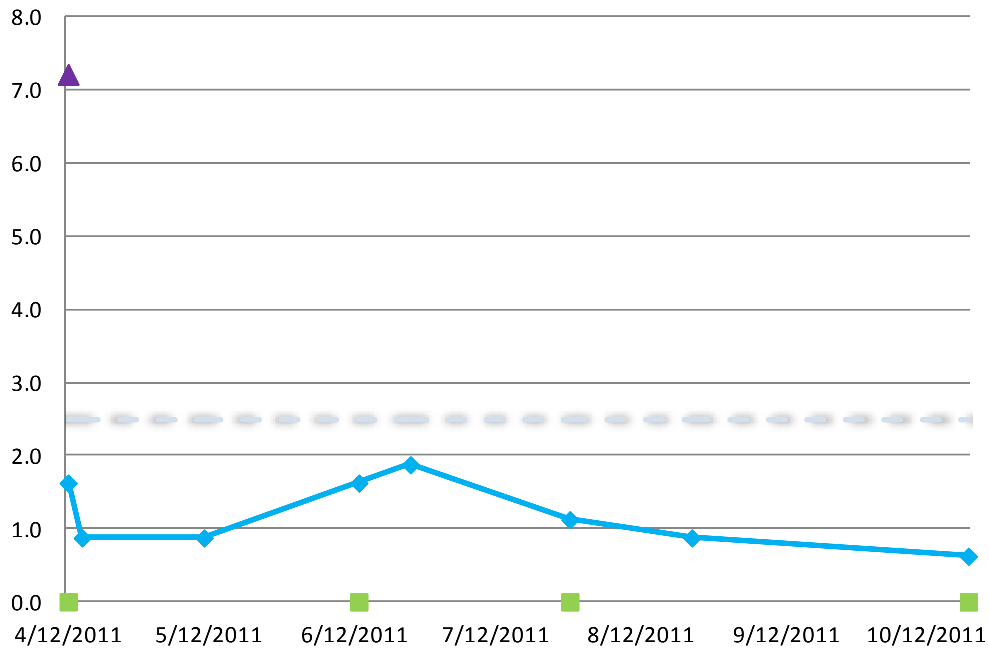


	4/1/2011	4/13/2011	4/22/2011	5/11/2011	6/7/2011	6/24/2011	7/14/2011	8/1/2011	8/2/2011	8/23/2011	10/21/2011
Secchi Disk Depth (ft)	8.3		5.9	4.1	5.6	3.9	2.9	2.9	2.6	2.6	3.4
Chara sp. Weight (kg)		18.109			5.725		2.295				0
Pond Dye (ft2)		3.2			3.5						
Target Secchi Disk (ft)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5



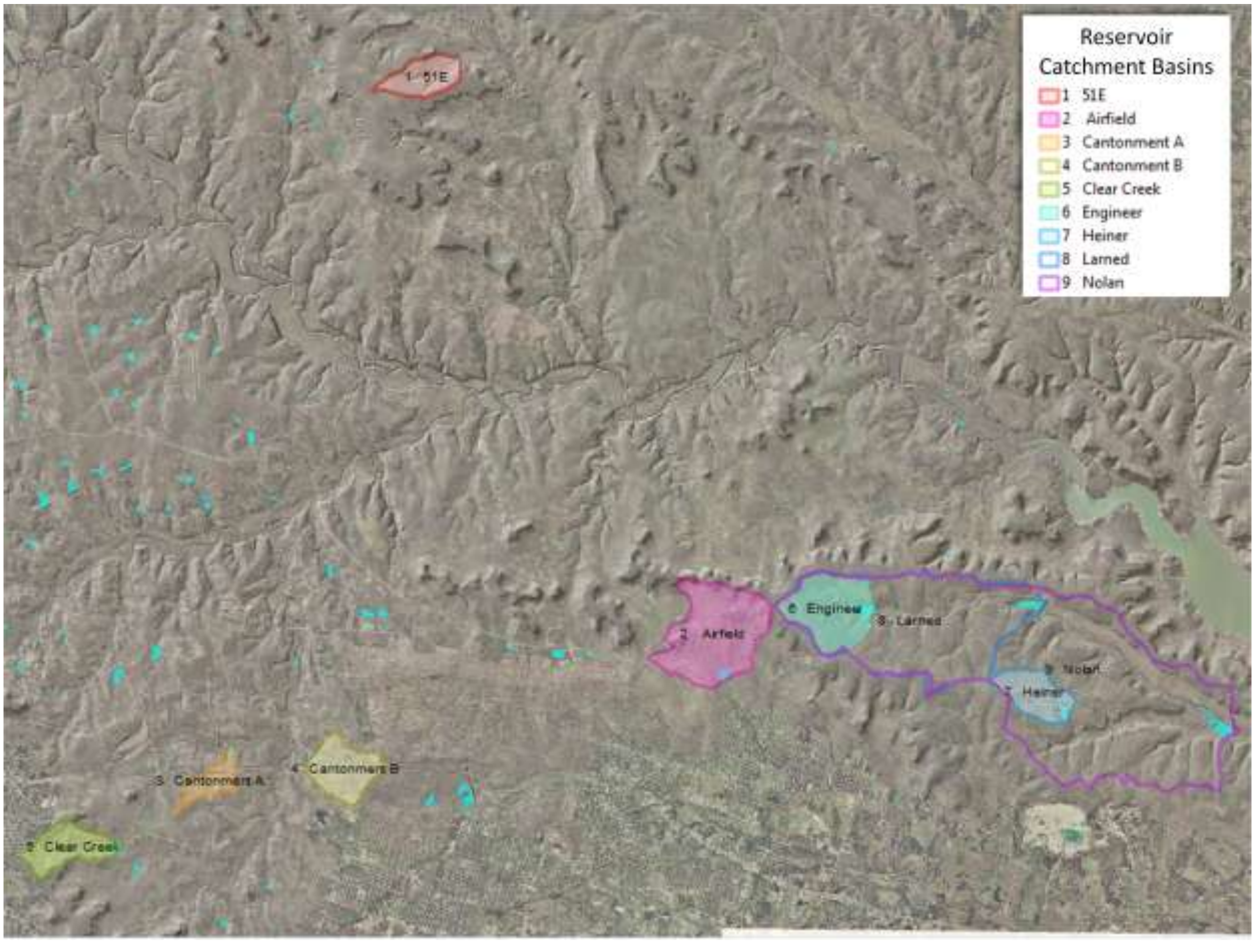
	4/19/2011	4/22/2011	5/17/2011	5/19/2011	6/13/2011	6/24/2011	7/28/2011	8/2/2011	8/31/2011	10/19/2011
Secchi Disk Depth (ft)	2.6	1.9	3.1	2.4	1.9	1.9		1.4	0.9	0.9
Chara sp. Weight (kg)	0.002				0		0			0
Pond Dye (ft2)	3.9		1.1							
Target Secchi Disk (ft)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5

Reservoir 9



	4/12/2011	4/15/2011	5/11/2011	6/13/2011	6/24/2011	7/28/2011	8/23/2011	10/21/2011
Secchi Disk Depth (ft)	1.6	0.9	0.9	1.6	1.9	1.1	0.9	0.6
Chara sp. Weight (kg)	0.001			0		0		0
Pond Dye (ft2)	7.2							
Target Secchi Disk (ft)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5

Appendix B. Distribution of reservoirs (blue) and catchment basins (see legend).



Appendix C. Photo documentation of methods.

Photo C1. PVC pipe square used at 51E Pond (Reservoir 1) on April 14th, 2011.

Photo C2. Vegetation sampling using a rake April 13th, 2011at Heiner Lake (Reservoir 7).

Photo C3. A charophyte from Cantonment B Kids Pond (Reservoir 4) on April 18th, 2011. *(Charra spp. oospores?)*

Photo C4. The Secchi disk that was used to measure visibility and in the second photo an intern, Army Specialist Justin King, practicing the Secchi disk measurement in Cantonment A Pond (Reservoir 3).

Photo C5. Pond dye applied to the surface of Larned Lake (Reservoir 8) on April 12th, 2011 by John Esseltine.

Photo C6. Larned Lake (Reservoir 8) April 12th, 2011as pond dye is being applied.

Photo C7. Larned Lake (Reservoir 8) approximately half an hour after the pond dye treatment was applied April 12th, 2011.

Photo C8. On April 13th, 2011 before pond dye treatment of Heiner Lake (Reservoir 7) the wide shoreline charophyte beds were clearly visible.

Photo C9. On April 15th, two days after the pond dye treatment was applied, the charophyte beds on Heiner Lake (Reservoir 7) were still visible but with reduced clarity.

Appendix D. Vegetation observed in Fort Hood waters.

Genus	Common Name
Carex	sedge
Chara	muskgrass
Cyperus	flate sedge
Echinodorus	burhead
Eleocharis	spikerush
Fuirena	bullrush
Hydrocotyle	water-pennywort
Justicia	American water-willow
Ludwigia	ludwigia
Nastrurtium	watercress
Nitella	nitella
Potamogeton	pondweed
Rorippa	yellowcress
Sagitarria	arrowhead
Scirpus	bullrush
Typha	cat-tail
Utricularia	bladderwart

Appendix E. Soil and Water Chemistry Samples. Samples from all reservoirs (n = 9) prior to pond dye treatment.

Soil Analysis	Minimum	Maximum	Mean	Standard Deviation
pH	7.6	8.0	7.8	0.1
Conductivity and Mehlich III by ICP	262	496	385	72
Nitrate-N(ppm)	1	6	2	1.7
Phosphorus (ppm)	1	38	10	11.7
Potassium (ppm)	86	375	234	110
Calcuim (ppm)	13157	35669	21737	6986
Magnesuim (ppm)	172	621	309	144
Sulfur (ppm)	18	69	37	18
Sodium (ppm)	36	163	68	40

Water Analysis	Minimum	Maximum	Mean	Standard Deviation
Calcuim (ppm)	20	71	50	16
Magnesuim (ppm)	3	18	9	5.6
Sodium (ppm)	4	11	8	2.3
Potassium (ppm)	1	4	3	1.1
Boron (ppm)	0.01	0.15	0.05	0.05
Carbonate (ppm)	0	0	0	0.0
Bicarbonate (oppm)	108	261	177	54
Sulfate (ppm)	4	27	16	6.5
Chloride (ppm)	3	21	15	5.8
Nitrate-N (ppm)	0.01	0.14	0.07	0.04
Phosphorus (ppm)	0.01	0.02	0.01	0.00
pH	7.17	8.00	7.43	0.28
Conductivity (umho/cm)	210	398	289	72
Hardness (grains CaCo3/gal)	6	14	9	2.8
Hardness (ppm CaCO3)	102	236	159	48
Alkalinity (ppm CaCO3)	88	214	145	44
Total Dissoled Salts (ppm)	193	386	277	72
SAR	0.2	0.4	0.3	0.1
Charge Balance	93	105	98	4

Appendix F. Fish species most commonly sampled in Fort Hood reservoirs. Source is FHNRMB (2006).

gizzard shad (*Dorosoma cepedianum*)

threadfin shad (*Dorosoma petenense*)

red shiner (*Cynprinella lutrensis*)

common carp (*Cyprinus carpio*)

golden shiner (*Notemigonus crysoleucas*)

bullhead minnow (*Pimephales vigilax*)

yellow bullhead (*Ameiurus natalis*)

channel catfish (*Ictalurus punctatus*)

flathead catfish (*Pylodictis olivaris*)

western mosquitofish (*Gambusia affinis*)

redbreast sunfish (*Lepomis auritus*)

green sunfish (*Lepomis cyanellus*)

warmouth (*Lepomis gulosus*)

bluegill sunfish (*Lepomis macrochirus*)

redspotted sunfish (*Lepomis miniatus*)

longear sunfish (*Lepomis megalotis*)

redear sunfish (*Lepomis microlophus*)

largemouth bass (*Micropterus salmoides*)

white crappie (*Pomoxis annularis*)

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