Recent Changes in Phytoplankton and Abundance in the Offshore Region of SE Lake Michigan

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INTRODUCTION

Lake Michigan has a long history of perturbations that have affected phytoplankton communities. From 1955-1970, increased phosphorus loading caused significant eutrophication (Schelske and Stoermer 1972). Subsequently, phosphorus loadings were reduced and phytoplankton communities responded (Fahnenstiel and Scavia 1987). In the 1980s, several non-indigenous species (NIS) were introduced that had the ability to significantly alter the phytoplankton community. Most noteable among these NIS, was the establishment of large Dreissinid populations, particularly the quagga mussel (*Dreissena rostriformis bugensis, Nalepa et al. 2009).*

From 1983 to the present, GLERL researchers have regularly sampled two stations in southeastern Lake Michigan to assess phytoplankton production and abundance. In this poster we report on trends in phytoplankton productivity and abundance during this 26 year period.

METHODS

Sampling was conducted at two offshore stations in southeastern Lake Michigan (Figure 1) during the 1980s (1983, 1984, 1986 and 1987), 1990s (1995-1998) and 2007 and 2008. These stations were sampled approximately biweekly from March/April through November/December, except 1983 and 1984 which were sampled from May through August.

RESULTS

Primary Production

Significant differences in mean estimates of daily integral primary production were noted among years and months at both stations (Figure 2). Because mean estimates of daily integral primary production at the two stations were not significantly different among months, years or overall, production estimates from the two stations were combined to provide an indication of offshore values. In the 1980s, mean values were low in March and increased through May/July (Fig. 2a). The highest daily integral values in 1983, 1984, 1986, and 1987 were 951 mg C·m-2·d-1 (July) 1202 mg C·m-2·d-1 (July), 1168 mg C·m-2·d-1 (May), and 1327 mg C·m-2·d-1 (May), respectively. Values decreased after July in all four years, and lowest values were found in November 1987 (320 mg C·m-2·d-1). The trend in daily integral primary production was similar in the 1990s. Values were low in March and increased during April and May with maximum values found in May/July (Fig. 2b). Maximum daily integral values in 1995, 1996, 1997, and 1998 were 1554 mg C·m-2·d-1 (June), 1185 mg C·m-2·d-1 (June), 1036 mg C·m-2·d-1 (May), and 1190 mg C·m-2·d-1 (June), respectively. After July/August, values decreased and lowest values were found during November/December. The one exception was 1995 where high values were found during October.

The trend in monthly primary production was significantly different in 2007/08 (Fig. 2c). During March-May, production values were similar unlike the increasing values found in the 1980s and 1990s. March, April, and May values from 2007/08 were significantly different than March, April, and May values from 1983/87 and 1995/98. In 2007/08 production estimates increased in June and by July were not significantly different from July values in 1983, 1987, 1997, and 1998. By August values from 2007/08 were very comparable to those in August in the 1980s and 1990s with the exception of 1996. For the rest of the year (September-December) values in 2007/08 were comparable to those in 1983/87 and 1995/98 (Fig. 2).

To facilitate comparisons among years, sampling was divided into 4 periods based on surface mixed-layer temperatures. The first period was the spring isothermal period which typically lasted from first sampling in March/April until mid May/early June. This period includes all sampling where the surface mixed-layer temperature was ≤ 4 ^{o}C. The second period was early stratification and was defined as the period where surface mixed were >4 ^{o}C but ≥ 15 ^{o}C. This period typically was very short, lasting for approximately 1 month or less due to the rapid heating of the shallow surface mixed-layer. The third period was mid stratification and was defined as the period where surface temperatures were > 15 ^{o}C. This period typically lasted from July through September. The final period was late stratification and was defined as the period where surface mixed layer temperatures were ≤15 ^{o}C but > 4 ^{o}C. This period typically lasted from October through late December.

Significant differences in mean daily integral production were noted during thermal periods. During the spring isothermal mixing period, production decreased approximately 78% from 1983/87 to 2007/08 (Fig. 3a). The 2007/08 values were also significantly lower (70%) than values from 1995/98, and the 1995/98 values were significantly lower (23%) than 1983/87 values. Because only half the years in the 1980s were sampled in March and April, a comparison of spring isothermal values from May only was also made (Fig. 3b). Comparisons across decades were similar to the spring isothermal period, except differences between the 1980s and 1990s were smaller (<10%).

During mid stratification, production values from 2007/08 were significantly less than values from 1983/87 and the 1995/98, but the differences (22% and 21%, respectively) were much smaller than those noted for the spring isothermal period (Fig 3c). Production values from 1983/87 and 1995/98 were similar, 867 and 855 (Fig 2c). For the late stratification period, daily integral production did not vary across decades (Fig. 3d). Mean daily values for 1983/87, 1995/98, and 2007/08 were 400, 386, and 335, respectively.

Chlorophyll

Mean surface mixed-layer chlorophyll concentrations were similar at both stations, and thus, concentrations were combined for further analysis. In 1983/87 and 1995/98, seasonal monthly trends in mean surface mixed-layer chlorophyll exhibited an April/May peak with another smaller peak in October (Fig. 4). Highest chlorophyll concentrations for 1983/87 and 1995/98 were found in April and May respectively. After the spring chlorophyll peak, concentrations decreased through September, and then increased again in October/November (Fig. 4). The high November 1987 value was associated with one sampling.

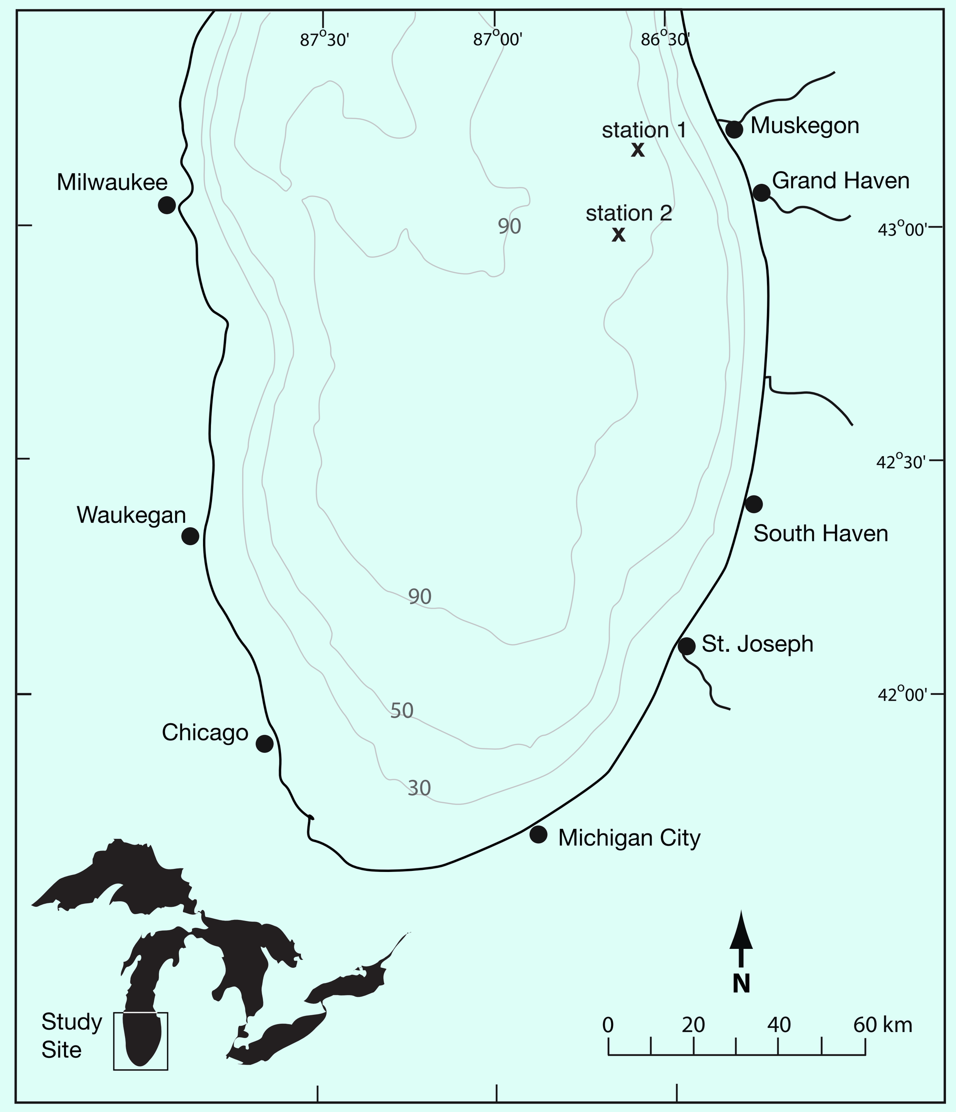

Figure 1. Map of southern Lake Michigan with two sampling stations.

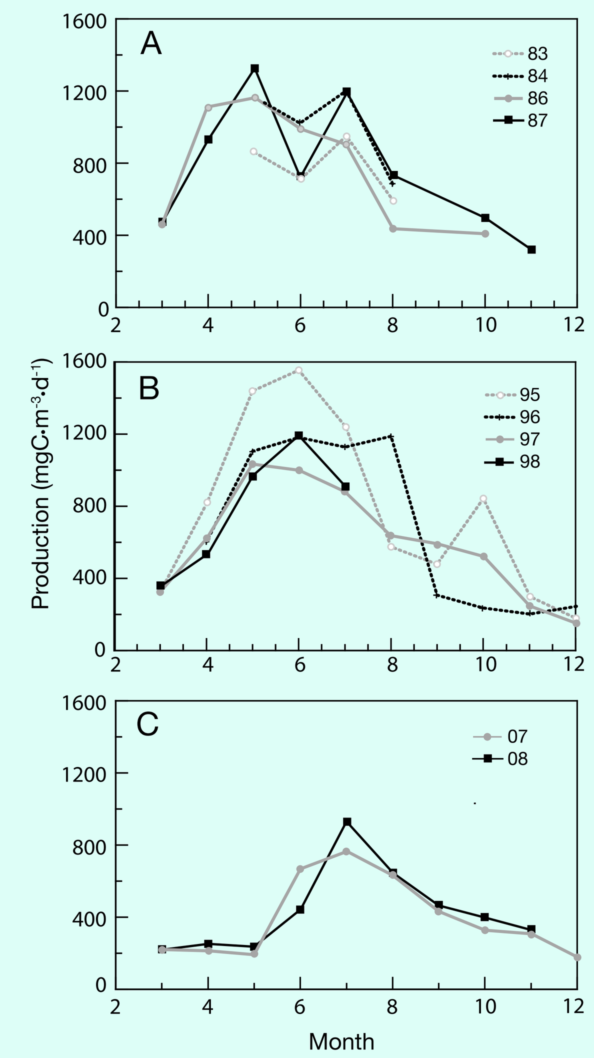

Figure 2. Mean estimates of daily areal integrated primary production (mg C·m-2·d-1) for months in a) 1980s, b) 1990s, and c) 2007/08.

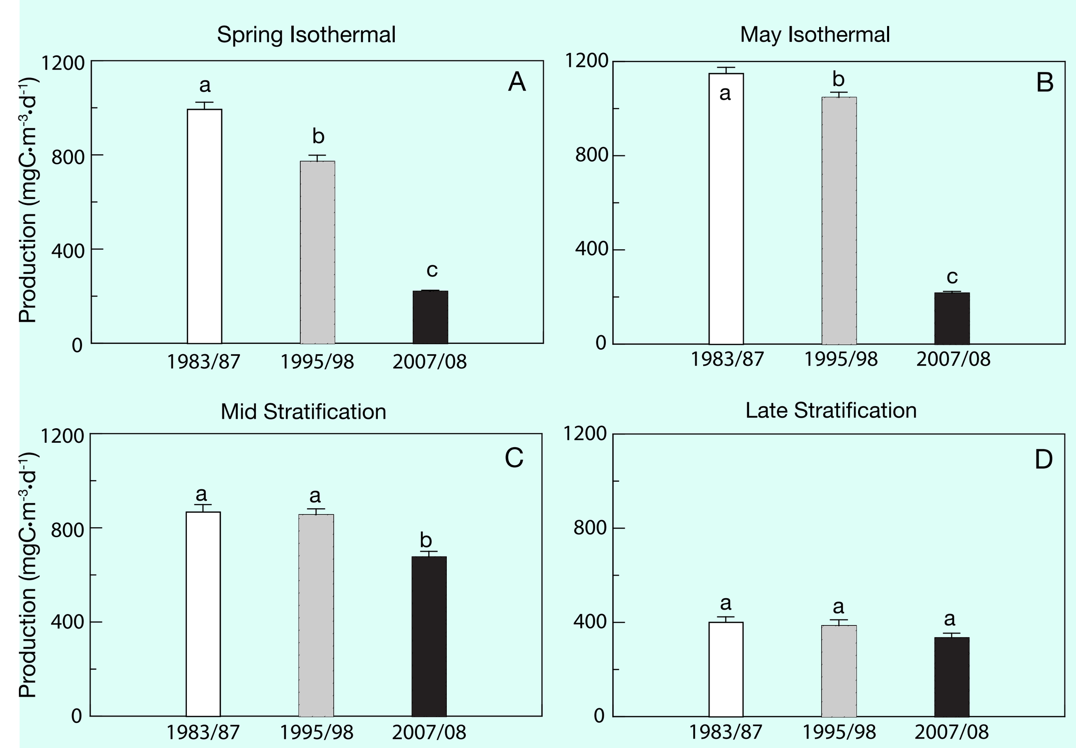

Figure 3. Mean estimates of daily areal integrated primary production (mg C·m-2·d-1) by decade in thermal periods, a) spring isothermal mixing, b) May isothermal mixing, c) mid stratification, d) late stratification. Data are means ± 1 standard error. Means with different letters (a,b,c) indicate significant difference (p<0.05).

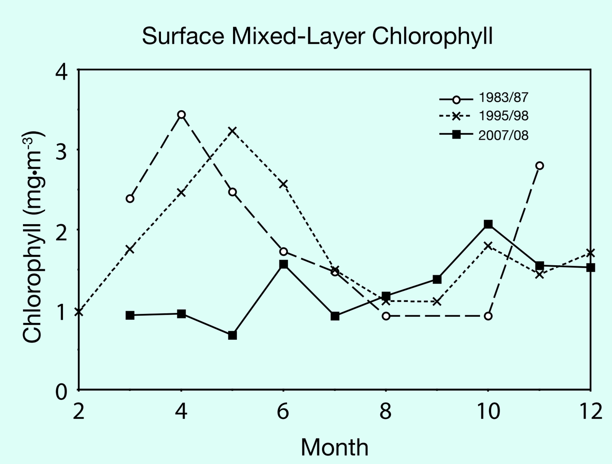

Figure 4. Mean surface mixed-layer chlorophyll concentrations (mg·m-3) for months in a) 1980s, b) 1990s, c) 2007/08.

In 2007/08, the seasonal trend in surface mixed-layer chlorophyll was significantly different from 1983/87 and the 1995/98 (Fig. 4). In 2007/08, chlorophyll concentrations from April and May were significantly less than those from in 1983/87 and 1995/98, and maximum concentrations were not found in April/May but rather in October (Fig. 4). By June, surface mixed-layer chlorophyll concentrations in 2007/08 were similar to those from in 1983/87 and 1995/98, and this pattern continued for the rest of the year (Fig. 4).

Surface mixed-layer chlorophyll concentrations varied significantly during the spring isothermal period (Fig 5a). Chlorophyll concentrations from 2007/08 were significantly lower than those from 1983/87 and 1995/98. Chlorophyll concentrations from 1995/98 were also significantly lower than 1983/87 values; however May isothermal chlorophyll concentrations were not significantly different in 1983/87 as compared to 1995/98 Fig. 5b). May isothermal concentrations from 2007/08 were significantly lower than both 1983/87 and 1995/98.

For the mid stratification and late stratification thermal periods, there were no significant differences in surface mixed-layer chlorophyll concentrations across decades (Figs 5c,d). For mid stratification, chlorophyll concentrations averaged 1.2, 1.3, and 1.1 mg·m-3 for 1983/87, 1995/98, and 2007/08, respectively. Similarly, for the late stratification period, chlorophyll concentrations averaged 1.4, 1.7 and 1.8 mg·m-3 for 1983/87, 1995/98, and 2007/08, respectively.

Phytoplankton

Phytoplankton biomass (mg C·m-3) trends were similar to chlorophyll. During the spring isothermal and May isothermal mixing periods, phytoplankton biomass in 2007/08 was significantly lower than biomass from 1983/87 and 1995/98 and no significant difference was noted between 1983/87 and 1995/98 (Fig. 6a). For the mid stratification and late stratification thermal periods no significant differences were noted across time periods (Fig. 6b,c).

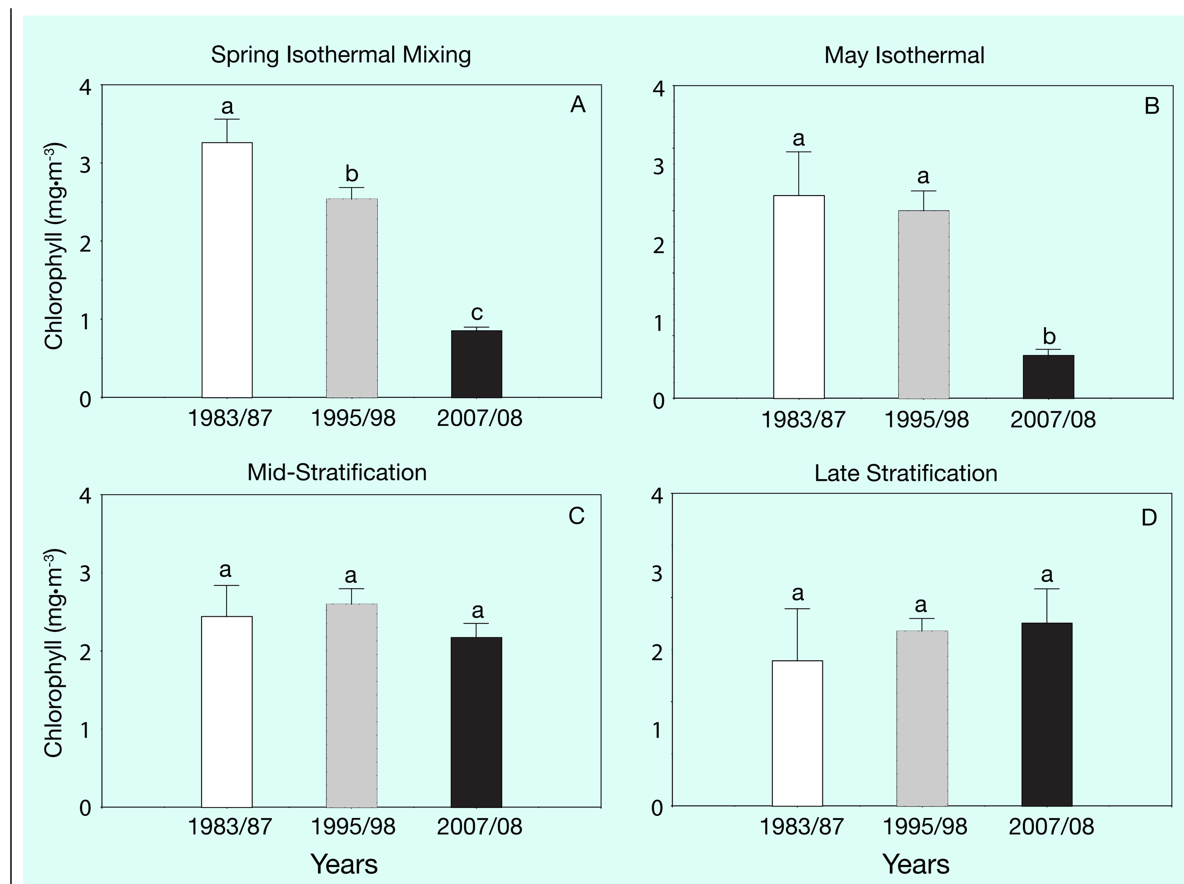

Figure 5. Mean surface mixed-layer chlorophyll concentrations (mg·m-3) by decade in thermal periods, a) spring isothermal mixing, b) May isothermal mixing, c) mid stratification, and d) late stratification. Data are means ± 1 standard error. Means with different letters (a,b,c) indicate significant difference (p<0.05).

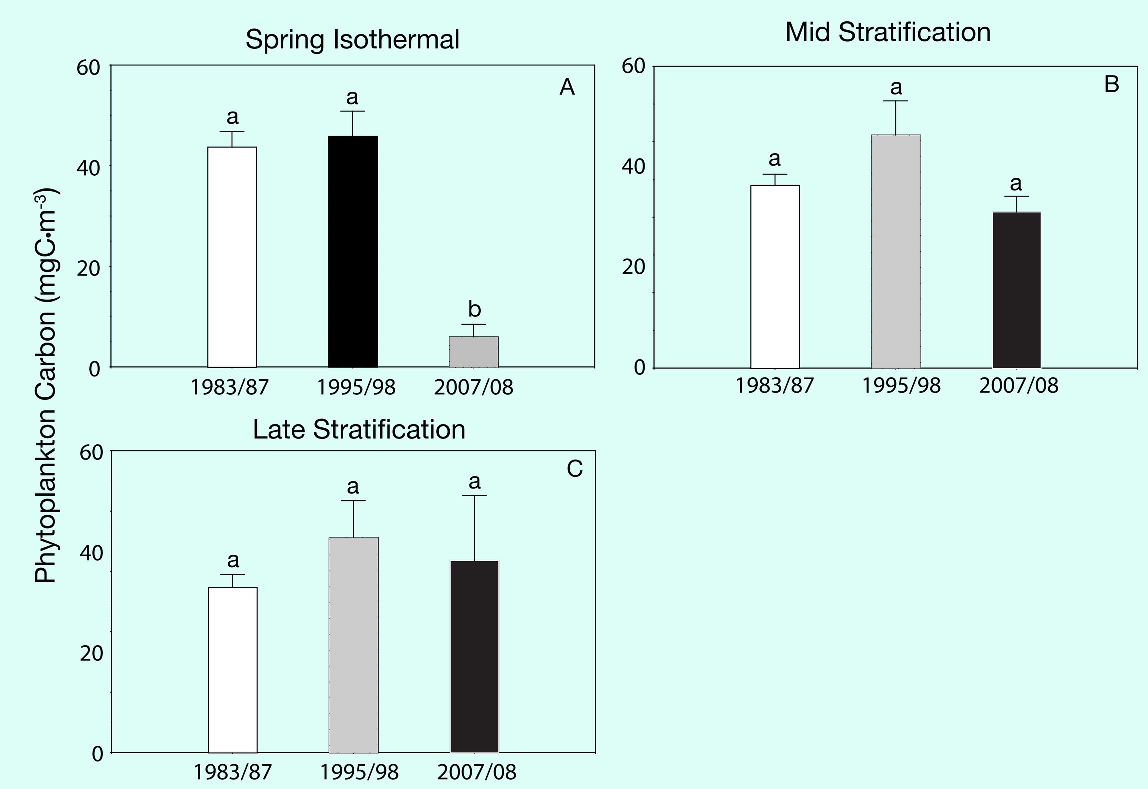

Figure 6. Mean surface mixed-layer phytoplankton carbon concentrations (mg·m-3) by decade in thermal periods, a) spring isothermal mixing, b) mid stratification, and c) late stratification. Data are means ± 1 standard error. Means with different letters (a,b,c) indicate significant difference (p<0.05).

DISCUSSION

1. The declines in primary production and phytoplankton abundance noted in this study are some of the more remarkable changes that have occurred in any offshore region of a Great Lake within a decade. These changes are remarkable not only for the magnitude and consistency of the changes in all measured parameters, but also for the seasonal isolation of these changes. These large changes were exclusively noted during the spring isothermal mixing period. During the spring isothermal mixing period, phytoplankton primary production, abundance and chlorophyll decreased approximately 70, 87, and 66%, respectively, from the 1995/98 to 2007/08. During the mid and late stratification periods, only one significant change was noted for phytoplankton primary production, abundance, and chlorophyll, and that change was much smaller (21%) than those noted during the spring isothermal mixing period.

2. The large changes noted in all measured parameters of this study are most likely due to the filtering impacts of dreissinid mussels, particularly the quagga mussels (*Dreissena rostriformis bugensis).* This conclusion is based on evidence from the following: 1) temporal coherence of documented changes and establishment of large populations of dreissinid mussels, 2) seasonal limitation of changes (spring isothermal mixing period only), and 3) calculated filtering effect of quagga mussels based on abundance and filtering rates.

Large populations of quagga mussel (*Dreissina rostriformis bugensis)* became established in Lake Michigan after 2000 (Nalepa et al. 2009). By 2005, quagga mussels populations had exploded nearshore, and their abundance was increasing offshore (stations >90 m). This increase in QM was noted in the vicinity of our sampling stations. Prior to the quagga mussel invasion, dreissinids were either not found in Lake Michigan (1983/87) or limited populations of the zebra mussel, Dreisseina polymorpha, were found in the nearshore region (depths <50m) of Lake Michigan (1994/95, Nalepa et al. 2009). Thus, the effects of dreissinid filtering would likely not have been noticed in the offshore region of Lake Michigan until after 2000, and most likely after 2005. This is consistent with the large changes we found in 2007/08 as compared to 1983/87 and 1995/98. Also, the filtering activities of dreissinids are only linked to phytoplankton in the surface waters when the water column is thoroughly mixed. There is only one time of the year when the offshore water column is completely mixed, and that is when water temperatures are < 4^{o}C, which roughly corresponds to January to mid/late May period (our spring isothermal mixing sampling period). Once the lake is thermally stratified, the surface-mixed layer is isolated from direct effects of mussel filtering. Thus, mussel filtering impacts would be expected to be found during this spring mixing period, and that is what was observed. Finally, calculated filtering effects are greater than the phytoplankton growth rates during this spring mixing period suggesting that quagga mussels can reduce/control phytoplankton abundance. At 2oC, quagga mussels can clear the entire water column in 2-5 days (H. Vanderploeg, unpubl. data). The community growth rates of phytoplankton during the spring isothermal mixing period is approximately 0.06 d-1, which corresponds to a doubling every 11 days (G. Fahnenstiel, unpubl. data).