ASSESSING CHARACTERISTICS OF KENOGAMA LAKE, A SHALLOW WATERFOWL LAKE IN NORTHERN MINNESOTA: PRELIMINARY FINDINGS

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SUMMARY OF FINDINGS

Kenogama Lake (Kenogama) is a shallow lake in western Itasca County, MN, contained within the boundaries of the Laurentian Mixed Forest. The lake is believed to be of considerable importance to migrating diving ducks, especially Lesser Scaup (*Aythya affinis*). During the past 15 years, anecdotal evidence indicates that fall use of Kenogama by diving ducks has diminished. Mechanisms responsible for these declines are unknown but may include changes in duck migration patterns, weather or precipitation dynamics, or changing availability of aquatic invertebrates or other food resources important in diets of migrating Lesser Scaup and other ducks. Of particular interest is whether historical use of Kenogama as a site for rearing of walleye (*Sander vitreus*) fry is related to changes in lake characteristics and habitat suitability for migrating ducks. During 2007, we monitored relative abundance of fish and aquatic invertebrates, water transparency, phytoplankton abundance, major nutrients, submerged macrophytes, and other characteristics of Kenogama. Fish were relatively abundant, with golden shiners (*Notemigonus crysoleucas*) and walleyes comprising most biomass in our samples. We observed sparse populations of macroinvertebrates such as aquatic insects and amphipods. Zooplankton were abundant, but only small taxa were numerous, probably reflecting high predation by zooplanktivorous fish. Water quality data and relative abundance of submerged aquatic plants were indicative of a shallow lake in a "clear-water state" with a lighted substrate and rooted aquatic plants present in most areas throughout the lake. Walleye stomach contents indicated considerable consumption of aquatic invertebrates. However, it is not yet known whether this consumption is responsible for apparent low density of macroinvertebrates throughout the lake. We plan additional monitoring efforts at Kenogama during 2008 and future data may help clarify influences of walleye and other fish in relation to Kenogama's ecological characteristics and suitability for waterfowl.

INTRODUCTION

Kenogama Lake holds considerable interest to wildlife managers in north central Minnesota due to its history of fall use by migrating diving ducks. Located in the Laurentian Mixed Forest, Kenogama also represents a type of shallow lake that has received little study, particularly within North America. In Minnesota and elsewhere, shallow lakes are believed to exhibit a bimodal distribution of characteristics, tending toward 1 of 2 opposite regime conditions along a continuum of water clarity and extent of submerged macrophyte development (Scheffer 2004). These "alternative states" are typically characterized by clear-water lakes containing abundant submerged macrophytes, and alternatively, by lakes with turbid water and sparse submerged macrophyte communities. In each alternative state, shallow lakes are believed to exhibit stability and resist changes toward the opposite extreme, especially at either very high or very low levels of background nutrients. However, at intermediate nutrients, shallow lakes in either stable state can shift to the opposite state in response to water level changes, winter hypoxia and resulting "winterkill", chemical fish kills, introduction of fish, and other perturbations. For example, shifts to a turbid state often follow increased density of planktivorous/benthivorous fish populations, prolonged increases in water depth, or increased nutrient loading (although we have fewer examples of the latter). Complete removal of fish from shallow Minnesota lakes has been shown to induce transitions toward clear-water states (Hanson and Butler 1994 a, Zimmer et al. 2002), but even then, regime shifts may be temporary.

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Mechanisms structuring characteristics of shallow lakes in forested regions of Minnesota and elsewhere are not well understood. At least some shallow northern lakes seem to follow the general pattern of alternative regimes (Bayley 2003, Zimmer et al. in prep). Minnesota's shallow lakes program has compiled data from 375 shallow lakes statewide, yet these efforts target relatively few lakes east of the transition zone from "parkland" to forested environment (Nicole Hansel-Welch, Personal Comm.). Data from Minnesota also indicate that patterns of shallow lake characteristics and behavior differ dramatically between prairie and transition ecoregions, perhaps indicating importance of different structuring mechanisms across regional gradients (Herwig et al. 2006).

Previous studies of shallow "parkland" lakes in north central Minnesota indicated that these sites often supported diverse fish communities (Herwig et al. 2006). Thus, we expected that Kenogama Lake might also contain a rich fish community. This seemed especially likely given the lake's size, history of angler interest, and the recent pattern of mild winters. Limited previous reports from Kenogama indicated that water clarity was good, that abundance of submerged aquatic plants was relatively high, and that plants were not limited by low water clarity (Hansel-Welch et al., unpublished data). Kenogama has been used to rear walleye since 1983 (MNDNR, unpublished data). Walleye fry are stocked in spring; juveniles (age-0) are removed during fall. Some unharvested walleye are known to survive over-winter because, at times, summer and winter angling was popular, at least during the past decade.

Recent research evaluating stocking of walleye fry in shallow prairie lakes indicated that adding juvenile (age-0) walleye to sites containing moderately dense cyprinid populations actually bolstered abundance of macroinvertebrates and zooplankton, and favored clear water shifts (Potthoff et al. 2008). However, it is currently not possible to predict long-term consequences of walleye fry stocking in a shallow lake with an unknown fish community, or where adult fish are removed at low rates (and do not winterkill). These are interesting questions for which good limnological monitoring at Kenogama might improve the general understanding of shallow lakes in forested landscapes in Minnesota and elsewhere.

During May 2007, we initiated a 2-year monitoring effort at Kenogama. Our objectives were to: (1) document current ecological conditions within the lake; (2) assess characteristics of the lake's current fish community; (3) characterize the invertebrate community, with special emphasis on selected taxa known to be important for water quality and as waterfowl food; and (4) draw broad comparisons between Kenogama and other shallow MN lakes recently studied. This interim report summarizes our efforts during May-September 2007; we also discuss some of our preliminary findings and offer some hypotheses about current characteristics of the lake. Interpretations may change with additional data gathering during 2008 and further data analyses.

METHODS

During May 2007, we chose 6 transects by randomly selecting 6 compass bearings (0-360 from north) from the approximate center of the lake. Two sampling stations were established along each of the 6 transects (total of 12), one 20 meters from the edge of the emergent vegetation and the second, at a location one-half the distance from the shoreline to the center of the lake. All sampling for aquatic invertebrates, fish, and water quality parameters was conducted at 2 locations along each of these transects.

Fish Community

Relative abundance and species composition of Kenogama's fish population was assessed using 3 gill nets, 12 mini-fyke (small trap) nets, and 12 minnow traps during 13-15 June and 7-9 August. For each sampling effort, a single mini-fyke net and a minnow trap were deployed along the shore, or at the deep margin of emergent vegetation along all 6 transects.

Gill nets were set concurrently; 1 at the deepest location along transects 2, 4, and 6. Sampling gear was deployed in the morning and checked approximately 24 hours later. All fish were identified to species, and wet weights (g) and total lengths (mm) were determined in the field. Random samples of stomachs and otoliths were taken from walleye. Because we were especially concerned with population characteristics and functional influences of walleye, we also examined walleye length at age distribution, length frequency, relative weights (Wr, Pope and Carter 2007), and stomach contents.

Aquatic Invertebrates

Aquatic invertebrates were sampled at approximately 2-3-week intervals using column samples (CS) (Swanson 1978) and vertical activity traps (AT) after the design of Muscha et al. (2001). CS and AT samples were gathered concurrently from deep and shallow collecting locations, respectively. CSs were concentrated by passage through a 64 µm-mesh funnel. ATs were deployed for approximately 24 hrs, then collected and condensed by passage through a 80 µm-mesh funnel. Both CS and AT samples were preserved in 70% ethanol.

Invertebrates were identified to the lowest feasible taxonomic group (mostly family, sometimes genus) and were counted in the lab at Bemidji State University. To facilitate analyses, we pooled organisms into the following eleven groups: all insects, all Diptera (Chaoboridae, Chironomidae, Culicidae), Corixidae, Ephemeroptera, Amphipoda, large cladocera (mainly *Daphnia, Ceriodaphnia, Simocephalus,* and Sididae), small cladocera (Chydoridae, Bosminidae, and *Diaphanosoma*), cyclopoid copepods, calanoid copepods, and *Leptidora*. Because we were interested primarily in assessing relative abundance and seasonal trends, we combined results of all CS and AT samples on each sampling date to develop a relative abundance estimate for each of the 11 groups listed above. We assessed trends in major taxa graphically, although we expect to perform statistical analyses as more data become available.

Plant Community

Relative abundance of submerged macrophytes was assessed on 2 August using methods of Deppe and Lathrop (1992) (an approach generally similar to that currently used by MNDNR Section of Wildlife Shallow Lakes Program staff and by researchers from MNDNR Wetland Wildlife Group). We selected 8 transects, with 5 sampling locations equidistant from one another and from shorelines. At each location, we collected plants using 2 casts of a weighted plant rake. We recorded presence/absence of all submergent species retained on each cast. We estimated relative abundance of each species as the number of occurrences (of a possible 40) that a species was sampled on at least 1 rake cast per sampling location. A maximum score of 40 would indicate that a species was present at all sampling stations.

Given our interest in comparing Kenogama to other shallow MN lakes, we applied 2 additional procedures using plant data. First, we constructed a plant relative-abundance matrix by combining Kenogama plant survey results with similar data from a recent (2006) study of 74 shallow lakes in MN (Herwig et al. 2006). We then used Principal Components Analysis (PCA) to identify patterns in presence and abundance of plant species, and especially, to assess similarity between plant communities of Kenogama and other shallow lakes in Minnesota. Second, we compared plant (% vegetated points) and water clarity characteristics (average Secchi/average lake depth) of Kenogama with other shallow lakes in a large data set supplied by the MNDNR Section of Wildlife Shallow Lakes Program (Nicole Hansel-Welch, unpublished data). These approaches allowed us to compare Kenogama with other shallow lakes statewide in terms of submerged plants and water clarity relationships.

Chemical Properties and Water Quality Features

We assessed water clarity, phytoplankton abundance (indexed using chlorophyll a (Chl *a*)), and concentrations of major nutrients at approximately 2-3 week intervals during 31 May-1 August. Chemical analyses were performed using surface-dip water samples collected at 3 central locations within the lake. Secchi disk transparency was measured at these 3 sites using a standard (20-cm) circular disk. We also measured turbidity directly using a LaMotte turbidity meter following transport of water samples back to the lab. Water samples collected for determination of total phosphorus (TP), total nitrogen (TN), and nitrate (NH_3) were frozen and transported to laboratory facilities. Water samples were also collected and later analyzed for total dissolved phosphorus (TDP) and phytoplankton abundance (Chl *a*). Previous work in shallow lakes indicated TDP is sometimes much more useful than TP for evaluating ecological change in shallow lakes (Potthoff et al. In press.). TDP samples were prepared by filtering lake water through GF/F glass fiber filters (0.7 µm nominal pore size) and immediately freezing the filtered water. Chl *a* samples were prepared by filtering lake water through a GF/F glass fiber filter; filters were then wrapped in tin foil and immediately frozen. TDP concentrations were determined using high-temperature persulfate digestion followed by ascorbic-acid colorimetry. Chl *a* was measured via fluorometric analysis following a 24 h, alkaline-acetone extraction of photosynthetic pigments. All chemical procedures for analysis of Chl *a*, TP, TDP, TN, and NH_3 were performed using laboratory facilities at the University of St. Thomas (St. Paul, MN). Preliminary evaluation of data trends was done graphically.

Relative Water Depth

Relative water level readings were recorded approximately biweekly from 31 May-15 August by reading a depth gauge near the boat access. On 8 June, using a Lowrance sonar unit, we also measured water depth at various locations around the lake.

RESULTS

Fish Community

Fourteen species of fishes were captured during the 2007 sampling period (Table 1). Based on results of mini-fyke (trap) nets, golden shiner, fathead minnow (*Pimephales promelas*) and walleye were the most abundant fishes (highest relative mass, Table 1). Walleye were the most abundant species captured in gill nets, although some were also sampled in mini-fyke nets. Golden shiners from several size (year) classes were captured in mini-fyke nets. Gill nets also collected golden shiners but only larger sizes (135-185 mm) representing older year classes.

We observed 3 peaks in length frequency of walleye collected during 2007 (Figure 1). Lengths of the walleye collected shifted between June and August sample dates, reflecting summer growth (Figure 1). Age-assignment based on otoliths confirmed the 3 (or more) year-classes indicated by length-frequencies in Figure 1. We observed that randomly selected walleye ranging from 230–300 mm were age-1 (2006 year class), fish ranging from 360–430 mm were age-2 (2005 year class), and larger walleye ranged from ages 3-5.

Walleye appeared to be in fair-good condition, with an average relative weight (W_r) ranging between 0.8 and 1.0 (Figure 2). Smaller fish demonstrated the highest W_r during the June sampling period, whereas the larger fish appeared healthier during August. In general, W_r values were negatively associated with total length during the first sample period, perhaps indicating that food availability most benefited smaller fish. During the second sampling period, feeding conditions probably favored larger fish, and this may have been reflected in a positive correlation between W_r and length.

Summer diet of adult walleye consisted largely of aquatic invertebrates (Table 2). Amphipods comprised the major percentage of food found in walleye stomachs during June (32.7% wet mass, N=8) and August (58.3% wet mass, N=9). Minnows (cyprinids) were absent in walleye stomachs examined during June, but occurred in 16.7 % of stomachs examined in August (31.3% wet mass, N=9). Other food items present in walleye stomachs were Decapoda (crayfish), Hirundea (leeches), and larval insects. Almost one-fourth of walleye stomachs were empty, and considerable proportions of stomach contents (19.4%) were decomposed, thus were unidentifiable.

Aquatic Invertebrates

Zooplankton samples during late May–September were numerically dominated by small bodied cladocerans and copepods. Small cladocerans occurred consistently and persisted through mid-September, but density peaked on 9 July (Figure 3a). Large cladocerans occurred in relatively low numbers throughout the summer, but peaked briefly on 1 August, when they increased by a factor of 4 (Figure 3a). *Leptodora* (large, predatory cladocera) were absent in samples from the first 3 sampling dates, but appeared in samples gathered on 9 July. *Leptodora* persisted only for a short period, with low densities by mid-September (Figure 3a).

Calanoid copepods persisted throughout the sampling period, but were highly variable throughout the summer (Figure 3b). In general, Calanoid densities followed a bimodal distribution, peaking during early July and early August (Figure 3b). Cyclopoid copepods were also common in samples from Kenogama, but with a slight decrease from late July through late September (Figure 3b). In general, calanoid copepods were more abundant than were cyclopoids.

Amphipods were captured in very low numbers throughout the sampling year. Lake-wide catches of amphipods (all traps combined) ranged from 0 (31 May and 1 August) to 4 individuals (23 July) (Figure 4b). As with amphipods, Corixidae (water boatmen) were periodically captured, but densities in our samples remained very low (< 5 individuals, lake-wide) (Figure 4a). Ephemeroptera (mayflies) occurred periodically in our samples, ranging from 0 (7 June and 1 August) to 18 (20 June) individuals during the sampling year, with a peak during June, then steadily decreasing during the remainder of the study period (Figure 4a).

Water Clarity, Phytoplankton, and Major Nutrients

Water clarity followed a typical summer pattern, decreasing from seasonal highs in May and June, to its lowest level in early August (Figure 5a). Because the annual ratio of mean Secchi/depth values falls far to the right of Figure 7b (and well above a ratio of 0.5, a theoretical limit of the photic zone), most of the substrate in Kenogama was sufficiently lighted to support submerged aquatic plants.

TP values in Kenogama remained relatively low throughout late May-early August, ranging from slightly below, to slightly above 25 *u*g L^{-1} (Figure 5b). Throughout late May–early August, TDP comprised >50 % of the TP pool in Kenogama (Figure 3b).

Phytoplankton abundance also remained very low during late May-early August, with mean values ranging from approximately 5.5 – 8.5 *u*g L^{-1} (Figure 6a). Seasonal patterns in ratios of Chl *a*:TP were also consistently low, indicating that considerable phosphorus was probably not associated with phytoplankton (Figure 6a).

Relative Water Depth

Lake depth generally decreased as the sampling season progressed (by approximately 0.5 ft (0.15 m)) during late May–15 August (Figure 6b). We assessed depths lake-wide only once on 8 June, when depth ranged from 3.1 – 4.9 ft (0.94 – 1.49 m) in various locations.

Submerged Aquatic Plants

Submerged aquatic plants were present at 100 % of sites sampled during 2007. However, only 3 species were widespread; these included Robbins' pondweed (*Potamogeton robbinsii*, collected at 100 % of sites), bushy pondweed (*Najas flexilis*, collected at 65 % of sites), and large-leaf pondweed (*Potamogeton amplifolius*, collected at 43 % of sites). Flatstem pondweed (*Potamogeton zosterformis)*, whitestem pondweed (*Potamogeton praelongus*), 1 *Sagittaria* spp., and 1 unidentified pondweed (*Potamogeton spp.*) were also collected, but these were far less abundant.

DISCUSSION

Kenogama supported a diverse fish community during 2007. Similar fish community data from shallow lakes in MN are scarce, but comparisons with results of recent studies of 74 lakes provide some general insight, especially since data from these broader studies were collected using identical gear. Species richness in Kenogama's fish community (14 taxa) was similar to the upper range of values reported from shallow parkland lakes in north central Minnesota (Herwig et al. 2006, Herwig et al. in prep.). Total fish mass captured (relative abundance) in Kenogama was within the range of values observed in the broader MN study (Table 1, Zimmer et al. In Prep.). In spite of Kenogama's high fish species diversity, the community was comprised of mostly planktivorous species and walleye. Excepting walleye, piscivores were absent, and benthivores were uncommon [low mass of only white sucker (*Catostomus commersoni*) and yellow bullhead (*Ameiurus natalis*)].

Kenogama's fish community differed sharply from other shallow lakes recently studied in MN in at least 2 ways. First, Kenogama supported a relatively robust walleye population that included fish from at least 3 year-classes. Second, Kenogama's golden shiner population is higher than we have previously observed in any shallow lakes in MN. Certainly Kenogama's walleye population results directly from operational walleye rearing activities here, and from incomplete recovery and removal of these fish during fall netting efforts. It is plausible that the dense population of golden shiners results, in part, from angling activities, as golden shiners are a popular regional bait fish, especially during winter months. This combination of abundant golden shiners (planktivores) concurrent with a well-established population of walleye (piscivores) is unusual and seems at odds with recent studies indicating that walleye stocking has potential to limit abundance of planktivores in shallow lakes (Potthoff et al., In Press). Different trophic relationships at Kenogama probably result from several things. First, previous research demonstrated that walleye fry sharply reduce fathead minnows; adult walleye apparently do not limit minnow abundance. Second, golden shiners may resist depredation by walleye to greater extent than did fathead minnows in previous work, especially since shiners are longer-lived and reach larger sizes than do fathead minnows. Finally, it is plausible that extensive stands of submerged macrophytes in Kenogama provide refuge areas for golden shiners and other planktivores, thus uncoupling predator and prey densities.

Comparison of Kenogama plant community characteristics with similar data from 74 other shallow MN lakes indicates considerable dissimilarity (Figure 7a). This is not unexpected and probably results from high densities of Robbins pondweed, bushy pondweed, and large-leaf pondweed, all of which were rare or absent at other shallow lakes in MN (Herwig et al. 2006). As is often the case, a large proportion of the submerged plants were senescent by mid-August.

Trophic relationships in Kenogama suggest that consumption of macroinvertebrates and zooplankton was very high during summer 2007. Surprisingly, amphipods comprised a major percentage of food found in walleye stomachs during June and August; minnows were absent in walleye stomachs examined during June and were only a minor food item in August. However, these results should be viewed cautiously because sample sizes were small (total of 17 stomach examined) and high water temperatures resulted in decomposition of some food items prior to dissection. Dominant planktivores (golden shiners and fathead minnows) were not dissected for diet analysis, but we expect that predation on zooplankton and macroinvertebrates by cyprinids was intense. This was reflected in the sparse zooplankton community, low levels of macroinvertebrates, and, perhaps, by the lack of amphipods in activity traps.

It is tempting to conclude that Kenogama's walleye population is responsible for the sparse macroinvertebrate community, especially given the high occurrence of macroinvertebrates in walleye stomachs. However, we urge caution in interpretation of these data because they were collected on 2 dates during a single summer. It is also likely that golden shiners and other planktivores are consuming a considerable proportion of available zooplankton and macroinvertebrates, although it is presently impossible to estimate consumption by various functional groups of fish. It would not be surprising if walleye depredation were a significant constraint on macroinvertebrates in Kenogama as Reed and Parsons (1999) concluded similar influences of walleye were operating in large prairie wetlands in west-central MN.

In general, Kenogama appears in a clear-water state with widespread submergent (or emergent) macrophytes (Figure 7b). This is consistent with our estimates that average lake depth is considerably less than that at which light availability becomes insufficient to maintain photosynthesis. However, during May–September 2007, the lake supported a relatively sparse invertebrate community. Zooplankton were dominated by small-bodied taxa known to be inefficient filter-feeders on phytoplankton, and macroinvertebrate relative abundance also appeared to be low (Hall et al. 1976). From the standpoint of zooplankton and macroinvertebrates, the lake seems to exhibit characteristics similar to a shallow lake in a turbid state. This probably underscores the need for better understanding of basic ecological characteristics of shallow lakes in forested regions of MN and elsewhere. Specifically, managers need to know what ranges of conditions are typical for shallow lakes statewide, and whether these lakes always provide good habitat for invertebrates and wildlife species simply because they exhibit clear water and moderately abundant submergent plants.

We are puzzled by relationships among water-column phosphorus concentrations, phytoplankton biomass (Chl *a*), likely zooplankton filter-feeding rates, and water clarity patterns. During all dates on which we measured water quality parameters, Chl *a* concentrations were always low (lake-wide average <10 ug L^{-1}). At the same time, dissolved phosphorus (TDP concentrations) comprised approximately 50 percent (or more) of the TP pool. This probably indicates that a very large portion of the phosphorus pool was available for plants (phytoplankton, periphyton, perhaps macrophytes), but remained unutilized. In other words, nutrient availability was not limiting phytoplankton growth. Given the predominance of small-bodied zooplankton in our samples (*Bosmina*, *Chydorus*, cyclopoid copepods, etc.) grazing rates were also not likely limiting phytoplankton. It seems plausible to expect that dissolved organic compounds might occur at high concentrations in Kenogama, thus limiting phytoplankton growth (Williamson et al. 1999), especially since the lake probably receives considerable inflows from peatland areas. However this too seems unlikely given relatively good water clarity in the lake. We are unable to explain the combination of high nutrient availability and low phytoplankton abundance, along with small-bodied zooplankton and clear water. However, if these patterns persist next year, we will consider this an important information need for shallow lakes in forested regions of MN.

Historical duck-use patterns at Kenogama are poorly documented. Anecdotal reports suggest limited interest in duck hunting here prior to the decade of the 1980s, probably due to abundant opportunity in nearby areas (Robert Jessen and Leon Johnson, personal comm.). However, hunting pressure on Kenogama increased during the 1980s and early-mid 1990s. High fall use by migrating Lesser Scaup was well documented during the early 1990s and hunting pressure on the lake was high. Duck use apparently declined during the later 1990s and appeared to remain relatively low during the period of 2000-2007.

At a broad scale, wetland and shallow lake quality certainly influences food availability and habitat suitability for migrating diving ducks (Anteau and Afton 2008). It is also obvious that high-density fish populations can (directly and indirectly) influence invertebrate abundance and water quality and, in some cases, these effects are reflected in habitat suitability for foraging ducks (Hanson and Butler 1994 a,b, Bouffard and Hanson 1997, Cox et al. 1997). Presently, available data are insufficient to determine reasons for apparent low abundance of aquatic invertebrates, or for the unusual patterns of phytoplankton abundance and nutrient availability observed in Kenogama. Waterfowl use sometimes increases following water quality (and invertebrate community) improvements in shallow lakes (Hanson and Butler 1994 a), however this is not always the case. Weather, annual recruitment, and other things work together to determine whether food resources are actually utilized in a potential waterfowl feeding lake. However, our results are consistent with the notion that food resources for some waterfowl (amphipods, for example) are relatively low in Kenogama and this may influence patterns of fall use, at least by Lesser Scaup.

We expect to repeat methods described here during spring-summer 2008. In addition, we plan to explore suitability of additional sampling methods for aquatic macroinvertebrates, with attention to whether relative abundance estimates of amphipods can be improved. Also, we anticipate collecting golden shiner stomachs for diet analysis, to develop a better understanding of factors constraining invertebrates. Finally, we hope it will be possible to include Kenogama in a core group of forest lakes to be used as sites for upcoming shallow lakes research. We believe that only by conducting multi-year studies of numerous lakes across regional gradients can we hope to clarify important mechanisms and influences structuring shallow lake communities in MN.

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Table 1. Relative abundance (mean weight (g) of catch per overnight set, standard error in parentheses) of fishes in Lake Kenogama, Minnesota, during summer 2007.

			14-Jun-07			9-Aug-07	
		Trap net	Gill net	Activity trap	Trap net	Gill net	Activity trap
Species	Common name	*N* = 12	*N* = 3	*N* = 12	*N* = 12	*N* = 3	*N* = 12
Cyprinidae							
Hybognathus hankinsoni	brassy minnow	0.4(0.4)	0.0(0.0)	0.0(0.0)	0.0(0.0)	0.0(0.0)	0.0(0.0)
Notemigonus crysoleucas	golden shiner	3759.8(791.6)	277.3(17.3)	0.0(0.0)	26.5(9.7)	150.2(93.0)	0.0(0.0)
Notropis heterolepis	blacknose shiner	23.5(5.1)	0.0(0.0)	0.0(0.0)	4.4(2.5)	0.0(0.0)	0.0(0.0)
Phoxinus eos	northern redbelly dace	68.5(27.8)	0.0(0.0)	0.0(0.0)	0.0(0.0)	0.0(0.0)	0.0(0.0)
Phoxinus neogaeus	finescale dace	11.3(5.4)	0.0(0.0)	0.0(0.0)	0.4(0.4)	0.0(0.0)	0.0(0.0)
Pimephales promelas	fathead minnow	292.6(129.6)	0.0(0.0)	0.3(0.3)	6.9(2.7)	0.0(0.0)	0.0(0.0)
Catostomidae							
Catostomus commersoni	white sucker	0.0(0.0)	720.0(361.2)	0.0(0.0)	0.0(0.0)	412.3(296.7)	0.0(0.0)
Ictaluridae							
Ameiurus natalis	yellow bullhead	48.3(48.3)	0.0(0.0)	0.0(0.0)	0.0(0.0)	0.0(0.0)	0.0(0.0)
Umbridae							
Umbra limi	central mudminnow	3.0(1.6)	0.0(0.0)	1.0(0.8)	17.9(13.5)	0.0(0.0)	0.5(0.5)
Gasterosteidae							
Culaea inconstans	brook stickleback	38.3(16.6)	0.0(0.0)	3.4(2.2)	0.2(0.2)	0.0(0.0)	0.2(0.1)
Percidae							
Etheostoma exile	Iowa darter	1.7(1.1)	0.0(0.0)	0.0(0.0)	0.0(0.0)	0.0(0.0)	0.0(0.0)
Etheostoma nigrum	johnny darter	0.3(0.2)	0.0(0.0)	0.0(0.0)	0.0(0.2)	0.0(0.0)	0.0(0.0)
Perca flavescens	yellow perch	0.0(0.0)	0.0(0.0)	0.0(0.0)	3.3(3.3)	303.7(303.7)	0.0(0.0)
Sander vitreus	walleye	260.5(180.5)	9445.7(1304.6)	0.0(0.0)	214.2(94.2)	11447.7(2868.0)	0.0(0.0)

Table 2. Percent by weight and prevalence (percent of stomachs containing a food item) of stomach contents of walleyes in Lake Kenogama, Minnesota, summer 2007.

	6/14/2007 *N* = 8 stomachs examined Empty stomachs = 1 (12.5%)		8/9/2007 *N* = 9 stomachs examined Empty stomachs = 3 (33.3%)		Overall *N* = 17 stomachs examined Empty stomachs = 4 (23.5%)	
Food	Percent by weight	Prevalence	Percent by weight	Prevalence	Percent by weight	Prevalence
Hirudinea	28.2	25			9.4	11.8
Crustacea						
Amphipoda	32.7	25	58.3	66.7	40.7	35.3
Decapoda	15.5	12.5			10.7	5.9
Insecta						
Odonata	9.3	12.5	2.1	16.7	7.1	11.8
Ephemeroptera			8.3	33.3	2.6	11.8
Diptera	0.1	12.5			0.3	5.9
Pisces						
Cyprinidae			31.3	16.7	9.7	5.9
Unidentified	28.2	37.5			19.4	17.6

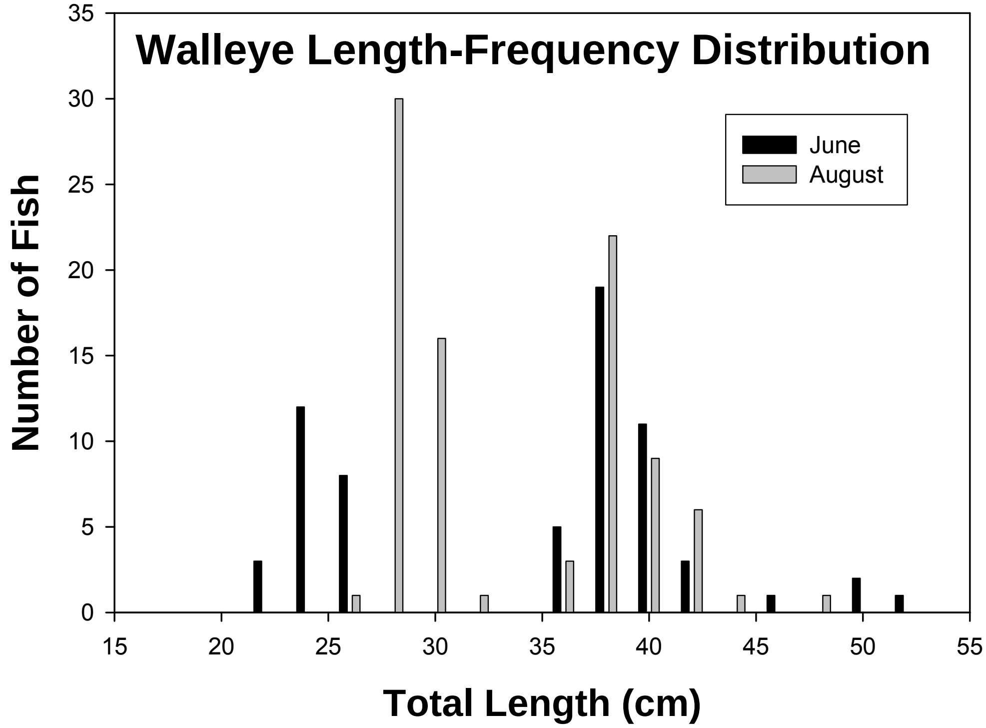


Figure 1. Length-frequency distribution of walleye captured in gill and mini-fyke nets during June and August 2007 in Kenogama Lake.

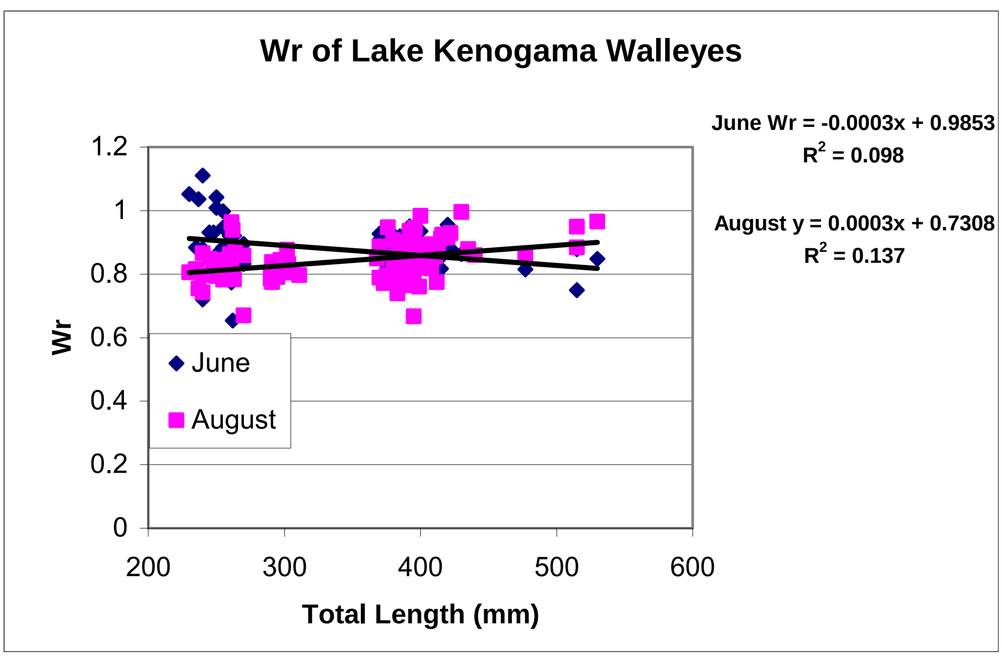


Figure 2. Relative weights (W_r) of walleyes sampled in Kenogama Lake during June and August 2007.

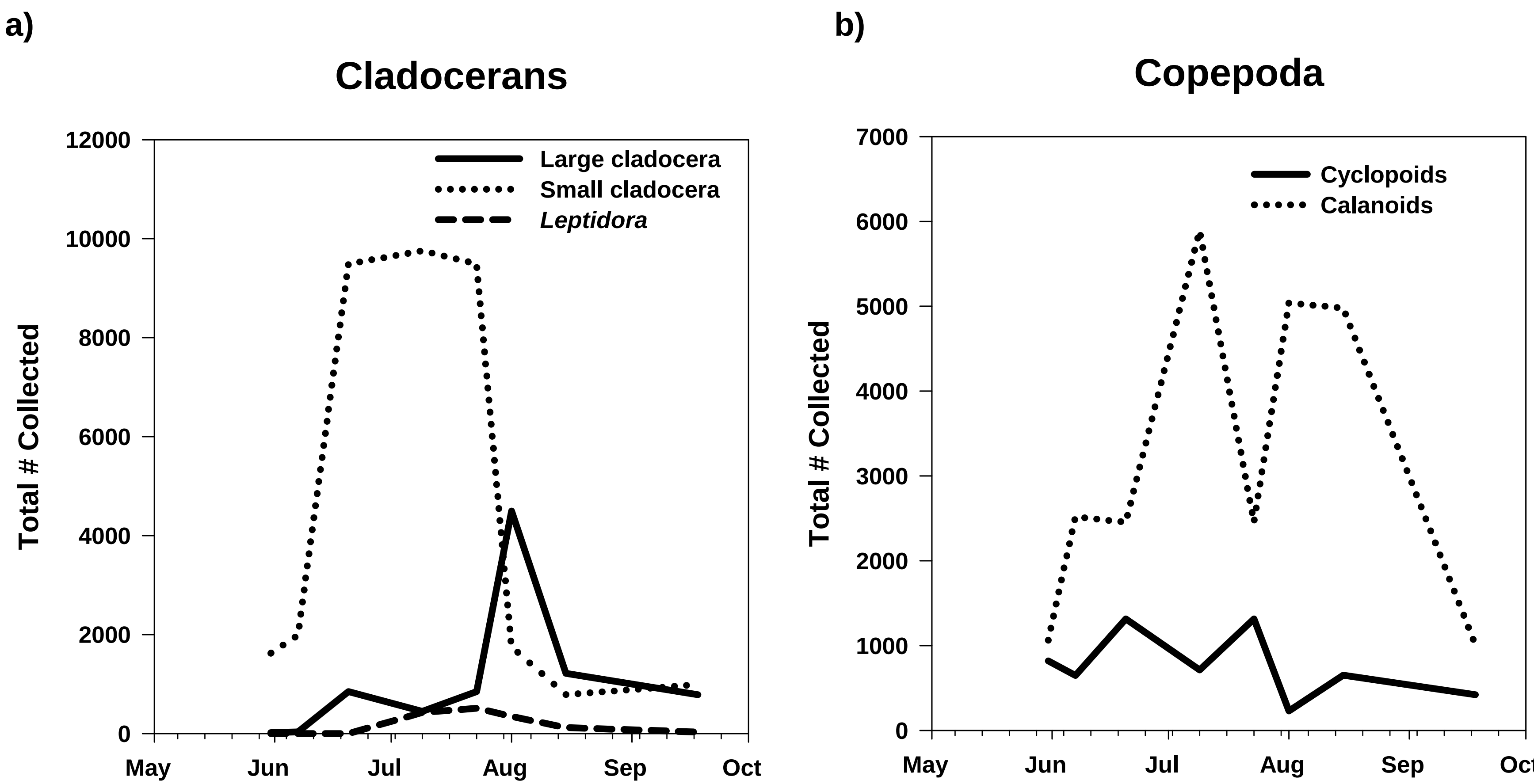
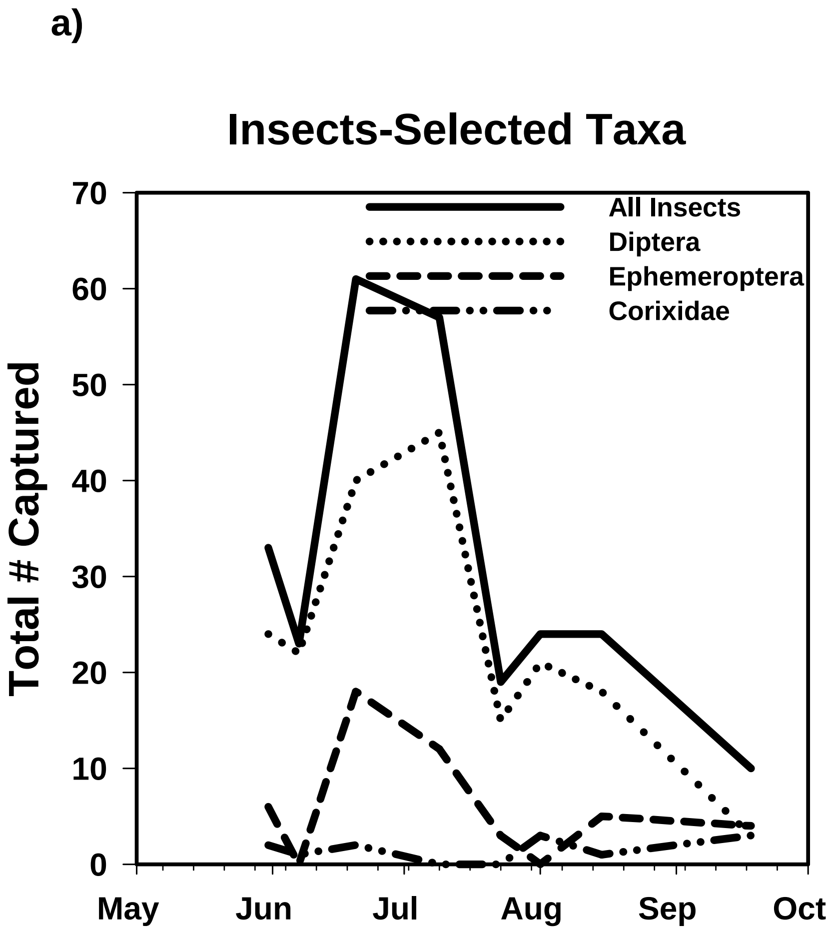


Figure 3. Seasonal patterns in total numbers of organisms captured in both activity traps (n=12) and vertical column sampler (n=12) on each sampling date. Large cladocerans (panel a) include *Daphnia, Ceriodaphnia,* Sididae, and *Simocephalus*; small cladocerans include Bosminidae, Chydoridae, and *Diaphanosoma*. Copepoda (panel b) were classified only to suborder.



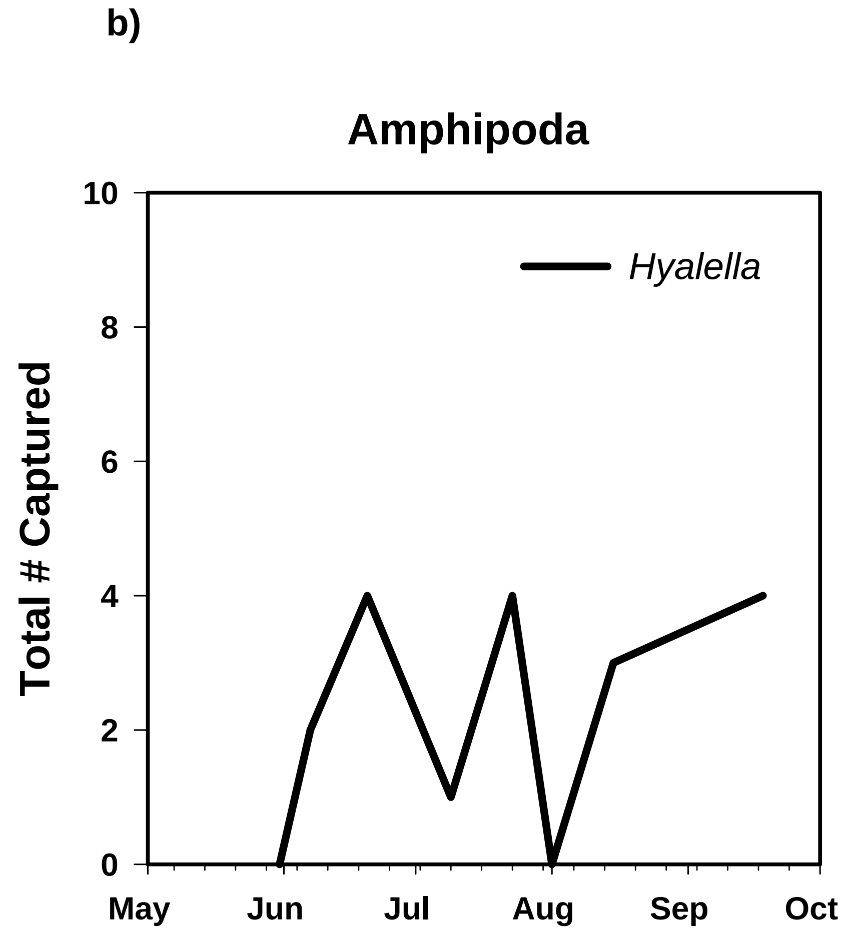


Figure 4. Seasonal patterns in total numbers of macroinvertebrates captured in Kenogama Lake during May-September 2007. Trend lines include total numbers of organisms captured in both activity traps (n=12) and vertical column sampler (n=12) on each sampling date.

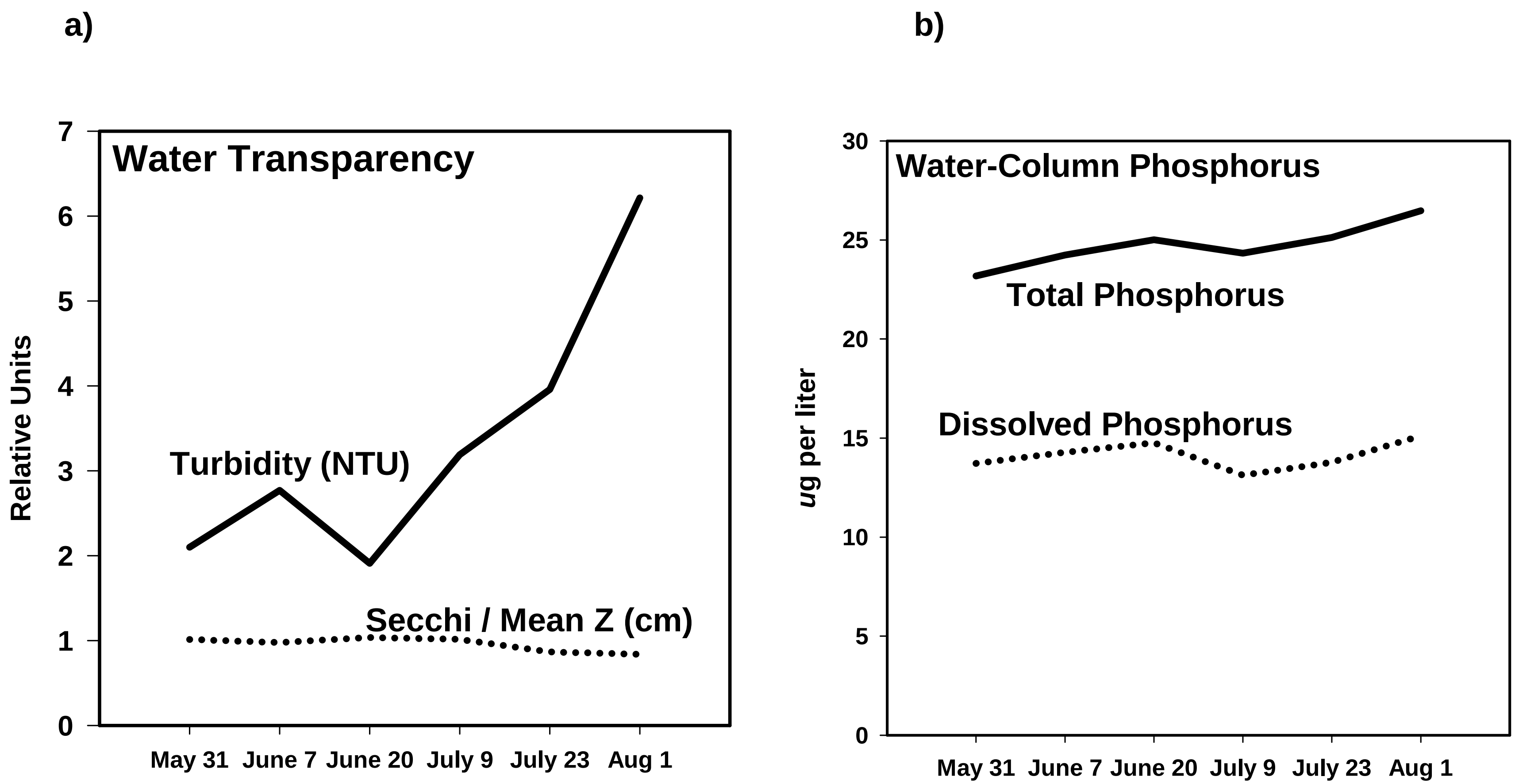


Figure 5. Water transparency patterns at Kenogama Lake during 2007 (a, left panel) depicted by ratio of Secchi disk transparency:mean lake depth, and turbidity measured using nephelometer. Total and dissolved phosphorus concentrations (2007) are summarized on right (panel b).

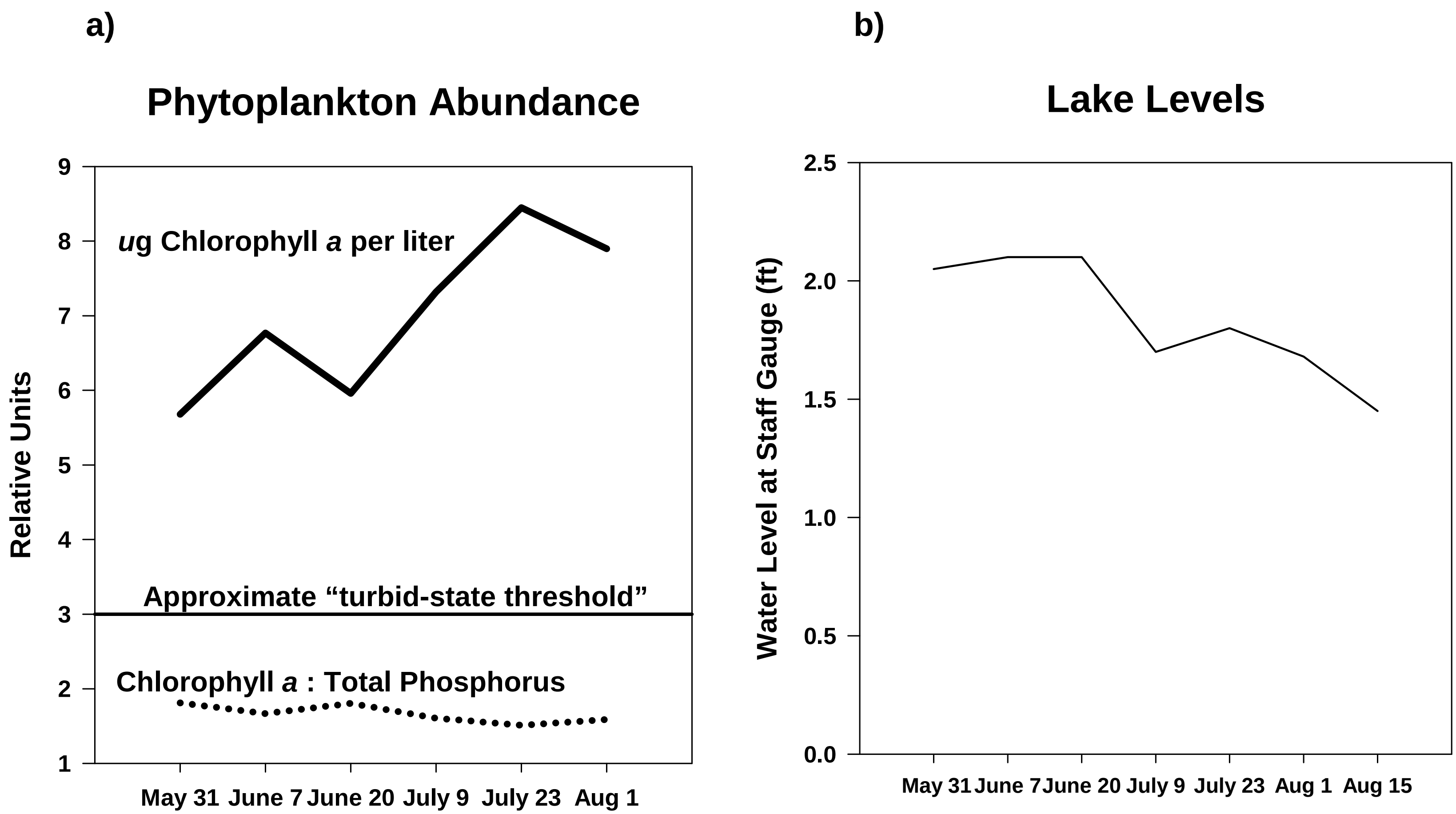


Figure 6. Phytoplankton abundance as indicated by water-column chlorophyll a concentrations (top line) at Kenogama Lake during 2007. Bottom (dashed) line depicts ratios of Chlorophyll a:Total phosphorus; values below theoretical threshold are usually associated with lakes in a clear-water state (Dokulil and Teubner 2003, panel a). Relative lake levels shown on right (panel b)

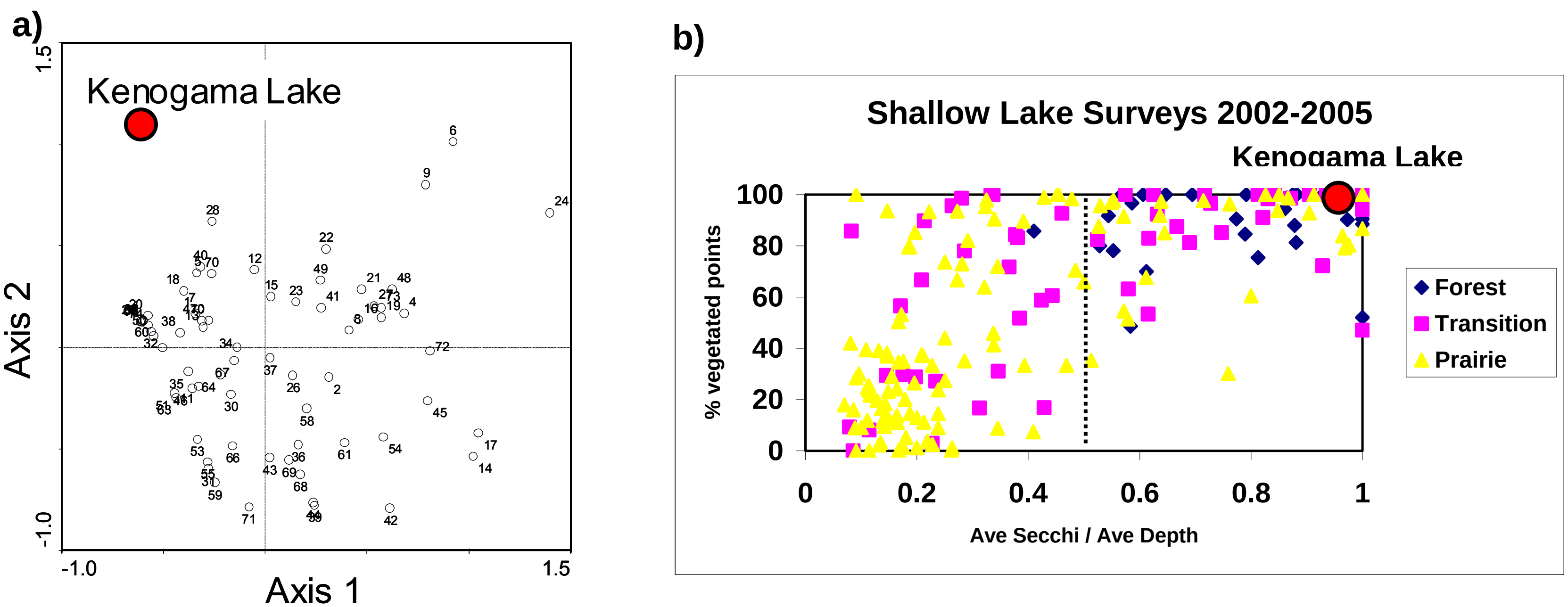


Figure 7. Plant community characteristics depicted by Principal Components Analysis (panel a, upper left; PCA) based on scores from a combined species matrix containing 74 shallow lakes (as numbered) in western and central MN, and Kenogama Lake. Panel b compares (upper right) water clarity and macrophyte relationships between Kenogama and other shallow lakes recently surveyed by MNDNR Shallow Lakes Program (data provided by Nicole Hansel-Welch et al.). Dashed line on right (panel b, Secchi/depth value = 0.5) indicates approximate threshold depth where light penetration is sufficient to support rooted plants at mean lake depth. Separation in PCA space and water clarity/plant relationships indicates extent of similarity in abundance and species composition of Kenogama and water transparency relative to other shallow lakes recently studied in MN.