

POSITION PAPER

EUTROPHICATION OF ALABAMA LAKES

Prepared by
Eutrophication Committee
of the
Alabama Fisheries Association

1996

TABLE OF CONTENTS

PAGE

EFFECTS OF CULTURAL EUTROPHICATION..... 1

- Aquatic Plant Problems
- Effects on Potable Water Supplies
- Effects on Aquatic Biota
- Effects on Water Clarity
- Effects on Temperature, Light Penetration and pH

TROPHIC STATUS OF ALABAMA LAKES 6

LAKE TROPHY AND SPORT FISHING 11

LAKE STANDARDS FOR EUTROPHICATION CONTROL12

WHY CONTROL CULTURAL EUTROPHICATION? 14

LITERATURE CITED 15

RESOLUTION

WHEREAS, the Alabama Fisheries Association is an organization comprised of aquatic resource scientists and managers concerned with protection and improvement of Alabama surface waters.

WHEREAS, recent economic studies have estimated the recreational value of Alabama surface waters at well over \$1 billion a year.

WHEREAS, eutrophication caused by nutrient enrichment has been identified by the Alabama Department of Environmental Management (ADEM) as an impairment or threat to thousands of surface acres of Alabama's multiple-use lakes.

WHEREAS, ADEM lake monitoring data reveal a steady increase in trophic status (eutrophication) of many Alabama lakes, some (e.g. Coosa river lakes) to significantly elevated levels.

WHEREAS, Alabama does not currently require permitted dischargers to monitor and report the nutrient content of their waste effluent, making it virtually impossible to identify sources (point and non-point) of nutrient pollution.

WHEREAS, Alabama does not currently have specific water quality criteria that relate directly to nutrient enrichment or to the biological manifestations of nutrient enrichment.

THEREFORE, be it resolved that, the Alabama Fisheries Association recommends to all relevant state and federal agencies, the following action:

- 1) require all major NPDES dischargers (\geq 0.5 MGD permitted flow) to measure and report total nitrogen and total phosphorus concentrations in their treated effluents each month unless or until it is clearly demonstrated that said discharger's effluent is not making a significant contribution to nutrient loading of the receiving waters; and;

- 2) establish lake specific, numerical water quality criteria related directly to nutrient pollution and its biological effects, that will include but not be limited to estimates of plankton algal biomass (e.g. corrected chlorophyll a or algal growth potential).

EFFECTS OF CULTURAL EUTROPHICATION

The word, eutrophic, means well-nourished and therefore eutrophication refers to the natural and artificial addition of plant nutrients to aquatic ecosystems and to the effects of the nutrients on these systems (National Academy of Sciences, 1970). Natural eutrophication usually proceeds relatively slowly in concert with the aging process of lakes. Lake trophic status refers to the nutrient content and biological expression of nutrients within a lake. Trophic categories in common use include; oligotrophic (few nutrients, low productivity), mesotrophic (moderate nutrients, medium productivity), eutrophic (abundant nutrients, high productivity) and hypereutrophic (excessive nutrients, excessive productivity).

Man's activities can greatly accelerate eutrophication in which case the term cultural eutrophication is more appropriate. Cultural eutrophication is a type of water pollution that has increased with population growth, industrialization, intensive agricultural and forestry production, recreational activities and development of shoreline properties. Cultural eutrophication causes changes in aquatic biota that can interfere with water uses, detract from natural beauty and reduce the economic value of the resource. In extreme cases, lakes can be virtually lost (National Academy of Sciences, 1970).

Accelerated eutrophication can cause the following problems:

- 1) development of excessive growths of aquatic plants (higher plants and algae);
- 2) increased quantities of organic matter that may interfere with potable water supplies;
- 3) greater oxygen demand that may cause chronic undersaturation of dissolved oxygen or anaerobic conditions affecting all aerobic biota;
- 4) decreased water clarity and;
- 5) wide fluctuations in pH, elevated surface water temperatures, and decreased light penetration.

Aquatic Plant Problems

Excessive amounts of plant nutrients entering surface waters stimulate aquatic plant colonization and growth. In Alabama lakes with extensive areas of shallow water and relatively stable water levels (limited winter drawdown) aquatic plants may create severe weed problems as is the case in lakes Guntersville and Seminole. In most Alabama lakes, however, an increase in plankton algae biomass (algal blooms) has been

the predominant biological manifestation of nutrient enrichment. These microscopic plants living suspended in water impart color (usually green) to lakes and ponds and block the penetration of light through the water (Laws 1993).

Both higher plants and algae are primary producers of organic matter through the process of photosynthesis and are essential to production of other desirable biota such as fish-food organisms and fishes. Submersed aquatic plants also supply dissolved oxygen to the water as a by-product of photosynthesis. However, at excessive densities, these benefits of aquatic plants are offset by an array of physical, chemical and biological alterations that adversely affect water use (Laws 1993).

Effects on Potable Water Supplies

Proliferation of aquatic plants causes a rise in organic matter (both dissolved and particulate) content of lake waters. This can cause problems in potable water supply lakes because chlorination of the water during the treatment process forms organohalides called trihalomethanes (THM's) that threaten human health (Cooke et al. 1986). Four organic compounds comprise THMs: trichloromethane (chloroform), bromodichloromethane, dibromochloromethane and tribromomethane (bromoform). These compounds are known or suspected of being carcinogenic and/or mutagenic agents and the U.S. Environmental Protection Agency has established a maximum contaminant level of 100 $\mu\text{g}/\text{l}$ in finished drinking water (Vogt and Regli 1981). Increasing THM levels in drinking water supplies across the country have raised concern about sources and control of organic THM precursor molecules entering treatment plants (EPA 1990). Although watershed features, like marshes, are known to be important sources of organic precursors, within-lake production of organic matter by algae and higher plants also contributes. Palmstrom et al. (1988) demonstrated that 30% of the precursors entering a treatment plant withdrawing water from an Ohio, water supply reservoir was generated within the lake, primarily by algae.

Accumulation of algae and organic matter frequently results in taste and odor in water that is difficult and expensive to remove during water purification (Cooke et al. 1986). Bluegreen algae produce substances that require greater quantities of treatment chemicals and decrease filter runs (EPA 1990).

Effects on Aquatic Biota

Many lakes in Alabama stratify thermally during the warm months. As a result three layers of water exist, one on top of the other. The uppermost layer, the epilimnion, is warmer and less dense than the other two layers. It remains well mixed by gravity and wind-produced currents and, being near the surface, is well lighted. The metalimnion is located between the epilimnion and the lower layer and is a transition zone in which temperature declines rapidly with depth. The deepest layer, the

hypolimnion, is the coolest, most stable and receives the least amount of light. Chemical stratification usually accompanies thermal stratification. The greater the organic matter load to the ecosystem, either from outside sources (e.g. untreated food processing waste) or from inside sources (e.g. photosynthesis), the greater the contrast in chemical conditions from top to bottom.

Oligotrophic lakes with few nutrients and low organic matter content, exhibit minimal chemical stratification. Even during periods of thermal stratification, chemical variables like dissolved oxygen, pH and carbon dioxide, remain similar from top to bottom. By contrast, a thermally stratified eutrophic lake chemically stratifies to the extent that the hypolimnion may not support aerobic life. Cultural eutrophication of lakes causes proliferation of organic matter (aquatic plants) that in turn consumes available dissolved oxygen. This oxygen consumption occurs in two ways. Living submersed aquatic plants (higher plants and algae) remove oxygen from the water during respiration. Normally, plants produce more oxygen during the day through photosynthesis than they consume during a 24-hour period through respiration. At high plant densities (e.g. phytoplankton blooms) caused by excessive nutrient enrichment, respiration needs may exceed available oxygen supply, especially during times when photosynthesis is impaired as, for example, during cloudy weather. In addition, phytoplankton blooms block light penetration (autos shading), thereby limiting photosynthesis and oxygen production to shallower areas. This can result in undersaturation of dissolved oxygen that can be stressful to aquatic organisms (Laws 1993).

When aquatic plants die their decomposition is carried out by microorganisms (e.g. bacteria) that respire but do not produce oxygen. The more organic matter present the greater the oxygen demand. In lakes, particulate organic matter sinks through the water column toward the bottom during decomposition. Larger particles may reach the bottom sediment where decomposition continues. In the upper water column (epilimnion) where light is available, the oxygen produced during photosynthesis usually supplies both respiration and decomposition demands. However, in the hypolimnion, where light is limited or absent, decomposition of the organic matter sinking through the water column toward the bottom, consumes all available oxygen. The hypolimnion of eutrophic lakes receives too little light to support photosynthesis and is thermally stratified to the point that the limited mixing with oxygenated waters from above is ineffective in supplying oxygen. As a result, eutrophic lakes usually have layers of anaerobic water that will not support aerobic life sometime during the growing season (Wetzel 1983).

The onset and duration of anaerobic conditions depends to a large extent on the degree of eutrophication. Increased organic matter, either added directly or formed in the lake as a result of nutrient enrichment, speeds oxygen depletion of the hypolimnion. Anaerobic conditions develop sooner and last longer as cultural eutrophication proceeds.

Prolonged anaerobic conditions negatively impact some of the most important uses of our lakes.

Anaerobic areas of lakes are not biologically productive and will not support fish-food organisms nor fish. Motile organisms like fish and zooplankton move to upper water layers where oxygen is available. However, nonmotile bottom-dwelling organisms do not survive. Warmwater species of fish and invertebrates usually thrive as long as minimum oxygen concentrations remain ≥ 5.0 mg/l (Alabaster and Lloyd 1980, EPA 1986 and Boyd 1990). While most fish species can avoid anaerobic hypolimnia and survive, there are exceptions. In eutrophic Alabama lakes during late summer, it is not unusual for dissolved oxygen concentrations ≥ 5 mg/l to be confined to water depths of <2 meters. Temperatures of these surface waters reach and sometimes exceed 32°C , a temperature higher than preferred for many warmwater fish species (Welch and Lindell 1980). In addition, striped bass, Morone saxatilis, have been routinely stocked into many southeastern reservoirs as an additional piscivorous sportfish. These anadromous fish that ascended streams to spawn historically, prior to wide-spread river impoundment, require a cool water ($20 - 24^{\circ}\text{C}$) refuge during the summer that has adequate dissolved oxygen (Coutant and Carroll 1980). In many eutrophic lakes, the cool water required is located in the anaerobic hypolimnion, making it unlikely that striped bass can survive. The few lakes that now support striped bass fisheries in Alabama could be lost to continued cultural eutrophication. Lake Martin, a mesotrophic lake, is now considered marginal striped bass habitat (W.C. Reeves, Alabama Game and Fish, Personal Communication).

All fish and aerobic organisms are threatened when forced into anaerobic conditions. In Alabama lakes this occurs most often when thermal stratification is suddenly disrupted or when hypolimnial waters are drawn through penstocks during hydroelectric power generation. High winds and cold rain associated with unusually intense summer storms or hurricanes can cause sudden mixing of thermally stratified lakes. If the oxygen demand of the anaerobic water layers is great enough to utilize available oxygen in the upper water column, then fish and other aerobic life will be stressed and die. The chemical reduction of elements and compounds as a result of prolonged anaerobic conditions in lake hypolimnia significantly increases oxygen demand of these waters (Boyd 1990). The accumulation of decomposition products such as CO_2 , CH_4 and NH_3 in the hypolimnion increases the toxicity of these waters to aquatic organisms. Cultural eutrophication of reservoirs has led to numerous "fish kills" in the Southeastern U.S.A. (R.L. Raschke, U.S. EPA, Personal Communication).

During hydroelectric power generation, lake water is drawn through the penstocks located in the dam and the water is ultimately released into the tailwaters. The location of the penstock openings in relation to the dynamic anaerobic hypolimnion of eutrophic lakes is critical to the water quality of the receiving stream. If excessive anaerobic waters are entrained during generation and there is no aeration, fish and other organisms may be killed in the tailwaters (Bayne et al. 1994a).

In summary, cultural eutrophication increases the quantity of organic matter in lakes. In highly eutrophic lakes the proliferation of organic matter hastens and intensifies chemical stratification of the lake during the growing season. The depletion of oxygen and accumulation of toxic decomposition products in the hypolimnion decreases available habitat for aerobic organisms, threatens the existence of all aerobic forms in the lake in the event of capricious weather and may negatively affect tailwater quality.

Effects on Water Clarity

Most lakes in Alabama are use-classified as swimming. Recreational users, particularly skiers and swimmers, prefer clearer water for aesthetic and safety reasons. A Secchi disk visibility of 1.2m (4 feet) or greater is recommended for swimming waters to allow sufficient visibility for rescue of a submerged drowning victim (National Academy of Sciences et al. 1973). Based on empirical relations in 32 impoundments in Alabama, Secchi visibilities $\leq 1.2\text{m}$ would occur at chlorophyll *a* concentrations $\geq 15 \text{ mg/l}$ (Maceina et al. In Press). Many of Alabama's eutrophic lakes have Secchi disk visibilities of $< 1.2\text{m}$ because of dense phytoplankton blooms (Bayne et al. 1989 ADEM 1994). Such dense blooms of phytoplankton normally do not enhance any use of lakes in Alabama.

Effects on Temperature, Light Penetration and pH

High densities of submersed aquatic plants near the water surface absorb solar energy causing surface water temperatures to rise, strengthening thermal stratification. The plant density near the water surface also interferes with light penetration through the water column. Cultural eutrophication, therefore, tends to accelerate and intensify thermal and chemical stratification of lake waters.

Green plants absorb CO_2 during photosynthesis and plants and animals release CO_2 during respiration. CO_2 reacts with water to form the rather weak carbonic acid (H_2CO_3). At night the accumulation of CO_2 in the water, in the absence of photosynthesis will increase the concentration of acid and reduce the pH of the water. During the day, CO_2 is consumed by green plants during photosynthesis and the pH rises. As plant densities increase, so do photosynthesis and respiration and the diurnal shift in pH for a given lake will increase. The magnitude of the shift is dependent upon the natural chemical buffering capacity of the lake. In fresh waters, bicarbonate (HCO_3^-) is the primary chemical buffer preventing sudden changes in pH. In well buffered (alkaline) lakes, dense plant communities may not cause harmful shifts in pH. However, in low alkalinity systems these diurnal shifts can be lethal to aquatic organisms. The Chattahoochee, Tallapoosa and Sipsey rivers in Alabama have waters that are poorly buffered (Bayne et al. 1989).

TROPHIC STATUS OF ALABAMA LAKES

Alabama has 39 publicly-owned lakes with a total surface area of 485,046 acres (ADEM 1994). Initial monitoring of these lakes to determine trophic status was begun in 1985 (Raschke 1985). Currently, ADEM samples all lakes on an alternate year basis. Additions of organic matter or inorganic nutrients to lakes usually increase trophic status. Exceptions occur when some other variable, for example light or water movement, limits biological expression of the additional nutrients. There are numerous methods available to evaluate the effects of cultural eutrophication in lakes (EPA 1990); however, two methods, the chlorophyll *a* trophic state index and the algal growth potential, are particularly well suited to routine monitoring.

Phaeophytin-corrected, chlorophyll *a* concentration is an indicator of phytoplankton biomass and is a variable often used to determine the trophic status of lakes in the absence of higher aquatic plants (Carlson 1977, EPA 1990). It is a variable that integrates the physical, chemical and biological environmental components into one expression of biotic response and is, therefore, superior to simple physical (e.g. water transparency) or chemical (e.g. nutrients) variables used to characterize trophic status (Hern et al. 1981). Chlorophyll *a* concentration measured in the photic zone of the water column during the growing season is converted to the Carlson trophic state index (TSI) using the formula suggested by Carlson (1977). The Carlson TSI rates lakes on a numerical scale of 0-100, and the scale values correlate with trophic state descriptive terms, e.g., TSI 10 < 40 oligotrophic, TSI 40 < 50 mesotrophic, TSI 50 < 70 eutrophic and TSI 70 < 90 hypereutrophic. Eutrophic lakes have corrected chlorophyll *a* concentrations ranging from about 6.4 $\mu\text{g}/\ell$ (TSI=50) to 56.0 $\mu\text{g}/\ell$ (TSI=70) (ADEM 1994).

The Algal Growth Potential Test (AGPT) determines the total quantity of algal biomass supportable by the test waters and provides a reliable estimate of the bioavailable and limiting nutrients (Raschke and Schultz 1987). Maximum algal dry weights below 5.0 mg/l are thought to assure protection from nuisance phytoplankton blooms and fish-kills in southeastern lakes, excluding Florida (Raschke and Schultz 1987). Mean maximum dry weights above 10.0 mg/l indicate highly productive waters that may be subjected to nuisance blooms. The AGPT is particularly useful in situations in which variables other than nutrients are limiting biological production (e.g. flow or light). Frequently, highest algal growth potential in Alabama lakes occurs at the most upstream riverine sampling station having relatively high nutrient content (Bayne et al. 1993a, Bayne et al. 1993b and Bayne et al. 1994a).

The Carlson TSI has been calculated and reported on all Alabama lakes since lake monitoring began in 1985 (ADEM 1994). The AGPT has been done on lakes subject to more intense study. Using the most recent TSI data available for each lake, 25 of the 39 publicly owned lakes in Alabama were eutrophic (ADEM, Personal Communication 1995). That represents 64% of all lakes and 77% (374,974 acres) of the

lake surface area in the state. The remaining 14 lakes (110,072 acres) were classified as mesotrophic. Two lakes, Martin and Lewis Smith, made up 55% of the surface area of mesotrophic lakes in the state. There were no oligotrophic lakes in Alabama in 1994 and 1995.

Trends of increasing lake trophic (eutrophication) are evident in many Alabama lakes. Of the 31 lakes sampled in 1994 or 1995, 17 had the highest TSI values ever measured; none had the lowest TSI value ever measured. The increases span the trophic range of Alabama lakes. Some lakes that were eutrophic (TSI >50) in 1985 have increased in trophic status during the past 11 years (Fig. 1). Two of those lakes on the Coosa River, Weiss and Neely Henry, are nearing hypereutrophic (TSI >70) status (Bayne et al. 1993b and Bayne et al. 1995).

Some lakes that were mesotrophic in 1985 have become eutrophic (Fig. 2). The largest increases in trophic status have occurred among lakes that were classified as oligotrophic (TSI <40) in 1985 (Fig. 3). Big Creek, a water supply reservoir for the city of Mobile, has increased from oligotrophic to eutrophic status during the 11 year period.

These trends clearly demonstrate the problem of cultural eutrophication of Alabama surface waters. Using data gathered only during the relatively short period of time (1985-1995) for which reliable trophic status records were kept, the majority of lakes sampled during the last 2-years were increasing in trophic status. Lakes located on the Coosa River had the highest mean TSI value, followed by lakes on the Alabama River and Tombigbee River.

Lakes on the Coosa River are of particular concern because they tend to have short mean hydraulic retention times (mean reservoir volume/mean discharge). For example, lakes Weiss, Neely Henry and Lay have mean retention times of 18.0 days, 5.8 days and 9.5 days, respectively. The relatively rapid flushing of reservoirs with such short retention times is not conducive to development of lacustrine phytoplankton communities that are responsible for most of the primary productivity of lakes devoid of aquatic macrophytes. Soballe and Kimmel (1987) reported that retention times of less than about 75 days were too short to allow full biotic expression of plant nutrients. Even with short retention times, the Coosa River lakes have the highest TSI's in the state. A reduction in Coosa River discharge caused by natural drought or upstream consumptive use of water, could increase hydraulic retention time and dramatically increase biomass of plankton algae. In a study of Weiss Lake conducted during the growing seasons of 1989 and 1990, seasonal mean chlorophyll *a* concentrations were 27 $\mu\text{g}/\ell$ during the unusually wet 1989 season but increased to 41 $\mu\text{g}/\ell$ during the relatively dry season of 1990 (Bayne et al. 1994b). Current debate between Alabama and Georgia concerning upstream water use in the Coosa, Tallapoosa and Chattahoochee basins will have important water quantity as well as water quality implications.

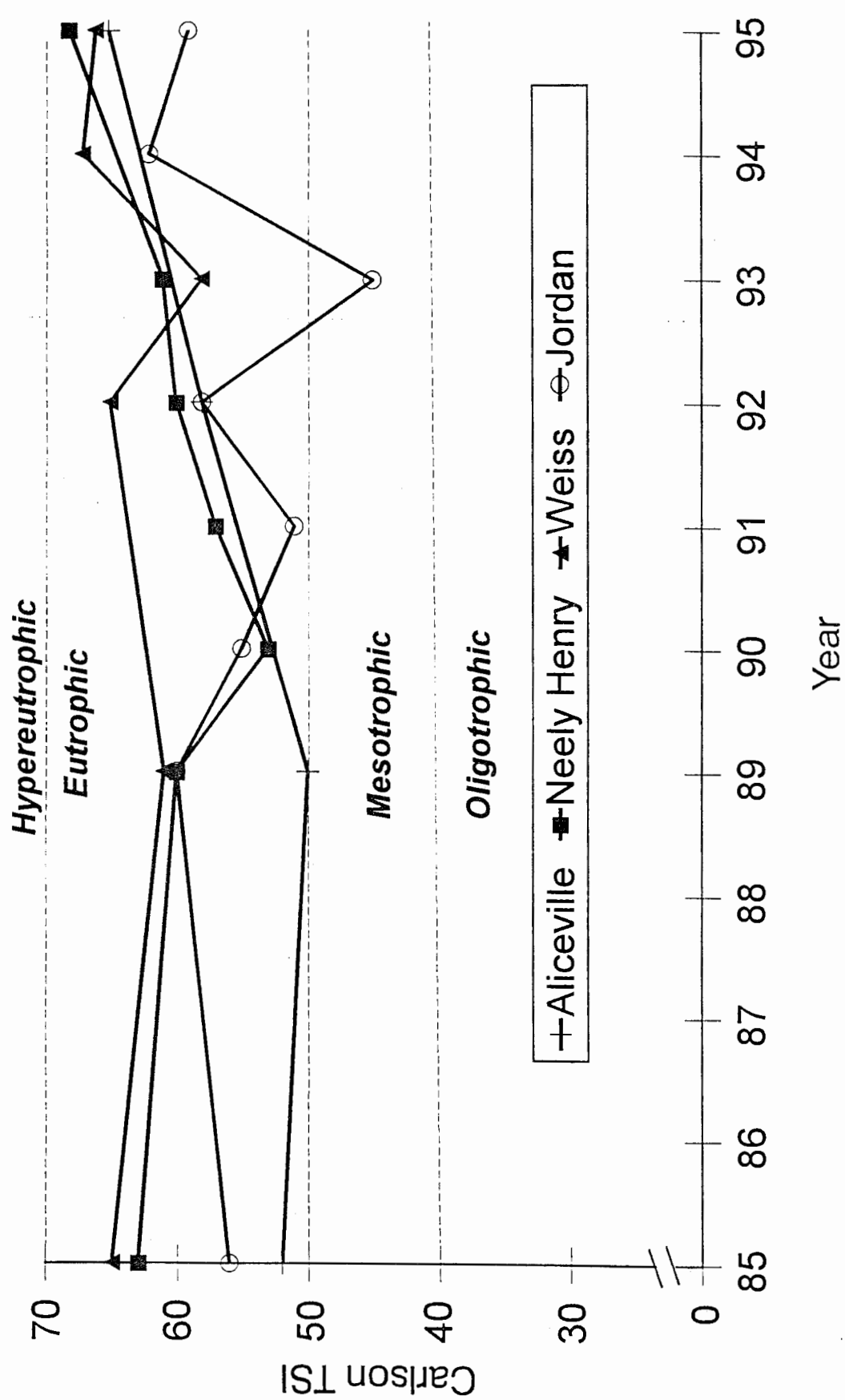


Figure 1. Temporal trends in trophic status among select eutrophic lakes in Alabama, 1985-1995.

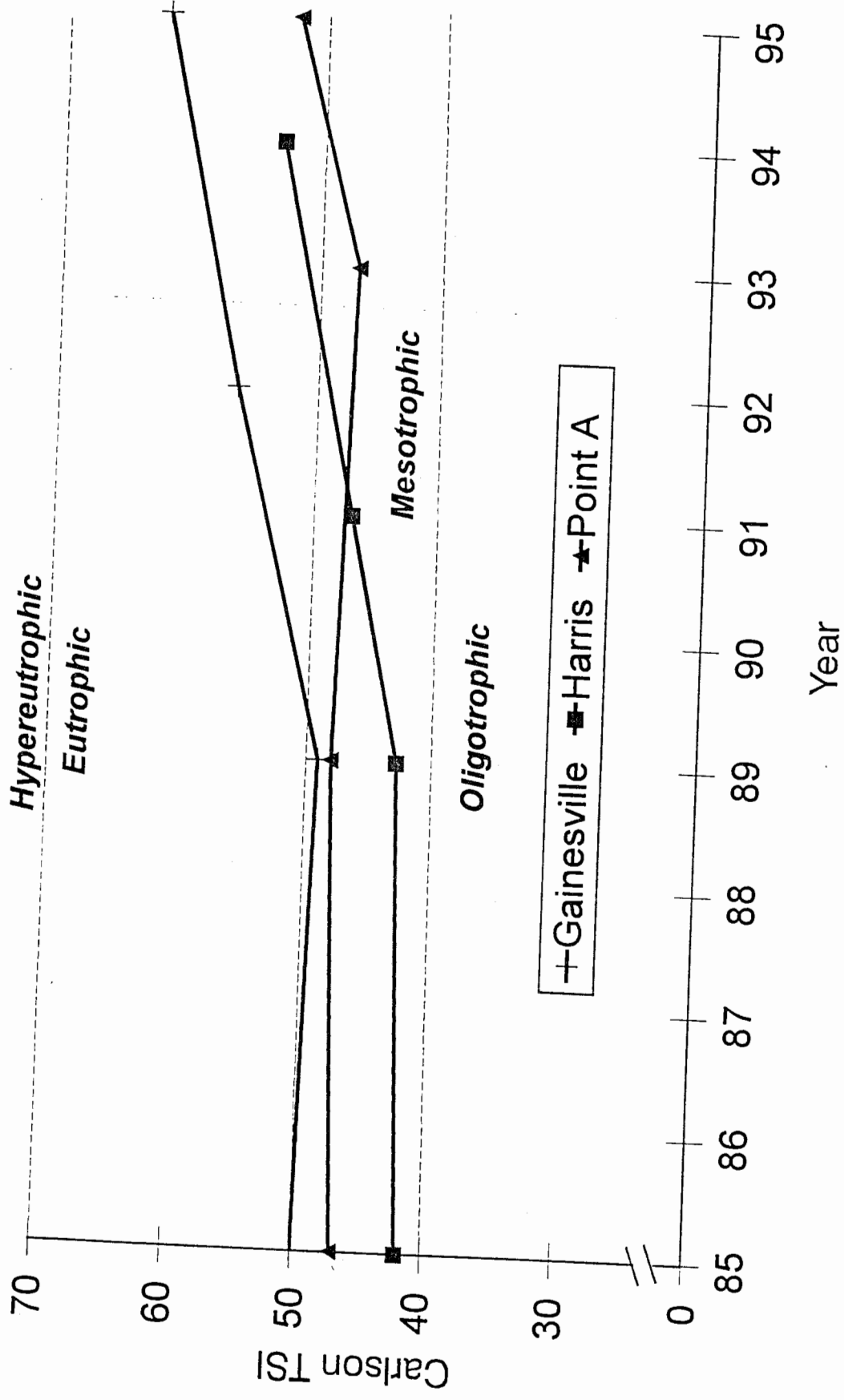


Figure 2. Temporal trends in trophic status among select mesotrophic lakes in Alabama, 1985-1995.

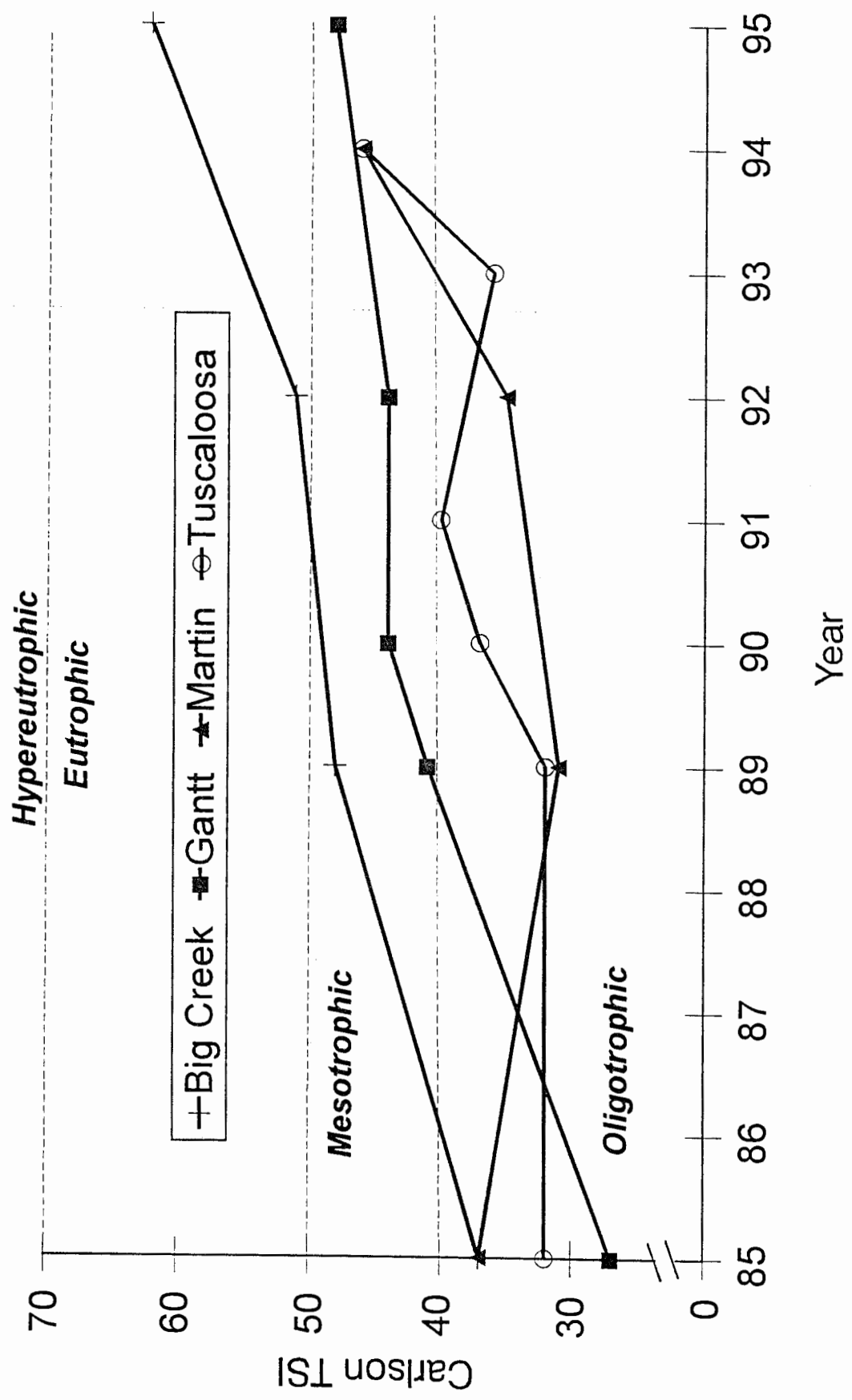


Figure 3. Temporal trends in trophic status among select oligotrophic lakes in Alabama, 1985-1995.

LAKE TROPHY AND SPORT FISHING

Sport fishing is one of the major recreational uses of Alabama's public lakes. Policy affecting multiple-use resources must take into consideration all user groups. The obvious question arising here is what effects nutrient limits might have on sport fish populations and on sport fishing (Yurk and Ney 1989, Ney et al. 1990).

Most limnologists and fishery biologists agree that increases in lake fertility (from infertile to fertile) will result in higher fish biomass and sportfish harvest (O'Brien 1990). Scientists have developed indices and empirical models to predict fish biomass or yield in natural lakes and reservoirs (reviewed by Carline 1986). It is not clear, however, whether increasing levels of algal biomass will produce better quality sport fisheries in warmwater systems. Scientists who have investigated this relationship report regional differences in response. For example, Kautz (1980) found sportfish biomass was highest in mesotrophic-eutrophic Florida lakes and commercial (primarily catfish, Ictaluridae) and rough fish biomass peaked in hypereutrophic lakes. However, in midwestern lakes and reservoirs, sportfish harvest increased linearly with chlorophyll *a* concentrations (Jones and Hoyer 1982). Clearly, some level of nutrient loading is essential to produce and maintain a desirable sport fishery. Reduction in phosphorus input and subsequent decline in primary productivity, due in part to improved wastewater treatment, led to enhanced water quality in Lake Mead (Nevada), but adversely affected the \$100 million sport fishery (Axler et al. 1988).

Two recent studies conducted by Auburn University scientists have shed some light on the trophic state/sportfish relationship in Alabama lakes. The first study involved the rather intensive examination of four lakes located in Alabama and Georgia (Bayne et al. 1994b). These four lakes spanned the trophic gradient (mean chlorophyll *a* concentrations of from $2\mu\text{g}/\ell$ to $34\mu\text{g}/\ell$) of all Alabama lakes. Limnological and fisheries studies conducted during 1989 and 1990 were designed to evaluate the effect of lake trophic status on fish and sport fishing quality. The second study (Maceina et al. In Press) examined the relations among water quality, crappie and black bass data from virtually all major (>400 hectares) Alabama lakes.

The findings of these two studies were similar and are summarized below.

- 1) Fish abundance and biomass increased with trophic status (oligotrophic, mesotrophic, eutrophic) with shad much more abundant in the eutrophic lakes.
- 2) Angler catch rates of black bass and crappie did not vary between mesotrophic and eutrophic lakes.
- 3) Larger fish were caught in eutrophic lakes than in mesotrophic lakes and angler caught black bass size was similar among the eutrophic lakes.

- 4) Within the range of eutrophic lakes in this study (chlorophyll a concentrations of from 6.4 $\mu\text{g}/\ell$ to 30.0 $\mu\text{g}/\ell$), sport fishing and population characteristics did not change with higher chlorophyll a concentrations.
- 5) Reductions of trophic status in southern USA reservoirs to chlorophyll a concentrations of 10-15 $\mu\text{g}/\ell$ (uncorrected for phaeopigments) will not necessarily be detrimental to black bass and crappie fisheries and will likely improve water clarity.

LAKE STANDARDS FOR EUTROPHICATION CONTROL

In 1986 the North American Lake Management Society (NALMS) began to focus national attention on the issue of lake water quality standards (NALMS 1988). The lead paper given at the national symposium that year was entitled "Numerical Standards for Managing Lake and Reservoir Water Quality". The plenary consisted of a panel discussion of the issue conducted by panel members representing government, industry and the environment. Following the symposium, a nationwide survey was conducted by a NALMS task force. Questionnaires were sent to each of the 50 state water pollution control administrators and 47 of the states responded to the survey.

The survey revealed that about one-half (24) of the states had lake water quality standards in place at the time and these standards dealt directly with the problem of cultural eutrophication (NALMS 1988). Of the 24 states with lake standards, most included a criterion for total phosphorus and some had developed criteria for plankton chlorophyll a or Secchi transparency. The primary use for lake standards was for regulatory-type activities although a few states used them for planning and implementation activities. To slow eutrophication, most states were controlling waste water discharges. The overwhelming majority of states opposed federal (EPA) mandates for lake trophic standards although many welcomed federal assistance that would allow states to do a better job of lake monitoring. NALMS (1992) published a guidance manual for developing eutrophication standards for lakes comparing approaches taken by various states and agencies across the nation.

Georgia, one of the three states that failed to respond to the 1987 NALMS questionnaire, enacted one of the nations toughest lake protection laws in 1990 (McCullough and Taggart 1990). This development occurred because of timing and a special set of circumstances that were somewhat unique. The severe pollution of West Point Lake by the City of Atlanta was widely publicized. Environmentalists, led by Georgians for Clean Water, were applying pressure to politicians, and there was a gubernatorial race underway. One of the candidates for governor, Sen. Roy Barnes, sensing concern of citizens for lake water quality sponsored a Clean Lakes bill that ultimately became Georgia's new lake protection law.

In short, the law requires that each public lake (>1,000 surface acres) be adequately studied prior to adopting lake water quality standards. Within 1-year after the completion of the comprehensive lake study the Director of the Georgia Department of Natural Resources must establish specific numerical water quality standards which include but are not limited to criteria for pH, fecal coliform bacteria, chlorophyll *a*, total nitrogen, total phosphorus and dissolved oxygen. Use-classification within each lake must be swimmable, fishable and potable unless these uses are shown to be unattainable. The public participates in the process through written comment and public hearings. Georgia's first lake-specific standards were adopted by the Department of Natural Resources Board for West Point Lake in August 1995 (Kamps 1995).

Georgia's new law is relevant to Alabama in several ways. Georgia lakes are similar to Alabama lakes, predominately mainstream, river impoundments. The states share three major river systems, the Coosa, Tallapoosa and Chattahoochee. The quantity and quality of water flowing from Georgia into Alabama via these three streams is already a matter of contention between the two states. Future growth in north Georgia, including the Atlanta metropolitan area, is dependent to a large extent upon available surface water. Georgia's plans to use more water from these three rivers is the focal point of the current debate. In the impending settlement over water usage, Georgia will likely emphasize their progressive approach to water management.

Alabama does not have lake water quality standards that directly address cultural eutrophication. Existing standards for inland waters apply to both streams and lakes and contain no criteria that relate to plant nutrients (e.g. total phosphorus or total nitrogen) or plant biomass (e.g. phytoplankton chlorophyll *a* or algal growth potential). Current standards will not prevent Alabama lakes from becoming excessively productive because of nutrient loading from both point and nonpoint sources. For example, secondary treatment of municipal wastewater removes only 12% of the total phosphorus and 58% of the total nitrogen (EPA 1990). Not all waste treatment in Alabama is that efficient at nutrient removal. It is not surprising that many Alabama lakes are increasing in trophic status.

Another problem related to the cultural eutrophication of Alabama waters deals with the lack of information available to determine sources (point vs. nonpoint) of nutrient enrichment. The following simple equation can be used to identify sources of plant nutrients to lakes:

$$\begin{array}{rcccl} \text{Point source} & & \text{Nonpoint source} & & \\ \text{loading} & + & \text{loading} & = & \text{Total loading.} \end{array}$$

If any two of the three values are known the third (unknown) value can be determined algebraically. Total loading can be estimated by measuring nutrient concentration and hydraulic discharge overtime. Nonpoint source nutrient loading is so diffuse and sporadic that it is virtually impossible to estimate in large complex systems like large lakes. A

reliable estimate of point source loading would allow calculation of nonpoint source loading since total loading can be estimated. Estimating point source nutrient loading is relatively simple if point source dischargers are required to measure and report nutrient content of their waste effluent on a regular basis. Although Alabama currently requires major NPDES dischargers to monitor and report some variables (e.g. effluent volume temperature, dissolved oxygen or biochemical oxygen demand) at monthly intervals, plant nutrients are generally not included. Adding total phosphorus and total nitrogen to the list of monitored variables required of permitted dischargers would enable resource managers to identify sources of excessive nutrient enrichment in aquatic systems in Alabama. Such a step is essential if the problem of cultural eutrophication of Alabama lakes is to be addressed.

WHY CONTROL CULTURAL EUTROPHICATION?

There are no uses of Alabama lakes, other than waste assimilation, that are enhanced by nutrient enrichment beyond moderately eutrophic levels ($10\text{-}15\mu\text{g}/\ell$ chlorophyll \bar{a}). Fish growth, biomass and sport fishing likely benefit from increases in chlorophyll \bar{a} up to $10\text{-}15\mu\text{g}/\ell$ but beyond that, water quality worsens and fish habitat shrinks (Bayne et al. 1994, Maceina et al. In Press). Oxygen depletion and accumulation of toxic products in deeper waters of highly eutrophic reservoirs greatly increases the risk of fish (and other animal) kills in tailwaters or in the lake itself, if the water column is suddenly mixed. Mixing of lake waters during severe summer storms is not uncommon (Davies et al. 1979). Increases in trophic status beyond moderately eutrophic levels degrades the quality of the resource for virtually all recreational users. Even processed water for municipal and industrial supply is negatively affected by excessive eutrophication.

Alabama lakes are multi-billion dollar resources. The economic impact of Weiss Lake to Cherokee County Alabama in 1994 was estimated in excess of \$200 million (Bell et al. 1995). Weiss is but one of 39 publicly-owned lakes in the state. Recent studies have revealed sport fishing to be a major Alabama industry (Travnichek and Clonts, In Review). In 1994 anglers expended over \$1.1 billion dollars on equipment, food, lodging and transportation to fish in Alabama waters. The estimated total economic impact of sport fishing to the state that year was over \$2.0 billion (Travnichek and Clonts, In Review).

The economic value of clean, healthy aquatic environments will increase in the future as greater demands are placed on finite resources by an expanding human population. Conserving and protecting the quantity and quality of our aquatic resources is in the best interest of the citizens of Alabama. Placing limits on cultural eutrophication of Alabama lakes is a step in the right direction.

LITERATURE CITED

- ADEM. 1994. Water quality report to congress. Alabama Department of Environmental Management, Montgomery, Alabama.
- Alabaster, J.S. and R. Lloyd. 1980. Water quality criteria for freshwater fish. Butterworths, Boston. 297pp.
- Axler, R., L. Paulson, P. Vaux, P. Sollberger and D.H. Baepler. 1988. Fish aid-the Lake Mead fertilization project. *Lake and Reservoir Management* 4:125-135.
- Bayne, D.R., W.C. Seesock and L.D. Benefield. 1989. Water quality assessment of Alabama public lakes 1989. Alabama Department of Environmental Management. Montgomery, Alabama. 169pp.
- Bayne, D.R., E.M. Reutebuch, W.C. Seesock and P.P. Emmerth. 1993a. Limnological study of Lay Lake. Kimberly-Clark Corporation, Childersburg, Alabama.
- Bayne, D.R., W.C. Seesock, P.P. Emmerth, E. Reutebuch and F. Leslie. 1993b. Weiss Lake phase I diagnostic/feasibility study, draft report. Alabama Department of Environmental Management, Montgomery, Alabama.
- Bayne, D.R., P. Bush, V. Blazer, W.C. Seesock, R.P. Emmerth, E. Reutebuch and F. Leslie. 1994a. West Point Lake phase I diagnostic feasibility study, final report. Alabama Department of Environmental Management, Montgomery, Alabama. 220pp.
- Bayne, D.R., M.J. Maceina and W.C. Reeves. 1994b. Zooplankton, fish and sport fishing quality among four Alabama and Georgia reservoirs of varying trophic status. *Lake and Reservoir Management* 8(2):153-163.
- Bayne, D.R., W.C. Seesock, E. Reutebuch, D. Watson. 1995. Lake H. Neely Henry phase I diagnostic/feasibility study, final report. Alabama Department of Environmental Management, Montgomery, Alabama. 173pp.
- Bell, F.W., H. McGinnis, C. Storey and P. Rose. 1995. The economic value of Weiss Lake. A.L. Burruss Institute of Public Service. Kennesaw State College, Kennesaw, Georgia. 105pp.
- Boyd, C.E. 1990. Water quality in ponds for aquaculture. Auburn University Agricultural Experiment Station. Auburn, Alabama. 482pp.

- Carline, R.F. 1986. Indices as predictors of fish community traits. Pages 46-56 in G.E. Hall and M.J. Van Den Avyle, eds., Reservoir fisheries management: strategies for the 80's. American Fisheries Society, Bethesda, Maryland.
- Carlson, R.E. 1977. A trophic state index. *Limnology and Oceanography* 22(2):361-369.
- Cooke, G.D., E.B. Welch, S.A. Peterson and P.R. Newroth. 1986. Lake and reservoir restoration. Butterworths, Boston. 391pp.
- Coutant, C.C. and D.S. Carroll. 1980. Temperature occupied by ten ultrasonic-tagged striped bass in freshwater lakes. *Transactions of the American Fisheries Society* 109(2):195-202.
- Davies, W.D., W.L. Shelton, D.R. Bayne and J.M. Lawrence. 1979. Fisheries and limnological studies on West Point Reservoir, Alabama-Georgia. Tech. Report EL-79-4. U.S. Army Engineer District, Mobile, AL. 231pp.
- EPA. 1986. Quality criteria for water 1986. Office of Water Regulations and Standards. U.S. Environmental Protection Agency. Washington, D.C.
- EPA. 1990. The lake and reservoir restoration guidance manual, 2nd ed. EPA-440/4-90-006. U.S. Environmental Protection Agency, Office of Water, Washington, D.C. 326pp.
- Hern, S.C., V.W. Lambou, L.R. Williams and W.D. Taylor. 1981. Modifications of models predicting trophic state of lakes. Project summary. EPA-600/3-81-001. Environmental Monitoring Systems Laboratory, U.S. Environmental Protection Agency, Las Vegas, Nevada.
- Jones, J.R. and M.V. Hoyer. 1982. Sportfish harvest predicted by summer chlorophyll *a* concentrations in midwestern lakes and reservoirs. *Transactions of the American Fisheries Society* 111:176-179.
- Kamps, D., ed. 1995. Clean lakes. Georgia Lake Management Society Quarterly Newsletter 5(4).
- Kautz, R.S. 1980. Effects of eutrophication on the fish communities of Florida lakes. *Proceedings Annual Conference Southeastern Association Fish Wildlife Agencies* 34:67-80.
- Laws, E.A. 1993. Aquatic pollution. An introductory text, 2nd ed. John Wiley & Sons, Inc. New York. 611pp.

- Maceina, M.J., D.R. Bayne, S. Hendricks, W.C. Reeves, W.P. Black and V.J. Dicenzo. IN PRESS. Compatibility between water clarity and quality black bass and crappie fisheries in Alabama: Can all recreational users be satisfied? in L.E. Miranda and D.R. DeVries, editors. Multidimensional approaches to reservoir fisheries management. American Fisheries Society Symposium.
- McCullough, S. and J. Taggart. 1990. Georgia enacts strong lake protection law. *Lake Line* 10(5):7-9.
- NALMS. 1988. Water quality standards for lakes, a survey. North American Lake Management Society. Merrifield, Virginia. 128pp.
- NALMS. 1992. Developing eutrophication standards for lakes and reservoirs. North American Lake Management Society. Alachua, Florida. 55pp.
- National Academy of Sciences. 1970. Eutrophication: causes, consequences, correctives. Proceedings of a Symposium. National Academy of Sciences. Washington, D.C. 661pp.
- National Academy of Sciences and National Academy of Engineering. 1973. Water quality criteria. U.S. Government Printing Office, Washington, D.C.
- Ney, J.J., C.M. Moore, M.S. Tisa, J.J. Yurk and R.J. Neves. 1990. Factors affecting the sport fishery in a multiple-use Virginia reservoir. *Lake and Reservoir Management* 6:21-32.
- O'Brien, W.J. 1990. Perspectives on fish in reservoir limnology. Pages 209-225 in K.W. Thornton, B.L. Kimmel and F.E. Payne, eds. *Reservoir limnology: ecological perspectives*. John Wiley and Sons, Inc. New York.
- Palmstrom, N.S., R.E. Carlson and G.D. Cooke. 1988. Potential links between eutrophication and the formation of carcinogens in drinking water. *Lake and Reservoir Management* 4(2):1-15.
- Raschke, R.L. 1985. Alabama lakes---trophic classification. Ecological Support Branch, Environmental Services Division, U.S. Environmental Protection Agency, Athens, Georgia. 23pp.
- Raschke, R.L. and D.A. Schultz. 1987. The use of algal growth potential test for data assessment. *Journal Water Pollution Control Federation* 59(4):222-227.
- Soballe, D.M. and B.L. Kimmel. 1987. A large-scale comparison of factors influencing phytoplankton abundance in rivers, lakes and impoundments. *Ecology* 68:1943-1954.

- Travnicek, R.J. and H.A. Clonts. In Review. Effects of angler expenditure distribution on regional economics. Department of Agricultural Economics and Rural Sociology. Auburn University, Alabama.
- Vogt, C. and S. Regali. 1981. Controlling trihalomethanes while attaining disinfection. *Journal American Water Works Association* 73(1):33-40.
- Welch, E.B. and T. Lindel. 1980. Ecological effects of wastewater, applied limnology and pollutant effects. E&FN Spon, Chapman and Hall, New York. 337pp.
- Wetzel, R.C. 1983. *Limnology*, 2nd ed. Saunders College Publishing, New York. 767pp.
- Yurk, J.J. and J.J. Ney. 1989. Phosphorus-fish community biomass relationships in southern Appalachian reservoirs: can lakes be too clean for fish? *Lake and Reservoir Management* 5:83-90.