ECOLOGICAL AND WATER QUALITY EFFECTS OF THE MISSISSIPPI DELTA MANAGEMENT SYSTEMS EVALUATION AREA ON OXBOW LAKES

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ABSTRACT

Over the course of the past century, aquatic habitats have declined worldwide. Much of this loss has been attributed to draining and clearing for agriculture as well as non-point source pollution associated with agricultural runoff. The Mississippi Delta MSEA (Management Systems Evaluation Area) is a competitive agricultural systems-based research project designed to address the problems associated with these non-point source pollutants. This project is unique among MSEA projects, both because of its location in the Mississippi River alluvial plain and its strong ecological research component. Experimental design of the Mississippi Delta MSEA called for the development of land and cultural treatments targeted to reduce sediment and associated pollutants entering watershed oxbow lakes. Changes in lake water quality and fisheries characteristics were, and are still being used as measures of management success. Analyses of water quality prior to the implementation of best management practices (BMPs) indicated lakes that were stressed and ecologically damaged due to excessive in-flowing sediment. significant improvements in water quality were realized through the use of cultural and structural BMPs. Sediments were decreased 34 to 59%, while Secchi visibility and chlorophyll generally increased. The most dramatic improvements in water quality occurred in Thighman and Deep Hollow, which featured cultural practices and combinations of cultural and structural practices, respectively. Reducing suspended sediment concentrations in these oxbow lakes resulted in conditions favorable for phytoplankton production. Increases in phytoplankton production resulted in increased chlorophyll concentrations and higher concentrations of dissolved oxygen, leading to improved secondary productivity. Prior to implementation of BMPs, species richness was relatively low for all three MSEA lakes and sports fishes were generally poorly represented with the exception of white crappie and channel catfish. No largemouth bass were collected from Beasley or Thighman lakes. Post BMP fishery surveys indicate successful renovation of lakes protected with cultural or structural and cultural practices. Following renovation, fish catches and diversity were highest in Thighman and Deep Hollow while Beasley showed a decline in both standing stock and diversity. Bass populations lacking in two of the lakes before renovation and restocking were successfully reestablished in Deep Hollow and Thighman. In all likelihood, restocking in Beasley Lake failed due to continuing poor water quality despite the presence of structural BMPs. Results indicate that cultural BMPs may play the more vital role in improving lake water quality and may be needed in addition to structural measures to ensure improved fisheries in oxbow lakes receiving agricultural runoff.

Introduction

Water erosion removes 1.36 to 1.82 billion metric tons of U. S. topsoil each year and is a significant problem nationally. The Mississippi River alone transports 300 million metric tons of soil to the Gulf of Mexico annually (Brown, 1984). Fowler and Heady (1981) reported that in stream suspended sediments are, by volume, the most significant pollutants in the United States. Much of the worldwide decline in aquatic habitats over the course of the past century can be attributed to draining and clearing of land for agriculture. It is estimated that 60% of the approximately 2.72 billion tons of sediment per year deposited in waterways originates from agricultural lands. In addition, these sediments are often accompanied by other contaminants such as pesticides and nutrients. The natural lakes of the Mississippi alluvial plain, long known for their productivity and recreational value (Cooper et al., 1984) have not escaped the detrimental effects of soil erosion. Their popularity as recreational resources has decreased as water quality and fisheries have declined (Coleman, 1969). Cooper and Knight (1978) have attributed these declines, in part, to soil erosion and sedimentation. Detrimental impacts on stream and lake water quality due to erosion and sedimentation have been well documented (Knight et al., 1994; Waters, 1995).

Oxbow lakes are remnants of meandering floodplain rivers that have been cut off and physically isolated from their respective main river channels. Because of this isolated condition, changes begin to occur in the physical and chemical characteristics of the lake basin and in the floral and faunal assemblages. Over time, as allochthonous organic materials derived from previous connections with the floodplain river ecosystem are processed and energetically depleted, isolated oxbow lakes in agricultural regions tend to become less heterotrophic and more autotrophic. As a result, they become closed entities within themselves, functioning similarly to farm ponds and other small impoundments.

If suspended sediment concentrations are low enough to provide suitable light penetration, oxbow lakes provide conditions conducive to photosynthesis, primarily via phytoplankton, and may support a sustainable sport fishery. However, traditional tillage practices in the Mississippi Delta region often result in excessive soil erosion leading to increased turbidity in the oxbow lakes and subsequent inhibition of photosynthesis. Turbidity in oxbow lakes can be persistent in areas having soils with high clay content such as the Mississippi Delta. Although nutrients such as phosphorus are commonly associated with delta soils and isolated oxbow lakes tend to load nutrients, these systems may become energy starved and very unproductive due to lack of light penetration.

Best management practices (BMPs) designed to reduce sediment-laden runoff should reduce suspended sediment concentrations in the receiving waters of oxbow lakes. Although some reduction in nutrient in-flow may be realized, most oxbow lakes should be eutrophic enough to boost primary productivity and consequently support a sustainable fishery. Research is needed to examine the impact of these management practices on the water quality and productivity of oxbow lakes receiving runoff from these managed watersheds.

The Mississippi Delta MSEA (Management Systems Evaluation Area) is a competitive agricultural systems-based research project designed to address the problems associated with non-point source pollutants. The Mississippi Delta MSEA is unique among MSEA projects both because of its location in the Mississippi River alluvial plain and its strong ecological research component. Experimental design of the Mississippi Delta MSEA called for the development of comprehensive land and cultural treatments targeted to reduce sediment and associated pollutants entering watershed oxbow lakes. Major objectives of the MSEA project are: 1) to develop and evaluate alternative and innovative farming systems for improved water quality/ecology in the Mississippi Delta **2)** to increase the knowledge to design and evaluate economical environmentally-sound BMPs as components of farming systems and 3) to increase awareness and adoption by farmers/landowners of alternative farming systems to reduce adverse agricultural impacts on water resources and ecological processes.

This study examines and documents pre-management water quality and ecological conditions on three oxbow lakes and resulting water quality and fisheries improvements following lake renovation and the implementation of best management practices designed to control erosion and non-point source pollution.

Materials and Methods

Project Overview

The Mississippi Delta Management Systems Evaluation Area (MSEA) project was intended to demonstrate the effectiveness of farming systems designed to reduce nonpoint source pollution from agricultural runoff. These farming systems employed a variety of BMPs that fell into one of two categories, structural or cultural. Three oxbow lake watersheds were selected to receive management practices based on these different categories. One of the watersheds was protected solely with structural practices such as slotted pipes, slotted board inlets, grassed buffers and stiff grass hedges. Another watershed was protected with a combination of the aforementioned structural practices as well as cultural methods including conservation tillage and winter cover crops. The third watershed was originally planned to be a "control" watershed that would demonstrate conventional tillage and typical farming practices of the region. While no structural or cultural practices were recommended or encouraged, the farmers within this watershed began adopting conservation tillage at about the same time that the various BMPs were initiated in the other two watersheds. This resulted in a study were one watershed was protected with cultural practices, one with structural practices and a third with a combination of both.

Study Site

The Mississippi Delta MSEA study sites included the three oxbow lakes of Thighman and Beasley Lakes near Indianola. MS in Sunflower County and Deep Hollow Lake near Greenwood, MS in Leflore County. Thighman Lake has a watershed of approximately 769 ha and a surface area of 10 ha. Crop production included cotton, rice, soybeans and corn. In addition to runoff from these crops, Thighman Lake receives water discharged from catfish ponds. Much of the land originally farmed in conventional tilled cotton was farmed in conservation tilled cotton and corn beginning in 1996. Beasley Lake is a 16 ha oxbow with a large wooded riparian zone located in a 404 ha watershed. Conventionally tilled cotton was the principal crop in the watershed. Beasley Lake was managed with structural practices. Deep Hollow Lake has a surface area of 8 ha and a watershed size of 16 ha. This watershed was farmed in cotton and soybeans and received both structural and cultural management practices to reduce sediments and other non-point source pollutants.

Data collection

Three sampling sites on each of the three lakes were selected for water quality monitoring. Yellow Springs Instruments (model provided for information purposes only and should not be taken as an endorsement of any particular brand or product) automated water quality monitoring equipment was used to obtain hourly measurements of temperature, pH, dissolved oxygen and conductivity. Surface water quality was sampled biweekly for total, suspended, and dissolved solids, total phosphorus, filterable ortho-phosphate, ammonium nitrogen and nitrate nitrogen, chlorophyll, coliform and enterococci bacterial counts and Secchi visibility.

Analytical and chemical methods were based on procedures from APHA (1992). Calculation of means and statistical analysis was completed using SAS statistical software (SAS Institute, Inc., 1996). All parameters were tested for differences at the *5%* level of significance.

All three lakes were renovated using *5%* rotenone solution. Pre-management standing stock and other fisheries characteristics were estimated for each oxbow by sub-sampling fish from approximately 0.56 hectares of block netted lake. Fish were weighed, measured for total length and identified to species.

Each lake was re-stocked with largemouth bass (*Micropterus* salrnoides). a mix of bluegill (Lepomis *macrochirus*) and redear sunfish (Lepornis *microlophus*), and channel catfish (*Ictalurus punctatus*) at rates of 50, 500 and 150 per acre respectively. The bluegill - redear sunfish mix and channel catfish were introduced in the fall of 1996 followed by largemouth bass in the spring of 1997. Sampling was accomplished using a boat mounted Coffelt Model VVP-2C (model provided for information purposes only and should not be taken as an endorsement of any particular brand or product) electroshocker operating at 250 volts. Sampling effort was limited to one hour of electrofishing time per lake providing adequate survey coverage while minimizing damage to recovering populations. Captured fish were placed in holding tanks until they could be weighed, measured, and released. Capture mortality was generally limited to smaller individuals.

Results and Discussion

General Water Quality

Mean physical and chemical water quality data for the three MSEA lakes prior to establishment of erosion and pollution control structures and management practices may be found in Tables 1 and 2. Water quality of all MSEA lakes was statistically similar to one another prior to implementation of BMPs (Table 3). Thighman Lake had significantly higher conductivity, and concentrations of dissolved solids and nitrate than either Deep Hollow or Beasley Lakes, while Beasley and Deep Hollow had higher concentrations of ortho-phosphate.

Analyses of water quality prior to the implementation of management practices indicated that lakes were stressed and ecologically damaged due to excessive inflowing sediment. Mean total water column sediment concentrations ranged from 351 mgIL to 505 mgIL with maximum values reaching 2365 mgIL for Beasley Lake, 1094 mgIL for Thighman Lake and 804 mg/L for Deep Hollow Lake. High suspended solid concentrations on Thighman and Beasley Lakes corresponded to lower concentrations of chlorophyll and lower Secchi visibility. Deep Hollow Lake had the highest mean concentration of chlorophyll at 24.42 g/L as well as the lowest mean concentration of suspended sediment (269 mg/L). Temperature, conductivity and pH values fell within ranges expected for the oxbow lakes in the Mississippi Delta. While all three lakes experienced occasional periods of low dissolved oxygen concentrations, average annual dissolved oxygen concentrations were adequate to maintain warm water fisheries.

Nitrogen

Atmospheric nitrogen is highly soluble in fresh water and only rarely a limiting factor in lake or pond productivity. All steps in the nitrogen cycle may occur in fresh water and are typically controlled by biological processes. Boyd (1979) reported that ammonium nitrogen and nitrate nitrogen concentrations of unfertilized woodland ponds were 0.052 mg/L and 0.075 mg/L respectively while catfish ponds had concentrations of 0.50 mg/L ammonium nitrogen and 0.25 mglL nitrate nitrogen. Although the MSEA lakes exceeded these values, they never exceeded the 1 mg/L at pH 7 and 30 °C standard for ammonium nor the 0.02 mg/L standard for the highly toxic un-ionized form. MSEA lakes were also well below the 10 mg/L USEPA (1987) standard for water and fish ingestion. MSEA lakes had nitrate nitrogen concentrations that compared similarly to those values reported for Yazoo Basin lakes in 1969 (Knight et al. 1998). Best Management Practices had little discernable effect on the concentration of nitrogen compounds in the MSEA lakes (Figure 1). Deep Hollow was the only lake to show a significant decrease in ammonium nitrogen (Table 4).

Phosphorus

Phosphorus plays a major role in biological metabolism and is typically the limiting factor in lake productivity and eurtrophication (Hutchinson, 1957; Lee, 1970). Phosphate fertilizers are routinely added to ponds to increase primary productivity and fish growth (Mortimer, 1954; Hickling, 1962). Excessive amounts of phosphorus, however, may result in massive phytoplankton blooms and corresponding oxygen depletion. Boyd (1976) reported that fertilized farm ponds in Alabama averaged 0.17 mglL total phosphorus and 0.02 mg/L ortho-phosphate. USEPA (1987) stated that lake or reservoir waters should not exceed .025 mglL total phosphorus in order to prevent nuisance growth of plants and eutrophication. Total phosphorus in the three MSEA lakes prior to BMPs ranged from and average of 0.437 to 0.522 mg/L (Table 2). Although these values are rather high, they are not unexpected given the relatively high phosphorus content of Mississippi Delta soils. Decreases in total phosphorus occurred in all MSEA lakes following implementation of BMPs (Figure 1). These decreases ranged from 31 to 55 % (Table 4). While total phosphorus decreased, filterable ortho phosphate significantly increased on all lakes from 53 to 144%.

Sediment and chlorophyll

Few studies have been conducted to determine the effects of clay turbidity on warmwater fishes. Wallen (1951) found that concentrations of suspended sediments as high as 100,000 mglL were required for gills and opercular cavities to become clogged. However, stress related behaviors could be induced at concentrations as low as 20,000 mg/L. Wedemeyer et al. (1976) reported that concentrations of 80-100 mg/L are considered to be the maximum that most species of fish can tolerate on a continual basis without causing gill damage. Long-term exposures (several months) to concentrations of 200-300 mg/L have caused bacterial tail and fin rot in salmonids. as well as pathological changes is gill structure (Herbert and Merkins, 1961). While high concentrations of suspended solids rarely cause direct fish mortality relatively low concentrations can affect lake productivity (Murphy, 1962). Waters (1995) detailed the sources, effects and control of sediment in streams and provided a summary of research on the effects of sediments on aquatic organisms.

Suspended and total solids concentrations prior to implementation of management practices were sufficiently high to consider the MSEA lakes sediment stressed systems (Figure 2). Suspended sediment concentrations exceed water quality standards established for Alaskan water reported by Lloyd (1987). The MSEA lakes also had suspended solids concentrations that were 84.2 % higher than that of Morris Pond, a 1.09 ha farm pond located in the hill lands of central Mississippi (Cooper and Knight, 1990). Annual mean suspended solids concentration was 55.0 mg/L for Morris Pond compared to 405 mg/L, 429 mg/L, and 289 mg/L respectively for Thighman, Beasley and Deep Hollow. When compared to historical turbidity data collected from Yazoo Basin lakes from 1969, the three MSEA lakes exceeded estimated suspended solids concentrations of all lakes with the single exception of Arkabutla Reservoir (Knight et al., 1998; USCOE, 1975). It should be noted that this 1969 data was collected prior to the increase of intensive cultivation of soybeans in the Mississippi Delta that occurred in the 1970's and is based on sediment-turbidity models developed by Sigler et al. (1984).

Cultural and structural management practices as well as combinations of the two reduced total and suspended sediments on all three MSEA lakes. The greatest percent reduction occurred in Deep Hollow Lake (76%), which features a combination approach to erosion control. This reduction in suspended sediment significantly improved Secchi visibility in two of the MSEA lakes. Prior to BMP establishment, Secchi visibility was. exceptionally low averaging less than 17 cm and further supporting the contention that the MSEA lakes were sediment stressed. As a result of sediment reductions due to management practices, Secchi visibility increased to 25 cm on Deep Hollow Lake. This represents a 108% increase in water visibility. Secchi visibility also improved on Thighman, increasing by 36%.

Cooper and Bacon (1980) reported that primary productivity was adversely affected when suspended sediments exceeded 100 mg/L. At this concentration of suspended sediments, chlorophyll concentration was reduced to less than 20 mg/L. Cooper et al. (1995) demonstrated that when suspended sediments were reduced through diversion of sediment laden runoff chlorophyll concentration doubled. Cooper and Bacon (1980) reported mean annual suspended sediment concentrations of 117, 198, and 262 mg/L for the years 1977, 1978 and 1979, which were lower than the means for the three MSEA lakes. While chlorophyll concentrations were also impacted by high suspended sediments in the MSEA lakes, reductions in sediments due to management practices contributed to corresponding increases in chlorophyll on all MSEA oxbows, ranging from 61 to 629% (Figure 2).

Fisheries Evaluation

Renovation - Summary fishery characteristics prior to implementation of BMPs may be found in Table 5. Fish species identified in the rotenone sampling were typical of oxbow lake fauna. By number, gizzard shad (*Dorosoma* cepedianum), white crappie (Pomoxis *annularis*) and bluegill (*Lepomis macrochirus*) were the dominant species in Thighman Lake while white crappie, mosquito fish (*Gambusia affinis*) and gizzard shad where most abundant in Deep Hollow. White crappie, gizzard shad and madtom catfish (*Noturus gyrinus*) were numerically dominant species in Beasley Lake. Species richness was relatively low for all three MSEA lakes even though Mississippi is home to over 300 species of freshwater fishes (Ross and Brenneman 1991).

By weight, gar (Lepisosteus sp.), common carp (*Cyprinus* carpio), white crappie and paddlefish (Polyodon *spathula*) were important in all MSEA lakes. Deep Hollow Lake had the greatest standing stock at 292 kg/ha, followed by Thighman with 282 kglha and Beasley with 152 kglha. These standing stocks roughly fall within the ranges reported in the literature for various natural and unfertilized man-made lakes. Swingle and Smith (1938; 1939) reported 168 to 337 kg/ha for bass bluegill ponds in Alabama. Carlander (1955) reported natural lakes ranging from 196 to 1010 kglha. Cooper et al. (1963) reported that standing stocks in natural lakes ranged from 56 to 168 kglha while artificial ponds ranged from 224 to 499 kg/ha. He attributed this difference in productivity to the low fertility of the natural glacial lakes and to nutrient rich runoff entering the artificial lakes from surrounding agricultural land. Ponds in Oklahoma ranged from 64 to 1045 kglha with a mean of 383 kg/ha (Jenkins, 1958). Carlander and Moorman (1956) reported standing stocks of 1246 kg/ha in flood plain ponds in Illinois and 31 to 1386 kg/ha in Iowa. While the standing stock is in agreement with those reported in the literature much of the weight of fish from the MSEA lakes is made up of undesirable species such as gizzard shad, various species of gar (Lepisosteus sp.) and common carp.

Sports fishes were generally poorly represented with the exception of white crappie in all of the lakes and channel catfish (*Ictalurus punctatus*) in Thighman Lake. No largemouth bass were collected from Beasley or Thighman lakes. Catfish production ponds located nearby and draining into Thighman Lake may account for the healthy population of channel cattish found in that oxbow. While all three lakes support large numbers of the popular game fish, white crappie, these fish were typically small averaging 19 to 29 grams.

Electrofishing - First year fishery surveys evaluating BMPs for improving the water quality and fisheries of oxbow lakes indicate successful renovation of the two lakes with the greatest improvement in water quality. Monitoring of the three lakes shows little or no change in the water quality of Beasley Lake, but a marked improvement in Thighman and Deep Hollow. Fish numbers in Thighman Lake which was treated with cultural based BMPs and Deep Hollow Lake affected by comprehensive structural and cultural BMPs showed increasing populations (Fig. 3) and decreased diversity (Fig. **4)** while the lake receiving only structural BMPs (Beasley) showed a decline in both populations and diversity (Figs. 3 and **4).** Bass populations demonstrated good survival in Deep Hollow and Thighman (Fig. 5). Increased diversity seen in Figure **4** for Thighman Lake may be from species introduction from other portions of the drainage, escapees from adjacent catfish ponds, or fish released by fishermen.

Summary

This study examined and documented pre-management water quality and fisheries conditions on three oxbow lakes and resulting changes following the implementation of Best Management Practices. Analyses of water quality prior to the implementation of management practices indicated lakes that were stressed and ecologically damaged due to excessive in-flowing sediment. Mean total suspended sediment concentrations for the three MSEA lakes exceeded concentrations estimated for regional lakes in 1969 as well as levels acceptable for fish growth and health. Because all MSEA lakes had low concentrations of chlorophyll despite relatively high concentrations of phosphorus it is reasonable to assume that high suspended solid concentrations likely suppressed phytoplankton production. This conclusion was further supported by the fact that Deep Hollow Lake had the highest mean concentration of chlorophyll of the three lakes as well as the lowest mean concentration of suspended sediment. Reducing suspended sediment concentrations through the use of best management practices produces conditions favorable for phytoplankton production as indicated by the increased water visibility and chlorophyll production.

Fish species identified in the rotenone sampling were typical of oxbow lake fauna. Species richness was relatively low for all three MSEA lakes. Deep Hollow Lake had the greatest standing stock followed by Thighman and Beasley. Standing stocks roughly fell within the ranges reported in the literature for various natural and unfertilized man-made lakes. While the standing stock is in agreement with those reported in the literature much of the weight of fish from the MSEA lakes was made up of undesirable species such as gizzard shad, various species of gar (*Lepisosteus sp.)* and common carp.

Sports fishes were generally poorly represented with the exception of white crappie in all of the lakes and channel catfish (*Ictalurus punctatus*) in Thighman Lake. No largemouth bass were collected from Beasley or Thighman lakes.

Post BMP fishery surveys indicated successful renovation of lakes protected with cultural or structural and cultural practices. While all three lakes demonstrated improved water quality, the most significant improvements occurred when cultural (Thighman) or combinations of cultural and structural practices (Deep Hollow) were used. Following renovation fish catches and diversity were highest in Thighman and Deep Hollow while Beasley showed a decline in both standing stock and diversity. Bass populations lacking in two of the lakes before renovation and restocking were successfully reestablished in Deep Hollow and Thighman. In all likelihood, restocking in Beasley Lake failed due to continuing poor water quality despite the presence of structural BMPs. Land and farm management practices designed to control erosion and reduce transport of soil, organic matter, and agricultural chemicals do indeed improve water quality. Results indicate that cultural BMPs may play the more vital role in improving lake water quality and may be needed in addition to structural measures to ensure improved fisheries in oxbow lakes receiving agricultural runoff.

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Table 1. Physical data from MSEA lakes before implementation of best management practices in

Lake	Temp C	Conductivity mS/cm	Dissolved Oxygen mg/L	pH	Secchi cm	Solids Total mg/L	Solids Dissolved mg/L
T	29.80 (2.44)	0.309 (0.127)	5.06) (2.17)	7.21 (0.39)	11.5 (8.52)	505 (256)	115 (52)
B	25.61 (12.98)	0.072 (0.0 17)	6.38 (3.74)	7.00 (0.37)	16.6 (16.87)	482 (430)	58 (23)
DH	24.42 (6.52)	67.89 (46.21)	4.04 (1.59)	6.68 (0.75)	12.2 (9.37)	351 (224)	52 (22)

T= Thighman, B= Beasley, DH = Deep Hollow

Table 2. Chemical data from MSEA lakes before implementation of best management practices i

Lake	Filterable ortho-PO_4 Mg/L	Total Phosphorus	Coliform Count Colonies/ 100mL	Enterococci Count #Colonies/ 100mL	NH_4 Mg/L	NO_3 Mg/L	Chl
T	0.018 (0.021)	0.437 (0.218)	4593 (5416)	27 (43)	0.168 (0.144)	1.157 (0.9 17)	(
B	0.032 (0.018)	0.496 (0.301)	86 (86)	7 (16)	0.123 (0.067)	0.534 (0.617)	(
DH	0.019 (0.062)	0.522 (0.256)	863 (958)	0 (0)	0.189 (0.144)	0.393 (0.375)	(

T= Thighman, B= Beasley, DH = Deep Hollow

Table 3. Water quality differences between MSEA lakes before and after implementation of BMI

	Pre BMP			Post BMP	
	Beasley	Deep Hollow	Thighman	Beasley	Deep Holl
Secchi	A	A	A	B	A
Total Solids	A	A	A	B	A
Suspended Solids	A	A	A	C	A
Dissolved Solids	A	A	B	C	A
Nitrate N	A	A	B	C	A
Ammonium N	A	A	A	A	A
Total P	A	A	A	A	A
Filterable Onho P	A	B	B	A	A
Chlorophyll	A	A	A	A	B

Different letters indicate significant differences between lakes within a pre or post category ($P < 0$

Table 4. Pre- and post BMP comparisons of water quality for MSEA Lakes from 1996 through 1999.

Parameter	Beasley Pre	Beasley Post	Beasley Percent Change	Deep Hollow Pre	Deep Hollow Post	Deep Hollow Percent Change	Thighman Pre	Thighman Post	Thighman Percent Change
Secchi (cm)	14	17	21	12	25	108*	11	15	36*
Total Solids (mg/L)	482	265	-45*	351	143	-59*	505	334	-34*
Suspended Solids (mg/L)	429	202	-53*	289	70	-76*	405	169	-58*
Dissolved Solids (mg/L)	58	65	12	52	75	44*	115	166	44*
Nitrate N (mg/L)	0.534	0.553	4	0.393	0.387	-2	1.157	0.85	-27
Ammonium N (mg/L)	0.123	0.139	13	0.189	0.116	-39*	0.168	0.224	33
Total P (mg/L)	0.496	0.344	-31*	0.522	0.233	-55*	0.437	0.299	-32*
Filterable Ortho P (mg/L)	0.032	0.049	53*	0.019	0.046	142*	0.018	0.044	144*
Chlorophyll (µ/L)	16.6	118.9	89*	24.4	61	150	9.9	72.2	629*

* Indicates a significant difference (Prob. < 0.05)
Note that negative percent change indicates a decrease from pre to post conditions

Table 5. Fisheries Characteristics of MSEA lakes prior to implementation of Best Management Practices.

	Thighman	Deep Hollow	Beasley
Catch (kg)	157	163	85
Number	2139	1473	886
Number of Species	17	21	15
Kg/ha	282	292	152

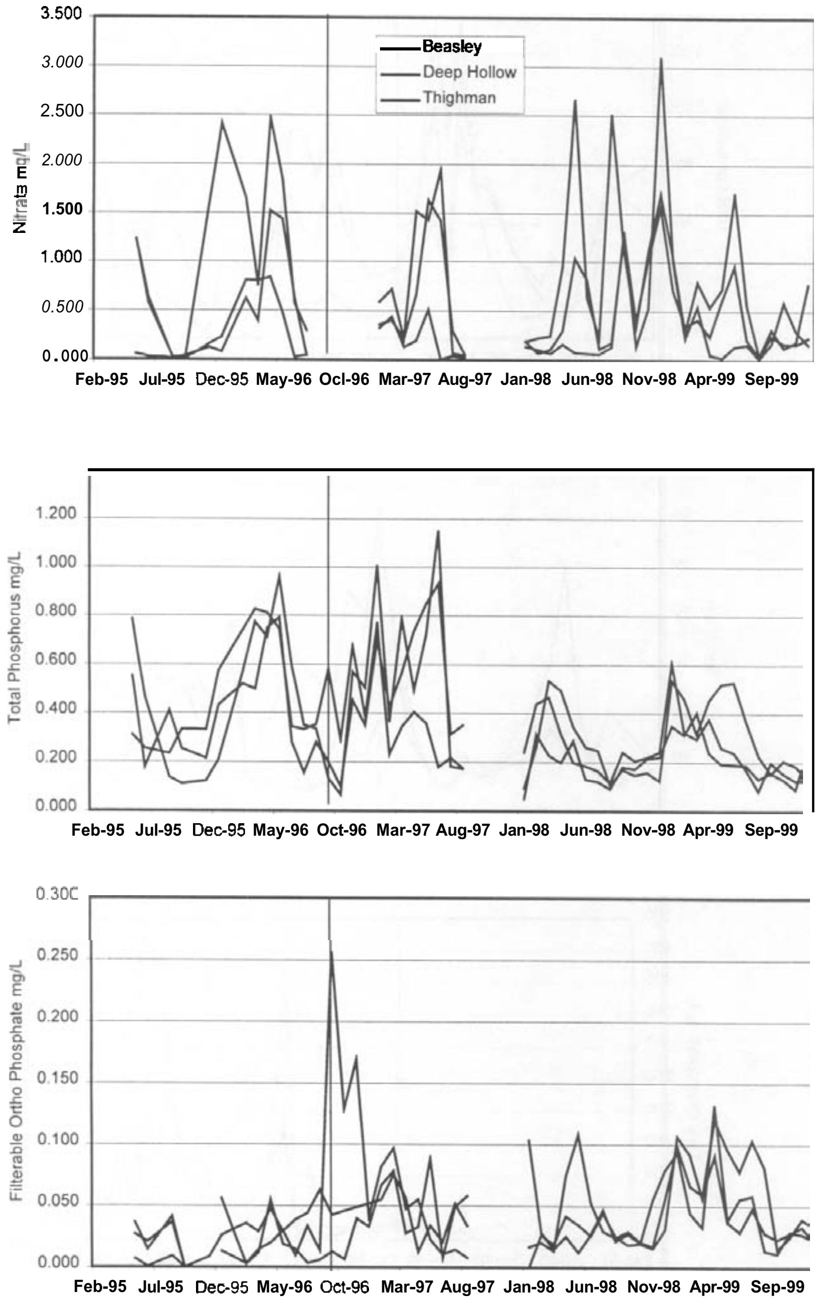

Figure 1. Monthly mean nitrate N, total P, and filterable ortho P for MSEA Lakes from 1996 though 1999. The vertical lines indicate implementation of BMPs.

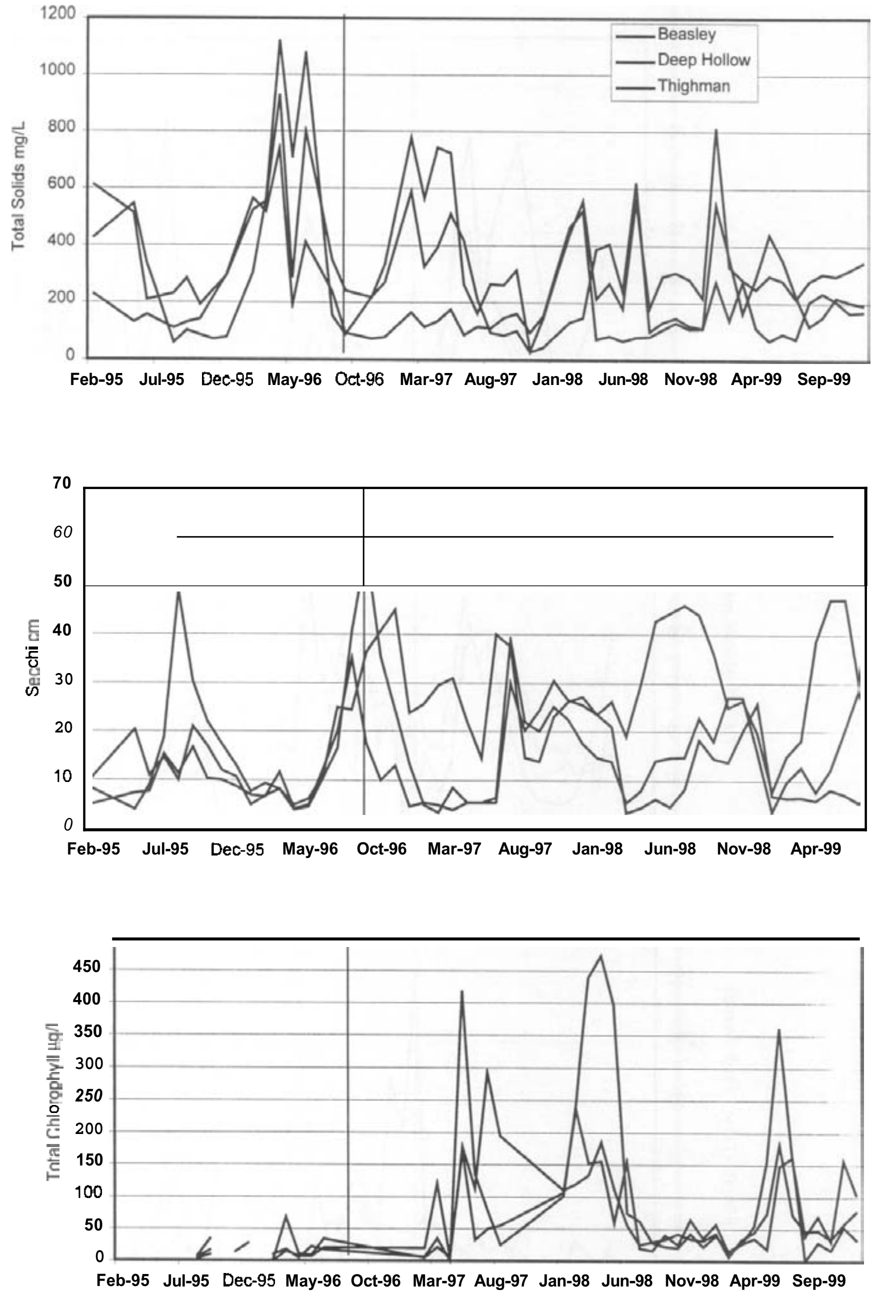

Figure *2*. Monthly mean total solids, Secchi visibility, and total chlorophyll for MSEA Lakes from 1996 though 1999. The **vertical** lines indicate implementation of BMPs.

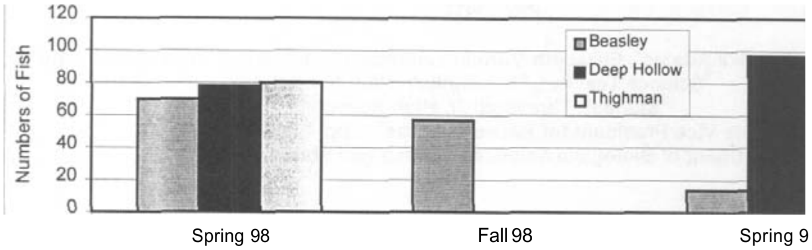

Figure **3**. Electrofishing catch from **MSEA** *lakes* following lake renovation.

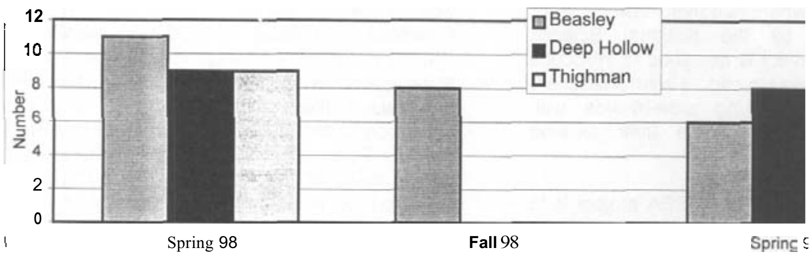

Figure **4**. Number of species from electrofishing catches from **MSEA** lakes following **lake** renova

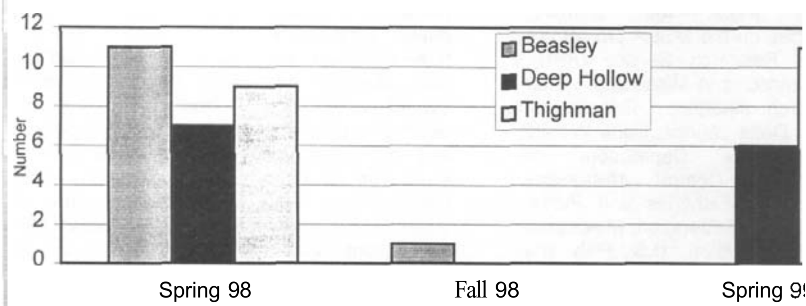

Figure *5*. Number of largemouth bass *Micropterus salmoides* from Electrofishing catches from M following lake renovation.