TRENDS IN PHYSICAL AND CHEMICAL LIMNOLOGY; SEASONAL VARIATION IN ZOOPLANKTON COMMUNITIES OF OKANAGAN LAKE AND KALAMALKA LAKE - 1996 THROUGH 1998

by

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INTRODUCTION

Dramatically reduced numbers of kokanee (*Oncorhynchus nerka*) in Okanagan Lake during the last two decades has recently led to a multidisciplinary task group being formed to address the problem. Known as the Okanagan lake Action Plan (OLAP), Ashley and Shepherd (1996, MS) described the background rationale and formation of the working group and Ashley et al. (1998, MS) have reported on the preliminary findings.

The main goal of the Okanagan Lake Action Plan (OLAP) is to "rebuild and maintain the biodiversity of kokanee stocks (and other indigenous fish species) in Okanagan Lake" (Ashley and Shepherd 1996, MS). A major strategy currently under development is that of *Mysis* harvesting; the purpose of this strategy is to reduce the population of *Mysis relicta* in order to decrease the competition with kokanee fry for their common food source, zooplankton (Ashley and Shepherd 1996, MS).

Currently there are no known methods of controlling *Mysis* populations (Northcote 1991) but basic measurements of life history parameters and research on pheromones and behavioural cues identified in Ashley et al. (1998, MS) may produce some practical solutions. To aid in this research, baseline limnological sampling began in 1996 and the once per year mysid sampling was expanded to a monthly sampling regimen. In 1996, Kalamalka Lake was also added to the sampling program for comparitive purposes, as it contains *Mysis* but has a relatively healthy kokanee population. The limnological sampling program has also been expanded to match the mysid sampling schedule.

Limnological data collected in these initial years will provide valuable baseline information for use in planning decisions, and be a major determinant of the direction of the OLAP.

METHODS

The OLAP limnological sampling stations (Table 1; see Map 2) both for *Mysis*, plankton and water chemistry correspond closely to those previously established on Okanagan and Kalamalka Lakes. As of April 1998, KA3 and OK2 were dropped from the mysid sampling program; KA1,OK2, OK4 and OK5 were dropped from the monthly limnological sampling (OK4 was sampled in August and November only, after April 1998).

Table 1. Names and depths of sampling sites.

Site Designation	Site Number	Site Name	Maximum Depth (m)
KA1	0500246	Kalamalka L. South End	80
KA2	0500847	Kalamalka L. Deep Basin	150
KA3	0500247	Kalamalka L. Opposite Rattlesnake Point	135
OK1	0500454	Okanagan L. South Prairie Creek	90
OK2	0500729	Okanagan L. South Squally Point	115
OK3	E223295	Okanagan Lake Opposite Rattlesnake Island	140
OK4	0500236	Okanagan Lake DNS Kelowna STP	90
OK5	0500456	Okanagan Lake UPS Kelowna STP	146
OK6	0500730	Okanagan Lake N. Ok. Centre	225
OK7	E206611	Okanagan Lake @ Vernon Outfall	90
OK8	0500239	Okanagan Lake Central Armstrong Arm	55

Physical Limnology

Vertical profiles of temperature and dissolved oxygen were obtained on a monthly basis at the stations on Okanagan Lake and Kalamalka Lake. A YSI Oxygen Meter was used to measure dissolved oxygen and temperature at 2m intervals from 0-20m, then at 4m intervals from 24-44m, inclusive. Secchi disk transparency was measured at each site.

Water Chemistry

At each site on a monthly basis, a Van Dorn water bottle was used to obtain discrete samples at 45m and 20m, and an integrated sample from 1-10m. These samples were placed in coolers with ice, and shipped to Environment Canada Laboratories, Pacific Environmental Science Centre (PESC), North Vancouver, BC where they were analyzed for major nutrients (nitrogen - ammonia, nitrite, nitrite+nitrate, total; phosphorus - total dissolved, total), and reactive silica. (Data on SEAM file, Penticton Fisheries Office.)

Phytoplankton

At each site on a monthly basis, a Van Dorn water bottle was used to obtain integrated samples at 1-10m depth.. Samples to be used for phytotaxonomy were preserved with Lugol's iodine solution. Selected samples were sent to Fraser Environmental Services, Surrey, BC where dominant species were identified to species and nondominant species to genus.

Samples to be used for chlorophyll a analysis were placed immediately in brown bottles, and placed in coolers with ice. In the Penticton lab, these samples were filtered (at least 500ml each) with the addition of a couple of drops of $MgCO_3$, sealed in plastic bottles with a small amount of silica gel, and shipped with the water samples in coolers with ice, to PESC for analysis.

Zooplankton

From August 1996 through May 1997, two 45m vertical hauls were taken at each site using a 0.5m diameter plankton net of mesh size of 153 µm. Starting in June 1997 and following recommendations of Thompson (1997, MS), this procedure was changed to three 45 m hauls taken at each site. One sample was taken at mid-lake, and the other two at approximately 500m to each side, east and west, in order to account for possible effects of Langmuir spirals. The samples were preserved in 70% ethanol; each sample was also back-filtered to eliminate dilution of the preservative.

In the lab, the samples were split using a two-chambered Folsom plankton wheel and counted in a square gridded dish using a dissecting microscope at 10X magnification. Cladocerans and copepods were identified to genus.

Mysids

Mysis samples were collected on a monthly basis, at night, around the period of the new moon. The mysid net used was 1m square, with mesh size 1000 µm at the top, 210 µm in the terminal cone and 438 µm in the bucket. From August to October 1996, inclusive, two vertical hauls were taken midlake at each sampling station to within two meters of the bottom, and an additional two vertical hauls were taken near shore (either east or west) at a depth of around 40 meters. This procedure was changed in November of 1996 to two replicate hauls midlake plus one vertical haul on each of the east and west shores at a depth of around 40 meters. A hydraulic winch was used for all hauls. The speed of the winch was approximately 1 m/3 sec. Samples were preserved with 100% denatured alcohol (85% ethanol, 15% methanol) and shipped to Dr. D. Lasenby at Trent University in Peterborough, Ontario for analysis.

This sampling regimen and the equipment used is modeled on the techniques developed for the Kootenay Lake fertilization experiment (see Ashley and Thompson 1993) and will allow comparison of results between these two large lake projects.

RESULTS AND DISCUSSION

Physical Limnology

Okanagan Lake and Kalamalka Lake reached maximum thermal stratification in late July/early August in each of the past three years, with surface temperatures of around 20 ° C (Fig. 1). The upper hypolimnion was around 20m in Okanagan Lake (Fig. 1 a-f) and slightly higher in Kalamalka Lake (Fig. 1g-i) at approximately 15m. Epilimnetic temperatures were highest in 1998, with surface temperatures >25 ° C (Fig. 1). Both lakes underwent mixing after late October (Fig. 2) and remained isothermal into April (Fig. 3).

In general, both Okanagan Lake and Kalamalka Lake exhibited the orthograde dissolved oxygen profiles typical of oligotrophic lakes in midsummer (Wetzel 1975), with dissolved oxygen concentrations lowest at the surface and highest in the hypolimnion (Fig. 4). The lower surface concentrations are probably a result of warmer temperatures, as the solubility of oxygen in water decreases with increasing temperature (Wetzel 1975). In contrast, Armstrong Arm (OK8) exhibited a clinograde profile typical of eutrophic lakes (Wetzel 1975), where the hypolimnetic dissolved oxygen concentrations were less than 1 $mg \cdot L^{-1}$ by mid-October (Fig. 5). Armstrong Arm is relatively shallow, with a maximum depth of 54m, and thus is greatly affected by the oxygen uptake during oxidation of organic matter which is particularly high at the sediment-water interface (Wetzel 1975).

Secchi disc transparencies in Okanagan Lake were generally lower at the north end sites (OK5-7) than at the south end sites (OK1-4), and lowest in Armstrong Arm (OK8) for all three years (Fig. 6). Water clarity in Kalamalka Lake (KA1-2) was higher than in Armstrong Arm, but secchi disc transparencies were lower than at the north end sites in Okanagan Lake (Fig. 6).

Differences in oxygen levels and water clarity between Armstrong Arm and the other sampling stations is indicative of differing levels of productivity. Armstrong Arm has been categorized as mesotrophic (or moderately productive), while Kalamalka Lake and the main basin of Okanagan Lake have been categorized as oligotrophic (or low in productivity) (Bryan 1990, MS). Indicators of trophic status include levels of the major nutrients (i.e. nitrogen and phosphorus), chlorophyll a concentrations, water clarity and hypolimnetic oxygen depletion (Wetzel 1975).

Water Chemistry

Total nitrogen concentrations in the main body of Okanagan Lake (OK1-4 and OK5-7) remained relatively stable at average concentrations of around 0.20 $\mathrm{mg \cdot L^{-1}}$ (Fig. 7). Kalamalka Lake (KA1-2) and Armstrong Arm (OK8) had higher nitrogen concentrations than the main body of Okanagan Lake, but also exhibited greater variability, ranging from around 0.3 $\mathrm{mg \cdot L^{-1}}$ to over 0.65 $\mathrm{mg \cdot L^{-1}}$ (Fig. 7).

Levels of ammonia and nitrite nitrogen were extremely low to undetectable over the three-year sampling period (Appendix 3).

Nitrate nitrogen showed strong seasonal variability (Fig. 8), with the highest levels present in spring when dissolved organic nitrogen is added to the lake through run-off. Epilimnetic concentrations dropped to undetectable levels at all stations by early summer (Fig. 8a) probably due to biological uptake. Both total nitrogen and spring nitrate nitrogen have shown a slight increase over the past 25 years in Okanagan Lake and Kalamalka Lake. However, these levels are still low relative to other oligotrophic lakes with comparable spring phosphorus levels (Jensen,1999, MS).

Concentrations of both total phosphorus (TP, Fig. 9) and total dissolved phosphorus (TDP, Fig. 10) displayed seasonal variability over the sampling period. Spring phosphorus levels were highest in Armstrong Arm (OK8, Fig. 9), a trend which has been consistent over the past 25 years (Jensen 1999, MS). Year-to year variation was also evident as phosphorus levels (both TP and TDP) were lower in 1998 than either 1997 or 1996 (Fig. 9 and Fig. 10). Such variation is not uncommon, as there is increased phosphorus loading from the watershed during years of higher run-off (Jensen 1999, MS).

Algae and aquatic macrophytes require both nitrogen (N) and phosphorus (P) for growth, and lake productivity is often limited by the relative availability of these nutrients (Wetzel 1975). An N:P ratio of ≤ 10 is indicative of nitrogen limitation, a ratio of ≥ 17 is indicative of phosphorus limitation and an N:P ratio between 10 and 17 is generally indicative of no limiting nutrients (Smith 1982). Ratios of N:P calculated for both Okanagan Lake and Kalamalka Lake in spring, summer and fall indicate phosphorus limitation in both lakes (Fig. 11). Only Armstrong Arm (OK8) appears to have no nutrient limitations for 1996 and 1997, but phosphorus limitation in 1998 (Fig. 11).

Although TN:TP ratios did not indicate nitrogen limitation, the fact that nitrate nitrogen (the biologically available form of nitrogen) drops to undetectable levels in the summer (Fig. 8) suggests that these lakes are most likely nitrogen-limited as well, at least for part of the year.

Concentrations of reactive silica showed little variation in the main body of Okanagan Lake (OK1-4 and OK5-7) ranging from around 5 $\mathrm{mg \cdot L^{-1}}$ to 7 $\mathrm{mg \cdot L^{-1}}$ (Fig. 12). In contrast, reactive silica in Kalamalka Lake (KA1-2) ranged from greater than 7.5 $\mathrm{mg \cdot L^{-1}}$

in the spring to less than 5 mg·L^{-1} in the summer (Fig. 12); levels in Armstrong Arm (OK8) tended to be higher than at the other sites (Fig. 12). Silica is critical for the growth of diatomaceous algae and can be another limiting factor in lake productivity (Wetzel 1975). However, the relatively high levels in both lakes indicate that silica limitation is unlikely.

Chlorophyll a levels were relatively stable throughout the 1996 and 1997 sampling periods, with the highest concentrations found in Armstrong Arm (OK8, Fig. 13). In 1998, however, levels fluctuated widely, with peaks occurring in March (8μg·L^{-1} at OK5-7) and August (13μg·L^{-1} at OK8); the lowest levels occurred in November in the southern part of Okanagan Lake (OK1-4) where concentrations were less than 0.4μg·L^{-1} (Fig. 13).

Zooplankton

Distribution and abundance

Over the three year sampling period, the average annual densities of zooplankton (cladocerans and copepods) ranged from a low of 1.19 individuals·L^{-1} in the main basin of Okanagan Lake (OK1-7) in 1998, to a high of 6.82 individuals·L^{-1} in Armstrong Arm (OK8) in 1997 (Table 4). Average annual densities were lowest in 1998 for both lakes (Table 4). With average annual densities <3 individuals·L^{-1} in both Kalamalka Lake and the main basin of Okanagan Lake, these lakes appear to be unproductive as compared to the Arrow Lakes with 7 individuals·L^{-1} in 1997 (Pieters et al. 1999) and Kootenay Lake with 19 individuals·L^{-1} in 1997 (Ashley et al. 1999).

Peak densities usually occurred in July in 1997 and 1998 (no samples available for July 1996) and ranged from a low of 7.75 individuals·L^{-1} in the main basin of Okanagan Lake (OK1-7) in 1998 to a high of 85.20 individuals·L^{-1} in Armstrong Arm (OK8) in 1997 (Table2).

Table 2. Average and peak densities of zooplankton in the main basin of Okanagan Lake (OK1-7), Armstrong Arm (OK8) and Kalamalka Lake (KA1-3) over the three-year sampling period.

	Okanagan Lake (OK1-7)			Armstrong Arm (OK8)			Kalamalka Lake (KA1-3)		
	Density		Peak	Density		Peak	Density		Peak
	Ave. (#/L)	Peak (#/L)	Month	Ave. (#/L)	Peak (#/L)	Month	Ave. (#/L)	Peak (#/L)	Month
1996*	2.77	15.63	Aug.	4.73	31.69	Aug.	2.16	12.73	Oct.
1997	2.43	23.09	July	6.82	85.20	July	2.16	19.07	July
1998	1.19	7.75	July	2.09	17.58	May	1.33	11.15	July

* samples from Aug. through Oct. (OK1-4, OK8 and KA1-2) and Aug. through Nov. (OK5-7) only

From August 1996 through November 1998, copepods (*Diaptomus, Cyclops* and *Epischura*) were the dominant zooplankters in both Okanagan Lake and Kalamalka Lake, at all stations and for all dates (Fig. 14a-c). Copepods constituted 97% (by number) of the zooplankton in the main basin of Okanagan Lake for all three years, ranged from 93% to 98% in Armstrong Arm and from 92% to 96% in Kalamalka Lake .

Except for the months of February, March and April when calanoid copepods (primarily *Diaptomus*) were more abundant, cyclopoid copepods (i.e. *Cyclops*) were the dominant zooplankter in both Okanagan Lake (Fig. 14a-b) and Kalamalka Lake (Fig. 14c). The switch in dominance between calanoids and cyclopoids may be a function of their changing food supply. Calanoids are herbivorous filter feeders while cyclopoids are carnivorous, preying on microcrustaceans, dipteran larvae and oligochaetes (Wetzel 1975). Some phytoplankton growth as measured by chlorophyll a concentrations wasevident from February-April (Fig. 13) while cladocerans were not present in the zooplankton during those months (Fig. 14a-c).

Trends in cladoceran (*Daphnia, Diaphanosoma* and *Bosmina*) abundance in the main body of Okanagan Lake (Fig. 15a) and in Armstrong Arm (Fig. 15b) mirrored overall zooplankton abundance in that densities were highest in 1997 and lowest in 1998. Cladoceran abundance in Kalamalka Lake in 1998 was only slightly less than in 1996 and 1997 (Fig. 15c). Cladocerans constituted only 3% (by number) of the zooplankton in the main body of Okanagan Lake (OK1-7) for all three years, ranged from 2- 7% in Armstrong Arm (OK8) and from 4-8% in Kalamalka Lake (KA1-3). Again, these values are low in comparison to the Arrow Lakes with 21% cladocerans in 1997 (Pieters et al, 1999) and with Kootenay Lake at an average of over 8% cladocerans over the past six years (Ashley et al. 1998).

Daphnia were detectable in the main basin of Okanagan Lake (OK1-7) from August to October of 1996 at densities of < 0.60 individuals·L^{-1}, from June to September in 1997 with a peak densitiy of 1.05 individuals·L^{-1} in August and from May to August in 1998 with densities of <0.30 individuals·L^{-1} (Fig. 15a). In Armstrong Arm (OK8) *Daphnia* were detectable from August to October of 1996 with a peak density of 0.66 individuals·L^{-1} in October, from June to December of 1997 with a peak density of 6.95 individuals·L^{-1} in December and from April to June and October to November in 1998 with a peak density of 0.66 individuals·L^{-1} in May (Fig. 15b). *Daphnia* were detectable in Kalamalka Lake (KA1-3) from August to October of 1996 at densities <0.15 individuals·L^{-1} , from June to September of 1997 with a peak density of 0.77 individuals·L^{-1} in July, and from May to July of 1998 with densities of <0.25 individuals·L^{-1} (Fig. 15c).

The cladoceran population in Okanagan Lake and Kalamalka Lake was mainly comprised of *Daphnia, Diaphanosoma* and *Bosmina.* Also occasionally present in the samples, but in numbers too low for enumeration purposes, was the cladoceran *Leptodora kindtii*;. A record was made if it was spotted during sample splitting (Appendix 2). It is interesting to note that although *Leptodora* was seen in mid-summer samples in 1996 and 1997, none were captured in the net hauls in 1998 (Appendix 3). As well, none were captured in the net hauls in Kalamalka Lake over the duration of the sampling period, although *Leptodora* were present in 1951 and 1971 as enumerated in the Okanagan Basin Agreement studies (1974).

Historical comparison

Historically, Okanagan Lake and Kalamalka Lake have been sampled on a regular basis for zooplankton, but only in early spring and late fall when cladoceran numbers are reduced or absent altogether (Fig. 14a-c). Occasionally samples were taken in late August or early September and these have been used for comparison. Based solely on % cladocerans, Okanagan Lake had the highest % (by number) cladocerans from 1978 through 1980 (Fig. 16). Interestingly, percentages from 1996 through 1998 were higher than percentages from 1971 and higher than percentages observed in the early 1990s (Fig. 16).

Based on actual densities, and again using only late August or early September samples for comparison, the 1998 zooplankton density in Okanagan Lake was the lowest on record for the data available (Fig. 17a). The highest densities occurred in the late 1970s (Fig. 17a). In Armstrong Arm (Fig. 17b) and Kalamalka Lake (Fig. 17c), the 1998 densities are also low, but densities in 1996 and 1997 are similar to those in 1979 and 1980. Actual densities of *Daphnia* were highly variable, ranging from a low of 0 individuals $\cdot L^{-1}$ in 1991 and 1992 to a high of 1.21 individuals $\cdot L^{-1}$ in 1980 (Table 3).

Table 3. Average density of *Daphnia* in Okanagan Lake from 1969 through 1998 (late August or early September samples only).

Daphnia Density (#/L)									
1969	1971	1979	1980	1991	1992	1993	1996	1997	1998
0.42	0.48	0.46	1.21	0	0	0.39	0.53	1.05	0.03

Overall, there does not appear to have been any dramatic change in zooplankton density over the past 27 years.

ACKNOWLEDGEMENTS

This project would not have been possible without funding from the British Columbia Conservation Foundation. Thanks to all those people at the Ministry of Environment, Penticton, for their support, and especially to Vic Jensen for his patience and invaluable advice concerning the chemical limnology. Thanks also to Lisa Thompson and the other knowledgeable people for their input regarding the zooplankton sampling methods and

analysis. And finally, my special thanks to Graham Young and Nick Ipatowicz for their invaluable assistance in the field under frequently adverse conditions.

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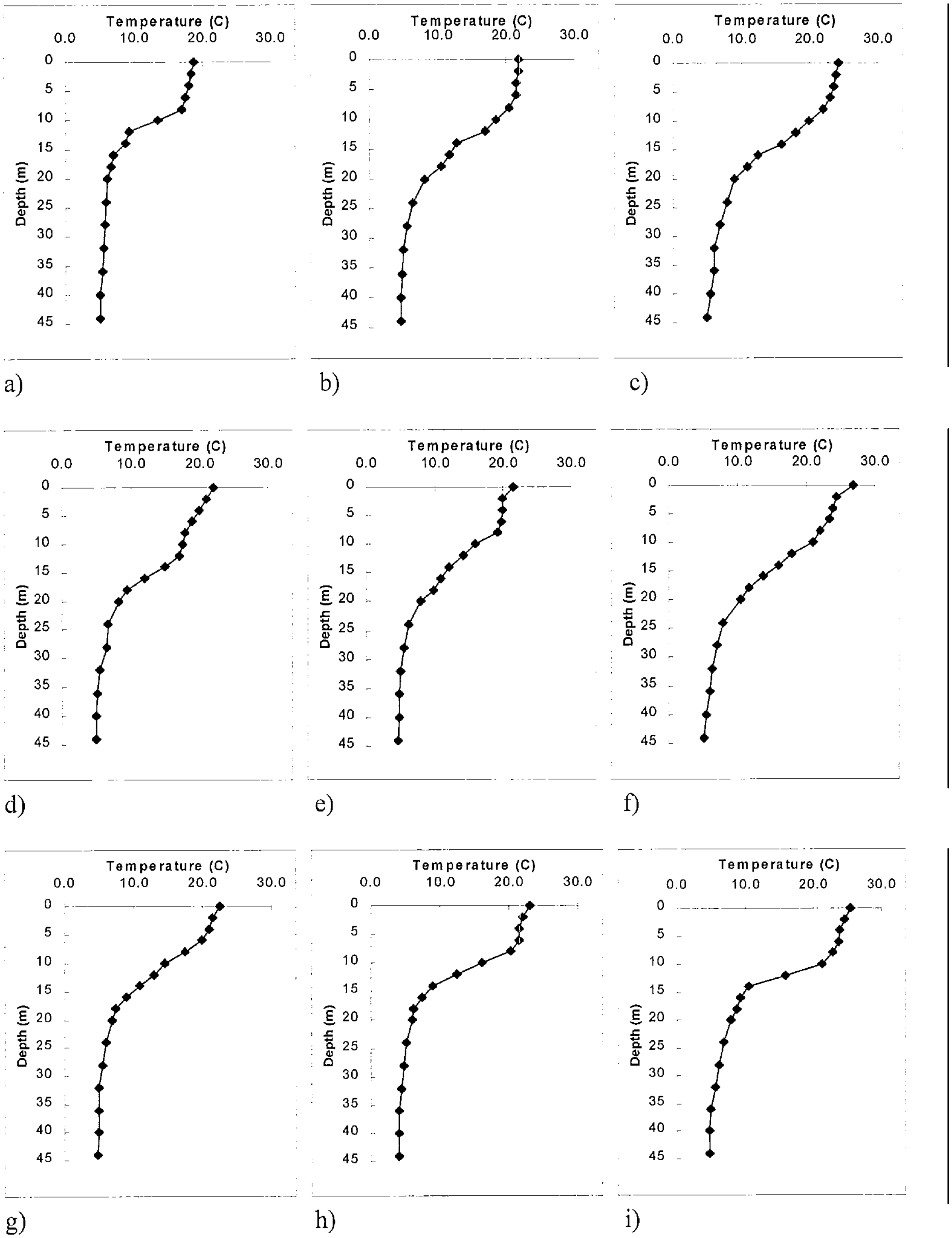


a) b) c)

d) e) f)

g) h) i)

Figure 1. Summer temperature profiles at OK3 in a)1996, b)1997 and c)1998; at OK6 in d)1996, e.1997 and f)1998; and at KA2 in g)1996, h)1997 and i)1998.

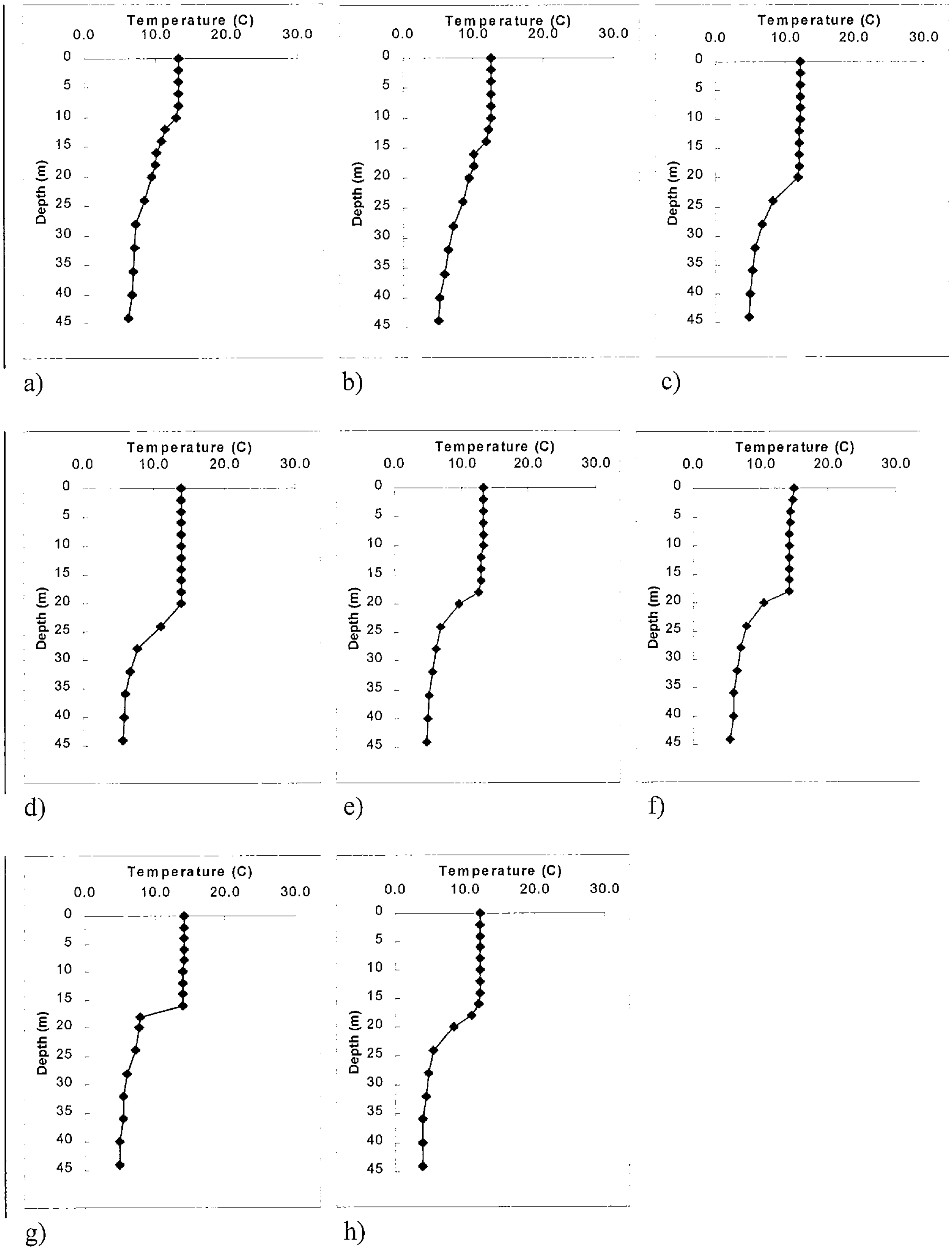


Figure 2. Fall temperature profiles at OK3 in a)1996, b)1997 and c)1998; at OK6 in d)1996, e)1997 and f)1998; and at KA2 in g)1996 and h)1997.

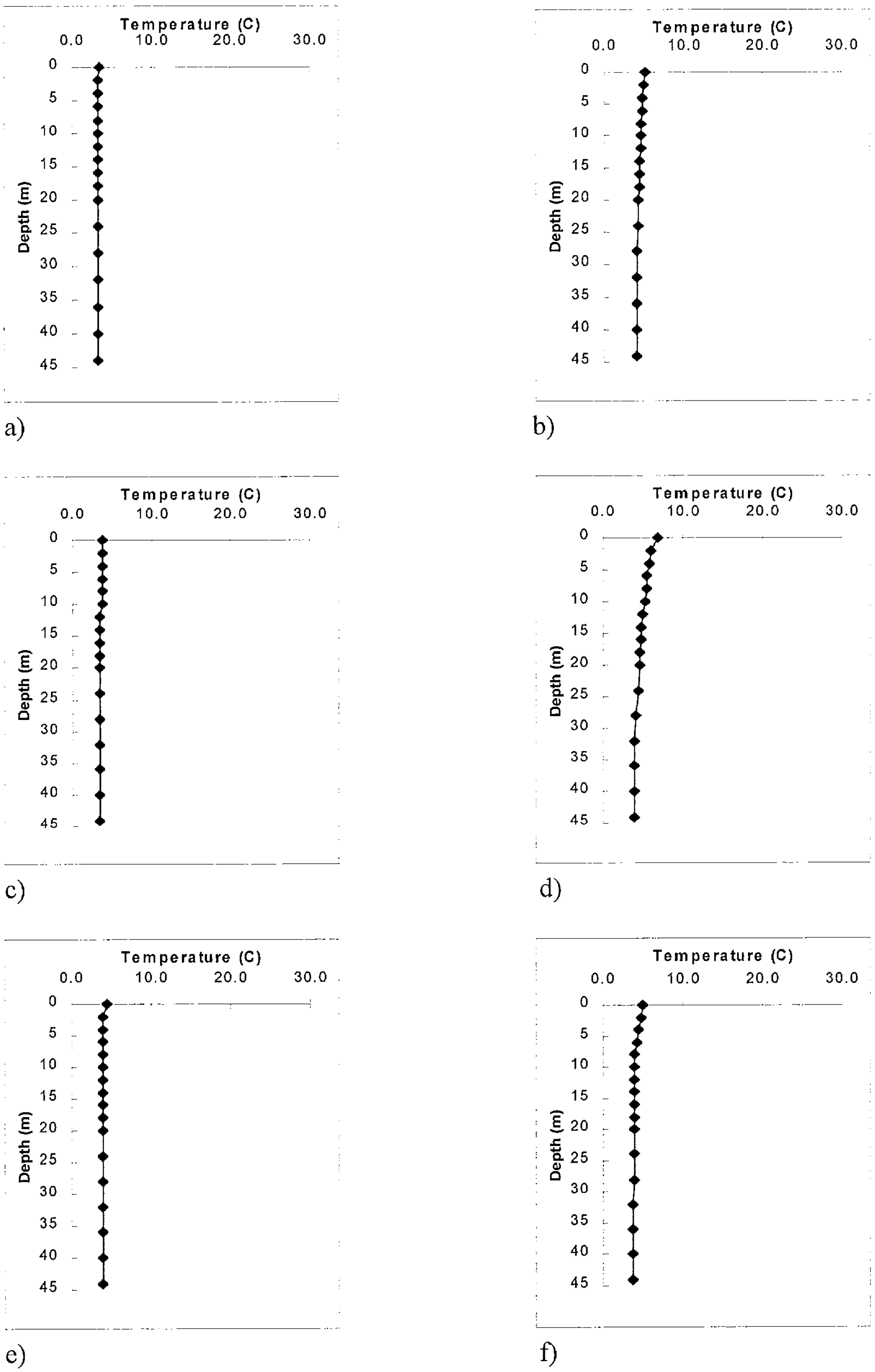


Figure 3. Spring temperature profiles at OK3 in a)1997 and b)1998; at OK6 in c)1997 and d)1998; and at KA2 in e)1997 and f)1998.

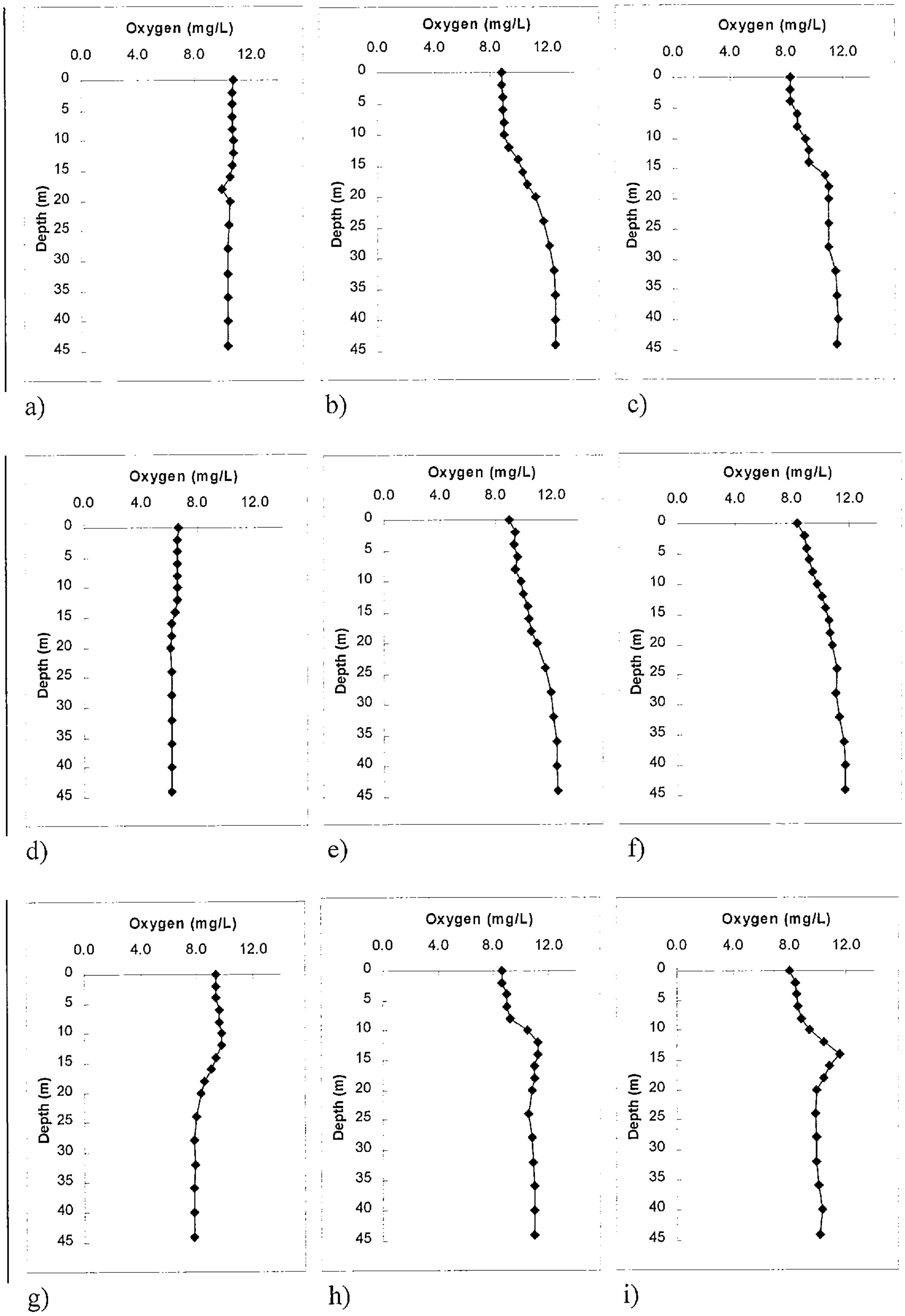
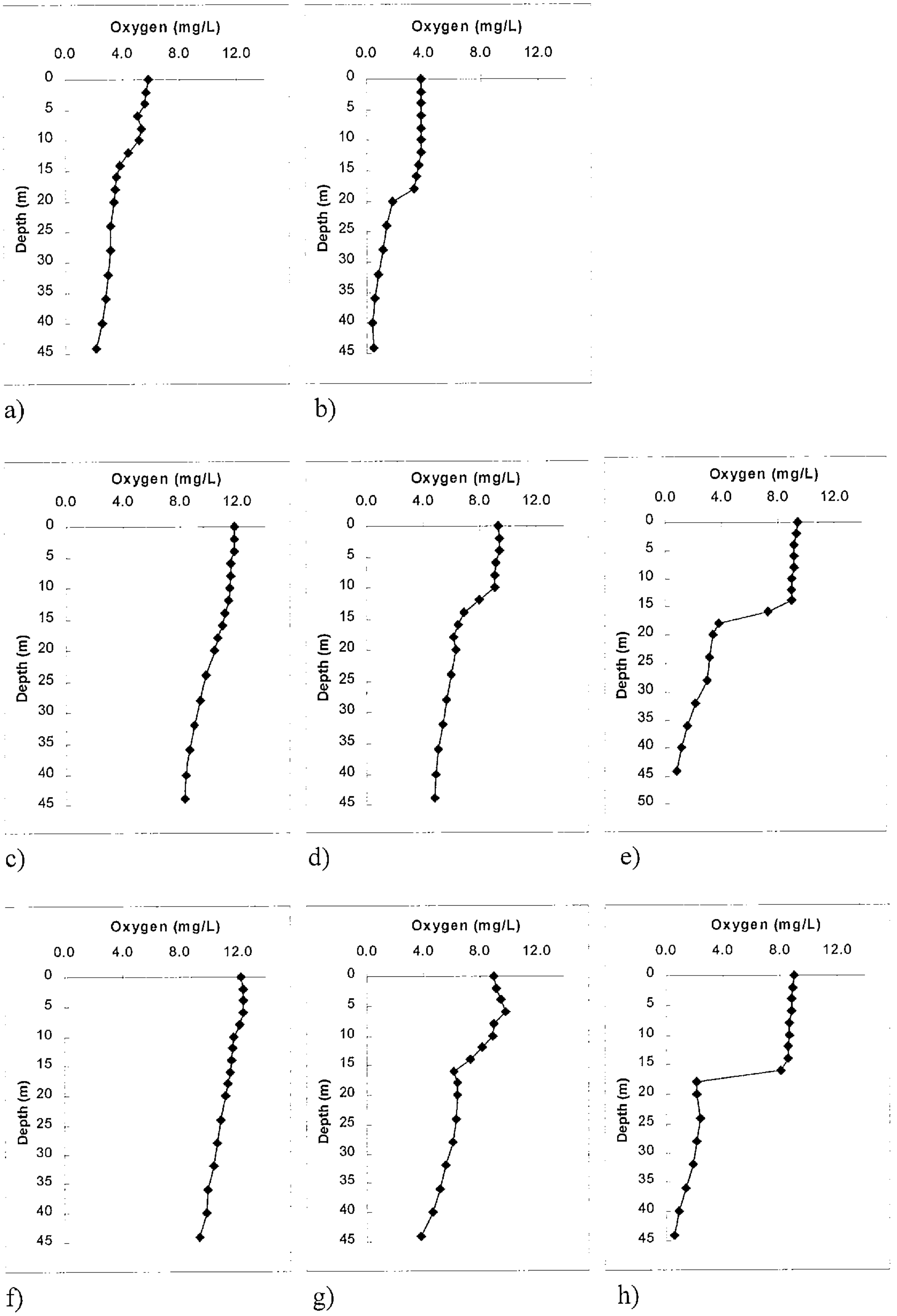


Figure 4. Summer oxygen profiles at OK3 in a)1996, b)1997 and c)1998; at OK6 in d)1996, e)1997 and f)1998 and at KA2 in g)1996, h)1997 and i)1998.



a)
b)
c)
d)
e)
f)
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Figure 5. Oxygen profiles at OK8 in a)July 1996, b)October 1996, c)April 1997 d)August 1997, e)October 1997, f)April 1998, g)July 1998 and h)October 1998.

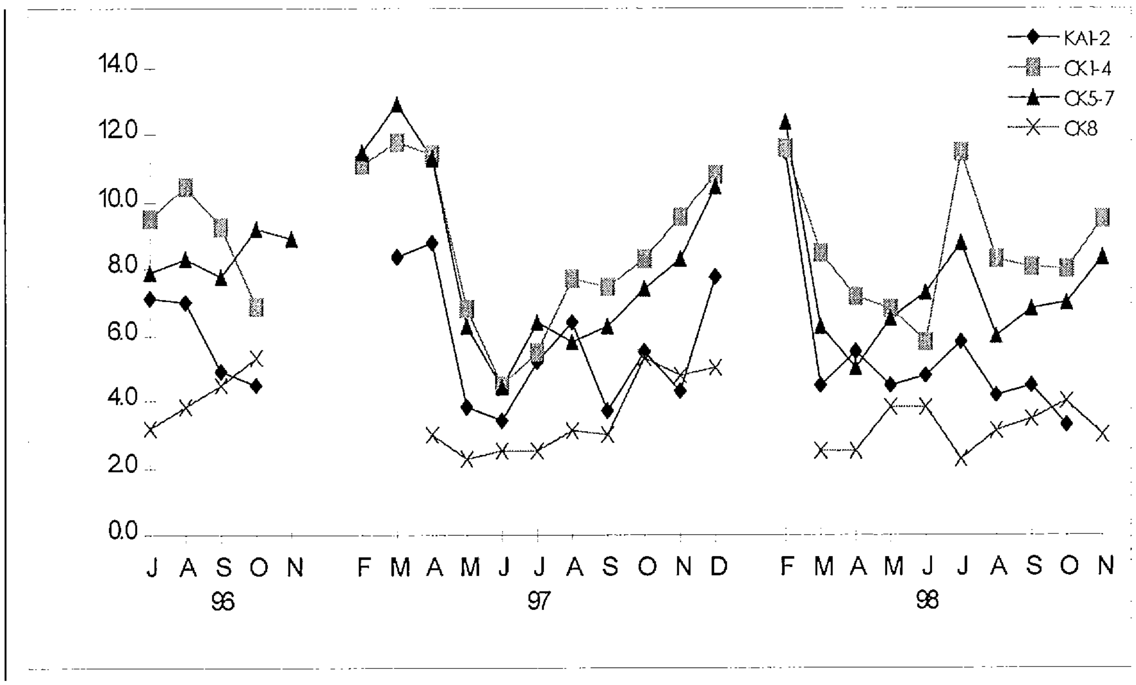


Figure 6. Secchi disk transparencies in Okanagan Lake at the south end sites (OK1-4), the north end sites (OK5-7), in Armstrong Arm (OK8) and in Kalamalka Lake (KA1-2).

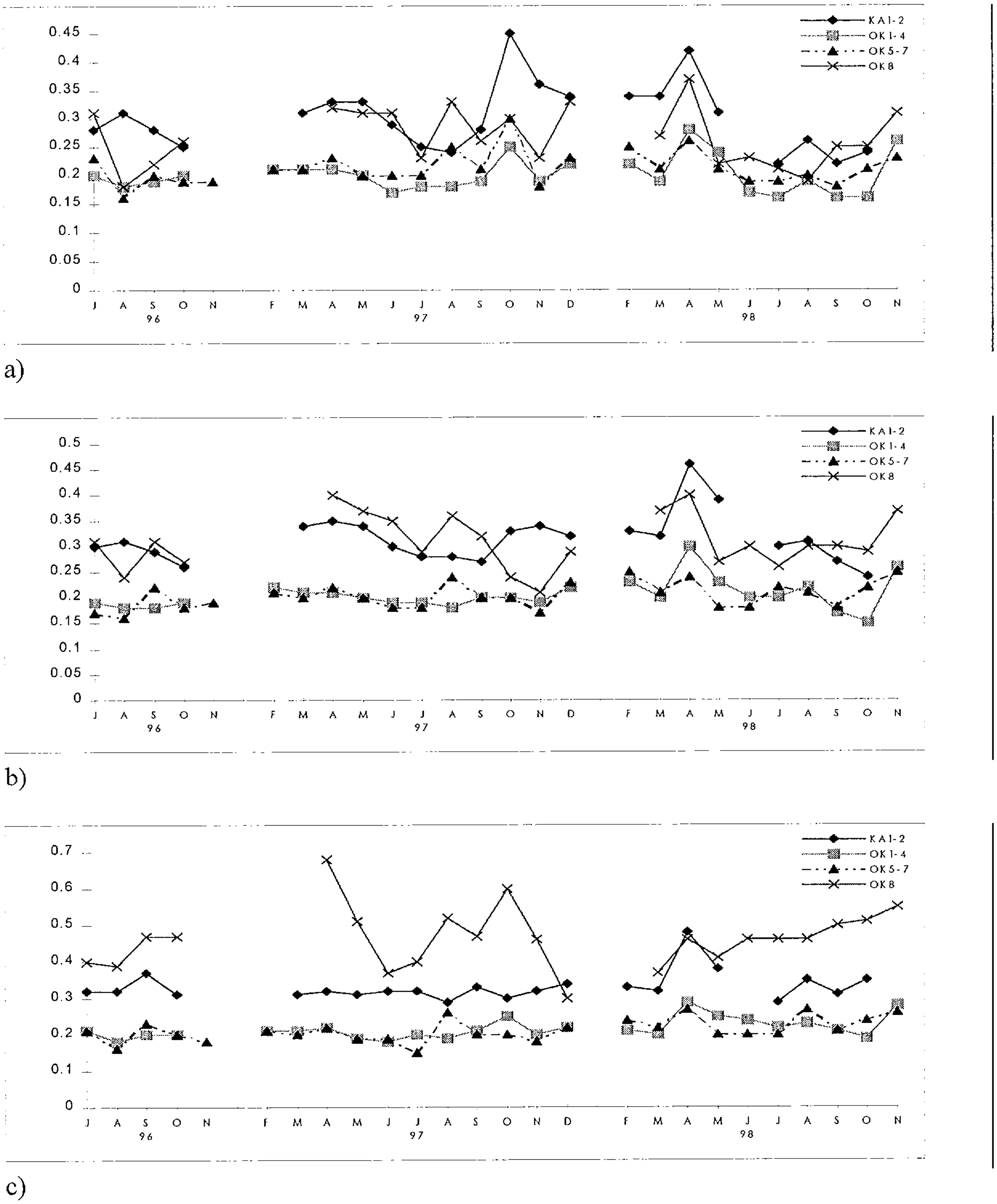


Figure 7. Concentrations of total nitrogen (TN) in Okanagan Lake at the south end sites (OK1-4), the north end sites (OK5-7), Armstrong Arm (OK8) and in Kalamalka Lake (KA1-2) in a) 1-10m, at b) 20m and at c) 45m.

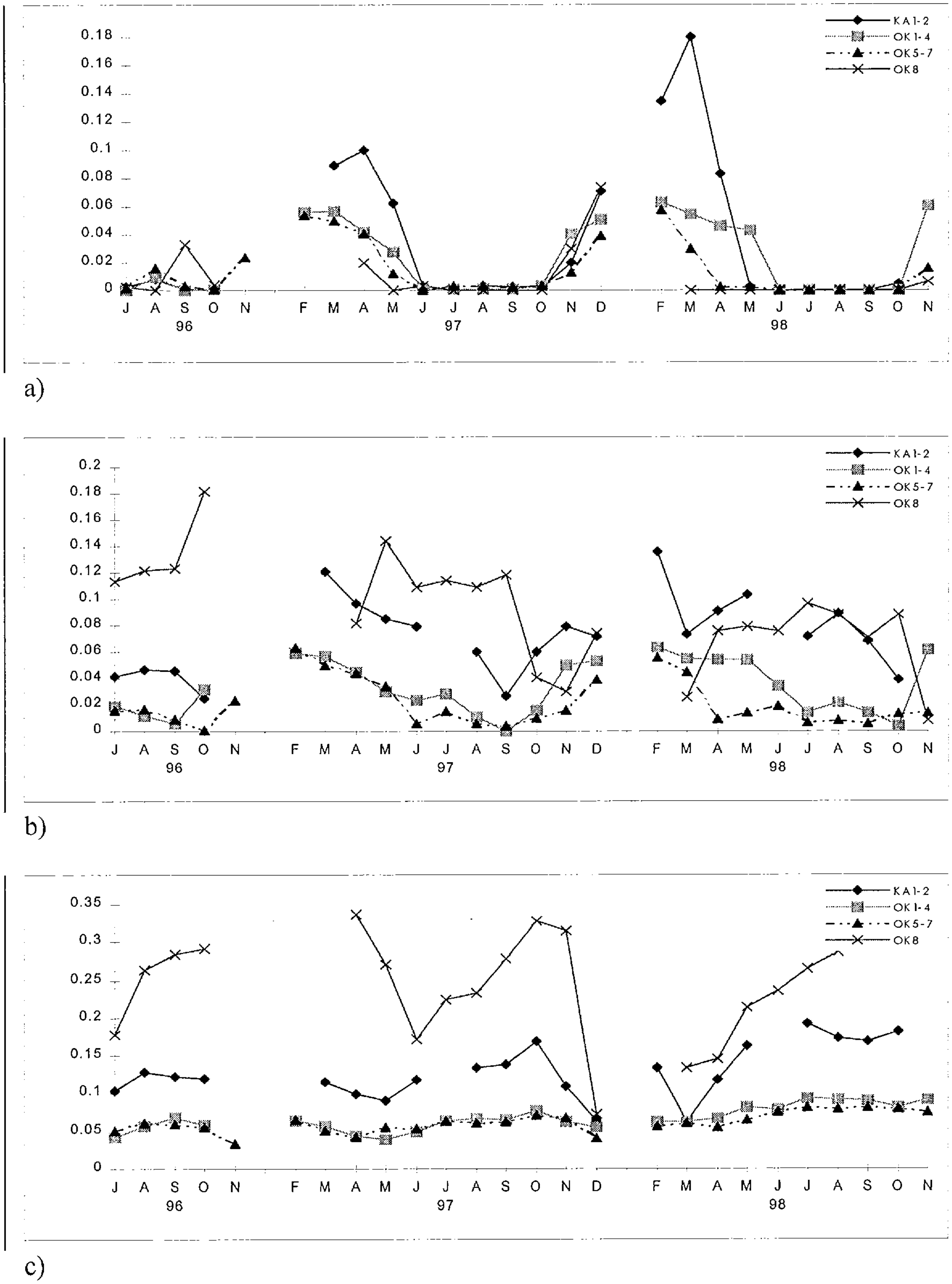


Figure 8. Concentrations of nitrite+nitrate nitrogen (NO2-3) in Okanagan Lake at the south end sites (OK1-4), the north end sites (OK5-7), Armstrong Arm (OK8) and in Kalamalka Lake (KA1-2) in a) 1-10m, at b) 20m and at c) 45m.

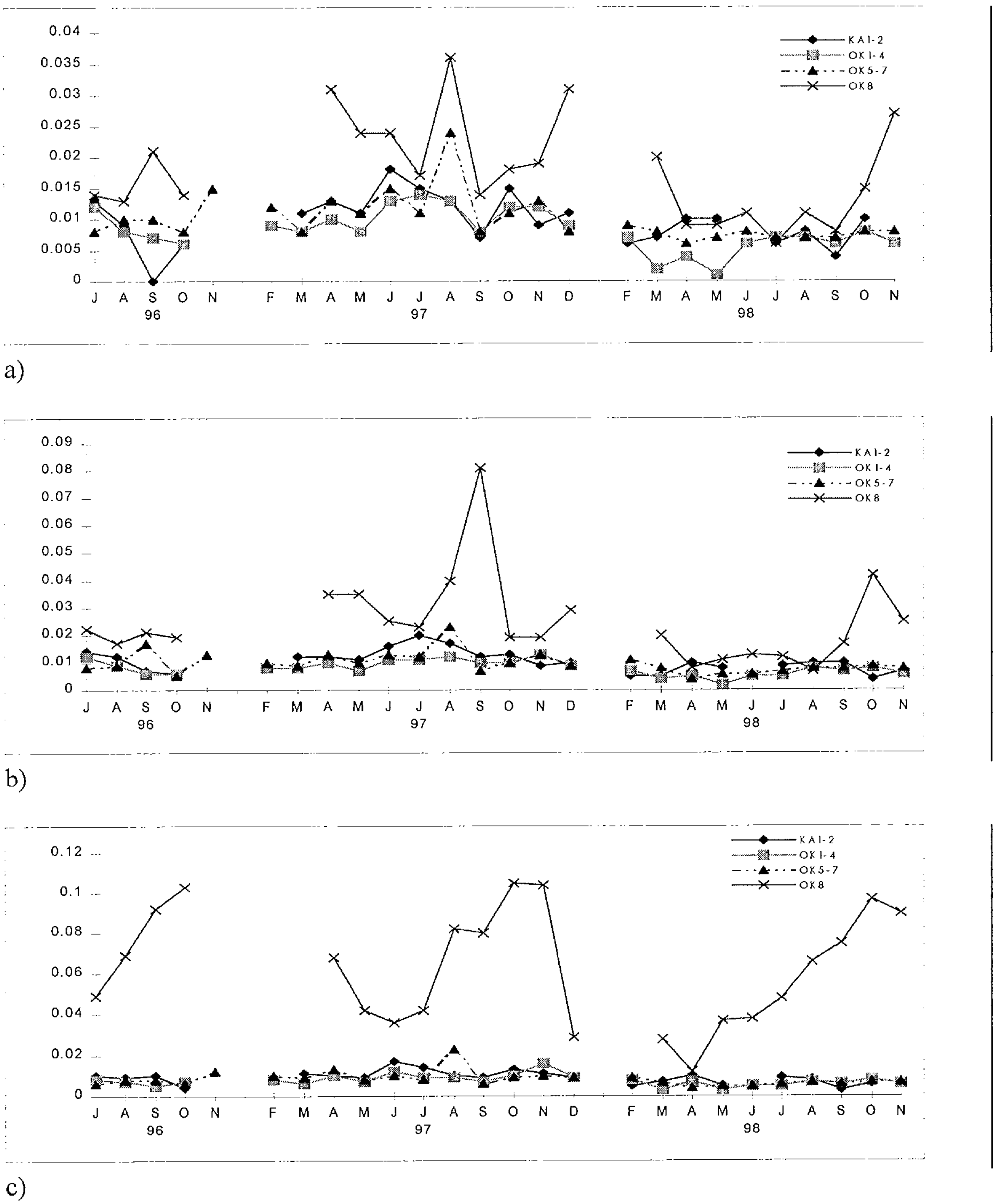


Figure 9. Concentrations of total phosphorus (TP) in Okanagan Lake at the south end sites (OK1-4), the north end sites (OK5-7), Armstrong Arm (OK8) and in Kalamalka Lake (KA1-2) in a) 1- 10m, at b) 20m and at c) 45m.

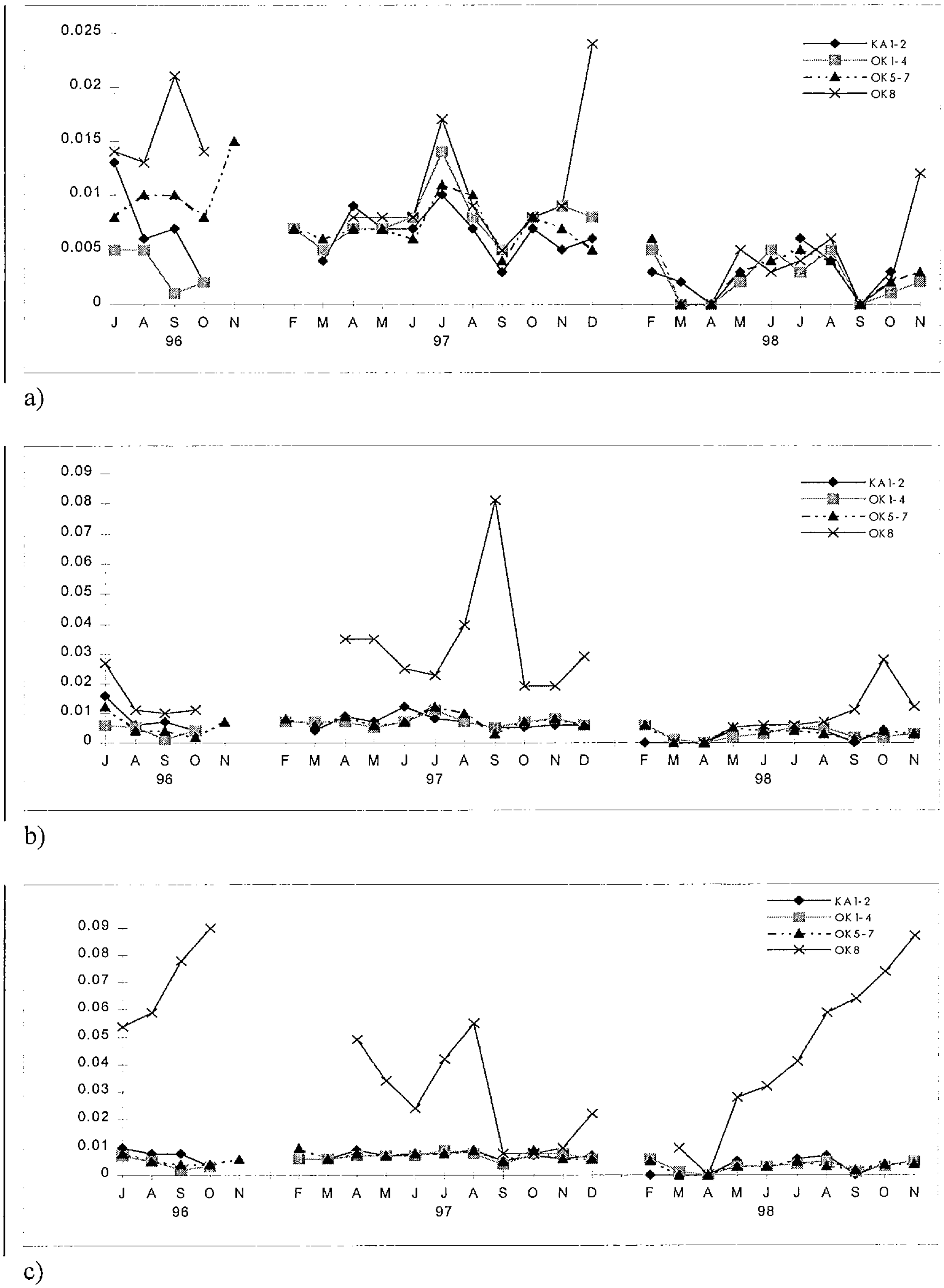


Figure 10. Concentrations of total dissolved phosphorus (TDP) in Okanagan Lake at the south end sites (OK1-4), the north end sites (OK5-7), Armstrong Arm (OK8) and in Kalamalka Lake (KA1-2) in a) 1- 10m, at b) 20m and at c) 45m.

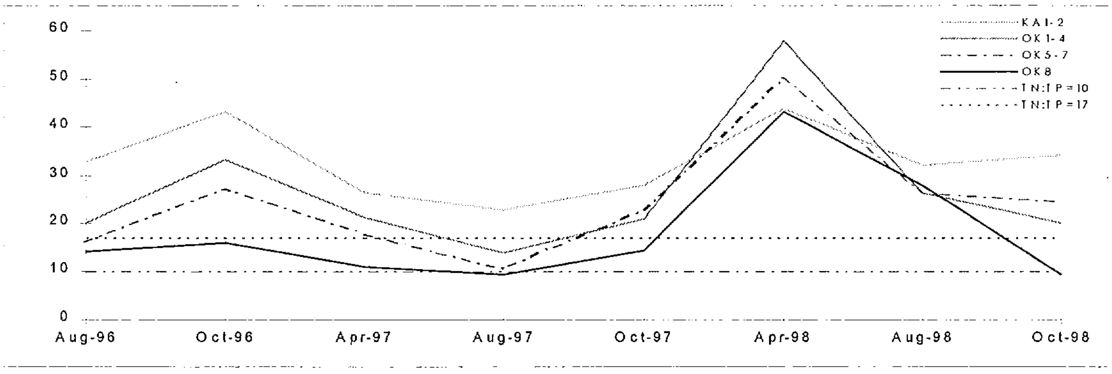


Figure 11. Ratios of total nitrogen to total phosphorus (TN:TP) on selected dates in Okanagan Lake at the south end sites (OK1-4), at the north end sites (OK5-7), Armstrong Arm (OK8) and in Kalamalka Lake (KA1-2). Ratios greater than 17 indicate phosphorus limitation; ratios less than 10 indicate nitrogen limitation (Smith 1982).

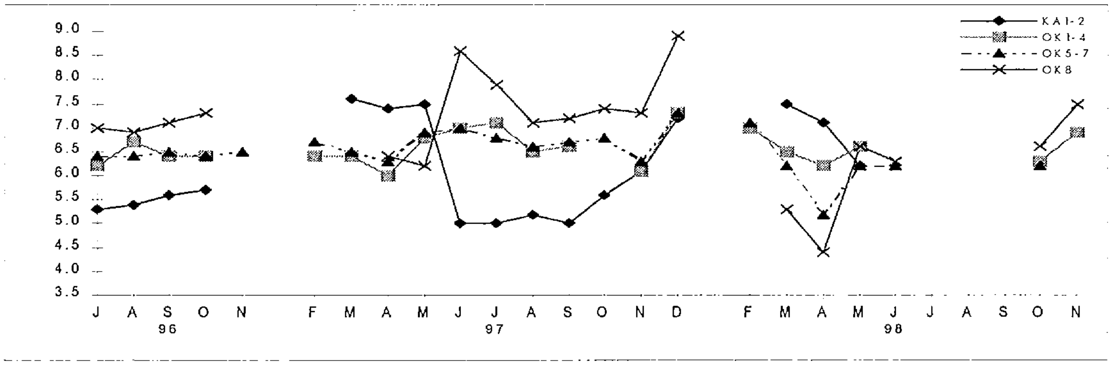


Figure 12. Concentrations of reactive silica in Okanagan Lake at the south end sites (OK1-4), the north end sites (OK5-7), Armstrong Arm (OK8) and in Kalamalka Lake (KA1-2).

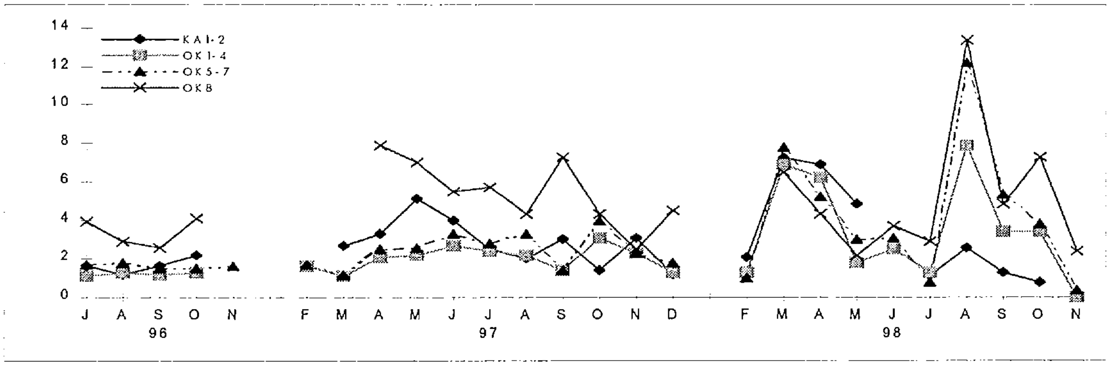


Figure 13. Chlorophyll a concentrations in Okanagan Lake at the south end sites (OK1-4), the north end sites (OK5-7), Armstrong Arm (OK8) and in Kalamalka Lake (KA1-2).

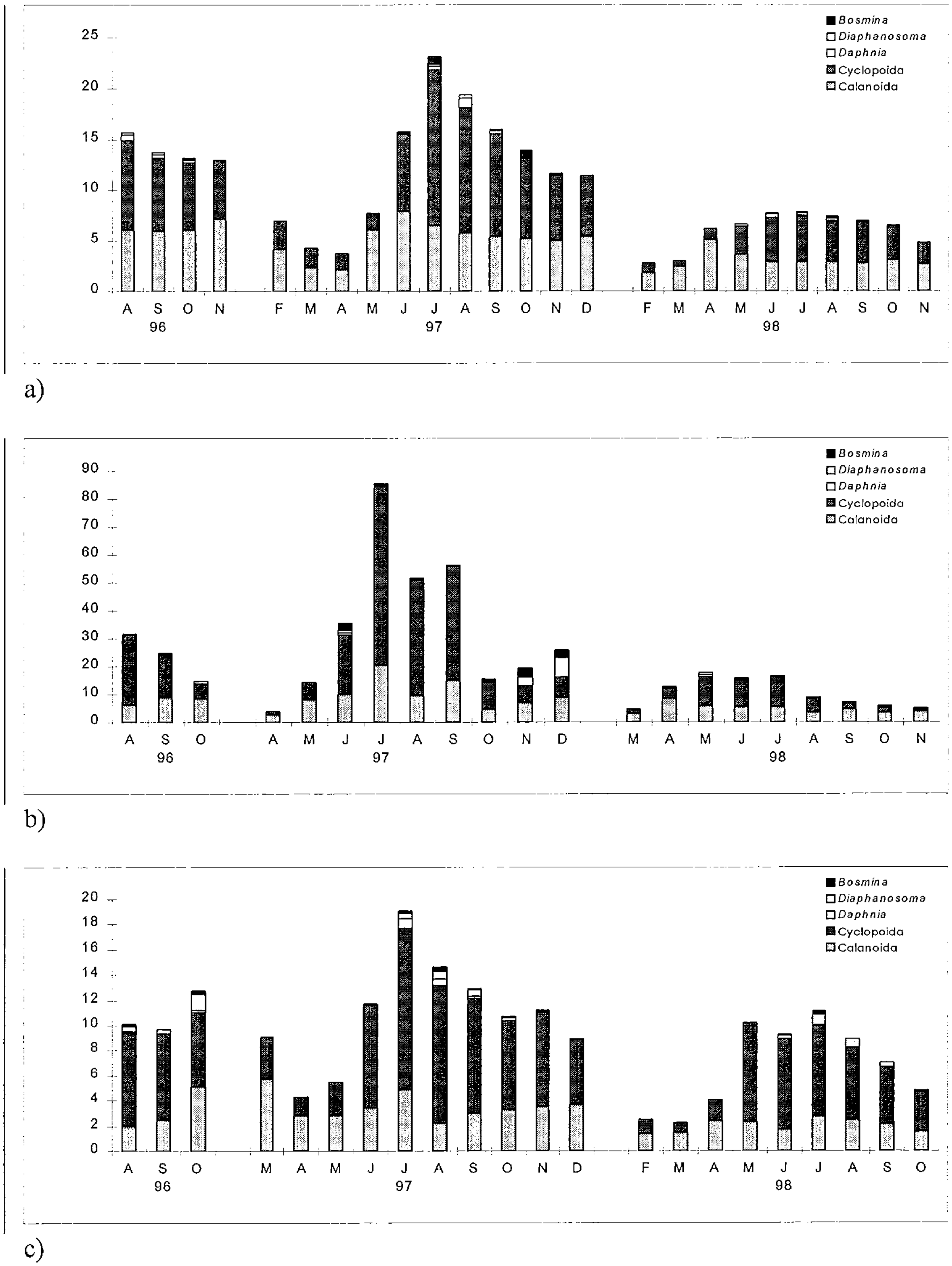
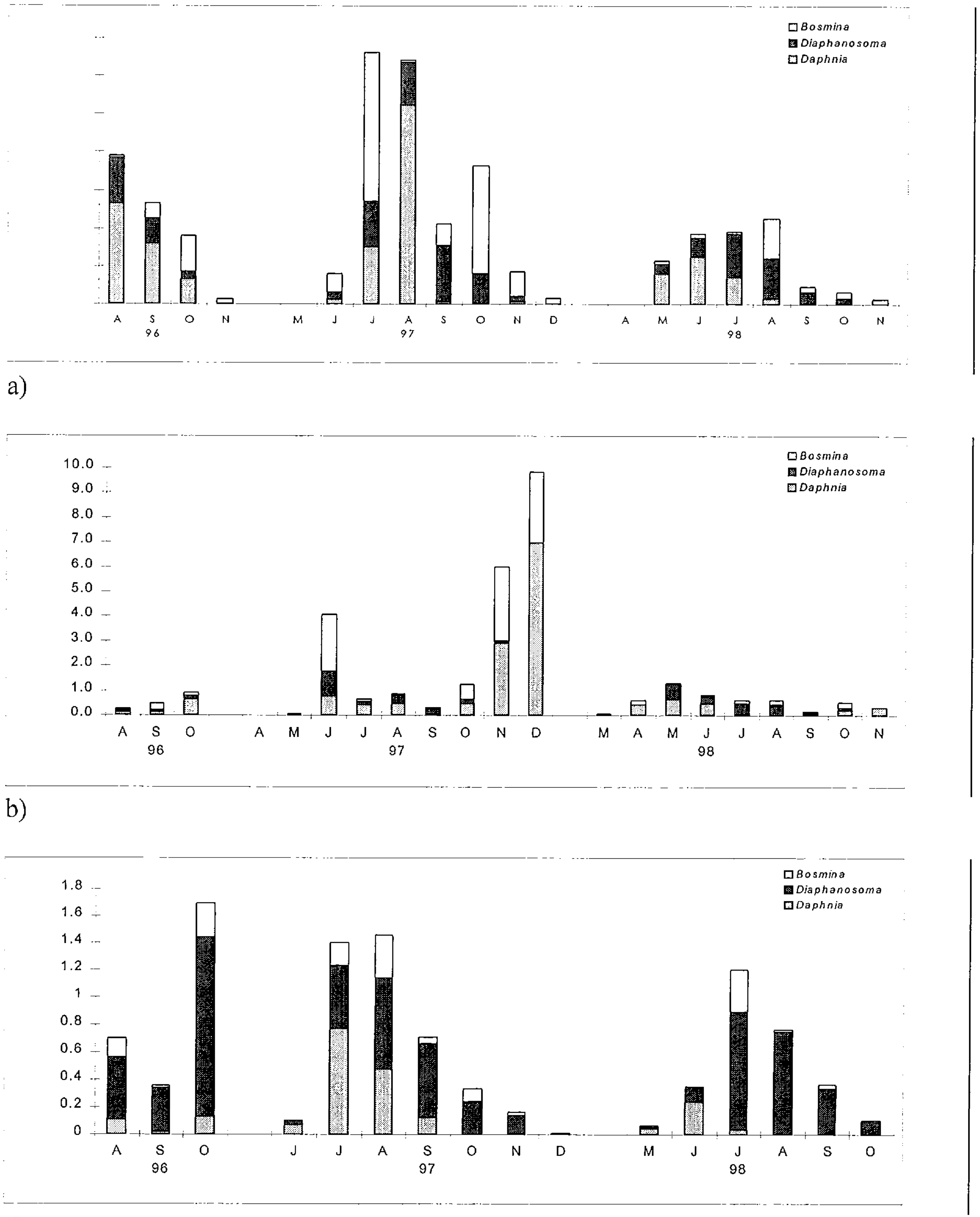


Figure 14. Zooplankton density (1996-1998) for a) Okanagan Lake (OK1-7), b) Armstrong Arm (OK8) and c) Kalamalka Lake (KA1-3).



a)

b)

c)

Figure 15. Cladoceran density for a) Okanagan Lake (OK1-7), b) Armstrong Arm (OK8) and c) Kalamalka Lake (KA1-3).

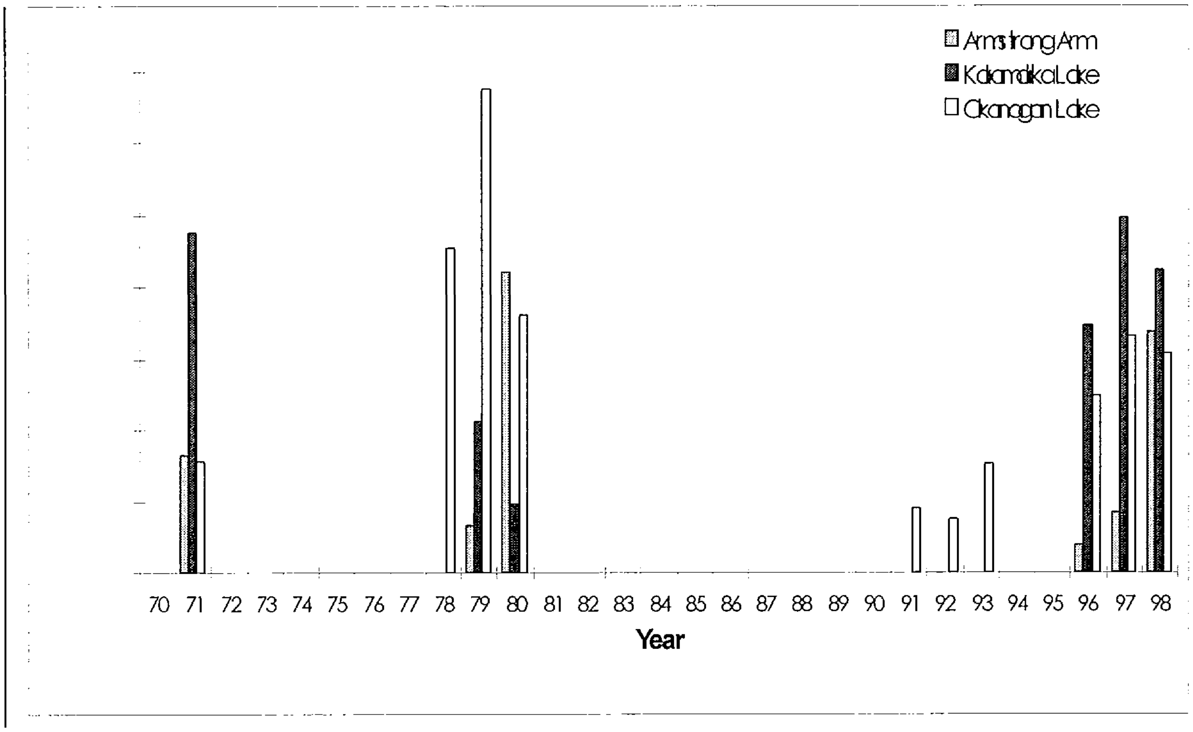


Figure 16. Percentage of cladocerans present in Okanagan Lake, Armstrong Arm and Kalamalka Lake from 1971 through 1998. 1971 values are from Patalas and Salki (1973); 1978 values are from Truscott and Kelso (1979); all other values from routine monitoring by B.C. Environment or under OLAP program (data on file Penticton Fisheries office).

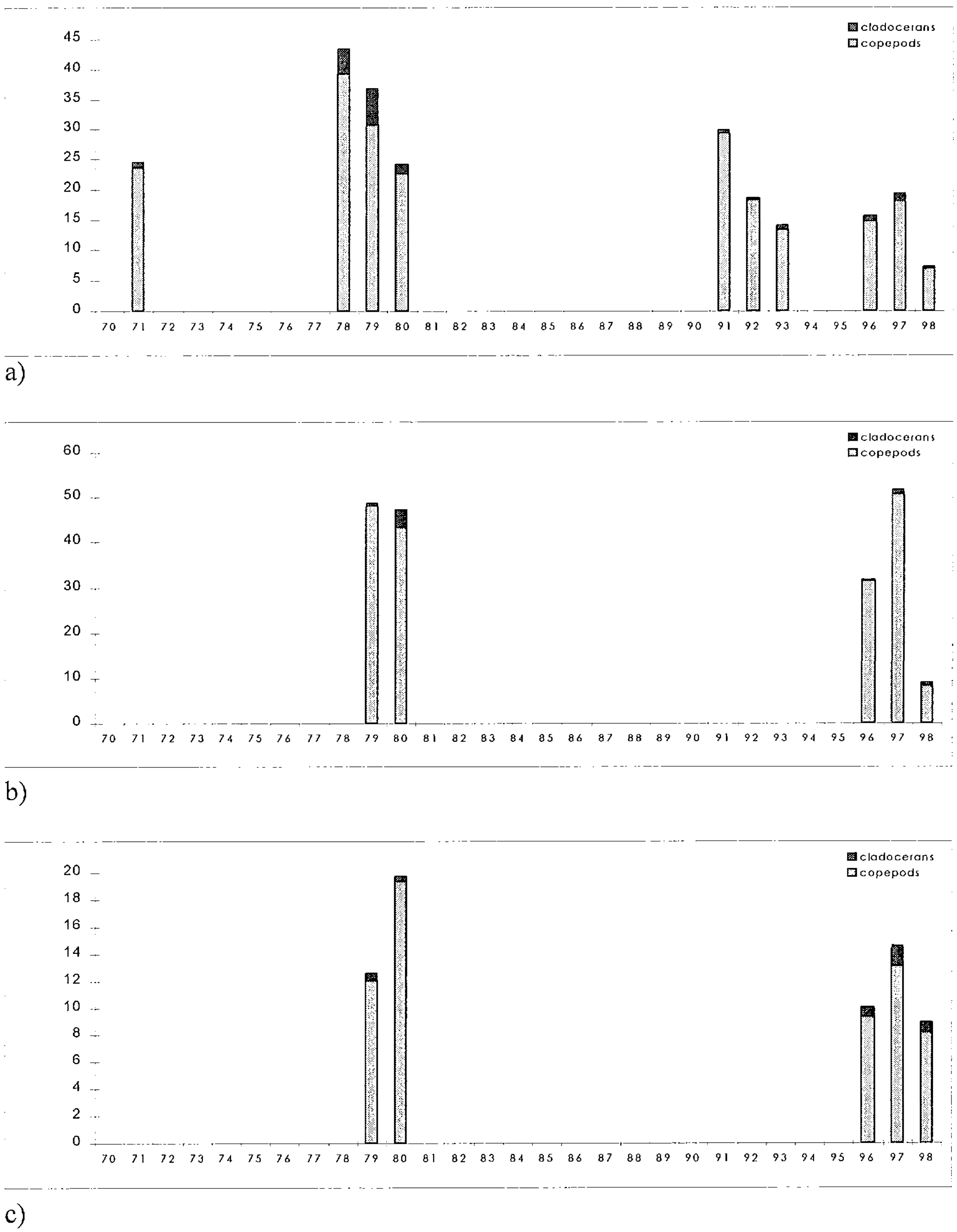


Figure 17. Densities of cladocerans and copepods for a) Okanagan Lake, b) Armstrong Arm and c) Kalamalka Lake. 1978 values from Truscott and Kelso (1979); all other values from routine monitoring by B.C. Environment or under OLAP program.

Appendix 1.

Langmuir circulation

To assess the requirement for taking three separate zooplankton hauls as suggested by Thompson (1998, MS), a crude analysis was undertaken to determine whether differences existed among hauls taken at the center versus those taken 500m to the east and west sides. For each date and site in 1997 and 1998, a note was made as to which site had the highest number of organisms, whether east, center or west (Table 1). Totals for each station were calculated for each lake (Table 2). For example, of the nine dates on which KA1 was sampled in 1997, zooplankton densities were highest on four of those dates on the west side, on two of those dates in the center and on three of those dates on the east side (Table 2).

Table 1. Zooplankton haul with highest number of organisms, whether west (W), center (C) or east (E), on each sampling date.

	KA1	KA2	KA3	OK1	OK2	OK3	OK4	OK5	OK6	OK7	OK8
1997											
April	E	C	-	C	W	W	C	C	C	E	W
May	E	E	-	W	W	W	C	C	W	C	E
June	C	W	-	C	E	C	W	C	C	C	E
July	W	C	-	E	W	E	C	W	W	C	W
August	W	C	C	E	-	E	W	W	E	W	E
September	W	W	E	C	C	W	E	W	C	C	W
October	E	W	-	-	-	W	E	E	C	C	E
November	C	E	C	W	E	C	C	E	C	C	W
December	W	C	W	-	C	W	C	W	E	C	C
	KA1	KA2	KA3	OK1	OK2	OK3	OK4	OK5	OK6	OK7	OK8
1998											
Feb. 2-9	-	-	-	W	C	E	W	W	W	E	-
Feb. 23-Mar.12	C	E	C	W	C	C	W	C	C	E	-
Mar. 23-Apr. 4	W	W	W	W	W	E	W	W	E	W	W
Apr. 20-28	W	W	-	E	-	W	-	-	E	W	E
May 26-June 10	-	E	-	E	-	W	-	-	W	W	E
June 17-July 6	-	E	-	C	-	W	-	-	E	W	E
July 28-30	-	W	-	W	-	F	-	-	E	C	E
Aug. 23-26	-	C	-	E	-	C	E	-	E	W	W
Sept. 24-Oct. 6	-	C	-	C	-	W	-	-	W	W	E
Oct. 20-27	-	W	-	E	-	C	-	-	C	E	E
Nov. 30-Dec.8	-	-	-	E	-	-	EW (tie)	-	W	W	E

Table 2. Total number of dates for which zooplankton densities were highest in the west (W), center (C) or east (E) hauls.

	1997			1998		
	W	C	E	W	C	E
KA1	4	2	3	2	1	0
KA2	3	4	2	4	3	3
KA3	1	2	1	1	1	0
Total	8	8	6	7	4	3
OK1	2	3	4	4	2	5
OK2	3	2	2	1	2	0
OK3	5	2	2	4	3	3
OK4	2	5	2	3	0	1
OK5	4	3	2	2	1	0
OK6	2	5	2	4	2	5
OK7	1	7	1	7	1	3
OK8	4	1	4	2	0	7
Total	23	28	19	27	11	24

For Kalamalka Lake, zooplankton distribution was approximately equal across the lake in 1997 but tended to be more heavily concentrated on the west side in 1998. For Okanagan Lake, zooplankton densities tended to be highest in the center in 1997 but lowest in the center in 1998. There were no consistent trends within sites over the two years. For example, OK7 showed the highest concentrations at the centre on seven of nine dates in 1997 but in 1998 showed the highest concentrations on the west side on seven of eleven dates (Table 2).

The helical (spiral) flow of Langmuir currents generated by wind and wave energy form a series of parallel clockwise and counterclockwise rotations that result in linear alternations of divergences and convergences (Wetzel 1975). The effect of this action can be a patchiness in horizontal distribution of zooplankton as they aggregate in streaks in these divergences, a phenomenon which is common on waveswept lakes of any significant size (Wetzel 1975).

Because of the observed variation among the 1997 and 1998 hauls and lack of consistent trends, it is recommended that the practice of taking three vertical hauls at geographically spaced locations be continued for future sampling programs.

Appendix 2. Zooplankton densities from 1996 through 1998.

Appendix 3. Laboratory analyses of water samples from Okanagan Lake and Kalamalka Lake, 1996 through 1998.

Appendix 4. Field measurements in Okanagan Lake and Kalamalka Lake, 1996 through 1998.