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Ecological Engineering 24 (2005) 379–389

ECOLOGICAL ENGINEERING

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Integrating vertical and horizontal approaches for management of shallow lakes and wetlands

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Received 27 April 2004; received in revised form 16 December 2004; accepted 21 January 2005

Abstract

Most lake restoration/rehabilitation schemes are biased toward vertical lake management practices generally applicable to deep lakes. Unfortunately, most schemes fail to or inadequately consider their actions within the context of horizontal lake management, an especially critical component when considering shallow lakes. Two Greek lakes, phytoplankton-dominated Koronia and macrophyte-dominated Chimaditida, are used to illustrate the importance of integrating vertical and horizontal considerations in the management of shallow lakes experiencing pronounced water level reduction. Attempting to manage the structure and function of fringing wetlands via vertical manipulations of the water column are doomed to failure without consideration of changes in physical and chemical aspects of the "memory" (sediments, soils). Fringing wetlands must not be considered as monotypic habitats interacting with lakes in direct proportion to their aerial extent. A predominately vertical lake management approach is probably valid for systems such as Lake Koronia without a history of significant submersed or emergent macrophytes. For those lakes embedded within significant wetlands like Lake Chimaditida, however, failure to consider horizontal lake management as a significant component of the overall system rehabilitation will likely diminish its successful outcome. Finally, definitions of wetlands currently used by Ramsar and aquatic scientists based primarily on structural aspects of ecosystems need to be modified to recognize the overriding importance of aerially differentiated functional aspects within vegetated communities as well as fundamental differences between vegetated and open-water habitats.

Keywords: Chimaditida; Koronia; Phytoplankton-dominated systems; Lake management

1. Introduction

The world is facing a fresh water crisis. What historically has been a problem of water quality is fast becoming a double-faceted problem of quality and quantity. In many regions, centers of population growth

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doi:10.1016/j.ecoleng.2005.01.006

and water resources do not overlap, leading governments to consider elaborate schemes both for water transfer across political and catchment boundaries and for over exploitation of groundwater resources. The World Summit on Sustainable Development in Johannesburg, South Africa, during 2002 recognized that improving the economic and health status of most people on earth is linked to critical shortages of fresh water resource quantity and quality and that this problem is rapidly expanding into a worldwide concern that is independent of economic status (United Nations, 2003).

Current and projected problems with the quality and quantity of surface freshwater resources are profound for shallow lakes and wetlands of arid and semi-arid areas of Africa (Crisman et al., 2003b), Southern Balkans (Loeffler et al., 1998; Mitrakı et al., 2004), Near East (Bayar et al., 1997; Beklioglu and Moss, 1996; Green et al., 1996; Hovhanissian and Gabrielyan, 2000) and Middle East (Gophen, 2000). Many of these sites are of paramount importance for migrating and overwintering bird species and have been designated as Wetlands of International Importance (Frazier, 1996).

Both the number and magnitude of environmental perturbations to these lakes and wetlands have increased dramatically in the past two decades. Many systems have displayed progressive and profound reduction in water level due to over extraction of ground water for domestic and agricultural purposes (Mitrakı et al., 2004), landscape alterations (Chapman and Chapman, 2003; Crisman et al., 2003a) and climate change (Hollis and Stevenson, 1997). Such perturbations are not limited to arid and semi-arid regions. Shallow lakes and wetlands in west-central Florida, an area of moderately high rainfall, have undergone progressive water level reductions often leading to complete dessication due to overextraction of groundwater to meet domestic demands of cities surrounding Tampa Bay (Wiley, 1997).

Even slight reduction in lake depth can produce significant changes in the structure and function of shallow lakes. Responses are complex and dictated principally by basin morphology, prior trophic state, and the balance between phytoplankton and macrophyte biomass. Littoral zones of low to moderately productive lakes with well-established macrophyte communities prior to water level reduction often expand to dominate autotrophic production in response to increased light availability, while moderately productive lakes characterized by either co-dominance of phytoplankton and macrophytes or dominance by phytoplankton tend to become completely dominated by phytoplankton following water level reduction due to increased nutrient cycling via resuspension of sediments leading to decreased light penetration and increased flocculence of sediments. Pronounced reduction in lake level in phytoplankton-dominated systems can shift the overall metabolism of the system from autotrophy to heterotrophy in spite of a progressive increase of cultural eutrophication (Mitrakı et al., 2004). Such shifts to complete dominance by phytoplankton or macrophytes can result in extremely stable autotrophic conditions of low habitat diversity (Scheffer, 1998).

Limnologists have long recognized that deep lakes are inherently different from shallow systems due to their pronounced physical, chemical and biological stratification and seasonally restricted water column mixing (Wetzel, 2001), but the distinction between shallow lakes and wetlands remains unclear. While the Ramsar Convention on wetlands in 1971 defined wetlands as water bodies less than 6 m depth, it is understood that lakes and rivers of greater depth are covered entirely by the intent of the convention (Ramsar Convention and Secretariat, 2004). Such a purposefully broad definition of wetlands ignores intrinsic differences in structural and functional properties among shallow systems reflecting basin morphology, water depth, and the balance between open-water and vegetation cover. Such a definition lends confusion to any attempts to differentiate among shallow lakes, deep lakes, and wetlands to recognize the importance of water depth for inherent differences in structural and functional aspects of these three systems.

Ramsar was correct in recognizing that adjacent deep and shallow systems should be considered as a single functional unit. It is inherent in such an approach that wetlands are critical for the transformation and storage of watershed physical/chemical exports (hydrology, sediments, nutrients), thereby regulating structural and functional aspects of adjacent deep water systems. Until recently, lake management considered only the linkage between point/non-point exports from uplands and responses of open-water foodwebs, and ignored the role of vegetated aquatic ecotones as a driving factor. In marked contrast, lotic ecologists have recognized the importance of horizontal linkages with the floodplain, including the nutrient spiraling (Newbold-et al., 1981; Webster and Patten, 1979) and flood pulse (Junk et al., 1989) concepts, as driving factors of river structure and function.

This paper examines traditional approaches for lake management and proposes an alternative approach that recognizes the role of shallow ecotonal areas as regulators of open-water structure and function. It recognizes changing relationships relative to gradients of water depth and begins to address the question of minimum water level necessary for management of aquatic systems.

2. Vertical management of lakes and wetlands

Until the recent appearance of top–down perspectives employing biomanipulation to alter foodwebs directly, most investigations approached lake and wetland management using bottom–up approaches emphasizing nutrient concentrations and availability to control primary production, and hence consumers within the foodweb (Fig. 1). Such bottom–up approaches recognize the importance of source and nonpoint horizontal loadings of nutrients and sediments from the watershed as the ultimate control over production of aquatic ecosystems, but until very recently few studies looked at the importance of shallow water vegetated areas in the transformation (chemistry to biomass) and storage of such inputs prior to their entering open-water. Processing of watershed chemical, sediment, and hydrological signals may be via incorporation into floral and faunal biomass, short to medium term storage in biomass and detritus, and export to open-water as living biota, detritus, or dissolved nutrients and carbon. A secondary source of chemical loading, the atmosphere–water interface, has been the focus of particulate and dissolved loading mostly in ultra-oligotrophic lakes embedded within nutrient poor geologic matrices and/or influenced by pronounced acid rain (Psenner, 1994). Regardless of source, such management approaches have focused on either measure to reduce nutrients at their source or to intercept them prior to entering the aquatic ecosystem (Mitsch et al., 2001).

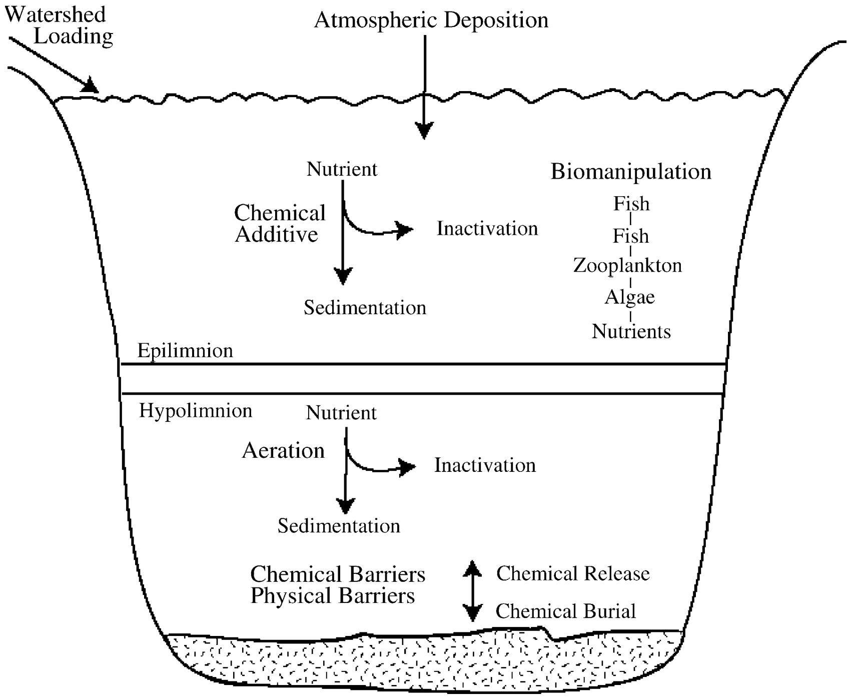

Fig. 1. Common approaches to the vertical management of lakes that focus on the water column (epilimnion and/or hypolimnion) and the sediment–water interface.

There are two general categories of in-lake management approaches: sediment–water and water column interactions (Cooke et al., 1993). Management practices focused on sediment–water interactions seek to reduce nutrient release to increase permanent storage and nutrient availability for biotic production within the water column, thereby reducing potential lag times between implementation of a management action and a positive ecosystem response. Both physical barriers of silt and clay overlying lacustrine sediments and creation of chemical barriers within or at the surface of sediments utilizing phosphorus binding compounds like alum have been effective at stopping recycling of phosphorus from relatively firm, mainly macrophyte produced sediments (Hansen et al., 2003). Similarly, chemical inactivation via addition of either solutions or powders of an aluminum salt, usually aluminum sulfate (alum) and or sodium aluminate (Reitzel et al., 2003), ferrous iron (Deppe and Benndorf, 2002), calcite (Dittrich and Koschel, 2002) or gypsum (Salonen et al., 2001) into the water column can reduce nutrient availability for primary production of phytoplankton, often forming precipitates that are eventually deposited on the lake bottom promoting long term nutrient storage in sediments.

Total water column aeration has proven effective at oxygenating both the water column and the sediment–water interface in shallow lakes characterized by extremely flocculent sediments resulting from phytoplankton domination of autotrophic production to reduce nutrient availability (Cooke et al., 1993). In lakes deep enough to develop a stable hypolimnion, however, hypolimnetic aeration is preferred, as it does not promote water column holomixis, is effective at reducing sediment nutrient release and provides an oxygenated deep water refuge for fish and invertebrates (Soltero et al., 1994).

The addition of biomanipulation to alter the structure and biomass of pelagic foodwebs (top–down) is a relatively recently alternative to traditional bottom–up management approaches that focus on reducing nutrient availability to the primary production base of the ecosystem (Carpenter and Kitchell, 1989). Most biomanipulation schemes seek to restructure fish communities to either promote a cascading of interactions among trophic levels of the foodweb leading to altered taxonomic composition and/or biomass reduction of the phytoplankton assemblage via elevated predator fish populations, direct grazing on phytoplankton by phytophagous fish or decreased nutrient cycling from sediments by elimination of the bioturbation actions from benthivorous fish such as catfish or carp. An indirect benefit of biomanipulation is often reduction in nutrient cycling via sedimentation of intact feces and degradation resistant body parts. All biomanipulation schemes seek to alter biotic structure directly to alter the function of pelagic food webs independent of controls over nutrient availability.

Thus, traditional management practices of open-water ecosystems have taken a strictly vertical perspective incorporating air–water, sediment–water and within water column interactions. Such approaches recognize the importance of horizontal loadings from the watershed, but largely ignore the importance of shallow water vegetated areas at mediating such inputs prior to entering open-water. As such, the solution to management of shallow lakes experiencing significant loss of water level has taken a vertical perspective to add sufficient water to reduce the importance of sediment–water interactions for nutrient cycling and to provide sufficient oxygen to favor fish communities capable of structuring the pelagic foodweb to support a specific management object (Crisman, 1986).

3. Horizontal management of lakes and wetlands

Shallow lakes are controlled more by system memory (sediments) and interactions with the water column than are deep lakes because of their lack of thermal stratification and increased sediment disturbance thorough wave and current action. Given that the shallower the lake, the greater the interactions with sediments and the lower water column, management of such lakes has focused primarily on vertical approaches to minimize recycling of sediment memory by increasing the depth of the water column (Cooke et al., 1993). Increased stability of the sediment–water interface favors permanent burial of nutrients, thereby reducing the lag time between implementation of a management scenario and a positive response of the aquatic system.

Reflecting basin configuration, shallow lakes tend to be surrounded by extensive littoral zones and wetlands, and are thus also strongly influenced by horizontal processes and interactions (Fig. 2). As noted earlier,

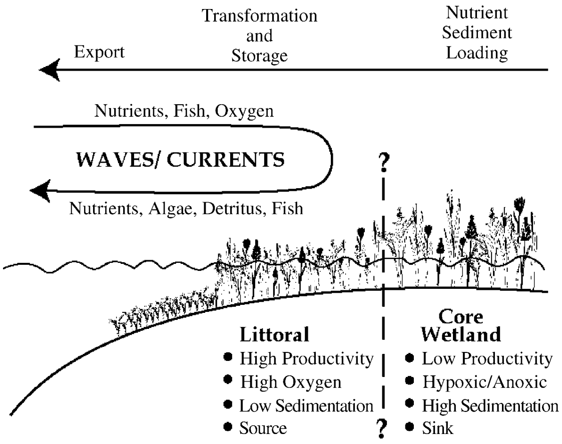

Fig. 2. Processes operating from the terrestrial–wetland and wetland–pelagic interfaces in shallow lakes emphasizing differences between the littoral zone and the core wetland.

vegetated littoral zones and fringing wetlands receive loadings of chemicals and sediments from uplands, and through transformation and storage processes, in turn regulate their subsequent export rate and form (detritus, living biomass, dissolved nutrients) to openwater. Therefore, shallow vegetated areas strongly control pelagic metabolism (Wetzel, 2001). This metabolic kidney function is short circuited, however, when loading rates exceed the growth capacity of the plant community in combination with water residence time in the wetland. Wide, densely vegetated shorelines have the greatest likelihood of having the longest residence time and achieving maximum nutrient uptake via plant and sediment processes, including denitrification, with possible medium to long-term storage in accumulating sediments.

The functional role of a fringing wetland in lake metabolism is controlled not only by its width, plant density, and productivity, but also by the extent of direct interactions at its ecotonal boundary with the pelagic area of the lake (Fig. 2). The width of the pelagic–wetland interaction zone is influenced mainly by a balance between wetland hydrological export and the counterbalancing force of waves and currents entering the wetland from the pelagic, mediated by the physical obstruction offered by plant density and growth habit (free-floating, emergent, submersed). The width of this zone can be highly variable, extending just a few meters into fringing wetlands of even large lakes characterized by strong currents and long fetch, and its innermost boundary can be characterized by a sharp declining gradient in oxygen (Chapman et al., 2002; Rosenberger and Chapman, 1999).

While near shore portions of fringing wetlands function as nutrient sinks through plant transformations, sediment accumulation and denitrification, the wetland–pelagic interaction zone tends to be a source of nutrients and organic matter for the pelagic zone (Fig. 2). Wave and current action keep the area well oxygenated and productivity of attached algae is expected to be greater than that of interior portions of wetland beyond pelagic zone influence. Although poorly studied, it is clear that wetlands can be major exporters of fish and invertebrate biomass and detritus to the pelagic zone (Wetzel, 2001). There are also major interactions from the pelagic to the vegetated areas. Many pelagic fish species use near shore vegetated areas for breeding and exhibit a sequence of on–offshore movements at various parts of their maturation cycle reflecting both varying needs in food quality and quantity and refuge from differential predation pressure (Frankiewicz et al., 1996). While increasing biomass of submersed macrophytes can benefit populations of the predaceous invertebrate midge *Chaoborus* and fish, there is a progressive loss of abundance and population fitness of both as the percentage of the water column colonized by macrophytes increases above 50% in lakes (Crisman and Beaver, 1990).

One critical unanswered question remains regarding the horizontal extent of vegetated shallows necessary for proper management of adjoined shallow lakes. Such areas are designated littoral zones by limnologists and fringing wetlands by wetland scientists. The distinction is not one of semantics, but rather one of implied function. Historically, wetlands scientists were botantists viewing wetlands as waterward extensions of terrestrial plant communities, while limnologists viewed them as landward extensions of submersed macrophyte communities. It is time to reconcile differences in such definitions and to assign functional attributes.

It is proposed that the structurally based definition of littoral zones (Wetzel, 2001) be modified to include a functional landward boundary that delineates the limit of the wetland–pelagic interaction zone, thus recognizing its paramount importance in the metabolism of the pelagic (Fig. 2). The remainder of the emergent vegetated shallow water would constitute a core wetland area that interacts with open-water only during either major storm events and associated waves or major rain events to promote watershed runoff. It is important to note that while shorelines of individual lakes can be structurally similar from the shore outward to open-water, this definitional modification removes the implication that structure implies function throughout. Such a distinction will become increasingly important in the management of shallow lakes surrounded by extensive wetlands when only a portion of the wetland can be expected to be saved from anthropogenic activity, especially conversion to agriculture.

Key to this ammended definition of the littoral is the ability to define precisely its horizontal inner boundary. While the core wetland tends to be an area of lower sessile algal productivity, hypoxic to anoxic conditions, and medium to long-term sediment accumulation, the wetland–pelagic interface (littoral) is an area of high-algal productivity, high-oxygen concentrations through pelagic wave and current action and a low-sediment accumulation via the action of current winnowing to open-water. Therefore, selection of parameters for assessing the boundary between these two zones should consider that the core wetland is a sink, while the littoral is a highly dynamic interaction zone and source of nutrient and carbon export to the pelagic. Parameters with great promise for defining the littoral-wetland boundary are dissolved oxygen, specific conductivity and pH for short-term (hourly–daily changes in metabolism and water movement), attached algae and benthic invertebrates for medium-term (monthly–seasonal) and sediment chemical profiles for long-term (interannual) temporal boundary position and conditions. The relative partitioning of shallow vegetated areas of lakes into littoral and core wetlands will be site specific and strongly controlled by bottom configuration; the horizontal extent, density and growth habit of the vegetation; and basin size and orientation to dominant wind direction.

4. Integrating vertical and horizonal management

Case histories from two lakes in northern Greece are used to illustrate integration of vertical and horizontal approaches in the management of shallow lakes surrounded by extensive wetlands (Chimaditida) versus those without (Koronia). Both lakes have undergone pronounced water level reduction during the past 20 years as a result of agricultural activities.

4.1. Lake Chimaditida

Lake Chimaditida (21°34′05″ longitude, 40°35′45″ latitude) is approximately 200 km west of Thessaloniki and receives water from smaller Lake Zazari via a 2 km long stream. The combined watershed for these lakes is 228 km^2, much of which is in crop production. Chimaditida has experienced major water-level decline in the past three decades from a maximum depth of 8 m in 1970 to approximately 1.8 m in 2001. Drainage of the extensive marsh system to the north of the lake for agricultural production began in the early 1960s and was expanded later in the decade to 22 km^2, when a dike 0.5–1 m high was constructed at the lake outlet to regulate and lower water level.

The major water-level reduction following drainage, diversion actions and dike construction in the 1960s and 1970s resulted in a profound reduction in the landward extent of the *Phragmites*-dominated wetland and a loss of lake pelagic area from wetland expansion into open-water. After completion of most of drainage operations in 1970 and associated loss of the most landward wetland portions, Chimaditida still had wetland and open-water areas of 91 and 946 ha, respectively. By 1997, however, the open-water area had been reduced 83% to 164 ha, while wetland area had expanded 10 times to 904 ha through invasion of previously pelagic areas of the lake.

As with a majority of Greek lakes, there are few historical data to evaluate the total ecosystem response to major environmental perturbations. Cyanobacteria blooms are common, but the limited phosphorus data (range 1250–1650 μg/L for 1986 and 1992) are insufficient to delineate the history of trophic state for the lake.

4.2. Lake Koronia

Lake Koronia (23°08′48″ longitude, 40°41′21″ latitude), approximately 15 km northeast of Thessaloniki, was once the fourth largest lake in Greece, but it recently has shrunk drastically from its 4620 ha extent in the 1980s to approximately 3440 ha as a result of lowering of lake level from >4 m to <1 m (Zalidis and Mantzavelas, 1994). The lake lies in a tectonically active faulted basin, and its watershed (approximately 350 km^2) is drained by three creeks and a ditch. It is listed as a Wetland of International Importance by RAMSAR in recognition of its importance for nature conservation, especially birds. Although the lake had an active commercial fishery in the late 1980s, concerns were expressed for its sustainability as a result of progressive water-level decline (Economidis et al., 1988; Fotis et al., 1992). Unfortunately, the fishery totally collapsed during the 1990s.

Agriculture intensified in the basin during the 1960s and especially the 1970s accompanied by a progressive increase in the number of irrigation wells. Additional stress on groundwater resources was associated with establishment of industries at the western end of the lake in the 1970s and their expansion in the 1980s. The main point-source discharge for agricultural and industrial activities to the lake is a ditch at the western end of the lake, and heavy metal concentrations in sediments are high where the stream enters the lake (Anthemidis et al., 1997).

Lake Koronia has experienced a progressive increase in trophic state associated with decreasing water level since the early 1990s (Mitrakı et al., 2004). Water-column conductivity remained at 1100–1300 μS cm^{-1} from 1977 to 1989, then increased rapidly to exceed 6500 by 1996. The most rapid increase was during 1994–1996. An identical trend is displayed by total phosphorus, with values remaining at < 200 μg/L from 1977 to 1989, then increasing rapidly to peak values of > 1000 μg/L by 1996. Lake Koronia displayed the second highest chlorophyll (206 mg/m^3) and lowest Secchi disk transparency (0.2 m) of 14 Macedonian lakes survey by Koussouris et al. (1992) and was clearly hypertrophic by the end of the 1980s. Conditions have only gotten worse since then as macrophytes have disappeared and the system has become completely dominated by cyanobacteria.

The period of greatest increase in trophic state coincided with the progressive reduction in lake level from at least 1986 (water depth = 4.0 m) through 2001 (water depth < 1.0 m). This decline was independent of regional rainfall trends and is attributed to overextraction of ground water resources for agricultural and industrial purposes (Mitrakı et al., 2004). The Mygdonia Basin, which includes Koronia and adjacent Lake Volvi, has over 2069 wells for irrigation purposes, of which 1091 are in the vicinity of Lake Koronia (HMEPPPW, 1996). Most of these, as well as those for industrial purposes, were drilled in the late 1970s and 1980s prior to legal curtailment of new wells in the early 1990s.

4.3. Restoration scenarios

Proposals are being formulated to increase water levels in both lakes Koronia and Chimaditida in order to enhance conservation value and reverse the effects of cultural eutrophication. While Scheffer (1998) recognized both fundamental differences in the structure and function of shallow versus deep lakes and the presence of alternative stable states for autotroph dominance (macrophytes and phytoplankton), initiation of a shift between these two states is strongly controlled by system “memory” (sediments) and hydrology.

A conceptual model is proposed for the response of phytoplankton (Koronia) and emergent-macrophyte (Chimaditida)-dominated shallow lakes to altered water level that incorporates sediment physical influences on likely ecosystem restoration success (Fig. 3). Lake Koronia was phytoplankton-dominated prior to hydrologic alterations with few submersed and emergent macrophytes. Our ongoing paleolimnological investigation of the lake suggests that sediments deposited at this time were uniform in character and somewhat flocculent. The progressive lowering of water level since at least the 1980s has established cyanobacteria as the dominant autotrophs in the lake resulting in highly flocculent sediment that is readily suspended into the shallow water column. Emergent macrophytes only sparsely colonize the rapidly retreating shoreline, and submersed macrophytes are essentially absent due to low transparency and flocculent sediments.

Although it is unlikely that any rehabilitation scheme for Lake Koronia will have sufficient water to return water depth to 1980 values, the relative dominance of phytoplankton and macrophytes will depend on both the temporal extent of sediment exposure to the atmosphere and the speed of water level change. The longer the drawdown period, the greater the extent of dewatering, compaction and oxidation of exposed sediment to affect nutrient cycling. Under this scenario, flocculent sediments would be aerially restricted to the deepest portion of the basin that is continually flooded, while sediments higher in the basin morphometric

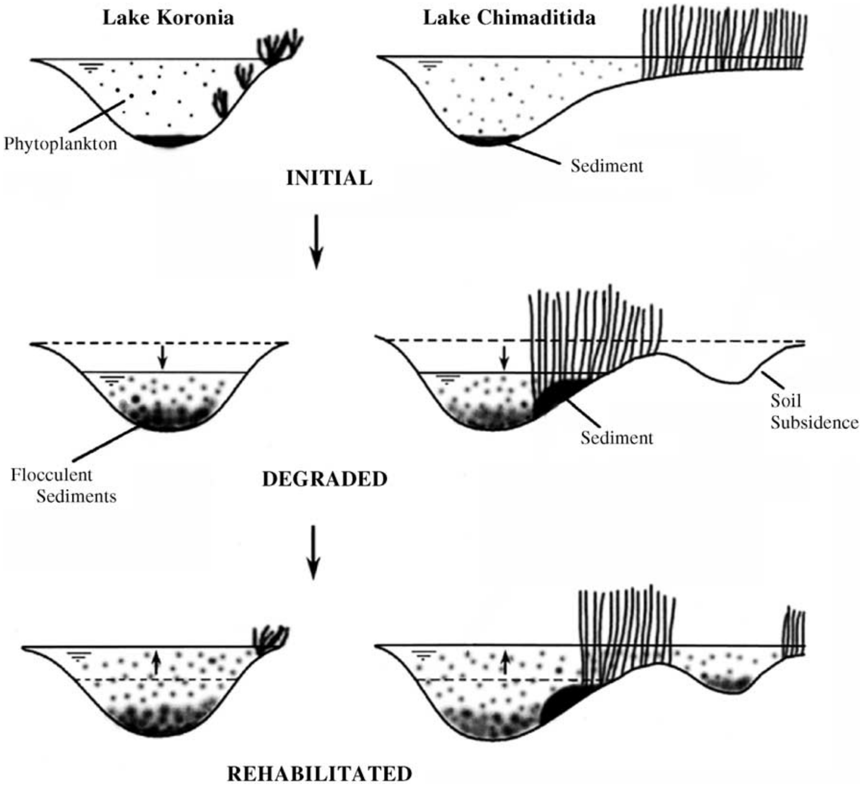

Fig. 3. Likely responses of two Greek lakes, Koronia and Chimiditida, to progressive water level reduction and hydrological rehabilitation.

profile could support rooted macrophytes upon reflooding because of development of a firm substrate.

Key in establishing a vegetated littoral zone is the speed of water-level return and the slope/configuration of the basin. The faster the return, the less likely the establishment of submersed macrophytes due to shading from the likely continuing dominance of cyanobacteria supported by sediment release of nutrients from flocculent sediments in deeper water and potential pumping of nutrients from sediments by macrophytes. Thus, it is extremely difficult to reverse phytoplankton dominance without close attention to physical and chemical characteristics of system "memory" (sediments). Thus, raising water level will likely produce little change in cyanobacteria as the dominant stable state of the lake.

Lake Chimaditida shifted to nearly complete dominance by emergent macrophytes (*Phragmites*) following profound reduction in water level (Fig. 3). Former wetland areas were farmed and the wetland fringe expanded into the pelagic to reduce its extent significantly. It appears that exposure of organic wetland soils for agricultural production has promoted soil compaction, dewatering and decomposition, thus lowering soil surface elevation over the past two decades. Similar operations in former wetlands of Louisiana and the Florida Everglades have resulted in soil subsidence approaching 3.0 cm/year (Shih et al., 1998; Trepagnier et al., 1995). Conversely, *Phragmites* expansion into formerly pelagic areas has likely increased accumulation of organic sediments as suggested by the 0.25–1.1 cm/year rates noted by Reddy et al. (1993) for a comparable emergent macrophyte, *Cladium jamaicense*, in the Florida Everglades. Pelagic areas of eutrophic Lake Chimaditida would be expected to accumulate sediments at <1.0 cm/year (Brenner et al., 1999a,b). As happened at Lake Apopka, Florida, long-term farming of former wetlands surrounding a eutrophic shallow lake can result in the sediment surface of the former wetland being meters below that of the adjacent lake bottom.

Increasing water level in Lake Chimaditida will likely push the *Phragmites* front closer to the shore as water depths exceed plant colonization and maintenance limits, but because of sediment accumulation patterns and associated shoaling, it is unlikely that the front will return to its 1970 position. In addition, reflooded former wetland areas are likely to develop into a mosiac of open and vegetated areas reflecting differential sediment loss during the drawdown period, and there is likely to be significant flooding associated phosphorus release at least in the short-term (Calzada-Bujak et al., 2001).

5. Implications for lake wetland management

Most lake restoration/rehabilitation schemes are biased toward vertical lake management. Lakes are considered from a pelagic perspective, whereby increasing water level will reduce the manifestation of cultural eutrophication by reducing nutrient availability in the water column through reduced physical sediment-resuspension and possible trapping in a restored hypolimnion (provided the lake is deep enough). Even without a reduction in nutrient availability, possibly higher oxygen concentrations under higher water regimes may favor biomanipulation of pelagic and benthic components of the foodweb to enhance grazing on excess autotrophic production (Carpenter and Kitchell, 1989).

Unfortunately, most restoration/rehabilitation schemes fail to or inadequately consider their actions within the context of horizontal lake management. It is usually assumed that littoral zones and broader fringing wetlands, like the pelagic, will return to their former extent, structure and function through a management plan. As demonstrated for Lakes Koronia and Chimaditida in Greece, failure to consider changes in physical and chemical aspects of the “memory” (sediments, soils) may invalidate such assumptions.

Wetlands must not be considered as monotypic habitats interacting with lakes in direct proportion to their aerial extent. Extensive wetlands surrounding lakes can be divided into three distinct zones: (1) an upland-wetland ecotone, (2) a wetland-pelagic ecotone and (3) an interior core area that rarely interacts directly with either upland or lake (Crisman et al., 2003a). As illustrated by Lake Chimaditida, there is likely to be a differential response of these zones to elevated water levels, especially after a prolonged period of lower water and sediment exposure. Proposals to harvest reeds from fringing wetlands to manage nutrient loading to Greek lakes (Nikolaidis et al., 1996), for example, may prove largely ineffective in lakes like Chimaditida if the wetland zone in question is so large and isolated that it rarely interacts with the pelagic zone of the lake.

The relative importance of vertical versus horizontal lake management aspects in overall lake rehabilitation schemes is governed by a number of factors including basin morphometry in conjunction with current and projected lake depth and structural/functional aspects of macrophytes versus phytoplankton communities. Above all, it is important to develop sound management goals for the rehabilitated lake that include both terrestrial and aquatic aspects. A predominately vertical lake management approach is probably valid for systems such as Lake Koronia without a history of significant submersed or emergent macrophytes. For those lakes embedded within significant wetlands like Lake Chimaditida; however, failure to consider horizontal lake management as a significant component of the overall system rehabilitation will likely diminish its successful outcome.

Nations throughout the Balkans, Near East, and Middle East are facing the unpleasant reality that there is likely not to be sufficient available fresh water resources to return lakes to previous water levels. They must establish clear objectives for both pelagic and littoral/wetland lake areas and strive to achieve these by determining how little water is needed both to manage the structure and function of regional lakes and to determine critical times annually when it must be present. Finally, definitions of wetlands currently used by Ramsar and aquatic scientists based primarily on structural aspects of ecosystems need to be modified to recognize the overriding importance of aerially differentiated functional aspects within vegetated communities as well as fundamental differences between vegetated and open-water habitats.

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