Shallow and Deep Lakes:

Determining Successful Management Options

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Shallow lakes are far more abundant than deep lakes, and more people are concerned about their quality, management, and rehabilitation. Knowledge about them has not developed as rapidly as knowledge of deep lakes, but progress now is being made. Much of this work is European, for example the works of Moss, Hosper, Scheffer, Meijer, Van Donk, Jeppesen, Sondergaard, Persson, Benndorf, Hansson, and Bronmark, as well as North American (e.g., Havens, Bachmann, Hoyer, Canfield, Carpenter, and Schelske). The purpose of this report is to provide some basic ideas about shallow lake ecology, especially about the differences between shallow and deep lakes, and to use this information to describe some shallow lake management ideas. Table 1 is a summary of these comparisons.

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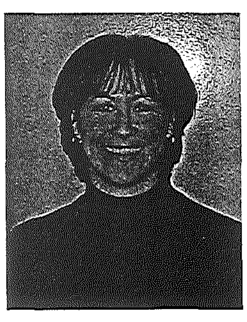

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A shallow lake has an average depth of about 3 meters (10 feet) or less, excluding small "deep holes" or small deep areas behind a dam, has a large surface area relative to mean depth, and does not have summer-long thermal stratification. Many lakes that meet these criteria are impoundments of small streams, which may have a large drainage area relative to lake area. Because stream nutrient levels are often high it may be very difficult and/or expensive to lower nutrient concentrations in these small impoundments. Some shallow lakes may be part of a former, usually large, wetland complex.

The first step in conventional lake management is the reduction of external nutrient loading to lower the concentration of nutrients (phosphorus, nitrogen, etc.) in the water column and thereby reduce the abundance of algae. This may be sound advice, but it is based on our understanding of deep lakes where open water phosphorus concentrations often are the result of external loading. Shallow lakes may differ greatly from deep lakes in their responses to this action.

Table 1. Characteristics of shallow and deep lakes

Characteristic	*Shallow*	*Deep*
1. Likely Size of Drainage Area to Lake Area	High	Lower
2. Responsiveness to Diversion of External P Loading	Lower	Higher
3. Polymictic	Often	Rarely
4. Benthic-Pelagic Coupling	High	Low
5. Internal Loading Impact on Photic Zone	High	Low
6. Impact of Benthivorous Fish on Nutients/Turbidity	High	Low
7. Fish Biomass Per Unit Volume	Higher	Lower
8. Fish Predation on Zooplankton	High	Lower
9. Nutrient Control of Algal Biomass	Lower	Higher
10. Responsiveness to Strong Biomanipulation	Higher	Lower
11. Chance of Turbid State with Plant Removal	Higher	Lower
12. Probability of Fish Winterkill	Higher	Lower
13. % Area/Volume Available for Rooted Plants	High	Low
14. Impact of Birds/Snails on Lake Metabolism	High	Lower
15. Chance of Macrophyte-free Clear Water	Low	Higher

Nutrient Dynamics

Water column nutrient concentrations in shallow lakes are the product of both external loading (nutrients from land runoff, direct precipitation and other sources *outside* the lake) and internal loading. Internal phosphorus loading is the release of phosphorus from storage in lake sediments to the water column. Because shallow lakes frequently are mixed from top to bottom, internal loading can be as significant as external loading in increasing water column phosphorus concentration. During drier summer months, it is the dominant nutrient source.

Deep lakes may have lower surface water nutrient concentrations after diversion or control of external nutrient sources because nutrients released from sediments in deep, oxygen-free water mostly remain there, and because materials that have settled (sedimented) to the lake bottom also remain there. External nutrient diversion and/or control therefore can produce a lower concentration in surface waters of deep lakes and possibly fewer algae.

Shallow lakes may continue to have high concentrations after treatment or diversion of external loading because continued internal loading affects the entire water column. These lakes therefore are resistant to long-term change in nutrient concentrations and may continue to have algal blooms and turbid water after a significant and expensive nutrient diversion.

A major mechanism of internal phosphorus loading involves thermal stratification, which prevents water column mixing. In productive lakes, there may be loss of dissolved oxygen in deep water through microbial respiration, and the subsequent release of phosphorus from iron complexes in the mud. In deep lakes, the water column remains thermally stratified all summer so that released phosphorus cannot reach the upper, lighted waters to stimulate algae growth except by diffusion or by certain climatic events. But in shallow lakes, phosphorus released from lake sediments influences the entire water column because shallow lakes usually destratify and mix several times per summer. For example, shallow lakes may stratify on warm, calm days, followed by rapid oxygen depletion in deeper water and a significant phosphorus release. Cooler, windier weather that follows causes complete mixing and introduction of the released phosphorus to the entire lake. This can occur rapidly in shallow lakes because water volume is low, leading to more rapid heating and cooling, and to rapid loss of dissolved oxygen. Algal blooms may follow each stratification/destratification event.

The probability that a lake will remain stratified all summer— for example, a deep or "dimictic" lake (circulates twice a year)—or mix often—for example, a shallow or "polymictic" lake (frequent circulation)—can be estimated by the ratio of lake mean depth to lake area by using the Osgood Index (OI). The Index estimates the probability of complete mixing during summer months. Lakes with an OI of 3-4 or less are polymictic and may be strongly affected by internal loading, regardless of the amount of external loading.

The **Osgood Index** = mean depth (in meters) divided by the square root of lake area (in km^2) or O.I. = $\bar{z} / \sqrt{A_O}$

Shallow, nutrient-rich lakes appear to exist in one of two highly stable conditions—either turbid and dominated by algae or clear and dominated by rooted plants (macrophytes or "weeds"). Many lake users view either of these conditions as highly undesirable and expend large amounts of effort and/or money to obtain a clear, weed-free lake. In addition to internal nutrient loading, there are aspects of the ecology of shallow lakes that make them unlikely to remain clear and weed-free for any significant period of time.

Role of Fish

Fish may play a very significant role in maintaining turbid, algae-rich water in shallow lakes, and can prevent them from becoming clear water systems. The entire water column is habitable by fish in shallow lakes, their biomass per unit volume is greater, and their impact on lake metabolism may be much greater than in deep lakes. Benthivorous fish (bottom-dwellers), like common carp and bullheads, mix bottom sediments and nutrients into the water column, and may do so over the entire area of a shallow lake when it is mixing and dissolved oxygen is abundant. They also excrete large quantities of urine and fecal matter (grass carp eliminate half of their daily food intake), further increasing the available nutrient levels in the lake's water column. Common carp and amurs (grass carp) are very destructive to rooted plants. We have carefully documented a turbid, algae-dominated shallow lake in northeastern Ohio where grass carp and common carp prevent the lake from becoming clear and dominated by macrophytes.

In deep lakes, fish disturbance of shallow water sediments is limited to the near shore area.

Algal Dominance in Shallow Lakes

High pH (9 or above) promotes phosphorus release from iron complexes and sediments, even in the presence of abundant dissolved oxygen. High pH is caused by intense photosynthesis, perhaps during an algae bloom or in areas of dense rooted plant growth. Shallow lakes are more susceptible than deep lakes to this process because water volume is lower and photosynthesis occurs throughout the water column, and even on the lake sediments if the water is clear. Many shallow lakes do not have the chemical buffering capacity of deep lakes so pH changes occur faster and over a wide range. This process can be significant in maintaining the algae-dominated lake.

Algae may be found throughout the water column in a mixing lake, but only in the surface water of a deep stratified lake (unless light reaches the lake's bottom or the algae are in a "resting stage" in lake sediments). But, sometimes the quantity of algae can be very low despite high nutrient concentrations, producing clear water conditions. This is caused by microscopic animals called zooplankton that graze on algae. One group of zooplankton, the genus *Daphnia,* is particularly significant in reducing algal biomass through grazing.

Zooplankton-eating fish called "planktivores" dominate many shallow and deep lakes. Examples include young-of-the-year of most species, plus juvenile or stunted bluegill, European carp, crappie, other sunfish, perch, and gizzard shad. The presence of dense populations of planktivores will mean blooms of algae because zooplankton grazing control is low or absent. This is an important mechanism that maintains the algae-dominated, turbid water condition even when nutrient concentrations have declined through nutrient diversion or from treatment of the internal loading process with alum.

The amount of algae in deep lakes is greatly influenced by zooplankton grazing, especially when nutrient diversion has produced a significant change in an essential nutrient concentration. But in shallow lakes, there is a more complex array of factors, all related to the intense coupling of sediments and water, and to the roles of fish. In these lakes, internal nutrient loading, partly influenced by fish activities, can maintain high concentrations and an algae-rich water column. If zooplankton that graze algae are abundant, a condition most likely to occur when planktivorous fish are rare, then the water column will be clear, macrophytes will grow, and sediment erosion will be less likely.

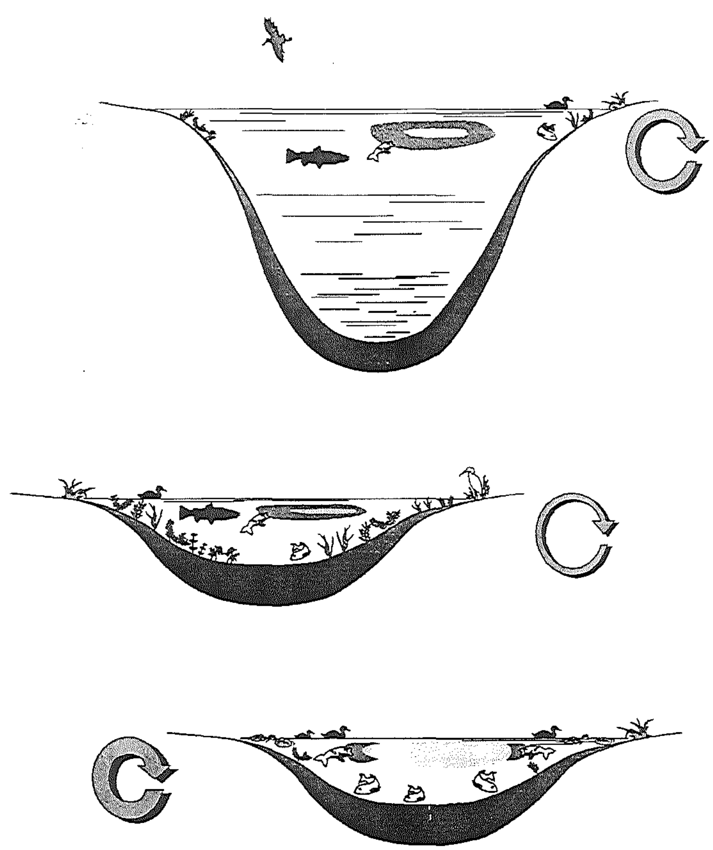

Figure 1. Main characteristics of deep (top) and shallow lakes (center and bottom). In deep lakes, the bulk of nutrient-rich sediments remains in the deepest portion of the lake. Nutrient recycling is limited in the upper water layers, and macrophytes and benthivores are limited to a small area in the shallow littoral. Clear water is maintained by piscivores (which could spawn in the vegetated littoral), which keep zooplanktivorous fish density low. Zooplankton (dark areas) limit the biomass of suspended algae (light areas). In shallow lakes, water mixes throughout the water column, and nutrients are easily entrained from the sediments (internal loading). If enough submerged vegetation is present, sediment resuspension by wind or benthivores is limited. Plants support abundant piscivores which control planktivore and benthivore abundance, and zooplankton thrive keeping suspended algae low. Water is clear and plant and animal diversity is high. When enough nutrients or silt enter a shallow lake, suspended algae and turbidity may increase to the point that the resulting lack of light in deeper waters could kill most of the submerged vegetation, leaving only floating-leaved plants (waterlilies). Piscivores would be limited, and their prey (zooplanktivores and benthivores) would thrive, resulting in reinforcement of high turbidity by unchecked growth of suspended algae and sediment stirring. Internal nutrient loading would be high, and high densities of coarse fish and waterfowl, lured by the open lakescaping that often surrounds shallow lakes, would add to the problem.

Macrophyte Dominance in Shallow Lakes

Shallow lakes differ from deep lakes in another significant way. In many shallow lakes, rooted plants thrive across most or all of the lake area, whereas in deep lakes rooted plants are usually limited to water less than ten feet deep because sufficient light does not penetrate beyond that depth. In some deep lakes, the area of shallow water is so small that macrophytes are never abundant. Dense macrophyte growths in shallow lakes help stabilize shoreline and bottom sediments. Because plants themselves are a type of habitat, biodiversity in shallow lakes can be high. Benthivorous and planktivorous fish may be less abundant, relative to piscivorous fish such as largemouth bass, and algae-eating zooplankton thrive and maintain clear water. In addition, macrophytes appear to produce compounds that inhibit algae growth. The combination of abundant plants, few or no benthivorous and planktivorous fish, and more predatory fish and zooplankton, results in a shallow lake with few algae and clearer water. This condition can be very stable, just like the turbid, algae-dominated condition, even when nutrient concentrations are high.

When rooted plants are absent, whether from light limitation in turbid, algae-rich lakes, or from some management procedure such as a grass carp application, there will be shoreline and lake bottom erosion from the action of boats and wind. Such erosion increases turbidity and internal loading and helps to maintain the turbid state even when external loading is less.

Management Considerations

Shallow lakes are susceptible to strong biomanipulations (fish additions or removals that affect the entire aquatic food web). Turbid, plant-free lakes may be more desirable than clear, weedy lakes due to recreational considerations (e.g., swimming, boating), but they can be switched to the clear state by fish removal or through fish winterkill. Winterkill occurs when respiring organisms and decomposing bacteria consume all the oxygen beneath winter lake ice. Since little oxygen is produced by photosynthesis beneath snow-covered lake ice and since oxygen replenishment from the atmosphere can't occur through lake ice, oxygen concentrations may decline to lethal levels for some fish.

The types and abundances of fish appear to be the keys to carrying out a biological manipulation of a shallow lake. Adding grass carp is a powerful manipulation and almost always produces a switch from a macrophyte-dominated lake to a more turbid and algae-dominated state, assuming enough grass carp are added. Removal of common carp, grass carp, bullheads, and sunfish, followed by re-stocking with largemouth bass, bluegills, and channel catfish may induce a shift to clear water, but such manipulations are difficult, costly, and require maintenance. Bass fishing in lakes of this type can be very good, although the use of minnows for bait should be banned because this is a good way to re-introduce planktivores to the lake. Swim areas in the macrophyte-dominated clear water state can be maintained with a harvester or judicious use of an herbicide.

Rough fish removal and re-stocking with predatory fish and bluegills could fail in nutrient-rich polymictic lakes because dissolved oxygen may fall to low levels during temporary stratification or during ice and snow cover, eliminating the game fish and thus predator control of small, zooplanktivorous fish. Therefore, an attempt to switch a lake from turbid to clear may have to be accompanied by the installation of artificial circulation to maintain adequate dissolved oxygen. Artificial circulation also could reduce phosphorus release from oxygen-free lake sediments.

An alum application is an additional or alternative means of controlling internal loading in polymictic lakes. This technique is highly effective in shallow lakes. When properly used, it is not toxic to lake biota, including rooted plants. Welch and his colleagues from the University of Washington have clearly demonstrated this in shallow Washington lakes. Clear water and macrophyte dominance should continue in an alum-treated shallow lake if the planktivorous and benthivorous fish density is low. Alum treatments of deep lakes will control sediment phosphorus release, but may have little impact on surface water algal blooms unless the lake has significant phosphorus transport from deep to shallow waters.

Waterfowl play a major role in shallow lake and pond ecology. Some birds are plant eaters and can prevent the establishment of rooted vegetation following fish removal. Bird exclosures may have to be constructed over beds of new plants until plants are established and spreading.

Much new knowledge about how lakes function has been obtained from studies of shallow lakes.

Clearer water may provide an ideal situation for fish-eating wading birds, which in turn may shift fish fauna in the lake. More than one grass carp stocking to a clear, plant-dominated lake has been foiled by Great Blue Herons. Canada geese and mallard ducks are capable of greatly altering lake water quality. Geese, for example, may defecate up to 90 times per day in winter, adding nutrients to the lake. Geese appear to be less attracted to lakes where land vegetation extends to the shoreline (lakescaping), versus lakes where land along the shore has been cleared for monoculture lawns to the lakeshore. Birds are also attracted to lakes where residents provide food. Manipulation of a shallow lake to produce clear water therefore may involve land management to discourage nuisance waterfowl, and lakescaping to reduce inflows of lawn fertilizers and pesticides.

We have tested Bronmark and Weisner's idea that snails can be significant in maintaining the clear water state. Snails graze on the biofilm of algae, which can cover submerged plant leaves and sharply reduce light availability to them. Snail exclusion experiments, which mimic effects of snail-eating fish, produced rich growths of algae on plant leaves and a decline in plant growth rate. Snails therefore appear to be another buffer that maintains the clear-water, macrophyte-dominated condition.

What about herbicides and algicides as shallow lake management tools? Both types of chemicals can act as switches to induce the turbid algal bloom state. Some herbicides are highly effective in eliminating submersed plants for the season. Some of them have low toxicity to non-target organisms, making them ideal tools for this purpose. The turbid state with algae will appear if nutrient levels in the treated lake are high and if planktivorous fish are abundant. A lake free of submergent plants may be highly desirable for recreation. Most fish biologists have concluded, however, that a sustainable game fishing lake (e.g., largemouth bass fishery) requires 20-40 percent rooted plant coverage. Partial lake treatment with certain herbicides, or the use of a harvester, may be the best option. In most cases, the algicide used is copper sulfate. It is only briefly effective when applied in nutrient-rich lakes, and very small amounts eliminate algae-eating zooplankton just like planktivorous fish can do, thereby acting as a switch for a change to the turbid state, or acting as a stabilizing mechanism for already turbid lakes. Copper use in shallow lakes can produce a "chemical dependence" when natural grazing controls have been eliminated.

Nutrient-rich shallow lake and pond users and owners are faced with a choice of clear water, dominated by submersed plants, turbid water dominated by algae, or continuous and expensive mechanical-chemical treatments to maintain a highly unnatural and unstable state of few algae and macrophytes. The key to switching from one to the other, at a given nutrient level, is in the types and abundances of fish and possibly of snails. When nutrient concentrations are lower, which may occur from control of external and/or internal loading, a switch to a stable clear water state is more likely. ➡

➠ Shallow and Deep Lakes

A shallow lake or pond that has low amounts of algae and submersed plants is uncommon, unexpected, and essentially unattainable in most areas of North America without regular chemical treatment. Exceptions are lakes in areas where soils are not nutrient-rich or where toxic drainage influences the lake. Another exception occurs in extreme northern lakes where the cold climate and short growing season limits algae and macrophyte growth.

Instead, many of our watersheds are partly or wholly urbanized, or have been converted to agriculture. Both of these watershed conditions add more nutrients. This makes algae blooms inevitable, especially where fish or algicides have removed zooplankton.

Summary

Europeans, Japanese, and others view the clear water, macrophyte-dominated shallow lake as highly desirable. They are horrified by our willingness to destroy habitat and biodiversity in our quest for a mostly illusory goal of clear, macrophyte-free shallow lakes. An alternative is to accept reality and to carry out plant removal at swim and dock areas only, and to work towards maintaining clear water. If there are deep, macrophyte-free areas, paths to them can be provided. A most important way to rehabilitate lake biodiversity and to reduce nutrient loading is to "lakescape" all shoreline residential properties. This means, at a minimum, planting a two- to three-meter wide buffer zone along the lakeshore. This should eliminate geese, stop lawn fertilizer runoff, sharply reduce lawn care costs, and provide habitat for the other lake shore/littoral zone residents.

Much new knowledge about how lakes function has been obtained from studies of shallow lakes. We know that nearly all of them will be biologically productive, but that the type of dominant organisms will vary, depending upon the presence and strengths of buffering mechanisms such as fish planktivory, internal loading, or zooplankton grazing on algae. Shallow lake users and owners can take steps to promote, maintain, or switch lake state between clear water, macrophyte-dominated or the turbid, algae-dominated states depending upon their desired lake activities.

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