B O N N E V I L L E   P O W E R   A D M I N I S T R A T I O N

Kootenay Lake Fertilization Experiment

Years 11 and 12

Technical Report 2002 - 2003 | February 2007 | DOE/BP-00004029-5

This Document should be cited as follows:

Schindler, E., K. Ashley, R. Rae, L. Vidmanic, H. Andrusak, D. Sebastian, G. Scholten, P. Woodruff, F. Pick, L. Ley, P. Hamilton, "Kootenay Lake Fertilization Experiment; Years 11 and 12", 2002-2003 Technical Report, Project No. 199404900, 207 electronic pages, (BPA Report DOE/BP-00004029-5)

Bonneville Power Administration
P.O. Box 3621
Portland, OR 97208

This report was funded by the Bonneville Power Administration (BPA), U.S. Department of Energy, as part of BPA's program to protect, mitigate, and enhance fish and wildlife affected by the development and operation of hydroelectric facilities on the Columbia River and its tributaries. The views in this report are the author's and do not necessarily represent the views of BPA.

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Fisheries Project Report No. RD 114
2006

Fish and Wildlife Science and Allocation
Ministry of Environment
Province of British Columbia

Major Funding by

Fish and Wildlife Compensation Program -
Columbia Basin

KOOTENAY LAKE FERTILIZATION EXPERIMENT, YEARS 11 AND 12 (2002 AND 2003)

by

E. U. Schindler[1], K. I. Ashley[2], R. Rae[3], L. Vidmanic[4], H. Andrusak[5], D. Sebastian[6],

G. Scholten[6,] P. Woodruff[7], F. Pick[8], L. M. Ley[9] and P. B. Hamilton[9].

[1] Fish and Wildlife Science and Allocation Section, Ministry of Environment, Province of BC, 401-333 Victoria St., Nelson, BC, V1L 4K3

[2] Department of Civil Engineering, University of British Columbia, 2324 Main Mall, Vancouver, B.C. V6T 1W5

[3] Sumac Writing & Editing, 9327 Milne RD, Summerland, BC V0H 1Z7

[4] Limno-Lab Ltd., 506-2260 W.10th Ave., Vancouver, BC V6K 2H8

[5] Redfish Consulting Ltd., 5244 Hwy 3A, Nelson, BC, V1L 6N6

[6] Aquatic Ecosystem Science Section, Biodiversity Branch
Ministry of Environment, Province of BC
PO Box 9338 STN PROV GOVT, Victoria, BC, V8W 9M2

[7] Biological Contractor, BC Conservation Foundation,
206-17564 56th Ave., Surrey, BC, V3S 4X5

[8] University of Ottawa, Department of Biology, Ottawa, ON, K1N 6N5

[9] Canadian Museum of Nature, P. O. Box 3443, Station D, Ottawa, ON, K1P 6P4

ACKNOWLEDGEMENTS

Funding for the eleventh year (2002) of the Kootenay Lake Fertilization Experiment was provided by the Fish and Wildlife Compensation Program – Columbia Basin and the Ministry of Water, Land and Air Protection (presently the Ministry of Environment). Funding for the twelfth year (2003) was provided by the Fish and Wildlife Compensation Program – Columbia Basin, the Ministry of Water, Land and Air Protection (presently the Ministry of Environment) and the Kootenai Tribe of Idaho. Thanks to the British Columbia Conservation Foundation for administering a portion of the funding provided by the Kootenai Tribe of Idaho in 2003.

The Fish and Wildlife Compensation Program – Columbia Basin is a joint initiative between BC Hydro, BC Ministry of Environment and Fisheries and Oceans Canada. The program was established to conserve and enhance fish and wildlife compensation populations affected by BC Hydro dams in the Canadian portion of the Columbia River Basin.

The ministry's vision is a clean, healthy and naturally diverse environment that enriches people's lives, now and in the future.

The Kootenai Tribe of Idaho receives funding from the Bonneville Power Administration through the Northwest Power and Conservation Council's Columbia Basin Fish and Wildlife Program.

ABSTRACT

This report examines the results from the eleventh and twelfth years (2002 and 2003) of the Kootenay Lake fertilization experiment. Experimental fertilization has occurred with an adaptive management approach since 1992 in order to restore productivity lost as a result of upstream dams. One of the main objectives of the experiment is to restore kokanee (*Oncorhynchus nerka*) populations, which are a main food source for Gerrard rainbow trout (*Oncorhynchus mykiss*).

Kootenay Lake is located between the Selkirk and Purcell mountains in southeastern British Columbia. It has an area of 395 km^2, a maximum depth of 150 m, a mean depth of 94 m, and a water renewal time of approximately two years.

The quantity of agricultural grade liquid fertilizer (10-34-0, ammonium polyphosphate and 28-0-0, urea ammonium nitrate) added to Kootenay Lake in 2002 and 2003 was similar to that added from 1992 to 1996. After four years of decreased fertilizer loading (1997 to 2000), results indicated that kokanee populations had declined, and the decision was made to increase the loads again in 2001. The total load of fertilizer in 2002 was 47.1 tonnes of phosphorus and 206.7 tonnes of nitrogen. The total fertilizer load in 2003 was 47.1 tonnes of phosphorus and 240.8 tonnes of nitrogen. Additional nitrogen was added in 2003 to compensate for nitrogen depletion in the epilimnion. The fertilizer was applied to a 10 km stretch in the North Arm from 3 km south of Lardeau to 3 km south of Schroeder Creek.

The maximum surface water temperature in 2002, measured on July 22, was 22 ºC in the North Arm and 21.3 ºC in the South Arm. In 2003, the maxima were recorded on August 5 at 20.6 ºC in the North Arm and on September 2 at 19.7 ºC in the South Arm. The maximum water temperature in the West Arm was 18.7 ºC on September 2, 2003. Kootenay Lake had oxygen-saturated water throughout the sampling season with values ranging from about 11–16 mg/L in 2002 and 2003. In both years, Secchi depth followed the expected pattern for an oligo-mesotrophic lake of decreasing in May, June, and early July, concurrent with the spring phytoplankton bloom, and clearing again as the summer progressed.

Total phosphorus (TP) ranged from 2–11 µg/L in 2002 and 2–21 µg/L in 2003. With average TP values generally in the range of 3–10 µg/L, Kootenay Lake is considered to be an oligotrophic to oligo-mesotrophic lake. Total dissolved phosphorus (TDP) followed the same seasonal trends as TP in 2002 and 2003 and ranged from 2–7 µg/L in 2002 and from 2–10 µg/L in 2003.

Total nitrogen (TN) ranged from 90–380 µg/L in 2002 and 100–210 µg/L in 2003. During both the 2002 and 2003 sampling seasons, TN showed an overall decline in concentration with mid-summer and fall increases at some stations, which is consistent with previous years' results.

Dissolved inorganic nitrogen (DIN) concentrations showed a more pronounced declining trend over the sampling season compared with TN, corresponding to nitrate (the dominant component of DIN) being used by phytoplankton during summer stratification. DIN ranged from 7–176 µg/L in 2002 and from 8–147 µg/L in 2003. During 2003, discrete depth sampling occurred, and a more detailed look at the nitrate concentrations in the epilimnion was undertaken. There was a seasonal decline in nitrate concentrations, which supports the principle of increasing the nitrogen loading and the nitrogen to phosphorus (N:P) ratio during the fertilizer application period.

Chlorophyll *a* (Chl *a*) concentrations in Kootenay Lake were in the range of 1.4–5.1 µg/L in 2002 and 0.5–4.9 µg/L in 2003. Over the sampling season, Chl *a* at North Arm stations generally increased in spring corresponding with the phytoplankton bloom, decreased during the summer, and increased again in the fall with mixing of the water column. The trend was similar, but less pronounced, at South Arm stations in these years, and spring Chl *a* concentrations were lower.

During 2002, total algal biomass averaged during June, July and August was lower in the North Arm than the South Arm. This was the first time this occurred since the commencement of the North Arm fertilization experiment. Results in 2002 indicated Kootenay lake continues to be a diatom dominated lake (80 to 89% of the total average biomass).

The overall trend observed throughout the 2003 sampling season was one of a slight decline in algal biomass from the North Arm stations towards those in the South Arm. Kootenay Lake continued to be a diatom-dominated lake (76–83% of total average biomass). *Synedra* spp. and some *Asterionella*, as in the previous three years, dominated the early biomass increase in 2003, but the peak biomass in July was largely due to *Tabellaria*.

Depth profiles of biomass in 2003 showed that the distribution of algae was not uniform with depth in the top 20 m of the water column. This was particularly evident in the fertilization zone in August when exceedingly high biomass was reached in the upper surface waters and it declined rapidly with depth. In particular, station KLF 1 reached a total algal biomass of 3.1 g/m^3 at 2 m; this was largely due to *Tabellaria* (contributing to 40% of the total), *Fragilaria*, *Cyclotella*, and *Asterionella*. *Tabellaria* tended to decline with depth at North Arm stations. The same surface "bloom" was not as pronounced from stations KLF 2 through KLF 4, although a peak was observed at the latter station at 5 m due to high abundance of both *Fragilaria* and *Tabellaria*. In contrast, depth profiles from stations in the South Arm tended to exhibit higher biomass at greater depths (below 10 m) in mid-summer. The composition of the samples at depth indicated a greater proportion of diatoms contributing to the biomass; the diatoms were most likely derived from earlier epilimnetic growth.

The zooplankton populations in Kootenay Lake were a diverse species assemblage, with a relatively consistent population density in 2002 and 2003. The Kootenay Lake zooplankton density is numerically dominated by copepods, which averaged 91% and 85%

of the population in 2002 and 2003 respectively. *Daphnia* spp. comprised 3% and 5% respectively, and cladocerans other than *Daphnia* spp. comprised 6% and 10% respectively. The decline in the proportion of cladocerans in 2002 may have been due to a decrease in the biomass of grazeable phytoplankton (nanoplankton, 2–22 µm). As a result, zooplankton biomass may have declined and may not have been high enough to keep pace with the grazing rate imposed by the higher number of kokanee in the lake.

Zooplankton biomass had similar trends in both the North and South arms of Kootenay Lake. In 2002, total biomass decreased in both arms, as did the biomass of other cladocerans and of *Daphnia*. Copepod biomass decreased in the South Arm but increased in the North Arm of the lake. However, in 2003 biomass in all categories increased in both the North and South arms. There was a distinct increase (more than three fold) in the biomass of other cladocerans in the North Arm, as well as an increase (more than two fold) in *Daphnia* biomass in both the North and South arms. The significant increase of total zooplankton biomass in 2003 was due to increases in the density of *Diaphanosoma brachiurum* and *Daphnia spp*., which was reflected in increased biomass.

During 2002 and 2003, a sharp decrease in mysid abundance was recorded. During the study period from 1993 onward, mysid densities at deep stations fluctuated along the length of the lake. Average mysid density was higher in the South Arm in 1993, 1994, 2001, and 2002. However, in the period from 1995–2000 and again in 2003, density was higher in the North Arm. During the season, densities increased through summer and declined in winter. Mysid density and biomass tended to be higher at the deep sites than at near-shore sites.

Near-shore samples predominantly contained juveniles and immature males and females, while mature and breeding males and females were rare. In 2002 and 2003, mysids in Kootenay Lake were most actively breeding from January to April. During the breeding season, deep samples contained a higher proportion of mature and breeding individuals than near-shore samples. The number of brooding females was low in the fall-winter seasons of 2001–2002 and 2002–2003, which was reflected in the lower number of juveniles during the summer of 2002 and 2003 and in decreased mysid density .

Estimated kokanee escapement to Meadow Creek was 0.35 million in 2002, representing the third consecutive low escapement since 1992 when lake fertilization commenced and the lowest escapement since 1991. The three years of low numbers contrast with most escapements in the latter part of the 1990s, which ranged from 0.5–1.1 million. The explanation for this major decrease in 2000–2002 is believed to be linked to the reduced fertilizer loadings from 1997–2000.

Despite the small escapement in 2002, the spawning channel was filled to capacity (~300,000 kokanee). In sharp contrast, the 2003 Meadow Creek numbers were close to 0.9 million spawners, nearly triple the 2002 numbers. The 2003 estimate represents the first sizeable increase in numbers in the last four years, but there were still fewer fish than in the parent year (1999) which had about 1.2 million.

Mean size of female kokanee returning to Meadow Creek in 2002 was slightly higher (23.3 cm) than the 37-year average of 22.2 cm. Mean size of 2003 kokanee was slightly lower than the 37-year average (males 21.5 cm, females 21.4 cm). Mean fecundity in 2003 was 208 eggs, much lower than the 37-year average, but similar to the levels recorded in the mid-1980s and late 1990s. Decreased mean size and fecundity in 2002 and again in 2003 likely signals a density-growth response as the whole lake population rebuilds following increased fertilization that began in 2001. As the kokanee population rebuilds towards lake carrying capacity, it is predicted that fecundity and fish length will decline and stabilize close to the long-term average.

Kokanee fry production from Meadow Creek in the spring of 2002 was about 23 million with 94% produced in the spawning channel. This estimate was the second highest in 27 years of records and nearly twice the average of about 11.9 million. The highest fry production on record occurred in 1994, as a result of high fecundity. The 2003 fry production estimate was slightly lower than the 2002 estimate with approximately 17.9 million produced from the channel and a total of 18.3 million fry from the whole system.

Kokanee fry-to-adult survival rates for the 1996–1998 year classes were low and the Meadow Creek recruit:spawner ratios were also very low with replacement not achieved for these cycles. The impact of nutrient reduction commencing in 1997 and continuing through 2000 should be most evident with the 1996–1999 cohorts. This appears to have been the case based on the adult survival estimates four years later (2000–2002). If lake fertilization positively influences kokanee survival as contended in the above analysis, then fertilizer loading increased to the rates applied from 1992–1996 should result in improved in-lake survival for the 2000–2003 cohorts. The increases in 2003 escapements and in-lake abundance estimates lend support to this hypothesis. The trend data suggest that 2004 escapements will be high, possibly one million fish at Meadow Creek.

It is believed that the status of the Gerrard rainbow trout population is closely tied to the abundance of kokanee. The increased numbers of kokanee observed throughout most of the 1990s appear to have resulted in very good rainbow trout fishing conditions and escapements in the latter part of the 1990s. The 2001 and 2002 rainbow trout sport fisheries were very poor but some improvement was evident in 2003. There was an increase in the success rates, not only for the smallest trout but also for those in the 2–5 kg size category, and in 2003 there was a slight increase in the 5–7 kg category. There appears to be a time lag of about three years between increased kokanee abundance and increased rainbow trout abundance. The extent to which increasing predation pressure affects kokanee recovery has not been quantified, although it is possible that greater numbers of Gerrard rainbow trout in the late 1990s contributed to the rapid decline of kokanee during the period of reduced fertilization in 1997–2000.

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CHAPTER 1

INTRODUCTION

KOOTENAY LAKE FERTILIZATION EXPERIMENT
YEARS 11 and 12 (2002 and 2003)

by

Eva U Schindler
Ministry of Environment
Nelson, BC

Kootenay Lake is located between the Selkirk and Purcell Mountain ranges and is part of the upper Columbia River drainage in southeast British Columbia (Figure 1.1). The main lake is approximately 395 km^2, 107 km in length, and has a mean depth of 94 m, a maximum depth of 154 m, and a water renewal time of 1.8 years (Daley et al. 1981). The lake has two main tributaries, the Duncan River in the north and the Kootenay River in the south. The upper end of the West Arm is where the outlet of the lake forms at Balfour, BC. The West Arm is approximately 40 km in length, with a mean depth of 13 m and comprises a series of shallow basins. The West Arm becomes the lower Kootenay River where it joins the Columbia River at Castlegar, BC.

Kootenay Lake has a range of fish species (Table 1.1). Information about several of these fish species and descriptions of sport fishing in Kootenay Lake have been well documented in other reports (Northcote 1972, Andrusak *in* Wright et al. 2002).

Kootenay Lake has experienced several anthropogenic stressors during the past sixty years. These influences have altered lake productivity and have affected fish populations, especially the kokanee (*Oncorhynchus nerka)* and Gerrard rainbow trout (*Oncorhynchus mykiss*).

The stressors include the introduction of mysid shrimp *(Mysis relicta)* in 1949, cultural eutrophication during the1960s and early 1970s, and the construction of large upstream hydroelectric impoundments in 1967 and 1972. The Duncan Dam impounded the Duncan River at the north end of the lake, and the Libby Dam impounded the Kootenay River in the south. These upstream impoundments retained nutrients and as a result, phosphorus loading decreased below historical values and phytoplankton biomass and fisheries declined (Northcote et al. 2005).

Mysid shrimp were introduced to Kootenay Lake as an additional food source for Gerrard rainbow trout, but the trout have not benefited from the introduction (Northcote 1991). Initially, however, the mysid shrimp introduction was thought to be partially successful, because the shrimp were observed in the outlet in 1964 (Sparrow et al. 1964) and West Arm kokanee were able to eat them due to the shallower depth at the outlet of the lake (Martin and Northcote 1991). It has been suggested that mysids are partially responsible for the decline in main lake kokanee populations (Ashley et al. 1997, Northcote 1991, Walters et al. 1991).

Cultural eutrophication of Kootenay Lake resulted from abundant phosphates released by a fertilizer plant operating on one of the tributaries to the Kootenay River (Northcote 1973) The fertilizer plant began implementing clean up activities in 1969 and in the 1970s and 1980s the lake became oligotrophic, the results of which were well documented (Daley et al. 1981).

The construction of the Duncan Dam in 1967 and the Libby Dam in 1972 resulted in nutrient retention, and the nutrient input to the lake declined to below pre-dam conditions (Daley et al. 1981, Binsted and Ashley 2006). As a result, kokanee populations decreased and caused fisheries managers great concern.

In 1991, a workshop was held and fisheries managers concluded the only option to reverse the decline in kokanee was to add nutrients in the form of liquid fertilizer to Kootenay Lake. They proceeded even though the Kootenay Lake Fertilization Response Model predicted fertilization would not be successful (Walters et al. 1991).

In 1992, a five-year experimental fertilization adaptive management program began with a mixture of agricultural grade liquid nitrogen (N; urea ammonium nitrate, 28-0-0) and liquid phosphorus (P; ammonium polyphosphate, 10-34-0). The seasonal loading and timing of the fertilizer additions was designed to simulate freshet conditions. Fertilizer was added for 20 weeks from the end of April to the beginning of September. The results have been well documented in a series of reports (Ashley et al. 1997, Ashley et al. 1999). The nutrient additions were successful in increasing phytoplankton biomass and zooplankton and kokanee populations.

In 1997, fertilizer additions were decreased by 60% to determine if there were any carryover effects of productivity. The results indicated a decrease in kokanee populations, and so in 2001, the nutrient additions were increased again to the 1992 to 1996 loading rates.

This report documents the results from the Kootenay Lake Fertilization Experiment's year 11 (2002) and year 12 (2003) sampling seasons. A number of scientists, biologists, contractors, and administrative personnel participated in the program for these two years. A list of the participants and their primary function is shown in Table 1.2. A list of sampling activities is in Table 1.3 for 2002 and Table 1.4 for 2003. Additional monitoring, which is included in Table 1.4, was implemented in 2003 from funding provided by the Kootenai Tribe of Idaho.

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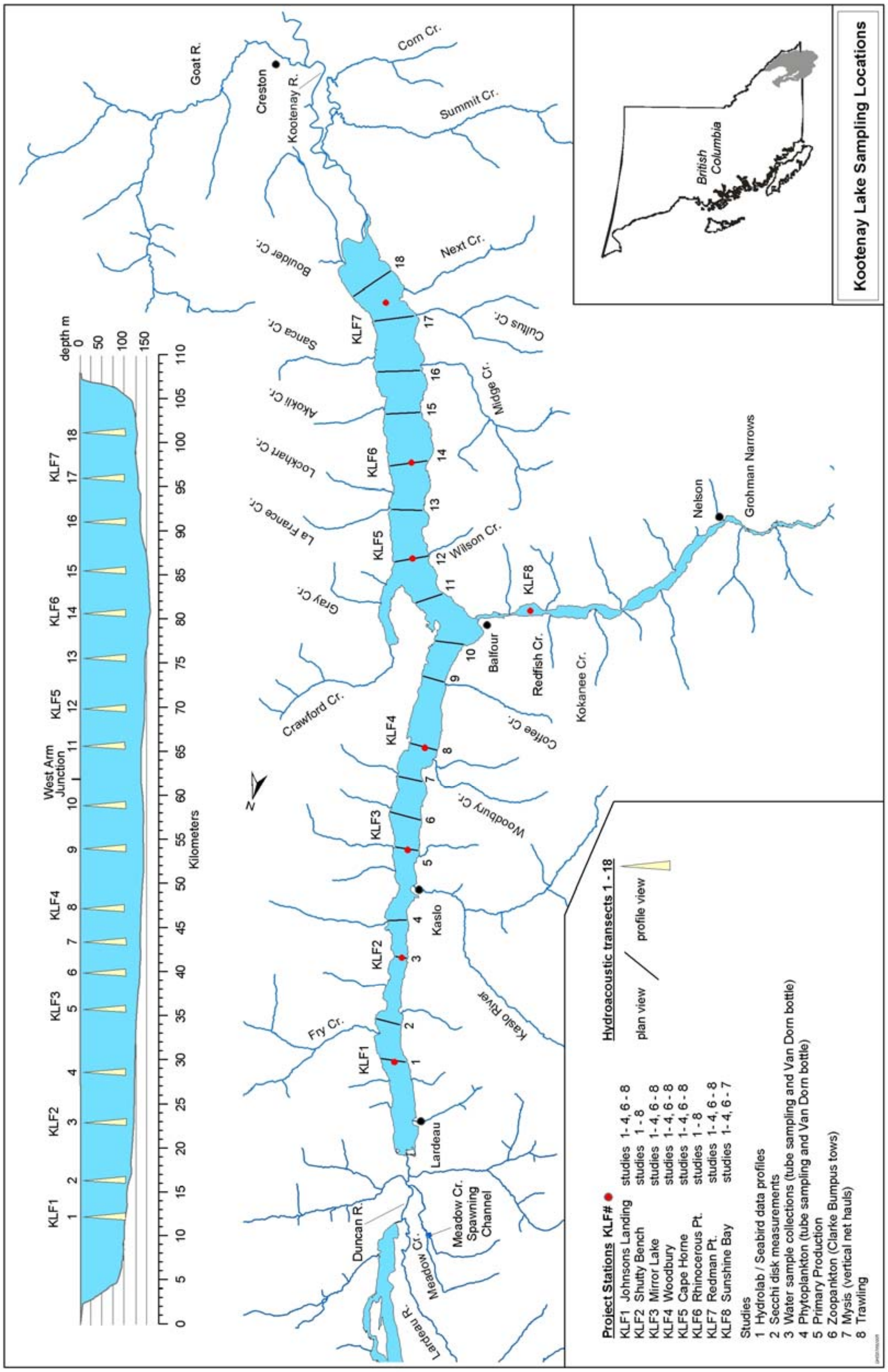

Figure 1.1. Kootenay Lake, British Columbia, sampling station sites.

Table 1.1. List of fish species in Kootenay Lake (from McPhail and Carveth 1992).

Common name	**Scientific name**
Black bullhead	*Ameiurus melas*
Bridgelip sucker	*Catostomus columbianus*
Brook trout	*Salvelinus fontinalis*
Bull trout	*Salvelinus confluentus*
Burbot	*Lota lota*
Carp	*Cyprinus carpio*
Coarsescale sucker	*Catostomus macrocheilus*
Finescale sucker	*Catostomus catostomus*
Kokanee	*Oncorhynchus nerka*
Lake chub	*Couesius plumbeus*
Lake whitefish	*Coregonus clupeaformis*
Large mouth bass	*Micropterus salmoides*
Longnose dace	*Rhinichthys cataractae*
Mountain whitefish	*Prosopium williamsoni*
Northern Pike minnow	*Ptychocheilus oregonensis*
Peamouth chub	*Mylocheilus caurinus*
Pumpkinseed	*Lepomis gibbosus*
Pygmy whitefish	*Prosopium coulteri*
Rainbow trout	*Oncorhynchus mykiss*
Redside shiner	*Richardsonius balteatus*
Slimy sculpin	*Cottus cognatus*
Torrent sculpin	*Cottus rhotheus*
Westslope cutthroat	*Oncorhynchus clarki*
White sturgeon	*Acipenser transmontanus*
Yellow perch	*Perca flavescens*

Table 1.2. Kootenay Lake activities, participants, and affiliation for 2002 and 2003 studies.

Contribution	Personnel	Affiliation
Fertilizer schedule, loading	Dr. Ken Ashley	Ministry of Water, Land & Air Protection[1]
Fertilizer application	George Veale	G. Veale Holdings Ltd.
Physical limnology, water chemistry, phytoplankton, zooplankton, mysid sampling	Don Miller Harald Manson	Kootenay Wildlife Services Ltd. CBFWCP[2]
Physical limnology and water chemistry analysis	Dr. Rowena Rae Eva Schindler	Sumac Writing and Editing Ministry of Water, Land & Air Protection[1]
Phytoplankton analysis and ecology	Dr. Frances Pick Linda Ley Paul Hamilton	Biology Department, University of Ottawa Canadian Museum of Nature Canadian Museum of Nature
Zooplankton and mysid analysis and biology	Dr. Lidija Vidmanic	Limno-Lab Ltd.
Kokanee acoustic sampling	Dale Sebastian George Scholten Patricia Woodruff	Ministry of Water, Land & Air Protection[1] Ministry of Water, Land & Air Protection[1] British Columbia Conservation Foundation
Kokanee trawling	Don Miller	Kootenay Wildlife Services Ltd.
Meadow Creek fry kokanee enumeration	John Bell Murray Pearson	Ministry of Water, Land & Air Protection[1] Ministry of Water, Land & Air Protection[1]
Meadow Creek adult kokanee enumeration	John Bell Murray Pearson	Ministry of Water, Land & Air Protection[1] Ministry of Water, Land & Air Protection[1]
Kokanee and rainbow trout analysis and biology	Harvey Andrusak	Redfish Consulting Ltd.
Regional support, logistics	John Bell Colin Spence	Ministry of Water, Land & Air Protection[1] Ministry of Water, Land & Air Protection[1]
Project co-ordination and scientific liaison	Ken Ashley Harald Manson	Ministry of Water, Land & Air Protection[1] CBFWCP
Administration	Harald Manson Beth Woodbridge	CBFWCP CBFWCP
Editorial comments	Eva Schindler Dr. Rowena Rae	Ministry of Water, Land & Air Protection[1] Sumac Writing and Editing
Fisheries Technical Committee	Dr. Ken Ashley Colin Spence David Wilson Gary Birch	Ministry of Water, Land & Air Protection[1] Ministry of Water, Land & Air Protection[1] BC Hydro BC Hydro
Steering Committee	Jamie Alley Wayne Stetski Dave Cattanach Hugh Smith Joe Nicolas Greg Mustard Richard Spilker Pat Wells	Ministry of Water, Land & Air Protection[1] Ministry of Water, Land & Air Protection[1] BC Hydro BC Hydro First Nations Representative Public Representative Public Representative Public Representative

[1]Presently Ministry of Environment
[2]Columbia Basin Fish and Wildlife Compensation Program

Table 1.3. Sampling activities – Kootenay Lake, 2002.

Parameter sampled	Sampling frequency	Sampling technique
Temperature, dissolved oxygen, pH, ORP, specific conductance and turbidity	Monthly, April to October	Hydrolab at 1-m intervals at stations KLF 2, 4, 6, 7 from 0–50 m, and at 5-m intervals from 50–100 m as depth permits.
Transparency	Monthly, April to October	Secchi disk (without viewing chamber) at stations KLF 2, 4, 6, 7..
Water chemistry TDS, specific cond., pH, silica, alkalinity and nutrients (TP, TDP, LL, SRP, NO_3+NO_2, NH_3) Total metals	Monthly, April to October	a) Integrated sampling tube at 0–30 m plus a bottle sample 5 m off the bottom at stations KLF 2, 4, 6, 7. b) June and September bottle samples at 50 m, 100 m & 150 m (KLF 1-7) as depth permits.
Chlorophyll *a (not corrected for phaeophytin)*	Monthly, April to October	Integrated sampling tube 0–20 m at stations KLF 2, 4, 6, 7.
Phytoplankton	Monthly, April to October	Integrated sampling tube at 0–20 m at KL stations KLF 2, 4, 6, 7. Samples fixed with Lugol's solution.
Macrozooplankton	Monthly, April to October	3 oblique Clarke-Bumpus net hauls (3minutes each) from 40–0 m at stations KLF 2, 4, 6, 7 (150 μm net mesh).
Mysids	Monthly, April/02 to March/03	3 replicate hauls with mysid net, two deep and one shallow at stations KLF 1-7.
Kokanee acoustic sampling	1 survey in the fall	Standard MWLAP Simrad and Biosonics hydroacoustic procedures at 18 transects.
Kokanee trawling	Fall trawl series	Standard trawl series using oblique hauls at 18 transects.
Adult kokanee enumeration	Fall spawning period at Meadow Creek, the Lardeau River, and selected streams tributary to Kootenay Lake	Standard MWLAP, Region 4 procedures.
Kokanee fry enumeration	Spring monitoring at Meadow Creek Spawning Channel	Standard MWLAP, Region 4 procedures.

Table 1.4. Sampling activities – Kootenay Lake, 2003.

Parameter sampled	Sampling frequency	Sampling technique
Temperature, dissolved oxygen, pH, ORP, specific conductance and turbidity	Monthly, April to November	Hydrolab at 1-m intervals at stations KLF 1-8 from 0–50 m, and at 5-m intervals from 50–100 m as depth permits.
Transparency	Monthly, April to November	Secchi disk (without viewing chamber) at stations KLF 1-8.,
Water chemistry TDS, specific cond., pH, silica, alkalinity and nutrients (TP, TDP, LL, SRP, NO_3+NO_2, NH_3) Total metals	Monthly, April to November Monthly, August to November	(a) Integrated sampling tube at 0 – 30m plus a bottle sample 5 m off the bottom at stations KLF 2, 4, 6 and 7. (b) Integrated sampling tube at 0 – 30 m plus a bottle sample 5 m off the bottom at stations KLF 1, 3, 5 and 8. (c) September bottle samples at 50 m, 100 m & 150 m (KL 1-7) as depth permits.
Discrete N and P (NO_3^- + NO_2^-), ammonia, SRP, TP, DP and silicic acid. A 1-L subsample taken for Chlorophyll *a* at 2 m, 5 m, 10 m and 15 m (but not at 20 m).	Monthly, June to October Monthly, August to October	Bottle samples at 2 m, 5 m, 10 m, 15 m and 20 m at station KLF 2 and KLF 6, Bottle samples at 2 m, 5 m, 10 m, 15 m and 20 m at station KLF 1, 3, 4, 5, 7,
Chlorophyll *a (not corrected for phaeophytin)*	Monthly, April to November Monthly, August to November Monthly, June to October Monthly August to October	Integrated sampling tube 0–20 m at station KLF 2, 4, 6, and 7. Integrated sampling tube 0–20 m at station KLF 1, 3, 5, and 8. Discrete samples at 2 m, 5 m, 10 m, 15 m at station KLF 2 and 6. Discrete samples at 2 m, 5 m, 10 m and 15 m at station KLF 1, 3, 5, and 8.
Phytoplankton	Monthly, April to November Monthly, August to November	Integrated sampling tube at 0–20 m at station KLF 2, 4, 6, and 7. Integrated sampling tube at 0–20 m at station KLF 1, 3, 5, and 8. Samples fixed with Lugol's solution.
Discrete phytoplankton	Monthly, August to October	Bottle samples at 2 m, 5 m, 10 m, 15 m and 20 m at stations KLF 1-7.
Macrozooplankton	Monthly, April to November Monthly, August to November	3 oblique Clarke-Bumpus net hauls (-minutes each) from 40–0m at station KLF 2, 4, 6, and 7 (150 μm net mesh). 3 oblique Clarke-Bumpus net hauls (3 minutes each) from 40–0 m at station KLF 1, 3, 5, and 8.
Mysids	Monthly, April/03 to March/04	3 replicate hauls with mysid net, two deep and one shallow at stations KLF 1-8.
Kokanee acoustic sampling	1 survey in the fall	Standard MWLAP Simrad and Biosonics hydroacoustic procedures at 18 transects.

Kokanee trawling	Fall trawl series	Standard trawl series using oblique hauls at 18 transects.
Adult kokanee enumeration	Fall spawning period at Meadow Creek, the Lardeau River, and selected streams tributary to Kootenay Lake	Standard MWLAP, Region 4 procedures.
Kokanee fry enumeration	Spring monitoring at Meadow Creek Spawning Channel	Standard MWLAP, Region 4 procedures.

CHAPTER 2

FERTILIZER LOADING IN KOOTENAY LAKE
YEARS 11 and 12 (2002 and 2003)

by

Eva U Schindler

Ministry of Environment
Nelson, BC

and

Ken I. Ashley

Department of Civil Engineering, UBC
Vancouver, BC

Fertilizer type

Fertilization of the North Arm of Kootenay Lake occurred using an agricultural grade liquid fertilizer blend of ammonium polyphosphate (10-34-0, N-P_2O_5-K_2O; % by weight) and 28-0-0 urea-ammonium nitrate (N-P_2O_5-K_2O; % by weight). The total quantity of fertilizer added in 2001 was increased to the quantity added from 1992 to 1996 (47 tonnes of phosphorus and 234 tonnes of nitrogen). The nitrogen to phosphorus ratio of the fertilizer added varied throughout the season (the range was from 0.67:1 in the early spring to 8.2:1 later in the summer). The fertilizer in 2002 was dispensed weekly from 22 April to 02 September and in 2003, it was dispensed weekly from 22 April to 31 August.

Fertilizer application

The nutrients were applied using a tug and barge as in previous years. The barge was fitted with two tanks capable of carrying 81 tonnes of fertilizer. Details of application are described in previous reports (Ashley et al. 1997, Wright et al. 2002).

Seasonal loading and timing

The loading and timing of the nutrient additions were designed to simulate the loading during spring freshet conditions (pre dam condition). Weekly loading rates of phosphorus decreased during the summer while nitrogen rates increased. This was conducted as in previous years to adaptively manage for nitrogen consumption in the water column as the season progressed (Table 2.1, Table 2.2, Fig 2.1 and Fig. 2.2). The total load of fertilizer in 2002 was 47.1 tonnes of phosphorus and 206.7 tonnes of nitrogen. The total fertilizer load in 2003 was 47.1 tonnes of phosphorus and 240.8 tonnes of nitrogen. Additional nitrogen was added in 2003 to compensate for nitrogen depletion in the epilimnion.

Acknowledgements

Thanks to G. Veale Holdings Ltd for fertilizer dispensing.

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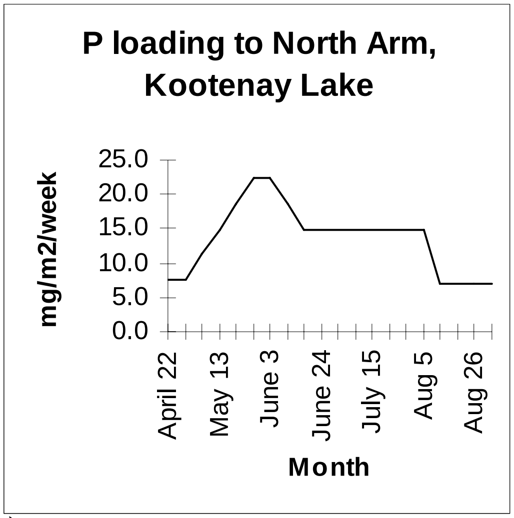
Table 2.1. Kootenay Lake nutrient loading of fertilizer during 2002– ammonium polyphosphate (10-34-0) and urea ammonium nitrate (28-0-0).

			Phosphorus			Nitrogen		
Week	Date	Load	Amount	10-34-0	Load	Amount	28-0-0	N:P ratio
		mg/m^2	kgs	Tonnes	mg/m^2	kgs	Tonnes	wt:wt
1	Apr 22	7.5	1300	8.8	5.0	876	0.00	0.67
2	Apr 29	7.5	1300	8.8	5.0	876	0.00	0.67
3	May 06	11.2	1950	13.1	7.6	1313	0.00	0.67
4	May 13	15.0	2600	17.5	10.1	1751	0.00	0.67
5	May 20	18.7	3250	21.9	68.9	9777	27.10	3.7
6	May 27	22.5	3900	26.3	83.1	11811	32.80	3.7
7	Jun 03	22.5	3900	26.3	83.1	11811	32.80	3.7
8	Jun 10	18.7	3250	21.9	97.1	14677	44.60	5.2
9	Jun 17	15.0	2600	17.5	77.7	11747	35.70	5.2
10	Jun 24	15.0	2600	17.5	77.7	11747	35.70	5.2
11	Jul 01	15.0	2600	17.5	77.7	11747	35.70	5.2
12	Jul 08	15.0	2600	17.5	100.2	15639	49.60	6.7
13	Jul 15	15.0	2600	17.5	100.2	15639	49.60	6.7
14	Jul 22	15.0	2600	17.5	100.2	15639	49.60	6.7
15	Jul 29	15.0	2600	17.5	100.2	15639	49.60	6.7
16	Aug 05	15.0	2600	17.5	122.9	19587	63.70	8.2
17	Aug 12	7.0	1208	8.1	57.1	9102	29.60	8.2
18	Aug 19	7.0	1208	8.1	57.1	9102	29.60	8.2
19	Aug 26	7.0	1208	8.1	57.1	9102	29.60	8.2
20	Sep 02	7.0	1208	8.1	57.1	9102	29.60	8.2

Table 2.2. Kootenay Lake nutrient loading of fertilizer during 2003– ammonium polyphosphate (10-34-0) and urea ammonium nitrate (28-0-0).

			Phosphorus			Nitrogen		
Week	Date	Load	Amount	10-34-0	Load	Amount	28-0-0	N:P ratio
		mg/m^2	kgs	Tonnes	mg/m^2	kgs	Tonnes	wt:wt
1	Apr 20	7.5	1300	8.8	5.0	876	0.00	0.67
2	Apr 27	7.5	1300	8.8	5.0	876	0.00	0.67
3	May 04	11.2	1950	13.1	7.6	1313	0.00	0.67
4	May 11	15.0	2600	17.5	10.1	1751	0.00	0.67
5	May 28	18.7	3250	21.9	56.3	9777	27.10	3.0
6	May 25	22.5	3900	26.3	68.0	11811	32.80	3.0
7	Jun 01	22.5	3900	26.3	68.0	11811	32.80	3.0
8	Jun 08	18.7	3250	21.9	84.5	14677	44.60	4.5
9	Jun 15	15.0	2600	17.5	67.6	11747	35.70	4.5
10	Jun 22	15.0	2600	17.5	67.6	11747	35.70	4.5
11	Jun 29	15.0	2600	17.5	112.3	11747	63.40	7.5
12	Jul 06	15.0	2600	17.5	112.3	15639	63.40	7.5
13	Jul 13	15.0	2600	17.5	112.3	15639	63.40	7.5
14	Jul 20	15.0	2600	17.5	112.3	15639	63.40	7.5
15	Jul 27	15.0	2600	17.5	112.3	15639	63.40	7.5
16	Aug 04	15.0	2600	17.5	134.7	19587	77.30	9.0
17	Aug 10	7.0	1208	8.1	62.6	9102	35.90	9.0
18	Aug 17	7.0	1208	8.1	62.6	9102	35.90	9.0
19	Aug 24	7.0	1208	8.1	62.6	9102	35.90	9.0
20	Aug 31	7.0	1208	8.1	62.6	9102	35.90	9.0



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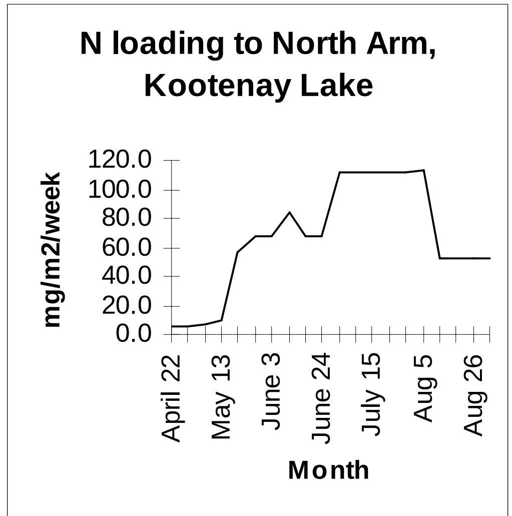

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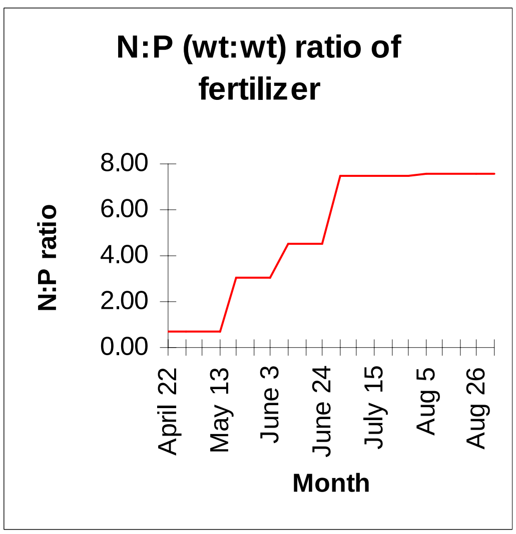

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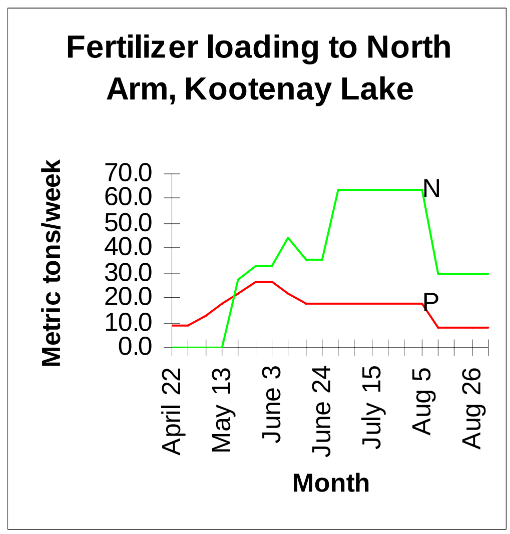
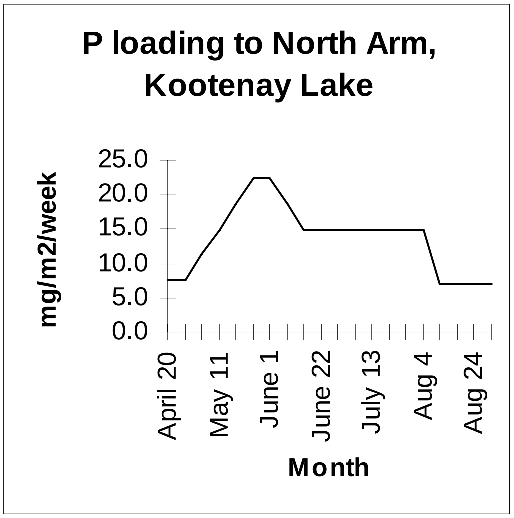


d)

Figure 2.1. Kootenay Lake nutrient loading in 2002 with weekly distributions of:
a) phosphorus loading to the North Arm, b) nitrogen loading to the North Arm, c) the N:P ratio (wt:wt) of fertilizer dispensed and d) the combined nutrient loading of metric tons per week.



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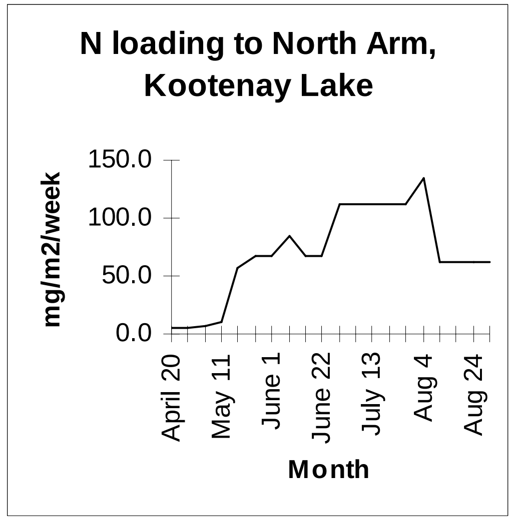

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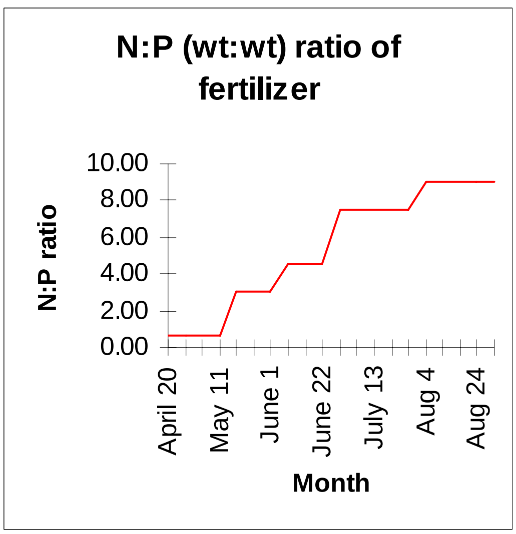

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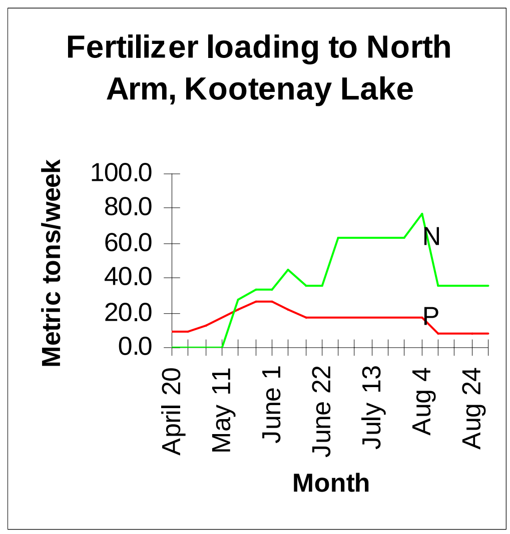

d)

Figure 2.2. Kootenay Lake nutrient loading in 2002 with weekly distributions of:
b) phosphorus loading to the North Arm, b) nitrogen loading to the North Arm, c) the N:P ratio (wt:wt) of fertilizer dispensed and d) the combined nutrient loading of metric tons per week.

CHAPTER 3

PHYSICAL LIMNOLOGY AND WATER CHEMISTRY RESPONSES TO EXPERIMENTAL FERTILIZATION YEARS 11 and 12 (2002 and 2003)

by

Dr. Rowena Rae

Sumac Writing and Editing
Summerland, BC

and

Eva U Schindler

Ministry of Environment
Nelson, BC

Introduction

Experimental nutrient additions to Kootenay Lake began in 1992 and have continued annually with fertilizer applications occurring from spring through fall. The nutrient load applied to the lake has varied over the past 12 years. In each of 2002 and 2003 (11th and 12th years of fertilization), the nutrient load contained 47.1 tonnes of phosphorus. The nitrogen load was 207 tonnes in 2002 and 241 tonnes in 2003.

The experimental fertilization program was initiated to recover declining kokanee salmon and rainbow trout populations in Kootenay Lake (Ashley et al. 1997). The lake had undergone oligotrophication following reductions in anthropogenic nutrient loading and the construction of dams on Duncan and Kootenay rivers, the lake's two main tributaries. As a result of fewer nutrients entering the lake, the phytoplankton community composition was altered (Daley and Pick 1990, Pick et al. 2002) and had repercussions for higher trophic levels in the lake. The experimental fertilization was designed, therefore, to stimulate production of the phytoplankton community, which would lead to increased cladoceran zooplankton biomass and provide more food for juvenile kokanee and ultimately rainbow trout (Walters et al. 1991).

This report summarizes the physical, chemical, and chlorophyll *a* data collected on Kootenay Lake in 2002 and 2003. Measurements from previous years are shown in the tables and discussed in relation to 2002 and 2003 but are not included in graphs. Previous years' data can be found in earlier Kootenay Lake Fertilization Experiment annual reports (Wright et al. 2002).

Materials and Methods

Physical and chemical data were collected at established KLF sampling sites simultaneously with the collection of phytoplankton and zooplankton samples (see Map 1.1 in the Introduction to this KLF report). Sampling was conducted monthly from April to November of both 2002 and 2003. Samples have been collected from up to eight stations (Table 3.1), but consistently from four stations, two in the North Arm (KLF 2, KLF 4) and two in the South Arm (KLF 6, KLF 7).

Table 3.1. Kootenay Lake Fertilization Program limnological sampling sites.

Site ID	EMS site no.	Site name	Depth (m)
KLF 1	E216949	Kootenay Lake at Johnson's Landing	100
KLF 2	E216950	Kootenay Lake at Kembell Creek	120
KLF 3	E216951	Kootenay Lake at Bjerkeness Creek	120
KLF 4	E216952	Kootenay Lake at Hendricks Creek	135
KLF 5	E216953	Kootenay Lake at Crawford Bay	140
KLF 6	E216954	Kootenay Lake at Rhinoceros Point	150
KLF 7	E218832	Kootenay Lake at Redman Point	125
KLF 8	E252949	Kootenay Lake – West Arm	35

In 2002 and 2003, temperature and oxygen profiles were taken at approximately 1-m intervals from 0-50 m and at 5 m intervals from 50 to 100 m at KLF 1-7 using a Hydrolab (Surveyor III) probe. In

August 2003, KLF 8 in the shallow West Arm of Kootenay Lake was added to the sampling regime. The Hydrolab probe also recorded pH, reduction-oxidation or redox potential, and conductivity. Except where noted, these data are not shown in graphs or tables but are mentioned in the text. Conductivity analysis was also conducted by the water chemistry lab, and these data are graphed. Water transparency was measured using a standard 20-cm Secchi disk.

Water samples were collected at KLF 2, 4, 6, and 7 over the course of the sampling season using a 2.54 cm (inside diameter) tube sampler to collect an integrated water sample from 0-30 m. Water samples were shipped within 24 h of collection to PSC Analytical Services (now Maxxam Analytics, Inc.) in Burnaby, B.C. Samples were analyzed for turbidity, conductivity, total phosphorus (TP), total dissolved phosphorus (TDP), orthophosphosphate (OP), total nitrogen (TN), dissolved inorganic nitrogen (DIN), silica, alkalinity, total organic carbon (TOC), and chlorophyll *a* (Chl *a*). Prior to shipping to the lab, Chl *a* samples were prepared by filtering a portion of the integrated water sample through a filter with 0.45 µm pore size. At the lab, the filters were placed in centrifuge tubes with 90% buffered acetone and sonicated to rupture the algal cells and homogenize the filters. Chl *a* concentrations were then calculated from formulae using the absorbance of the supernatant at specific wavelengths.

In 2003, additional water samples were taken at discrete depths, using a Van Dorn sampling bottle, in both the epilimnion and hypolimnion of Kootenay Lake. Epilimnion samples were obtained from depths of 2, 5, 10, 15, and 20 m for analysis at the lab (as above) of TP, TDP, OP, DIN, Chl *a*, and silica. Chl *a* samples were generally analyzed only for depths of 2-15 m. Samples were taken monthly from June to October at KLF 2 and 6, from August to October at KLF 1, 3, 4, 5, and 7, and in August and September at KLF 8. Discrete water samples from the hypolimnion were obtained in September at depths of 50 and 100 m and at a third depth that varied among the stations between 112 and 145 m. A single hypolimnion depth was sampled between 30 and 33 m at the shallow KLF 8. Samples were taken for turbidity, TP, TDP, TN, DIN, silica, and alkalinity. In October and November, a single discrete sample was taken at the deepest depth possible for each station.

In this report, average measurements from the spring, summer, and fall of 1997-2003 are given for the North Arm (KLF 2 and 4) and the South Arm (KLF 6 and 7) of Kootenay Lake. Detailed data and analysis of the 1997-2001 data are available in previous annual reports. All data are on file at the BC Ministry of Environment office in Nelson, B.C.

Results and Discussion

Physical Limnology

Temperature

Kootenay Lake is a monomictic lake, generally mixing from late fall to early spring and stratifying during the summer. In April 2002, diurnal thermoclines were apparent in the surface layers of the lake, and the remainder of the water column was isothermal (Figures 3.1 - 3.7). In April 2003, only the four main stations were sampled (KLF 2 and 4 in the North Arm and KLF 6 and 7 in the South Arm) and showed an isothermal water column from surface to 100 m in the north (Figures 3.2 and 3.4) and slight diurnal stratification in the surface layer in the south with otherwise isothermal conditions (Figures 3.6 and 3.7).

Surface warming continued in both years through May and June, with a thermocline developing in July and becoming stable by the August sampling (Figures 3.1 - 3.7). The stable thermocline generally occurred between about 18 and 35 m depth, although it varied among the stations. The thermocline persisted through September of both years and continued to exist in November 2003, although it had declined to depths between 35 and 50 m. Station KLF 8 was sampled from August to November in 2003 and had an isothermal water column (Table 3.2).

In 2003, the North Arm tended to be warmer both at the surface and in upper layers of the epilimnion than it had been in 2002 (Figures 3.1- 3.4). However, in 2002 the lake attained higher maximum surface water temperatures in both the North and South arms. The highest surface water temperatures in 2002 were recorded on July 22 at 22 ºC in the North Arm and 21.3 ºC in the South Arm. In 2003, they were recorded on August 5 at 20.6 ºC in the North Arm and on September 2 at 19.7 ºC in the South Arm. KLF 8 in the West Arm attained a surface temperature of 18.7 ºC on September 2, 2003 (Table 3.2).

Table 3.2. Temperature and dissolved oxygen at KLF 8, Aug-Nov 2003.

	August		**September**		**November**	
	surface	**depth**	**surface**	**depth**	**surface**	**depth**
Depth (m)	0.1	31.8	0.4	31.7	0.4	33.2
Temperature (ºC)	18.1	18	18.7	18.2	8.9	10.3
Dissolved oxygen (mg/L)	12.4	11.6	12.3	11	14.6	12.1

Dissolved oxygen

Dissolved oxygen profiles in Kootenay Lake showed an oxygen-saturated water column throughout the sampling season with values ranging from about 11-16 mg/L in 2002 and 2003 (Figures 3.8 - 3.14). In April through July and again in November, oxygen concentrations remained fairly uniform throughout the water column. In August and September, epilimnion dissolved oxygen declined slightly to display an orthograde profile, which is typical of lakes with relatively low productivity (Wetzel 2001). An orthograde profile occurs as an oligotrophic lake stratifies and the temperature increase in the epilimnion causes the oxygen concentration to decrease. During the orthograde periods of 2003, the epilimnion oxygen concentrations were generally 1-2 mg/L lower than the epilimnion concentrations during spring overturn. The July to September oxygen profiles had similar concentrations at all stations between 2002 and 2003. At KLF 8 in August to November, 2003, dissolved oxygen concentrations varied only slightly between the surface and 33 m depth (Table 3.2).

Redox potential

Redox potential in 2002 was measured as being very low, between 0 and 143 mV, which may have been an equipment error or miscalibration. In most lakes with 100% oxygen saturation, the redox potential is at about 500 mV and only declines below 200 mV near the mud-water interface when oxygen concentrations are low (Horne and Goldman 1994). In 2003 in Kootenay Lake, the measured redox values were higher than in 2002 with a range of 338-506 mV (data not shown). At each station in 2003, there was generally an increase of 10-20 mV from the surface to 100 m, and there was no north to south trend.

Secchi depth

In 2002, Secchi depth in Kootenay Lake varied between 3.4 m and 13.4 m in the North Arm and 2.1 m and 10.1 m in the South Arm (Figure 3.15). In 2003, the depth ranges were 4.3-12.8 m in the North Arm and 4.0-12.2 m in the South Arm. In both years, Secchi depth followed the expected pattern for an oligo-mesotrophic lake of decreasing in May, June, and early July, concurrent with the spring phytoplankton bloom, and clearing again as summer progressed.

Average spring Secchi depths in both North and South arms were similar in the period 2001 to 2003, but in these years Secchi depth was deeper (more transparent) than in 1997 and 1998 (Table 3.3). Over the period 1997-2003, the average spring values have ranged from 4.8-9.4 m in the North Arm and 3.1-7.7 m in the South Arm. In Table 3.3, the spring measurements are frequently deeper than the summer or fall measurements because April data were included in the spring averages and transparency tends to be highest in April (Figure 3.15). The increase of Secchi depth from 1997-98 to 2001-03 is not apparent in either summer or fall average measurements. Average summer Secchi depths showed the same range in the North Arm (5.2-7.6 m) as in the South Arm (5.1-7.5 m), while average fall depths varied more between the basins with 6.7-10.1 m in the North Arm and 4.7-9.6 m in the South Arm (Table 3.3).

Table 3.3. Average Secchi depth (m) from 0-30 m in spring (April-June), summer (July-September), and fall (October) for the North and South arms of Kootenay Lake, 1997-2003. The 2003 fall data are for October and November.

Year	North Arm KLF 2 & 4			South Arm KLF 6 & 7		
	Spring	**Summer**	**Fall**	**Spring**	**Summer**	**Fall**
1997	4.8	5.6	8.4	3.1	5.1	7.6
1998	6.6	7.6	6.7	5.2	7.5	7.5
1999	7.3	5.2	9.0	6.2	5.6	8.2
2000	6.4	6.0	7.3	6.4	6.5	9.6
2001	8.0	6.5	10.1	7.2	7.4	8.7
2002	9.4	5.8	7.9	6.6	5.5	4.7
2003	8.8	6.4	7.7	7.7	6.0	9.1

Turbidity

Turbidity measurements increased concurrently with the decrease in Secchi depth during the spring phytoplankton bloom and then declined through the summer and into the fall (Figure 3.15). This trend was more pronounced in 2002 than in 2003, but it was evident in both years. In the period 1997-2003, average turbidity values ranged from 0.29-0.99 NTU in the North Arm and 0.25-0.96 NTU in the South Arm, with a possible outlier of 1.80 NTU occurring in the South Arm in the spring of 1997 (Table 3.4).

Table 3.4. Average turbidity (NTU) from 0-30 m in spring (April-June), summer (July-September), and fall (October) for the North and South arms of Kootenay Lake, 1997-2003. The 2003 fall data are for October and November.

Year	North Arm KLF 2 & 4			South Arm KLF 6 & 7		
	Spring	Summer	Fall	Spring	Summer	Fall
1997	0.65	0.65	0.36	1.80	0.66	0.43
1998	0.46	0.72	0.44	0.74	0.39	0.25
1999	0.61	0.72	0.39	0.83	0.57	0.36
2000	0.42	0.47	0.55	0.69	0.41	0.25
2001	0.29	0.60	0.35	0.29	0.40	0.36
2002	0.61	0.99	0.42	0.96	0.73	0.48
2003	0.35	0.62	0.41	0.50	0.66	0.42

Conductivity

The conductivity or specific conductance of lake water indicates its resistance to electrical current, which is dependent on dissolved ions in the water (Wetzel 2001). In 2002, conductivity ranged from 121-164 µmhos/cm and in 2003 from 122-171 µmhos/cm (Figure 3.15). The 2003 measurements were taken with the Hydrolab only in early spring; for the remainder of the sampling period, conductivity was measured from water samples at the chemistry lab. In 1997-2003, conductivity in Kootenay Lake averaged 92-163 µmhos/cm in the North Arm and 133-183 µmhos/cm in the South Arm (Table 3.5).

Table 3.5. Average conductivity (µmhos/cm) from 0-30 m in spring (April-June), summer (July-September), and fall (October or November) for the North and South arms of Kootenay Lake, 1997-2003.

Year	North Arm KLF 2 & 4			South Arm KLF 6 & 7		
	Spring	Summer	Fall	Spring	Summer	Fall
1997	163	143	152	165	161	173
1998	153	146	148	164	169	176
1999	162	135	106	183	144	133
2000	92	132	134	146	153	159
2001		142	134		162	167
2002	155	125	127	151	157	150
2003	154	135	127	159	153	153

Chemical Limnology

Phosphorus

Total phosphorus (TP) ranged from 2-11 µg/L in 2002 and 2-21 µg/L in 2003 (Figure 3.16). The higher range in 2003 was due to sampling being continued into November when fall mixing had occurred and TP concentrations had increased. During the 2002 sampling season, TP increased between April and June as nutrients were brought into the lake by spring runoff. TP then decreased in July and August as thermal stratification set in and the phytoplankton spring bloom declined (Figure 3.16). Another increase occurred in September and may have been associated with the beginning of fall mixing, although the temperature profiles indicate that the lake remained fairly well stratified in September 2002. The 2003 data are less clear in terms of the expected pattern of TP during the season. A small increase in TP was seen in spring only at station KLF 2. TP then peaked in mid-summer, declined in early fall, and increased significantly with fall overturn in November (Figure 3.16).

With average TP values generally in the range of 3-10 µg/L (Table 3.6), Kootenay Lake is considered to be an oligotrophic to oligo-mesotrophic lake (Wetzel 2001). In the spring of 1997, however, TP concentrations averaged 14 µg/L in the North Arm and 22 µg/L in the South Arm, both of which were due to high June concentrations. There have been no consistent trends over the 1997-2003 period, and average concentrations in both basins of the lake have been comparable.

Table 3.6. Average total phosphorus (TP; µg/L) from 0-30 m in spring (April-June), summer (July-September), and fall (October) for the North and South arms of Kootenay Lake, 1997-2003. The 2003 fall data are for October and November.

Year	**North Arm KLF 2 & 4**			**South Arm KLF 6 & 7**		
	Spring	**Summer**	**Fall**	**Spring**	**Summer**	**Fall**
1997	14.0	10.5	5.0	22.2	8.8	6.0
1998	4.3	7.0	4.5	5.0	6.8	5.5
1999	4.8	5.5	4.5	6.2	5.3	6.5
2000	5.0	10.0	7.5	5.8	9.2	7.5
2001	7.7	6.0	3.0	3.5	4.8	2.5
2002	6.3	3.8	5.5	7.8	5.2	3.5
2003	3.5	5.0	7.8	4.3	4.5	4.0

Total dissolved phosphorus (TDP) followed the same seasonal trends as TP in 2002 and 2003 and ranged from 2-7 µg/L in 2002 and from 2-10 µg/L in 2003 (Figure 3.16). Since 1997, TDP concentrations have been 2-5 µg/L with a high of 8 µg/L in spring 1997 (Table 3.7), corresponding to the high TP recorded at this time. There was no apparent trend over the 1997-2003 period. When above detection limit (2 µg/L), TDP values tended to be slightly higher in the South Arm than in the North Arm in most seasons and most years (Table 3.7).

Table 3.7. Average total dissolved phosphorus (TDP; µg/L) from 0-30 m in spring (April-June), summer (July-September), and fall (October) for the North and South arms of Kootenay Lake, 1997-2003. The 2003 fall data are for October and November.

Year	North Arm KLF 2 & 4			South Arm KLF 6 & 7		
	Spring	Summer	Fall	Spring	Summer	Fall
1997	4.3	3.5	4.0	8.0	4.3	3.0
1998	2.7	2.0	2.0	3.3	2.0	2.0
1999	2.8	2.3	2.5	3.0	2.3	2.5
2000	2.0	3.5	4.0	2.5	5.0	4.5
2001	3.5	2.0	2.0	2.2	2.7	2.5
2002	4.0	2.8	4.0	4.0	4.0	3.0
2003	2.8	2.5	3.5	3.2	3.3	4.8

Nitrogen

Total nitrogen (TN) ranged from 90-380 µg/L in 2002 and 100-210 µg/L in 2003 (Figure 3.17). During both the 2002 and 2003 sampling seasons, TN showed an overall decline in concentration with mid-summer and fall increases at some stations. Less variability among stations and over the season occurred in 2003. Average TN values from 1997-2003 were 125-343 µg/L in the North Arm and 90-235 µg/L in the South Arm (Table 3.8). There have been no consistent trends over the 1997-2003 period, but in most years the declining trend from spring to fall was evident.

Table 3.8. Average total nitrogen (TN; µg/L) from 0-30 m in spring (April-June), summer (July-September), and fall (October) for the North and South arms of Kootenay Lake, 1997-2003. The 2003 fall data are for October and November.

Year	North Arm KLF 2 & 4			South Arm KLF 6 & 7		
	Spring	Summer	Fall	Spring	Summer	Fall
1997	218	143	130	212	130	125
1998	225	192	135	227	187	150
1999	220	190	275	228	180	220
2000	213			177		
2001	343	167	145	215	163	105
2002	200	177	175	210	180	235
2003	182	302	125	177	155	90

Dissolved inorganic nitrogen (DIN) consists of nitrite, nitrate, and ammonia, the latter two being the inorganic forms of nitrogen most readily available to phytoplankton. Ammonia is a waste product of aquatic animals and of bacterial decomposition. In the absence of anthropogenic sources, concentrations are usually low because ammonia is quickly converted to nitrite and then to nitrate by nitrifying bacteria (Wetzel 2001). DIN concentrations showed a more pronounced declining trend over the sampling season compared with TN, corresponding to nitrate (the dominant component of DIN) being used by phytoplankton during summer stratification. DIN ranged from 7-176 µg/L in 2002 and from 8-147 µg/L in 2003 (Figure 3.17). Since 1997, DIN concentrations have been 32-157 µg/L in the North Arm and 42-145 µg/L in the South Arm (Table 3.9). There was no apparent trend over the 1997-2003 period.

Table 3.9. Average dissolved inorganic nitrogen (DIN; µg/L) from 0-30 m in spring (April-June), summer (July-September), and fall (October) for the North and South arms of Kootenay Lake, 1997-2003. The 2003 fall data are for October and November.

Year	North Arm KLF 2 & 4			South Arm KLF 6 & 7		
	Spring	**Summer**	**Fall**	**Spring**	**Summer**	**Fall**
1997	118	89	70	113	64	62
1998	120	75	32	123	83	86
1999	147	94	90	130	80	77
2000	35	69	71	42	54	68
2001	157	82	69	145	83	57
2002	133	75	58	108	44	57
2003	108	50	67	114	71	63

Silica

Dissolved reactive silica concentrations declined over the sampling season in both 2002 and 2003 from values of approximately 5-6.5 mg/L in spring to 3-4 mg/L in the fall (Figure 3.18). Although silica declined over the season, the concentrations in fall were well above 0.5 mg/L, which is the concentration considered to be limiting to diatom algae (Wetzel 2001). Silica concentrations tended to be higher in the South Arm than the North Arm early in 2002 and later in 2003. This north-south difference and the declining seasonal trend are also evident in the 1997-2003 data (Table 3.10).

Table 3.10. Average silica (mg/L) from 0-30 m in spring (April-June), summer (July-September), and fall (October) for the North and South arms of Kootenay Lake, 1997-2003. The 2003 fall data are for October and November.

Year	North Arm KLF 2 & 4			South Arm KLF 6 & 7		
	Spring	**Summer**	**Fall**	**Spring**	**Summer**	**Fall**
1997	4.8	4.0	3.5	6.8	5.1	4.3
1998	4.9	4.2	3.5	6.3	5.3	4.7
1999	5.1	5.0	4.2	6.1	4.1	4.9
2000	5.4	4.4	3.3	6.4	5.4	4.3
2001	5.4	3.4	2.2	5.5	4.6	3.5
2002	5.2	3.5	4.0	6.0	4.2	4.7
2003	5.3	3.3	3.2	5.6	4.5	4.0

pH and alkalinity

At all stations, pH remained stable from the surface to 100-m depth (data not shown). In 2002, the pH range was measured at 7.5-8.1 and in 2003 at 7.6-8.8. These pH values indicate that Kootenay Lake is slightly alkaline and within the typical range for lakes. Alkalinity, not to be confused with an alkaline pH, is the buffering capacity of lake water to resist pH changes and involves the inorganic carbon components in most fresh waters (Wetzel 2001). Alkalinity in 2002 and 2003 decreased during the spring months and then rebounded or remained stable (Figure 3.18). The range measured was 51-76 mg $CaCO_3$/L in 2002 and 54-73 mg $CaCO_3$/L in 2003. From 1997-2003, average alkalinity remained stable with a range of 53-68 mg $CaCO_3$/L in the North Arm and 63-72 mg $CaCO_3$/L in the South Arm (Table 3.11).

Table 3.11. Average alkalinity (mg $CaCO_3$/L) from 0-30 m in spring (April-June), summer (July-September), and fall (October) for the North and South arms of Kootenay Lake, 1997-2003. The 2003 fall data are for October and November.

Year	North Arm KLF 2 & 4			South Arm KLF 6 & 7		
	Spring	**Summer**	**Fall**	**Spring**	**Summer**	**Fall**
1997	64	55	57	67	63	67
1998	65			67		
1999						
2000	62	58	57	63	66	70
2001		63	59		72	72
2002	68	53	58	66	67	69
2003	67	61	59	68	68	70

Total organic carbon

Total organic carbon (TOC) consists of both dissolved and particulate organic carbon, with most particulates being detrital material (Wetzel 2001). Living organisms (bacteria, phytoplankton, protozoans) represent only a small fraction of total particulate organic carbon. In Kootenay Lake, TOC in 2002 ranged from 0.8-2.7 mg/L with highest concentrations measured at KLF 6 in summer and at KLF 7 in spring and summer (Figure 3.19). These peaks are likely the result of allochthonous (origin outside the lake) organic inputs to the South Arm. In 2003, the range was slightly smaller (1-2.3 mg/L) and the South Arm peak less evident than in 2002. Average TOC from 1997-2003 was 0.6-1.8 mg/L in the North Arm and 0.9-1.9 mg/L in the South Arm (Table 3.12). These values are at the low end of the typical range of 1-30 mg TOC/L in natural waters (Wetzel 2001) and suggest that the lake does not receive large allochthonous organic inputs or produce large amounts of autochthonous organic carbon.

Table 3.12. Average total organic carbon (TOC; mg/L) from 0-30 m in spring (April-June), summer (July-September), and fall (October) for the North and South arms of Kootenay Lake, 1997-2003.

Year	North Arm KLF 2 & 4			South Arm KLF 6 & 7		
	Spring	**Summer**	**Fall**	**Spring**	**Summer**	**Fall**
1997	0.8	1.4	0.6	1.4	1.6	0.9
1998	1.1	1.5	1.2	1.5	1.8	1.5
1999	1.8	1.3	1.3	1.8	1.7	1.6
2000	1.0	1.1	1.1	1.3	1.3	1.2
2001	1.0	1.2	1.1	1.0	1.4	1.0
2002	1.2	1.2	1.2	1.6	1.9	1.6
2003	1.4	1.6	1.4	1.6	1.5	1.7

***Chlorophyll* a**

Chlorophyll *a* (Chl *a*) concentrations indicate a lake's phytoplankton standing crop and, to a lesser extent, its productivity (Burgis and Morris 1987). Concentrations in Kootenay Lake were in the range of 1.4-5.1 µg/L in 2002 and 0.5-4.9 µg/L in 2003 (Figure 19). Over the sampling season, Chl *a* at North Arm stations generally increased in spring corresponding with the phytoplankton bloom, decreased during the summer, and increased again in the fall with mixing of the water column. The trend was similar at South Arm stations in these years, but was less pronounced and had lower spring Chl *a* concentrations. From 1997-2003, average Chl *a* had similar ranges in both basins with 1.1-4.1 µg/L in the North Arm and 0.8-4.8 µg/L in the South Arm (Table 13). Average spring and summer Chl *a* concentrations were often, but not always, higher in the North Arm, which is the location of the experimental nutrient additions.

Table 3.13. Average chlorophyll *a* (Chl *a*; µg/L) from 0-30 m in spring (April-June), summer (July-September), and fall (October) for the North and South arms of Kootenay Lake, 1997-2003. The 2003 fall data are for October and November.

Year	North Arm KLF 2 & 4			South Arm KLF 6 & 7		
	Spring	**Summer**	**Fall**	**Spring**	**Summer**	**Fall**
1997	4.1	1.7	2.2	2.4	1.9	4.3
1998	2.0	1.5	1.0	2.3	1.6	1.1
1999	2.6	1.8	1.6	3.5	1.7	2.1
2000	3.5	1.5	1.1	1.1	1.2	1.1
2001	2.8	2.6	1.1	2.2	1.7	0.8
2002	3.2	3.5	4.1	2.4	3.8	4.8
2003	1.6	3.2	1.7	1.2	1.8	1.4

Discrete depth sampling in 2003

Epilimnion – North Arm

Water samples from 2, 5, 10, 15, and 20 m were analyzed for TP, TDP, DIN, silica, and Chl *a* in 2003. KLF 2 in the North Arm and KLF 6 in the South Arm were sampled monthly from June to October, and all other stations, including KLF 8 in the West Arm, were sampled monthly from August to October.

In the North Arm, TP and TDP generally varied little or not at all with depth (Figures 3.20 – 3.23). Exceptions were in August at KLF 1 and 3 where TP increased with depth (Figures 3.20 and 3.22) and in July at KLF 2 with a TP peak of 7 µg/L and TDP of 4 µg/L at 15 m (Figure 3.21). Other smaller variations were also measured in some months.

DIN was more variable, showing some increase with depth in June and July at KLF 2 (Figure 3.21), no increase with depth in August or October except in August at KLF 4 (Figure 3.23), and significant increases with depth in September at all North Arm stations (Figures 3.20 – 3.23). The uniform August values were also low, as expected in the stratified water column. The September increase may have been due to a weakening of the thermocline and entrainment of nutrient-rich water from the hypolimnion.

Chl *a* concentrations do not reflect the nutrient values, but do indicate that Chl *a* maxima, generally between 6-8 µg/L, frequently occurred at depths of 5 or 10 m (and likely between these depths) in August and September at North Arm stations (Figures 20-23). At 2 m and 15 m, Chl *a* concentration was most often at or less than 2 µg/L. Chl *a* measurements were not taken at 20 m.

Silica concentrations were generally uniform through the epilimnion, although they increased slightly with depth at all North Arm stations in September (Figures 3.20 – 3.23). The lowest concentrations measured were 1.2-1.4 mg/L at KLF 1 in August. Even the lowest of these concentrations is well above the concentration of 0.5 mg/L considered to limit diatom growth (Wetzel 2001).

Epilimnion – South Arm

At the South Arm stations, TP and TDP were low (2 µg/L) and uniform throughout the epilimnion in June and July at KLF 6 (Figure 3.25) and at all stations in September and October (Figures 3.24 – 3.26). In August, TP and TDP were higher, with increased TP (10-15 µg/L) at lower depths at KLF 5 and 6 and decreased TP at lower depths at KLF 7.

DIN generally increased with depth at all stations and months, except in October when DIN was uniform or declining with depth in the water column (Figures 3.24 – 3.26).

Chl *a* was uniform with depth and less than 2 µg/L in June and July at KLF 6 (Figure 3.25) and varied among depth and station in August to October. When present in these months, Chl *a* maxima tended to occur at depths of 5 or 10 m and to concentrations of 4-7 µg/L (Figures 3.24 – 3.26).

As in the North Arm, silica concentrations at South Arm stations were uniform throughout the water column except in September when they increased by 1-2 mg/L from 2-20 m depth (Figures 3.24 – 3.26).

Epilimnion – West Arm
At KLF 8 in the West Arm of Kootenay Lake, discrete samples were taken in August and September. August TP and TDP were higher at KLF 8 than at most other stations, with TP concentrations of 8-9 µg/L and TDP concentrations of 6-9 µg/L (Figure 3.27). In September, TP and TDP were similar to other stations and among depths, except for a TP peak of 9 µg/L at 15 m.

DIN was uniform in the epilimnion and at low concentration in both months (Figure 3.27). Unlike concentrations at all other stations in September, DIN at KLF 8 did not increase with depth.

Chl *a* showed a small increase from 2-5 m and then decreased to 15 m in August (Figure 3.27). In September, Chl *a* concentrations were higher at 2 and 5 m, decreased at 10 m and peaked at 15 m, corresponding to the TP peak at this depth.

Silica was uniform in the epilimnion in both August and September (Figure 3.27).

Hypolimnion – all stations
Water samples from 50 and 100 m and a third depth between 112 and 145 m were sampled in September, while single samples from the 112-145 m depth were taken in either or both of October and November. KLF 8, being shallow, had single samples taken in all three months from a depth of 30-33 m. In contrast to the figures of epilimnetic data, the data from the hypolimnion in all three months are included on the same plot.

Turbidity in September was highest at 33 m at KLF 8 with 0.32 NTU. At the North and South arm stations, values varied somewhat with depth, but no consistent trend was apparent (Figure 3.28).

TP and TDP concentrations were generally consistent with depth at 2 µg/L, with increases occurring at the deepest depths of KLF 2 and KLF 5 (Figure 3.29). In October at some stations and in November at all North and South arm stations, TP increased at depth to between 9 and 13 µg/L, in conjunction with fall overturn that mixed nutrients from deep in the lake. At 30-33 m at KLF 8, however, TP and TDP remained at or below 3 µg/L in both September and November (no October sample).

TN concentrations varied little at most stations in September, except at KLF 2 where TN increased from 250 µg/L at 50 m to 580 µg/L at 100 m (Figure 30). TN in October was, in most cases, similar to September concentrations; no TN samples were taken in November. DIN in the hypolimnion was consistently higher than concentrations in the epilimnion. With the exception of KLF 2 in September and KLF 5 in November, DIN was measured at 160-215 µg/L. At KLF 8, DIN was <60 µg/L in both September and November.

Silica increased slightly with depth in the hypolimnion at all North and South arm stations and tended to remain at similar concentrations in October and November (Figure 3.31). Concentrations ranged between 5 and 6.6 mg/L at most stations and depths. In November at KLF 5, silica declined to 3.8 mg/L and September and November concentrations at KLF 8 were 2.5 and 3.5 mg/L respectively.

Alkalinity increased with depth in September at all North and South arm stations from 64-72 mg/L (Figure 3.32). At North Arm stations, alkalinity decreased slightly in October and increased again in November, while at South Arm stations, alkalinity increased slightly in October and to a greater extent in November. At KLF 8, alkalinity remained close to 65 mg/L in both September and November.

TOC ranged from 0.9-1.8 mg/L at all stations in September and, at most stations, varied little with depth (Figure 3.33). An increase from 1.2 mg/L at 50 m to 1.8 mg/L at 130 m occurred at KLF 4 and was the greatest change measured. October concentrations were similar to September values.

Conclusions

Kootenay Lake is oligotrophic to mesotrophic based on nutrient and chlorophyll *a* concentrations in the epilimnion (0-30 m) from 1997-2003. Oxygen profiles in the North and South arms have an orthograde curve during thermal stratification that is consistent with low productivity. Kootenay Lake appears to be phosphorus limited and, at times, nitrogen limited. Summer nitrogen limitation was seen in several discrete samples taken in August and September from the epilimnion. Nitrogen limitation in summer was less evident from the 0-30 m integrated samples, emphasizing the value of conducting some discrete depth sampling. There is no evidence of silica limitation for the phytoplankton community. Limnological measurements were generally similar between the North and South arms of the lake, although TDP and silica tended to be higher at southern stations and Chl *a* higher at northern stations. This higher Chl *a* is consistent with the location of the fertilization zone in the lake's North Arm. The West Arm (KLF 8), which is the lake's outflow, differed from the main lake in some measurements, but comparisons are difficult with few data available for KLF 8 on a seasonal basis and no data from previous years. Discrete samples in the epilimnion indicated that a Chl *a* maxima frequently occurred at 5-10 m depth.

Acknowledgements

Kootenay Wildlife Services Ltd. collected the water samples and conducted the physical limnology measurements. Funding was provided by the Columbia Basin Fish and Wildlife Compensation Program, the Ministry of Water, Land and Air Protection and the Kootenai Tribe of Idaho.

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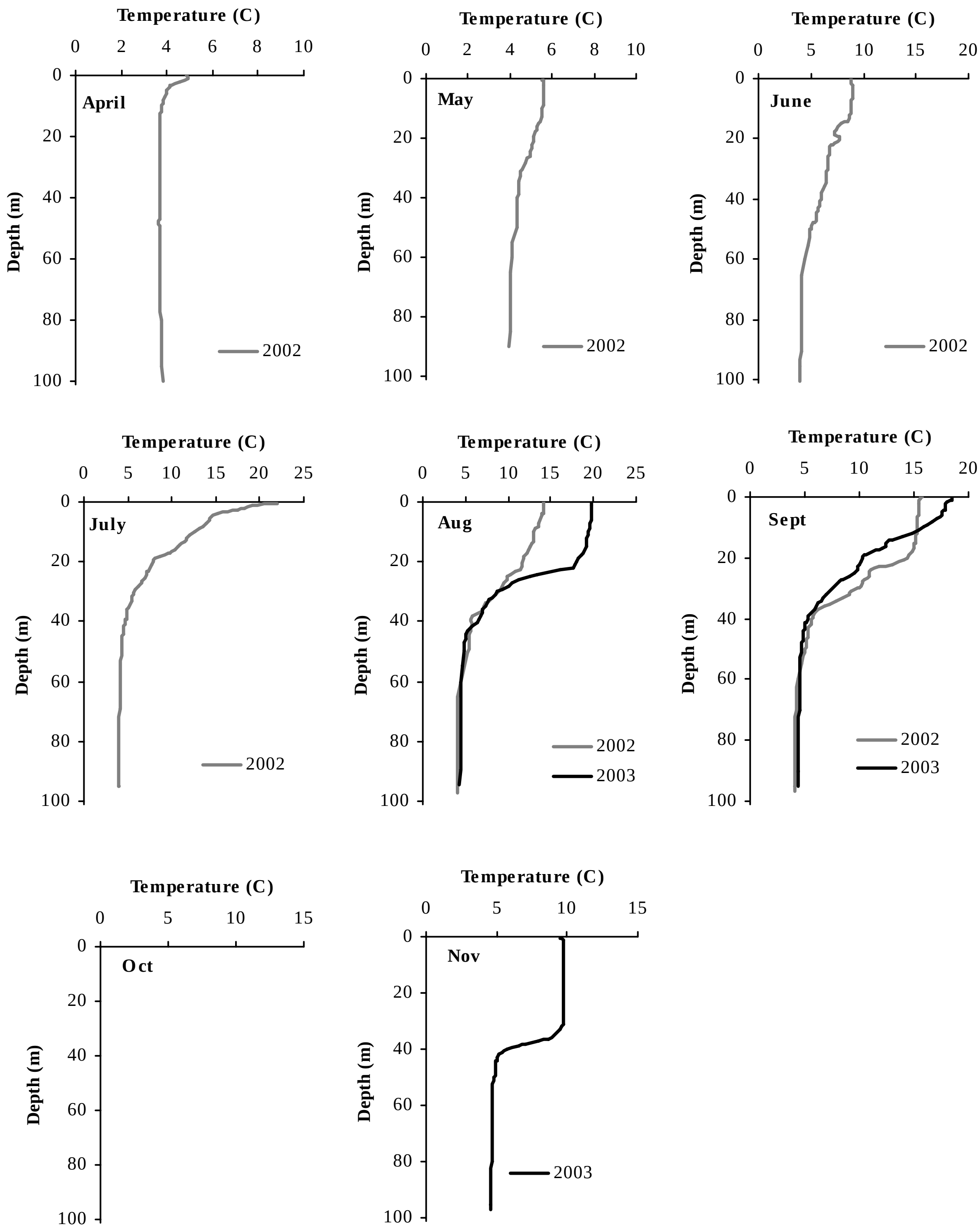

Figure 3.1. Temperature profiles at KLF 1 from April to November, 2002 and 2003.

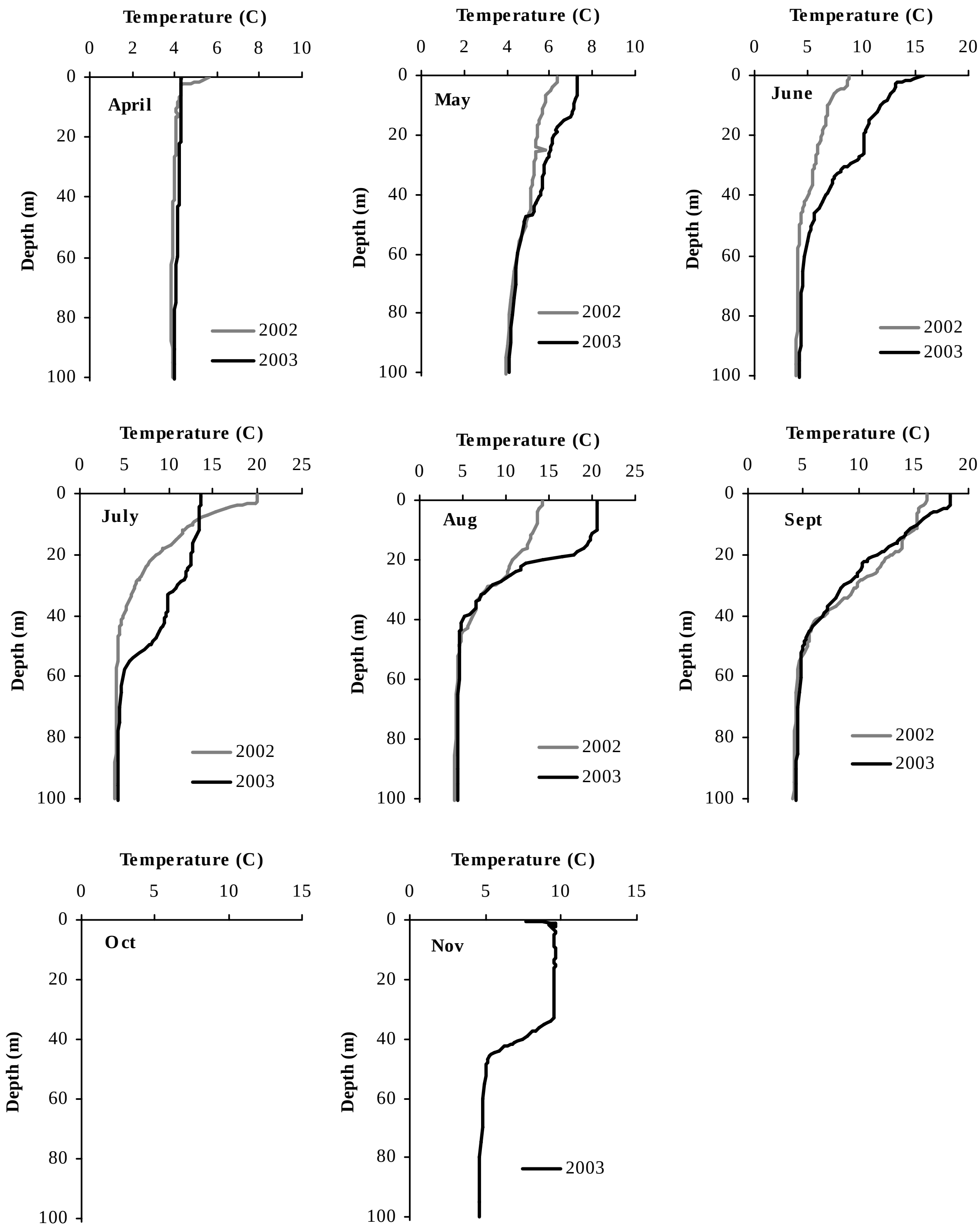

Figure 3.2. Temperature profiles at KLF 2 from April to November, 2002 and 2003.

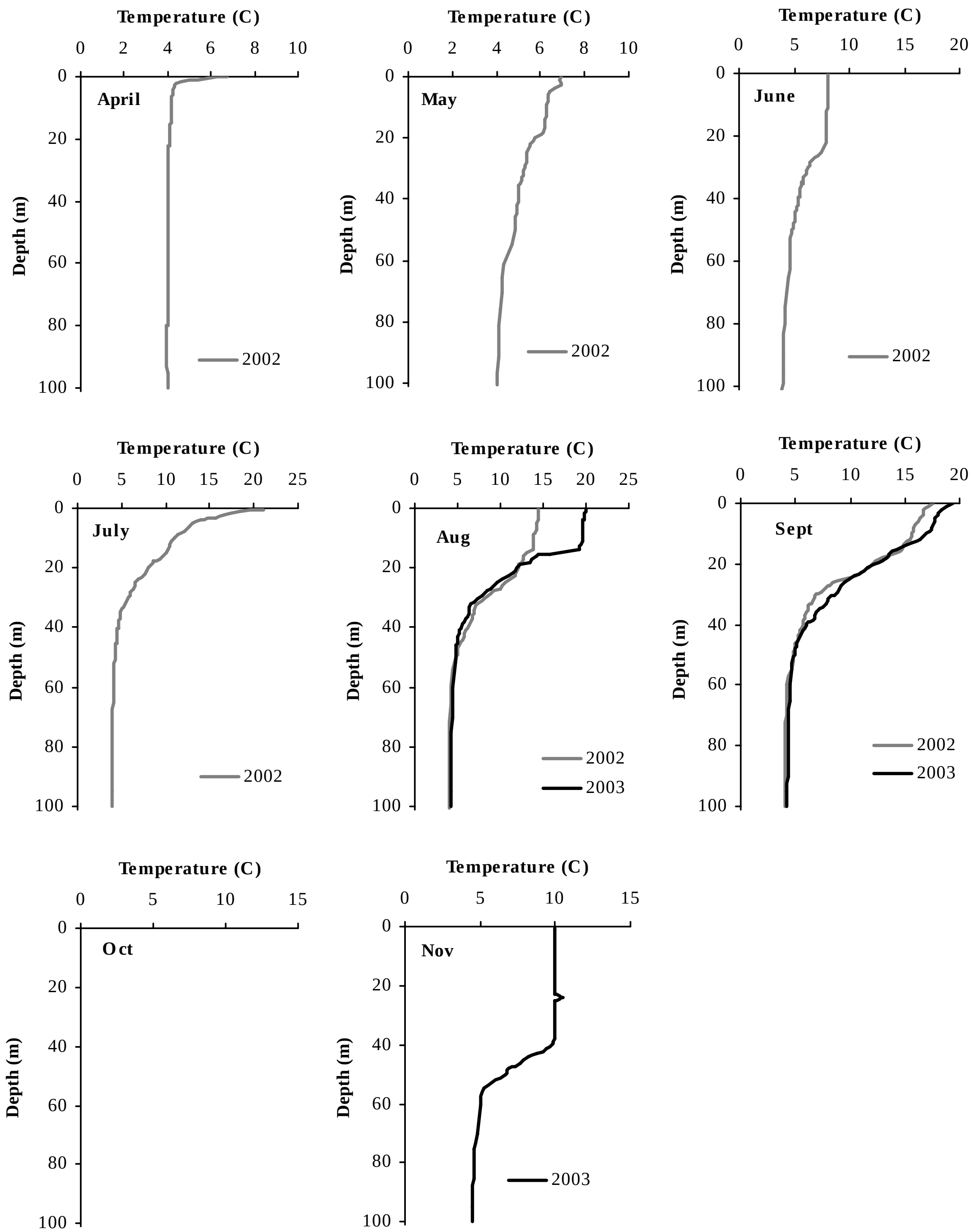

Figure 3.3. Temperature profiles at KLF 3 from April to November, 2002 and 2003.

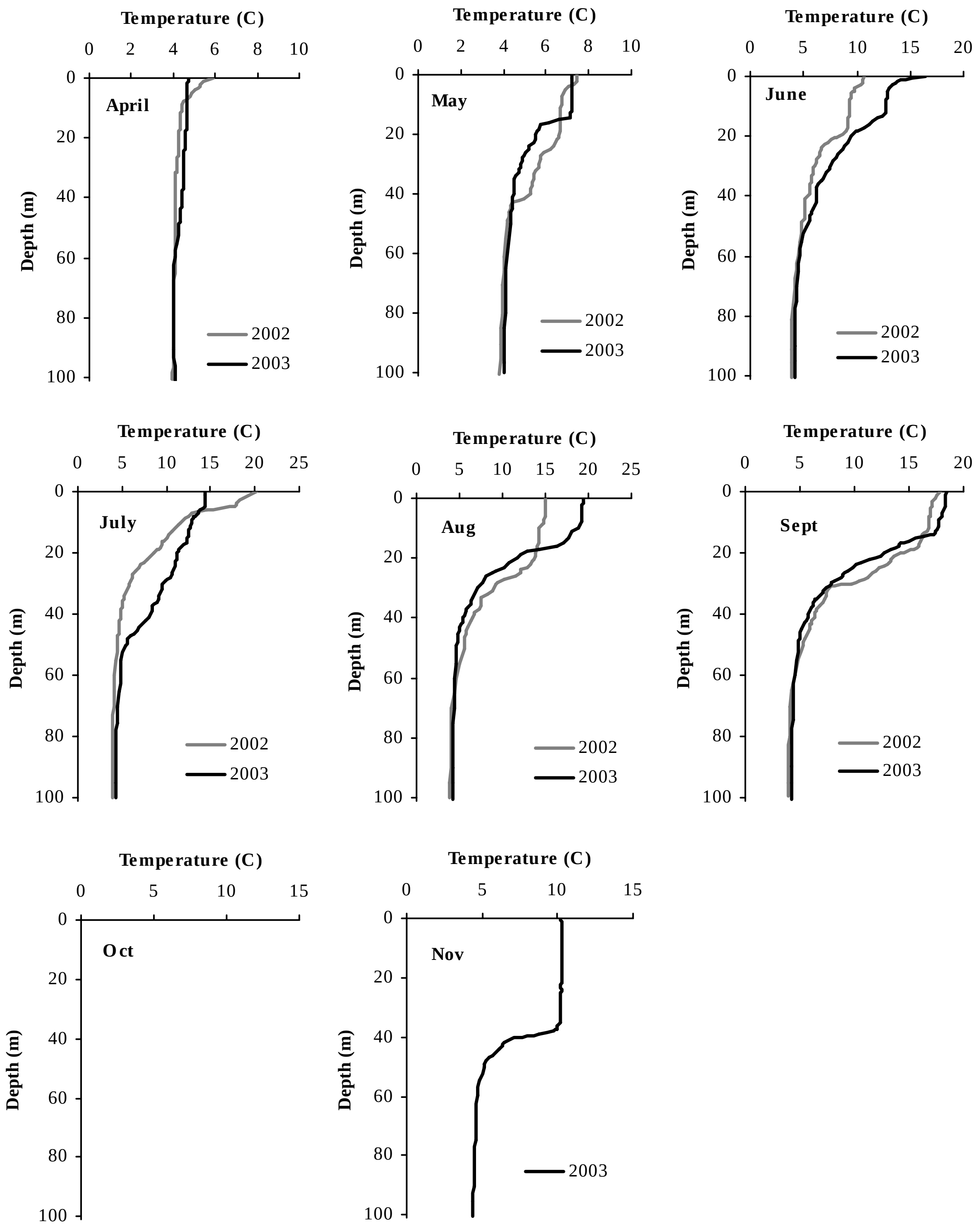

Figure 3.4. Temperature profiles at KLF 4 from April to November, 2002 and 2003.

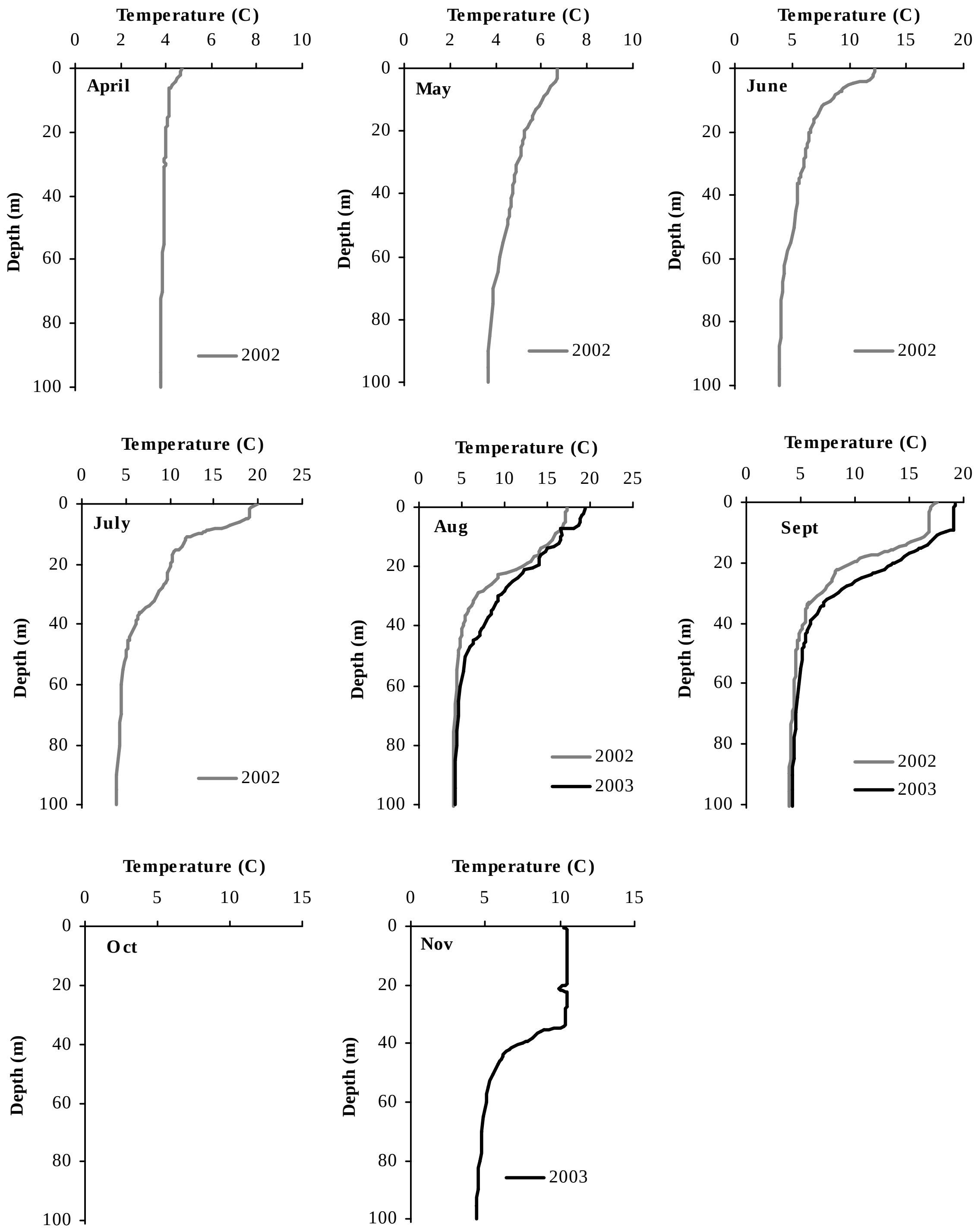

Figure 3.5. Temperature profiles at KLF 5 from April to November, 2002 and 2003.

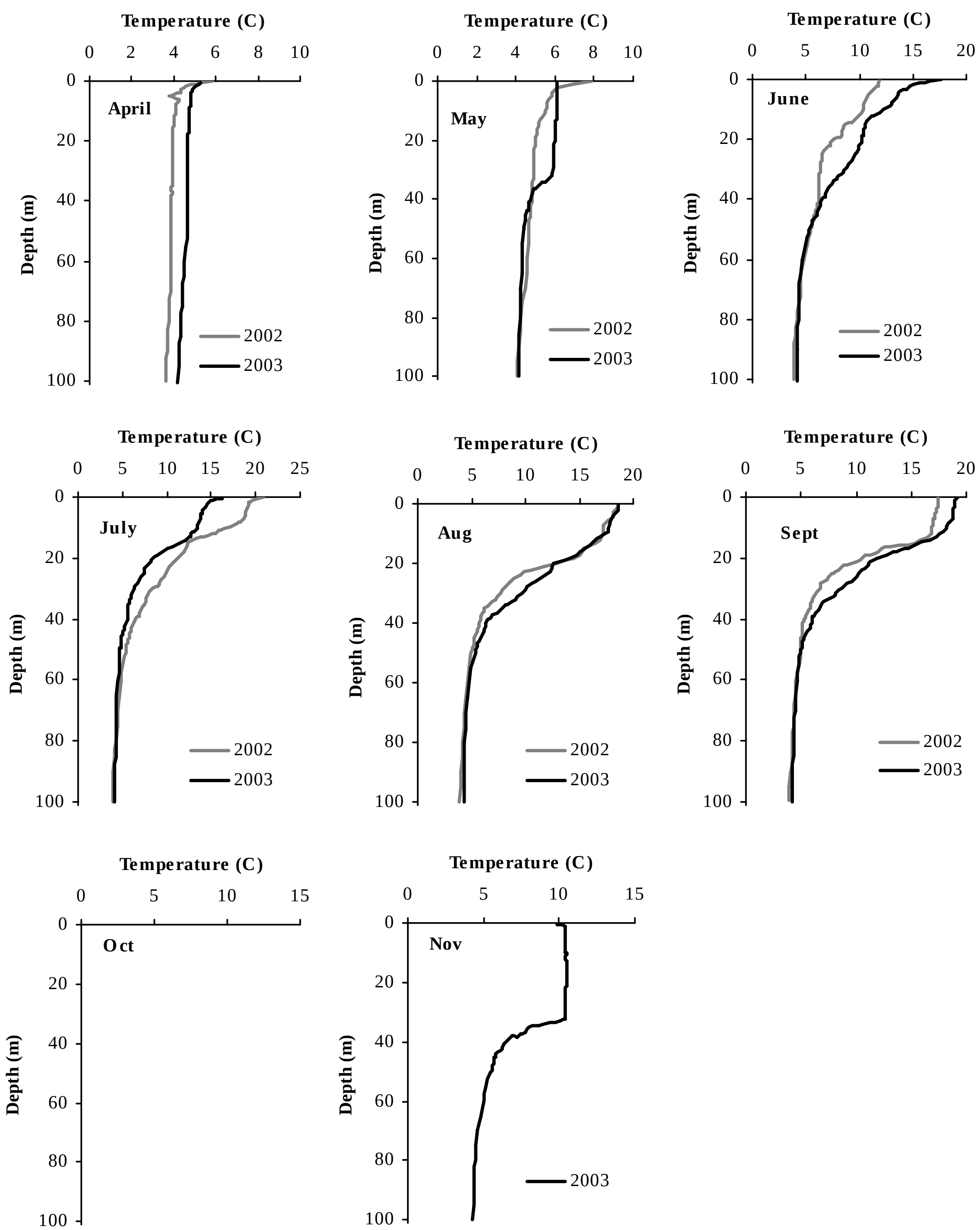

Figure 3.6. Temperature profiles at KLF 6 from April to November, 2002 and 2003.

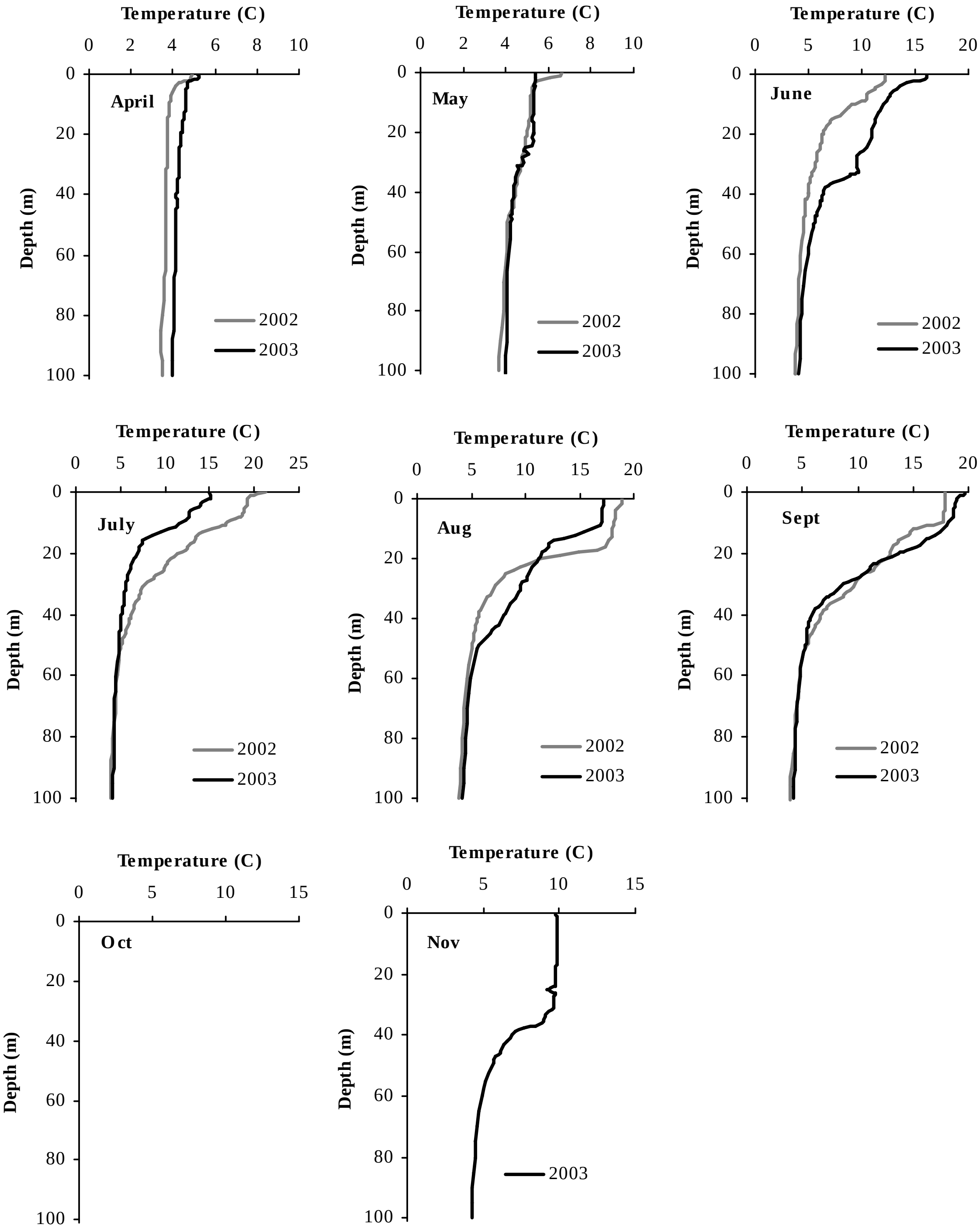

Figure 3.7. Temperature profiles at KLF 7 from April to November, 2002 and 2003.

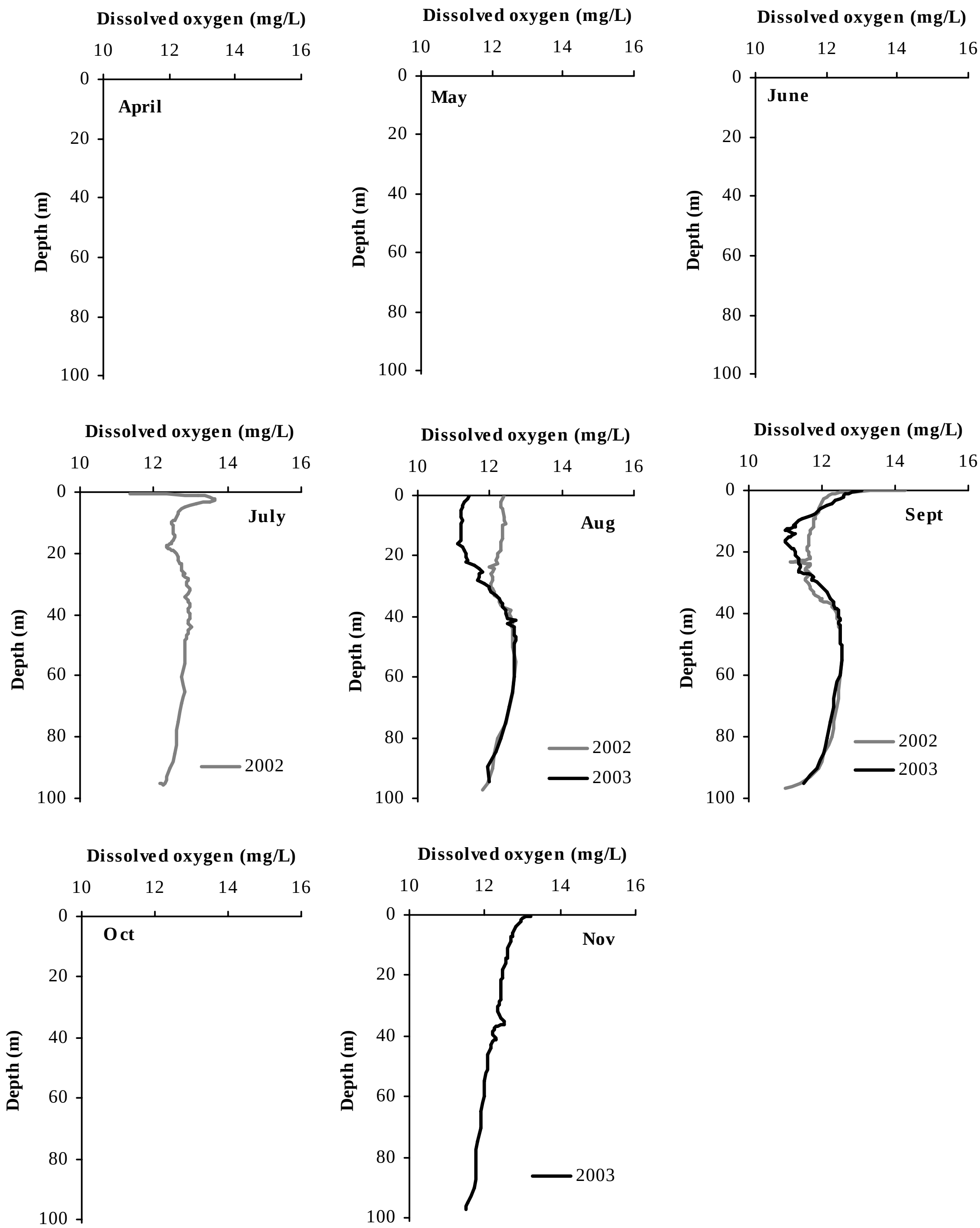

Figure 3.8. Dissolved oxygen profiles at KLF 1 from April to November, 2002 and 2003.

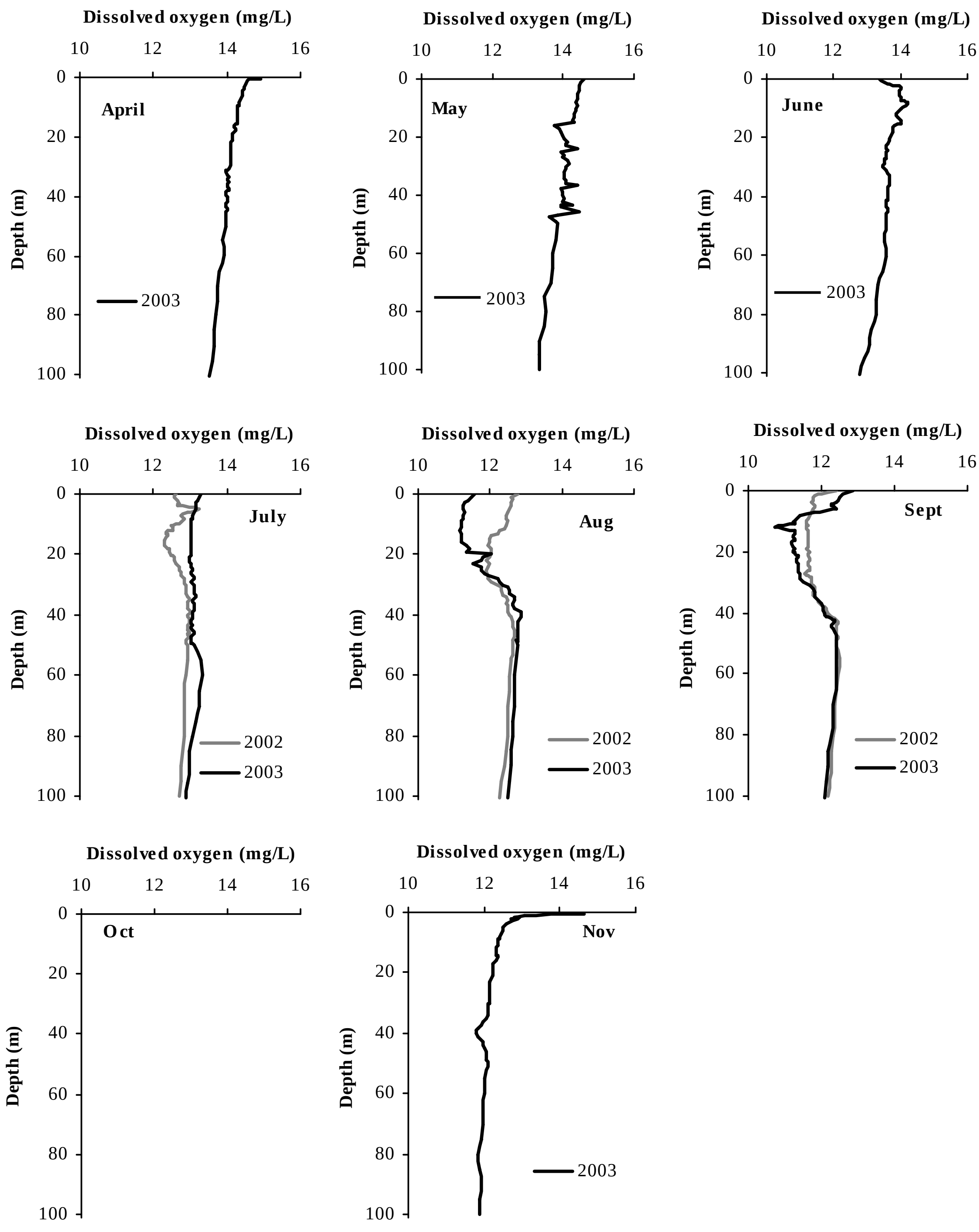

Figure 3.9. Dissolved oxygen profiles at KLF 2 from April to November, 2002 and 2003.

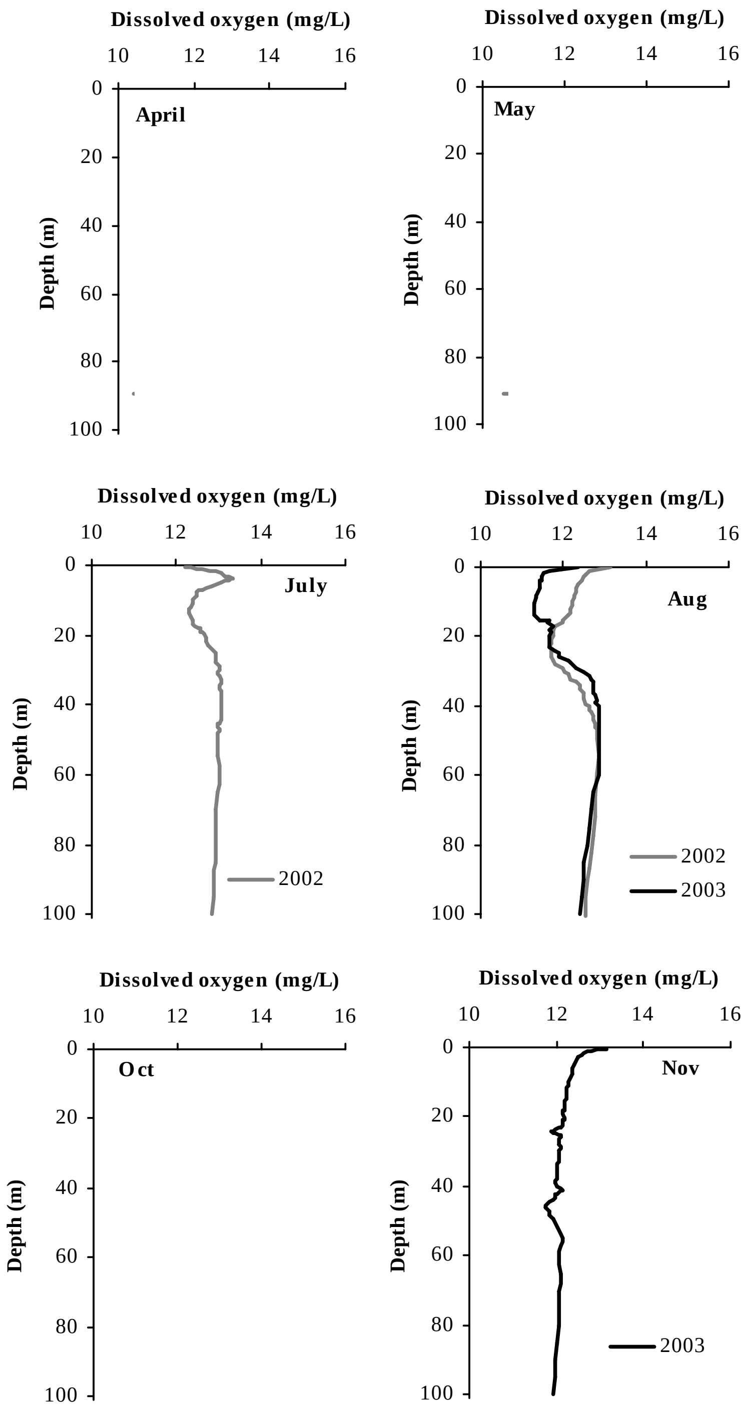

Figure 3.10. Dissolved oxygen profiles at KLF 3 from April to November, 2002 and 2003.

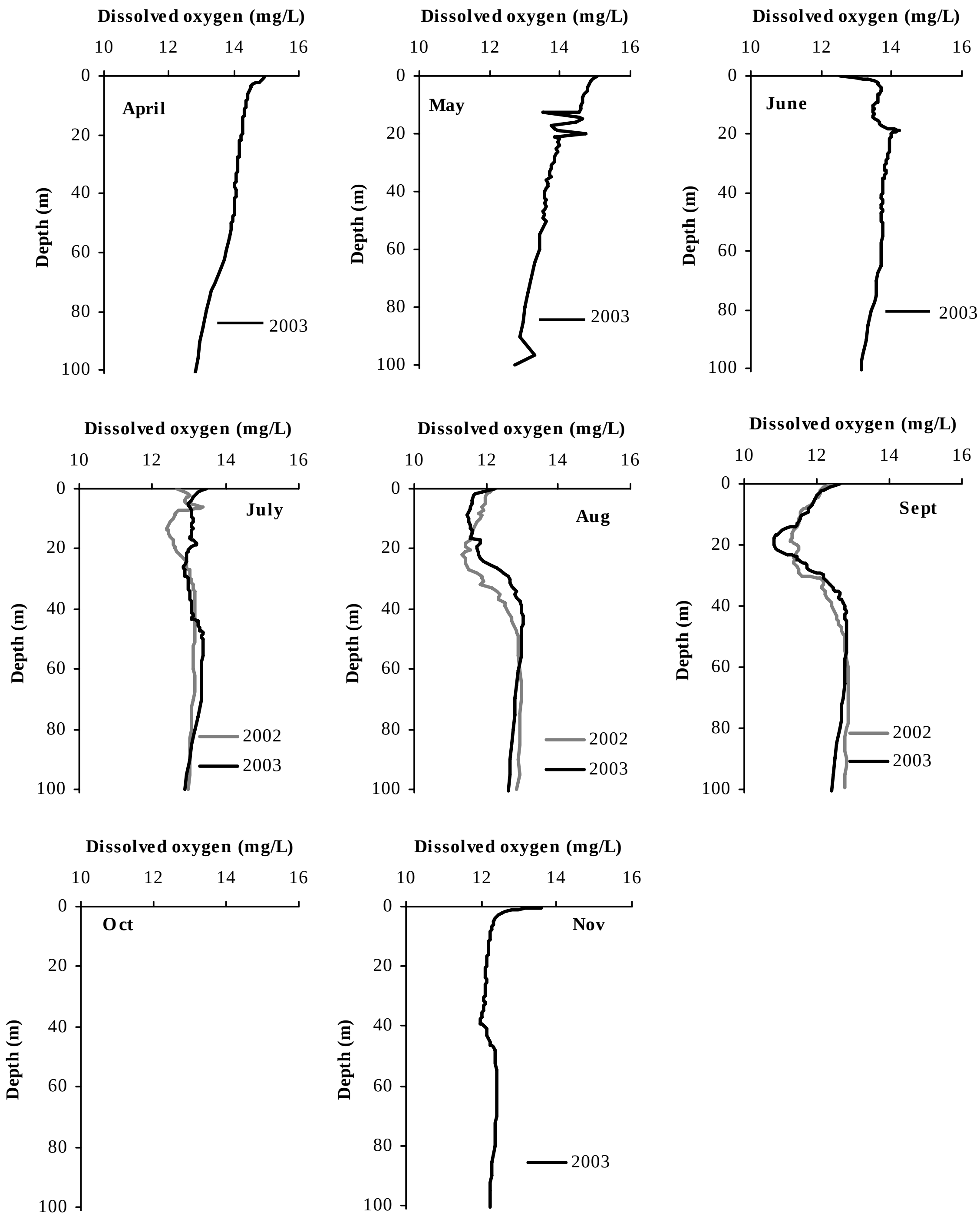

Figure 3.11. Dissolved oxygen profiles at KLF 4 from April to November, 2002 and 2003.

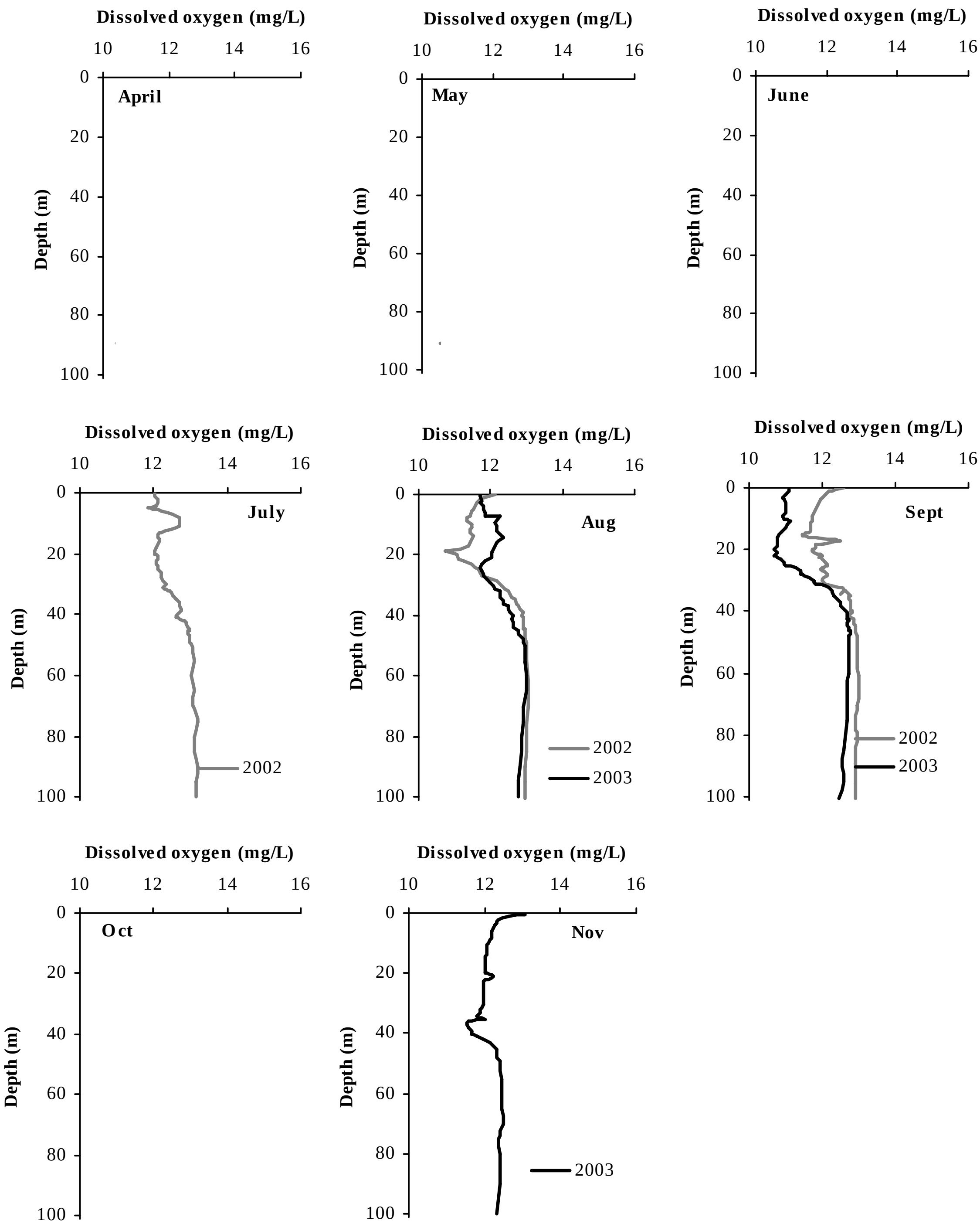

Figure 3.12. Dissolved oxygen profiles at KLF 5 from April to November, 2002 and 2003.

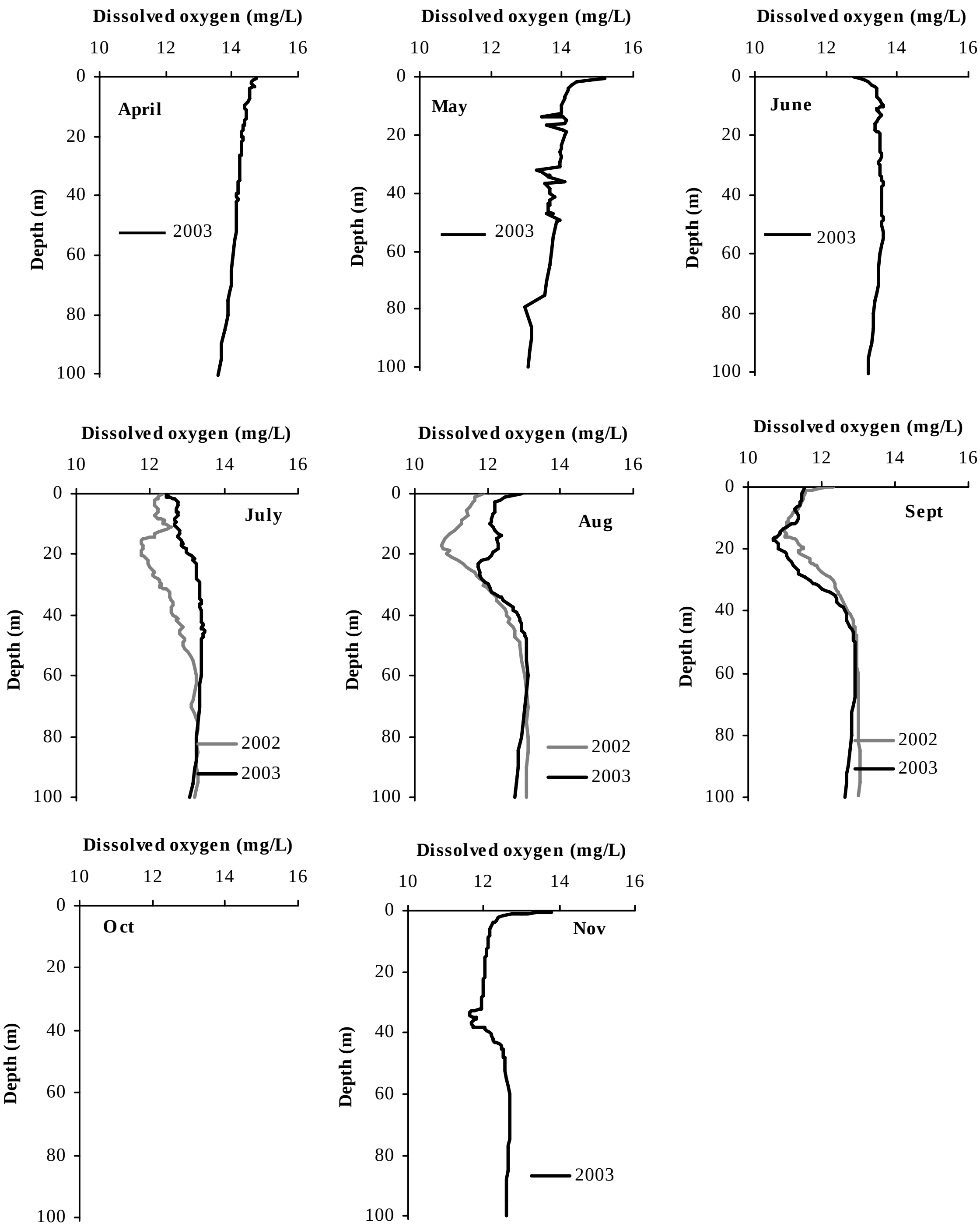

Figure 3.13. Dissolved oxygen profiles at KLF 6 from April to November, 2002 and 2003.

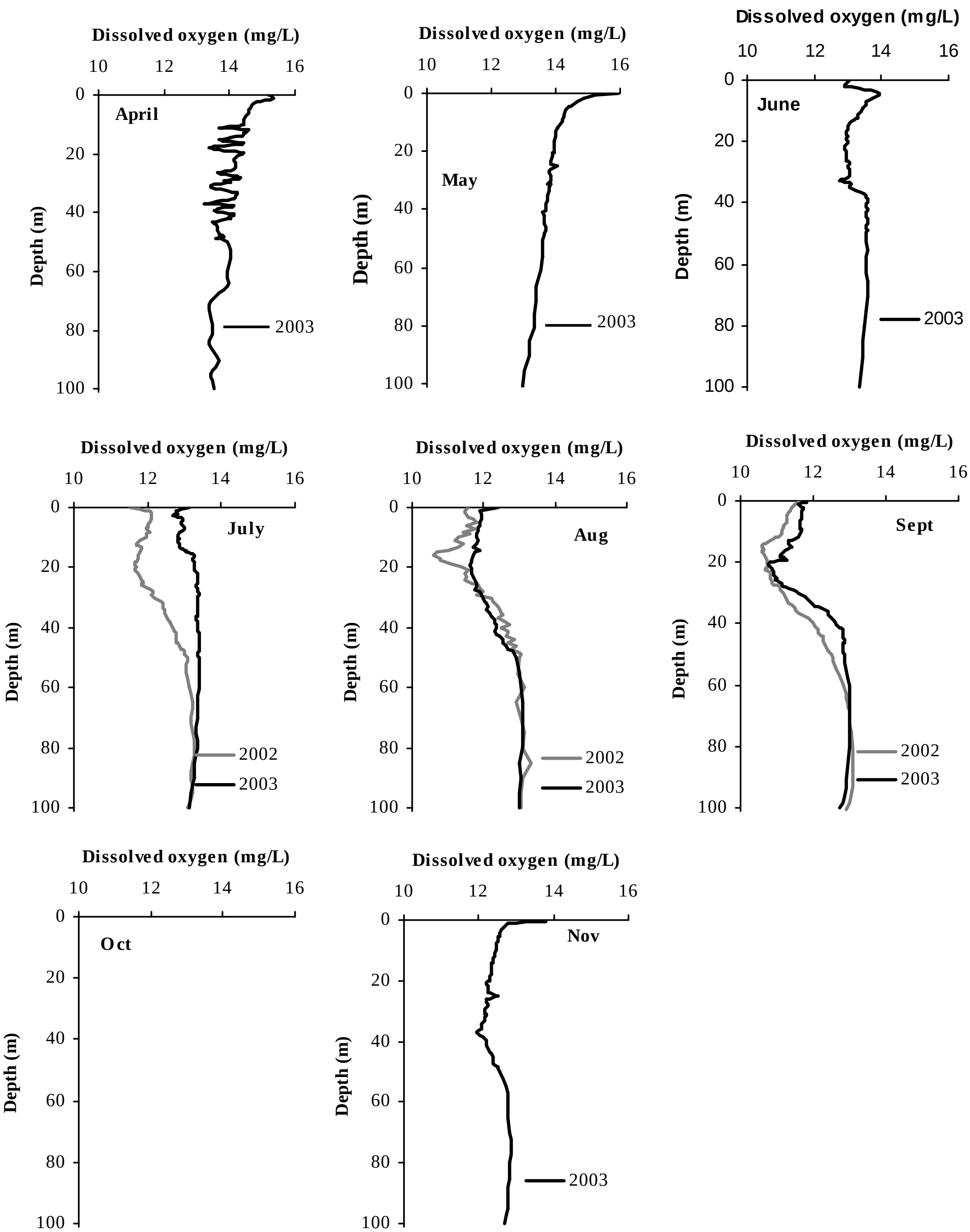

Figure 3.14. Dissolved oxygen profiles at KLF 7 from April to November, 2002 and 2003.

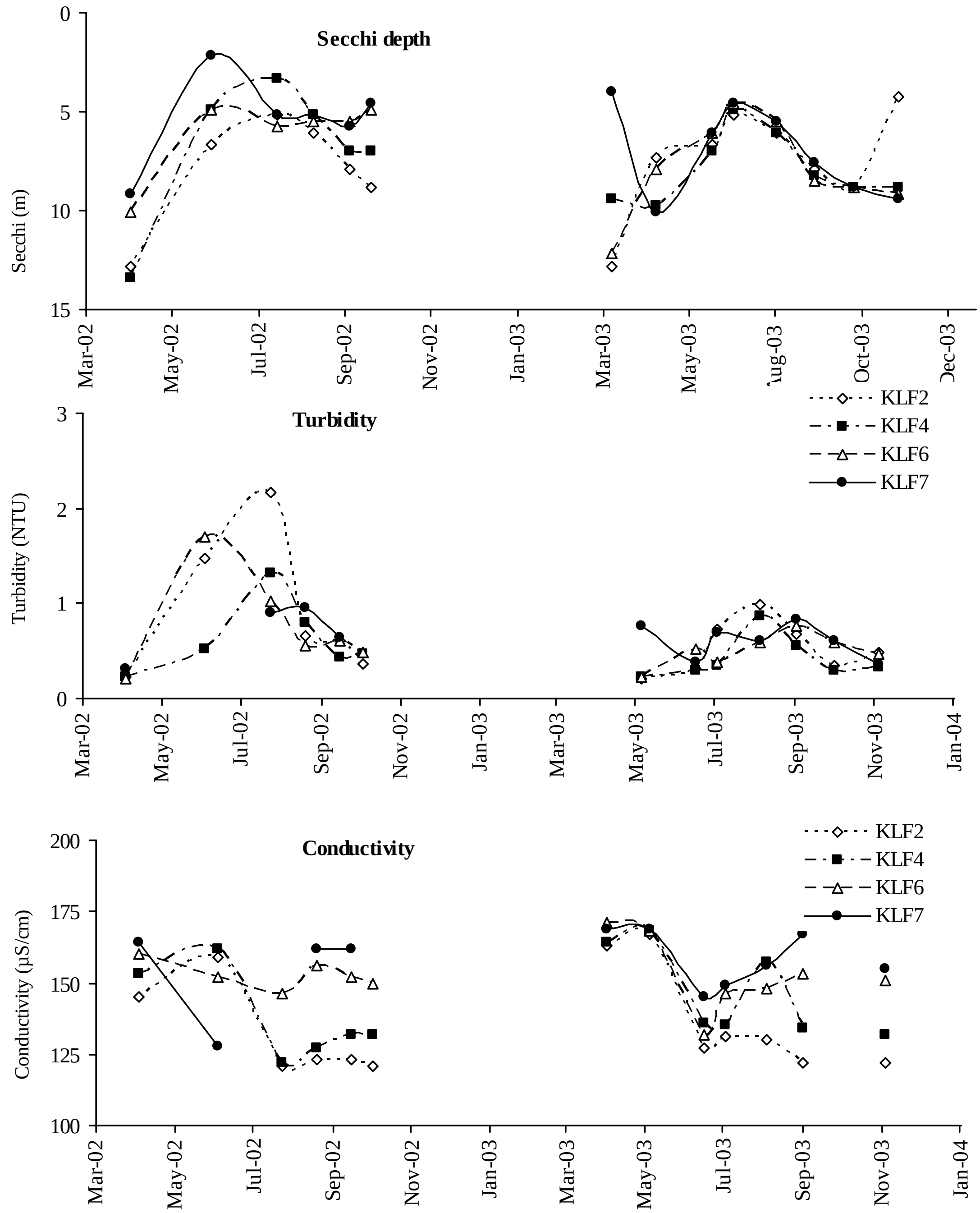

Figure 3.15. Secchi depth, turbidity, and conductivity at KLF 2, 4, 6, and 7 from April to November, 2002 and 2003.

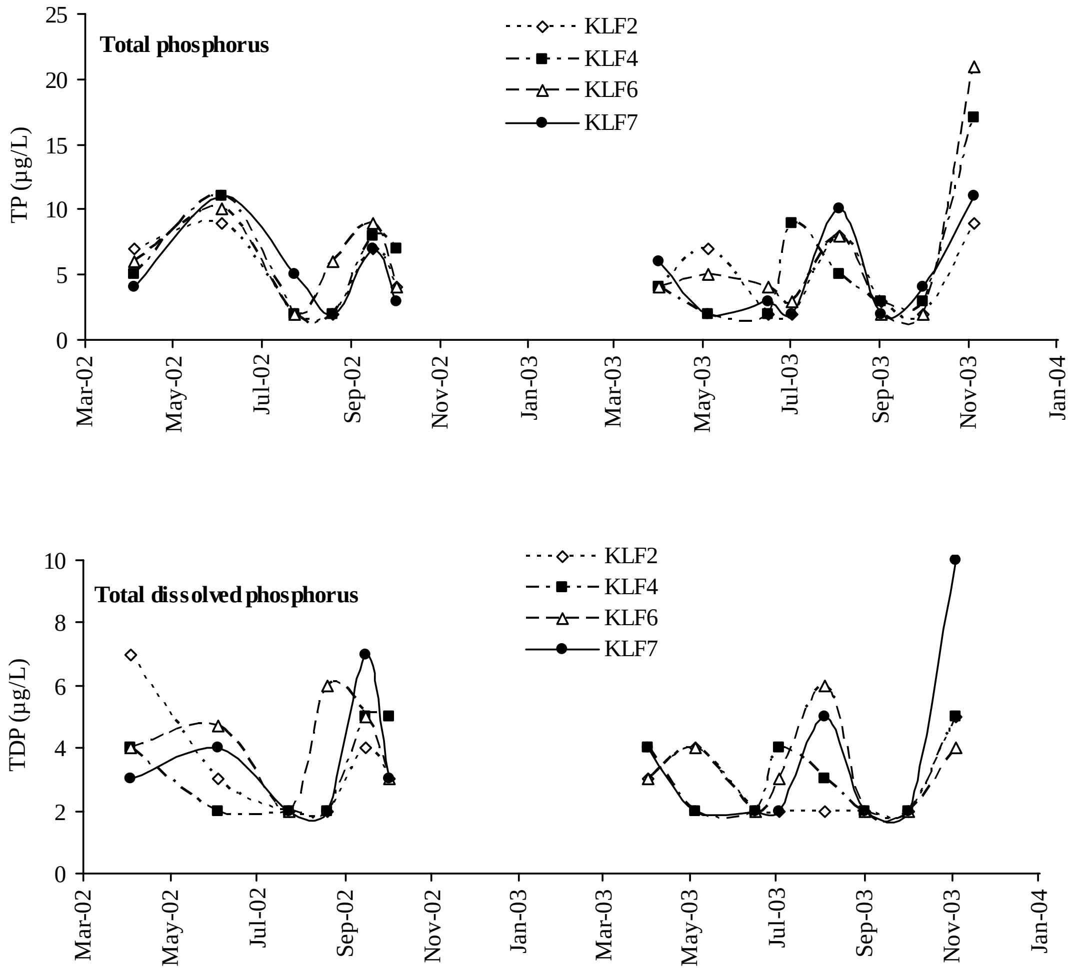

Figure 3.16. Total phosphorus (TP) and total dissolved phosphorus (TDP) at KLF 2, 4, 6, and 7 from April to November, 2002 and 2003.

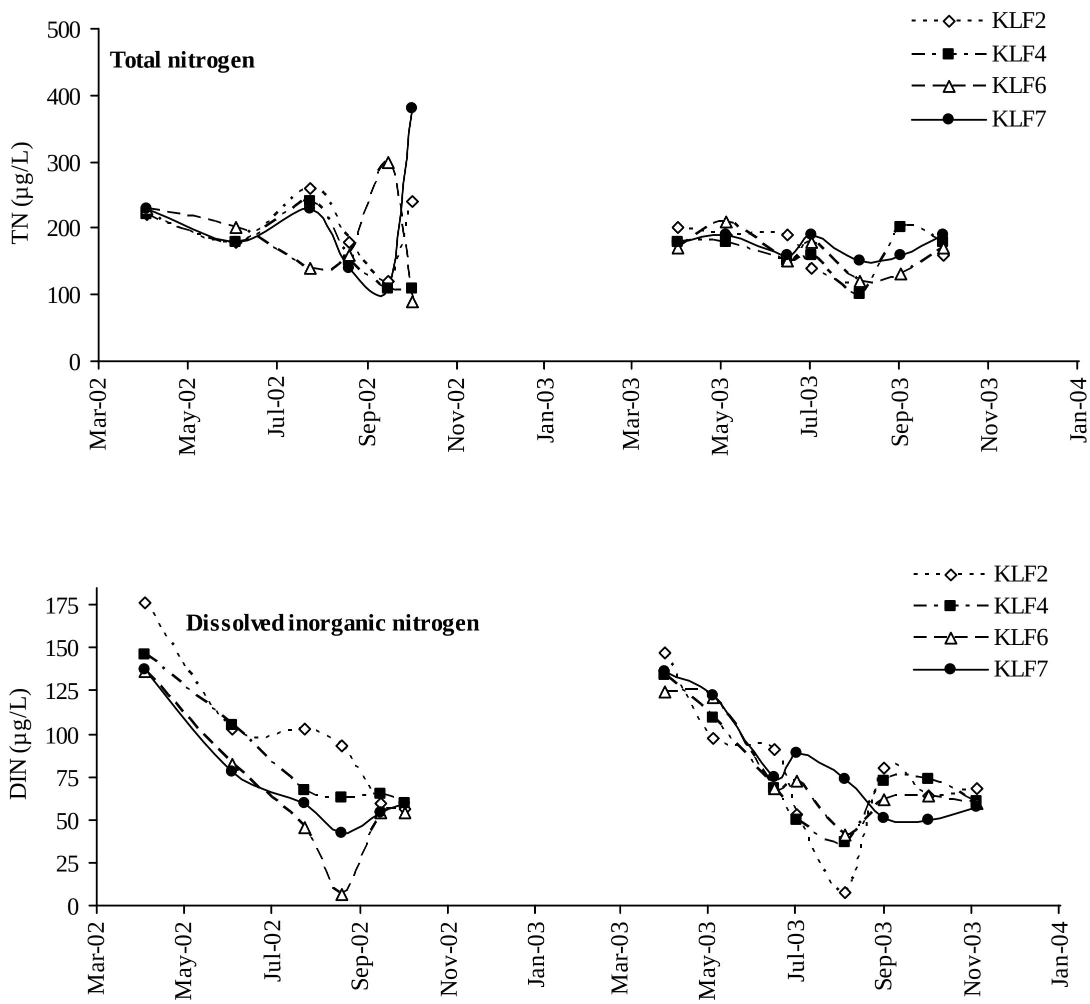

Figure 3.17. Total nitrogen (TN) and dissolved inorganic nitrogen (DIN) at KLF 2, 4, 6, and 7 from April to November, 2002 and 2003.

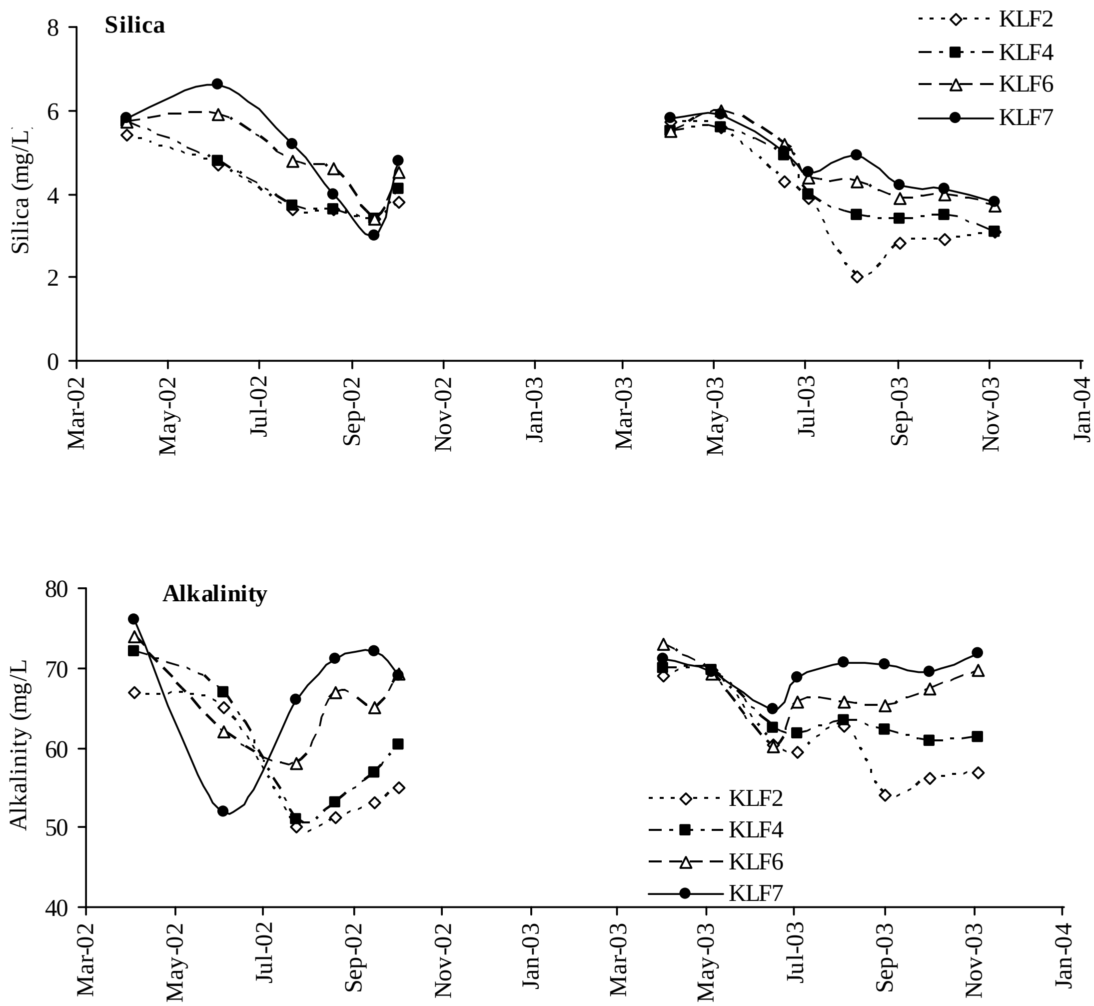

Figure 3.18. Silica and alkalinity at KLF 2, 4, 6, and 7 from April to November, 2002 and 2003.

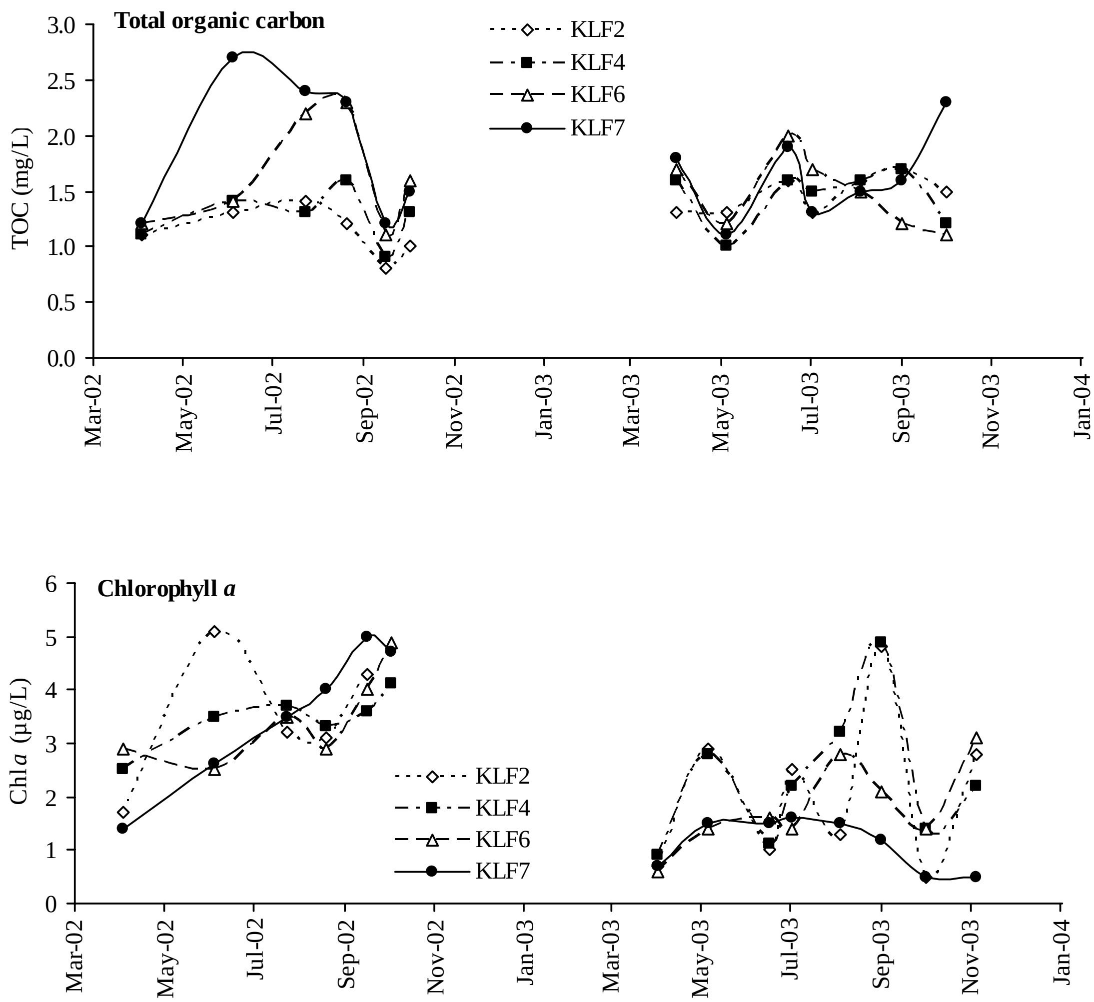

Figure 3.19. Total organic carbon (TOC) and chlorophyll *a* (Chl *a*) at KLF 2, 4, 6, and 7 from April to November, 2002 and 2003.

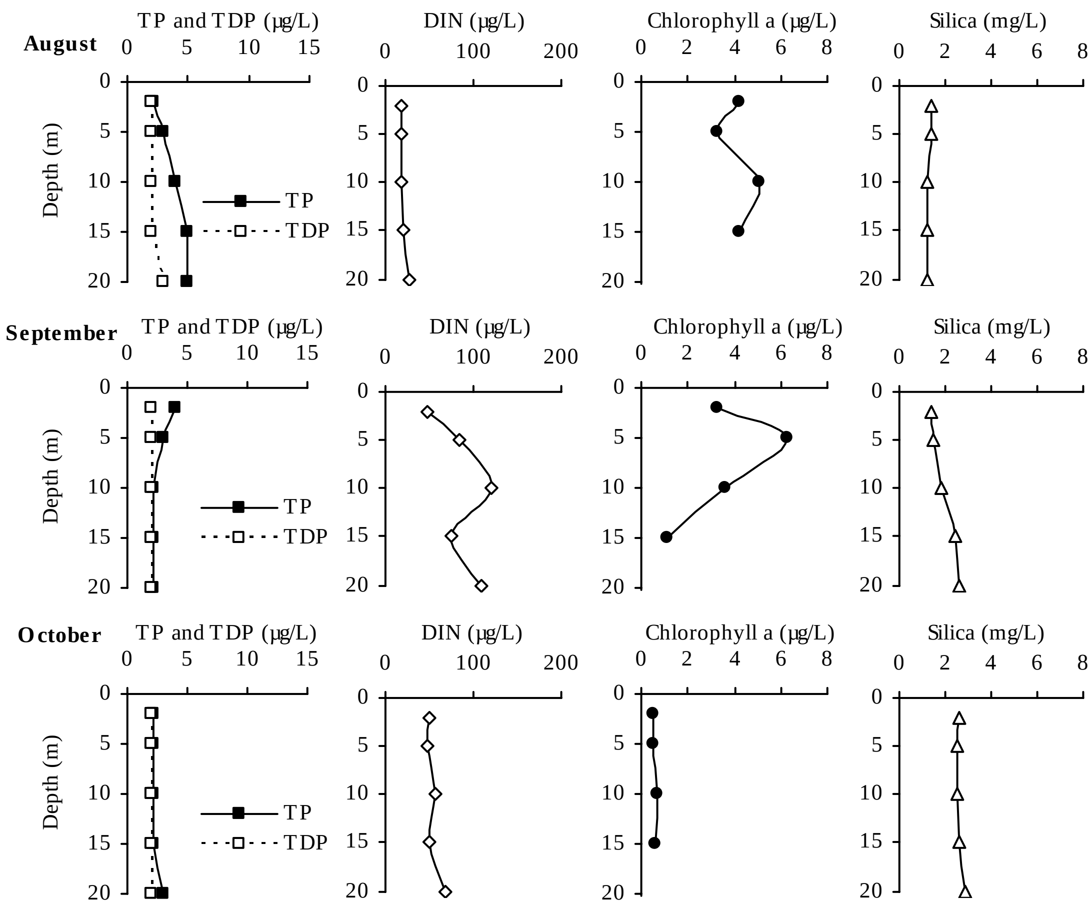

Figure 3.20. Measurements taken in the epilimnion at KLF 1, August-October, 2003.

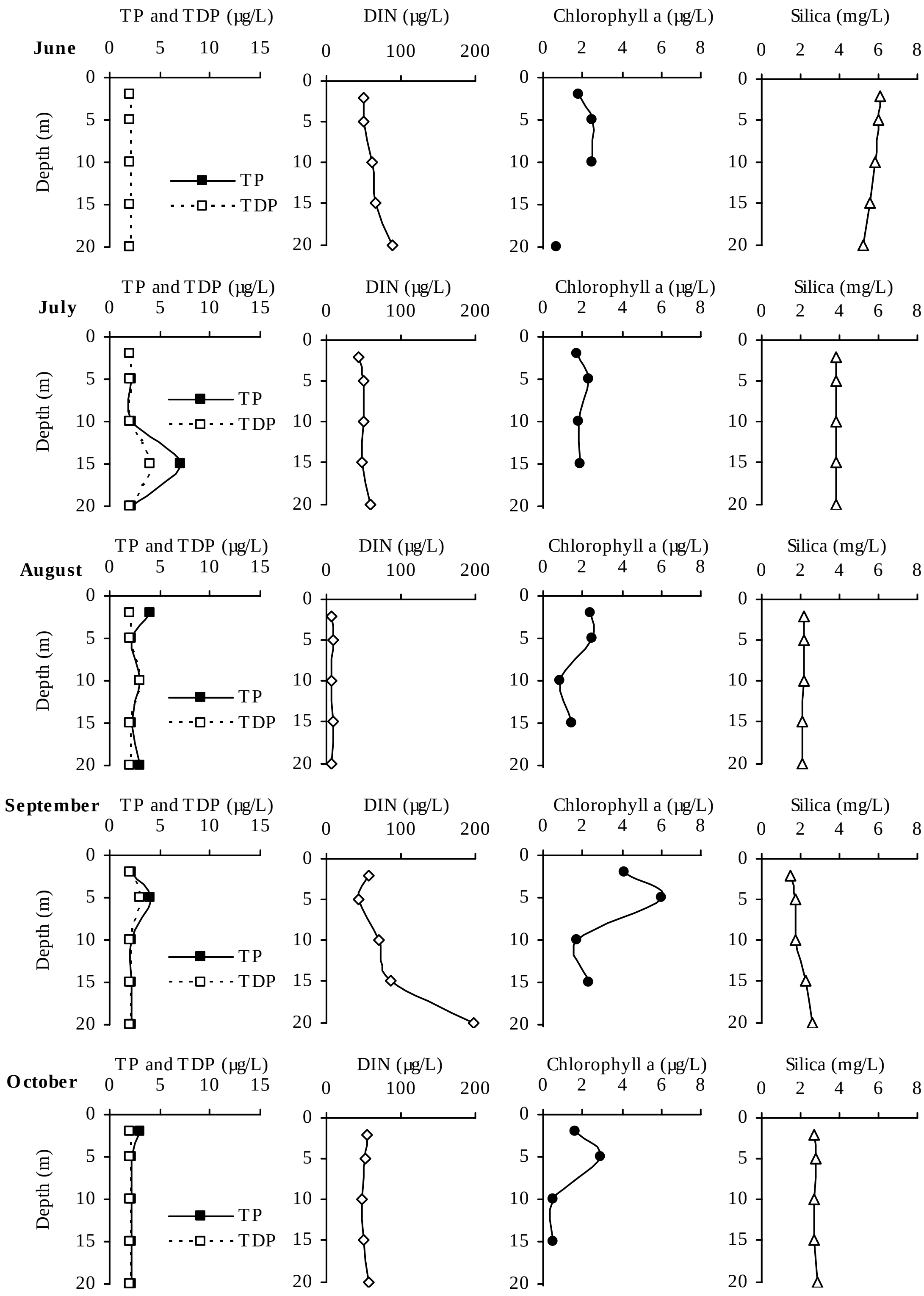

Figure 3.21. Measurements taken in the epilimnion at KLF 2, June-October, 2003.

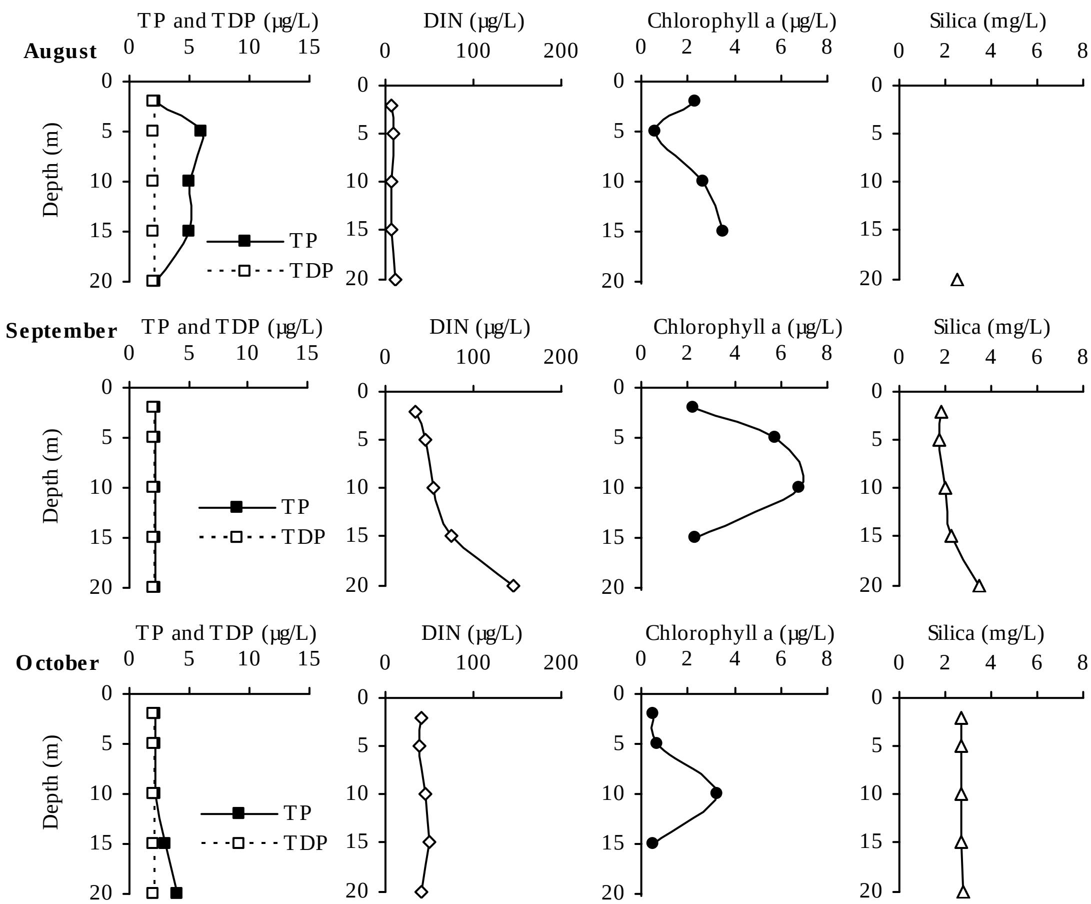

Figure 3.22. Measurements taken in the epilimnion at KLF 3, August-October, 2003.

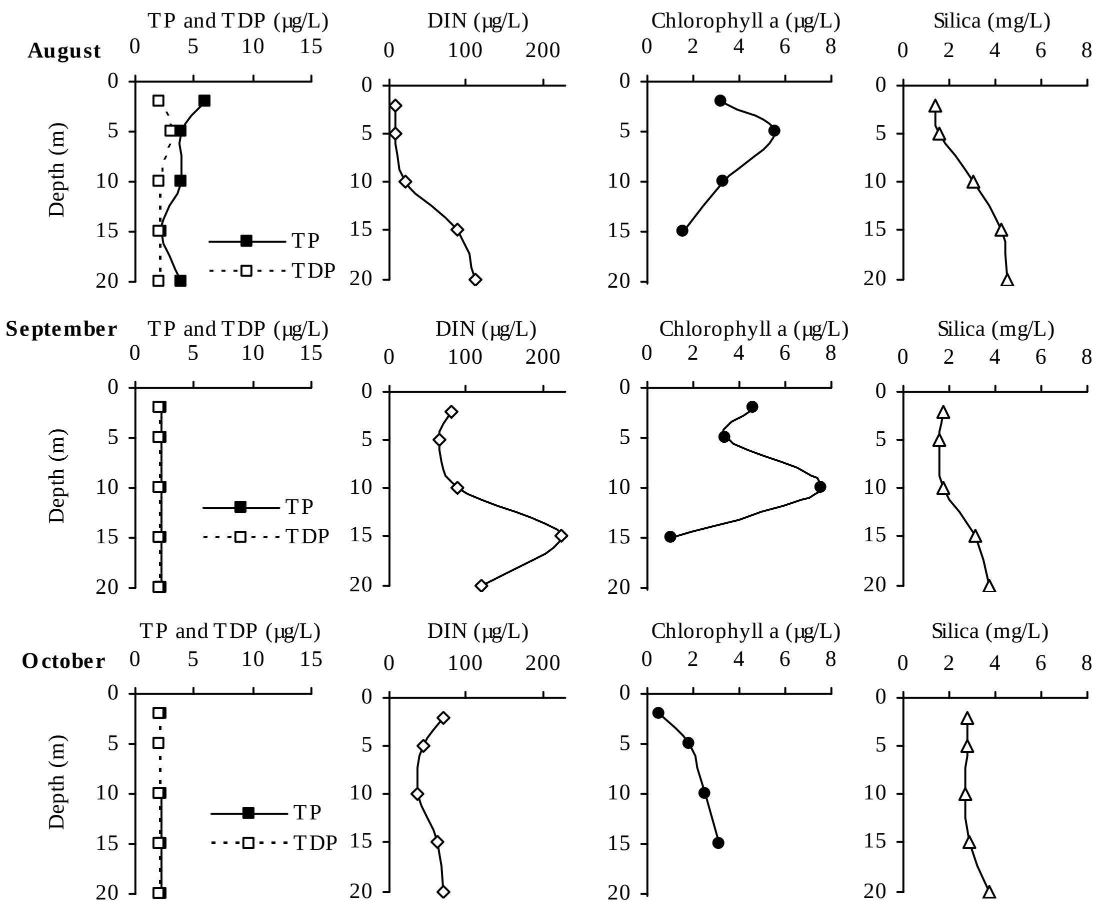

Figure 3.23. Measurements taken in the epilimnion at KLF 4, August-October, 2003.

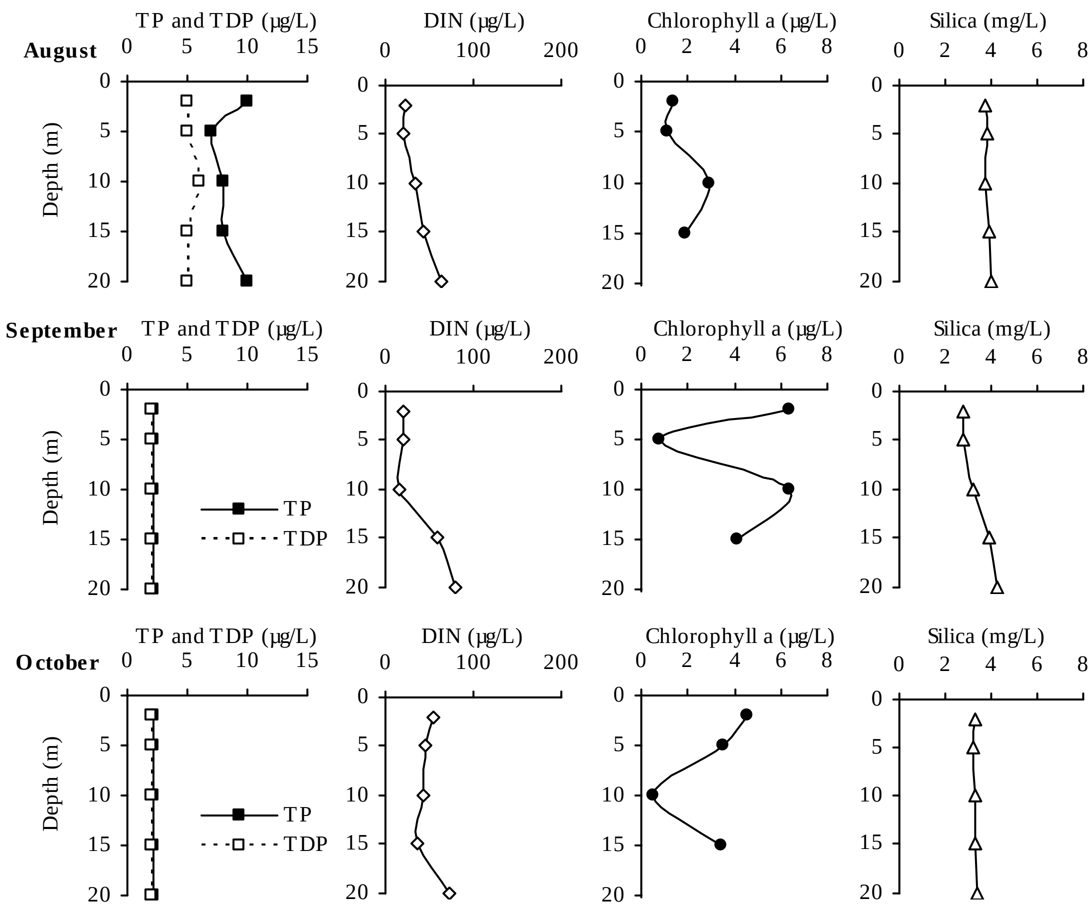

Figure 3.24. Measurements taken in the epilimnion at KLF 5, August-October, 2003.

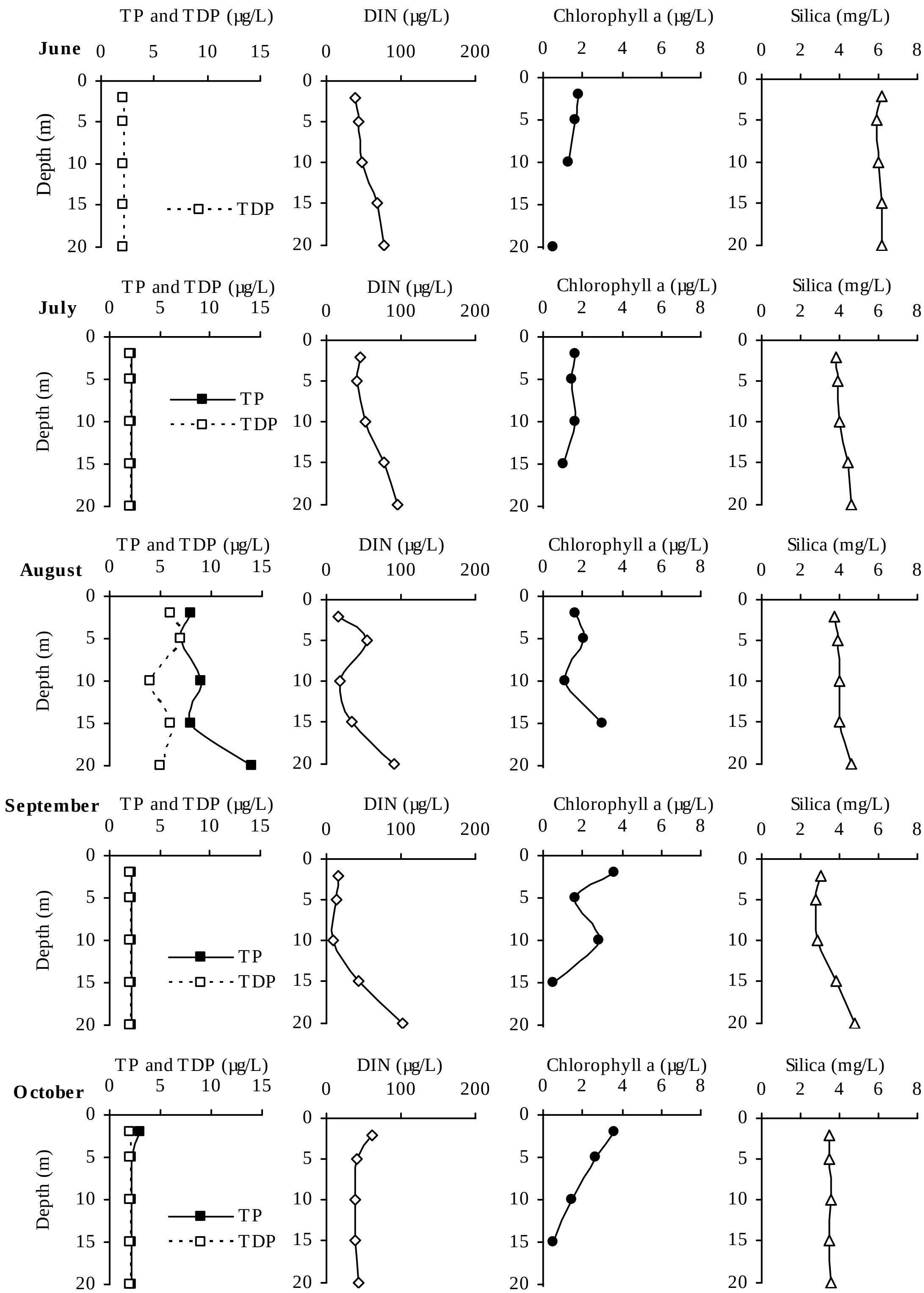

Figure 3.25. Measurements taken in the epilimnion at KLF 6, June-October, 2003.

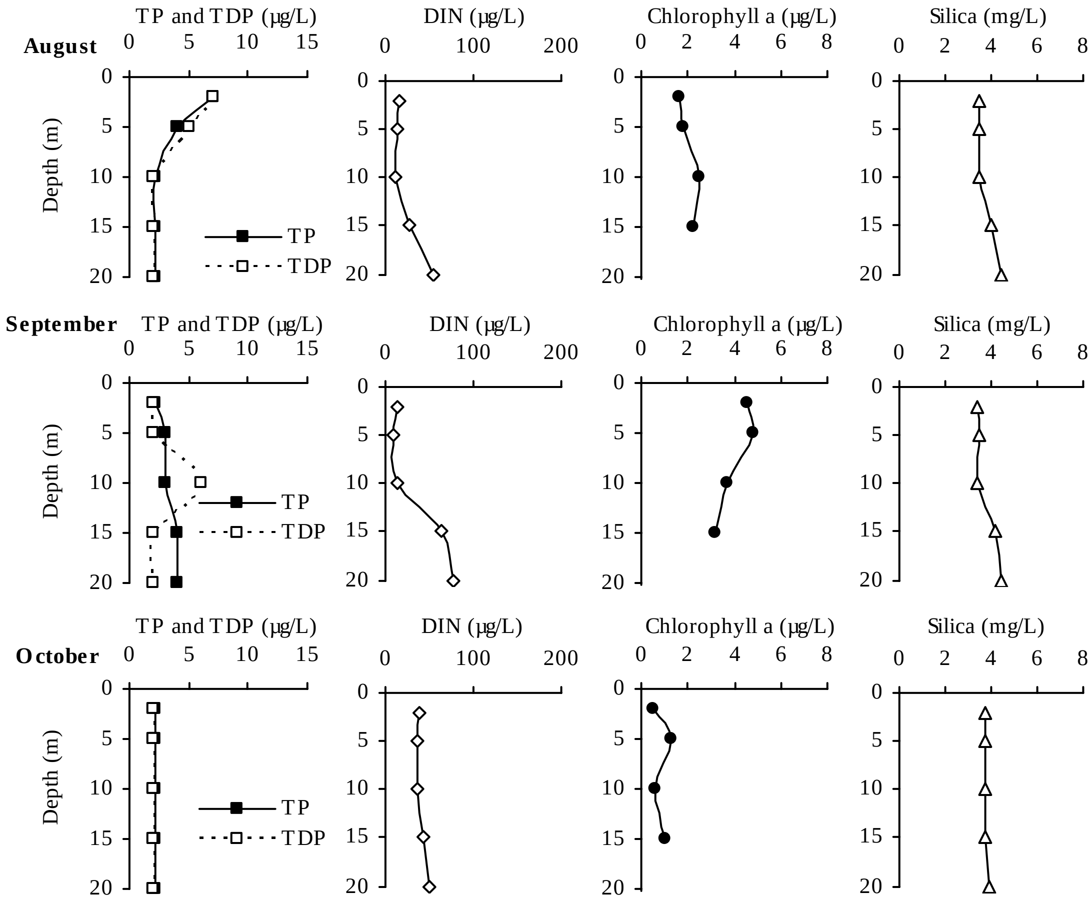

Figure 3.26. Measurements taken in the epilimnion at KLF 7, August-October, 2003.

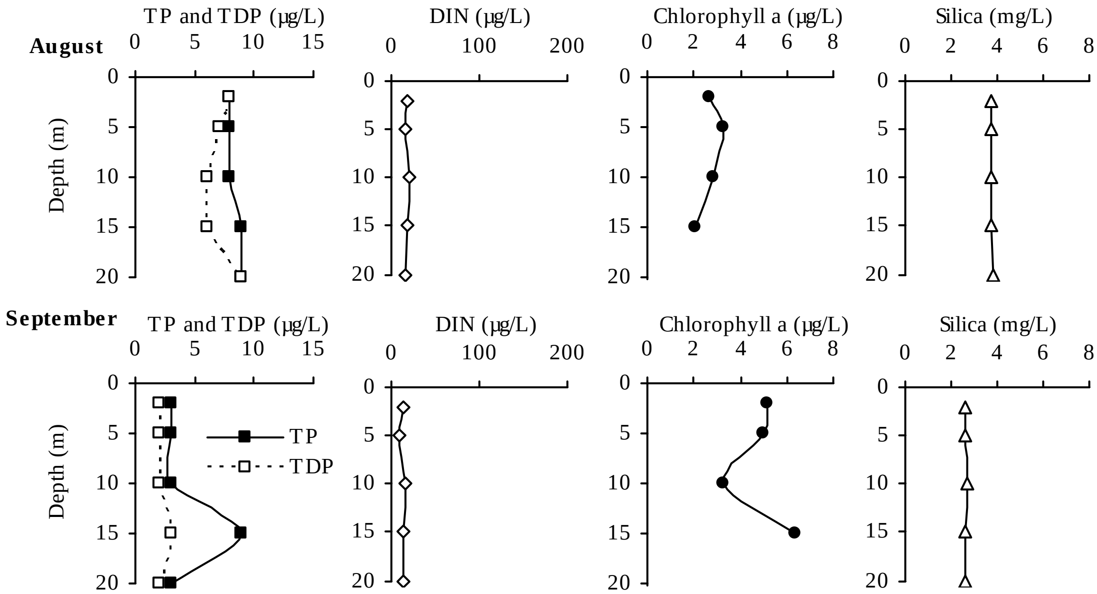

Figure 3.27. Measurements taken in the epilimnion at KLF 8, August-September, 2003.

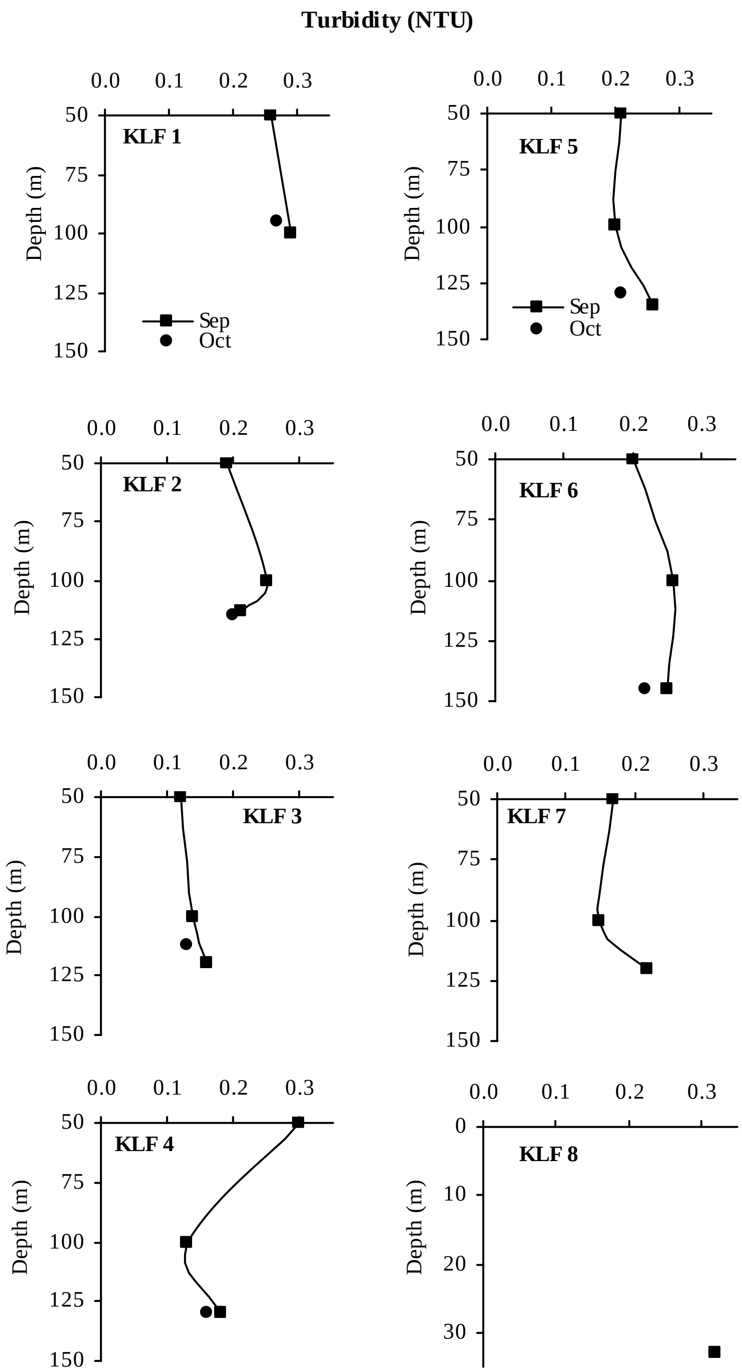

Figure 3.28. Turbidity in the hypolimnion at KLF 1-8, September-October, 2003.

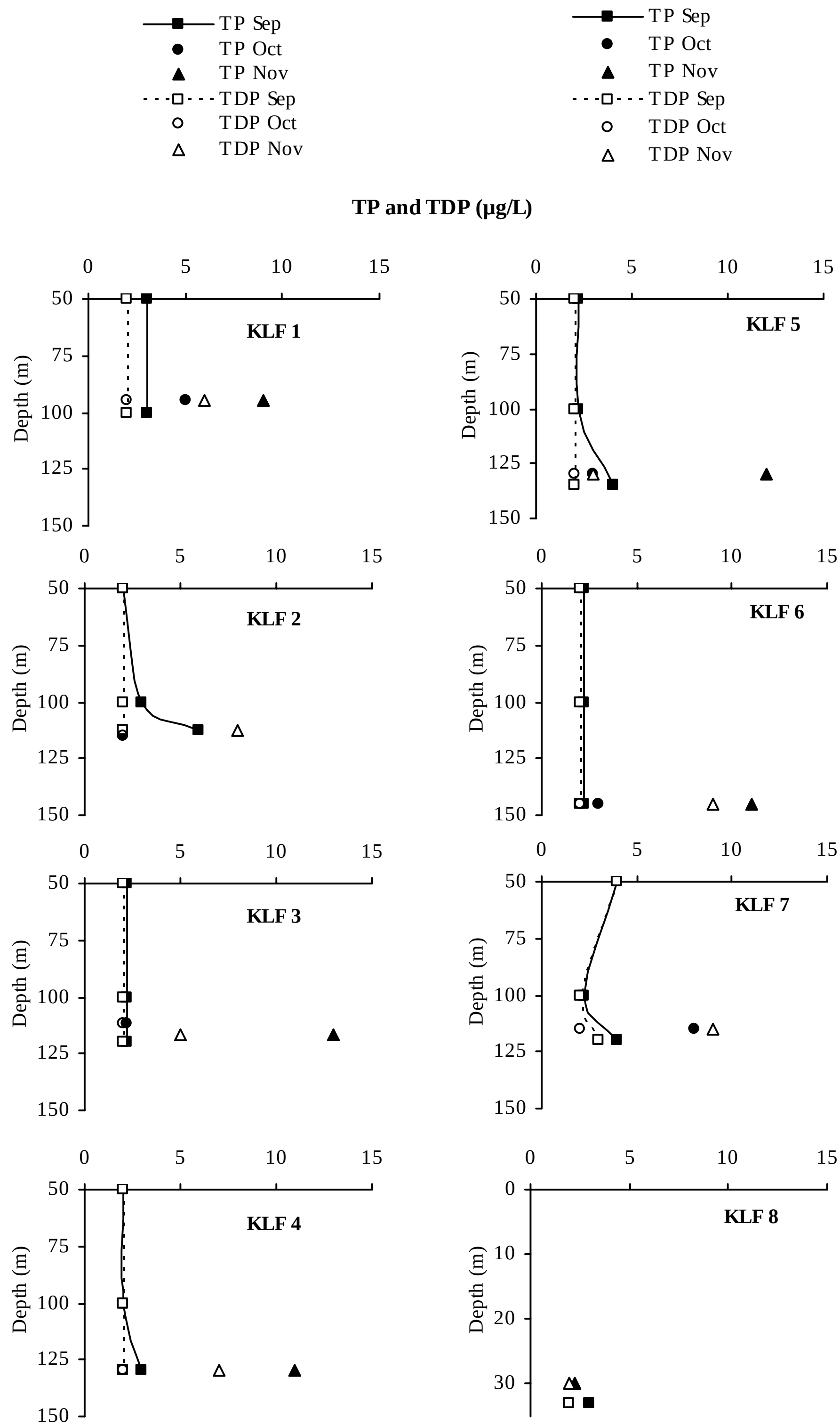

Figure 3.29. Total phosphorus (TP) and total dissolved phosphorus (TDP) in the hypolimnion at KLF 1-8, September-November, 2003.

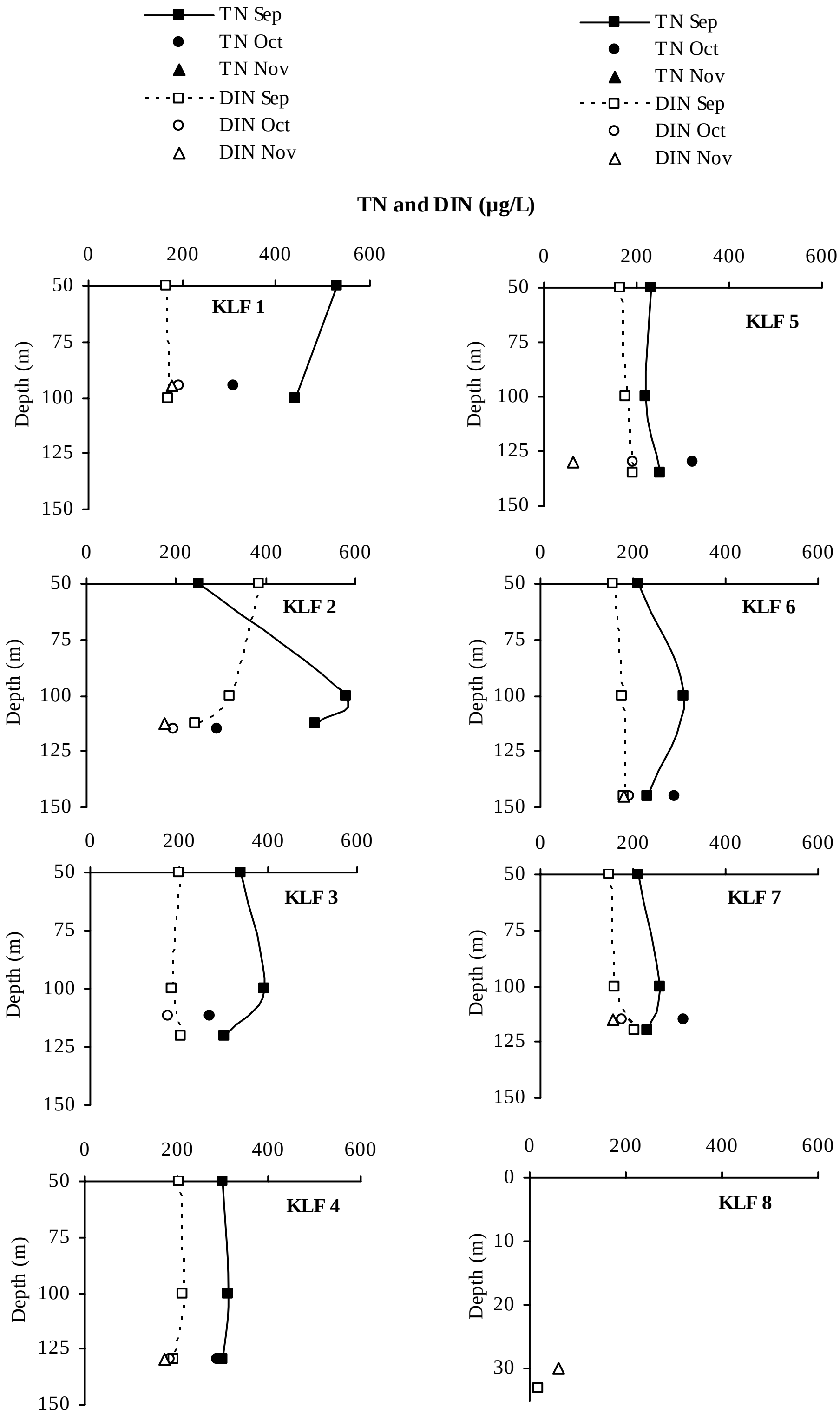

Figure 3.30. Total nitrogen (TN) and dissolved inorganic nitrogen (DIN) in the hypolimnion at KLF 1-8, September-November, 2003.

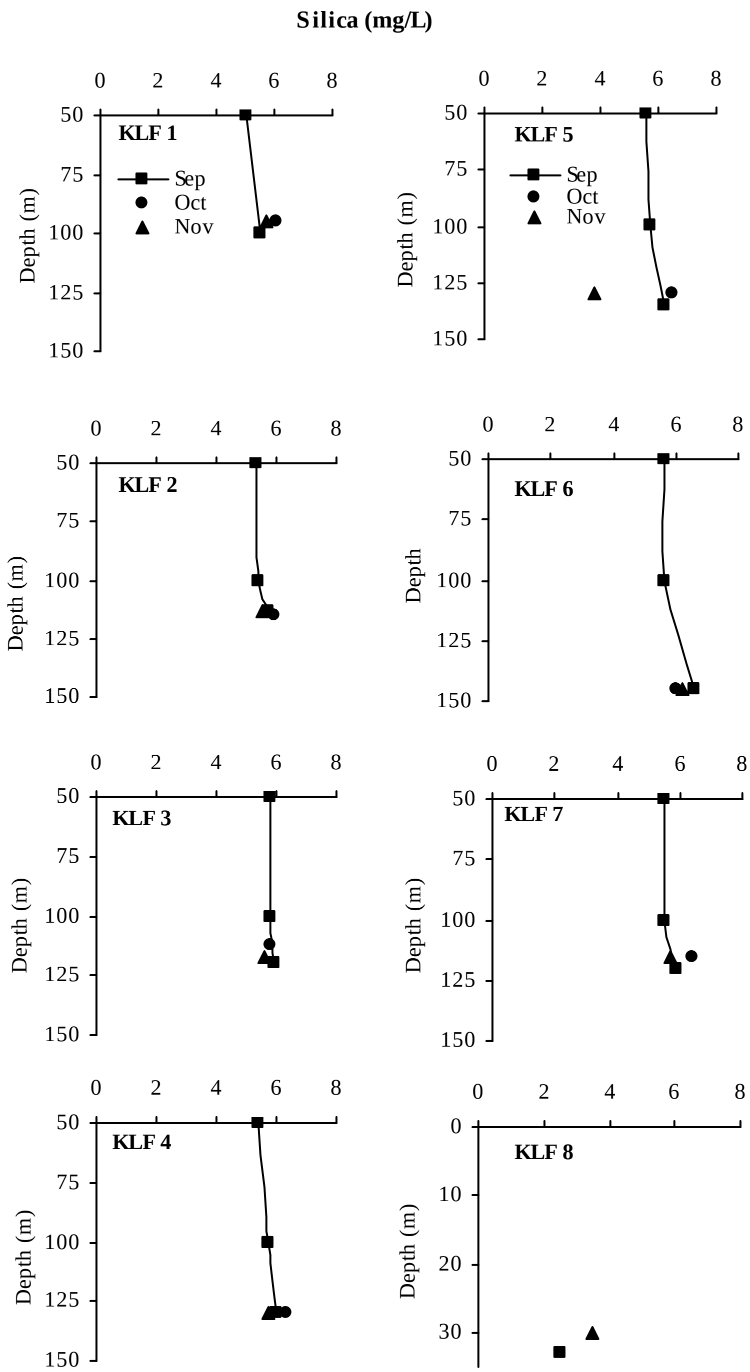

Figure 3.31. Silica in the hypolimnion at KLF 1-8, September-November, 2003.

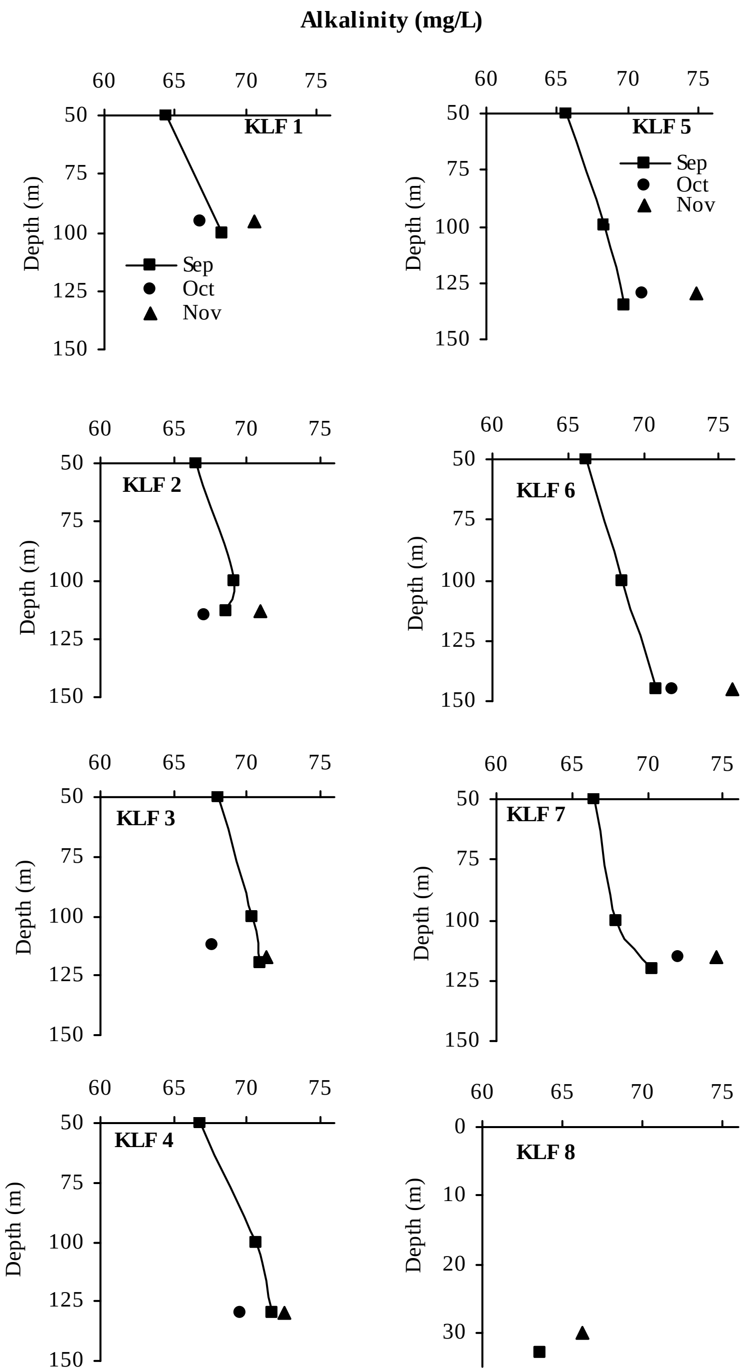

Figure 3.32. Alkalinity in the hypolimnion at KLF 1-8, September-November, 2003.

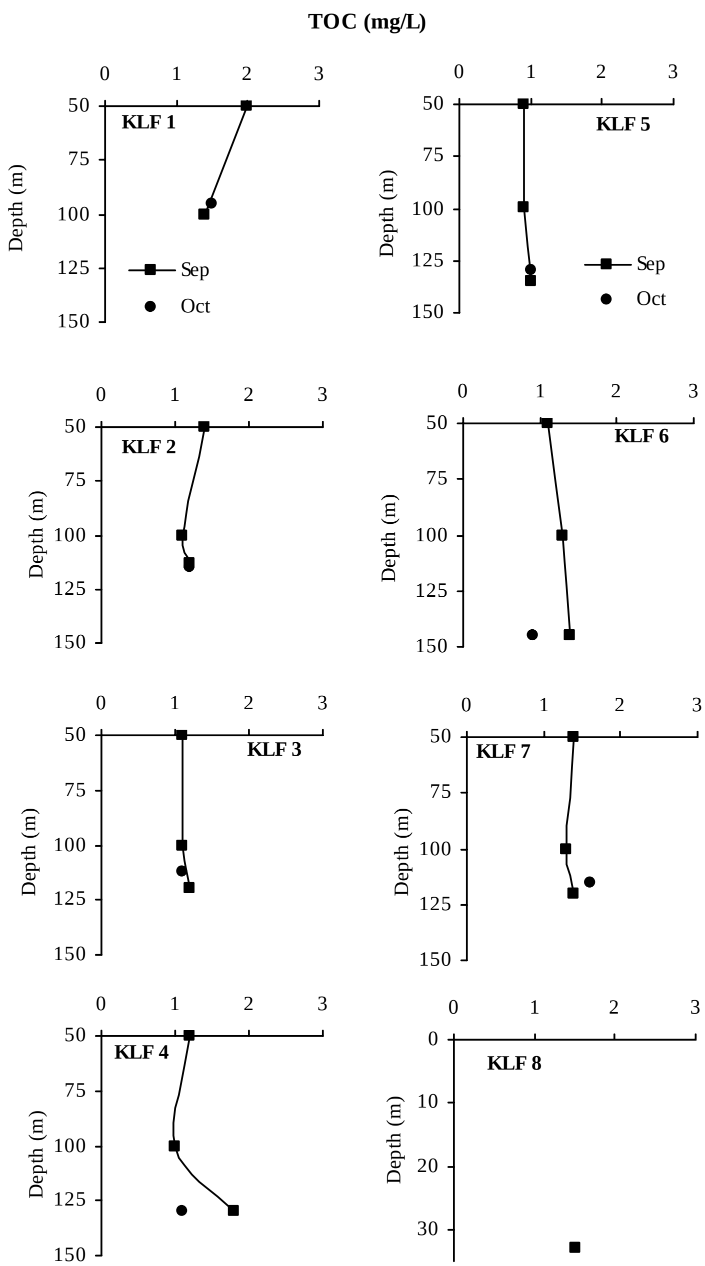

Figure 3.33. Total organic carbon (TOC) in the hypolimnion at KLF 1-8, September-October, 2003.

CHAPTER 4

RESPONSE OF PHYTOPLANKTON TO EXPERIMENTAL FERTILIZATION YEARS 11 AND 12 (2002 and 2003)

Frances R. Pick
Ottawa-Carleton Institute of Biology
Department of Biology
University of Ottawa
Ottawa, Ont.
K1N 6N5

and

Linda M. Ley
Paul B. Hamilton
Research Division
Canadian Museum of Nature
P.O. Box 3443, Station "D"
Ottawa, Ont.
K1P 6P4

2002

Introduction

Kootenay Lake, a large (390 km^2) fjord lake in South-Eastern British Columbia, was experimentally fertilized with 47.1 tons of agricultural grade fertilizer from spring to early fall, each year from 1992 to 1996, as part of a long-term program to rehabilitate declining populations of kokanee salmon (*Oncorhynchus nerka*) (Ashley et al. 1997, 1999). A further five-year adaptive management period of experimental fertilization was initiated in 1997 to document trophic level responses to changing loading rates of nitrogen and phosphorus. In 1997, fertilizer loading was lowered to 29.5 tons and this load was further reduced to 22.9 tons in each year of 1998 and 1999. In the 9th year of fertilization (2000) the load increased back to 29.5 tons as it was in 1997 and in the 10th year (2001) the load was further increased back to 47.1 metric tons as during 92-96.

The rationale for the fertilization programme was that the lake had been suffering from an "oligotrophication" due to the construction of dams on both major tributaries (Duncan and Kootenay Rivers) and reductions in anthropogenic nutrient loading. The historical record on the phytoplankton community dating from the early 1970s through the early 80s indicated subtle changes in species composition towards more oligotrophic taxa even though total algal biomass did not decline significantly during the same period (Daley and Pick 1990). With fertilization, an increase in primary production and algal biomass was anticipated to trigger an increase in cladoceran biomass for consumption by young of the year kokanee salmon (Walters et al. 1991). Other lakes in British Columbia have undergone artificial fertilization with apparently positive effects on fish production (Stockner and MacIssac 1996).

This report is an analysis of the changes, induced by fertilization, to the phytoplankton community of Kootenay Lake during 2002, the 11th year of fertilization. The data from the 2002 sampling are presented with a comparison to 1992-2001 data.

Methods

Water samples were collected integrating a 0-20 or 0-30 m water column, in keeping with the historical sampling procedure, at 4 stations along the length of the North Arm and into the South Arm. Collection dates for the samples enumerated from 2002 are given in Appendix I. Samples were enumerated from each of the four stations, at one-month intervals, from April through October.

Subsamples were preserved for phytoplankton analysis using Lugol's iodine solution. Enumerations were made using the Utermöhl method on a Wild M40 inverted microscope (Utermöhl 1938, Lund et al. 1958). Aliquots of 5-15 ml were settled overnight (16 hours) in 26 mm diameter sedimentation chambers. For each sample, a minimum of 300-350 phytoplankton cells was counted along randomly selected transects to ensure an 85-90% counting accuracy (Lund et al. 1958). The length of each transect equalled the diameter of the chamber. Cell counts and dimensions were recorded on a computerized counter (Hamilton 1990) to facilitate the calculations of the parameters describing phytoplankton community structure. For counting purposes cells were assigned to one of three magnifications: 400X, 200X and 100X, depending on their size and nature. The cells were consistently identified and enumerated at the assigned magnification.

The estimations of total algal biomass, and size and division distribution were derived from the enumerations. Algal biomass was determined from estimations of the volume of each algal taxon. One of seven preselected shapes (sphere, cone, double cone, ellipsoid, parallelepiped, half parallelepiped and rod) was assigned to each species (Hamilton 1990). The dimensions were measured on 3-10 individuals per species. The summation of the individual cell volumes: the biovolume was converted to biomass ($mg.m^{-3}$) assuming a density of 1 (Utermöhl 1958).

Taxa were assigned to specific size classes based on the mean of their longest dimension. Accordingly, total biomass was partitioned into six size classes: the picoplankton (<2.1µm), the ultraplankton (>2-10 µm), the nanoplankton (10.1-20 µm), the microplankton (20.1-64 µm) and the net plankton (>64 µm). Picoplankton, which can be very abundant in oligotrophic BC lakes, are difficult to enumerate accurately by inverted microscopy and need to be examined by epifluorescence microscopy.

Total biomass was further separated into seven main divisions: Cyanobacteria, Chlorophyta, Chrysophyta, Cryptophyta, Pyrrhophyta, diatoms, and Euglenophyta and Xanthophyta. The latter division was not recorded in Kootenay Lake and euglenophytes are extremely rare.

The list of samples with the total abundance and biomass is given in Appendix I. A species list for all phytoplankton enumerated is given in Appendix II along with the codes used for these species; the count sheets of the raw data are provided in Appendix III. Linda Ley conducted the enumerations using the same technique as in previous years with the same inverted microscope (Wild M40) and computer program (Hamilton 1990).

Results and Discussion

2002 Monthly transects

In contrast to previous years, the overall trend observed throughout the 2002 sampling season was one of either no change in algal biomass from the North Arm stations (stations KLF 2 and KLF 4) towards those in the South Arm (Stations KLF 6 and KLF 7) (Fig. 4.1) or later in the season an actual increase along the North to South Arm.

The lowest levels of biomass were observed in April (36 – 91 mg. m^{-3}) throughout the lake with little difference between stations. By the beginning of May, total biomass was 2-3 times higher than in April. Increases in cryptophytes and *Synedra* spp. as well as more modest increases in another pennate diatom, *Asterionella formosa* in the South Arm accounted for the increased biomass. This was similar to the early spring pattern of the previous year, 2001.

In early June further increases in pennate diatoms as well as a few centric diatoms (*Cyclotella* spp) were observed leading to higher biomass, relative to May, at all stations but, in particular, station KLF 7. Normally a spring biomass peak occurs in late June in Kootenay Lake, but this period was not sampled in 2002. The late July biomass for the lake was slightly higher to that obtained in early June because of increases in *Asterionella formosa* and a greater abundance as well as diversity of centric diatom species. Along the lake transect, station KLF 7 showed the highest phytoplankton biomass due mainly to much higher concentrations of *Fragilaria crotonensis.*

Biomass levels increased from July through September and for stations KLF 6 and KLF 7 through to October as well (Fig 4.2). Biomass increases were due to increases in pennate diatoms other than *Asterionella*, namely *Fragilaria crotonensis* and *Tabellaria.* The latter taxon was responsible for the very high biomass levels observed in the South Arm stations in September and October (~ 2,000 mg. m^{-3}). The more typical pattern for Kootenay Lake is a decline in algal biomass in the fall.

Overall taxonomic composition

Kootenay Lake continues to be a diatom dominated lake (80-89% of total average biomass) (Fig. 4.2a & Fig. 4.2b). *Synedra* spp. and some *Asterionella*, as in the previous two years, dominated the early biomass increase in 2002. In earlier years 1992-1996 with higher loading of nutrients *Fragilaria* was often the dominant pennate diatom during the spring “bloom” of late June and later in the season *Tabellaria fenestrata* occurred, which is a typical spring succession observed in oligo-mesotrophic temperate lakes (Reynolds 1984). *Tabellaria fenestrata* arose first in late August in the South Arm where it gained in dominance through the fall.

Cryptophyta (in particular *Cryptomonas erosa*, *C. reflexa*, *Rhodomonas minuta*) were only slightly stimulated by the fertilization in the spring (summer average of 80 vs 60 mg. m^{-3})as observed during high fertilization years. The Chrysophyta comprised the third major algal division in Kootenay Lake but chrysophyte biomass levels were generally similar between the two arms (2-3%).

Chlorophytes were an insignificant component of the total (<1%, indicated as “Others” in Fig. 4.2A and Fig. 4.2B). Cyanobacteria contributed slightly more biomass than the Chlorophyta but, as found in previous years, cyanobacterial biomass was very low (0.9-3% of total biomass). However, there was slightly more cyanobacterial biomass in the fertilized zone than at the reference stations. Sporadically, dinoflagellates (*Peridinium, Gymnodinium. Ceratium*) contributed some biomass in both Arms.

Overall, the most obvious difference between the fertilized zone and the reference stations in 2002 was the earlier appearance and very high abundance of *Tabellaria* in the South Arm relative to the North Arm.

Size distribution

Nanoplankton and ultraplankton (2-20 μm) were not consistently enhanced in the fertilization zone. This is in contrast to the years of higher nutrient loading when nanoplankton biomass was significantly enhanced by the fertilization. On average, the North Arm and South Arm both had significant proportions of netplankton (39-56% of annual average total biomass). However, the netplankton (> 64 μm) was elevated at the fertilized station relative to the "control" (station KLF 6) on all sampling dates (Fig. 4.3) and the percentage of netplankton biomass was lower in the fertilization zone (summer average of 42% vs 64%). Generally, netplankton are considered a less favourable food source for zooplankton.

Comparison with the previous ten years

The hypothesis that algal biomass would be higher at the fertilized stations relative to the unfertilized stations was not supported in 2002. Total algal biomass, averaged over the months of June, July and August, was in fact lower at the fertilized station in the North Arm of Kootenay Lake relative to the South Arm stations (Table 4.1, Fig. 4.4).

Phytoplankton biomass in the fertilized arm continues to be much lower than during the mid- 90s in the North Arm (Table 4.1, Fig.4.4, Fig.4.5), when fertilization loading was high and sustained over several years. In 2002, biomass levels at station KLF 2 were similar to the annual average biomass levels observed in the second year of fertilization of Kootenay Lake (1992, Table 4.1). In contrast, station KLF 6 in the South Arm showed the highest annual and summer average biomass levels since the beginning of the fertilization program in 1992. This is most likely due to high nutrient loading from the main tributary to the South Arm. In this respect, the year 2002 may be climatically similar to the year 1995 and 1996, when biomass in the South arm was also very high. It is clear that year-to-year differences in background nutrient loading can have significant effects on year-to-year biomass differences in the South Arm. Such year-to-year differences likely exist as well in the North Arm. The year 2002 was the first year on record where the fertilized stations actually had lower biomass than the "reference" stations.

Acknowledgements

Funding was provided by the Columbia Basin Fish and Wildlife Compensation Program. Thanks to Kootenay Wildlife Services Ltd for sample collection.

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Table 4.1. Biomass averages (mg.m^3) at the fertilized station (Stn KLF 2) in the North Arm and at the "control" station (Stn KLF 6) in the South Arm from 1992 to 2002.

	Annual (Apr. - Oct.) (n = 7 - 14)		Summer (Jun. - Aug.) (n = 3 - 6)	
	Stn KLF 2	Stn KLF 6	Stn KLF 2	Stn KLF 6
1992	445	359	534	473
1993	658	364	1091	455
1994	900	477	1183	557
1995	1366	800	1556	945
1996	1867	813	2483	1040
1997	626	337	1081	519
1998	436	323	516	462
1999	405	340	501	397
2000	500	316	419	395
2001	1011	438	1016	334
2002	572	875	881	1085

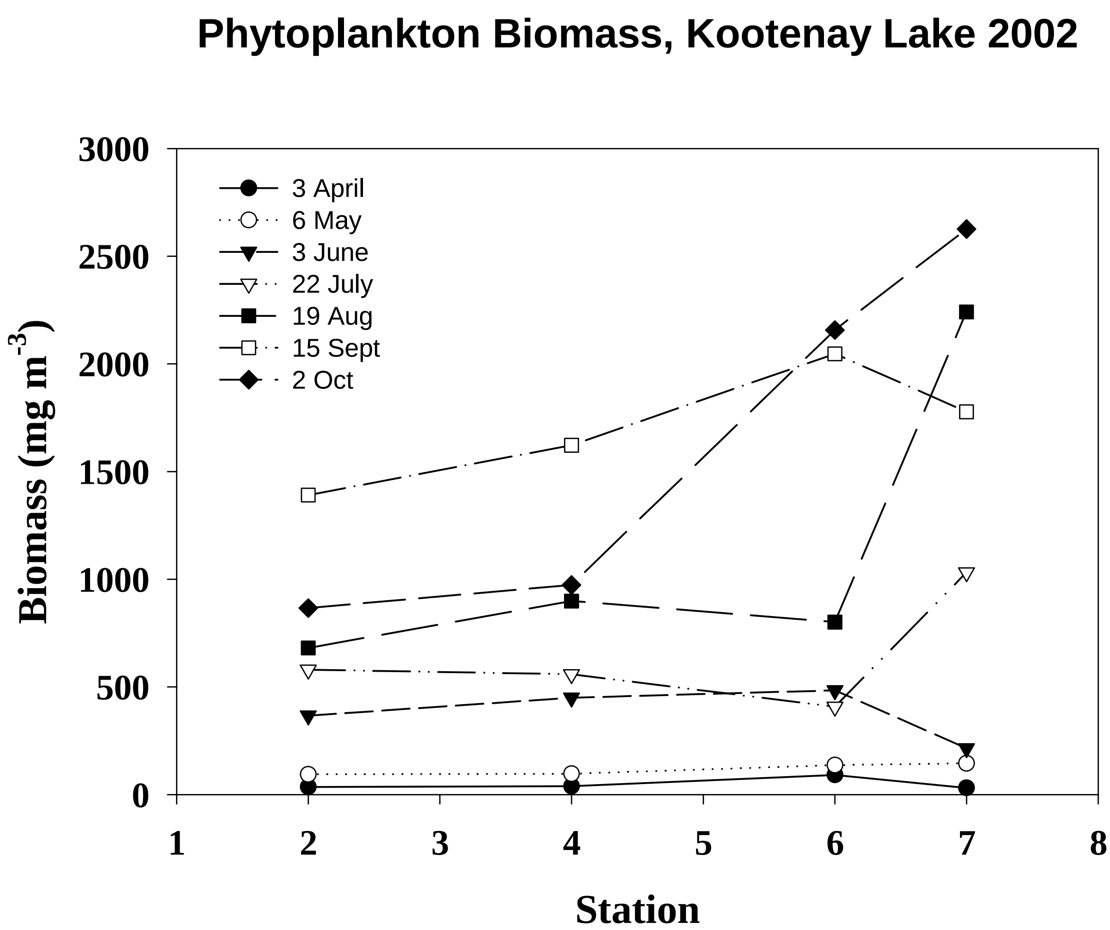

Figure 4.1. Total algal biomass, along the North South transect of Kootenay Lake, at one month intervals, from April through October of 2002.

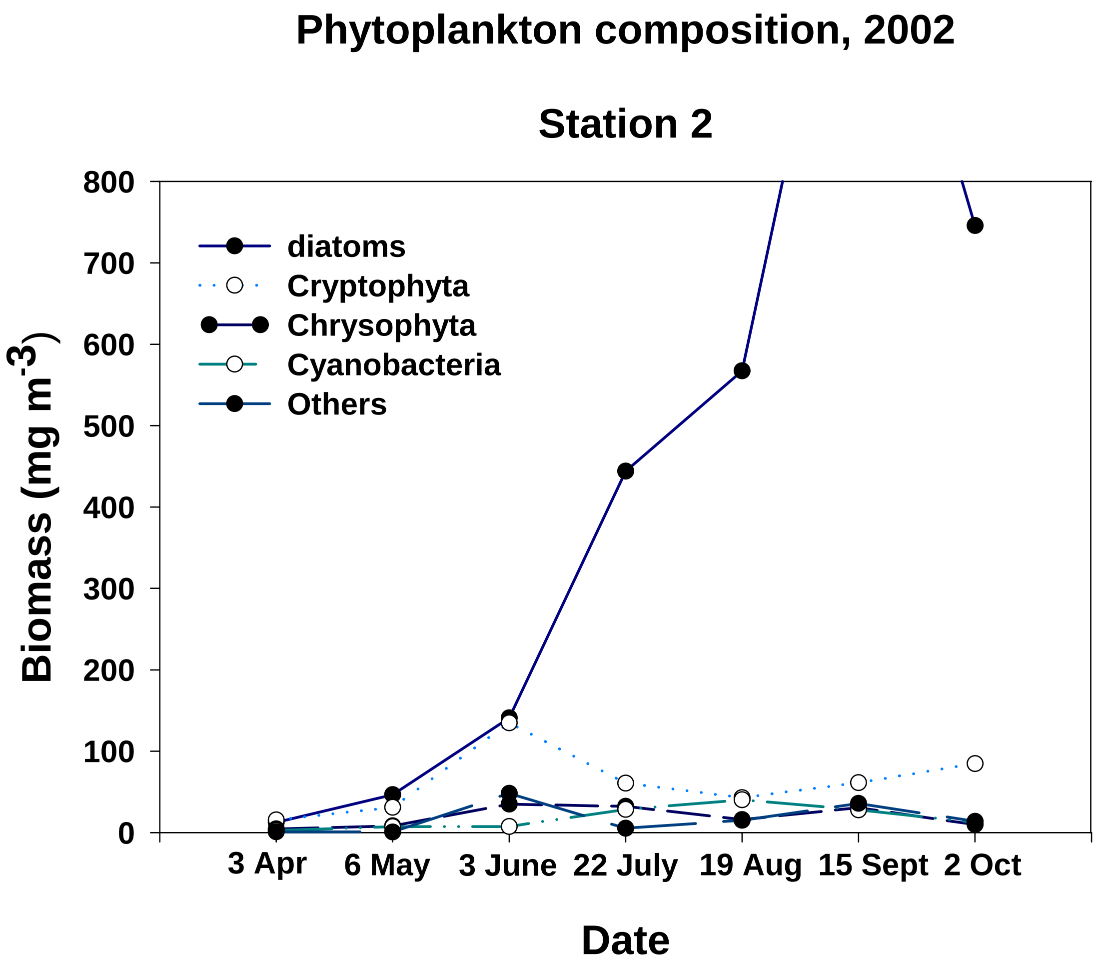

Figure 4.2a. Seasonal algal biomass, by algal division, for station KLF 2 in 2002. The point off scale for September 15 corresponds to 1236 mg m^{-3}. Lines correspond to divisions as indicated in the legend. "Others" correspond to chlorophytes and occasional pyrrhophytes (dinoflagellates).

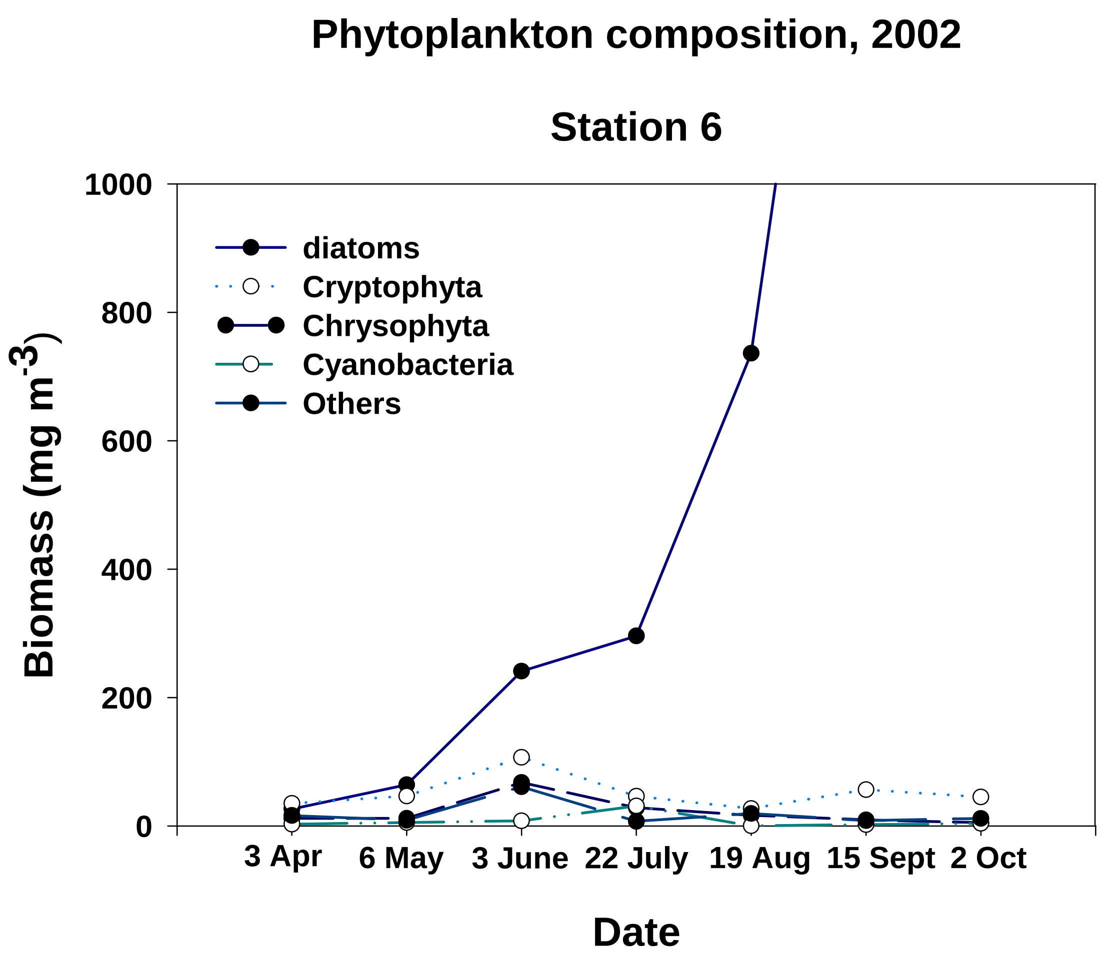

Figure 4.2b. Seasonal algal biomass, by algal division, for station KLF 6 South Arm in 2002.. Points off scale correspond to 1971 mg $m^{-3}$and 2092 mg m^{-3}, for September 15 and October 2 respectively. Lines correspond to divisions as indicated in the legend. “Others” correspond to chlorophytes and occasional pyrrhophytes (dinoflagellates).

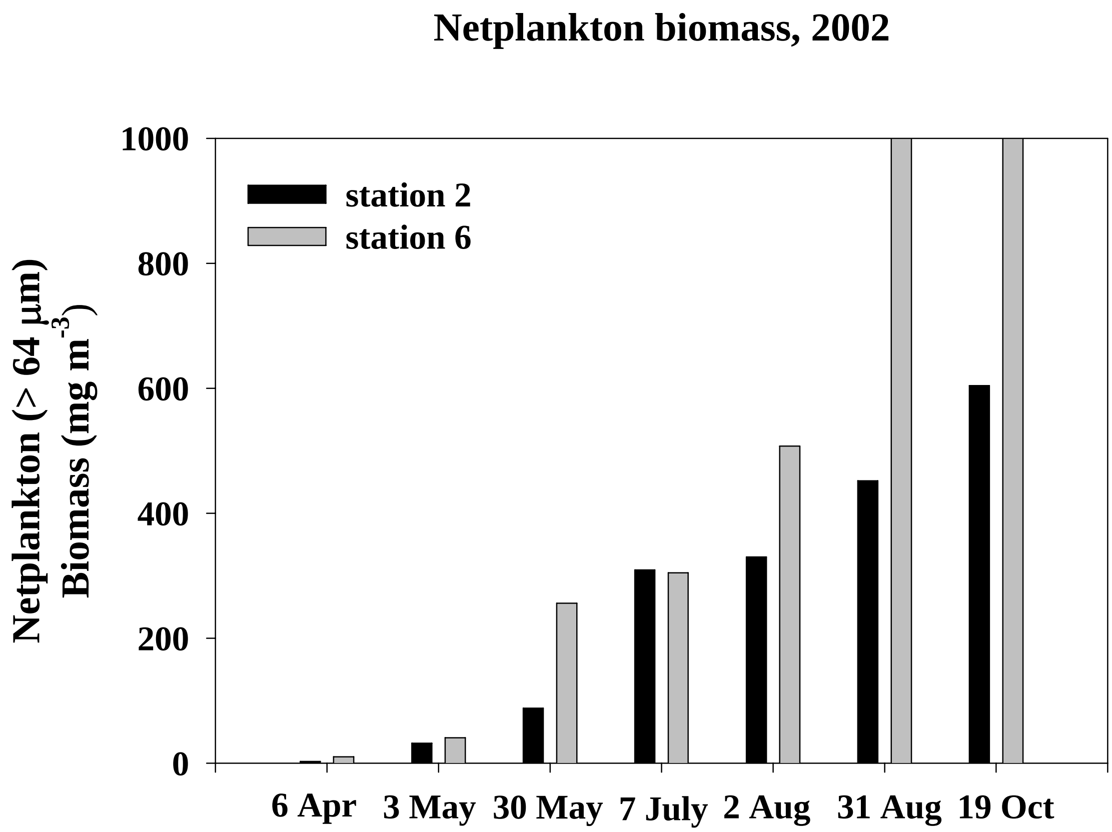

Figure 4.3. Seasonal biomass of netplankton (> 64 µm) at stations KLF 2 (dark histograms) and KLF 6 (grey histograms).

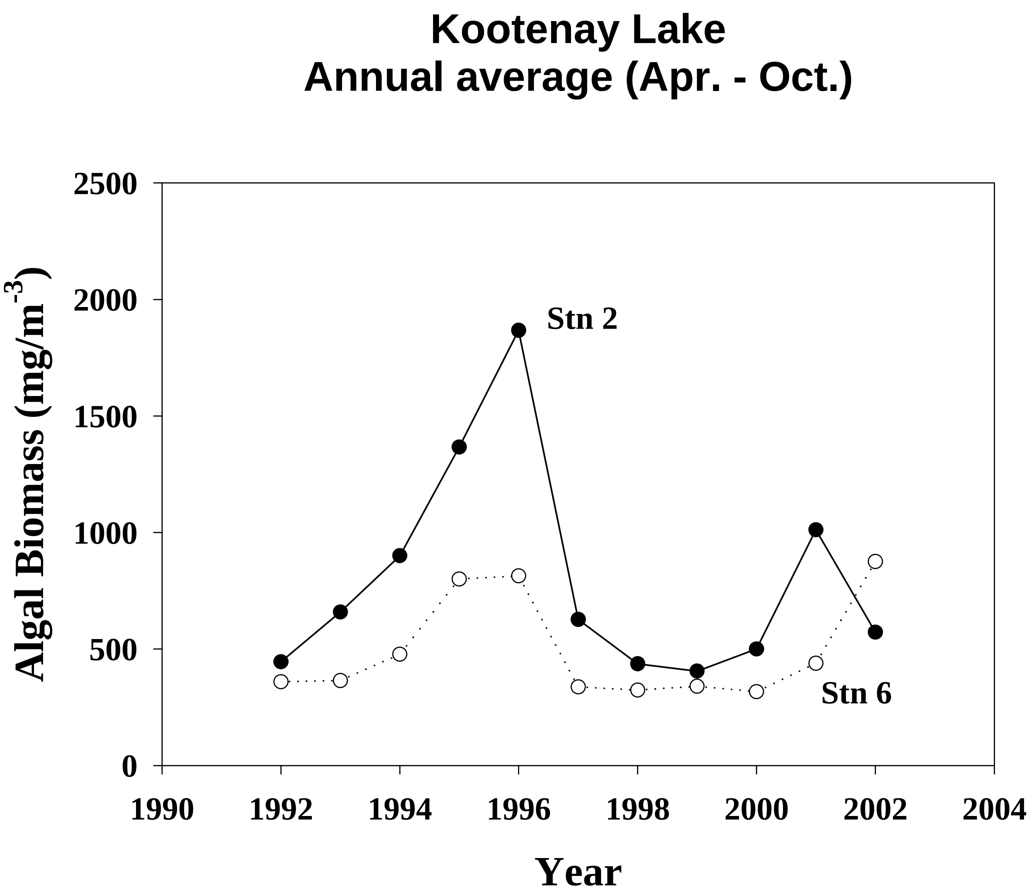

Figure 4.4. Average annual biomass of Kootenay Lake since 1992. Fertilized station KLF 2 in the North Arm compared to "control" station KLF 6 in the South Arm.

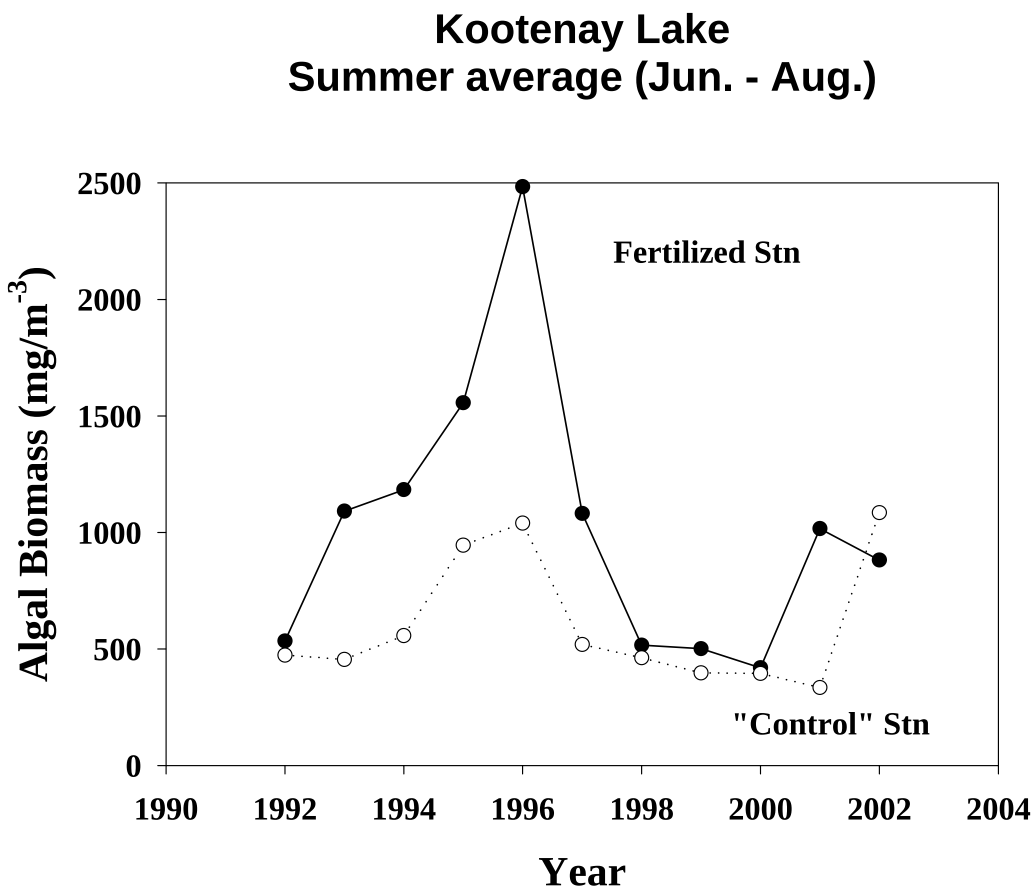

Figure 4.5. Summer average biomass of Kootenay Lake since 1992. Fertilized station KLF2 in the North Arm compared to “control” station KLF6 in the South Arm.

2003

Introduction

Kootenay Lake, a large (390 km^2) fjord lake in South-Eastern British Columbia, has been continuously fertilized since 1992 in an effort to rehabilitate declining populations of kokanee salmon (*Oncorhynchus nerka*) (Ashley et al. 1997, 1999). From 1992 to 1996 the fertilization treatment to the North Arm used 47.1 tons of agricultural grade fertilizer from spring to early fall. A further five-year adaptive management period of experimental fertilization was initiated in 1997 to document trophic level responses to changing loading rates of nitrogen and phosphorus. In 1997, fertilizer loading was lowered to 29.5 tons and this load was further reduced to 22.9 tons in each year of 1998 and 1999. In the 9th year of fertilization (2000) the load increased back to 29.5 tons as it was in 1997 and in the 10th – 12thyear (2003) the load was further increased back to 47.1 metric tons as during 1992-96.

The rationale for the fertilization programme was that the lake had been suffering from an "oligotrophication" due to the construction of dams on both major tributaries (Duncan and Kootenay Rivers) and reductions in anthropogenic nutrient loading. The historical record on the phytoplankton community dating from the early 1970s through the early 80s indicated subtle changes in species composition towards more oligotrophic taxa even though total algal biomass did not decline significantly during the same period (Daley and Pick 1990). With fertilization, an increase in primary production and algal biomass was anticipated to trigger an increase in cladoceran biomass for consumption by young of the year kokanee salmon (Walters et al. 1991). Other lakes in British Columbia have undergone artificial fertilization with apparently positive effects on fish production (Stockner and MacIssac 1996).

This report is an analysis of the changes, induced by fertilization, to the phytoplankton community of Kootenay Lake during 2003, the 12th year of fertilization. The data from the 2003 sampling are presented with a comparison to 1992-2002 data. In 2003 in addition to the standard stations KLF 2, 4, 6 and 7, the stations KLF 1, 3, 5 and 8 were also sampled. In addition, discrete depth profiles at selected stations were collected for comparison with depth integrated samples (0 – 20 m).

Methods

Water samples were collected integrating a 0 - 20 m water column, in keeping with the historical sampling procedure, at 4 stations along the length of the North Arm and into the South Arm. Collection dates for the samples enumerated from 2003 are given in Appendix I along with summary details of the number of transects examined, total species richness, total abundance and total biomass recorded. Samples were enumerated from each of the four stations, at one-month intervals, from April through October. Depth profiles of discrete samples were collected at these stations in August, September and October to compare with the integrated samples. In addition to these standard stations, intermediate stations (KLF 1, 3, 5 and 8), which were sampled in the early years of the fertilization program were also sampled along with depth profiles (2, 5, 10, 15 and 20 m) in August, September and October.

Subsamples of integrated or discrete depth samples were preserved for phytoplankton analysis using Lugol's iodine solution. Enumerations were made using the Utermöhl method on a Wild M40 inverted microscope (Utermöhl 1938, Lund et al. 1958). Aliquots of 5 - 15 ml were settled overnight (16 hours) in 26 mm diameter sedimentation chambers. For each sample, a minimum of 300-350 phytoplankton cells was counted along randomly selected transects to ensure an 85-90% counting accuracy (Lund et al. 1958). The length of each transect equalled the diameter of the chamber. Cell counts and dimensions were recorded on a computerized counter (Hamilton 1990) to facilitate the calculations of the parameters describing phytoplankton community structure. For counting purposes cells were assigned to one of three magnifications: 400X, 200X and 100X, depending on their size and nature. The cells were consistently identified and enumerated at the assigned magnification.

The estimations of total algal biomass, and size and division distribution were derived from the enumerations. Algal biomass was determined from estimations of the volume of each algal taxon. One of seven pre-selected shapes (sphere, cone, double cone, ellipsoid, parallelepiped, half parallelepiped and rod) was assigned to each species (Hamilton 1990). The dimensions were measured on 3-10 individuals per species. The summation of the individual cell volumes: the biovolume was converted to biomass (mg/m^3) assuming a density of 1 (Utermöhl 1958).

Taxa were assigned to specific size classes based on the mean of their longest dimension. Accordingly, total biomass was partitioned into six size classes: the picoplankton (<2.1µm), the ultraplankton (>2-10 µm), the nanoplankton (10.1-20 µm), the microplankton (20.1-64 µm) and the net plankton (>64 µm). Picoplankton, which can be very abundant in oligotrophic BC lakes, are difficult to enumerate accurately by conventional light microscopy and need to be examined by epifluorescence microscopy.

Total biomass was further separated into seven main divisions: Cyanobacteria, Chlorophyta, Chrysophyta, Cryptophyta, Pyrrhophyta, diatoms, and Euglenophyta and Xanthophyta. The latter division was not recorded in Kootenay Lake and euglenophytes were extremely rare.

A species list for all phytoplankton enumerated is given in Appendix II along with the codes used for these species; the count sheets of the raw data are provided in Appendix III for the standard stations and in Appendix IV for the additional stations and all the depth profiles. Linda Ley conducted the enumerations using the same technique as in previous years using the same computer program (Hamilton 1990). The Appendix lists are in hardcopy reports with the Ministry of Environment in Nelson, BC.

Results and Discussion

2003 Monthly transects

The overall trend observed throughout the 2003 sampling season was one of a slight decline in algal biomass from the North Arm stations (stations KLF 2 and KLF 4) towards those in the South Arm (stations KLF 6 and KLF 7) (Fig. 4.6a). When all stations were sampled in August, September, and October (Fig. 4.6b) the overall pattern observed was similar. However, in August the first station at the start of the fertilization zone had considerably more biomass that station KLF2. The biomass at West Arm station KLF 8 was higher than at station KLF 7 or KLF 6.

The lowest levels of biomass were observed in April (35 – 61 mg/m^3) throughout the lake with little difference between stations. By the beginning of May, total biomass was 2-3 times higher than in April. Increases in cryptophytes and some pennate diatoms (*Synedra* spp.) were responsible for the increase in biomass. This was similar to the early spring pattern of previous years.

In June further increases in pennate diatoms (*Synedra, Asterionella*) as well as centric diatoms (*Cyclotella* spp) were observed leading to higher biomass, relative to May, at all stations but, in particular, station KLF7 that experienced a significant increase in the pennate diatom *Tabellaria*. In late June further increases of *Asterionella* and *Tabellaria* were observed throughout the lake with the latter more dominant in the South Arm relative to the North.

The July total biomass was slightly higher than that obtained in June in the fertilized North Arm, because of further increases in *Tabellaria* and a high abundance of centric diatoms.

Biomass levels remained similar through August but with dominant diatoms shifting to *Fragilaria crotonensis, Synedra* and *Tabellaria* in the North Arm while these same taxa declined in the South Arm. In August, all 8 stations were sampled and station KLF 1 had a significantly higher biomass (2,473 mg. m^{-3}) than others in the North Arm due to a very high abundance of *Tabellaria*. In September as in August the full suite of stations was sampled revealing a similar pattern of high biomass in the North Arm declining to station KLF 5 or KLF 6 and then rising again through station KLF 7 and KLF 8. The rise in biomass at the latter stations is likely due to the influence of the Kootenay River, either providing nutrients or additional river plankton. Biomass was overall much lower during September and October as pennate diatoms declined at all stations.

Taxonomic composition at the division level

Kootenay Lake continues to be a diatom dominated lake (76 - 83% of total average biomass) (Fig. 4.7a and 4.7b). *Synedra* spp. and some *Asterionella*, as in the previous three years, dominated the early biomass increase in 2003 but the peak biomass in July was largely due to *Tabellaria*. In earlier years 1992-1996 with higher loading of nutrients *Fragilaria* was often the dominant pennate diatom during the spring “bloom” of late June and later in the season *Tabellaria fenestrata* occurred, which is a typical spring succession observed in oligo-mesotrophic temperate lakes (Reynolds 1984). Compared to the North Arm, the South Arm biomass peaked earlier with *Tabellaria* the taxon dominating the biomass.

Cryptophyta (in particular *Cryptomonas erosa, C. reflexa*, *Rhodomonas minuta*) were stimulated by the fertilization (summer average of 53 vs. 25 mg. m^{-3}) as observed during other years of high fertilization. The Chrysophyta comprised the third major algal division in Kootenay Lake, but chrysophyte biomass levels were on average similar between the two arms (4.6 - 5.2%).

Chlorophytes were an insignificant component of the total (<1%, indicated as “Others” in Fig. 4.7 a and 4.7b). Cyanobacteria contributed slightly more biomass than the Chlorophyta but, as found in previous years, cyanobacterial biomass was very low (5 - 14 mg/m^3 or 1.7-2.8 % of total biomass). However, there was slightly more cyanobacterial biomass in the fertilized zone than at the reference stations. Sporadically, dinoflagellates (*Peridinium, Gymnodinium, Ceratium*) contributed significant biomass in both Arms.

Size distribution

Nanoplankton and ultraplankton (2-20 μm) were not consistently enhanced in the fertilization zone. This is in contrast to the early years of high nutrient loading when nanoplankton biomass was significantly enhanced by the fertilization. On average, the North Arm and South Arm both had significant and similar proportions of netplankton (51-52%of annual total biomass). However, the netplankton (> 64 μm) was similar or elevated at the fertilized station relative to the “control” (station KLF 6) on the sampling dates (Fig. 4.8). Generally, netplankton is considered a less favourable food source for zooplankton.

Depth profiles in algal biomass

Depth profiles of biomass showed that the distribution of algae was not uniform with depth over the top 20 m (Fig. 4.9, Fig. 4.10). This was particularly evident in the fertilization zone in August when exceedingly high biomass was reached in the upper surface waters in the fertilization zone and declined rapidly with depth. In particular, station KLF 1 reached a total algal biomass level of 3.1 g m^3 at 2m (Fig. 4.9a); this would probably have been almost visible as a surface bloom and was largely due to *Tabellaria* (contributing alone 40% of the total), *Fragilaria*, *Cyclotella* and *Asterionella* (Appendix IV). *Tabellaria* tended to decline with depth at North Arm stations. The same surface “bloom” was not as pronounced from stations KLF 2 through KLF 4 although a peak was observed at the latter station at 5 m due to high abundance of both *Fragilaria* and *Tabellaria*. In contrast, depth profiles from stations in the South Arm tended to exhibit higher biomass levels greater depths (below 10 m) in mid-summer (Fig. 4.10a). The composition of the samples at depth indicated more diatom biomass derived most likely from earlier epilimnetic growth. For example, *Asterionella* which is normally produced earlier in the year appeared in greater concentrations with depth relative to surface waters at station KLF 5, although this pattern was not as pronounced at station KLF 6 (Appendix IV). While station KLF 7 also showed increased biomass with depth in August, centric diatoms (*Cyclotella bodanica, Cyclotella comensis*) contributed relatively more to the increase; the very different species composition of station KLF 7 is likely due to the influence of the Kootenay River.

Figure 4.11 shows general agreement between algal biomass estimates obtained from the integrated (0 -20 m) samples with estimates based on the average of the discrete samples over the same water column depth. The correlation between the two estimates is significant.

Comparison with the previous eleven years

The hypothesis that algal biomass would be higher at the fertilized stations relative to the unfertilized stations held in 2003, both on an annual average and summer average basis (Table 4.2, Fig. 4.12, Fig. 4.13).

Phytoplankton biomass in the fertilized arm continued to be lower than during the mid-90s in the North Arm (Table 4.2), when fertilization loading was high and sustained over several years. In 2003, biomass levels at station KLF 2 were similar to the annual average biomass levels observed in the previous year (2002, Table 4.2). However, in contrast station KLF 6 in the South Arm showed the lowest annual average biomass levels since the beginning of the fertilization program in 1992. An examination of the discharge record from the Kootenay River for 2003 would help determine whether the low biomass in the South Arm was due to lower flows into the lake. As a result biomass within the fertilization zone was indeed on average higher relative to the reference stations of the South Arm. The ratio of biomass between the North and the South Arm illustrates the amplitude of the effect regardless of year to year differences in climate. For 2003, the annual average ratio was about 1.8 for 2003 compared to the low ratio of 0.65 for the previous year (2002). The highest ratios of about 2.3 were observed in 1996 and 2001.

Acknowledgements

Funding was provided by the Columbia Basin Fish and Wildlife Compensation program for the four standard stations and by the Kootenai Tribe of Idaho for stations KLF 1, 3, 5 and 8 and all discrete sample collection and analysis. Thanks to Kootenay Wildlife Services Ltd for sample collection.

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Table 4.2. Biomass averages (mg.m^3) at the fertilized station (Stn KLF 2) in the North Arm and at the "control" station (Stn KLF 6) in the South Arm from 1992 to 2003.

	Annual (Apr. - Oct.) (n = 7 - 14)		Summer (Jun. - Aug.) (n = 3 - 6)	
	Stn KLF 2	Stn KLF 6	Stn KLF 2	Stn KLF 6
1992	445	359	534	473
1993	658	364	1091	455
1994	900	477	1183	557
1995	1366	800	1556	945
1996	1867	813	2483	1040
1997	626	337	1081	519
1998	436	323	516	462
1999	405	340	501	397
2000	500	316	419	395
2001	1011	438	1016	334
2002	572	875	881	1085
2003	509	276	720	340

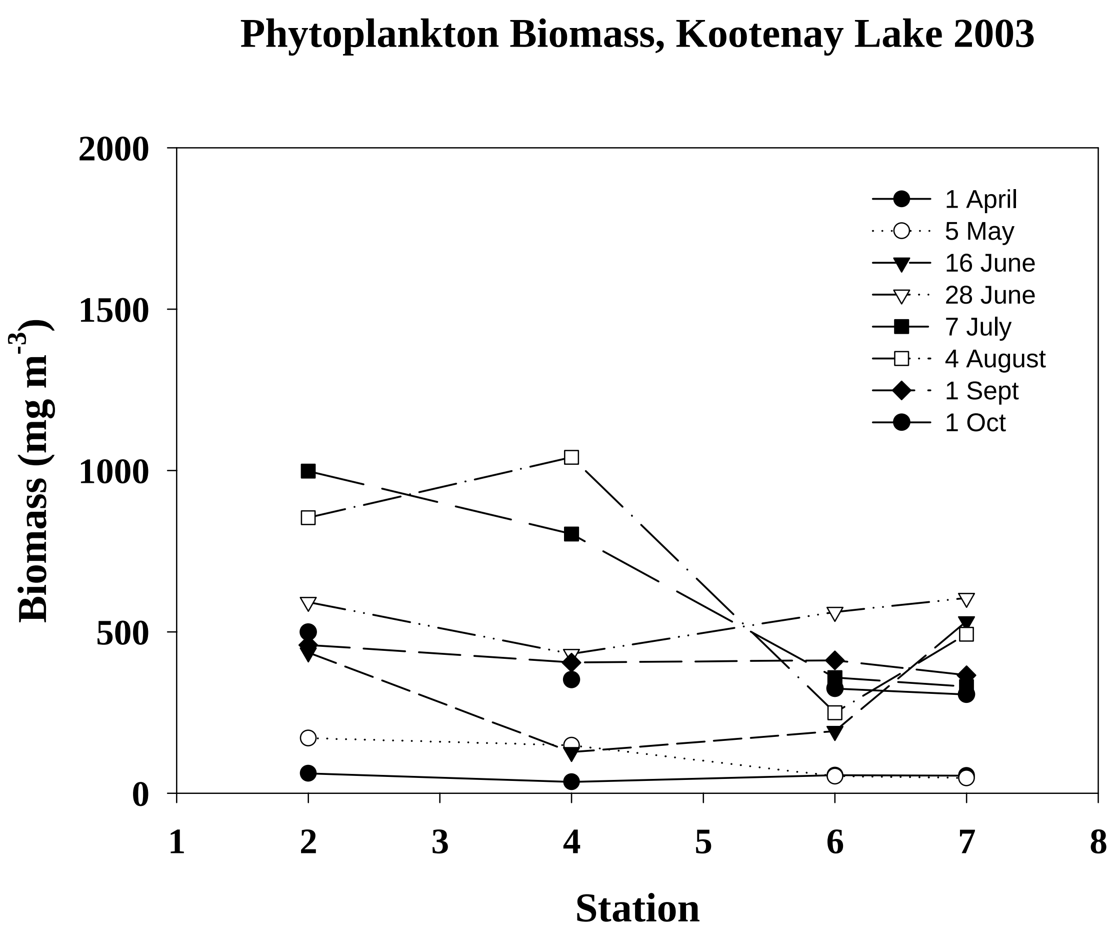

Figure 4.6a. Total algal biomass, along the North South transect of Kootenay Lake, from April through October of 2003. Stations KLF 2, 4, 6 and 7.

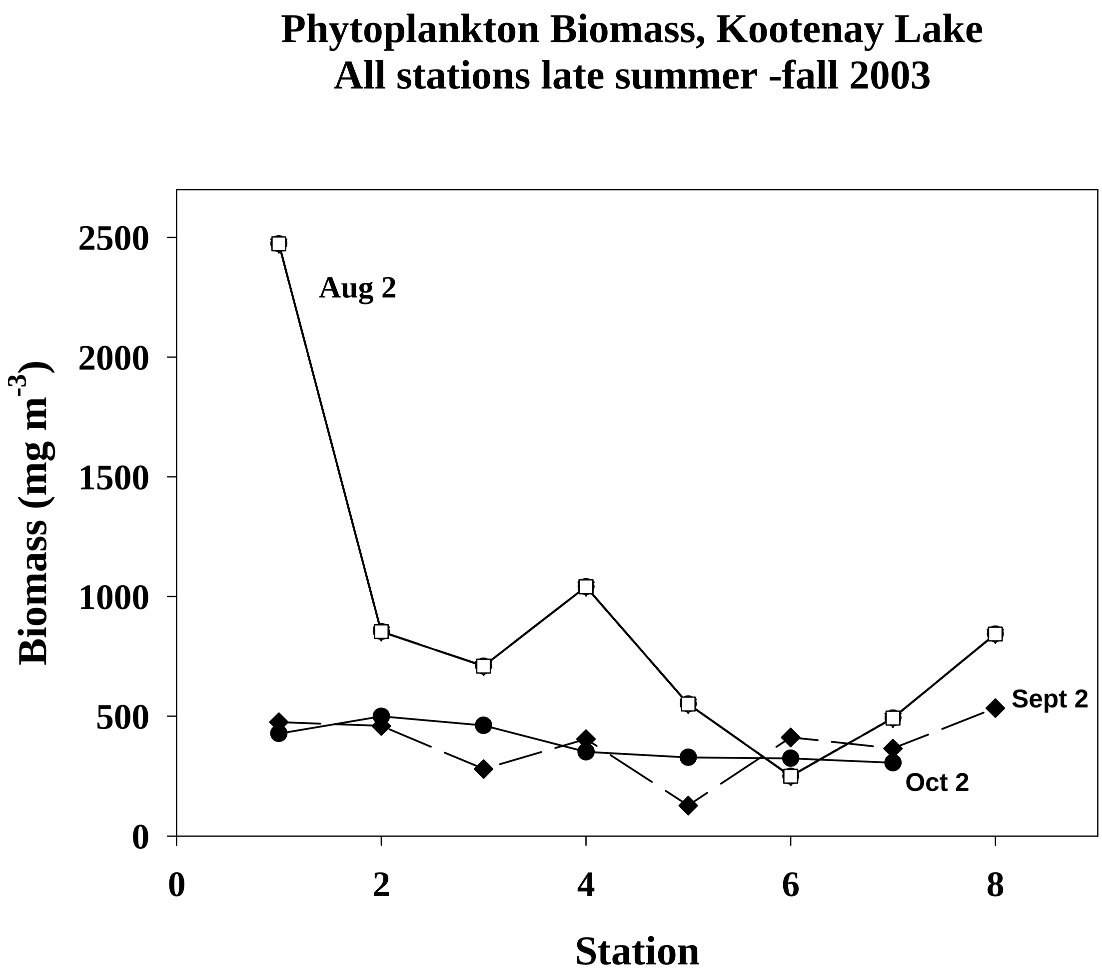

Figure 4.6b. Total algal biomass, along the along the North South transect of Kootenay Lake, from August through October of 2003. Stations KLF 1 through KLF 8.

Phytoplankton composition, 2003
Station 2

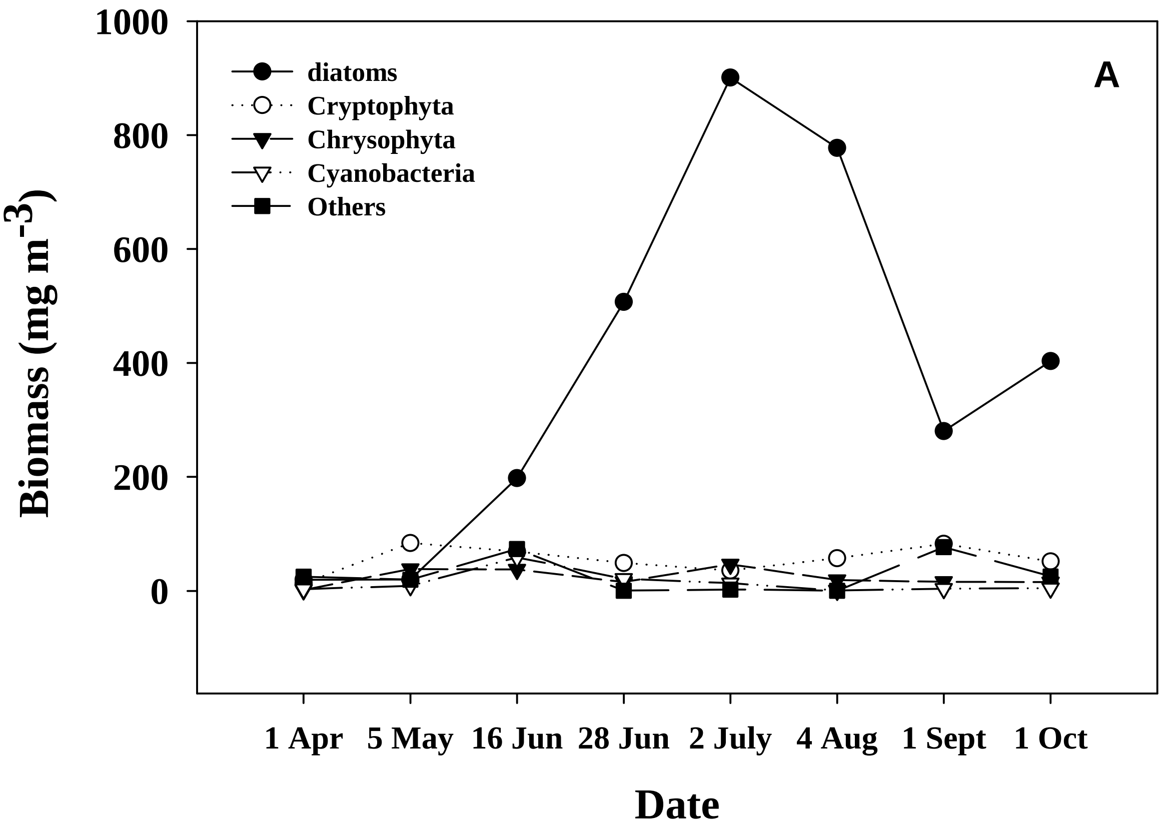

Figure 4.7a. Seasonal algal biomass, by algal division, for station KLF 2 North Arm in 2003. Lines correspond to divisions as indicated in the legend. “Others” correspond to chlorophytes and occasional pyrrhophytes (dinoflagellates).

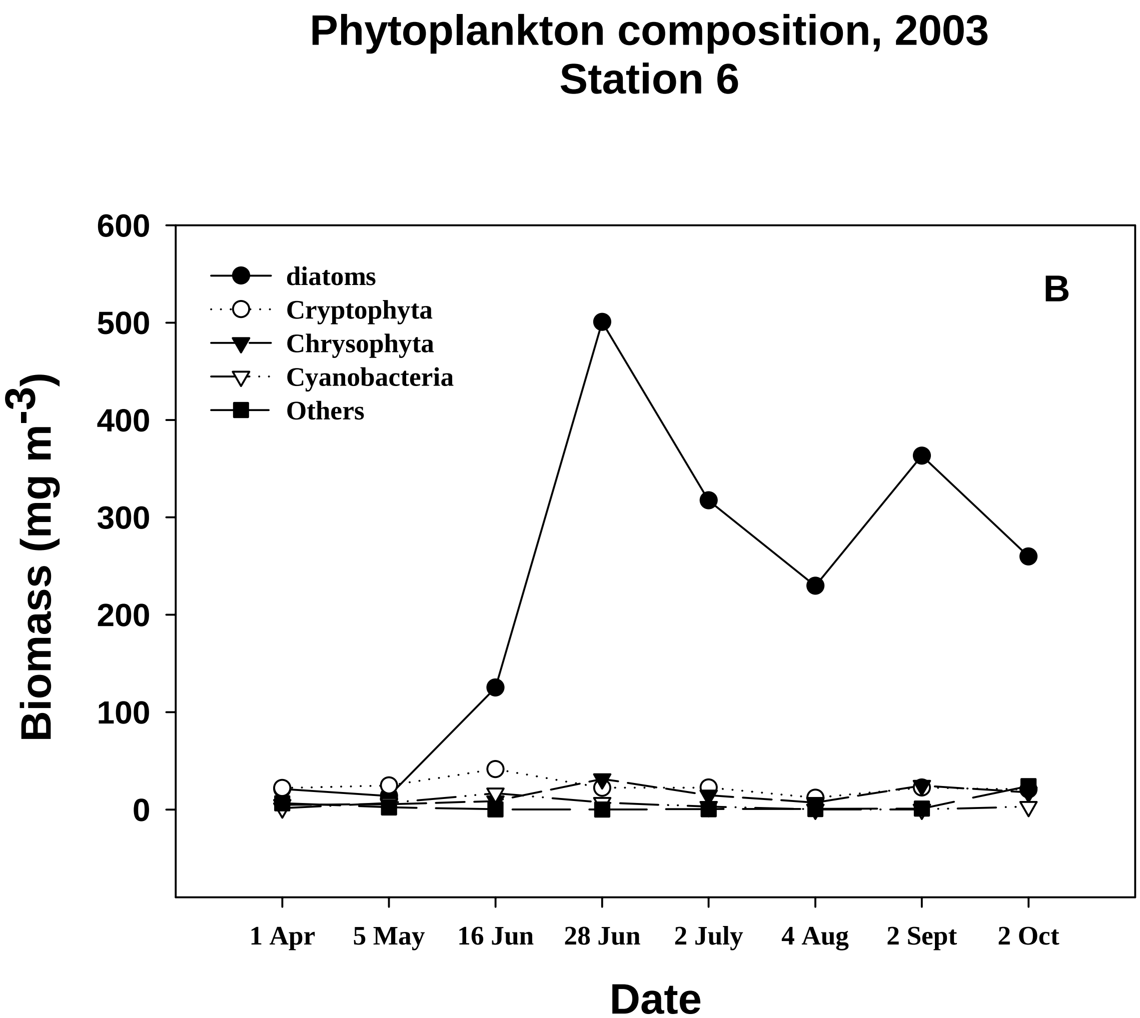

Figure 4.7b. Seasonal algal biomass, by algal division, station KLF 6 South Arm in 2003. Lines correspond to divisions as indicated in the legend. "Others" correspond to chlorophytes and occasional pyrrhophytes (dinoflagellates).

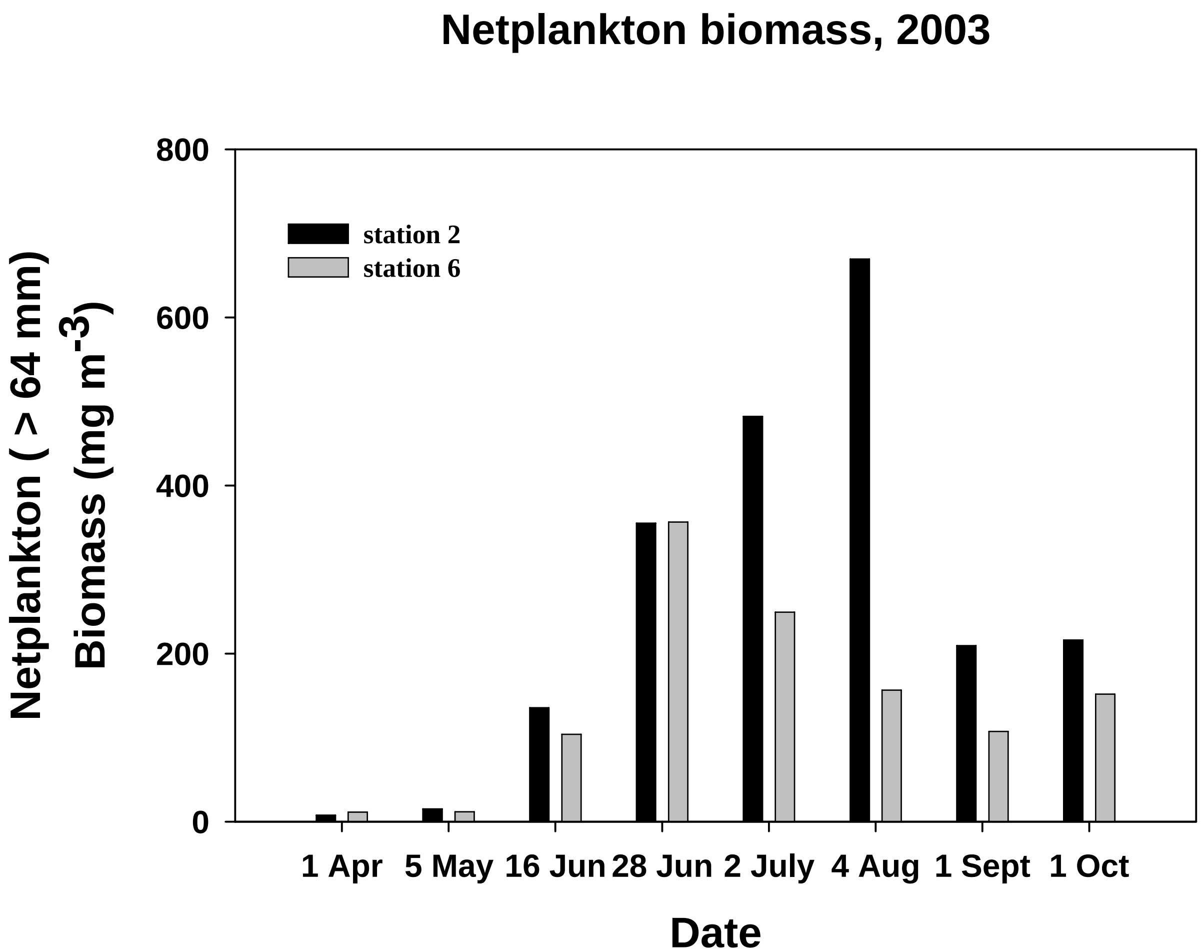

Figure 4.8. Seasonal biomass of netplankton (> 64 µm) at stations KLF 2 (dark histograms) and KLF 6 (light histograms).

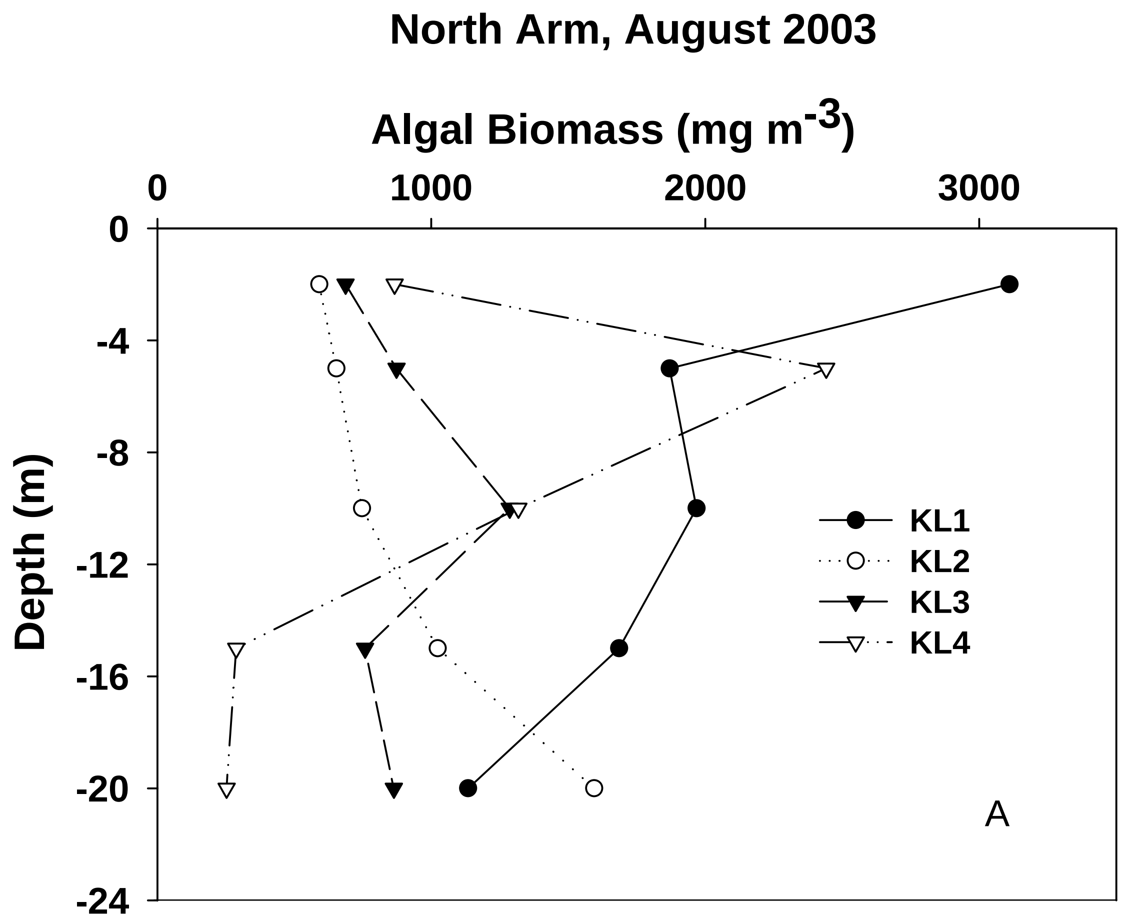

Figure 4.9a. Depth profiles for August from the North Arm of Kootenay Lake, 2003.

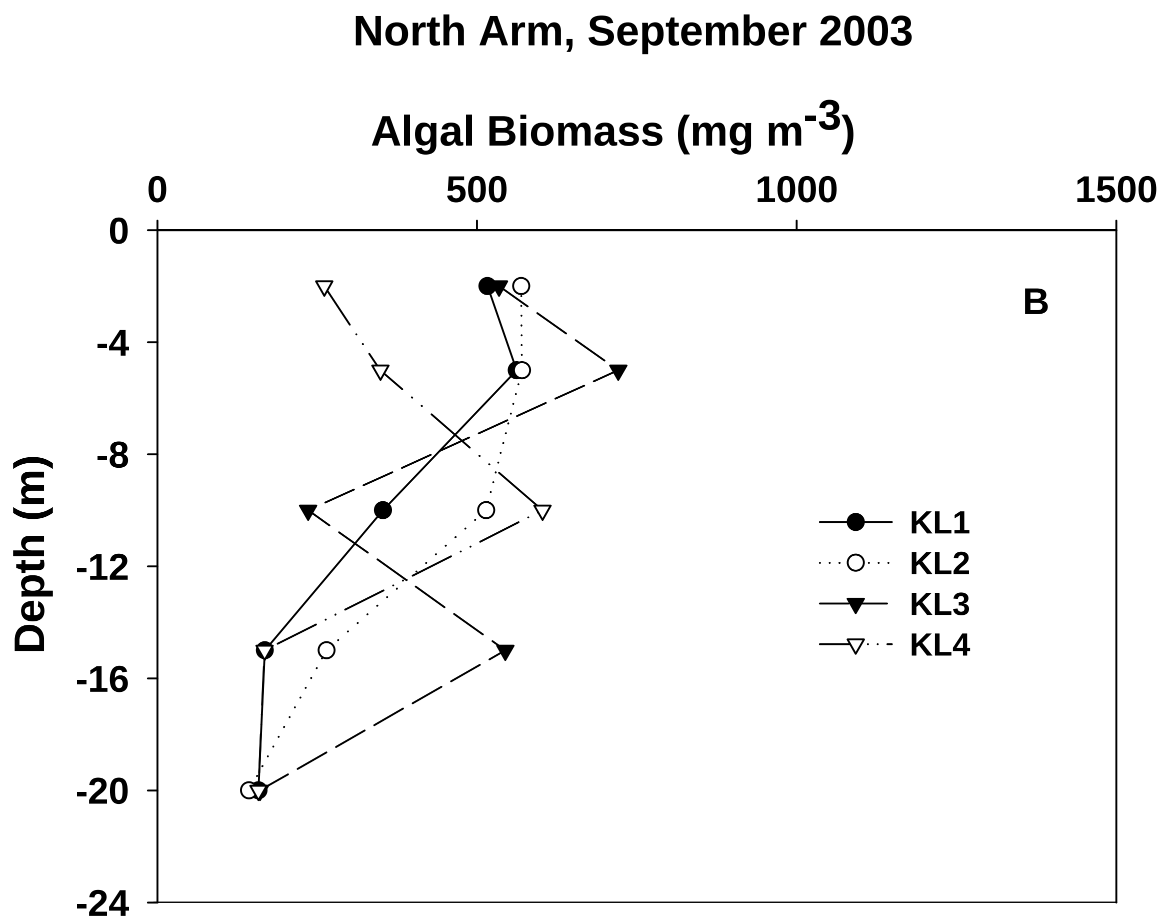

Figure 4.9b. Depth profiles for September from the North Arm of Kootenay Lake, 2003.

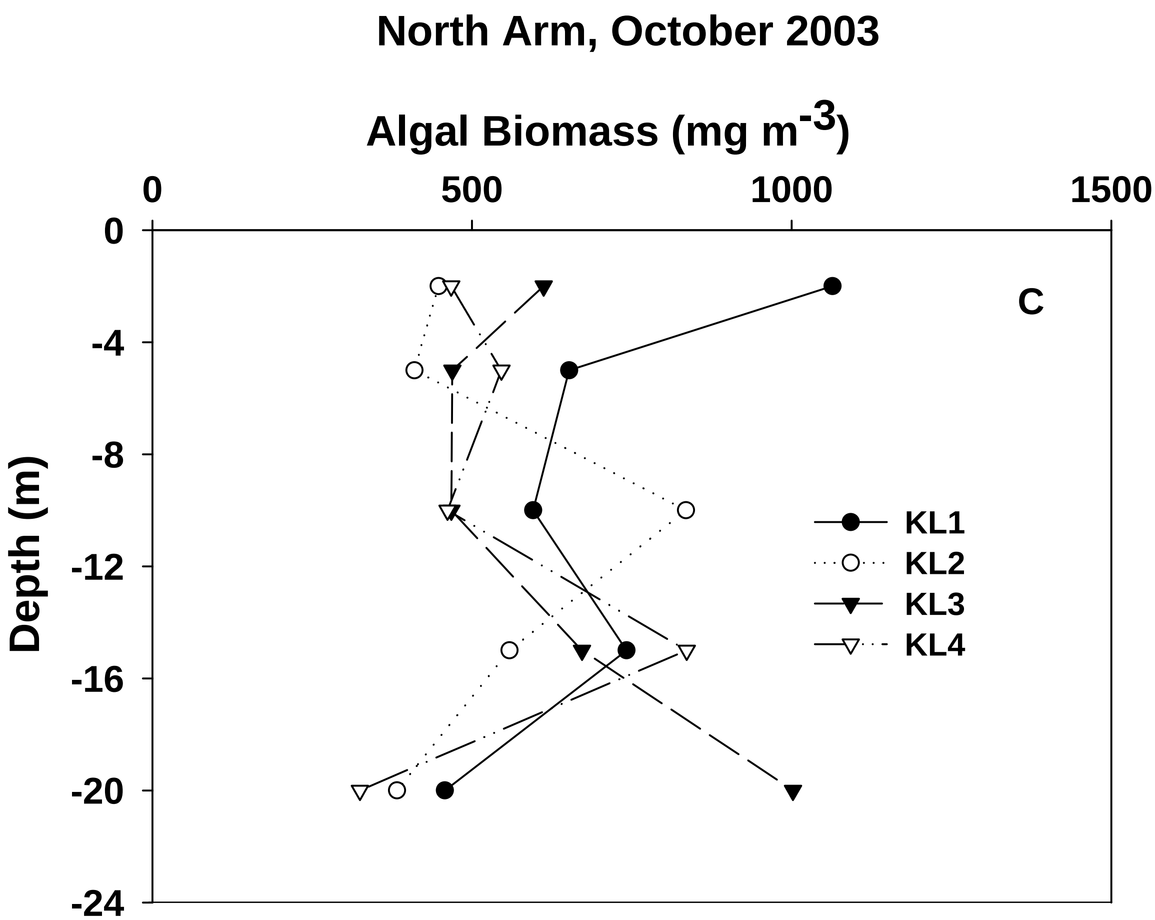

Figure 4.9c. Depth profiles for October from the North Arm of Kootenay Lake, 2003.

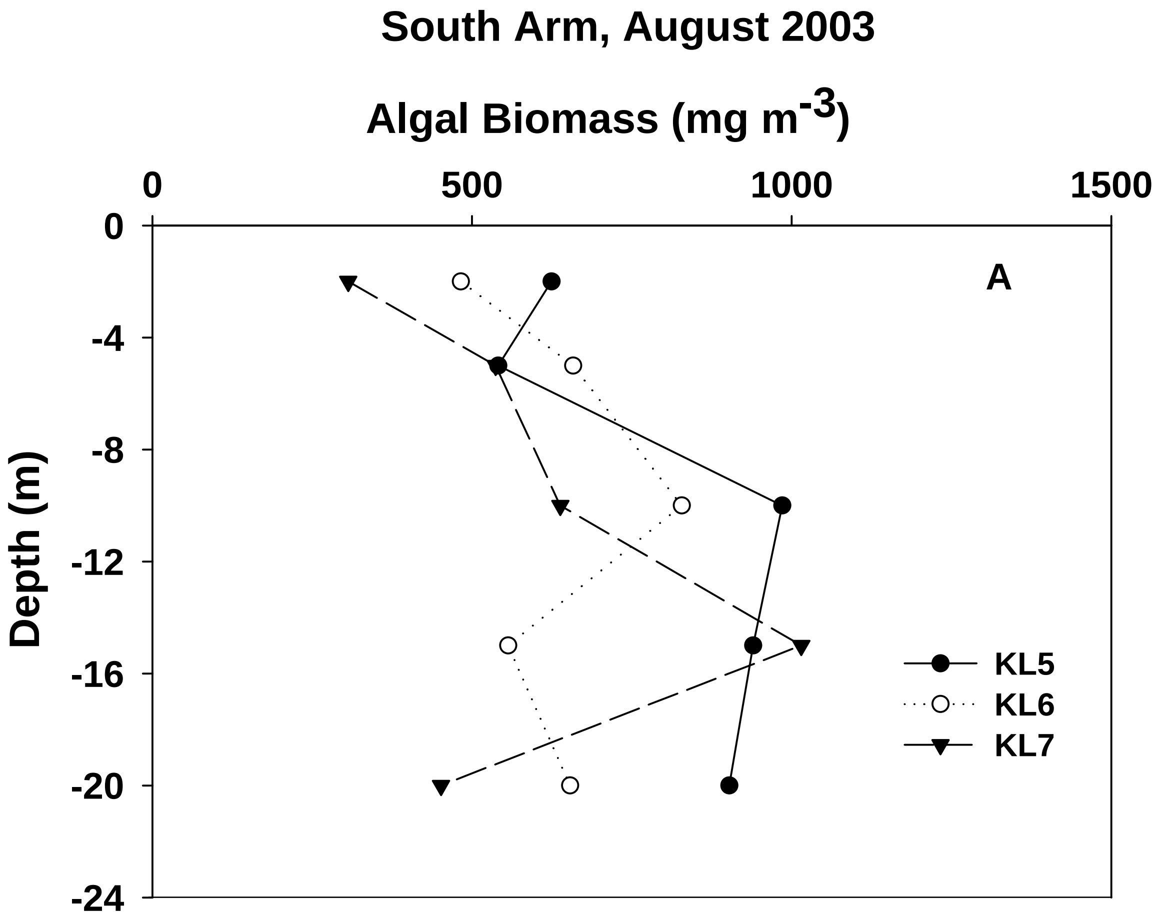

Figure 4.10a. Depth profiles for August from the South Arm of Kootenay Lake, 2003.

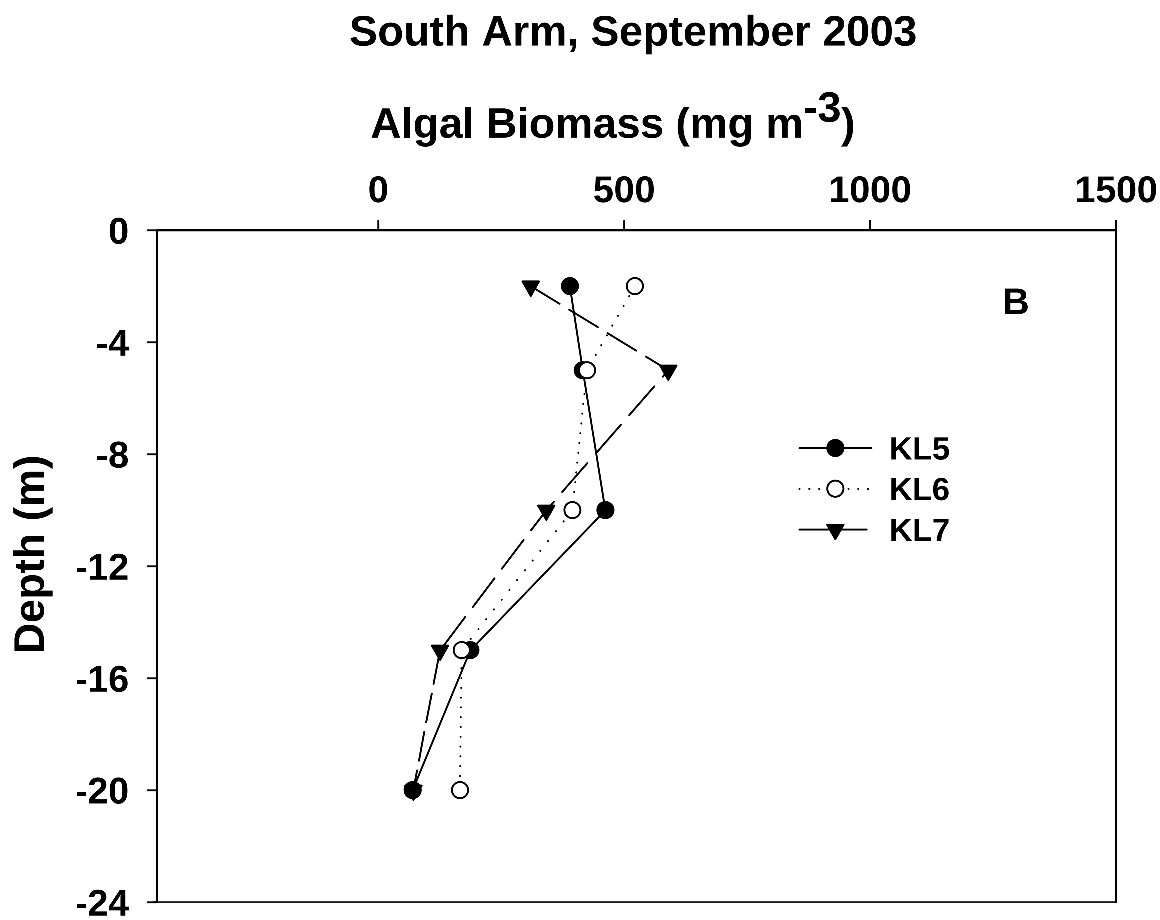

Figure 4.10b. Depth profiles for September from the South Arm of Kootenay Lake, 2003.

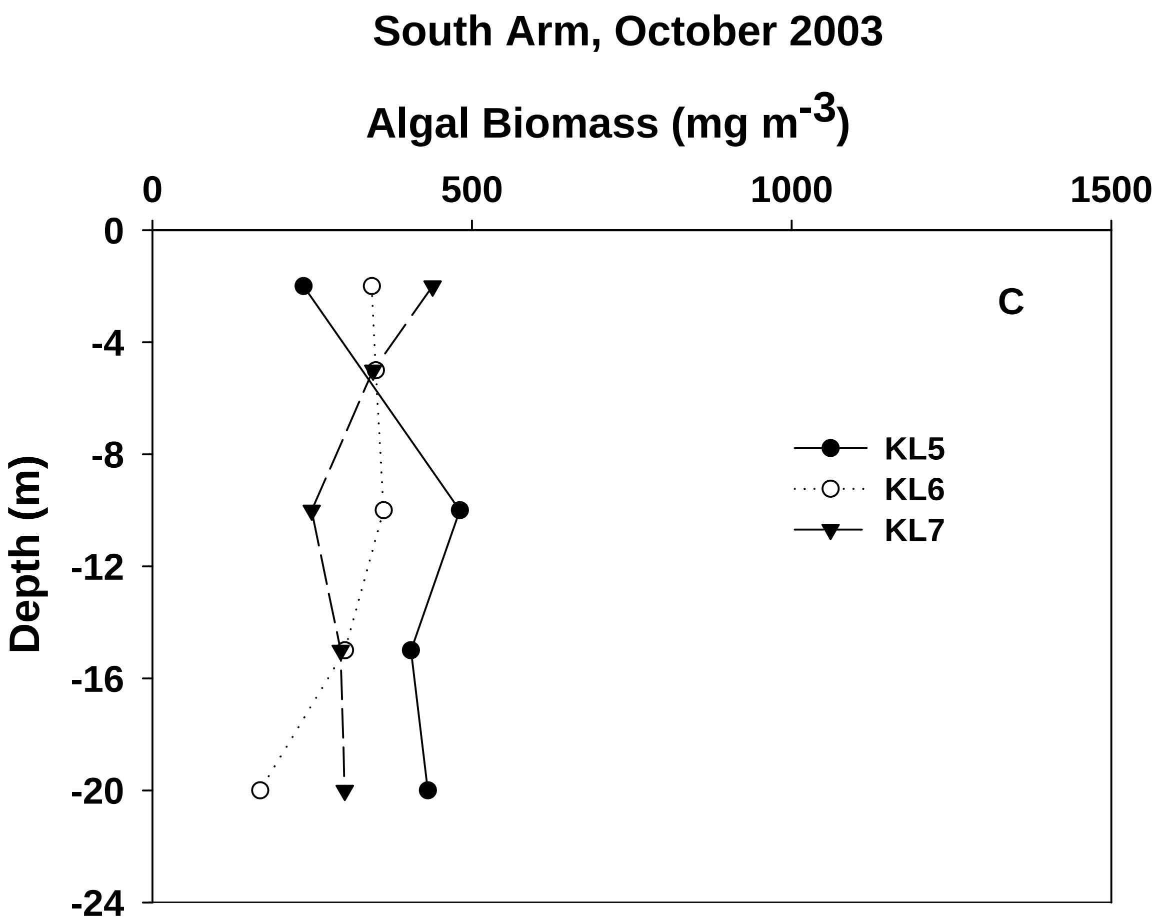

Figure 4.10c. Depth profiles for October from the South Arm of Kootenay Lake, 2003.

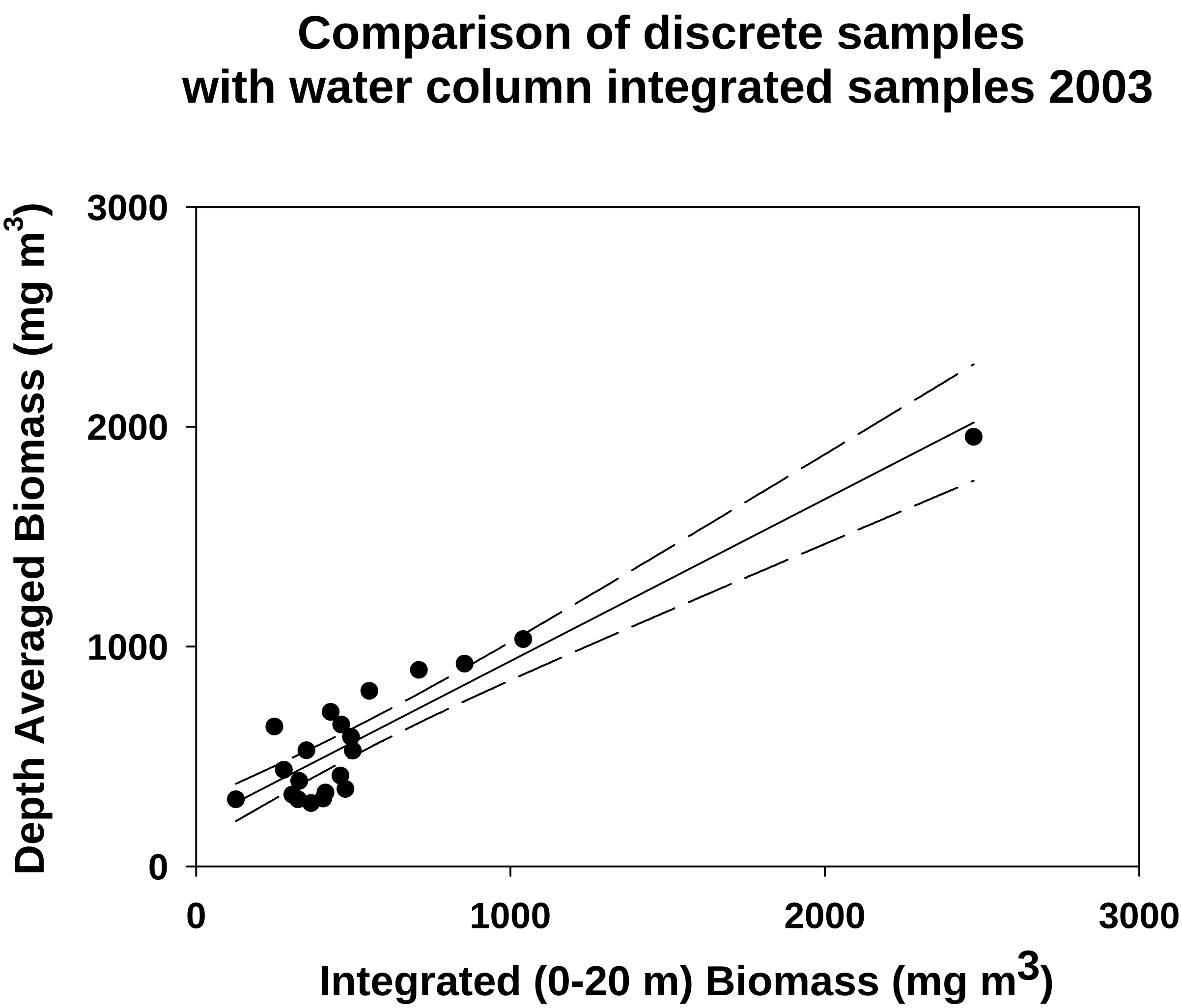

Figure 4.11. Relationship between depth integrated samples and the average of discrete samples with depth over the same water column (0 – 20 m) for August, September and October sampling. (r = 0.93).

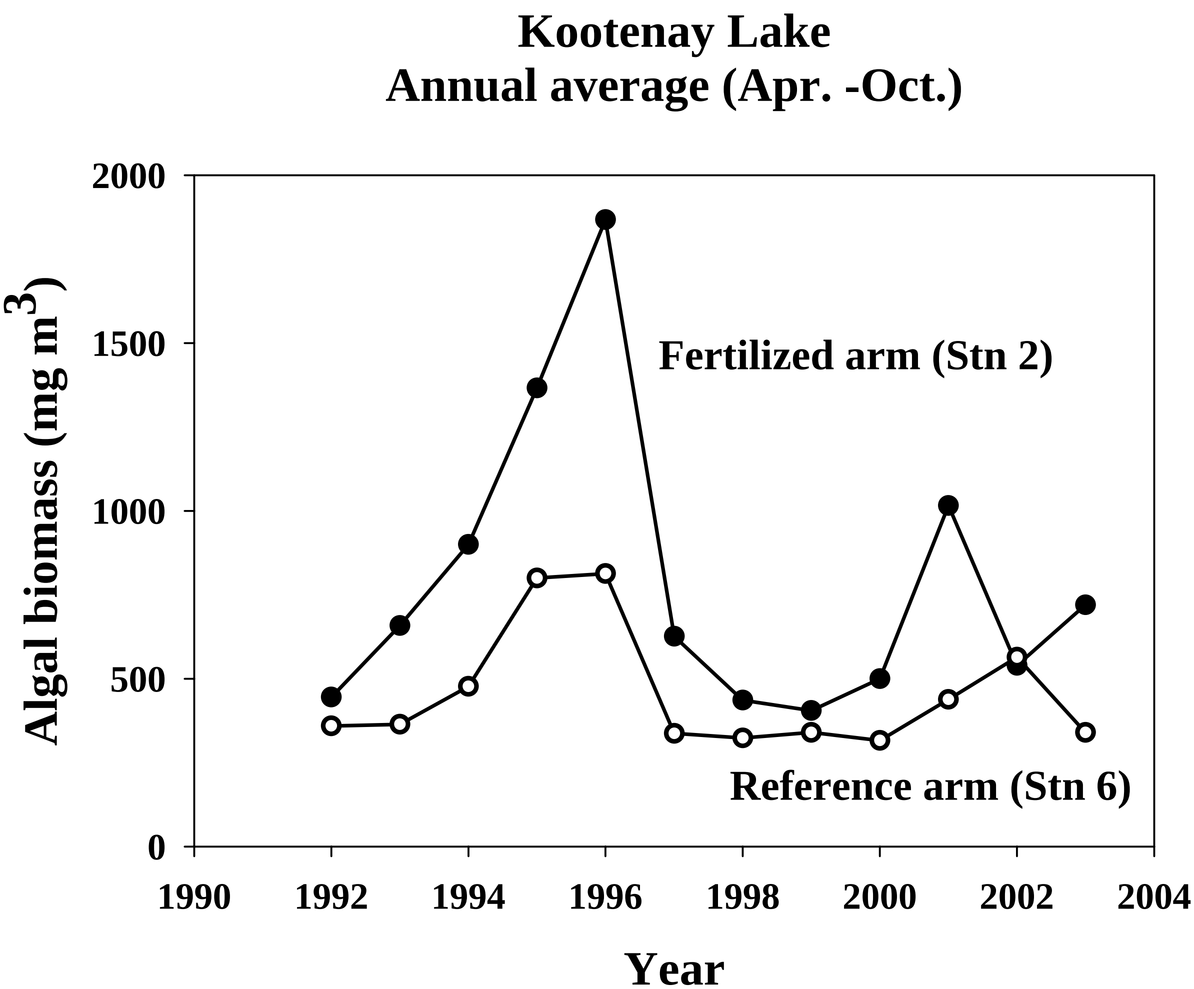

Figure 4.12. Average annual biomass of Kootenay Lake since 1992. Fertilized station KLF 2 in the North Arm compared to “control” station KLF 6 in the South Arm.

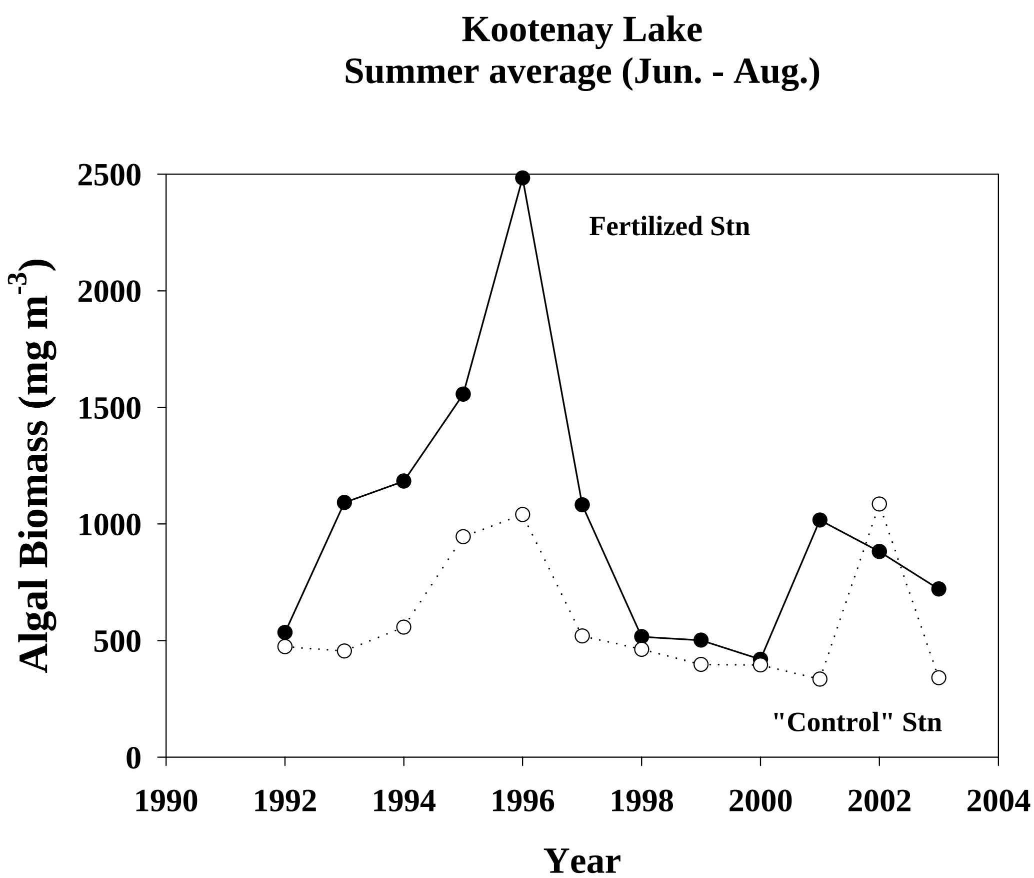

Figure 4.13. Summer average biomass of Kootenay Lake since 1992. Fertilized station KLF 2 in the North Arm compared to "control" station KLF 6 in the South Arm.

CHAPTER 5

RESPONSE OF ZOOPLANKTON TO EXPERIMENTAL FERTILIZATION YEARS 11 and 12 (2002 and 2003)

by

Dr. Lidija Vidmanic

Limno-Lab Ltd.
Vancouver, BC

Introduction

Experimental fertilization of Kootenay Lake began in 1992, in an effort to restore the lake's productivity to natural levels. Kokanee salmon (*Oncorhynchus nerka*) abundance had declined to an historical low in 1991, and there was concern that the stock might crash. Kokanee are planktivores that feed mainly on macrozooplankton such as *Daphnia*. The restoration experiment was further complicated by the presence of *Mysis relicta*, an exotic crustacean that competes with kokanee for zooplankton, particularly *Daphnia*.

After four years of decreased nutrient addition (1997-2000) fertilizer loading was increased from 2001 onward to the level used during the first five years (1992-1996). Fertilizer was added to the surface waters near station KLF2.

Methods

Sampling stations were established in 1992, numbered from north to south, with stations KLF 1-4 in the North Arm, and stations KLF 5-7 in the South Arm. There were no sampling stations in the West Arm. From 1997 onward zooplankton was sampled monthly from April through October at 4 stations KLF 2, 4, 6 and 7. However in 2003 a station (KLF 8) was established in the West Arm and samples were collected monthly from August to November. At the same time samples at stations KLF 1, 3, and 5 were also collected after a 6 year break.

In 2002 samples were taken from 04 April to 01 October, and from 04 April to 07 November in 2003, using a Clarke-Bumpus sampler. At each of the stations three replicate oblique tows were made. The net had 153 μm mesh and was raised from a depth of 40 to 0 m, at a boat speed of 1 $m \cdot s^{-1}$. Tow duration was 3 min, with approximately 2,500 L of water filtered per tow. The exact volume sampled was estimated from the revolutions counted by the Clarke-Bumpus flow meter. The net and flow meter were calibrated before and after the sampling seasons in a flume at the Civil Engineering Department at the University of British Columbia.

Zooplankton samples were rinsed from the dolphin bucket into a 100 μm filter to remove excess lake water, then preserved in 70% ethanol. Zooplankton samples were analyzed for species density, biomass (estimated from empirical length-weight regressions, McCauley 1984), and fecundity. Samples were re-suspended in tap water filtered through a 74 μm mesh and sub-sampled using a four-chambered Folsom-type plankton splitter. Splits were placed in gridded plastic petri dishes and stained with Rose Bengal to facilitate viewing with a Wild M3B dissecting microscope (at up to 400 X magnification). For each replicate, organisms were identified to species level and counted until up to 200 organisms of the predominant species were recorded. If 150 organisms were counted by the end of a split, a new split was not started. The lengths of 30 organisms of each species were measured, for use in biomass calculations, using a mouse cursor on a live television image of each organism. Lengths were converted to biomass (μg dry-weight) using empirical length-weight regression from McCauley (1984). The number of eggs carried by gravid females and the lengths of these individuals were recorded for use in fecundity estimations.

Rare species, e.g., *Polyphemus pediculus*, were counted and measured as "Other Cladocerans" or "Other Copepods " as appropriate. Zooplankton species were identified with reference to taxonomic keys (Pennak 1989, Wilson 1959, Brooks 1959, Sandercock and Scudder 1996).

Results

Species Present

The zooplankton population in Kootenay Lake has a diverse species assemblage. Sixteen species of macrozooplankton were identified in the samples over the course of the study, with copepods such as *Diaptomus ashlandi*, *Epishura nevadensis* and *Cyclops bicuspidatus thomasi,* and the cladoceran *Daphnia galeata mendotae and Bosmina longirostris* among the more numerous.

During the study period, three calanoid copepod species, *Epischura nevadensis* (Lillj.), *Leptodiaptomus ashlandi* (Marsh) and *Leptodiaptomus sicilisi* (Forbes), were identified in samples from the Kootenay Lake (Table 5.1). One cyclopoid copepod species, *Diacyclops bicuspidatus thomasi* (Forbes), was identified.

Twelve cladoceran species were present in the Kootenay Lake during the study period (Table 5.1). Seven species were present in samples in all six years: *Ceriodaphnia reticulata* (Jurine), *Daphnia galeata mendotae* (Birge), *Daphnia pulex* (Leydig), *Daphnia longispina* (O.F.M.), *Bosmina longirostris* (O.F.M.), *Leptodora kindti* (Focke), and *Diaphanosoma brachyurum* (Liéven). Other rare species such as *Scapholeberis mucronata* (O.F.M.), *Polyphemus pediculus* (L.), *Chydorus sphaericus* (O.F.M.), *Sida cristallina* (O.F.M.) and *Alona sp*. were observed sporadically. *Daphnia* spp. were not identified to species for density counts in any of the five years.

In all six years the zooplankton population composition has remained similar in both the North and South Arms of Kootenay Lake. The predominant copepods in Kootenay Lake are *L. ashlandi*, and *D. bicuspidatus thomasi*. The cladocerans *Daphnia* spp., and *B. longirostris* were common in all six years.

Table 5.1. List of zooplankton species identified in Kootenay Lake 1997-2003

Species	1997	1998	1999	2000	2001	2002	2003
Cladocera							
Alona sp.		+					
Ceriodaphnia reticulata	+	+	+	+	+	+	+
Chydorus sphaericus		+	+	+			+
Daphnia galeata mendotae	+	+	+	+	+	+	+
Daphnia pulex	+	+	+	+	+	+	+
Daphnia longispina	+	+	+	+	+	+	+
Diaphanosoma brachiurum	+	+	+	+	+	+	+
Bosmina longirostris	+	+	+	+	+	+	+
Leptodora kindti	+	+	+	+	+	+	+
Polyphemus pediculus	+	+					
Sida cristallina			+				
Scapholeberis mucronata	+		+	+			
Copepoda							
Diacyclops bicuspidatus	+	+	+	+	+	+	+
Epischura nevadensis	+	+	+	+	+	+	+
Leptodiaptomus ashlandi	+	+	+	+	+	+	+
Leptodiaptomus sicilis						+	

Density and Biomass

The zooplankton populations in Kootenay Lake show a diverse species assemblage, with relatively consistent population density between years 2002 and 2003. Kootenay Lake zooplankton density is numerically dominated by copepods which average 91% and 85% of the population in 2002 and 2003 respectively. *Daphnia* spp comprise 3% and 5%, and cladocerans other than *Daphnia* spp 6% and 10%.

Copepods are comprised of calanoids and cyclopoids. During the study period cyclopoids dominated in copepod community, however from April to July of both years 2002 and 2003 calanoids become more abundant in the South Arm (Fig. 5.2 and 5.3). Copepods were the most abundant zooplankton at each station from 1997 to 2003. They dominated during the entire sampling season, with populations peaking in July-August. The largest copepod population, averaging 59.83 individals/L, was observed at station KLF 4 in July 2002, and 74.69 individuals/L at station KLF2 in June 2003. *D. bicuspidatus* was the dominant copepod, with an average density of 16.06 and 6.91 in 2002 and 18.54 and 12.86 individuals/L in 2003 in the North and the South Arm respectively. *L. ashlandi* was the second most numerous copepod captured, at an average density of 11.18 and 9.19 in 2002 and 6.72 and 9.66 individuals/L in 2003 in the North and the South Arm. Cladocerans were occasionally captured at the beginning of the sampling season in April-May, but significant populations did not develop until August in each studied year.

Table 5.2. Seasonal average density of zooplankton in the North and South Arms of Kootenay Lake in 1997-2003. Values from Arrow Lakes Reservoir and Okanagan Lake are shown for comparison. Values are seasonal averages, calculated for samples collected between April and October 1997-2002 and April and November 2003. Density is in units of individuals/L.

Abundance	Lake	1997	1998	1999	2000	2001	2002	2003
Total Density	Kootenay-North	18.42	22.54	17.59	25.81	33.90	35.33	38.70
	Kootenay-South	21.25	18.00	17.93	23.03	28.32	26.20	33.43
	Upper Arrow	3.78	6.23	9.15	11.38	13.77	11.10	16.78
	Lower Arrow	10.48	8.9	14.29	23.94	14.75	20.30	28.43
	Okanagan	22.00	8.00	22.2	21.11	16.66	15.69	14.43
Copepod Density	Kootenay-North	17.58	20.50	16.74	24.86	24.77	32.99	32.61
	Kootenay-South	18.82	15.92	17.04	19.29	23.31	23.32	29.42
	Upper Arrow	2.30	4.39	6.99	10.04	11.25	10.11	12.47
	Lower Arrow	8.28	7.01	10.31	17.84	10.15	18.20	23.18
	Okanagan	21.1	7.4	20.76	20.36	15.84	15.21	13.67
Other Cladoceran Density*	Kootenay-North	0.57	1.23	0.46	0.62	7.96	1.40	3.88
	Kootenay-South	1.68	1.11	0.49	2.32	4.23	2.03	2.81
	Upper Arrow	0.63	0.92	0.63	0.55	1.71	0.76	3.80
	Lower Arrow	1.11	0.39	0.95	1.50	2.57	1.55	3.45
	Okanagan	0.46	0.2	0.9	0.29	0.61	0.31	0.28
Daphnia spp. Density	Kootenay-North	0.27	0.81	0.39	0.33	1.17	0.94	2.22
	Kootenay-South	0.75	0.97	0.39	1.43	0.78	0.85	1.20
	Upper Arrow	0.15	0.92	1.53	0.8	0.81	0.23	0.48
	Lower Arrow	1.06	1.50	3.04	4.6	2.03	0.55	1.80
	Okanagan	0.25	0.11	0.54	0.47	0.21	0.17	0.48

*Values do not include *Daphnia* spp. density.

Zooplankton density in the North Arm fluctuated from year to year during the study period (Fig. 5.4a, Table 5.2). However with the increased fertilizer load in 2001, zooplankton density increased significantly. The seasonal average zooplankton density (April to October) in the North Arm showed a steady increase from 1999 onward. Seasonal (April to October in 2002 and April to November in 2003) average abundance increased slightly, from 35.33 in 2002 to 38.70 individuals/L in 2003. These are the highest values observed during the fertilization experiment, even higher than the highest values observed in the early 1980's (Fig. 5.1). *Daphnia* spp. density was less or slightly above 1 individuals/L from 1997 to 2002, then increased in 2003 to 2.22 individuals/L. Other cladoceran density increased significantly in 2001 from 0.62 individuals/L to 7.96 individuals/L. After a sharp decrease in 2002 (1.4 individuals/L) other cladoceran density increased again in 2003 to 3.88 individuals/L (Table 5.2, Fig. 5.4b).

Zooplankton densities during the period of nutrient addition have been consistently higher than during the period from 1986 to 1991, and similar to the average densities observed from 1972 to 1985. In 2002 the zooplankton community in the North Arm was comprised of 93% copepods, 3% *Daphnia* spp., and 4% cladocerans other than *Daphnia* spp, while in 2003 copepods comprised 84%, *Daphnia* 6% and cladocerans other than *Daphnia* 10% of the total zooplankton. (Fig. 5.5). The proportion of cladocerans (including *Daphnia* spp.) varied from about 4-16% from 1997 to 2003 except in 2001 when cladocerans comprised 27% of zooplankton community.

Zooplankton density in last seven years studied was lower in the South than in the North Arm except in 1997 and 1999 (Fig. 5.4a, Table 5.2). In the South Arm the total zooplankton density fluctuated during seven years reaching its peak in 2003. A similar pattern was seen for other Cladocera. Copepoda density increased progressively from 1998 to 2003. (Fig. 5.4c, Table 5.2). *Daphnia spp.* density fluctuated in each successive year of the study. In 2002 the seasonal average density (April to October) of zooplankton in the South Arm was 26.20 individuals/L, while in 2003 it increased to 33.43 individuals/L. The zooplankton community in 2002 was comprised of 89% copepods, 3% *Daphnia* spp., and 8% cladocerans other than *Daphnia* spp. Zooplankton composition did not changed much in 2003, it was comprised of 88% copepods, 4% *Daphnia* spp. and 8% cladocerans other than *Daphnia* spp (Fig. 5.5). The proportion of cladocerans (including *Daphnia* spp.) decreased from 11% in 1997 and 1998 to 5% in 1999, then increased to 16% in 2000 and 18% in 2001, decreased to 11% in 2002 and slightly increased again to 12% in 2003.

Table 5.3. Seasonal average biomass of zooplankton in the North and South Arms of Kootenay Lake in 1997-2003. Values from Arrow Lakes Reservoir and Okanagan Lake are shown for comparison. Values are seasonal averages, calculated for samples collected between April - October 1997-2002 and April – November in 2003. Biomass is in units of μg/L.

Biomass	Lake	1997	1998	1999	2000	2001	2002	2003
Total Biomass	Kootenay-North	25.86	46.66	30.69	44.75	80.95	66.36	104.36
	Kootenay-South	35.77	46.85	32.67	56.31	60.70	51.93	73.88
	Upper Arrow	7.73	28.63	44.55	33.04	34.02	19.22	29.45
	Lower Arrow	30.56	47.89	71.57	107.41	55.97	37.26	71.58
	Okanagan	N/A	N/A	59.79	58.02	43.19	35.28	42.00
Copepod Biomass	Kootenay-North	21.49	31.62	24.60	36.98	41.67	48.18	51.26
	Kootenay-South	25.09	26.23	24.55	31.71	39.06	33.96	45.80
	Upper Arrow	4.41	7.85	12.4	17.01	19.53	14.45	18.24
	Lower Arrow	11.46	10.85	17.56	27.03	18.32	24.70	31.47
	Okanagan	N/A	N/A	41.9	41.8	34.8	28.92	27.00
Other Cladoceran Biomass**	Kootenay-North	1.31	3.34	1.22	2.23	18.94	3.56	12.17
	Kootenay-South	2.61	4.48	1.69	5.33	9.94	6.09	6.43
	Upper Arrow	0.95	1.67	0.94	0.92	2.15	1.16	4.58
	Lower Arrow	1.75	2.99	1.26	1.78	3.88	3.36	5.32
	Okanagan	N/A	N/A	4.25	2.01	2.65	1.86	1.05
Daphnia spp. Biomass	Kootenay-North	3.06	11.69	4.87	5.54	20.34	14.62	40.92
	Kootenay-South	8.07	16.15	6.42	19.27	11.69	11.87	21.65
	Upper Arrow	2.37	19.1	31.21	15.12	12.34	3.61	6.63
	Lower Arrow	17.36	34.05	52.75	78.59	33.77	9.20	34.79
	Okanagan	N/A	N/A	13.65	14.21	5.74	4.50	13.95

**Values do not include *Daphnia* spp. biomass.

Zooplankton biomass had similar trends in both the North and South Arms of Kootenay Lake. From 1997 to 2000 biomass fluctuated, and then in 2001 increased significantly in the North Arm, while in the South Arm only a minor increase in biomass was recorded (Table 5.3). A similar tendency was observed for all categories (total, copepod, cladoceran, *Daphnia* spp.) in both the North and South Arms. In 2002 total biomass decreased in both Arms, as well as biomass of other cladocerans and *Daphnia*. Copepod biomass decreased in the South but increased in the North Arm of the Lake. However, in 2003 biomass of all categories increased in both the North and South Arm. There was a distinct increase of other cladocerans biomass (more than three fold) in the North Arm, as well as *Daphnia* biomass in both the North and South Arm (more than two fold) (Table 5.3, Fig. 5.6, 5.7). The significant increase of total zooplankton biomass in 2003 was due to increases in the density of *D. brachiurum* and *Daphnia spp*., which was reflected in increased biomass. During 1997-2000 biomass was greater in the South Arm than in the North Arm for all categories except copepods (Table 5.3, Fig. 5.6b, 5.c). In the North Arm *Daphnia* spp. made up 12%, 25%, 16%, 12%, 25%, 22% and 39% of the total zooplankton biomass in 1997, 1998, 1999, 2000, 2001, 2002 and 2003. During the same period *Daphnia* spp. made up 23%, 34%, 20%, 34%, 19%, 23% and 29% of the total zooplankton biomass in the South Arm (Fig. 5.8).

Zooplankton density and biomass in Kootenay Lake did not show a steady increase across years (Table 5.2 and 5.3). Total average density and biomass, and *Daphnia spp*. average density and biomass fluctuated over the course of the years of study. Total average density in Kootenay Lake was higher than in either of the Arrow basins in each year of the study (Pieters et al. 2000, 2003). However, total biomass in Kootenay Lake was less than that of Lower Arrow in each year from 1998 to 2000 and less than that of Upper Arrow in 1999. These differences are due to the greater proportion of *Daphnia spp*. in the Arrow Lakes Reservoir zooplankton, since individual *Daphnia* have much greater biomass than individuals of most other zooplankton species in these reservoirs. In 2001 total zooplankton biomass in the North Arm of Kootenay Lake increased almost two fold, exceeding the total biomass in Arrow Lakes Reservoir. In 2002 despite the decrease of zooplankton density and biomass in Kootenay Lake, production was still higher than in Arrow Lakes Reservoir mainly caused by a significant decrease of *Daphnia* sp. in Arrow. In 2003 zooplankton density and biomass in both Arrow Lakes Reservoir and Kootenay Lake increased, but production was still higher in Kootenay Lake.

Seasonal and Along-Lake Patterns

In 2002 and 2003 copepods were the predominant form of zooplankton, but cladocerans were present throughout the sampling period. *Daphnia* spp. were observed from July to the end of the sampling season in both years. The seasonal development of zooplankton density and biomass was similar in the North and South Arms of Kootenay Lake in 2002 and 2003. Copepods dominated during the entire season, but in August in both years the density and biomass of other cladocerans and *Daphnia* spp. increased in both basins. Cladocerans were present in significant numbers in both basins. They reached their peak in 2002 in September, while in 2003 the density peak occurred in August. *Daphnia* spp. density and biomass reached their peak in 2002 in August in both basins, while in 2003 the *Daphnia* density peak occurred in August in the North Arm and in September in the South Arm. Early season years occurred in 1997 and 1998, with cladocerans and *Daphnia* spp. becoming numerous in July. Conversely, 1999 was a late-season year, in which cladocerans and *Daphnia* spp. began to bloom in September. In 2000 the bloom of cladocerans started in August in the South Arm while in the North Arm the season started later - in September. Late season years occurred in 2001, 2002 and 2003 with cladocerans and *Daphnia* blooming in August-September.

During 2002, peak total zooplankton densities were 59.49 and 65.24 individuals/L in the North and South Arms respectively, and occurred in August and July (Table 5.4). The peak total zooplankton biomass also occurred in August at 103.47 μg/L in the North Arm and in July at 95.27 μg/L in the South Arm. *Daphnia* spp. biomass reached its peak in October with 39.79 μg/L in the North Arm, and 33.88 μg/L in August in the South Arm (Table 5.4).

In 2003 peak total zooplankton density occurred in June and July at 95.66 individuals/L and 60.27 individuals/L, in the North Arm and South Arm respectively (Table 5.5). Biomass, however reached its peak later in the season in August and September at 211.30 µg/L and 143.33 µg/L in the North Arm and South Arm, while *Daphnia* biomass was the highest in September in both basins at 116.97 µg/L and 83.67 µg/L. *Daphnia* comprises only a small proportion of zooplankton density, but the large body size of the adults caused *Daphnia* biomass to comprise 50% and 36% in 2002 and 60% and 58% in 2003 of the zooplankton biomass in peak months in the North Arm and South Arm respectively.

During the seven years of the study, peaks in density tended to occur at the same time in both the North Arm and the South Arm. Similarly, biomass peaks in the North Arm and South Arm tended to coincide, or be only a month apart. Sometimes there is a one month delay between the density and biomass peak, due to the increase in *Daphnia* and other cladoceran density following the copepod density peak, and the large body size of individual cladocerans.

Table 5.4. Monthly average density and biomass of zooplankton in the North and South Arms of Kootenay Lake in 2002. Density is in units of individuals/L, and biomass is in units of µg/L.

Density		April	May	June	July	August	Sept.	October
North Arm	Copepoda	6.94	13.11	52.81	55.53	55.62	19.46	27.44
	Daphnia	0.00	0.00	0.00	0.25	2.41	1.78	2.14
	Other Cladocera*	0.01	0.01	0.00	0.85	3.27	6.80	3.82
	Total Zooplankton	6.95	13.12	52.81	56.44	59.49	26.70	31.79
South Arm	Copepoda	5.76	6.51	18.62	61.42	27.35	21.80	21.77
	Daphnia	0.00	0.00	0.00	0.87	2.84	1.01	1.22
	Other Cladocera*	0.00	0.02	0.00	3.61	5.80	6.57	2.66
	Total Zooplankton	5.76	6.53	18.62	65.24	33.86	28.63	24.74

Biomass		April	May	June	July	August	Sept.	October
North Arm	Copepoda	14.39	20.49	79.41	93.03	70.84	25.77	33.34
	Daphnia	0.00	0.00	0.00	4.63	30.29	27.61	39.79
	Other Cladocera**	0.01	0.00	0.00	0.65	2.35	14.97	6.95
	Total Zooplankton	14.40	20.50	79.41	98.31	103.48	68.34	80.08
South Arm	Copepoda	11.13	10.37	31.41	80.55	47.04	31.24	25.99
	Daphnia	0.00	0.00	0.00	10.53	33.88	16.59	22.11
	Other Cladocera**	0.00	0.03	0.00	4.20	12.94	20.13	5.34
	Total Zooplankton	11.13	10.40	31.41	95.27	93.85	67.97	53.45

*Values do not include *Daphnia* spp. density.
**Values do not include *Daphnia* spp. biomass.

Table 5.5. Monthly average density and biomass of zooplankton in the North and South Arms of Kootenay Lake in 2003. Density is in units of individuals/L, and biomass is in units of μg/L.

Density		April	May	June	July	Aug.	Sept.	Oct.	Nov.
North Arm	Copepoda	5.21	12.83	91.14	52.73	33.91	28.56	29.86	22.35
	Daphnia	0.00	0.00	0.00	0.59	7.37	4.97	0.56	0.12
	Other Cladocera*	0.01	0.09	4.52	1.67	13.44	4.76	1.64	0.27
	Total Zooplankton	5.22	12.92	95.66	54.99	54.72	38.29	32.06	22.74
South Arm	Copepoda	4.85	7.47	55.90	59.44	36.14	26.28	24.97	23.66
	Daphnia	0.00	0.00	0.00	0.06	2.25	3.90	1.71	0.08
	Other Cladocera*	0.02	0.02	1.07	0.78	10.77	4.09	2.42	0.20
	Total Zooplankton	4.87	7.48	56.97	60.27	49.16	34.27	29.10	23.94
Biomass									
North Arm	Copepoda	9.52	17.33	139.76	78.65	67.05	52.46	37.40	28.03
	Daphnia	0.00	0.00	0.00	9.40	109.40	116.97	11.91	2.57
	Other Cladocera**	0.01	0.20	7.00	2.25	34.85	25.72	5.80	1.95
	Total Zooplankton	9.52	17.53	146.76	90.29	211.30	195.15	55.11	32.55
South Arm	Copepoda	8.81	13.31	97.89	77.09	59.56	45.56	38.89	29.89
	Daphnia	0.00	0.00	0.00	0.25	27.37	83.67	31.76	1.36
	Other Cladocera**	0.02	0.02	1.46	1.06	17.12	14.10	8.60	1.36
	Total Zooplankton	8.83	13.33	99.35	78.40	104.05	143.33	79.25	32.62

*Values do not include *Daphnia* spp. density.
**Values do not include *Daphnia* spp. biomass.

Along the length of the North Arm (stations KLF 2 and KLF 4) and the South Arm (stations KLF 6 and KLF 7) zooplankton densities were similar at the beginning of the season of 2002 (Fig. 5.9). By August, density in both the North Arm and the South Arm had an increasing trend, but values were more than twice higher in the North Arm, except in July. In September densities started to decrease in both the North Arm and the South Arm, but in October numbers of Copepoda and *Daphnia* in the North Arm increased again resulting in an increase in total zooplankton density (Table 5.4). The largest zooplankton density in 2002 was found in July at the station KLF 6, averaging 73.98 individuals/L. Copepod densities peaked in July at most stations, except at station KLF 2 where densities peaked in August. Cladocerans were occasionally captured in April-May (when sampling began), but significant populations did not develop until August (Fig. 5.9). Peak *Daphnia* densities along the lake were generally 6-10% of the total zooplankton density, with the highest seasonal densities at station KLF 4, with 4.09 individuals/L recorded in August 2002. The pattern for biomass was similar to density, with a tendency towards higher biomass in the North Arm in May and June (Fig. 5.10). The highest *Daphnia* biomass was observed at station KLF2 (seasonal average 29.13 μg/L), and peaked at 63.47 μg/L in October 2002. Zooplankton density in 2002 fluctuated along the length of Kootenay Lake with the highest numbers observed in the South Arm in July, at station KLF 6 (Fig. 5.9). In July and September densities were slightly higher in the South Arm, but during the remainder of the season, densities were much higher in the North Arm. Zooplankton biomass was higher in the fertilized part of the lake during the entire season (Fig. 5.10).

In 2003, the pattern of sampling stations changed. Three more stations were monitored in the main body of the lake: stations KLF 1 and KLF 3 in the North Arm, and station KLF 5 in the South Arm. In the West Arm additional samples were also collected from station KLF 8. Changes in zooplankton community had a similar trend to the previous year. Total zooplankton density had an increased trend toward the summer months, and decreased in the fall. The North Arm had higher densities in all months except in July. The highest zooplankton density in 2003 was in June at station KLF 2, with 99.36 individuals/L (Fig. 5.9 and 5.11). In 2003, copepod density peaked at 92.89 individuals/L at station KLF 2 in June. *Daphnia* were the most abundant at station KLF 3 with 10.01 individuals/L, and other Cladocera at station KLF 4 with 16.05 individuals/L. Despite the low overall abundance compared to copepods, *Daphnia* biomass generally peaked at 202.24 µg/L at station KLF 2 in September, or 65% of the total biomass (Fig. 5.10 and 5.12). In previous years from August onward, biomass trends along the two basins were largely driven by the development of *Daphnia* spp., since *Daphnia* made up the majority of zooplankton biomass during that period. If zooplankton, particularly *Daphnia*, is available late in the growing season, it may allow fish and other predators to continue their growth into the fall. An increase in fish size prior to winter may lead to lower over-winter mortality (Johnson and Evans, 1991; Miranda and Hubbard, 1994).

In 2003 both densities and biomass were higher compared to 2002 results. These differences, in addition to other factors, could be a result of a more detailed study that was conducted by collecting samples from 8 stations in comparison to 4 stations during 2002.

Zooplankton Fecundity

Fecundity features of the four most common zooplankton species *L ashlandi*, *D. bicuspidatus thomasi*, *Daphnia spp*. and *B. longirostris* were studied from 1997 - 2003.

L. ashlandi females were gravid throughout the sampling period in 2002 and 2003 (Fig. 5.13). The proportion of females that were gravid was highly variable as in previous years, and was always below 0.5 except in August 2003 at station KLF 1 when it was 0.7. There was a tendency for females to carry more eggs in the South Arm than in the North Arm, except in 1998 and 2003. During the sampling season of 2002 (April - October), *L. ashlandi* females carried an average of 10.16 and 11.96 eggs per gravid female, while in 2003 females carried an average of 11.91 and 10.56 eggs per gravid female in the North and South Arms respectively (Table 5.6, Fig. 5.14). The number of eggs per water volume averaged 1.96 eggs/L in the North Arm and 1.08 eggs/L in the South Arm in 2002, and 2.74 eggs/L in the North Arm and 1.85 eggs/L in the South Arm in 2003. The number of eggs per capita averaged 0.15 and 0.12 eggs/individual in the North Arm and South Arm in 2002, while in 2003 its averages were 0.3 and 0.12 eggs/individual. Although all fecundity measures were consistently higher in the South Arm than in the North Arm across years, in

2002 and 2003 the pattern changed and all features (except number of eggs per gravid female in 2002) were higher in the North Arm.

Table 5.6. Fecundity data for *Leptodiaptomus ashlandi* in the North and South Arms of Kootenay Lake in 1997-2003. Values are seasonal averages, calculated for samples collected between April - October 1997-2002, and April-November 2003.

Fecundity Measure	Basin	1997	1998	1999	2000	2001	2002	2003
Proportion of gravid females	North Arm	0.16	0.12	0.11	0.13	0.13	0.18	0.21
	South Arm	0.19	0.14	0.16	0.18	0.15	0.11	0.09
# Eggs per gravid Female	North Arm	13.83	13.21	17.78	14.71	13.33	10.16	11.91
	South Arm	14.53	12.49	18.56	16.90	13.97	11.96	10.56
# Eggs per Litre	North Arm	1.04	1.34	1.08	0.77	3.61	1.96	2.74
	South Arm	2.22	1.65	1.13	2.19	3.42	1.08	1.85
# Eggs per Capita	North Arm	0.29	0.24	0.23	0.25	0.31	0.15	0.3
	South Arm	0.46	0.26	0.23	0.45	0.24	0.12	0.12

D. bicuspidatus thomasi females were gravid throughout the sampling period in 2002-2003 (Fig. 5.13). The proportion of gravid females ranged from 0 to 0.55 in 2002 and from 0.02 to 0.6 in 2003. From April to October 2002 the proportion of gravid females averaged 0.13 in the North Arm, and 0.20 in the South Arm, while the average proportion of gravid females from April to November 2003 was 0.14 and 0.15 (Table 5.7, Fig. 5.14). The seasonal average number of eggs per gravid female was 12.93 and 14.02 in 2002, and 12.04 and 12.1 in 2003 in the North and South Arms. During 2002 the number of eggs per litre of water averaged 3.96 and 2.89 eggs/L and 4.97 and 2.19 in 2003 in the North and South Arms. The number of eggs per capita averaged 0.34 and 0.53 eggs/individual and 0.27 and 0.26 in the North Arm and South Arm in 2002 and 2003 respectively. The proportion of gravid females, number of eggs per gravid female and number of eggs per capita were higher in the South Arm during the years except for the number of eggs per capita in 2003.

Table 5.7. Fecundity data for *Diacyclops bicuspidatus thomasi* in the North and South Arms of Kootenay Lake in 1997-2003. Values are seasonal averages, calculated for samples collected between April - October 1997-2002, and April-November 2003.

Fecundity Measure	Basin	1997	1998	1999	2000	2001	2002	2003
Proportion of gravid females	North Arm	0.28	0.09	0.12	0.11	0.12	0.13	0.14
	South Arm	0.26	0.16	0.16	0.13	0.13	0.20	0.15
# Eggs per gravid Female	North Arm	11.66	14.86	14.93	13.34	13.15	12.93	12.04
	South Arm	12.28	16.41	16.70	13.42	14.55	14.02	12.1
# Eggs per Litre	North Arm	2.72	2.55	2.64	3.72	2.41	3.96	4.97
	South Arm	2.77	2.11	4.55	2.81	3.27	2.89	2.19
# Eggs per Capita	North Arm	0.42	0.28	0.35	0.36	0.32	0.34	0.27
	South Arm	0.47	0.39	0.57	0.38	0.47	0.53	0.26

Daphnia spp. gravid females were observed in samples from July to the end of the sampling season in 2002 and 2003. In 1997 and 1998 *Daphnia* spp. gravid females were seen as early as June, in 1999 and 2000 they did not appear until July, and in 2001 they appeared in August. The proportion of gravid *Daphnia* spp. ranged from 0 to 0.55 (Fig. 5.15) in 2002 and averaged 0.22 and 0.18 in the North Arm and South Arm respectively. In 2003 the proportion of gravid females ranged from 0 to 0.66 and averaged 0.2 and 0.21. The proportion of gravid females remained at a similar level in 2002 and 2003 but was considerably higher than in the previous two years. The seasonal average fecundity in 2002 was 2.78 and 2.14, and in 2003, 2.61 and 2.1 eggs per gravid female, with a range of 1–5 eggs per gravid female. During the sampling season the number of eggs per litre of water averaged 0.49 and 0.28 in 2002 and 0.95 and 0.52 eggs/L in 2003 (Table 5.8, Fig. 5.16). The number of eggs per capita averaged 0.78 and 0.48 in the North Arm and the South Arm, and 0.55 and 0.47 eggs/individual in 2002 and 2003 respectively. There was a trend of a slightly higher fecundity in the North Arm in both years.

Table 5.8. Fecundity data for *Daphnia spp.* in the North and South Arms of Kootenay Lake in 1997-2003. Values are seasonal averages, calculated for samples collected between April - October 1997-2002, and April-November 2003.

Fecundity Measure	Basin	1997	1998	1999	2000	2001	2002	2003
Proportion of gravid females	North Arm	0.17	0.17	0.29	0.02	0.07	0.22	0.2
	South Arm	0.12	0.22	0.16	0.04	0.09	0.18	0.21
# Eggs per gravid Female	North Arm	2.19	2.17	2.71	1.75	1.71	2.78	2.61
	South Arm	2.24	2.41	2.42	2.24	1.83	2.14	2.1
# Eggs per Litre	North Arm	0.1	0.37	0.11	0.02	0.17	0.49	0.95
	South Arm	0.15	0.48	0.07	0.11	0.14	0.28	0.52
# Eggs per Capita	North Arm	0.41	0.36	1.05	0.04	0.13	0.78	0.55
	South Arm	0.26	0.71	0.6	0.14	0.17	0.48	0.47

B. longirostris gravid females were observed from May to the end of the sampling season in 2002 and 2003. In 1997 and 1998 gravid females were seen as early as April but in other years they did not appear until July (Fig. 5.15). The proportion of gravid females averaged 0.16 and 0.28 in 2002, while in 2003 it averaged 0.36 and 0.24 in the North Arm and South Arms respectively (Table 5.9). As in previous years, the number of eggs per gravid female did not have a clear tendency to be higher in either the North Arm or the South Arm. The seasonal averages were 1.52 and 1.67 in 2002 and 1.92 and 1.56 eggs per gravid female in 2003 in the North Arm and South Arms respectively (Fig. 5.16). During the sampling season the number of eggs per litre of water averaged 0.14 and 0.15 in 2002 and 1.55 and 0.9 eggs/L in 2003 in the North Arm and the South Arm of the reservoir. The number of eggs per capita averaged 0.25 and 0.41, and 0.72 and 0.37 eggs/individual in the North Arm and the South Arm duringf the study period. All fecundity features in 2002 were slightly higher in the South Arm, while in 2003 there were slightly more gravid females in the North Arm and they carried more eggs than those in the South Arm. None of the fecundity measures were consistently higher in either the North or South Arms during the seven year period.

Table 5.9. Fecundity data for *Bosmina longirostris* in the North and South Arms of Kootenay Lake in 1997-2003. Values are seasonal averages, calculated for samples collected between April - October 1997-2002, and April-November 2003.

Fecundity Measure	Basin	1997	1998	1999	2000	2001	2002	2003
Proportion of gravid females	North Arm	0.27	0.30	0.15	0.18	0.16	0.16	0.36
	South Arm	0.20	0.28	0.31	0.09	0.15	0.28	0.24
# Eggs per gravid Female	North Arm	2.43	3.26	2.25	1.75	1.52	1.52	1.92
	South Arm	2.14	2.50	2.13	1.56	1.45	1.67	1.56
# Eggs per Litre	North Arm	0.17	0.48	0.02	0.02	0.22	0.14	1.55
	South Arm	0.39	0.20	0.10	0.06	0.15	0.15	0.9
# Eggs per Capita	North Arm	0.57	1.02	0.31	0.27	0.29	0.25	0.72
	South Arm	0.47	0.70	0.62	0.14	0.26	0.41	0.37

Discussion

Total zooplankton densities in 2002 were similar to 2001, while in 2003 densities increased. During 2003, the highest densities were observed during the fertilization experiment, and were higher than those observed in the 1970's and 1980's. Seasonal average abundance and biomass of all categories in both the North Arm and the South Arm increased in 2003 in comparison to previous years. From 1997 to 2000 the fertilizer load was reduced relative to previous years, but in 2001 the fertilizer load was increased to the same level as at the beginning of the experiment. Although the grazeable nanoplankton and ultraplankton were not consistently enhanced in the fertilization zone in 2001, changes in the nutrient load resulted in an increase in cladoceran density and biomass. The decline in the proportion of cladocerans in 2002 may have been due to a decrease in the biomass of grazeable phytoplankton (nanoplankton, 2-22 μm). As a result zooplankton biomass may have declined, and may not have been high enough to keep pace with the grazing rate imposed by the higher number of kokanee in the lake.

During the period 1997-1998 zooplankton density and biomass fluctuated in both the North Arm and the South Arm. From 1999 to 2001 zooplankton biomass and density increased in both the North Arm and the South Arm and in 2002 only density in the North Arm increased. During 2002, density in the South Arm and biomass in both Arms declined. Climatic conditions, changes in algae composition, or changes in *Mysis relicta* and kokanee abundance may have made conditions more favourable for *Daphnia* spp. and other cladocerans in Kootenay Lake in 1999 and 2000. These same factors and potentially the increase of fertilizer load to the North Arm may have made conditions more favourable in 2001. A bloom of small cladocerans in 2001 was the first group to respond to the increase in the nutrient load, in 2002 their density decreased, and in 2003 the density significantly increased again. These changes have likely been due to a combination of nutrient load, predation and climatic changes. It is notable that total zooplankton, *Daphnia* and other cladocera abundance has increased in accordance with the decrease in abundance of kokanee, a major zooplankton predator. Mysid density also decreased (see Chapter 6). Estimated kokanee abundance in Kootenay Lake is 35.2 and 26.5 million (see Chapter 7), while mysid abundance is 125 and 90 individuals/m^2 for 2002 and 2003 respectively.

Kootenay Lake is at the more productive end of an oligotrophic lake (Wetzel 2001). Changes in zooplankton density and biomass in 2002 and 2003 suggest that the system has been shifted towards more productive conditions, compared to years with a lower nutrient load from fertilizer. Zooplankton densities and biomass of all categories in Kootenay Lake during 2002 and 2003 season are higher than those of Arrow Lakes Reservoir or Okanagan Lake. Total zooplankton biomass, and biomass of copepods, cladocerans and *Daphnia* have been relatively stable in Kootenay Lake during the period of lower nutrient load. Higher values were seen in 1998 and 2000, but with the increased fertilizer load in 2001 the biomass of cladoceran zooplankton in Kootenay Lake increased significantly, exceeding the biomass in Arrow Lakes Reservoir and Okanagan Lake. In 2002 these differences are more obvious since zooplankton density decreased in both Arrow Lakes Reservoir as well as in Okanagan Lake, while in 2003 density increased again but was lower than in Kooteany Lake.

A possible explanation for the lower *Daphnia* density and biomass in Kootenay Lake in comparison to Arrow Lakes Reservoir is that in previous years Kootenay Lake had higher predation pressure on zooplankton by mysid shrimp and kokanee. Kootenay Lake had approximately twice the density of *M. relicta* as Arrow Lakes Reservoir between 1997 and 1999 (Wright 2000b). Since *Daphnia* is the preferred prey of both kokanee and mysids, predation may be suppressing the standing stock biomass of *Daphnia* in Kootenay Lake, despite potentially high zooplankton productivity. In addition to predation other factors such as changes in the availability of grazeable algae may affect zooplankton biomass. Contrary to the previous years, zooplankton densities and biomass followed the nutrient gradient, and showed higher values in the fertilized part of the lake. During 2001 - 2003 it seems that favourable growing conditions prevailed over predation by kokanee and *M. relicta* and allowed increased productivity of zooplankton in the fertilized part of the lake (Wright 2000a, 2000c).

There were no obvious trends in average fecundity of the more common species of *Daphnia*. Fish may be able to crop down the largest, most fecund, females at such a high rate that very few large females are sampled, despite their presence in the reservoir. Kokanee in Kootenay Lake preferentially select the largest zooplankton, and the average zooplankton size in the diet samples is larger than the average size of the zooplankton samples from the lake (Thompson, 1999). However, *M. relicta* preys upon all sizes of *Daphnia* spp., and does not appear to preferentially select larger individuals.

Acknowledgements
Funding was provided by the Columbia Basin Fish and Wildlife Compensation Program for stations KLF 2, 4, 6 and 7 and by the Kootenai Tribe of Idaho for stations KLF 1, 3, 5 and 8. Thanks to Kootenay Wildlife Services Ltd for sample collection.

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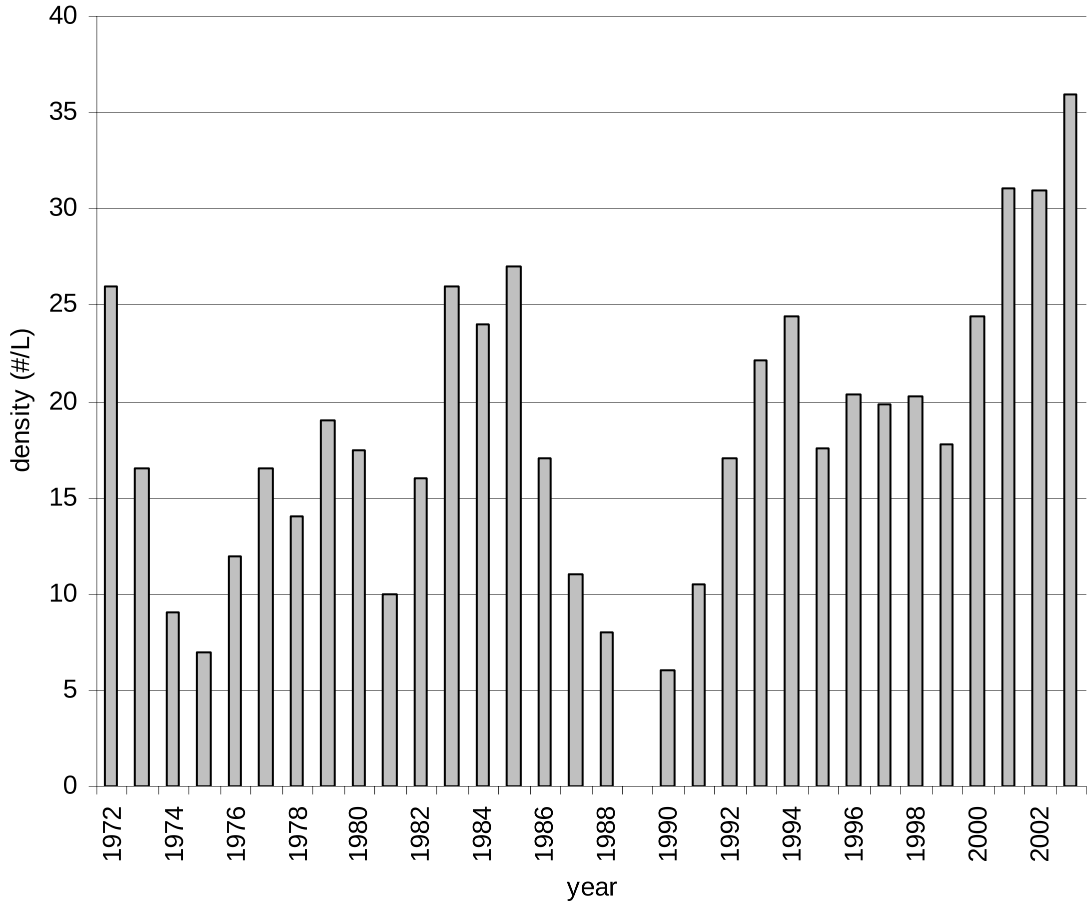


Figure 5.1. Zooplankton density in Kootenay Lake 1972-2003. (Note: 1972-1990 for mid-lake station, near current stations KLF 5 and 1992-2003 for whole-lake average.

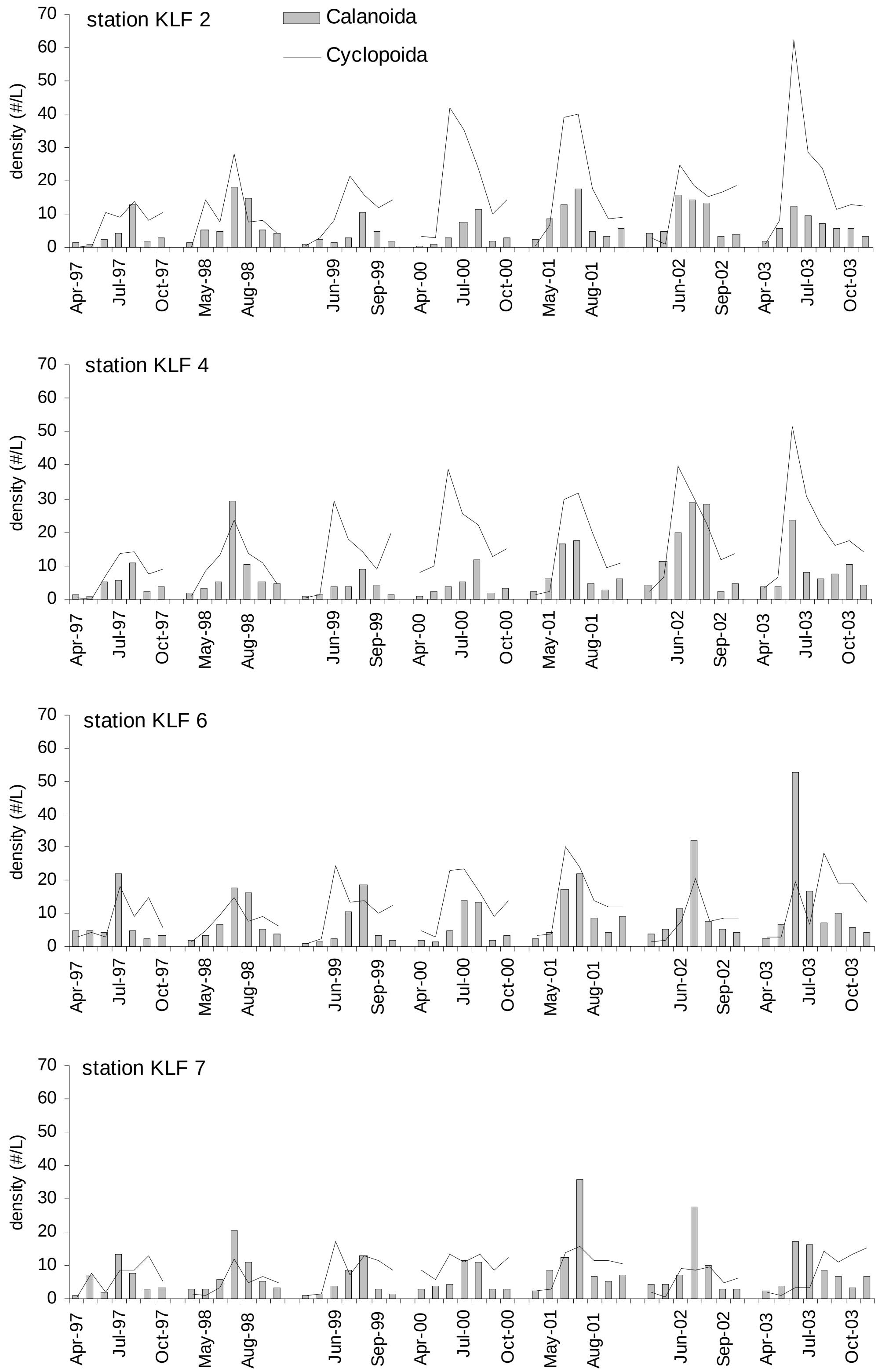


Figure 5.2. Density of calanoid and cyclopoid zooplankton in Kootenay Lake, 1997-2003.

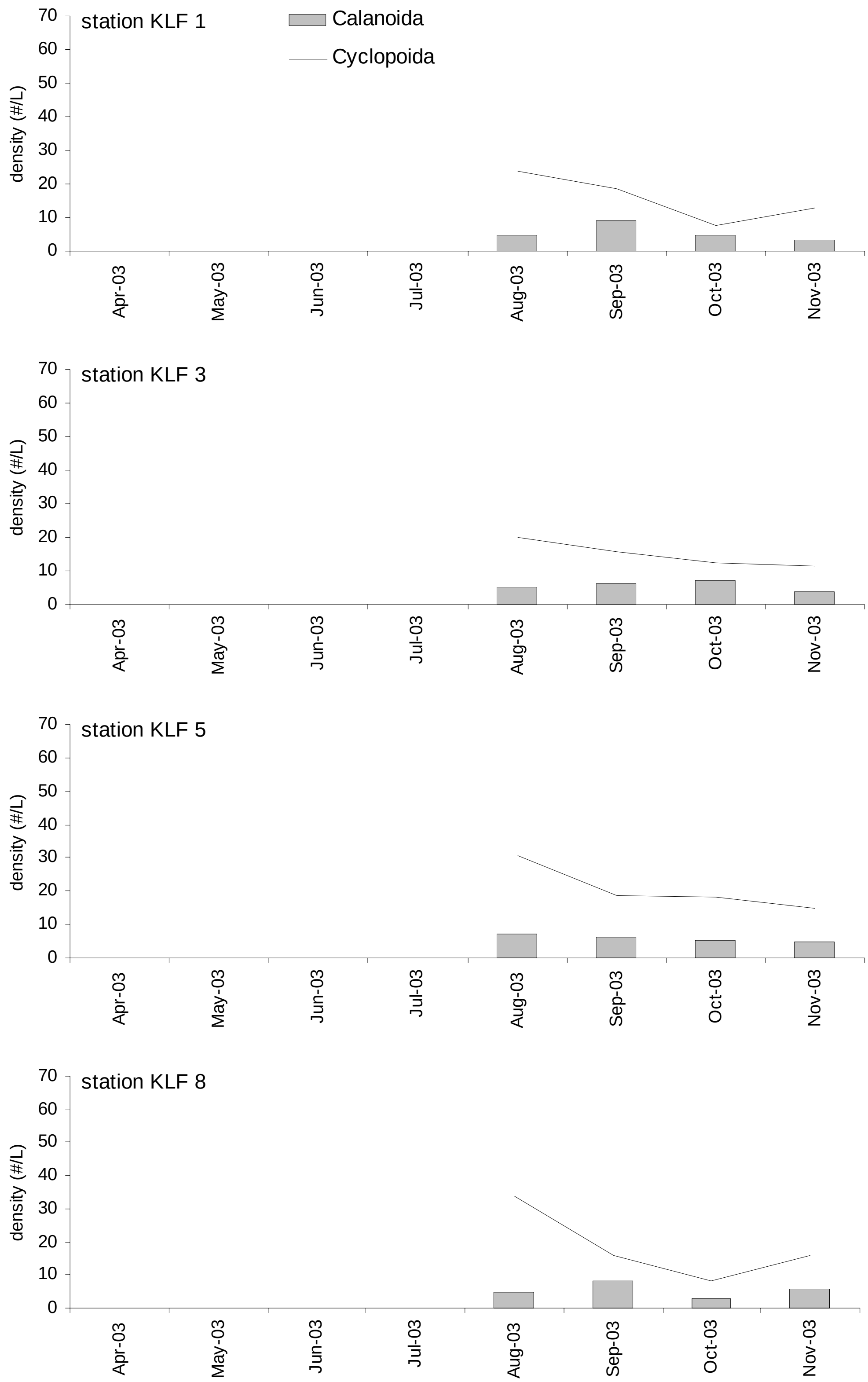
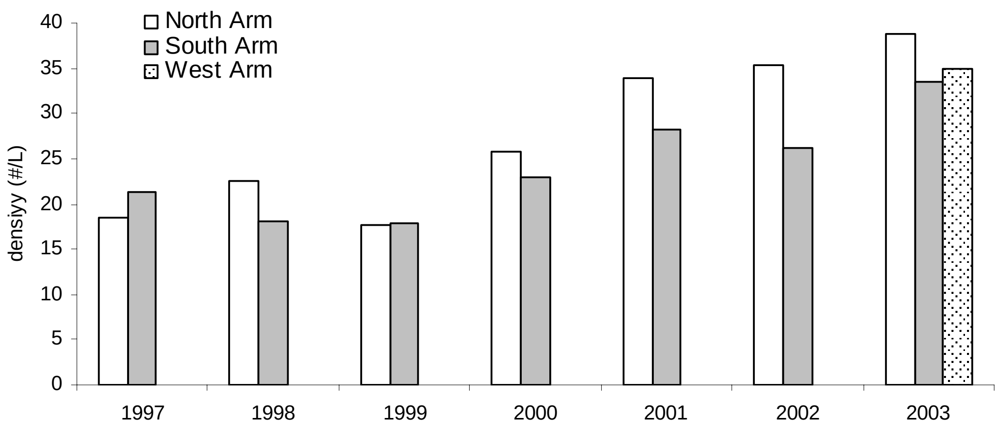
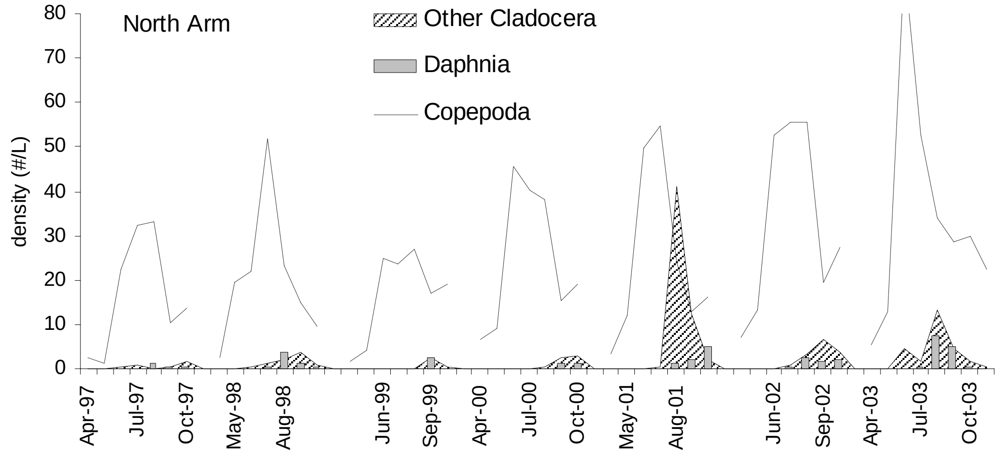


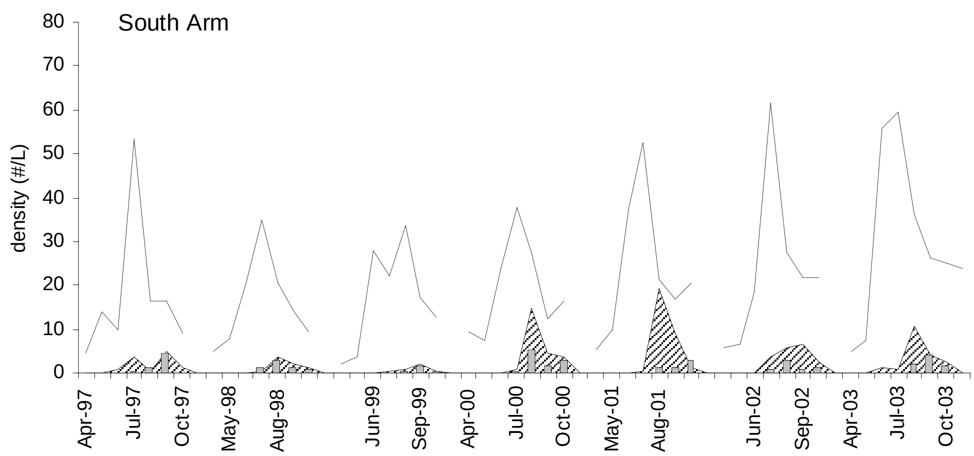
Figure 5.3. Density of calanoid and cyclopoid zooplankton in Kootenay Lake, 2003 (additional stations).



a. Seasonal average zooplankton density in the North, South and West Arms, Kootenay Lake.



b. Seasonal zooplankton density in the North Arm of Kootenay Lake, 1997-2003.



c. Seasonal zooplankton density in the South Arm of Kootenay Lake, 1997-2003.

Figure 5.4. Zooplankton density in Kootenay Lake, 1997-2003 (a, b, c).

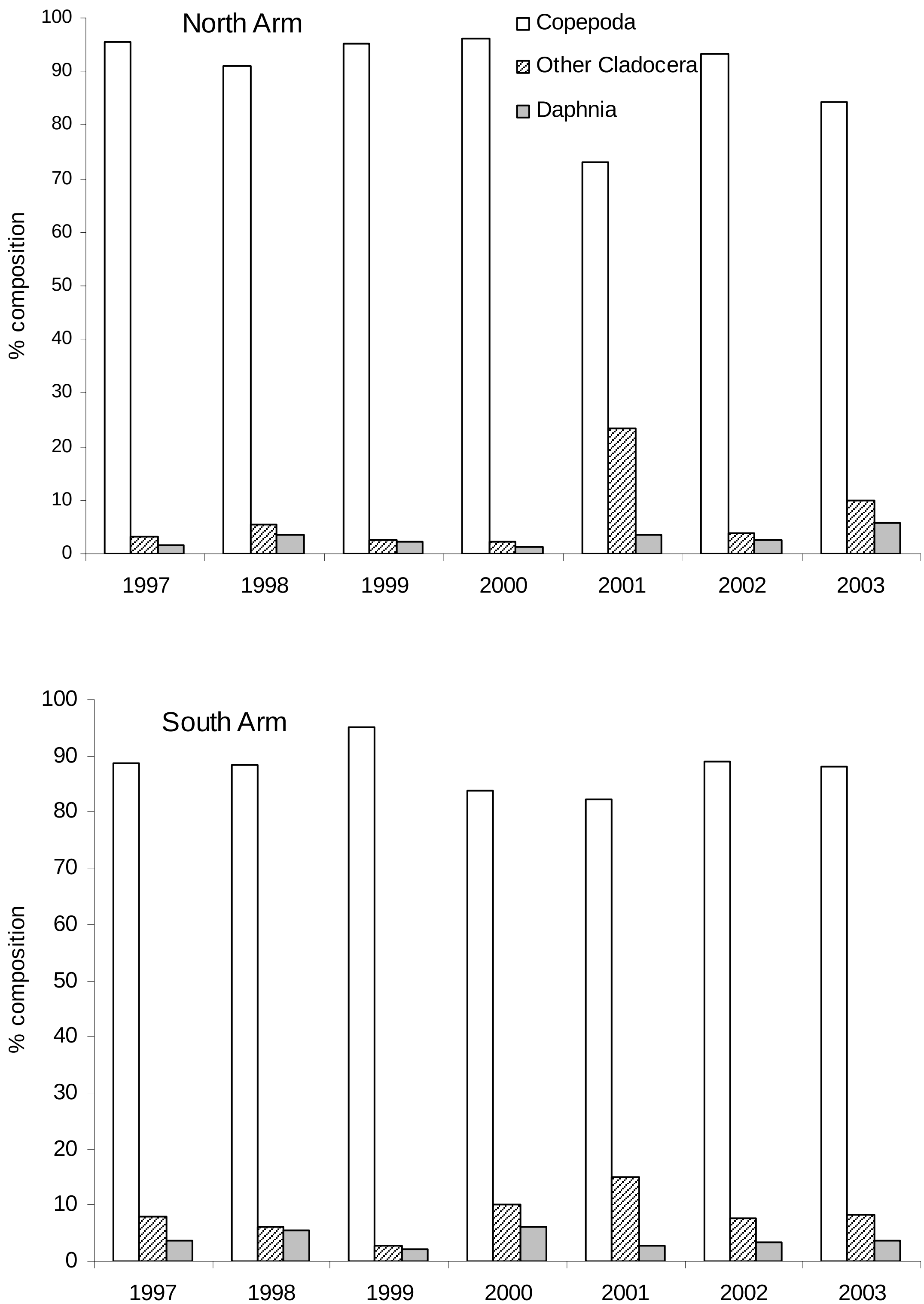
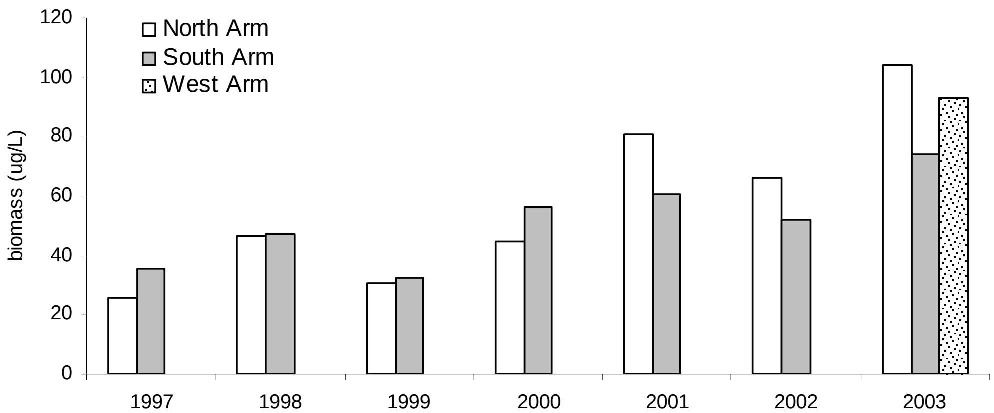
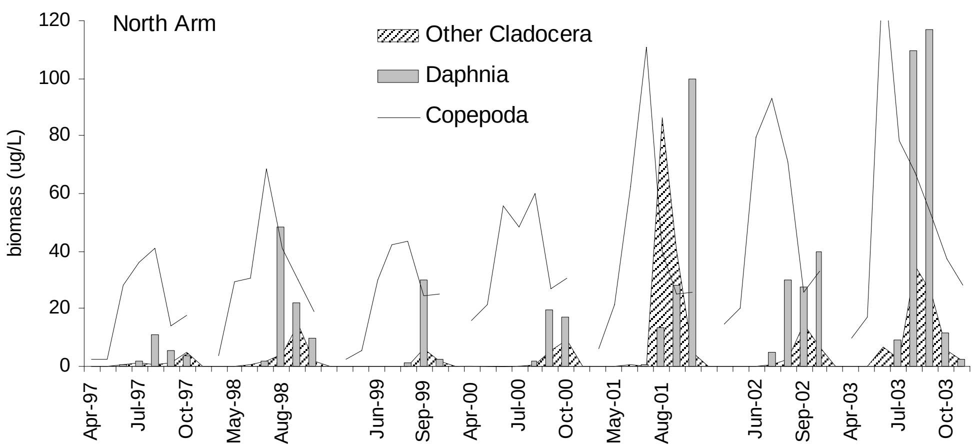


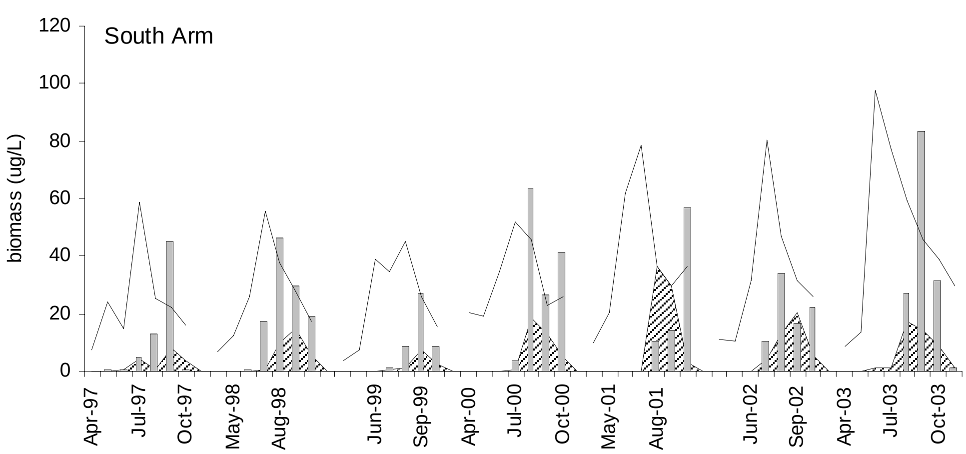
Figure 5.5. Seasonal average composition of zooplankton density in the North and South Arms of Kootenay Lake, 1997-2003.



a. Seasonal average zooplankton biomass in the North, South and West Arms of Kootenay Lake.



b. Seasonal zooplankton biomass in the North Arm of Kootenay Lake, 1997-2003.



c. Seasonal zooplankton biomass in the South Arm of Kootenay Lake, 1997-2003.

Figure 5.6. Zooplankton biomass in Kootenay Lake, 1997-2003 (a,b,c).

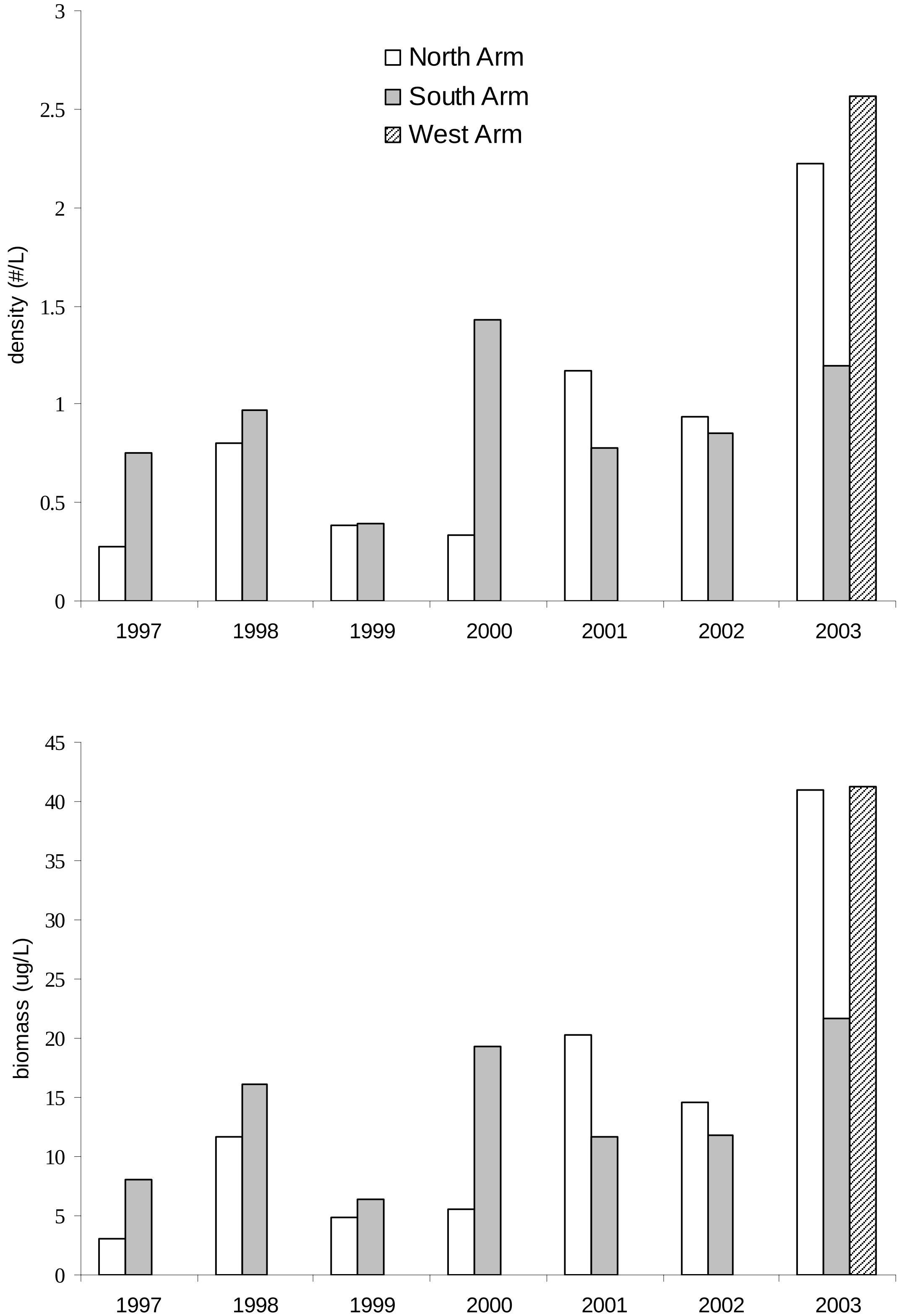


Figure 5.7. *Daphnia* sp. density (top) and biomass (bottom) in Kootenay Lake, 1997-2003.

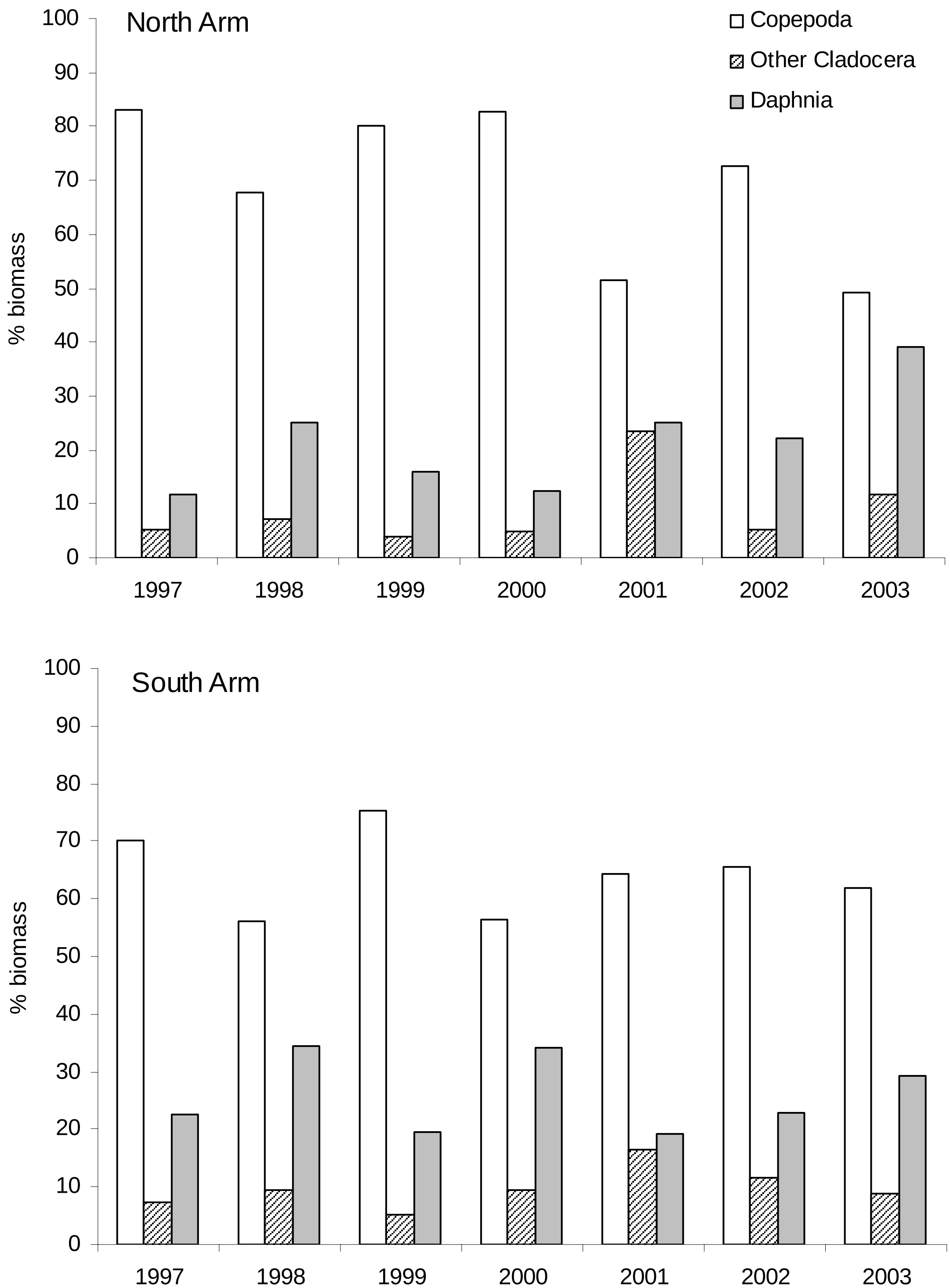


Figure 5.8. Seasonal average zooplankton biomass in the North and South Arms of Kootenay Lake, 1997-2003.

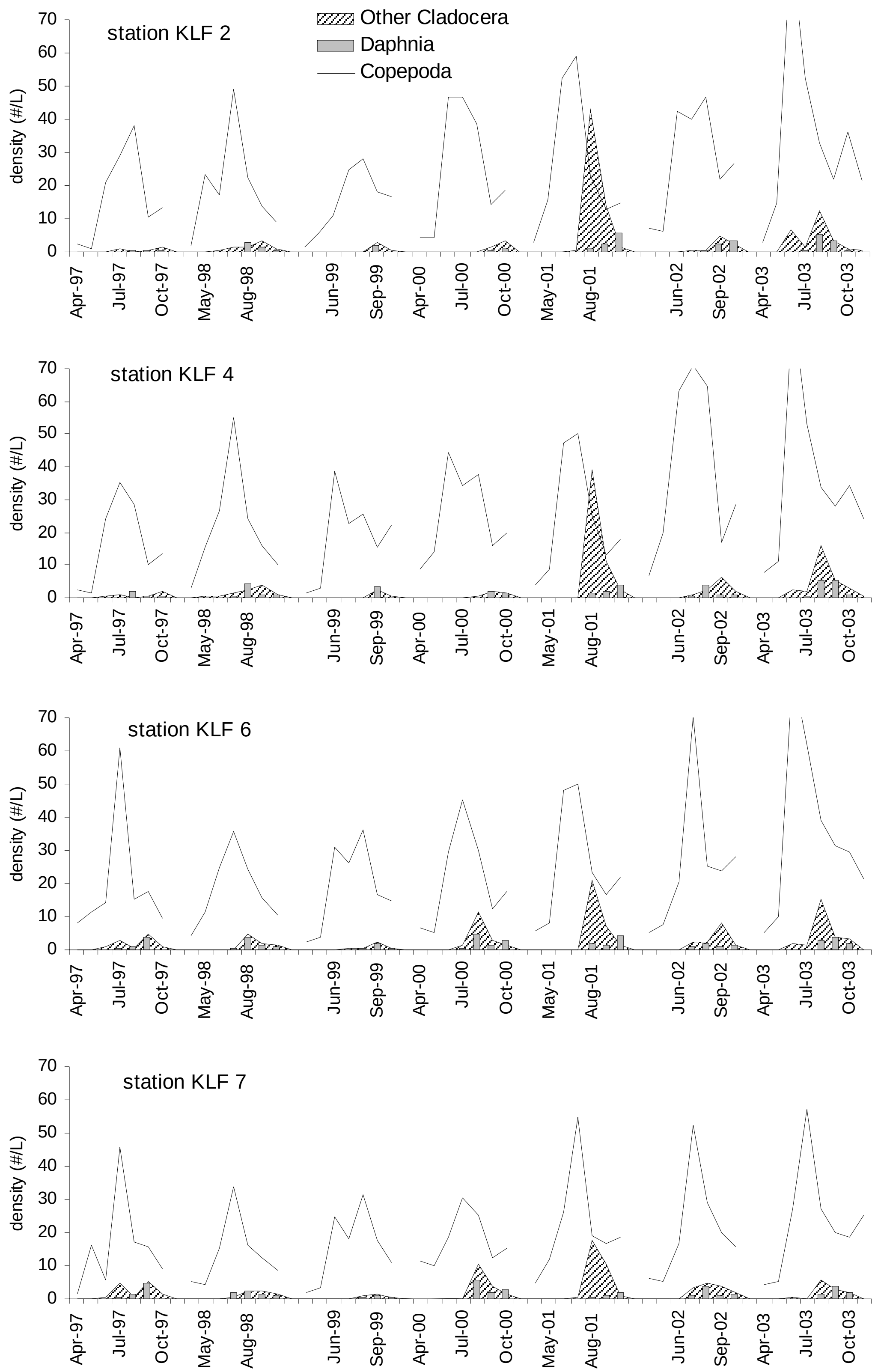


Figure 5.9. Density of cladoceran and copepod zooplankton in Kootenay Lake, 1997-2003.

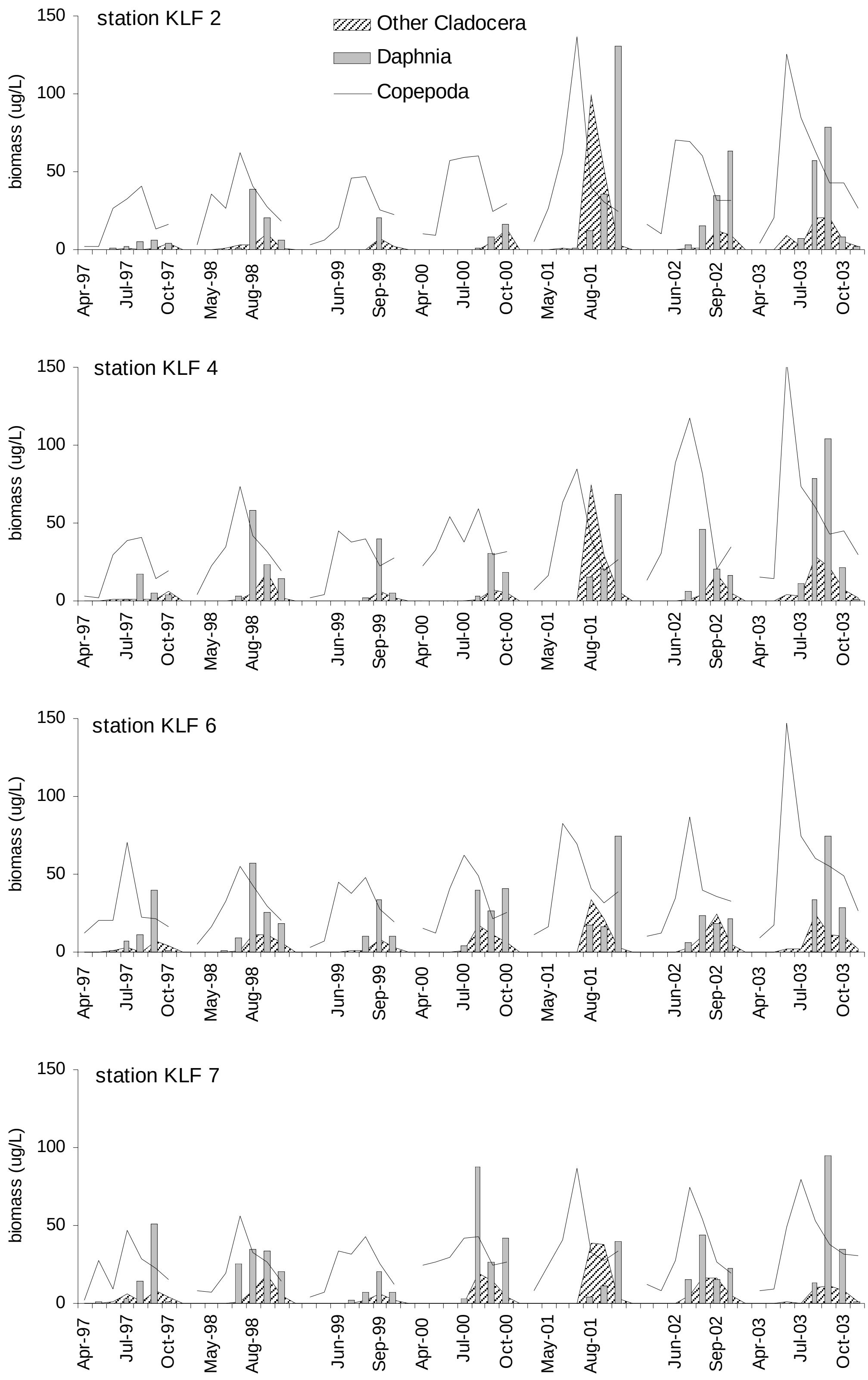


Figure 5.10. Biomass of cladoceran and copepod zooplankton in Kootenay Lake, 1997-2003.

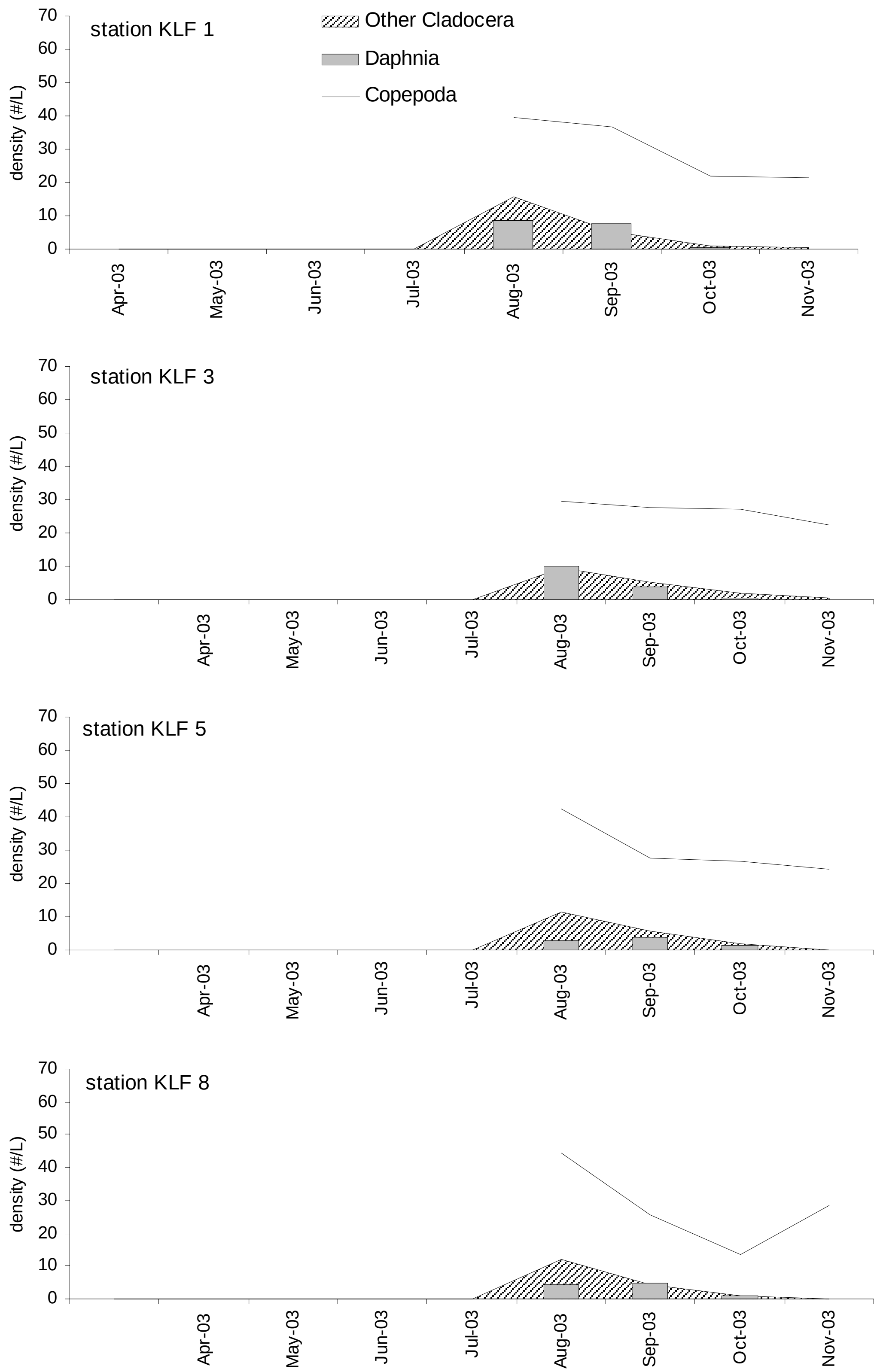


Figure 5.11. Density of cladoceran and copepod zooplankton in Kootenay Lake 2003 (additional stations).

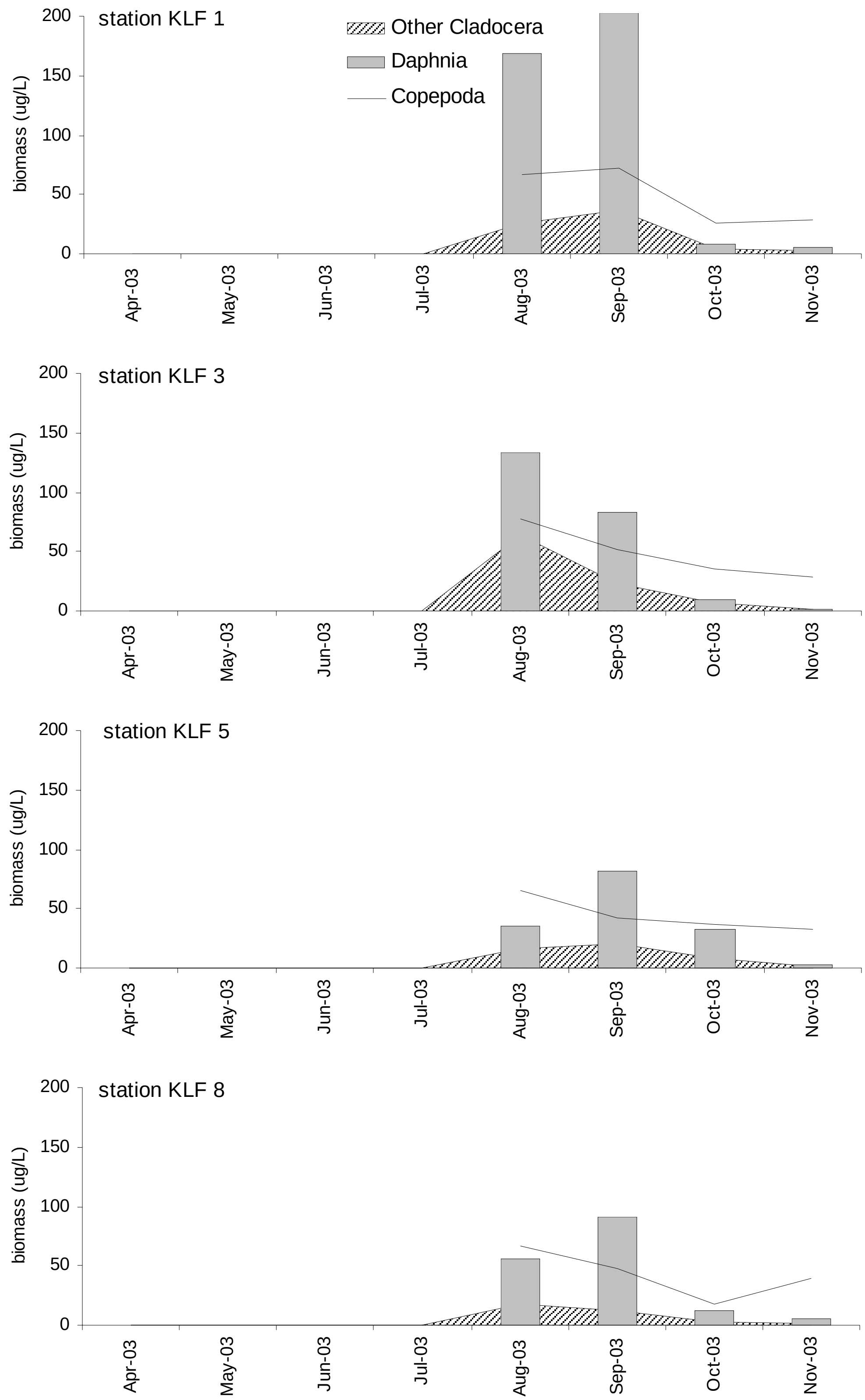


Figure 5.12. Biomass of cladoceran and copepod zooplankton in Kootenay Lake 2003 (additional stations).

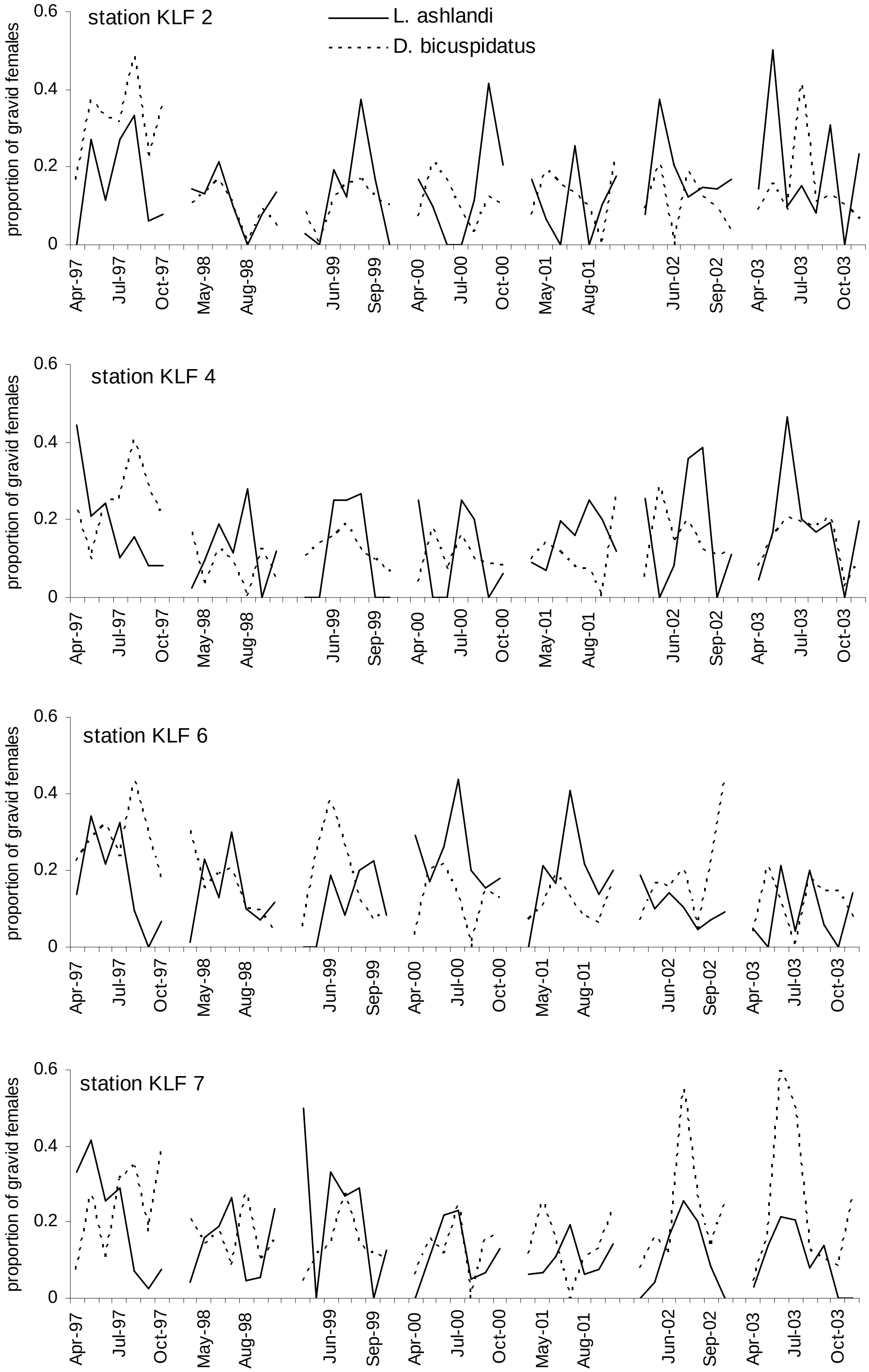


Figure 5.13. Proportion of gravid females of two species of Copepoda in Kootenay Lake, 1997-2003.

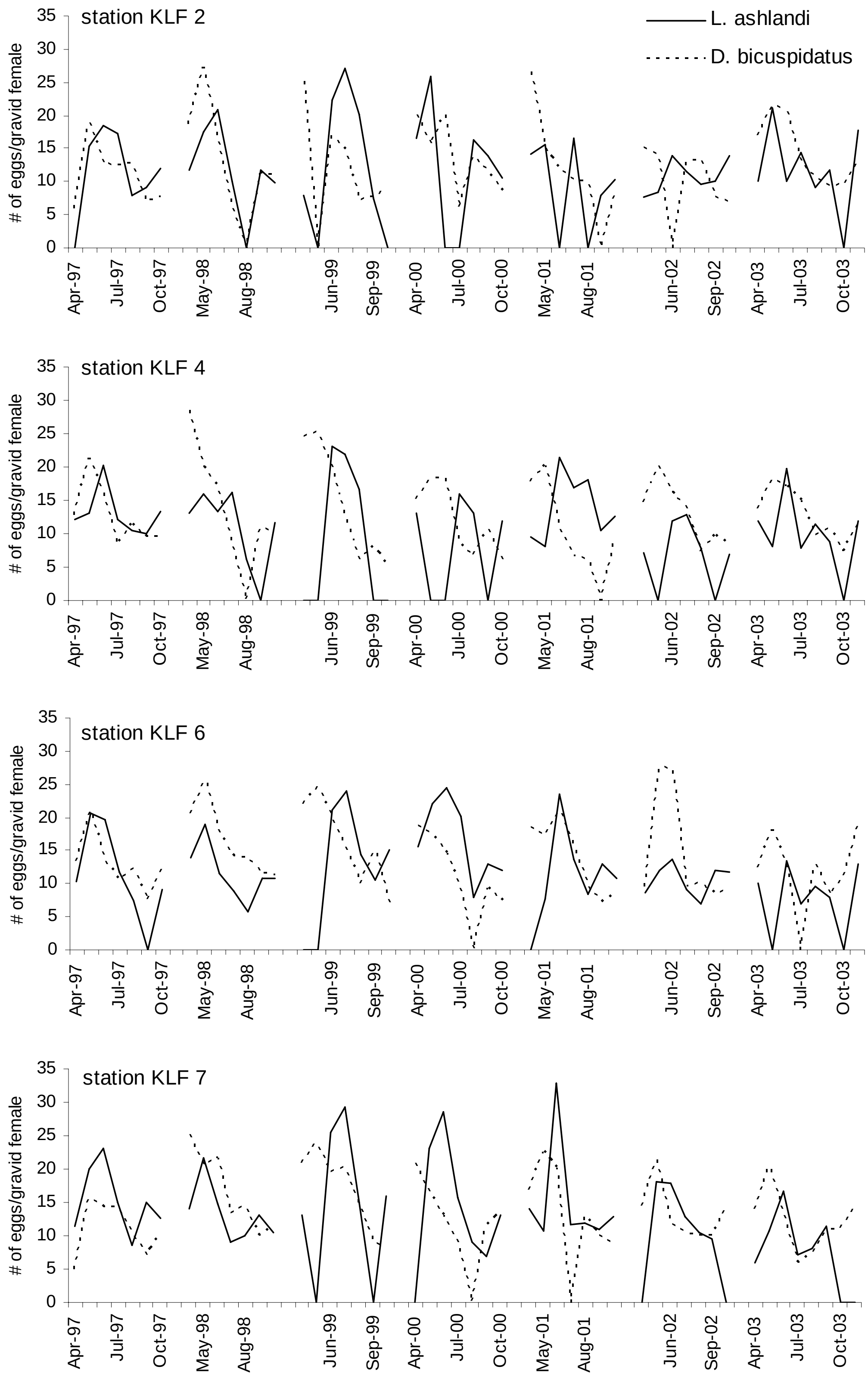


Figure 5.14. Number of eggs per gravid female in two species of Copepoda in Kootenay Lake, 1997-2003.

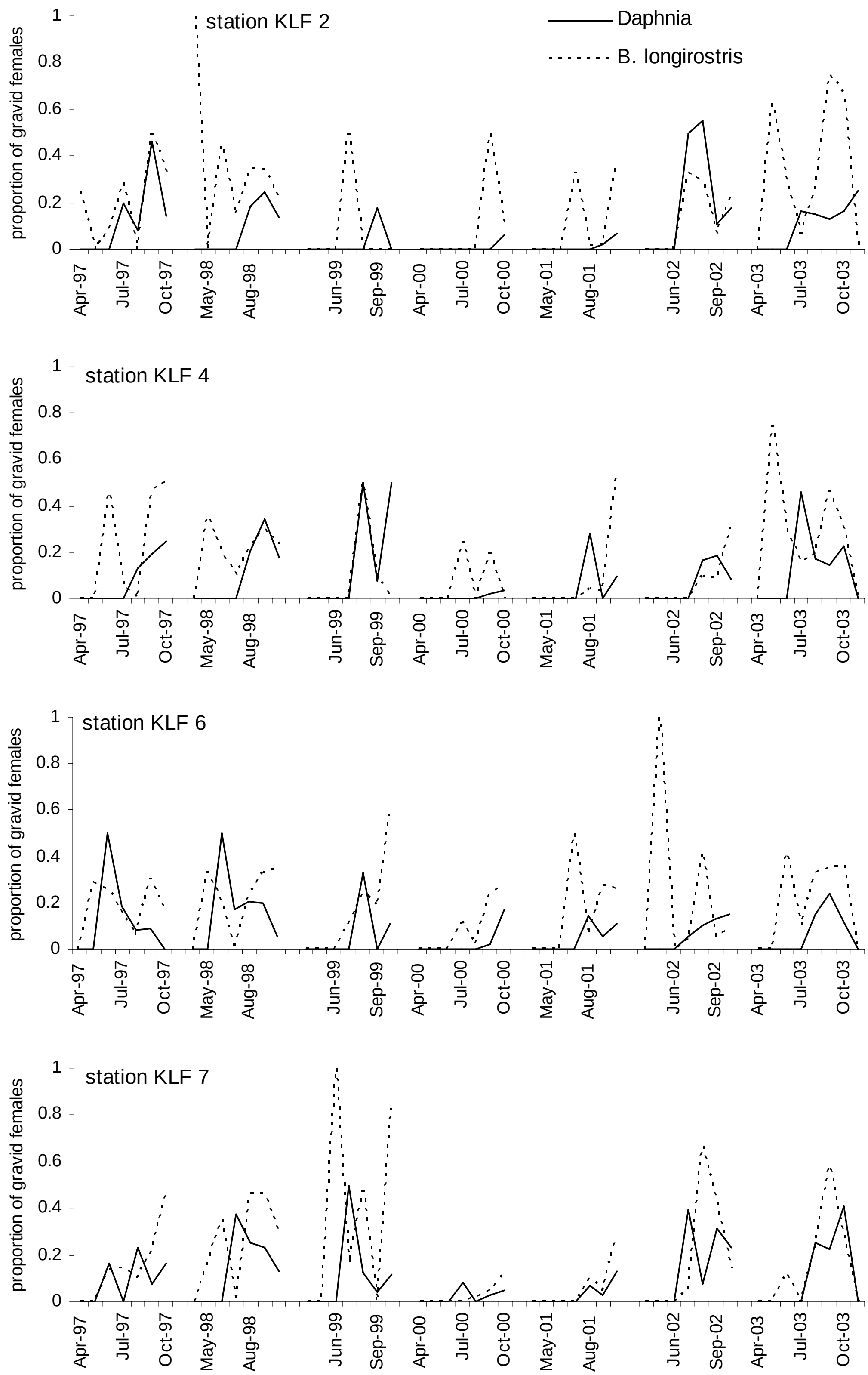


Figure 5.15. Proportion of gravid females of two species of Cladocera in Kootenay Lake, 1997-2003.

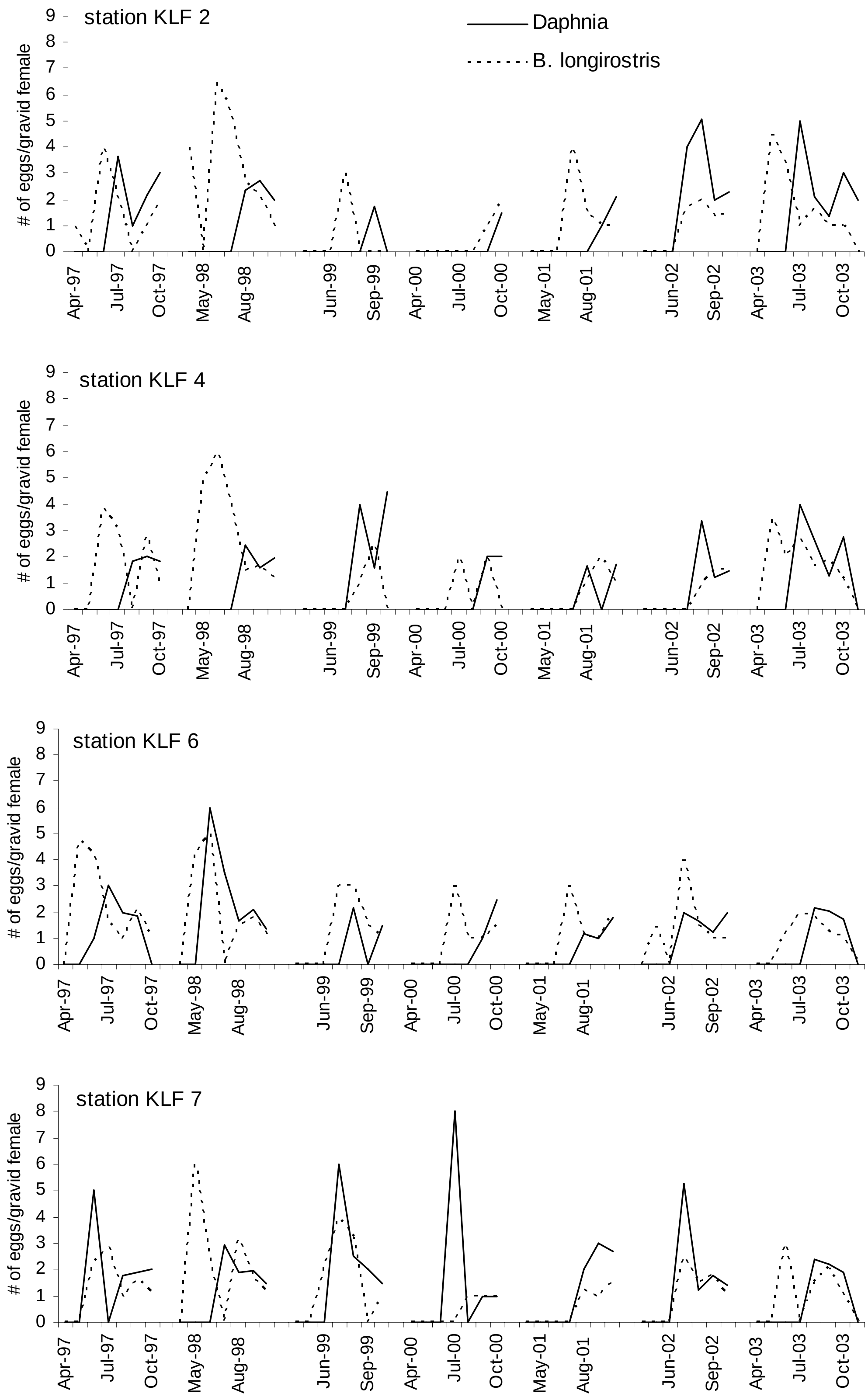


Figure 5.16. Number of eggs per female in two species of Cladocera in Kootenay Lake, 1997-2003.

CHAPTER 6

RESPONSE OF *MYSIS RELICTA* TO EXPERIMENTAL FERTILIZATION YEARS 11 and 12 (2002 and 2003)

by

Dr. Lidija Vidmanic

Limno-Lab Ltd.
Vancouver, BC

Introduction

Water quality and kokanee stocks in the Kootenay Lake reservoir have been influenced by anthropogenic changes during the last 55 years, including the introduction of *Mysis relicta* in 1949. The release of mysids interfered with established food webs and impacted benthic, phytoplankton, zooplankton and fish communities. Mysids feed on zooplankton and are in direct competition with kokanee for preferred zooplankton prey. The study of mysids in Kootenay Lake started in 1992 as part of a multidisciplinary project to restore kokanee stocks by the experimental fertilization of the North Arm of the lake.

Methods

Samples of mysids from Kootenay Lake were collected monthly from January to December, at seven stations (KLF 1-4 in the North Arm and KLF 5-7 in the South Arm of the lake). In August 2003 an additional station was established in the West Arm (station KLF 8). Sampling was done at night, around the time of the new moon, to decrease the chance of mysids seeing and avoiding the net. Three vertical hauls were done at each station, with the boat stationary, using a 1 m^2 square-mouthed net with 1,000 μm primary mesh, 210 μm terminal mesh and 100 μm bucket screen. Two hauls were made in deep water (0.5 nautical miles from both west and east location) and one haul was made in shallow water near either the west or east shore. The net was raised from the lake bottom with a hydraulic winch at 0.3 m/s. The contents of the bucket were rinsed into a filter to remove excess lake water, then preserved in 100% denaturated alcohol (85% ethanol, 15% methanol).

Samples were analyzed for density, biomass (estimated from an empirical length-weight regression), (Lasenby 1977), life history stage and maturity (Reynolds 1972). The life history stages identified were: juvenile, immature male, mature male, breeding male, immature female, mature female, brooding female (brood pouch full of eggs or embryos), disturbed brood female (brood pouch not fully stocked with eggs, but at least one egg or embryo left to show that female had a brood) and spent female (brood pouch empty, no eggs or embryos remaining).

Samples were re-suspended in tap water filtered through a 74 μm mesh filter, placed in a plastic petri dish and viewed with a Wild M3B dissecting microscope at up to 160X magnification. All mysids in each sample were counted, and had their life history stage and maturity identified. The body lengths (tip of rostrum to base of telson) of up to 30 individuals of each stage and maturity were measured, for use in biomass calculations, using a mouse cursor on a live television image of each organism. Fecundity of brooding females was estimated by removing and counting of eggs or embryos from the female brood pouch.

Results

Abundance and Biomass

During the course of the fertilization experiment, mysid densities were the highest in 1992, declined during the next four years (1993 – 1996), but increased again from 1997 to 2001.

In 2002 densities decreased significantly, almost twice in comparison to the previous year. A similar trend continued in 2003 (Fig. 6.1). The annual average mysid density at deep stations was higher in the South Arm than in the North Arm in 1993, 1994, 2001 and 2002, while during the period from 1995-2000 and in 2003 mysids were more abundant in the North Arm (Fig. 6. Table 6.1). Densities were below the historical high values seen in the late 1970's, and the mid-1980's (Fig. 6.1). However, the very erratic values observed during that period may have arisen due to sampling frequency and the methods used at that time. Samples were collected less regularly than during the current study, and the plankton net used had a finer mesh (Crozier and Duncan 1984). From 1992 onward, during the fertilization experiment, sampling of mysids began in January and continued until December, so all annual average values represent a twelve month period.

As in previous years densities were low in winter and spring, increased during the summer months, and declined in autumn, (Lasenby et al. 1998, Wright et al. 2002a, 2002b, 2002c). Deep samples tended to have higher densities than near-shore samples. From 1997 to 2003 mysid densities in both the North and South Arms were generally below 300 individuals/m^2 at both deep and shallow sites throughout the year (Fig. 6.3). However, in 1999, 2000 and 2001 this level was exceeded more often particularly from July to October. From 1997 to 2001 there was a tendency, from May to October, toward higher mysid densities at the deep stations in the North Arm, while in the South Arm higher densities at deep sites were recorded only in 2001 and 2002. Over this same period mysid densities at the shallow stations were at similar levels in both the North and South Arms.

During the seven years studied ,peak monthly values at shallow sites were usually recorded in June-July mainly due to a higher number of juveniles (Fig. 6.5 and 6.6). At deep sites there were usually two density peaks during the year, the first in May-June (the highest density of juveniles, Fig. 6.7 and 6.8) and the second in August-October, mainly due to a higher density of immature males and females**.** In 2002 mysid density decreased sharply at the deep sites, while at the shallow stations no significant changes were noted. The highest seasonal mysid abundance in 2002 at a deep site was found in June at station KLF 5 in the South Arm with 673 individuals/m^2 (mainly juveniles). The highest seasonal abundance of mysids at a shallow site occurred also in June but in the North Arm at station KLF 1 with 540 individuals/m^2 (mainly immature females). However, in 2003 the highest abundance at a deep site was found in the North Arm in August at station KLF 2 with 749 individuals/m^2 (immature male and female), while the highest abundance at a shallow site was observed at station KLF 1 in July with 147 individuals/m^2. In 2003 mysid abundance further decreased at deep sites except at station KLF 2 and station KLF 3. In comparison to 2002, the number of juveniles decreased more than twice at deep sites (except at station KLF 5) which was mirrored in lower numbers of immature and mature individuals later in the season, similar to the pattern that occurred in 2003 at deep sites except at stations KLF 2 and KLF 3.

Table 6.1. Annual average density and biomass of *Mysis relicta* in the North and South Arms of Kootenay Lake 1997-2003. Values are for deep sites only, calculated for samples collected between January and December 1997-2003. Density is in units of individuals/m^2, and biomass is in units of mg/m^2.

	Lake	1997	1998	1999	2000	2001	2002	2003
Total Density	Kootenay-North Arm	150	138	226	239	253	105	102
(individuals/m^2)	Kootenay-South Arm	92	94	150	149	300	152	74
	Upper Arrow	32	71	116	195	195	185	286
	Lower Arrow	63	99	134	223	259	158	101
	Okanagan Lake	N/A	N/A	184	310	338	201	237
Total Biomass	Kootenay-North Arm	N/A	N/A	1296	1239	1547	764	694
(mg/m^2)	Kootenay-South Arm	N/A	N/A	1143	940	1653	929	575
	Upper Arrow	154	268	544	816	855	782	1560
	Lower Arrow	263	450	712	1030	1063	598	597
	Okanagan Lake	N/A	N/A	2188	2266	3361	1385	2151

During the period 1999-2003 average mysid biomass was generally below 3000 mg/m^2 at all stations (Fig. 6.4). Biomass was low in winter and spring, increased in summer and fall, and began to decline in December. In 2002 and 2003 biomass was generally higher at deep sites. From January to May 2002 mysid biomass was below 800 mg/m^2 at deep sites and below 200 mg/m^2 at shallow sites. From May onward biomass at deep sites increased slightly and did not exceeded 1350 mg/m^2 by the end of the season. During January to June 2003, average biomass at deep sites in both Arms was less than 500 mg/m^2, and less than 200 mg/m^2 at shallow sites. From July toward the end of the year biomass at deep sites slightly increased, but did not exceed 1500 mg/m2 in the North Arm and 1200 mg/m2 in the South arm (Fig. 6.4).

From 1999 to 2001 mysid biomass frequently exceeded 2000 mg/m^2 from September onward. At the shallow sites there were occasional peaks in biomass such as in July of 2000 when biomass exceeded 3000 mg/m^2 at station KLF 5, as well as in June 2002 when biomass exceeded 4400 mg/m^2 at station KLF 1 and 2300 mg/m^2 at station KLF 5 (Fig. 6.9 and 6.10). At the deep sites of station KLF 1 in the North Arm and station KLF 7 in the South Arm there was a tendency toward an increase of biomass from 1999 to 2001. However, in 2002 biomass decreased at all deep sites, especially at stations KLF 1, KLF 2 and KLF 7. In 2003 biomass decreased even further at both deep and shallow sites (Fig. 6.11 and 6.12). Overall biomass was higher at deep stations than at the shallow stations, because of the greater proportion of older (and therefore larger) individuals in deeper water. Although average density and biomass was higher in the South Arm during 2002 the highest biomass values was detected at station KLF 1 in the North Arm of the lake, while density was the highest in the South Arm at station KLF 5. In 2003 the highest values of both biomass and density were detected at station KLF 2 in the North Arm.

Annual average density of mysids in the Kootenay Lake from 1997 to 1999 was approximately double the density observed in Arrow Lakes Reservoir and similar to that of

Okanagan Lake (Table 6.1). Mysid biomass in Kootenay Lake was about twice that of Arrow Lakes Reservoir but one half that of Okanagan Lake in 1999. In 2000 and 2001 mysid density and biomass in Arrow Lakes Reservoir had increased to the point that the density and biomass in Lower Arrow was similar to Kootenay Lake. Mysid density and biomass in Okanagan Lake remained higher than either Arrow Lakes Reservoir or Kootenay Lake. During 2002 both mysid density and biomass in Kootenay Lake decreased sharply by almost 50%, especially in the North Arm. During the same time mysid density and biomass decreased in Arrow Lakes Reservoir and Okanagan Lake bringing mysids biomass and density to a similar level in all three lakes. In 2003 density and biomass further decreased in in the North Arm but was more significant in the South Arm. The mysid population in the Upper Arrow and Okanagan Lake increased, bringing both biomass and density to more than twice observed in Kootenay Lake (Lasenby et al. 1998; Pieters et al 1998; Pieters et al. 1999; Pieters et al. 2000; Wright et al. 2002a, 2002b, 2002c; Andrusak et al. 2001).

Life Stages and Fecundity

The release of juveniles from females' brood pouches occurs in early spring, and is reflected by a density increase in April of each year. By July, the juveniles have grown into the immature stage, so during the summer and fall immature males and females dominate in the mysid population. Brooding females and breeding males increase in density in the late fall as they reach maturity. The highest density of gravid females occurs during the winter.

The mysid population in Kootenay Lake has been comprised of slightly more females than males. Density of developmental stages of *M. relicta* at deep sites is shown in Fig. 6.7 and 6.8. From January to March of 2002 and 2003, immature males, immature females, brooding females and spent females were consistently present, similar to observations in previous years. From April to July in both years the majority of individuals were juveniles, with presence of both immature males and females. From July to September the proportion of immature and mature males and females did not show any increasing trend as in previous years, except at station KLF 2 in 2003. From October to December very few juveniles were seen, but immature, mature and breeding males and brooding females were common. In 2002 the pattern of seasonal development at deep stations changed particularly in the North Arm. The number of brooding females was very low in the fall-winter season of 2001-2002 as well as 2002-2003, which resulted in a lower number of juveniles during the summer of both years (Fig. 6.13).

Timing of the progression through the development stages at the shallow sites in these two years has also been changed in comparison to previous years (Fig. 6.5 and 6.6). From January to April 2002 and 2003 very few individuals of any stage were seen. From May to July juveniles were present but did not dominate the distribution as in previous years. From July to September immature males and females dominated and from October to December very few individuals of any stage were seen.

From 1999 to 2003 gravid females were present in the samples from late fall (November) to late spring (May). In 1999 gravid females were more abundant in the North Arm of the lake (Fig. 6.14 a, data from deep sites only). At the beginning of the years 2000 and 2002 females in the South Arm were more likely to be gravid, but by December the proportion of gravid females was higher in the North Arm. In 2001 mature females were more likely to be gravid from late fall through to late spring. During January to April of 2002, 40-85% of mature females were gravid, except in February and March in the North Arm. This proportion declined in summer, as spent females died off, and increased in the fall, as the new cohort matured. By December, 10-50% of females were gravid. In 2003 70-85% of mature females were gravid from January to March. From April to October this proportion declined and in December it increased again to 40% in the South Arm and 60% in the North Arm.

The seasonal average number of eggs per gravid female in 2002 was 16 and 15 eggs per gravid female in the North Arm and the South Arm respectively. From January to June gravid females in the South Arm carried more eggs that those in the North Arm (Fig. 6.14 b). From July to October gravid females were not present in any of two basins, but by November a new cohort matured and gravid females started to appear. During the fall-winter season, the number of eggs per gravid female slightly differed between the two basins. In 2003, the number of eggs per gravid female during the twelve months averaged 19 and 18 eggs per gravid female in the North and the South Arms respectively. From January to March, females in the North Arm carried more eggs than those in the South Arm. From July to October in the North Arm and June to October in the South Arm gravid females were not present in the samples. At the end of the season gravid females carried slightly more eggs in the North Arm (23-24 eggs per gravid female) than in the South Arm (21-22 eggs per gravid female).

Discussion

The annual average mysid density and biomass data at deep stations suggest that the South Arm of Kootenay Lake was more productive than the North Arm in 2002. However there was not a consistent gradient in density along the lake during the year. From May to July of 2002 there was a trend toward higher mysid density at deep sites of the South Arm, while during the remainder of the year density slightly differed between the two basins. In 2003 the pattern changed, and annual average density at the deep sites was higher in the North Arm than in the South Arm.

Overall, the annual average number of mysids has decreased over the four years from 1993 to 1996 and gradual increased during the next five years from 1997 to 2001. During 2002-2003 a sharp decrease in mysid abundance was recorded. During the study period from 1993 onward, mysid densities at deep stations fluctuated along the length of the lake. Average mysid density was higher in the South Arm in 1993, 1994, 2001 and 2002. However in the period from 1995-2000 and again in 2003 density was higher in the North Arm. During the season densities increased through summer, and declined in winter. Mysid density and biomass tended to be higher in the deep sites than in near-shore sites. Near-shore samples contained predominantly juveniles, and immature males and females, while mature and breeding males and females are rare. In 2002 and 2003 mysids in Kootenay Lake were most actively breeding from January to April. During the breeding season deep samples contained a higher proportion of mature and breeding individuals than near-shore samples.

There was a pattern of higher mysid density in the South Arm (station KLF 5) in 2002, but in 2003 density was higher in the fertilized zone (station KLF 2). The number of brooding females was low in the fall-winter season of 2001-2002 and 2002-2003, which was reflected in the lower number of juveniles during the summer of 2002 and 2003, and a decreased density of the mysid population.

The number of juvenile and immature mysids in the pelagic areas of the South Arm was higher than in the North Arm in 2002, which resulted in an along-lake pattern of higher mysid density and biomass in the South Arm. A large number of juveniles in June 2002 at station KLF 5 in the South Arm was not reflected in a greater number of mysids in the following year. In comparison to other oligotrophic lakes in British Columbia, Kootenay Lake in the pre-fertilization period had a substantial mysid population. Since 1992, when the fertilization experiment started, mysid densities have increased, reaching a level similar to that of more productive years of the late 70's and early 80's. From 1993 onward mysid data indicates that the Kootenay Lake has been more productive than Arrow Lakes Reservoir even after the commencement of fertilization in Arrow Lakes Reservoir. However, in 2002 mysid densities in Kootenay Lake decreased almost 50% in comparison to previous years, and in 2003 decreased again and was lower than in Arrow Lakes Reservoir. Compared to Okanagan Lake, mysid densities and biomass were lower in Kootenay Lake despite the increased fertilizer load to Kootenay Lake in 2001 and mysid harvesting in Okanagan Lake from 1998 onward.

Annual average fecundity measures of *M. relicta* had similar trends in both the North and South Arms, with some slight differences and fluctuations. Mysids in Kootenay Lake breed most actively from October to June. During the beginning of the season of 2002, (from January to June), the number of gravid females was higher in the South Arm and during the same time it was more likely that they carry more eggs than females in the North Arm. However, from January to May in 2003 the number of gravid females was slightly higher in the South Arm, while during the same time females from the North Arm carried slightly more eggs than those from the South Arm.

Acknowledgements

Thanks to Kootenay Wildlife Services Ltd for sample collection. The Columbia Fish and Wildlife Compensation Program provided funding for stations KLF 1-7 and the Kootenai Tribe of Idaho provided funding for station KLF 8.

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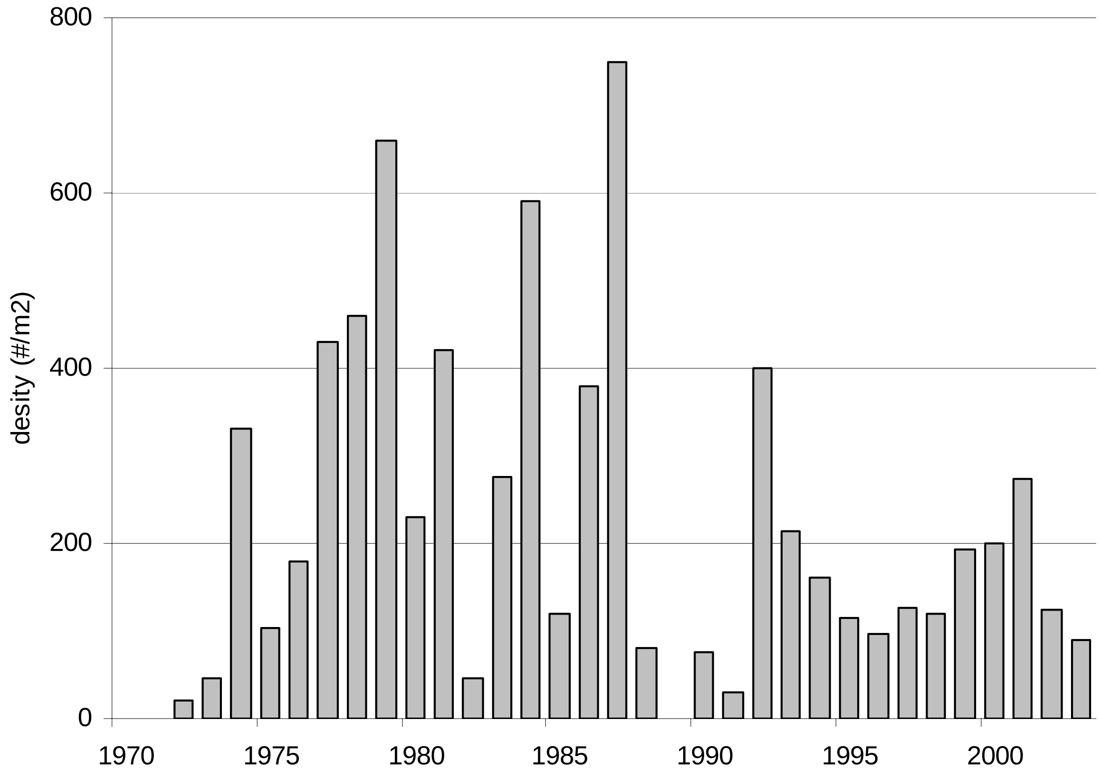


Figure 6.1. Annual average density of *M. relicta* from 1972 to 2003. Note: no data was collected in 1989. Values from 1972 to 1988 from Crozier and Duncan (1984); from 1990 to 1992, Richard Crozier (unpublished data), BC Ministry of Environment, Lands and Parks, 1992 to 1996 from Smokorowski et al. (1997); 1997 from Lasenby et al. (1998), 1998-2001 from Wright et al. (2001 a, b, c).

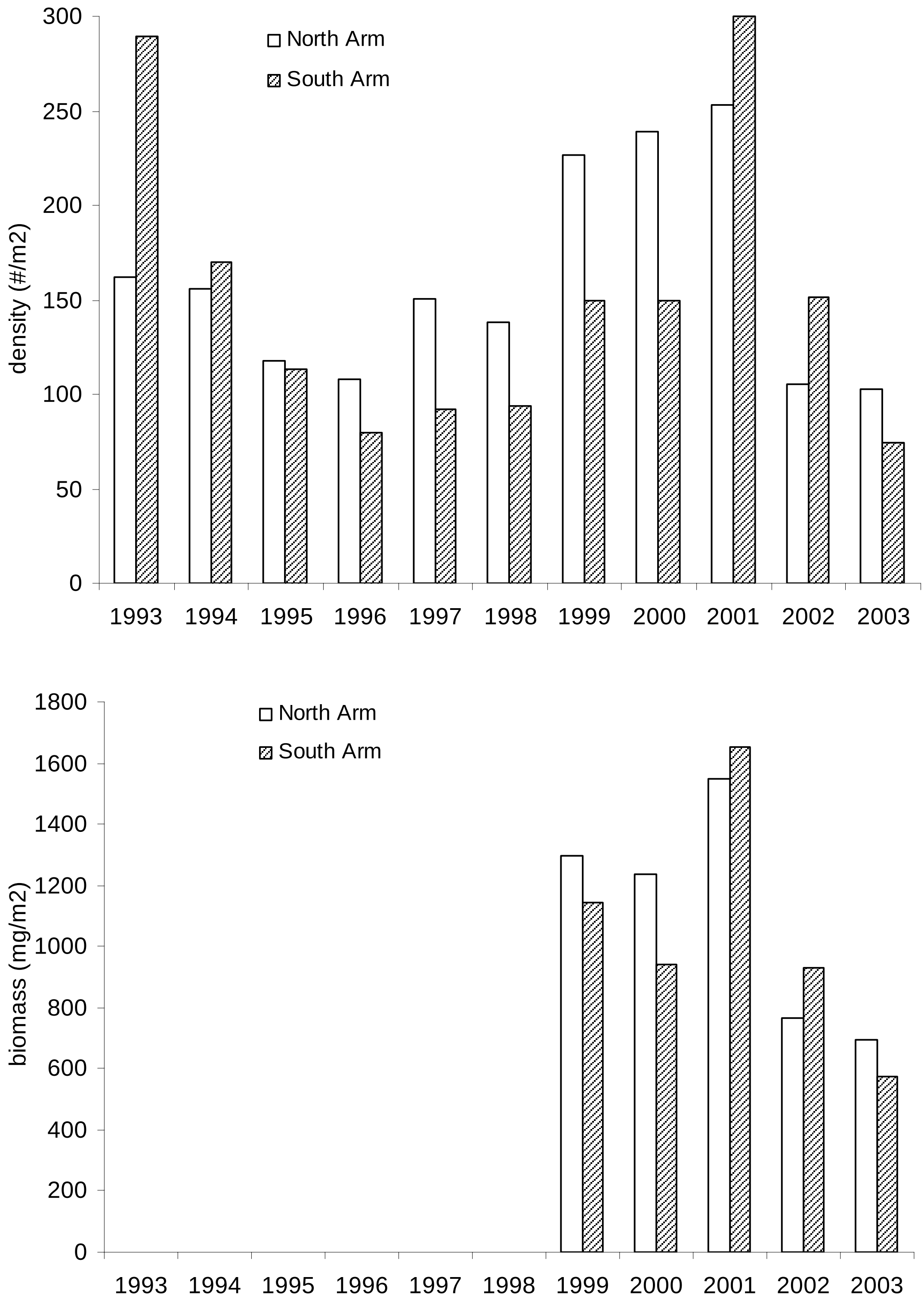


Figure 6.2. Annual average density (top) and biomass (bottom) of *M. relicta* in the North and South Arms of Kootenay Lake 1993-2003.

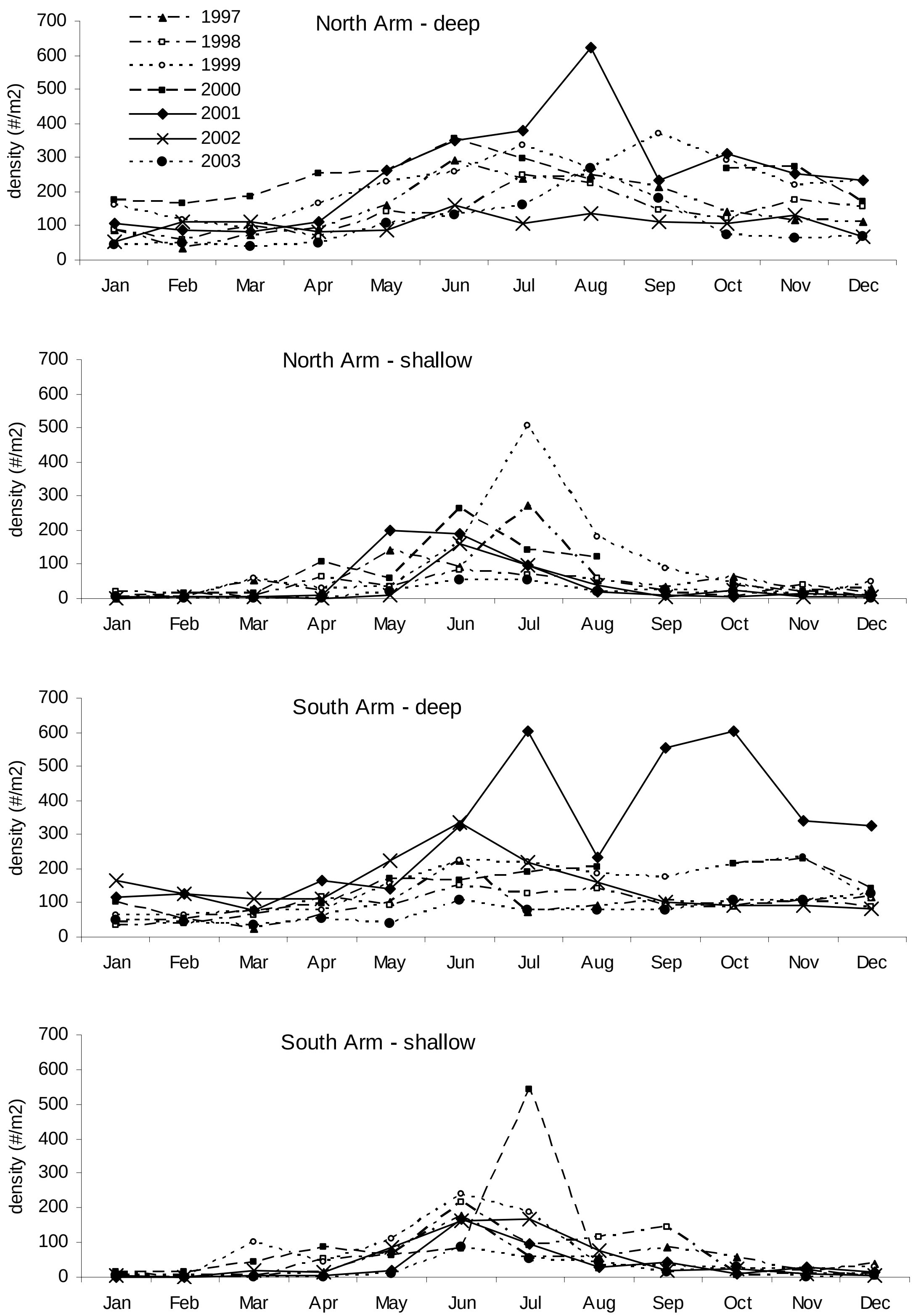


Figure 6.3. Monthly average density of *M. relicta* at deep and shallow sites, in the North and South Arms of Kootenay Lake, 1997-2003.

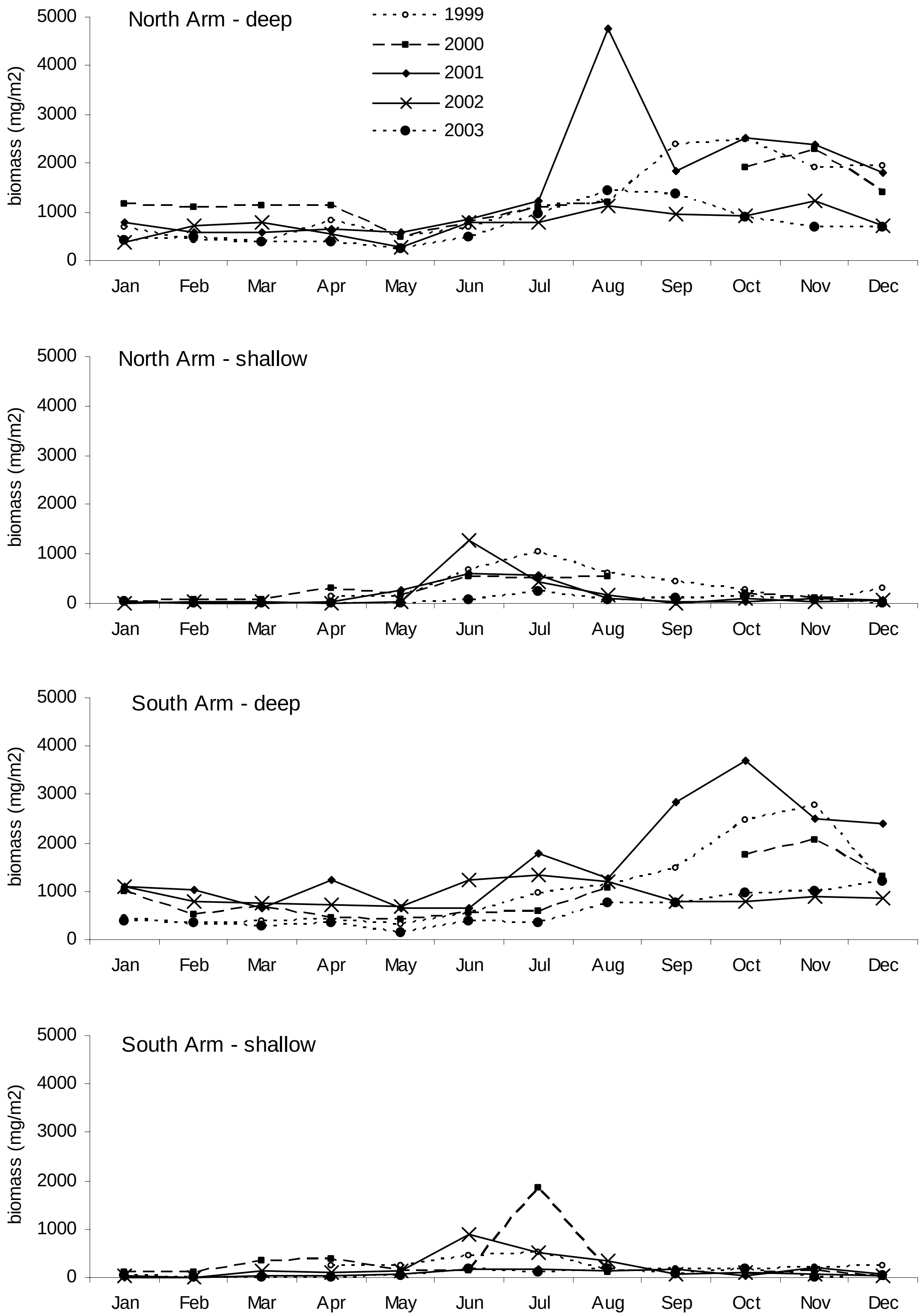


Figure 6.4. Monthly average biomass of *M. relicta* at deep and shallow sites, in the North and South Arms of Kootenay Lake, 1997-2003.

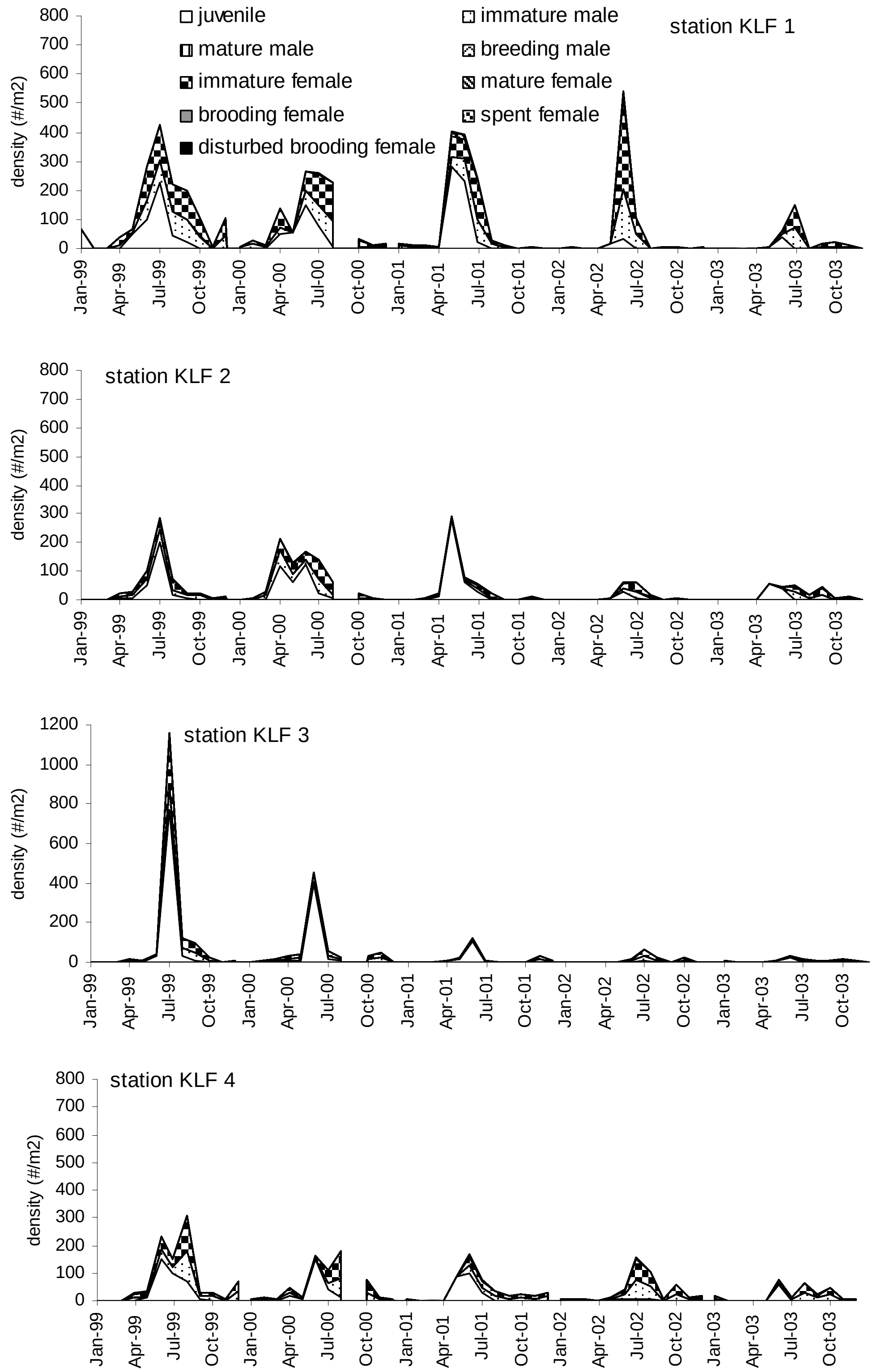


Figure 6.5. Density of developmental stages of *M. relicta* at shallow sites in the North Arm of Kootenay Lake, 1999-2003. Note: scale is different for station KLF 3.

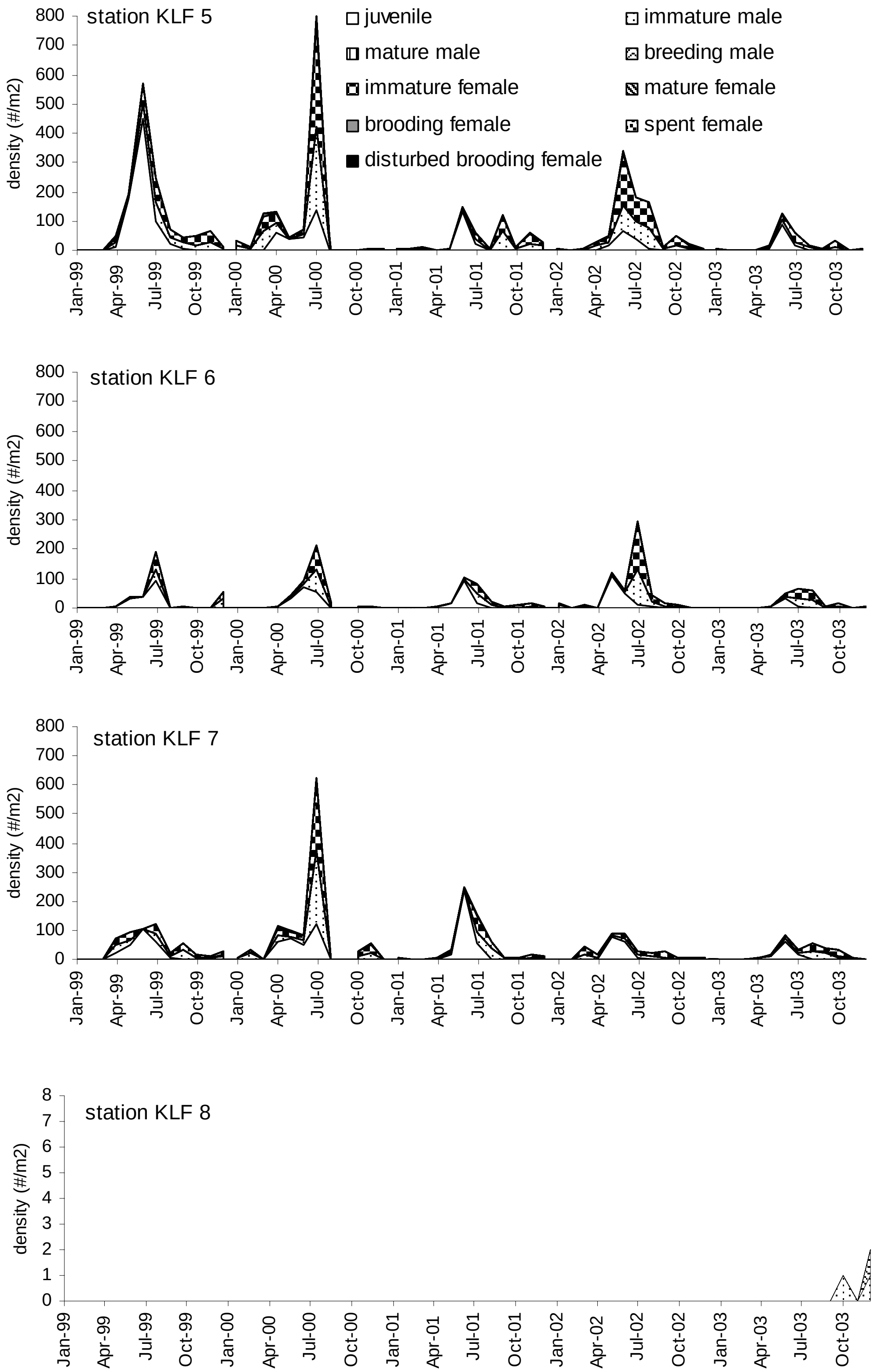


Figure 6.6. Density of developmental stages of *M. relicta* at shallow sites in the South Arm and West Arm of Kootenay Lake, 1999-2003. Note: scale is different for station KLF 8.

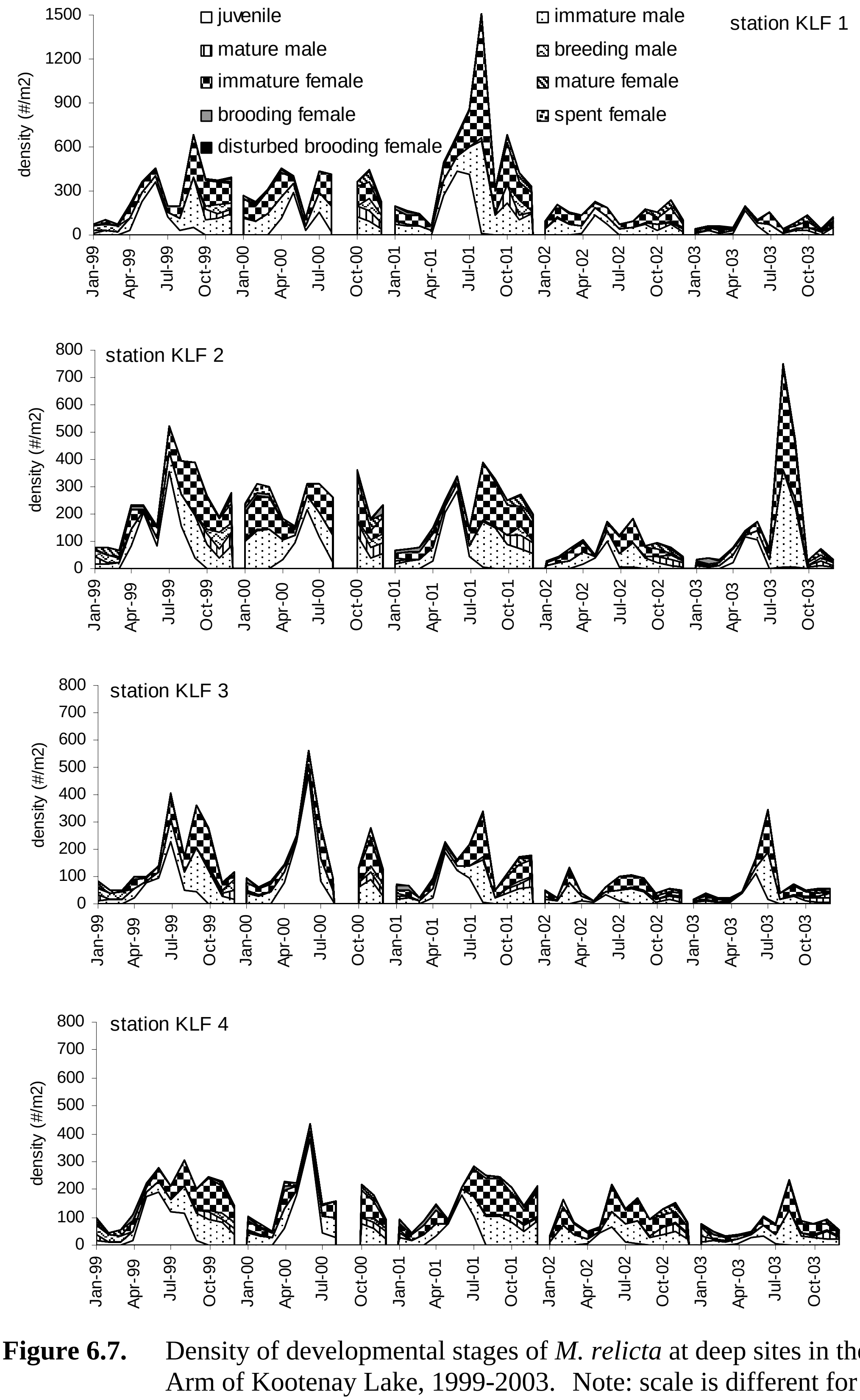


Figure 6.7. Density of developmental stages of *M. relicta* at deep sites in the North Arm of Kootenay Lake, 1999-2003. Note: scale is different for station KLF 1.

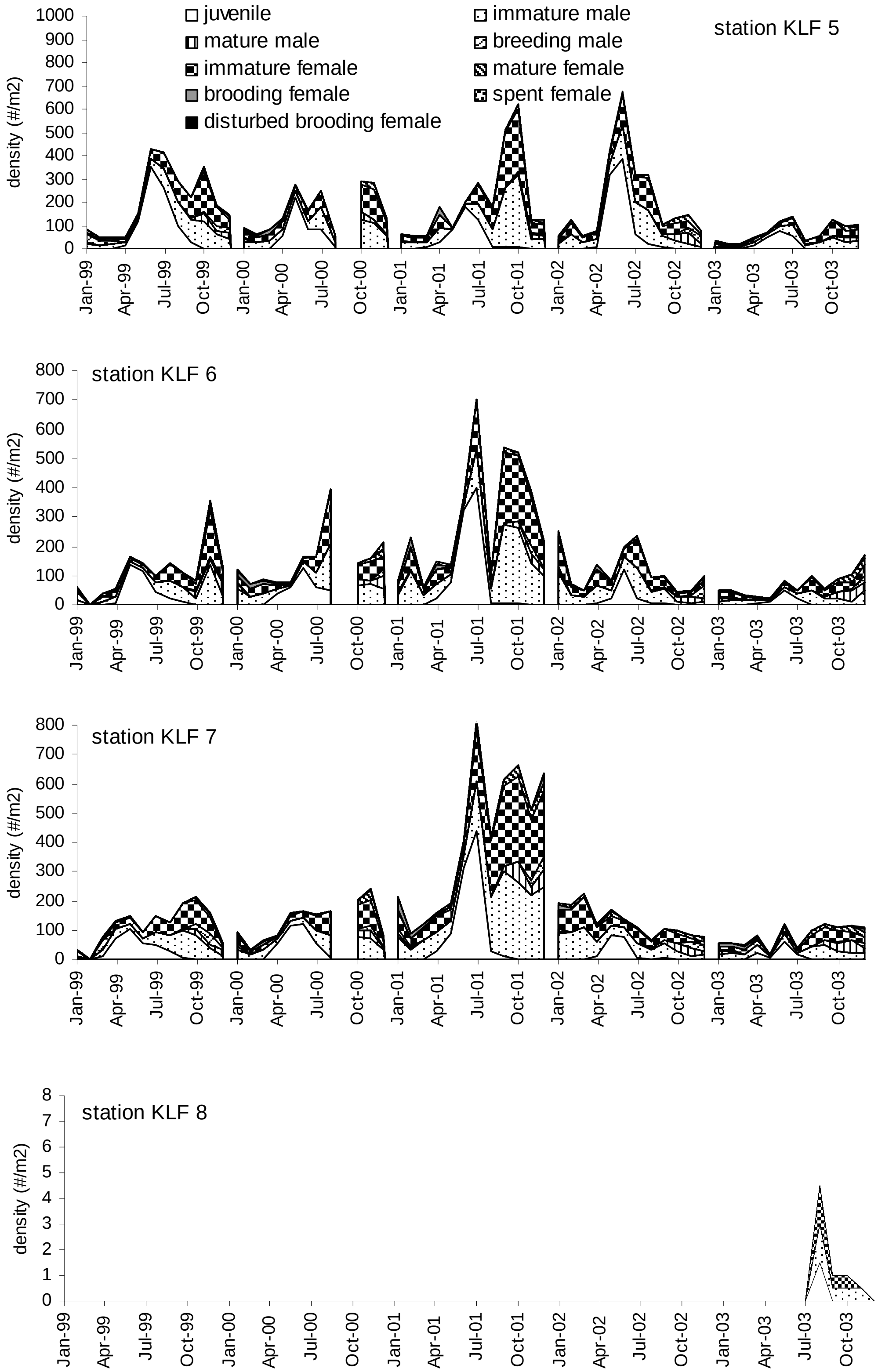


Figure 6.8. Density of developmental stages of *M. relicta* at deep sites in the South Arm and West Arm of Kootenay Lake, 1999-2003. Note: scale is different for station KLF 5 and station KLF 8.

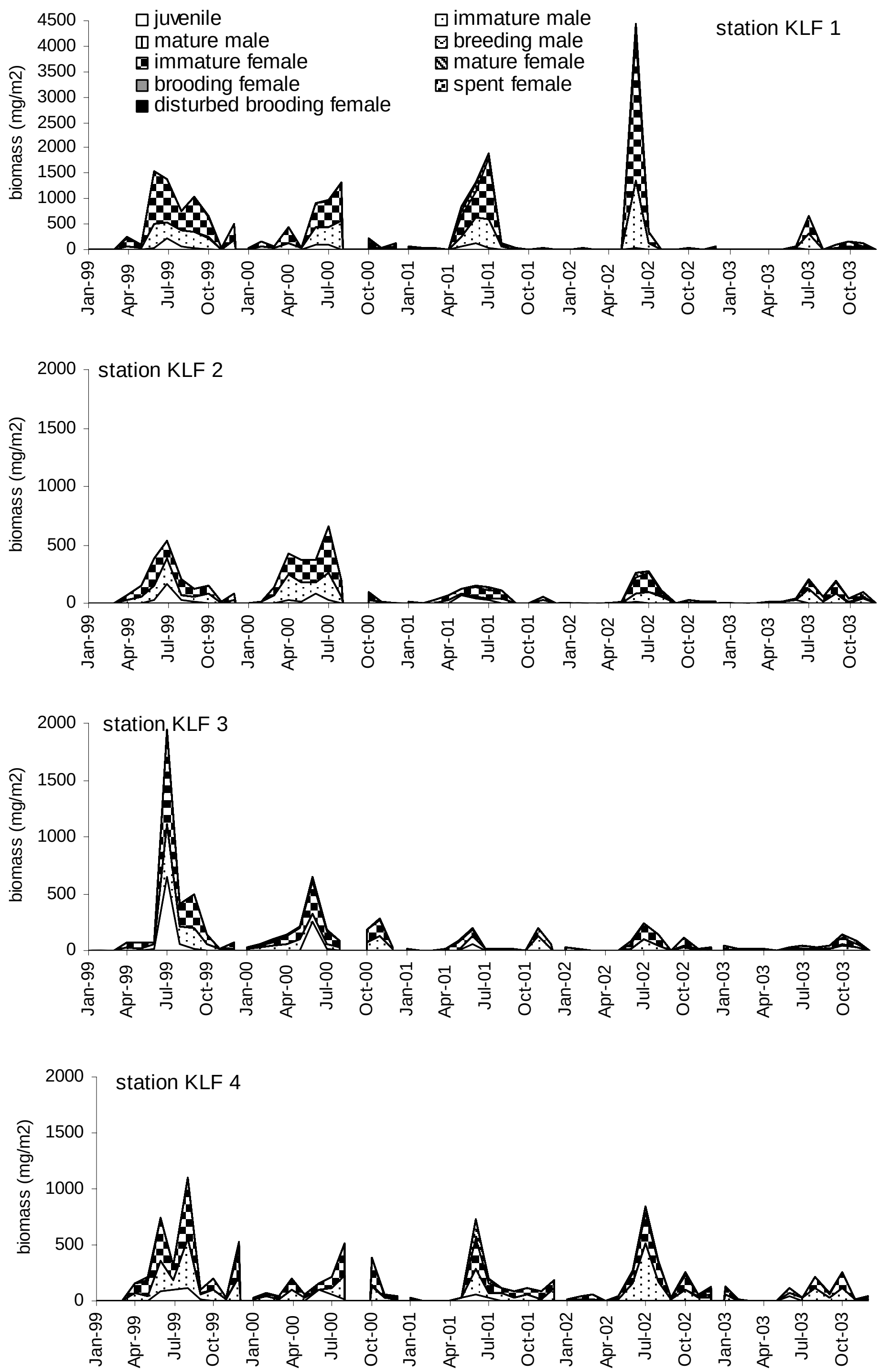


Figure 6.9. Biomass of developmental stages of *M. relicta* at shallow sites in the North Arm of Kootenay Lake, 1999-2003. Note: scale is different for station KLF 1.

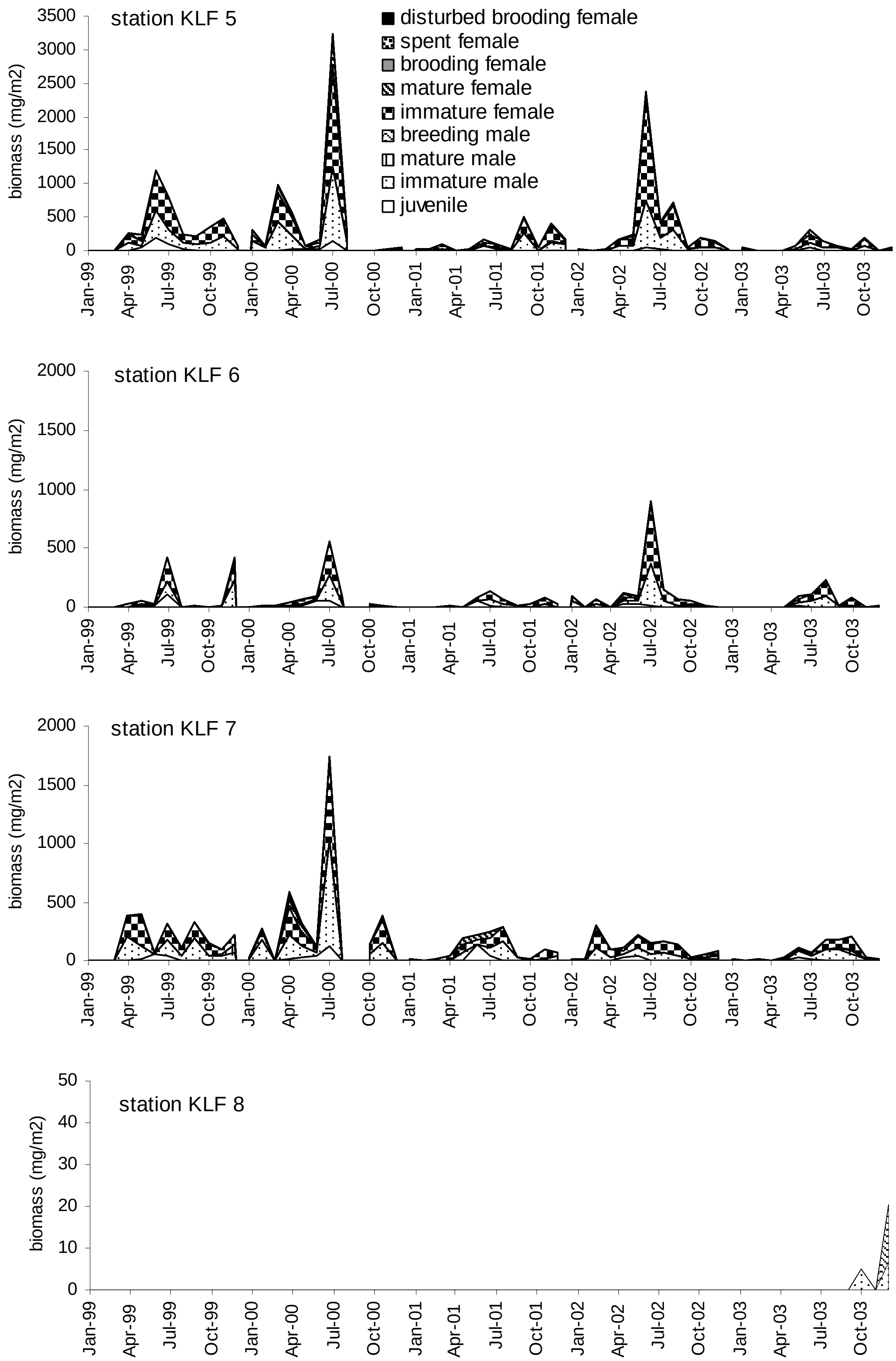


Figure 6.10. Biomass of developmental stages of *M. relicta* at shallow sites in the South Arm and West Arm of Kootenay Lake, 1999-2003. Note: scale is different for station KLF 5 and station KLF 8.

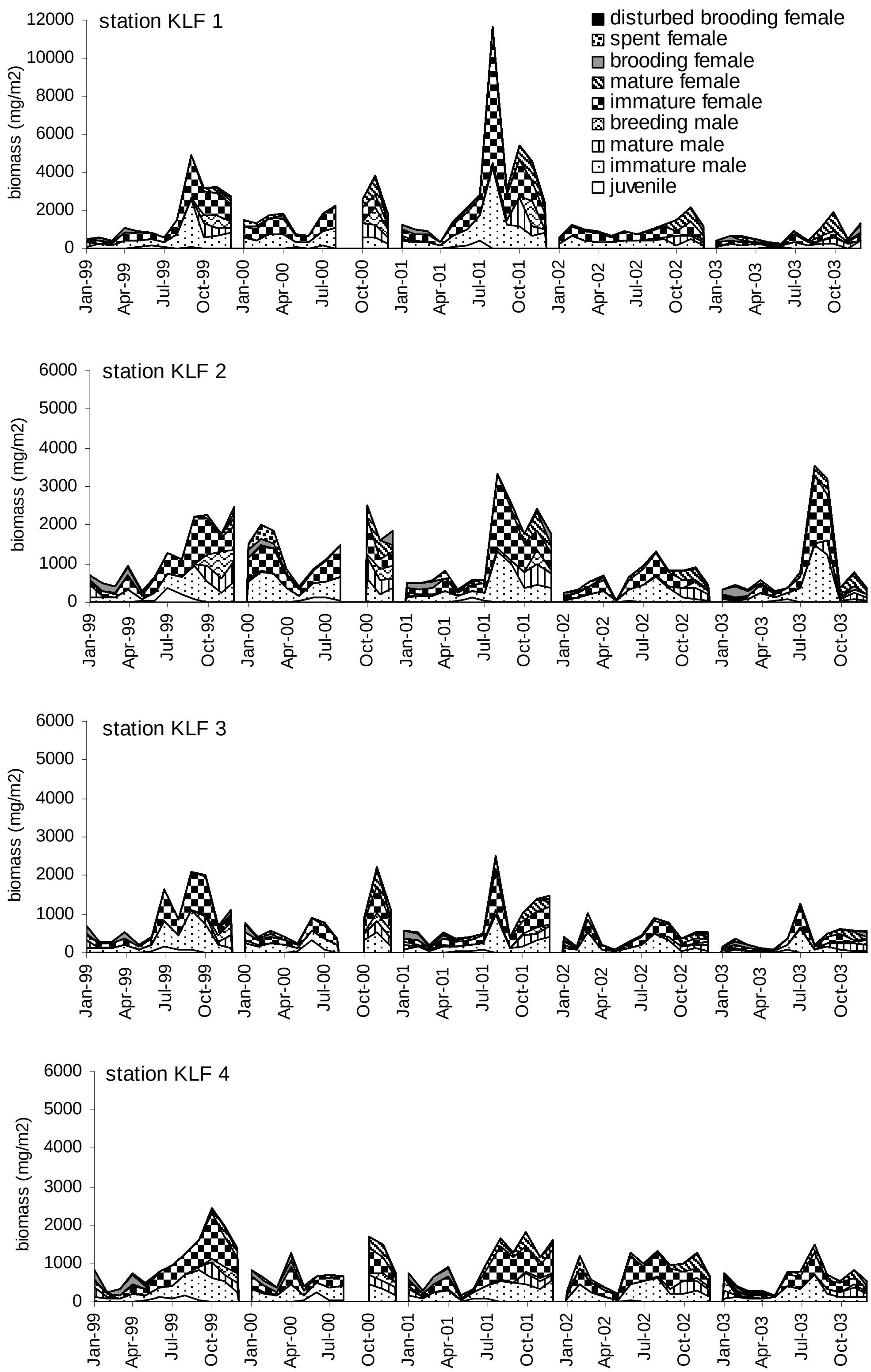


Figure 6.11. Biomass of developmental stages of *M. relicta* at deep sites in the North Arm of Kootenay Lake, 1999-2003. Note: scale is different for station KLF 1.

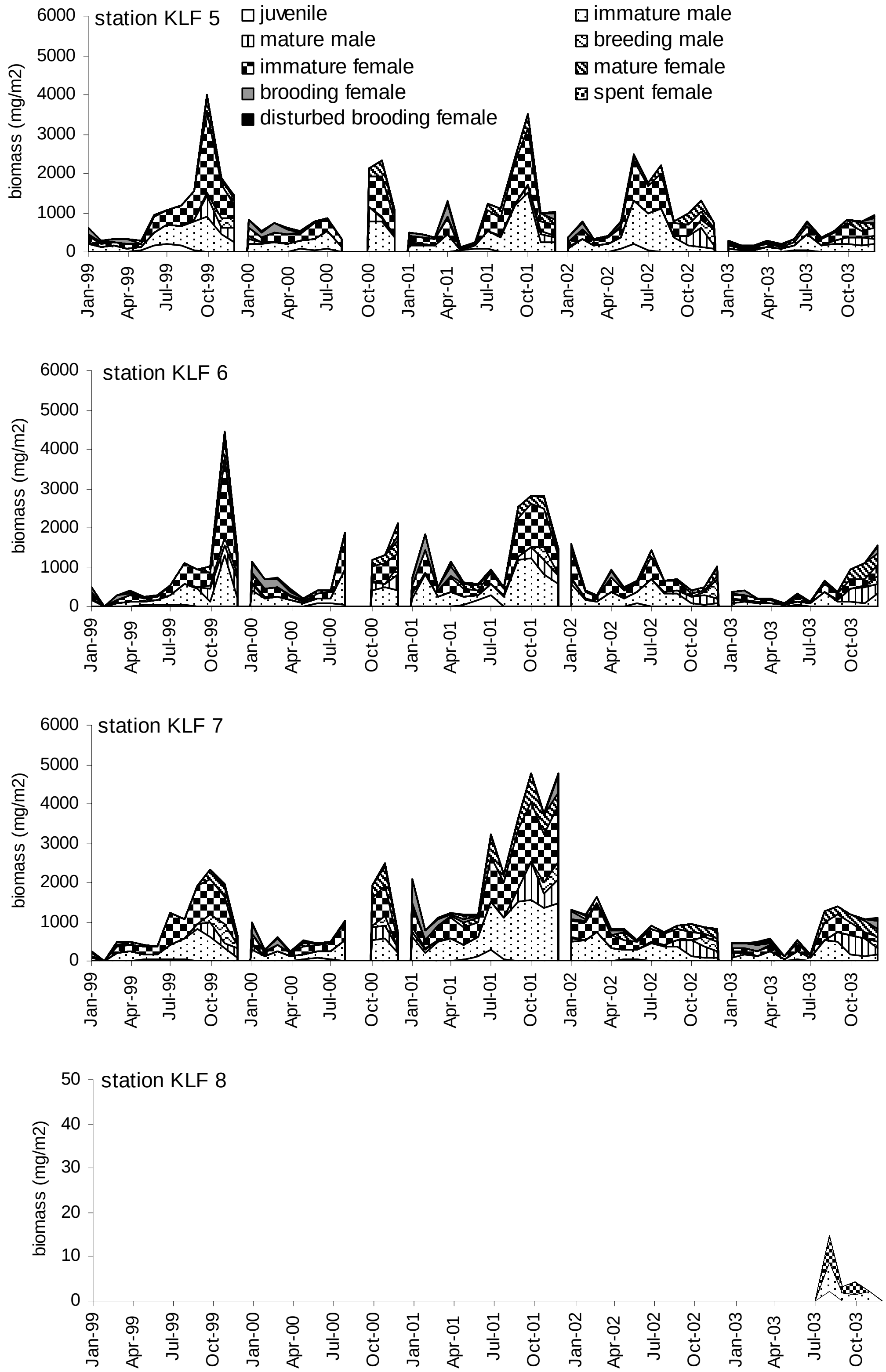
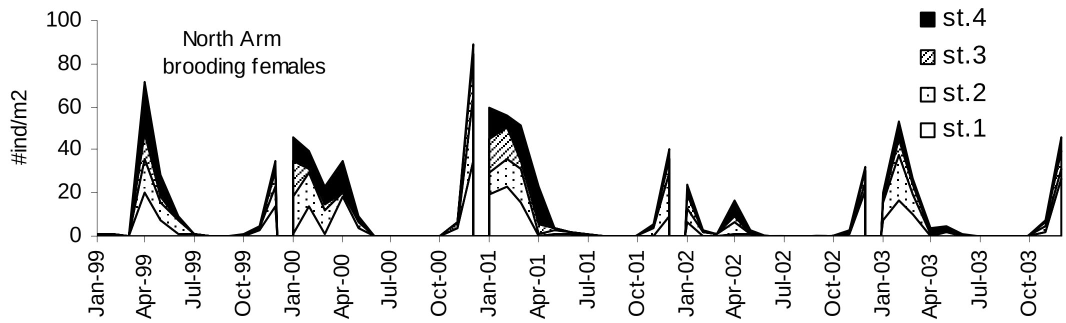
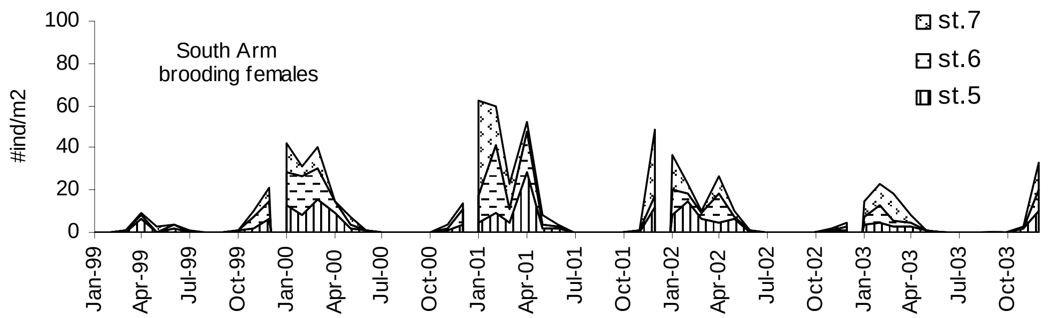


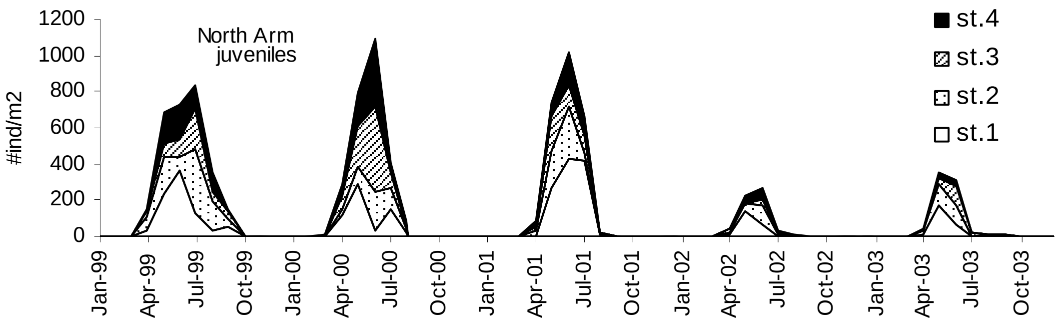
Figure 6.12. Biomass of developmental stages of *M. relicta* at deep sites in the South Arm and West Arm of Kootenay Lake, 1999-2003. Note: scale is different for station KLF 8.



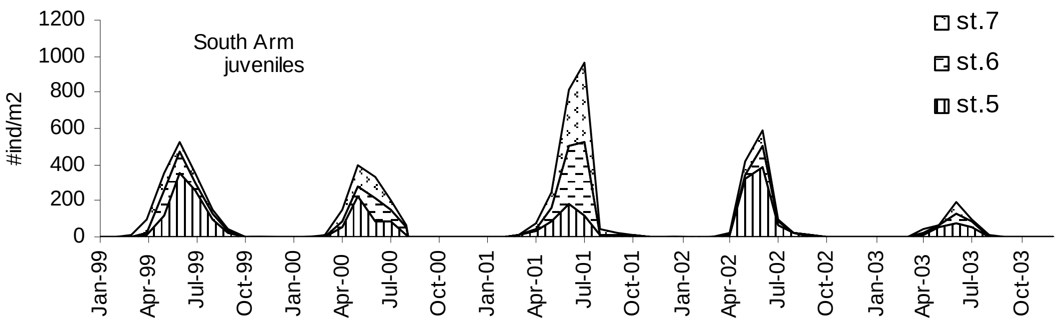
a. Density of gravid females of *M. relicta* at deep sites in the North Arm.



b. Density of gravid females of *M. relicta* at deep sites in the South Arm.

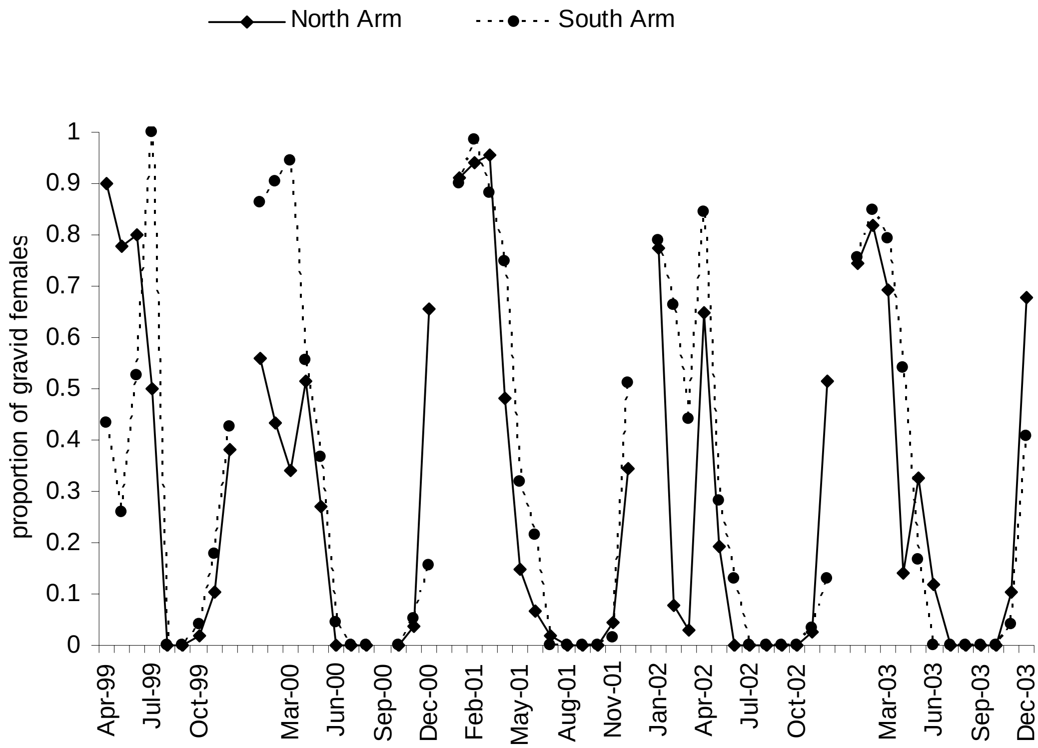


c. Density of juveniles of *M. relicta* at deep sites in the North Arm.

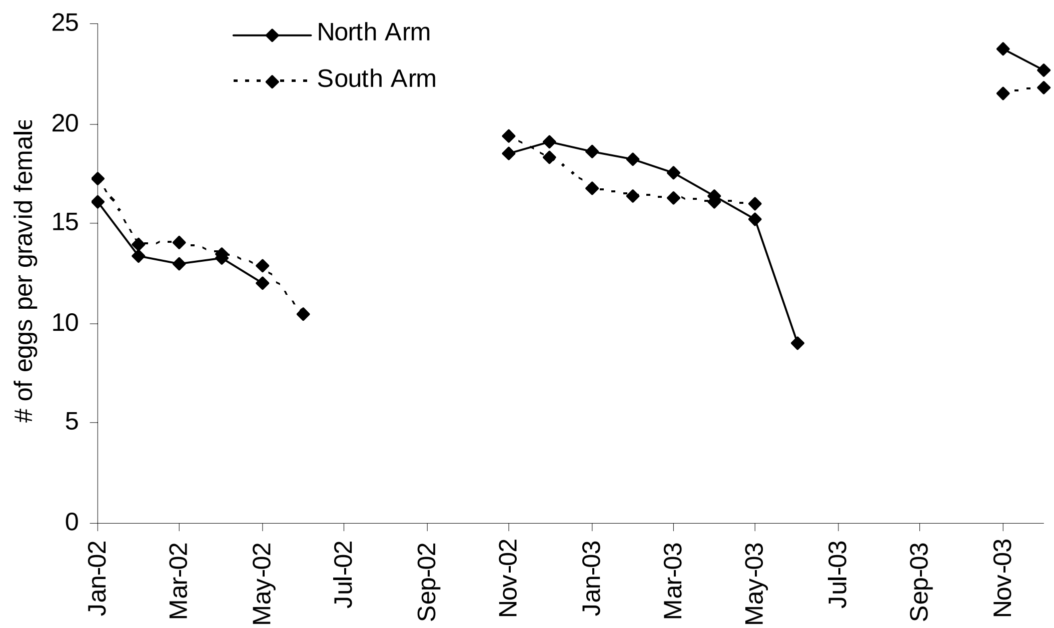


d. Density of juveniles of *M. relicta* at deep sites in the South Arm.

Figure 6.13. Density of gravid females (a,b) and juveniles (c,d) of *M. relicta* at deep sites in the North and South Arms of Kootenay Lake, 1999-2003.



a. Monthly average proportion of gravid females in the North and South Arms of Kootenay Lake, 1999-2003.



b. Monthly average number of eggs per gravid female in the North and South Arms f Kootenay Lake, 1999-2003.

Figure 6.14. Fecundity features of *M. relicta* in Kootenay Lake.

CHAPTER 7

RESPONSE OF KOKANEE TO EXPERIMENTAL FERTILIZATION YEARS 11 and 12 (2002 and 2003)

by

H. Andrusak

Redfish Consulting Ltd
Nelson, BC

and

D. Sebastian

Ministry of Water, Land and Air Protection[1]
Victoria, BC

and

G. Scholten

Ministry of Water, Land and Air Protection[1]
Victoria, BC

and

P. Woodruff

British Columbia Conservation Foundation
Surrey, BC

[1]Presently Ministry of Environment

Introduction

Until recently, there had been little investigative work directed at British Columbia's kokanee populations, aside for those that co-habit lakes with sockeye salmon (Sebastian et al. 2003; Redfish Consulting Ltd. 2004). One notable exception has been Kootenay Lake kokanee that likely are the most studied kokanee populations in British Columbia. Meadow Creek and the Lardeau River are the primary spawning systems for main lake kokanee and Meadow Creek escapements are used as an index of abundance. A kokanee spawning channel (original maximum capacity of 250,000, Redfish Consulting Ltd. 1999) was constructed on Meadow Creek as partial compensation for kokanee losses incurred due to construction of the Duncan Dam. This channel commenced operation in 1967 and Meadow Creek kokanee escapements have been monitored for nearly half a century. These estimates provide an excellent account of the major ecological changes that have taken place in Kootenay Lake. Meadow Creek has also been the primary kokanee egg collection site for the Province of British Columbia for nearly a century (Northcote 1973). The Meadow Creek stock has been planted in many systems throughout BC, including egg and fry plants in streams tributary to the South Arm of Kootenay Lake (Andrusak et al. 2004a).

Gerrard rainbow trout, indigenous only in Kootenay Lake, rely heavily upon kokanee as their food source (Andrusak and Parkinson 1984), and were of primary concern when the kokanee declined to such low numbers in the early 1990s. Similar sized pelagic piscivorous rainbow trout in Arrow Reservoir, Quesnel, and Shuswap lakes also are highly dependent upon kokanee (Arndt 2004; Sebastian et al. 2003; Andrusak et al. 2004c, draft report). Kootenay Lake pelagic piscivorous rainbow trout spawn at the outlet of Trout Lake that forms the Lardeau River, which flows south approximately 50 km where it empties into the North Arm of Kootenay Lake. Each year since 1957, these fish have been visually counted (daily) on the spawning grounds (known as Gerrard). Irvine (1978) studied the early life history of these trout and determined that the total number of spawners was approximately three times the peak count. Recently, Hagen and Baxter (2002, draft report) used the AUC method to estimate the annual total number of Gerrard rainbow trout and they concluded that the expansion factor of 3 was appropriate but felt more data was required on residence time.

During the 1950s and 1960s, Kootenay Lake had a very high level of productivity due to unregulated releases of phosphorus upstream (Northcote 1973). At that time North Arm escapement levels were high (1-3 million) as documented by Bull (1965) and Acara (1970). Meadow Creek numbers were <350,000 in 1964-1965 but increased thereafter due to Duncan River kokanee displacement caused by construction of the Duncan Dam. Meadow Creek spawning channel production began in 1967 and escapement levels gradually increased over two cycles until the late 1970s when escapements exceeded 1 million. During this same period, the fertilizer loading to the lake began to decline with closure of the upstream fertilizer plant. Coincidently, Libby Dam also became operational and while there were concerns about the impact of this dam on Kootenay Lake, the combined impact of reduction in P loadings and nutrient retention in Koocanusa Reservoir was largely unforeseen. Daley et al. (1981) documented the changes that resulted in a significant decline in lake productivity by 1980. Nutrient input to the lake declined <u>below</u> pre-dam conditions and the lake underwent a gradual reduction in productivity through to the early 1990s and Meadow Creek escapements reflected this decline.

Main lake kokanee stocks began to decline in the mid 1980s (Andrusak 1987, MS; Ashley et al. 1997). North and South Arm kokanee stocks decreased with virtually no South Arm fish evident while North Arm stock escapements dropped from a range of 0.5-4.1 million in the 1960s and 1970s to 0.3-0.5 million in the late 1980s and early 1990s (Ashley et al. 1999). This decline led researchers to consider means of reversing this trend, especially since the highly valued Gerrard rainbow trout are dependent upon kokanee as their primary food source (Andrusak and Parkinson 1984).

Faced with the prospect of a complete collapse of kokanee that inhabit the main portion of Kootenay Lake, fisheries managers in 1990 conducted a series of meetings amongst fisheries researchers and managers to consider what, if anything, could be done to reverse the downward trend. Korman et al. (1990) describes various alternatives that were contemplated. A Kootenay Lake fertilization response model (Walters et al. 1991) was developed to understand what would happen if the lake was fertilized to pre-impoundment and pre-cultural enrichment levels. The model predicted that fertilization would not likely be successful as it was believed that the introduced *Mysis relicata* would respond more rapidly to increased food supply and out-compete the kokanee. However, fisheries management, faced with declining kokanee numbers and no other option, proceeded to initiate a five-year fertilization experiment commencing in 1992. The primary objective of the experiment was to restore the nutrient balance that had been changed as a result of the two upstream reservoirs (Larkin 1998; Ashley et al. *in:* Murphy and Munawar 1999). Results of this experiment have been analyzed in a series of technical reports (Ashley et al. 1999; Wright et al. 2002) and the response of North Arm kokanee to lake fertilization has been very positive. Kokanee escapements to the North Arm's Lardeau River and Meadow Creek systems have once again surpassed 1 million, comparable to escapement levels of the 1960s and 1970s (Ashley et al. 1999). As part of the experiment there was a deliberate reduction in fertilizer loading from 1997-2000 that resulted in a steep decline in the kokanee population. This decline prompted fisheries managers to increase the loading rate commencing in 2001.

Experimental fertilization of a portion of the North Arm of Kootenay Lake has now been underway for over a decade with the most recent results reported by Wright et al. (2002). This report documents results of the North Arm kokanee response to 12 years (1992-2003) of lake fertilization, with emphasis on kokanee responses to different fertilizer loadings. The specific objectives of this report are:

1. To summarize and analyze 2002 and 2003 hydroacoustic, trawl and North Arm kokanee escapement data for kokanee.

2. To demonstrate the apparent response of kokanee and Gerrard rainbow trout to various levels of experimental fertilization since 1992.

Methods

North Arm Kokanee Escapement Estimates

Kokanee spawners have been enumerated annually using a permanent fish fence located at the lower end of the Meadow Creek channel. At the peak of spawner migration visual estimates are also made of kokanee numbers in Meadow Creek downstream of the channel. Any fish permitted to move upstream of the channel are also enumerated at a permanent fence located at the top end of the channel. Kokanee are sampled each year for length, age, sex ratio, and fecundity. Annual estimates of egg deposition are made and fry out-migration from the channel is monitored each spring. Redfish Consulting Ltd. (1999) summarized the spawning channel methods and data from 1966 to 1998 as part an evaluation of the performance of this channel.

Methods used to conduct visual estimates of kokanee in lower Meadow Creek, Lardeau River, and Arrow Lakes Reservoir tributaries are described by Sebastian et al. (2000) and Redfish Consulting Ltd. (1999). The Lardeau River is flown each year at the peak of spawning activity and a single escapement estimate is made supported by several days of visual ground truthing estimates. The peak of spawning is reasonably well known based on the daily count information of nearby Meadow Creek. Lardeau River estimates provide a data set for time series trend analysis but are not accurate enough to provide information for population estimates. Although the escapement methods are standardized, there are several sources of error with the most obvious being visibility (weather conditions), large braided river sections that are difficult to assess and determination of actual peak spawning date. An analysis of various methods used for determining spawner escapement for Nechako River chinook salmon was discussed by Hill and Irvine (2001), who emphasized the need to standardize methods and suggested the preferred method of area-under-the curve (AUC) be used for assessment. Recently, Parken et al. (2003) analyzed the uncertainties associated with AUC methodology and requisite sample size for estimating Nicola River chinook salmon but the required number of replicate counts is cost prohibitive for a system such as the Lardeau River. The Lardeau River estimate is a single peak count that is only intended to provide an order of magnitude estimate useful for understanding population trends.

Rainbow Spawner Counts

Daily counts have been conducted on rainbow spawning grounds at Gerrard near the outlet of Trout Lake throughout the spawning periods since 1957. The total annual run-size is estimated by expanding the peak daily count by a factor of three (Irvine 1978). Recently, Hagen and Baxter (2002, draft report) used the AUC method to estimate the annual total number of Gerrard rainbow trout and they concluded that the expansion factor of 3 was appropriate but more data was required on residence time.

Hydro Acoustics and Trawl Sampling

Complete nighttime hydroacoustic surveys of the limnetic habitat at 18 stations throughout the main portion of Kootenay Lake were conducted mid September 2002 and mid October 2003, concurrent with the annual trawl survey. Limnetic habitat for kokanee surveys is defined as habitat where water depth is greater than 20 meters depth at the time of survey. All surveys were conducted using standard methods outlined in Sebastian et al. (1995a) using a Simrad model EY200P operating at 70 kHz. The transducer was towed on a planer alongside the boat at a depth of 1.5 m and data was collected continuously along survey lines at 1-2 pings s^{-1} while cruising at 2 m s^{-1}. False bottom echoes necessitated a slower ping rate (0.5-1.0 pings s^{-1}) for some South Arm transects. The data was converted to digital format stored on a PC computer and backed-up on Sony Digital Audio Tape (DAT). Navigation was by radar and 1:40,000 Canadian Hydrographic Service chart. The Simrad system was calibrated at the Woodbury Marina dock at the beginning of each survey. Field calibrations were conducted by collecting target strength data from a copper sphere suspended in the center of the echo sounder beam at 15-20 m from the transducer. The received signal level was adjusted to -39.1 dB, which corresponds to the known strength of the sphere at 70 kHz. Details on data conversions and processing can be found in Sebastian et al. (2002).

Fork lengths of trawl caught fish were converted to the same acoustic scale using Love's (1977) empirical relation and compared to acoustic size distributions in order to verify the most appropriate size cut-off to separate age 0+ from age 1-3+ kokanee. Since it was not possible to distinguish between age 1, 2, and 3 fish using acoustic data, the proportions of these age groups could only be based on trawl catches.

Kokanee were sampled by trawl net in mid September 2002 and mid October 2003 during the new moon, when the fish were least able to avoid the sampling gear. Trawling for kokanee began one half hour after dusk with a standard 5 m X 5 m net (mesh size ranged from 0.6 cm to 10 cm) towed at a speed of 0.9 $m \cdot s^{-1}$. A depth sounder was used to determine efficient trawling depths. Three 40 minute hauls were made at each of Stations 1, 2, 4, 5, 6, and 7. If more than 75 fish/trawl were obtained, the number of trawls was reduced. Oblique hauls were made by towing the net for 8 minutes at each 5 m depth stratum, from 40 m to 20 m. The top of the net was at 40 m at the start of the trawl, so the actual depth range sampled was 20 m to 45 m. A sample area of 0.216 ha was covered by each haul. The survey design and sampling techniques were consistent with the kokanee stock monitoring that has been conducted annually on Kootenay Lake since 1989. A more detailed description of trawl and hydro acoustics methods can be found in Sebastian et al. (2002a, b) and Thompson (1999). Trawl data was used to monitor annual variation in kokanee density and length-at-age.

Trawl captured fish were kept on ice until processed the following morning. The species, fork length, weight, scale code, and stage-of-maturity were recorded. The trawl surveys provide species verification for the acoustic survey, an index of kokanee abundance, age structure, and size-at-age. Using length correction factors suggested by Sebastian et al. (1995b), kokanee lengths were adjusted to an October 1st standard enabling growth comparisons with previous fall surveys.

Results

2002 and 2003 Kokanee Escapements

Estimated kokanee escapement in 2002 to Meadow Creek was 0.35 million, representing the third consecutive low(er) escapement level since 1992 when lake fertilization commenced and the lowest level since 1991. The past three years of lower numbers contrast with most escapements in the latter part of the 1990s that ranged from 0.5-1.1 million (Fig. 7.1). Despite the small escapement in 2002, the spawning channel was filled to capacity (≈300,000). In sharp contrast the 2003 Meadow Creek numbers were nearly triple the 2002 numbers at close to 0.9 million spawners. This estimate represents the first sizeable increase in numbers in the last four years but still was less than the parent year (1999) of ≈1.2 million.

The 2002 Lardeau River escapement was estimated at ~0.11 million, an order of magnitude less than the parent year (1998) when a peak count was estimated at about 1.1 million (Fig. 7.2). The 2003 escapement was also low at ≈0.20 million, considerably less than the parent year of ≈0.5 million.

Kokanee returning to South Arm tributaries were again very few in numbers with most streams having fewer than 100 fish in both 2002 and 2003 (Andrusak et al. 2004a).

Spawner Size and Fecundity

Mean size of female kokanee returning to Meadow Creek in 2002 was slightly higher (23.3 cm) than the 37 year average of 22.2 cm (Fig. 7.3). For the first time since 1997 the mean size of females decreased as did fecundity, decreasing from 348 eggs in 2001 to 295 in 2002. The fecundity in 2002 was still somewhat higher than the 37 year average of 260 (Fig. 7.3). Mean size of 2003 kokanee was slightly lower than the 37 year average (males 21.5 cm, females 21.4 cm). Mean fecundity in 2003 was much lower (208), similar to the levels recorded in the mid 1980s and late 1990s and well below the 37 year average (Fig. 7.3).

The larger fish size and higher egg counts (Fig. 7.3) recorded from 1992-1996 reflects initial high growth experienced by North Arm kokanee during the first four years of lake fertilization. The lower fecundities recorded from 1996-1999 suggest a density response due to large numbers of fish produced by the 1992-1996 cohorts. Increased fecundity and fish length observed in 2000 and 2001 follows the decrease in the total kokanee abundance (shown by acoustics results) and is presumed to be in response to reduced fertilizer loading from 1997-2000. Decreased mean size and fecundity in 2002 and again in 2003 likely signals a density growth response as the whole lake population rebuilds following increased fertilization that began in 2001. As the kokanee population rebuilds towards lake carrying capacity it is predicted that fecundity and fish length will decline and stabilize close to the long-term average.

Meadow Creek Kokanee Fry Production

Kokanee fry production from Meadow Creek in the spring of 2002 was ~23 million with 94% produced in the spawning channel (Fig. 7.4). The total estimate includes production above and below the channel using an assumed 5% egg-to-fry survival rate. The estimated 2002 fry out-migration of nearly 23 million was the second highest in 27 years of records and nearly twice the average of ~11.9 million. The highest fry production on record occurred during year 3 of the fertilization as a result of high fecundity and record high fry production (Fig. 7.4). The 2003 fry production estimate was slightly lower than the 2002 with some 17.9 million produced from the channel and a total of 18.3 million fry from the whole system. Considering the age of this channel, production is excellent. Higher levels of fry production from the channel in the last decade reflect improved channel performance due to channel renovations and higher egg deposition resulting from increased escapement levels (Redfish Consulting Ltd. 1999). There appears to be an optimum spawner/fry density relationship that was not evident from earlier analyses (Redfish Consulting Ltd., 1999). High fry production estimates during the last decade suggests that number of spawners in the channel should be >300,000, possibly as high as 350,000 (Fig. 7.5).

Hydro Acoustic Abundance Estimates

Total kokanee abundance estimates for the main lake portion of Kootenay Lake have been standardized since 1991 and comparable manual echo counts go back to 1985. Throughout the late 1980s and early 1990s the total numbers were low, not exceeding 15 million (Fig. 7.6). Within two years of fertilization there was a sizeable increase in total numbers that surpassed 35 million by 1994 (Fig. 7.7). This increase was mainly due to rapid growth at the onset of fertilization (i.e., a classic density growth response to favorable in-lake conditions) which resulted in a peak of both fecundity and total egg deposition in 1993 (Fig. 7.3). The large majority of the increase in 1994 was observed in age 0+ fish although age 1-3+ fish had also began to increase. Fry production remained high for three consecutive years (i.e., 1994-1996) which led to increased numbers of age 1-3+ fish two years following (i.e., 1996-1998) (Fig. 7.7). The higher densities of age 1-3+ fish correlate with a three year period of low growth and fecundity suggesting that a combination of increased competition from age 1-3 fish and a decrease in fertilization led to smaller adults and reduced fry production (Figs. 7.3, 7.4, 7.7). The reduced numbers of fry during 1997-2000 was followed by reduced numbers of age 1-3+ fish again with a two year lag time. Similar to 1992-1995, the relatively low numbers of age 1-3 fish in 1999-2001 were concurrent with a period of rapid growth and increase in spawner size and fecundity (Figs. 7.3, 7.7). Increased (juvenile) abundance estimates from 2001-2003 ranging from ≈24-35 million are most likely due to the combined result of increased fry production and improved rearing conditions from increased fertilizer loadings that began in 2001. The upward swing in abundance of ages 1-3 in 2002 and 2003 is most encouraging and this trend foreshadows much larger escapements, as evidenced by Meadow Creek escapement numbers rising sharply in 2003 (Fig. 7.1). Based on this trend it also suggests a likelihood that growth, fecundity and fry production should all decline shortly in response to higher levels of age 1-3+ abundance and competition.

Prior to fertilization, kokanee appeared to be in greater abundance in the South Arm of Kootenay Lake. However, shortly after fertilization commenced, abundance of kokanee in the North Arm increased relative to the South Arm to the point where contributions were more similar (Figs. 7.8, 7.9). Since North and South Arm areas are different in size it is more appropriate to compare densities than absolute numbers of fish. Prior to fertilization, late summer densities were higher in the South Arm five out of six years. In the 12 years of fertilization, densities were either similar or higher in the North Arm, except for three years, 2000, 2002, and 2003 (Fig. 7.9). Reasons for the recent apparent shift back to the South Arm having higher production may be related to other factors such as relative contribution of natural nutrient inputs during extremely dry years. Also not considered in the analyses is variable kokanee recruitment to the South Arm from entrainment at the Libby Dam with unknown numbers moving downstream into Kootenay Lake to rear. When mature, these fish migrate up the Kootenay River as far as the natural barrier located near Libby, Montana (S. Ireland, Director of Fish and Wildlife, Kootenai Tribe of Idaho, Bonners Ferry, Idaho, pers. comm.). In some years, escapements have been >100,000 and a snag fishery has been permitted in the Montana portion of the river. Additional hydroacoustics work in early summer may shed some light on the origin of the kokanee found in the South Arm.

Length-At-Age

Mean lengths of the 2002 kokanee trawl samples were: age 0+ 54.0 mm, age 1+ 140 mm, and age 2+ 188 mm while in 2003 they were 57, 137, 188 mm respectively. The trend(s) in kokanee size-at-age data (Fig. 7.10) reflect initial fertilization (1992-1996), decrease in loading (1997-2000) and subsequent increased loading (2001-2003). The mean sizes increased in response to initial fertilization due to low total numbers in the lake, then declined as age 1-3+ numbers increased to peak abundance (1995-1996), and then increased again when fertilizer loadings were decreased (1997-2000). Ashley et al. (1997) initially pointed out that growth of fry and 1+ fish has not appreciably changed since the fertilization experiment began. This remains the case for fry, however from 1999-2001 age 1 growth was lower until 2002 and 2003 when the mean size returned close to that recorded prior to 1999. Taking into account a time lag of 2-3 years, density dependent growth is most evident in ages 2+ and 3+ reflecting the fertilizer loading rates. Growth rates for the older age fish (3+) increased in concert with the fertilization program for the spawner years 1991-1993 (Figs. 7.3, 7.10), but then declined during 1994-1997, most likely reflecting intraspecific competition as total whole lake abundance of age 1-3+ fish increased (Fig. 7.3, 7.7, respectively). The size-of-age 3+ fish for year classes 1999 and 2000 increased probably because of low total lake densities of age 1-3+ fish during this period (Fig. 7.7). With total abundance of age 1-3+ fish once again exceeding about 7-8 million since 2000, size-at-maturity is expected to decrease following above-average mean sizes for the last three years. As the total lake population returns to numbers >25 million the size of the age 3+ fish will most likely decline to just over 20 cm similar to that recorded for the 1993-1996 year classes (Fig. 7.10).

Age-At-Maturity

Vernon (1957) reported that virtually 100% of North Arm kokanee matured at age 3+. Martin (1984) reaffirmed that most North Arm kokanee spawn at age 3+. Thompson (1999) observed a shift in age-at-maturity of Meadow Creek fish from 1993 to 1996. Although Thompson (1999) found the dominant age-at-maturity remained age 3+ from 1989-1992, a higher percentage (ranging from 15-42%) of 2+ fish were evident from 1993-1996, as well as a greater contribution of 4+ fish. These results are not surprising given the radical changes to lake productivity that were occurring during the time these cohorts were growing in Kootenay Lake. As growth slowed due to the unproductive state of the lake in the late 1980s, some delay in maturation might be expected. The accelerated growth noted by Thompson (1999) in the early 1990s was likely due to a combination of low kokanee densities and lake fertilization that probably resulted in some fish maturing early. The same growth response and shift in age-at-maturity was noted in Upper Arrow Reservoir kokanee soon after the fertilization operation began in 1999 (Pieters et al. 2000).

Although age analysis has not been conducted on recent spawners from Meadow Creek, a return to a dominant age of 3+ at maturity would be expected due to the higher densities of kokanee in the lake and greater competition for food. The length-frequency distribution of kokanee captured by trawl in 2002 display obvious modes for ages 0+, 1+ and 2+ fish (Fig. 7.11). These fish were aged by scale analysis. The frequency distribution of a large sample (n=628) of 2002 Meadow Creek spawners has been superimposed on the frequency distribution of the 2002 trawl caught fish to illustrate that four age groups comprise the majority of kokanee in Kootenay Lake. Based on the size-at-age data (Fig. 10) and the length-frequency graph (Fig. 7.11), the majority of kokanee that spawned in Meadow Creek in 2002 were age 3+. The 2003 data (Fig. 7.10) also suggests age 3+ at maturity.

Fry-to-Adult Survival Rates

To better understand the impact of lake fertilization on kokanee an attempt has been made to compare their apparent survival in the lake. Fry-to-adult survival rates were estimated using long-term data available from Meadow Creek. While there are clearly some limitations on the accuracy of the data (especially fry estimates) the data has been collected in a consistent fashion using the same methods over a long period of time. Assumptions made in determining survival rates include:

- one dominant age at spawning (i.e., age 3+);
- minimal harvest that does not appreciably influence escapement levels; and
- natural stream egg-to-fry fry production of 5-10% used for fry estimates above and below the Meadow Creek spawning channel.

Based on the analysis of kokanee lengths obtained from recent trawl data and Meadow Creek spawners (Figs. 7.10, 7.11), it is fairly evident that the dominant age-at-maturity in 2002 and 2003 was age 3+ and, therefore, the 2002 and 2003 fry-to-adult survival rates have been calculated on the basis of age 3+ at time of spawning.

Meadow Creek fry-to-adult survival rates were quite high during the early 1970s (Fig. 7.12), especially when compared to Okanagan Lake and Arrow Lakes Reservoir for that same time period (Andrusak et al. 2004b). These cohorts would have grown in Kootenay Lake when nutrient levels were highly elevated as a result of phosphorus being released into Kootenay Lake from Cominco's fertilizer plant (Daley et al. 1981). The Duncan Dam became operational in 1967, blocked very large numbers of spawning kokanee (>1 million) resulting in very limited spawning success. During the late 1960s and early 1970s the lake would have been relatively productive, but likely received only one half the normal numbers of kokanee due to the loss of Duncan River fry production. In addition, the Meadow Creek spawning channel did not produce large numbers of fry during initial years (late 1960s and 1970s) of operation (Fig. 7.4). No fry production estimates were made during most of the 1980s but low in-lake survival rates were likely in the late 1980s and early 1990s given declining escapements (Fig. 7.1) reflecting the period of reduced nutrient levels in the lake (Ashley et al. 1997).

Annual production of fry from Meadow Creek (Fig. 7.4) greatly increased from ≈4-10 million in the 1980s to 10-30 million in the 1990s as a result of a combination of improved spawning channel performance (data on file Nelson office MoE) and better growth and survival in the lake. At the onset of fertilization low in-lake densities led to better growth, a doubling of average fecundity and a peak in fry production of 28 million by 1993 (Fig. 7.3). Fry-to-adult survival increased from about 5% to nearly 10% by 1996 and then declined to just under 3% by 2002 (Fig. 7.12). As the number of spawners peaked, spawner size, fecundity, fry production, and fry-to-adult survival rates all declined indicating a strong density dependent response. This response was most likely heightened by a concurrent reduction in fertilization rates from 1997-2000 and led to a very rapid decline in population abundance to 2000 (Figs 7.6, 7.7). By resuming full fertilization during 2001-2003, the population rapidly rebuilt through increased fecundity, fry production and growth.

The decrease in fry-to-adult survival rates in the late 1990s compared to the mid 1990s would be expected as a result of higher kokanee densities and greater competition for food. The very low survival rates recorded in the last four years (2000-2003) mirrors the combination of density dependent growth and reduction in lake productivity due to decreased fertilizer loading from 1997-2000. With the lake once again at near record levels of kokanee abundance it is predicted that survival rates will remain low in the lake but kokanee abundance relatively high, provided fertilization continues.

Recruit-Spawner Relationship

A generalized stock-recruitment relationship can be generated from the Meadow Creek spawning channel data, based on 11 cycles of relatively consistent enumeration. This analysis assumes dominant age of spawners was 3+ and that the sport catch has been minimal. Over the last three decades when data is available, there have been four distinct productivity events described by Northcote (1973), Daley et al. (1981) and Ashley et al. *in:* Murphy and Munawar 1999). These events are illustrated quite well by analyzing the North Arm kokanee recruit-spawner relationships (Fig. 7.13). Through most of the 1970s replacement levels were achieved when the lake was in a highly productive state but the spawning channel was producing fairly low numbers of fry. During this period all of these cycles replaced themselves. Towards the end of the 1970s and persisting through to the early 1990s was a period when replacement levels were not attained probably for two very different reasons. Firstly, lake productivity began to decline by the late 1970s (Daley et al. 1981) largely due to the negative impacts of the Duncan and Libby dams (Larkin 1998). Secondly, spawning channel production was increasing so in-lake competition kept fish size and fecundity below average (Fig. 7.4), i.e., increased kokanee production at a time of declining productivity.

The third productivity event occurred during most of the 1990s when replacement was easily accomplished for two consecutive cycles (1992-1999) as kokanee numbers greatly increased. Each cohort virtually doubled in number (Figs. 7.7, 7.13) coinciding with lake fertilization.

The fourth productivity phase, already taken place during the early 2000s, is expected to be of short duration. Very low replacement levels were recorded from 2000-2003 at Meadow Creek with the decline coinciding with the deliberate reduction of fertilizer loading that started in 1997 (Fig. 7.6). The recruit:spawner ratios for Meadow Creek from 2000-2002 were the lowest recorded since 1989 with the 2002 return the lowest of record. The short-term reduction in the fertilizer loadings from 1997-2000 is the most likely explanation why these cycles did not replace themselves. The 1996-1999 year classes experienced lower lake productivity at some stages of their four years of growth in Kootenay Lake with the 1996-1998 cohorts impacted the most since the fry for these cycles entered the lake from 1997-1999 respectively, the time of lower fertilization levels. The result has been very low spawner numbers from 2000-2002. The in-lake abundance estimates (Figs. 7.8, 7.9) indicated that increased numbers of age 1+ fish were present by 2001 once the fertilizer loading was again increased and that some improvement could be expected in spawner numbers by as early as 2003. It was expected that the 2000 cohort would replace itself since they had grown in the lake with fertilization again at the initial loading rate. Although there was improvement with the 2000-2003 cycle, replacement was not achieved. The abundance estimates do suggest that escapements should greatly increase in 2004.

Lardeau River escapements for years when data is available (data on file, Ministry of Environment, Fisheries Branch, Nelson, BC) also suggest kokanee numbers increased throughout most of the 1990s. Seven of the last nine cycles (1994-2002) have exceeded replacement levels but in the last three years replacement levels have not been achieved similar to Meadow Creek (Fig. 7.12). It should be noted that the 1996-2000 Lardeau River cycle exceeded replacement level, while the same Meadow Creek cycle did not. The Lardeau River estimate is a single count, and is therefore, subject to many sources of error. The most likely explanation for this anomaly is that the escapement numbers were overestimated in 1996 resulting in a >1 replacement level. Meadow Creek data is based on daily counts made throughout the spawning period, and is therefore, a much more reliable indicator of the status of the lake's kokanee population.

Lake Fertilization and Status of Gerrard Rainbow Trout

The 2002 escapement of Gerrard rainbow trout peaked at 222 while the 2003 run topped just over 300 (Fig. 7.14). The 2002 count represents the lowest count since 1992 and considerably below the 47 year average of 288. The original premise of Kootenay Lake fertilization was that increasing the forage base for Gerrard rainbow trout (and other piscivores) would ensure their long-term sustainability. In retrospect, increased kokanee abundance due to lake fertilization through most of the 1990s appears to have met the original objective of experimental fertilization, i.e., kokanee numbers increased and coincidentally the downward trend of Gerrard rainbow trout reflected in escapements of the early 1990s was reversed (Fig. 7.12). A steady Increase in escapements occurred until 1999 with a concomitant improvement in rainbow trout fishing through the mid 1990s that peaked in 1997-1998 (Redfish Consulting Ltd. 2003).

Decline in kokanee abundance in the late 1990s (Figs.7.1, 7.2, 7.6, 7.7) most likely due to reduced fertilizer loading may have impacted the Gerrard rainbow trout population with the 2001-2002 escapements below the long-term average. However, the intensive fishery for

Gerrards confounds analysis of the Gerrard rainbow trout population relative to kokanee abundance. There seems to be a good relationship between annual Gerrard rainbow trout escapements and sport fish catch data that suggests trout numbers have increased since the fertilization experiment began (Redfish Consulting Ltd. 2003). Catch of smaller sized rainbow trout (2-5 kg) began to increase 1-2 years after fertilization even though fishing pressure was fairly constant (or in slight decline) during the early 1990s. As these younger year classes moved through the fishery over time, angler success rates (measured as catch per hour) and catches of large (5-7 kg) trout increased. The current downward trend in the fishery was initially reflected in catch rates of smaller trout that fell in 1998. This decline continued with poor catches of larger trout beginning in 2000 and carrying through 2002. However, there was a slight improvement in 2002 and again in 2003 in catch rates of younger trout (data on file MoE Nelson office) and this may be a signal that the trout population is again responding to increased kokanee numbers.

Discussion

A recent downward trend in kokanee escapements to Meadow Creek continued in 2002 with the lowest number (≈354,000) estimated since 1991. However, in 2003 escapements to Meadow Creek increased and the 2002 and 2003 in-lake abundance estimates indicate a reversal has occurred with very high densities recorded for all age groups (Figs. 7.6- 7.9). Escapements for the three year period (2000-2002) were well below those recorded in the mid 1990s (Fig. 7.1), and the explanation for this major decrease is believed linked to the reduced lake fertilization loadings from 1997-2000. The 1996-1998 fry were the first cohorts to experience reduction in lake productivity due to decreased fertilizer loadings initiated in 1997. The in-lake survival rates for these three cohorts declined as indicated by the 2000-2002 return years (Figs. 7.8, 7.9, 7.12). As total in-lake numbers declined in the late 1990s (Fig. 7.6) growth again increased (Fig. 7.10) due to lower densities, (i.e., density growth response) and probably increased lake productivity (fertilizer loading increased from 2000 onward). By 2001, growth had improved (Figs. 7.8, 7.9; ages 0, and 1+) with total numbers (25-35 million) increasing to the levels recorded during the mid 1990s. As the whole lake kokanee numbers rebuild, growth and size-at-maturity beyond 2003 is expected to decrease similar to the pattern observed in the mid 1990s when North Arm productivity was relatively high.

Kokanee fry-to-adult survival rates for the 1996-1998 year classes were low (Fig. 7.12) and the Meadow Creek recruit:spawner ratios were also very low with replacement not achieved for these cycles (Fig. 7.13). The impact of nutrient reduction commencing in 1997 and continuing through 2000 should be most evident with the 1996-1999 cohorts. This appears to have been the case based on the adult survival estimates four years later (2000-2002). If lake fertilization positively influences kokanee survival as contended in the above analysis then increased fertilization loading back to the rates applied from 1992-1996 should result in improved in-lake survival for the 2000-2003 cohorts. The increase in 2003 escapements and in-lake abundance estimates lend support to this hypothesis. The trend data suggests that 2004 escapements will be high, possibly one million fish at Meadow Creek.

It is believed that the status of the Gerrard population is closely tied to the abundance of kokanee. The substantially increased numbers of kokanee observed throughout most of the

1990s appears to have resulted in very good rainbow trout fishing conditions and escapements (Fig. 7.14) in the latter part of the 1990s (Redfish Consulting Ltd. 2003). The decline in kokanee abundance from 1998-2000 (Fig. 7.6) appears to have negatively impacted the rainbow trout population as evidenced by a recent decline in Gerrard rainbow trout escapements and reduction in the catch of larger trout in the lake (Redfish Consulting Ltd. 2003). The 2001 and 2002 rainbow trout sport fisheries were very poor but some improvement was evident in 2003. It was speculated in 2001 (Redfish Consulting Ltd. 2002b) that if there was a correlation between angler success rates and fertilizer loading then success rates for smaller trout should increase by 2002. Increased numbers of smaller trout should be evident as a result of increasing the fertilizer loading and ultimately prey abundance. There was an increase in the success rates not only for the smallest sized trout but also for those in the 2-5 kg size category and in 2003 a slight increase in the 5-7 kg category (Redfish Consulting Ltd. 2003). There appears to be a time lag of about three years between increased kokanee abundance and increased rainbow trout abundance. The extent to which increasing predation pressure affects kokanee recovery has not been quantified although it is possible that larger numbers of Gerrards in the late 1990s contributed to the very rapid decline of kokanee during the period of reduced fertilization in 1997-2000.

The kokanee response to fertilization of a portion of Kootenay Lake has recently been duplicated on nearby Arrow Lakes Reservoir. Arrow Lakes Reservoir kokanee began to decline in the early 1990s and fell to very low numbers by 1996 (Pieters et al. 2000). Nutrient loss due to upstream impoundments is the primary cause of the kokanee decline on Arrow Lakes Reservoir (Pieters et al. 2000). However, fertilization of Upper Arrow basin began in 1999 and there has been a phenomenal kokanee response resulting in near record escapements from 2000-2003. Abundance of Arrow Lakes Reservoir kokanee has increased from about 3 million to nearly 12 million in 2003. Actual mechanisms involved in increased survival of kokanee in both Arrow Reservoir and Kootenay Lake has not been investigated but there is growing evidence that high lipid content in macrozooplanktors (e.g., daphnids) is critically important to juvenile kokanee survival (Rae and Ashley *in* Andrusak et al. 2004b; Steinhart and Wurtsbaugh 2003).

The initial increase in Kootenay Lake kokanee fry-to-adult survival rates from 1994-1996 was almost certainly due to the beneficial influence of lake fertilization that commenced in 1992, i.e., increased lake productivity including production of preferred zooplankton (*Daphnia sp.*) resulted in improved kokanee growth. At that time, the total lake kokanee abundance was low (Fig. 7.6). Cladocerans, with high lipid content, were available in higher densities and much later in the growing season under fertilized conditions as suggested by Wright et al. (2002). This would allow juvenile kokanee to enter the winter months at a relatively high maintenance level thus surviving at higher rates than pre-fertilization conditions. In support of this theory, Steinhart and Wurtsbaugh (2003) discuss the importance and critical nature of lipid content when they measured juvenile kokanee mortality during the winter months in Stanley Lake, Utah. Decline in Okanagan Lake kokanee survival rates is suspected to be due to poor quality phytoplankton (blue-greens) with low fatty acid content consumed by cladocerans that are in turn utilized by juvenile kokanee (Andrusak et al. 2004b).

The South Arm kokanee escapements remain at near extinction levels (Andrusak et al. 2004a) and this anomaly has been puzzling for some time, i.e., they should respond to the fertilization program in a similar manner to the North Arm stock. Recent discussions with Idaho Fish and Game personnel may have shed some light on why there has not been the expected response of South Arm kokanee. Apparently, hundreds of thousands of displaced kokanee from Libby Reservoir have been observed migrating upstream to spawn in the Kootenai River below the natural barrier downstream of Libby, Montana. These fish almost certainly reared in Kootenay Lake and probably represent a large portion of the whole lake totals shown in Figures 7.6 and 7.7. This strong “stock” of fish of Libby Reservoir origin and those from Meadow Creek and Lardeau River are all produced from productive spawning habitat compared to most of the other South and North Arm tributaries. It is speculated that the “weak” stocks do not fare well compared to the “strong” stocks in the lake where competition and predation is very high.

The wealth of information gathered on Kootenay Lake over the course of the fertilization experiment points to a highly successful program. Kokanee have once again reached near record numbers and mysid numbers have remained constant if not slightly lower (E. Schindler, Research Limnologist, MoE, Nelson, BC, pers. comm.).

Acknowledgements

Funding was provided by Columbia Basin Fish and Wildlife Compensation Program. Thanks to Kootenay Wildlife Services Ltd for conducting the trawl surveys.

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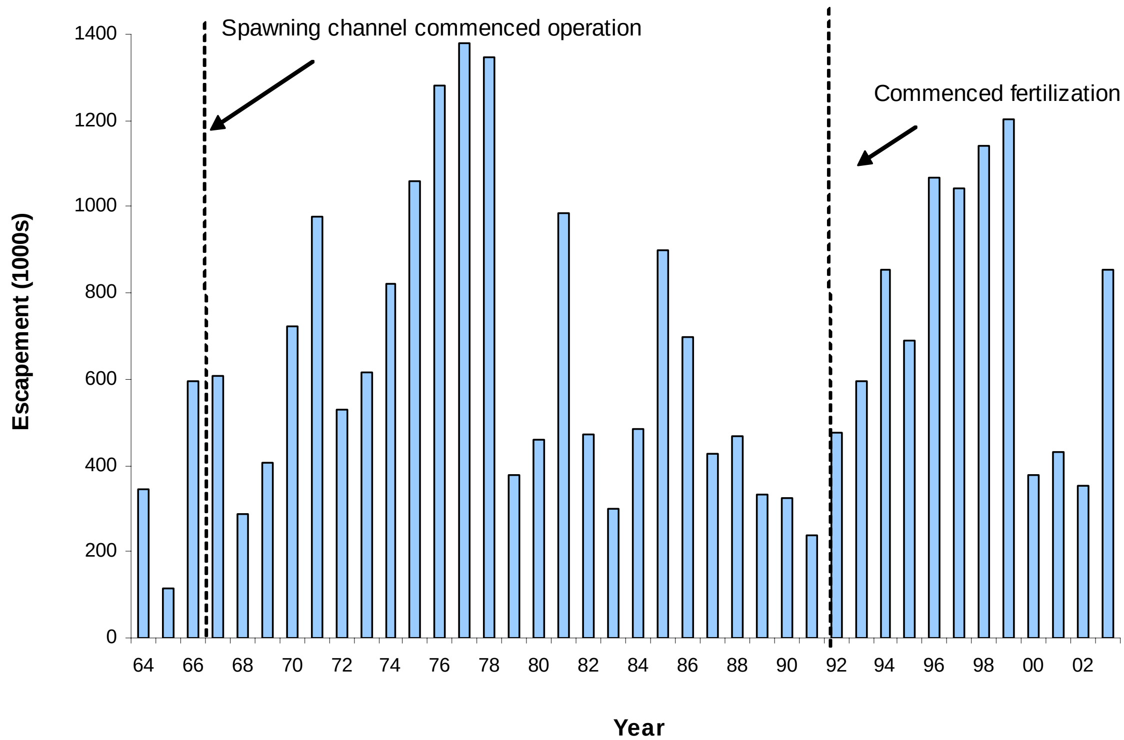

Figure 7.1. North Arm of Kootenay Lake kokanee escapements to Meadow Creek, 1967-2003. (Note: 1964-1968 data from Acara 1970 unpubl. MS).

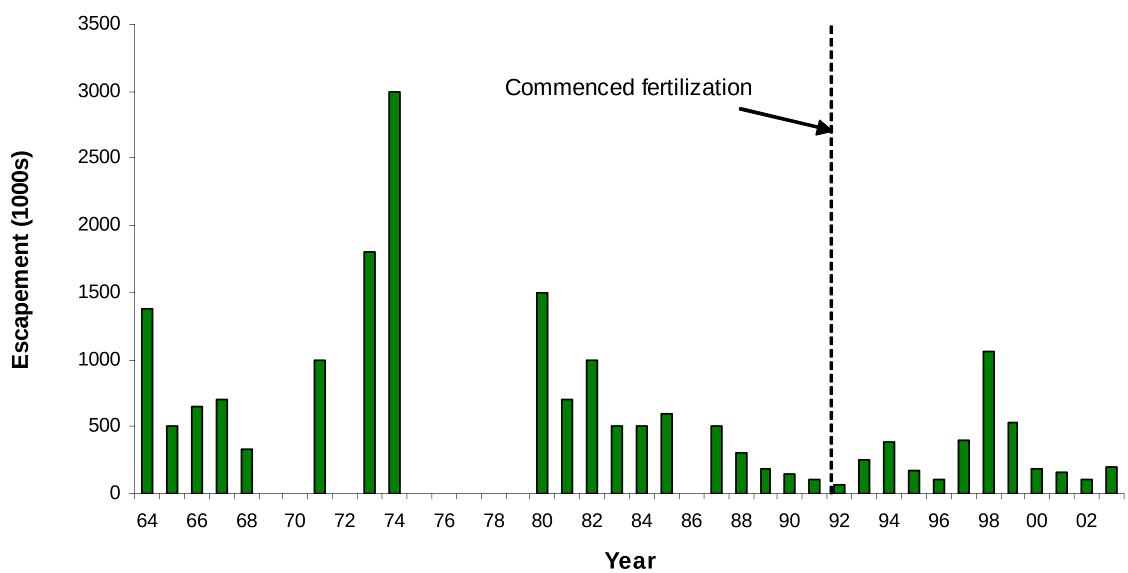

Figure 7.2. North Arm of Kootenay Lake kokanee escapements to Lardeau River, 1964-2003. (Note: 1964-1968 data from Acara 1970 unpubl. MS).

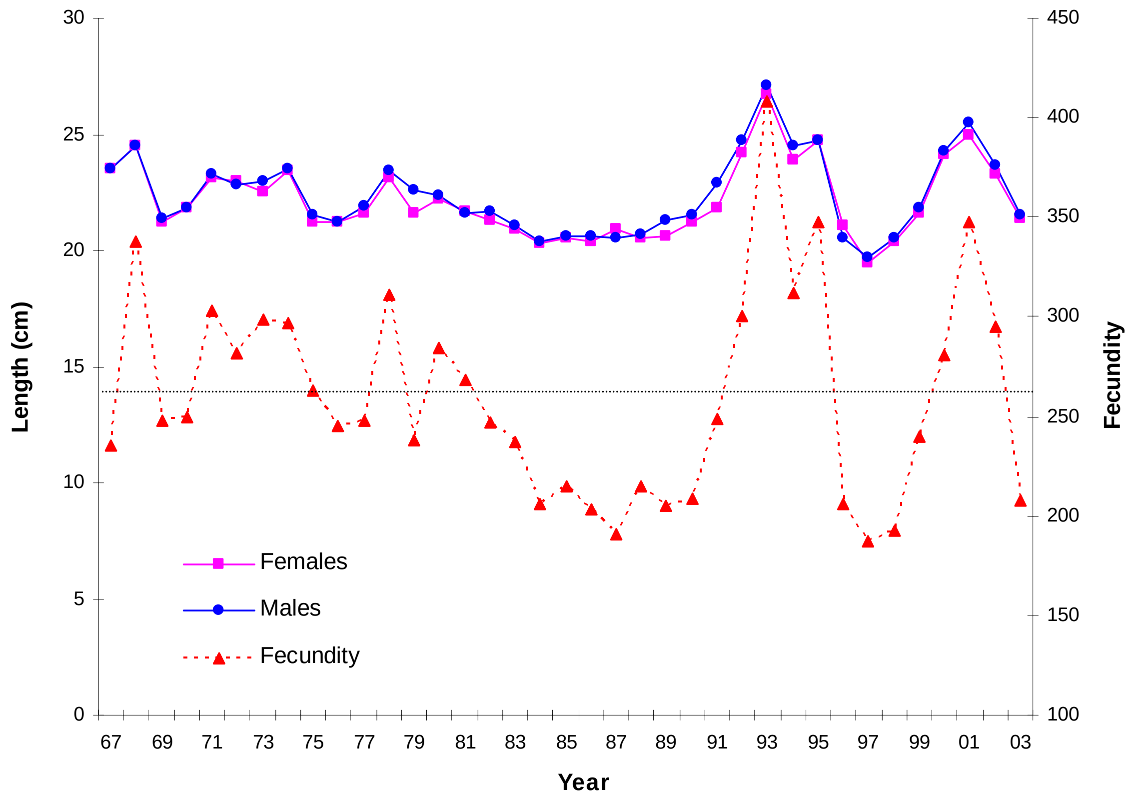

Figure 7.3. Mean length (cm) of Meadow Creek female and male kokanee spawners and fecundity, 1967-2003. Dotted horizontal line illustrates 37 year average fecundity of 260.

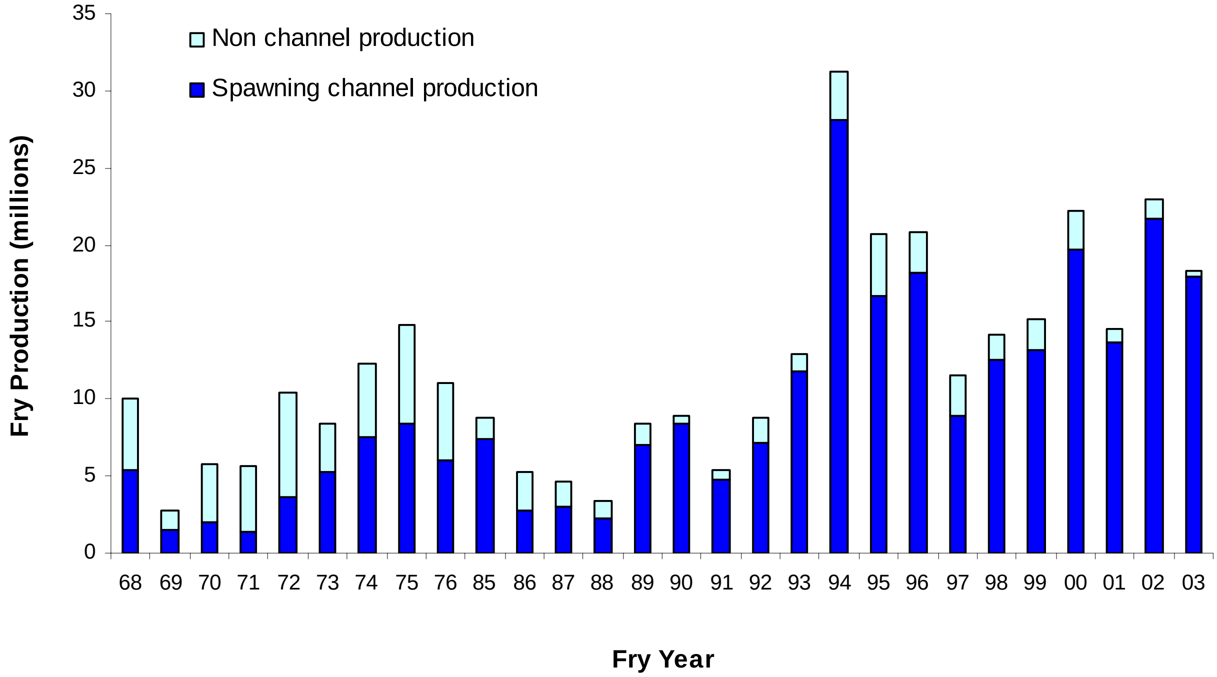

Figure 7.4. Kokanee fry production estimates from the Meadow Creek system and that portion from the spawning channel 1968-2003.

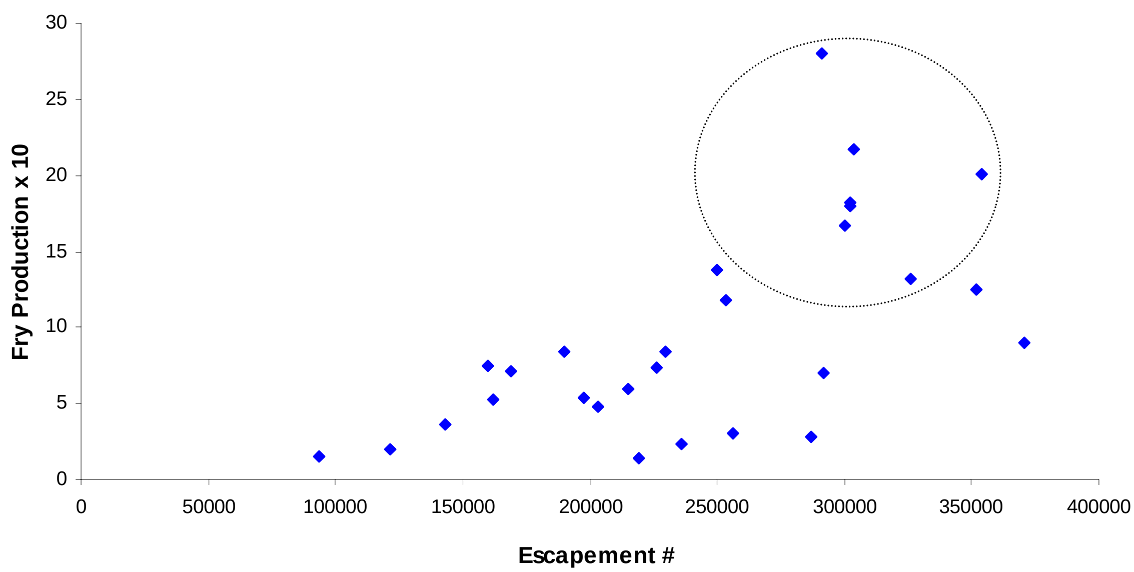

Figure 7.5. Scatter plot of fry production vs. number of spawners utilizing the Meadow Creek spawning channel. Dotted circle illustrates optimum number of spawners that produce maximum number of fry.

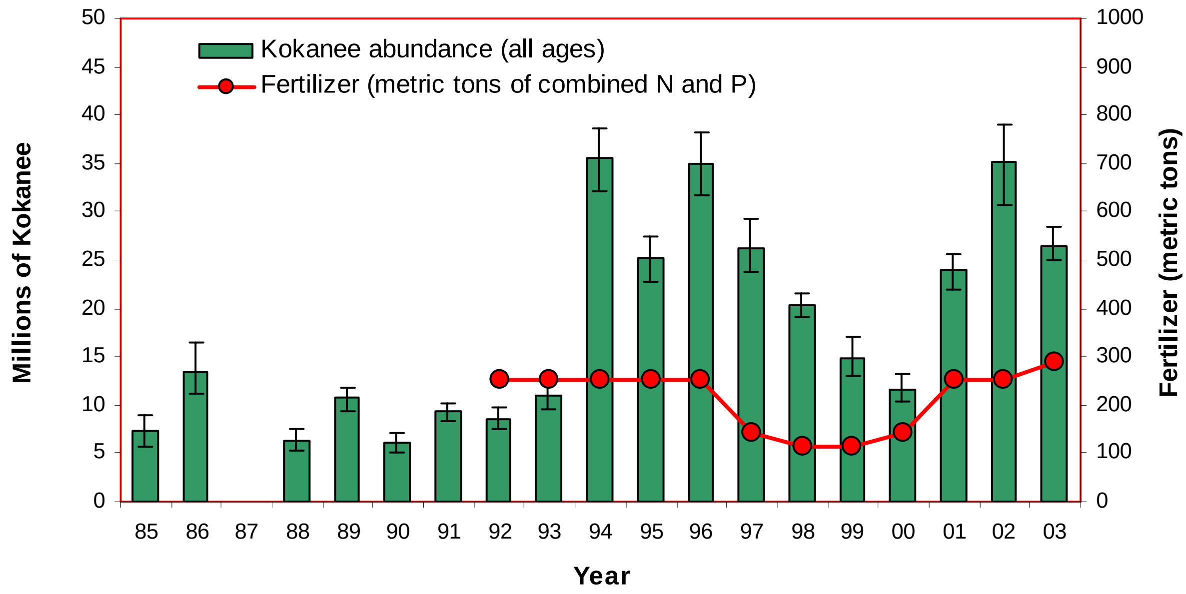

Figure 7.6. Total kokanee abundance estimates in Kootenay Lake based on fall acoustic surveys. Error bars denotes bounds at 95% confidence.

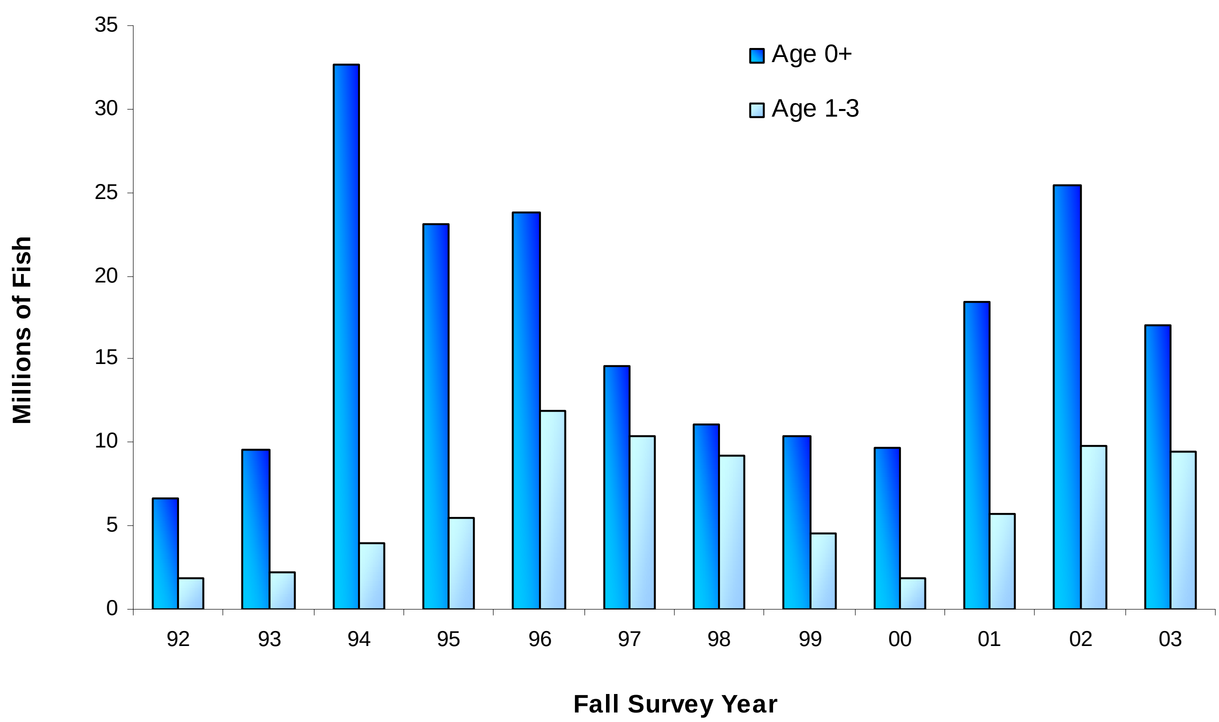

Figure 7.7. Trends in Kootenay Lake kokanee abundance by age groups, 1992-2003.

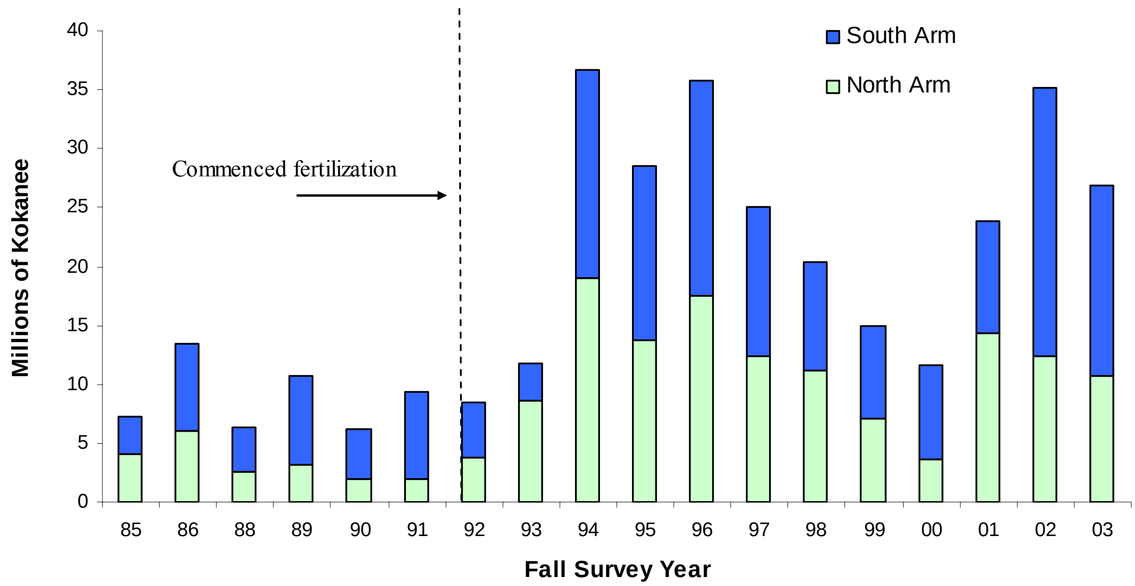

Figure 7.8. Comparison of kokanee abundance trends in North and South Arms of Kootenay Lake based on annual fall acoustic monitoring, 1985-2003.

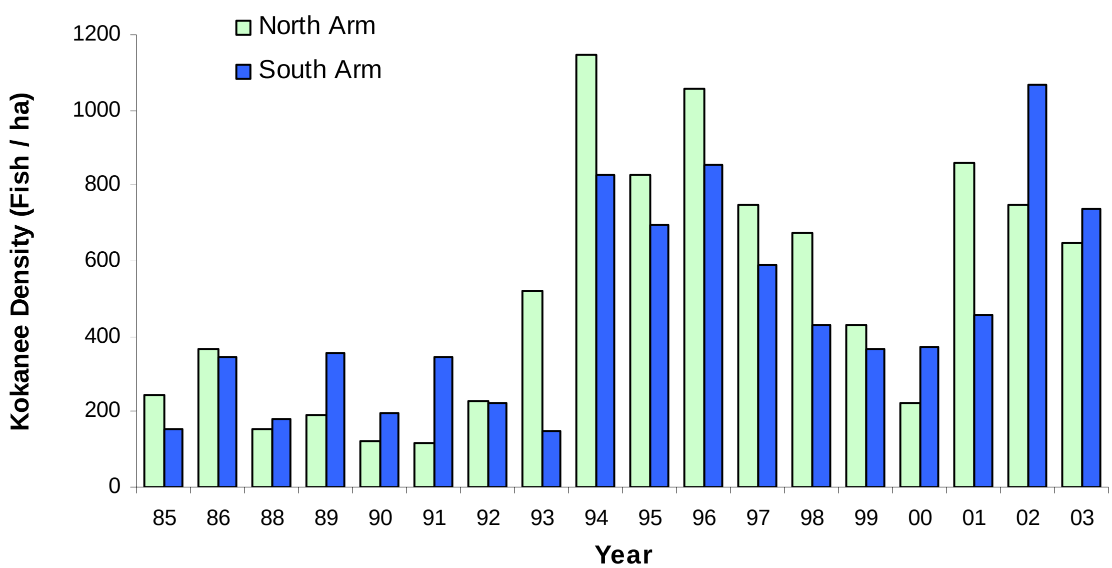

Figure 7.9. Comparison of kokanee density in North and South Arms of Kootenay Lake based on annual acoustic monitoring, 1985-2003.

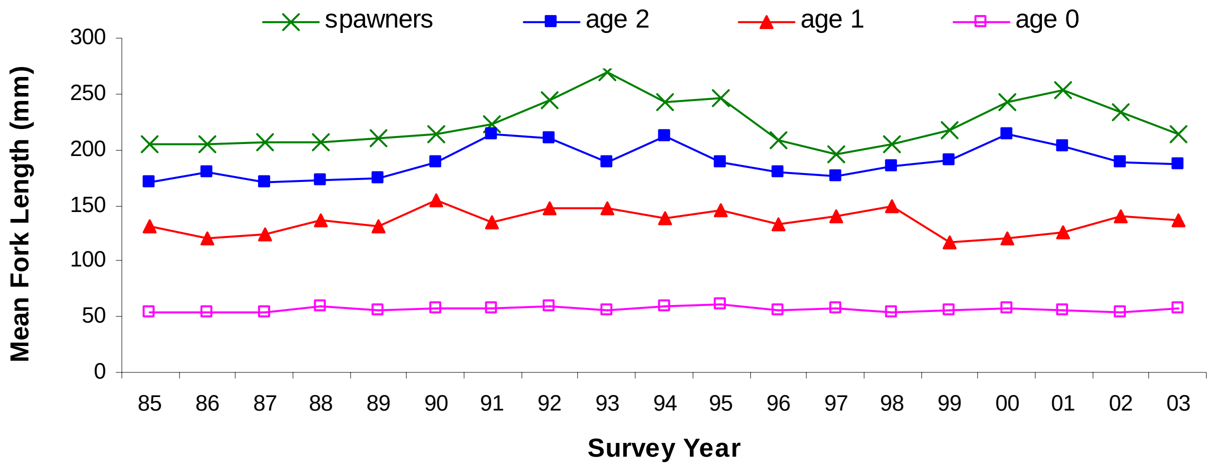

Figure 7.10. Mean size-at-age for kokanee in Kootenay Lake based on fall trawl surveys, 1985-2003. All sizes adjusted to October 1st.

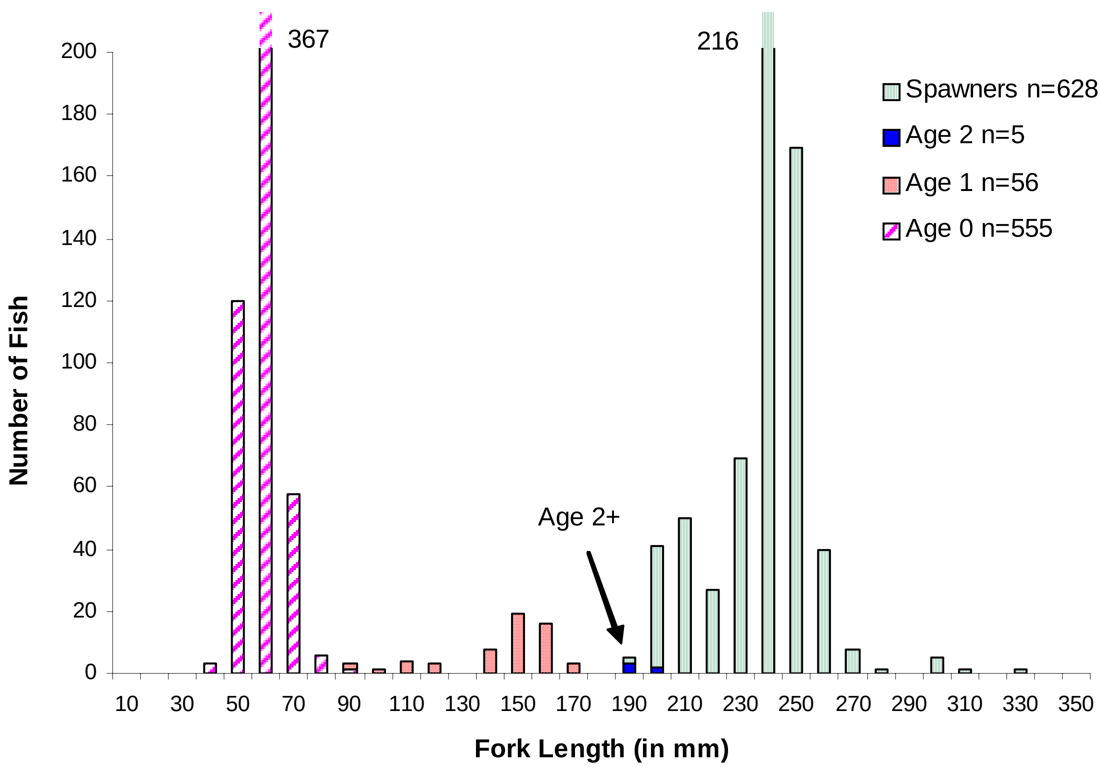

Figure 7.11. Length-frequency histograms for trawl caught kokanee (ages 0-2) from Kootenay Lake, September 8-10 2002. Length-frequency of Meadow Creek spawners (age 3+) superimposed to illustrate four age groups for this population.

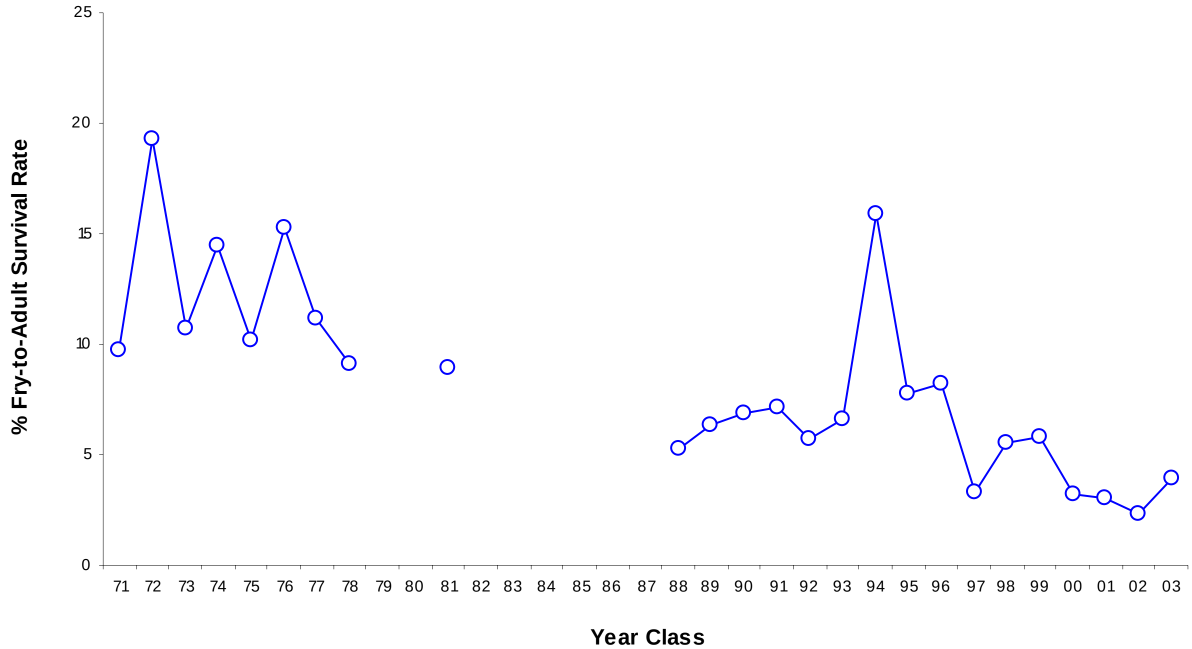

Figure 7.12. Estimated % fry-to-adult survival rate for Meadow Creek kokanee. Note fry production above and below channel have been factored in using available estimates of natural stream egg-to-fry survival rates (5-10%). This analysis assumes single age-at-maturity of 3+.

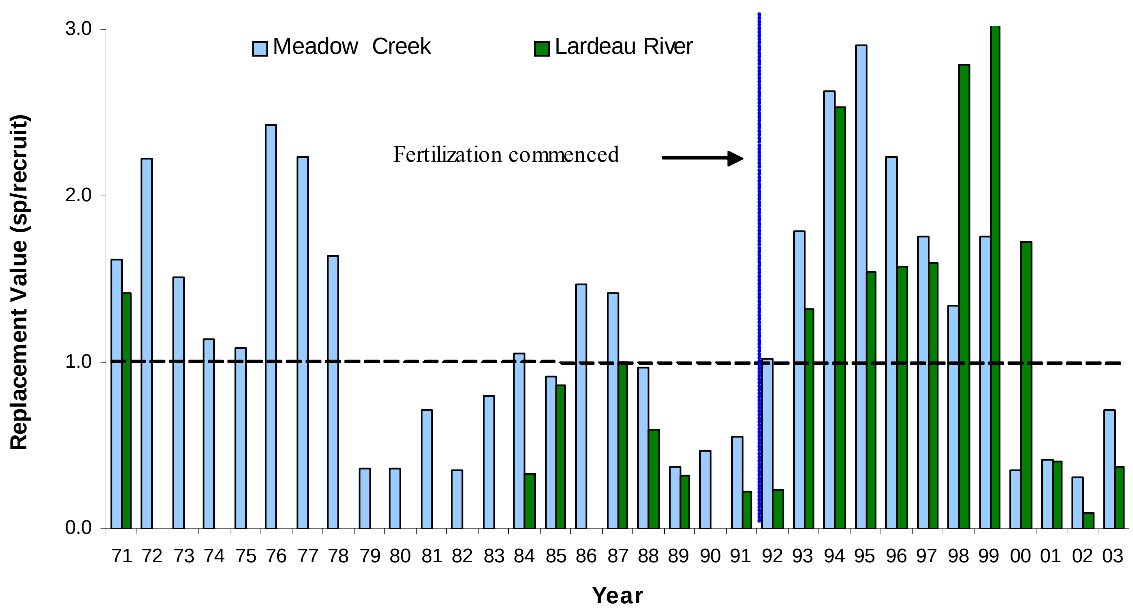

Figure 7.13. Recruit-spawner relationship for Meadow Creek kokanee (1971-2003) and Lardeau River (1990-2003). Line indicates replacement level of 1.0. This analysis assumes single dominant age of spawning at age 3+.

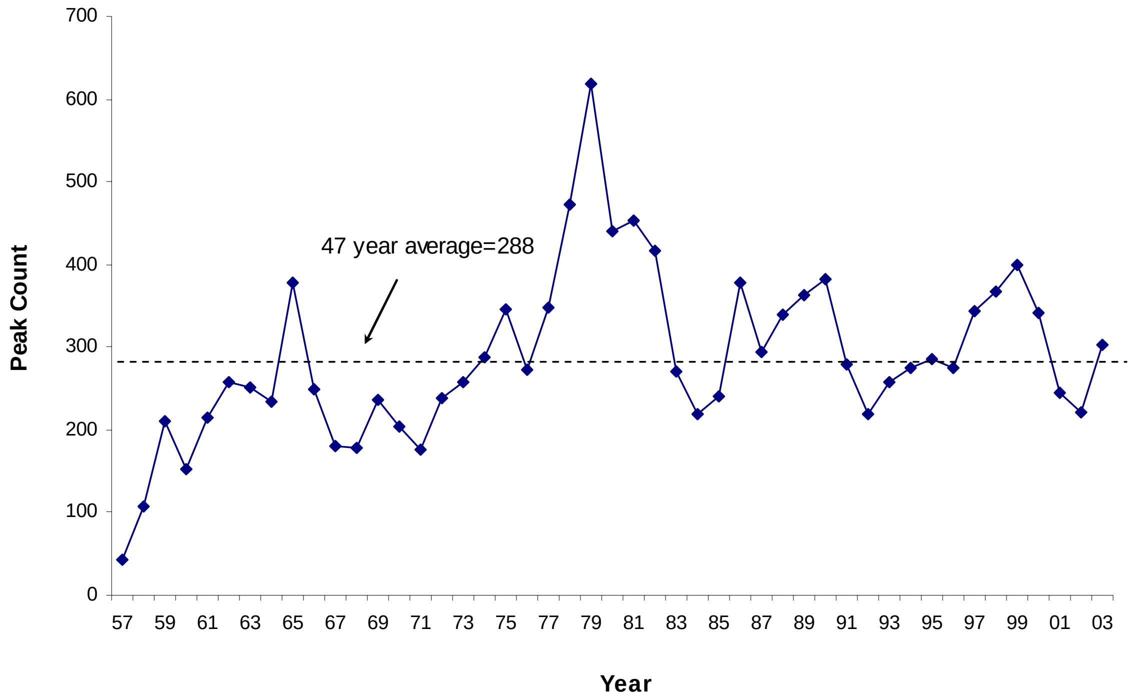

Figure 7.14. Annual escapement of Gerrard rainbow trout measured by the highest single day count (peak count), 1957-2003.