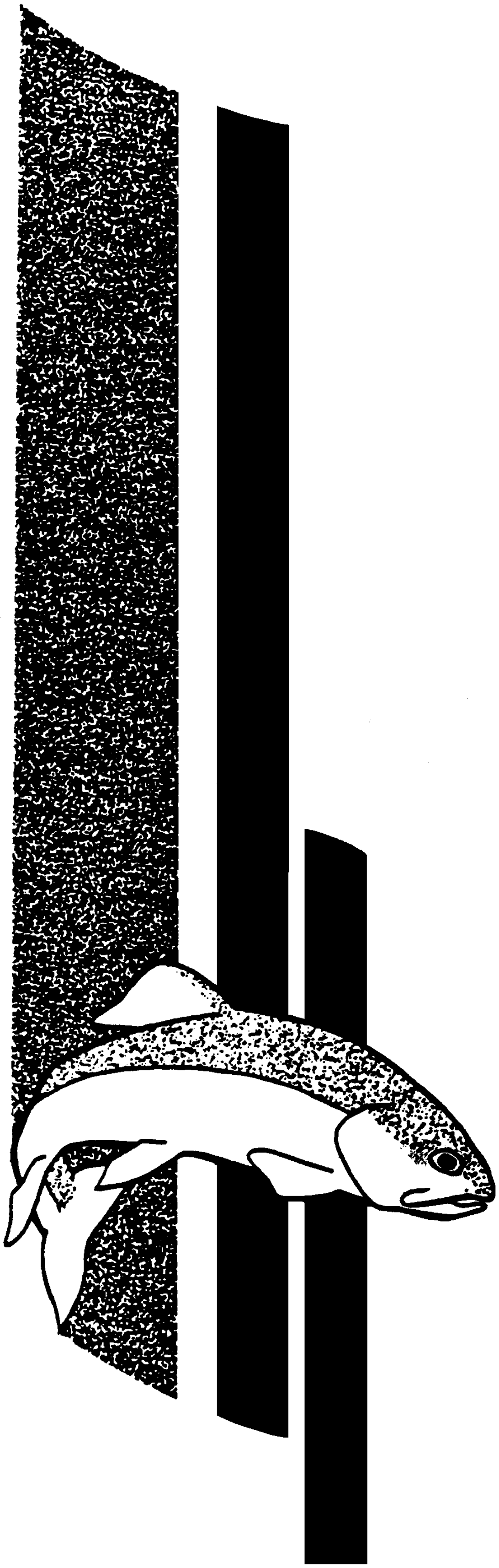

KOOTENAY LAKE NUTRIENT RESTORATION PROGRAM, YEAR 17 (NORTH ARM) AND YEAR 5 (SOUTH ARM) (2008) REPORT

by

E.U. Schindler, D. Sebastian,

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COMPENSATION PROGRAM
A partnership between BC Hydro, the Province of B.C.
and Fisheries and Oceans Canada

Fish and Wildlife Compensation Program

and

Kootenai Tribe of Idaho

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EXECUTIVE SUMMARY

This report summarizes results from the seventeenth year (2008) of nitrogen and phosphorus additions to the North Arm of Kootenay Lake and five years of nitrogen additions to the South Arm. These nutrient additions were conducted using an adaptive management approach in an effort to restore lake productivity lost as a result of nutrient retention and uptake in upstream reservoirs. The primary objective of this program is to restore kokanee (*Onchorhynchus nerka*) populations, which are the primary food source for Gerrard rainbow trout (*Onchorhynchus mykiss*) and bull trout (*Salvelinus confluentus*).

Kootenay Lake is a warm monomictic lake with a water renewal time of approximately two years. It is 395 km^2 in size with an average depth of 94 metres and a maximum depth of 154 metres. Surface water temperatures were warmest in August at 18.0ºC and 20.4ºC in the North and South Arms, respectively. Dissolved oxygen concentrations in the lake were similar to previous years, with the lake being well oxygenated from the surface to bottom depths at all stations.

Secchi disc measurements at all stations indicated a typical seasonal pattern of decreased spring transparency associated with increased phytoplankton biomass and turbidity from stream runoff, followed by increased transparency in the late summer and fall months.

Nutrients added were in the form of liquid agricultural grade fertilizer (10-34-0, ammonium polyphosphate (phosphorus, P) and 28-0-0, urea ammonium nitrate (nitrogen, N). The total amounts added in 2008 were 45.8 tonnes of phosphorus and 242 tonnes of nitrogen to the North Arm; 265 tonnes of nitrogen only were added to the South Arm.

Total phosphorus concentrations ranged from 4 to 10 ug/L with the peak occurring in May. The results were similar amongst all sampling stations. Over the spring to fall sampling season, nitrate collected from integrated surface samples decreased, with the decline corresponding with phytoplankton uptake and utilization during summer stratification.

As in the past five years, discrete water chemistry samples were taken to more accurately monitor nitrate concentrations in the photic zone. Nitrate is essential for maintaining optimal N:P ratios to ensure growth of edible phytoplankton. As expected, there was a seasonal decline in photic zone nitrate concentrations in July and August, followed by increasing concentrations in September.

Phytoplankton composition in integrated samples (0-20 m) was dominated by chrysophytes and crytophytes in the spring (April to June) and bacillariophytes from July onward. This pattern was also observed in the discrete phytoplankton samples (collected from 2, 5, 10, 15 and 20m). The trend of chrysophytes and cryptophytes being dominant in the spring and decreasing in the summer and fall months coincides with the increase in *Daphnia spp.* biomass, indicating grazing on phytoplankton is likely occurring.

In 2008, zooplankton abundance and biomass in the main lake was similar to results from the previous year. Copepods dominated in the spring with *Daphnia spp.* being dominant in the late summer and fall months, a consistent trend seen in previous years. In the West Arm, there was a slight decrease in abundance and biomass, especially in *Daphnia spp.* compared to the previous year.

The annual average mysid biomass at deep stations was slightly higher than in 2007. Mysid densities increased through the summer and then decreased into the fall, a trend seen in previous years. The average whole lake mysid values remain within pre-nutrient addition densities.

Kokanee escapement to Meadow Creek increased to 940,000 fish compared to approximately 400,000 fish in 2007. The Lardeau River also had increased escapement with 409,000 fish, the largest return in the previous nine years. Kokanee escapement in South Arm tributaries remained virtually at zero.

The mean size of female and male kokanee from Meadow Creek was 25.4 cm and 25.9 cm, respectively. The long term average was 22.3 cm and 22.6 cm, respectively. Fecundity decreased from the 2007 results with 379 eggs/female (the long-term average was 265 eggs/female).

Spring hydroacoustic surveys indicated higher densities of fry in the North Arm compared to the South Arm. By fall, the distribution was fairly uniform throughout the lake, a trend observed in previous years. Fall hydroacoustic estimates for all age groups increased to 26.9 million (23 million was the estimate in 2007). Biomass of kokanee in the lake has increased from 3.5 $kg\cdot ha^{-1}$ in the pre nutrient addition years to 9.6 $kg\cdot ha^{-1}$ since nutrient addition.

The results of the 2008 nutrient additions to the North and South arms indicate that trophic level response has been positive. Phytoplankton composition was suitable for growth of desirable zooplankton. Kokanee escapement and in-lake abundance increased, indicative of a positive response to the adaptive management of closely monitored seasonal applications of limiting macronutrients.

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INTRODUCTION

TROPHIC LEVEL RESPONSES TO NORTH ARM (Year 17) AND SOUTH ARM (YEAR 5) KOOTENAY LAKE NUTRIENT ADDITIONS - 2008

by

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Introduction

Hydroelectric power project alterations to the Columbia River have been enormous, resulting in the loss of aquatic habitat with irreversible consequences to anadromous and resident fish populations. Within British Columbia, the Columbia River hydro developments have profoundly affected fish communities of the former Arrow, Duncan and Kootenay lakes, with many changes occurring over long periods of time. Wetzel (2001) provides an excellent summary of the physical and chemical changes that occur with impoundment and damming of large lakes and rivers, and emphasizes that human restoration of impacted systems is required since these formerly natural ecosystems are no longer able to repair themselves.

While it is often quite obvious that fish populations and their habitats decline soon after dam construction and impoundment, the limnological changes that occur are not so obvious. For example, it was nearly two decades after construction of upstream dams on the Kootenay Lake system before there was a realization that profound changes to lake productivity were occurring .A major scientific investigation by Daley et al. (1981) was required to determine that the lake was changing from an oligotrophic to ultra-oligotrophic state. Lake productivity was declining due to the upstream reservoirs retaining key nutrients that previously contributed to downstream system productivity (Stockner 2003; Perrin et al. 2006). Since Daley's work, Ashley et al. (1997) and Schindler et al. (2010a) have documented changes to the limnology of Kootenay Lake while Pieters et al. (*in* Stockner 2003) and Schindler et al. (2010b) provide summaries of changes that have occurred to the Arrow Lakes Reservoir. After three decades, limnological research continues on the Columbia River reservoirs. For example, Matzinger et al. (2007) described an additional impact to Arrow Lakes Reservoir productivity. Weekly hydraulic alterations to reservoir inflows results in high flow-through (i.e. brief hydraulic residence time) that flushes out limiting nutrients required for primary production.

Kootenay Lake, which was greatly affected by hydroelectric developments, is world renowned for its production of trophy sized rainbow trout (*Oncorhynchus mykiss*), and the angling community has always been attuned to the status of the Gerrard rainbow trout population. Protecting and maintaining this unique trout population has been a long term goal of Provincial fisheries managers. This population slowly recovered over a thirty year period after undergoing a catastrophic decline in the 1950s due to a combination of unsustainably large egg collections from the spawners, and some suspected overfishing (Irvine 1978; Andrusak 2005). However, shortly after record spawner numbers were recorded in the late 1970s their numbers again began to decline. It was about the same time that Daley et al. (1981) identified that nutrient impoverishment in the lake was the result of nutrient retention by newly formed upstream reservoirs, and correctly predicted that the lake would become ultra-oligotrophic by the mid 1980s. The consequences of this change in lake productivity became apparent by the late 1980s. Kokanee (*Oncorhynchus nerka*) numbers declined at an alarming rate and by 1991 there were < 0.25 million spawners compared to numbers typically > 1 million. With the kokanee decline came the dire prediction that the Gerrard trout population would be in jeopardy, thus the impetus for restoring nutrients to the lake was actually prompted by public concern for this population which has always been the primary focus of the economically valuable Kootenay Lake sport fishery. Experimental fertilization commenced on the North Arm in 1992 in an effort to reverse the kokanee decline which in turn would ensure conservation of the Gerrard population. This bottom-up approach to increasing fish production assumes that each trophic level will respond positively to nutrient addition. Hence it is important to examine each trophic level response, thus supporting the monitoring program that is conducted annually.

Fertilization of the lake was aimed at ensuring the sustainability of the Gerrard trout as well as the highly regarded bull trout (*Salvelinus confluentus*). In fact the concern about Kootenay Lake's ultra-oligotrophic status meant the entire lake's assemblage of predators and their prey was at risk. Thus, the fertilization program has actually been aimed at the entire fish community in Kootenay Lake, not solely kokanee and rainbow trout. The 1992 strategy that was implemented was basic: add nutrients (P and N) equal to pre-impoundment loading rates to stimulate primary and secondary production that would be beneficial to planktivorous fish, especially kokanee. Ashley et al. (1997) concluded after only four years of fertilizer additions that this bottom-up approach had been highly successful in rebuilding the North Arm kokanee population.

While the North Arm fertilization project has been quite successful in restoring kokanee numbers, the opposite scenario was occurring in the south arm, i.e. numbers of spawners in South Arm streams continued to decline and by the early 2000s there were virtually none observed (Andrusak 2009). At the same time Kootenay Lake kokanee that spawn in northern Idaho streams were also becoming extinct (Ericksen et al. 2009). Consequently the Kootenai Tribe of Idaho (KTOI), the State of Idaho (Idaho Department of Fish and Game - IDFG) and the provincial Ministry of Environment (MOE) collaborated to secure Bonneville Power Authority (BPA) funding for experimental nutrient addition to the South Arm in an effort to restore South Arm kokanee (Anders et al. 2003; Ericksen et al. 2009). This project began late in 2004 and has since been fully implemented during the entire growing season through 2008.

Recently the fertilization projects have become integrated into a much larger ecosystem restoration program. The IDFG and KTOI are now aiming to restore the productivity of the Kootenai River in Idaho and Montana. This river also became nutrient deficient due to the retention and uptake in the Koocanusa Reservoir located upstream at Libby, Montana (BPA 2005). Since this reservoir was completed in the mid 1970s, substantial declines in abundance of most Kootenai River fish species have been documented (Paragamian 2002). In the early 2000s, the KTOI and IDFG proposed to add nutrients to the river similar to stream and river restoration projects carried out in British Columbia (Stockner 2003; Stockner and Ashley *in* Stockner 2003). Since 2005 low concentrations of liquid fertilizer (phosphorus only) have been added to the river near the Montana-Idaho border, and a comprehensive annual monitoring program of all trophic levels is underway. Results of this program are not reported here, but it should be noted that this project, as well as others in Idaho, are all ultimately aimed at restoring Kootenay Lake fish populations and their habitat.

Study Area

Kootenay Lake lies in a north-south glacial trench between the Selkirk and Purcell mountain ranges in the southeast corner of British Columbia (Fig. 1.1). The main lake is 107 km long, approximately 4 km wide with a mean depth of 94 m and a maximum of 154 m (Daley et al. 1981). The lake is fed by two major river systems - the Lardeau/Duncan system at the north end and the Kootenay/i River that originates in BC and flows through parts of Montana and Idaho before entering the lake's south end. The outlet of the main lake near its midpoint on the west side, at Balfour, BC, forms the upper end of the West Arm. At this outlet, a sill lies at a depth of approximately 8 m producing a distinct boundary between the main lake and the West Arm. The West Arm is about 40 km long with a mean depth of only 13 m. It is physically and limnologically different from the main lake, comprised of a series of rapidly flushed shallow basins interconnected by narrow riverine sections. The West Arm of Kootenay Lake flows in a westerly direction forming the lower Kootenay River, which flows into the Columbia River at Castlegar, BC. The entire West Arm has an annual mean retention time of about 5-6 days (Martin and Northcote 1991). The main basin of the lake has a retention time of 1.8 years (Daley et al. 1981). A more detailed description of the limnology of Kootenay Lake can be found in Northcote (1973), Daley et al. (1981), Northcote et al. (1999) and Schindler et al. (2010a).

Background

Kootenay Lake has long been the focus of fishery investigations primarily because it arguably has always supported the most intensive inland fishery in the province with the primary interest of most anglers being the Gerrard strain of rainbow trout. These trout are the largest sized wild trout known to exist in North America with some growing as large as 15 kg with their size highly dependent on an abundance of kokanee, their main food supply (Andrusak and Parkinson 1984). Research on the lake dates back to the 1940s (Larkin 1950) with most work conducted in response to the multitude of major impacts that have occurred. Larkin (1950) provided some excellent baseline limnological data that has been particularly useful in understanding the lake prior to eutrophication that began in the early 1950s (Northcote 1973).

Mysid introductions

Larkin was also responsible for introduction of the opossum shrimp *Mysis relicta* (this species is now renamed *Mysis diluviana*) (Audzijonyte and Vainola, 2005) into Kootenay Lake in 1949 that resulted in a major ecological impact due to their competition for zooplankton with kokanee (Northcote 1991). The original objective of this non-indigenous introduction was to provide an intermediate macrozooplanktor for the Gerrard rainbow trout (Northcote 1991). Successful survival of these shrimp was not confirmed until 1964 when they were observed drifting through the lake outlet (Sparrow et al. 1964). Unfortunately, as it turned out, these trout utilize mysids on a very limited basis (Andrusak and Parkinson 1984). As with so many other mysid introductions in North America, they have had a negative impact especially to kokanee since they and kokanee both prey upon cladocerans, especially *Daphnia* sp. (Northcote 1991). Lasenby et al.

(1996) documented the growth and food habits of mysids in Kootenay Lake confirming that they do prefer *Daphnia* sp. Most researchers believe they have been at least partially responsible for the decline of kokanee in the main lake (Martin and Northcote 1991; Walters et al. 1991; Ashley et al. 1997), but the larger issue of decreased lake productivity almost certainly overshadows the mysid impact (Daley et al. 1981).

The mysid introduction did have a positive impact on West Arm kokanee. This population have been the primary beneficiaries of the mysid introduction largely due to the unique flow features of the upper West Arm (Northcote 1973). Mysids in the vicinity of the outlet move to the surface at night where they are entrained in the outlet current and displaced over the sill, thereby becoming highly vulnerable to kokanee predation (Thurber Consultants 1981). In the late 1960s and 1970s West Arm kokanee grew to exceptionally large size, with some as large as 4 kg. These large fish attracted anglers from afar and the outlet area of the lake during the 1970s supported the largest inland sport fishery in the province with annual catches exceeding 100,000 (Andrusak 1987). Although this fishery today is far less intensive, the kokanee still utilize mysids and grow to an exceptional size (Andrusak and Andrusak 2007).

Cominco fertilizer plan discharges

Limnological changes in Kootenay Lake began in the 1950s with unregulated amounts of phosphorus entering the South Arm from an upstream fertilizer plant (Northcote 1973). The 1973 Northcote report provided an excellent summary of the early anthropogenic impacts on Kootenay Lake and chronicles events leading to eutrophication. It is clear from the data Northcote presented that huge quantities of fertilizer (primarily phosphorus) from Cominco's fertilizer plant located in Kimberley, BC, were responsible for eutrophication during the late 1950s and throughout the 1960s (Northcote 1973). This is not to suggest that other impacts, especially hydro development, didn't have a negative effect on the lake as discussed below.

Located on the St. Mary River at Kimberley, BC, the Cominco Ltd. fertilizer plant during the 1950s to the early 1970s discharged hundreds of tonnes of fertilizer that flowed into the Kootenay River and ultimately into Kootenay Lake. As a consequence Kootenay Lake productivity during this era increased substantially. The lake's N:P ratio was about 14:1 prior to the fertilizer plant commencing operations in 1953 but changed to about 5:1 by 1962 and remained at that level until 1972 (Daley et al. 1981). The lake became so productive that blue-green algae blooms were evident during the summers and Zyblut (1970) noted that zooplankton numbers had increased threefold compared to data collected by Larkin (1950). In retrospect the kokanee populations in the 1960s were probably at historical but artificially high levels although no estimates of spawner numbers were made prior to 1964. In 1964, Bull (1965) estimated over 4 million kokanee spawned in the Lardeau-Duncan system, probably reflecting the highly productive state of the lake at that time. The Duncan Dam was completed in 1967 thus eliminating virtually all Duncan River spawning habitat for Kootenay Lake rainbow trout, whitefish, bull trout and kokanee. The Meadow Creek spawning channel was built in 1967 as partial compensation for construction of the Duncan Dam.

The presence of blue-green algal blooms in such a large lake with high public use resulted in public demand to reduce the fertilizer discharge. This led to government action that forced Cominco to control their fertilizer discharge. Pollution abatement was well in hand by 1973, which coincided with completion of the Libby Dam. The cumulative impact of these two events was largely unforeseen, but it did cause the federal government in the mid 1970s to launch a major limnological investigation led by Dr. Ralph Daley of Environment Canada, Inland Waters Directorate. This multi-disciplinary team investigated the lakes' physical and chemical limnology from 1976-1979 and their study concluded that cessation of phosphorus discharge and nutrient retention behind hydroelectric dams on the two major inflow rivers (Kootenay and Duncan) were the primary reasons for the lake again becoming oligotrophic (Daley et al. 1981; Ashley et al. 1999). In fact, nutrient input to the lake declined below pre-dam conditions and the lake underwent a gradual productivity decline through to the early 1990s as the lake became ultra-oligotrophic (Binsted and Ashley 2006). The observed reduction in nutrients, especially phosphorus, led to phytoplankton biomass decline followed by decreases in kokanee. In a very short period of time large scale change occurred from high abundance of kokanee in the 1960s and early 1970s due to eutrophic conditions to a period of very low abundance in the 1980s during ultra-oligotrophic conditions with record lows of < 0.25 million spawners recorded in 1990 and 1991. During this latter period the South Arm kokanee population virtually disappeared.

Hydroelectric projects

While nutrient enrichment followed by nutrient depletion has had a profound impact on Kootenay Lake the cumulative impacts of hydroelectric developments on fish habitat have been irreversible. The two major inflowing systems - Kootenay and Duncan rivers - and the outlet (lower Kootenay River) have all been dammed. Historically, the initial dam (Corra Linn) affecting the lake was constructed on the Kootenay River downstream of Nelson in the early 1930s. This dam results in the potential storage of about 2 m on the main lake but it has had more of an effect on the West Arm due to the extent and length of time of drawdown (Andrusak and Andrusak 2007).

The Duncan Dam was built on the Duncan River in the mid-1960s approximately 12 km upstream of the north end of the lake. This dam eliminated hundreds of kilometers of spawning habitat used by kokanee, rainbow trout, bull trout and numerous other species. There was blockage to, and elimination of, spawning habitat for more than a million kokanee (Bull 1965), loss of a spawning run of Gerrard-size rainbow trout (numbers unknown), and blockage to spawning habitat for possibly a few thousand bull trout. It also resulted in retention of nutrients, the impact of which has been much greater than initially predicted (Larkin 1998; Binsted and Ashley 2006). To this day remnant rainbow trout and bull trout spawning runs persist below this dam and a great deal of effort is underway to improve habitat conditions for these fish (RL&L Environmental Services Ltd. 2000).

Over half the entire flow into Kootenay Lake originates in the upper Kootenay River watershed that forms at the base of the Rocky Mountains in the East Kootenay. This river flows southwards into Montana before turning west into Idaho then north into Kootenay

Lake. Binsted and Ashley (2006) estimate the Kootenay River watershed contributes nearly 57% of the total inflow to Kootenay Lake. In the mid 1970s the Libby Dam in Montana was built on the Kootenay River about 300 km upstream of the South Arm of Kootenay Lake. Daley et al. (1981) initially documented the enormous impact that the Libby Dam has had on Kootenay Lake as a result of nutrient retention. Binsted and Ashley (2006) have analyzed in greater detail the phosphorus contributions to the lake from the Kootenay and Duncan rivers before and after completion of this dam. They calculated that phosphorus (SRP) loadings to the lake prior to lake fertilization was less than half than natural conditions that existed prior to cultural eutrophication and Libby Dam formation. i.e. less than half the nutrients compared to pre 1950 levels due to reservoir (s) retention of nutrients. Furthermore, nutrients stripped out of the system by the Kootenai River below the Libby Dam combined with reservoir uptake are the most likely causes of reduced river productivity in Idaho, and this has prompted initiation of a major river restoration program involving nutrient additions (Holderman and Hardy 2004; Bonneville Power Authority 2005). Aside from nutrient reductions fisheries investigators in Idaho have identified major problems with burbot and sturgeon spawning success as a result of the Libby Dam altering the hydrological regime of the Kootenay River (Bonneville Power Authority 2005; Paul Anders, Cramer Fish Scientists, University of Idaho pers. comm. 2008).

Cumulative impacts

The loss of major spawning habitat due to construction of the Duncan Dam, altered hydrograph on the Kootenay/i River that negatively affects spawning and rearing and nutrient retention in upstream reservoirs have combined to significantly change Kootenay Lake. Some restoration activities such as spawning channels at Meadow, Redfish and Kokanee creeks have been successful in maintaining North and West Arm kokanee stocks (Redfish Consulting Ltd. 1999). However, these major kokanee production sites alone cannot restore all kokanee, let alone other fish species if lake productivity limits their growth and survival. In reality it was quite apparent by 1990 that lake productivity had decreased so much that the kokanee population(s) was at risk and on the brink of collapse. It was obvious to most that the Gerrard rainbow population was also in jeopardy given their reliance on kokanee. As mentioned, the desire to restore the lakes' productivity to the pre-dam/pre-fertilizer plant level was largely driven by public demand to retain the lake's highly popular and regionally significant sport fisheries.

Adaptive environmental assessment workshop

In response to these dire circumstances and public concern the provincial government organized an Adaptive Environmental Assessment (AEA) workshop at the University of British Columbia in February, 1991, to contemplate all options including the merits of experimentally fertilizing a portion of the lake in an attempt to halt the lake productivity decline. Korman et al. (1990) describe various alternatives that were discussed. Walters et al. (1990) developed a Kootenay Lake Fertilization Response Model to understand what could potentially happen if the lake was fertilized to pre-impoundment and pre-cultural enrichment levels. The model predicted that fertilization would not be successful in restoring kokanee, and that mysids, not kokanee, would be the most likely beneficiaries. In retrospect Walters and Martell (2007) discuss the reasons why the model failed to detect net benefits to kokanee through lake fertilization.

The notion of reversing the ultra-oligotrophic status of Kootenay Lake was initially met with some public and scientist concern and skepticism. Anders and Ashley (2007) discuss the public policy conflict between adding nutrients to restore fish populations and the public's desire to have "clear water". This conflict was not a major issue for Kootenay region residents and at public meetings there was near unanimous support to proceed with experimental lake fertilization. A convincing argument at that time was the fact that the federal government (DFO) had conducted a number of lake fertilizations in British Columbia to increase sockeye populations (Hyatt and Stockner 1985; Stockner and MacIsaac 1996). Furthermore the literature was fairly supportive of aquatic fertilization with a number of formal publications on nutrient additions to various lakes elsewhere in Canada, USA, Sweden and Scotland (Ashley et el. 1999; Hyatt et al. 2004; Perrin et al. 2006). Sockeye enhancement work through lake fertilization undertaken by DFO in the late 1960s had proven quite successful (Stockner 2003; Hyatt et al. 2004).

Adaptive management experiment

With strong public support and despite the model's negative prediction, fisheries managers committed to a five year experimental fertilization program at the north end of the lake. The north end was chosen since it was known that most of the kokanee production originates from Meadow Creek and the Lardeau River (Schindler et al. 2010a). Due to the inherent uncertainty of the experiment, an intensive monitoring program of all trophic levels was launched in 1992 by a multi-disciplinary group of scientists to track the physical and biological responses to experimental addition of P and N. Results of this experiment have been widely reported in a series of technical reports (Ashley et al. 1999; Wright et al. 2002a, b; Schindler et al. 2010a) with the response by North Arm kokanee quite spectacular. Briefly, after only four years of fertilizer addition, kokanee escapements to the North Arm's Lardeau River and Meadow Creek systems were once again over 1 million, comparable to spawner numbers of the 1960s and 1970s (Ashley et al. 1999).

Kootenay Lake fertilization has had its critics despite initial success reflected in the strong response by kokanee. It was argued that the experiment did not include a control hence it could not be stated with absolute certainty that kokanee recovery was due solely to nutrient addition. Thus the experiment was modified by reducing the nutrient loading from 1997-1999 by nearly 50% to determine if fertilization was the primary reason for the striking increase in kokanee numbers. The immediate response to reduced fertilizer loads was a decrease in productivity reflected in declining numbers of kokanee. The 2000-2002 Meadow Creek kokanee numbers fell to < 0.4 million with concurrent sizeable decreases in the same cohort fry-to-adult survival rates. With such dramatic decreases in so little time the fertilizer-loading rates were increased in 2000 and by 2001 the load had increased to the original 1992 level. Following this increase spawner numbers again increased to ~ 1 million.

Positive trophic responses to nutrient additions have also been observed in several other reservoirs that have recently been subjected to experimental fertilization. Nearby Arrow Lakes Reservoir fertilization began in 1999 (Schindler et al. 2010b) and initial results were similar to Kootenay Lake; i.e. kokanee growth and numbers increased immediately once fertilizer was added. Kokanee biomass in the reservoir increased to ~ 10 kg/ha compared to ~3 kg/ha prior to fertilization. Recently the numbers and biomass have declined due to several factors including poor fry production from the Hill Creek spawning channel and increased in-lake flow through (that lowers productivity) due to downstream hydroelectric demands.

In the lower Fraser Valley experimental fertilization began on the Alouette Reservoir in 1999 and kokanee responded immediately, increasing threefold (Harris et al. 2007). Another small coastal reservoir, Wahleach Lake, has also been fertilized and Perrin et al. (2006) reported an increase in fish yield as a result of nitrogen and phosphorus additions.

Recreational angling – rainbow trout

Cultural eutrophication of Kootenay Lake during the 1950s and 1960s led to some highly productive but unsustainable fisheries. Pearse and Laub (1969) estimated the sport fishery had a net worth of $5.8 million. Exceptionally large kokanee and burbot in the West attracted large numbers of anglers from afar and due to the lake’s close proximity to Idaho and Washington, foreign anglers represented nearly 50% of the total angling effort. During this era most of the fishing was directed at kokanee and burbot that concentrated at the lake’s outlet at Balfour BC. However, the trophy-sized Gerrard rainbow trout has always been the greatest attraction. Even at the turn of the century rainbow trout > 15 kg were highly sought by local anglers (Northcote 1973; Irvine 1978) and this fishery remains very popular to this day. The Gerrard rainbow population supports virtually all the trophy fishery and for this reason, as well as for stock management purposes the Gerrard rainbow trout spawning run has been monitored annually since 1957 and there is a good correlation between catch and escapement (Andrusak and Andrusak 2006). In the face of intensive fishing pressure this trout population today is sustainable primarily because of their high fecundity, an abundance of kokanee and a very high rate of catch-and-release (Andrusak and Andrusak 2006). Spawner numbers have been enumerated in record numbers during the last four years and there is strong evidence that lake fertilization has been the primary reason for such high counts. Anecdotal information from anglers suggests the bull trout population is also flourishing.

The lake supports at least two other ecologically distinct rainbow trout populations. Cartwright (1961) described the West Arm population that grows up to 4 kg but seldom preys upon kokanee. These trout provide excellent fly fishing opportunities during the summer months. Recently, an updated assessment of this fishery by Andrusak (2006) suggests that this fishery targets several stocks including some fish that spawn in a few Kootenai River tributaries in Northern Idaho. Growth rates of these fish today are far lower than those measured in 1966 with the decrease attributed to the change in lake productivity and reduction of the hydrograph. A lesser known rainbow trout population inhabits the South Arm of Kootenay Lake. These trout also provide good fishing opportunities during the summer and fall (Andrusak 1987; 2006).

Bull trout

Bull trout appear to be abundant in Kootenay Lake and they are also a popular sport fish that are caught using the same methods as rainbow trout fishing i.e., trolling plugs, bucktail flies and spoons but usually at slightly greater depths. These fish occasionally exceed 7kg but most are 3-4 kg. In recent years these fish have become an important alternative sport species especially during the late winter months when rainbow trout catchability is low. Little assessment work has been directed at bull trout and until the 2000s there was no estimate of spawner numbers. O'Brien (1999) and Olmstead et al. (2001) documented migration of large numbers of bull trout through the Duncan Dam with estimates of ~ 500-1000 spawners. Andrusak (2008) employed a combination of redd counts and a resistivity counter on the Kaslo River to estimate ~1100 spawners. Based on these two estimates, and the large number of streams that also support adfluvial forms, it is likely that Kootenay Lake supports large numbers of bull trout compared to rainbow trout numbers.

Kokanee

Vernon (1957) investigated Kootenay Lake kokanee and found through meristic analysis and age determinations that there were three strains of kokanee with each arm supporting separate populations. Currently the main lake continues to provide small but abundant numbers for summer anglers. The West Arm kokanee population was the center of attention during the 1970s when the lake was highly productive (Andrusak and Brown 1987). This fishery peaked in the 1970s with annual catches close to 100,000 fish but with the decline of this population in the late 1980s there has been considerably less fishing for them despite the recovery evident in the late 1990s. A combination of some over-fishing due to a mixed stock fishery and the severe decline in lake productivity has relegated this once famous fishery to a modest, seasonal fishery with a small annual catch quota of about 5,000. Ericksen et al. (2009) provide an updated account of kokanee in the Kootenay lake system and found that genetic analysis indicates that North Arm (Meadow Creek stock) remain distinct from the West and South Arm stocks.

White sturgeon

White sturgeon (*Acipencer transmontanus*) that inhabits the Kootenay River at the south end of the lake once supported a low-level sport fishery. However, these fish have been severely threatened due to impacts of the Libby Dam and the fishery has been closed for well over two decades due to conservation concerns. Research currently underway has confirmed that this population is in decline due to poor spawning success and limited recruitment. A recovery strategy that includes juvenile hatchery production in Idaho has been initiated and the success of this program is now being monitored (P. Anders, Cramer Fish Sciences Moscow Idaho pers. comm. 2009).

Burbot

During the 1960s and 1970s a highly intensive fishery occurred for burbot (*Lota lota*) at the outlet area near Balfour, BC. This fishery was examined by Martin (1976) for possible overfishing. Martin (1976) concluded that overfishing was not excessive but more conservative regulations were required. Very restrictive regulations were imposed on this fishery but the population collapsed by the early 1980s and has not recovered despite a total closure that has remained in effect for over twenty years. Lake and river assessment work during the last six years has failed to identify any appreciable numbers of burbot anywhere in the lake (C. Spence, Fisheries Biologist, BC Ministry of Environment, Nelson, BC, pers. comm., 2008).

The above brief description of the lakes' sport fish populations underlines the importance the public place on recreational fishing. To ensure their sustainability in the face of the numerous impacts the lake has experienced and the current constraints to production there is little question that annual fertilization is required. Considering the cost of this project, continued comprehensive monitoring of nutrient inputs is essential to ensure optimal energy and carbon transfer to higher trophic levels. This report summarizes results of the 2008 monitoring program that tracks trophic level responses to experimental fertilization of the North and South Arms of Kootenay Lake.

Objective of the Kootenay Lake Nutrient Restoration Program

Restoration of a disturbed ecosystem to its former state is the goal of this on-going program. Since the beginning of experimental fertilization in 1992 in the North Arm of Kootenay Lake, the specific objective of this program has been to rebuild the kokanee population by increasing lake productivity to the level that existed prior to 1950. Thus this fertilization program has been tasked with ensuring sufficient forage, specifically kokanee, for the lake's piscivores. Commencing in 2004 this program was expanded to include the South Arm in an effort to restore South Arm kokanee in BC and Idaho.

The scientific basis and direction of the experimental fertilization program on Kootenay Lake originated with Dr. K. Ashley who was the senior research biologist for the Ministry of Environment at the beginning of the project. Eva Schindler, limnologist for the Ministry of Forests, Lands and Natural Resource Operations located in Nelson, BC, is the biologist responsible for all aspects of the monitoring program as well as for determining the weekly amounts of fertilizer applied to the lake. A large number of scientists, fisheries biologists and administrative personnel participated in the 2008 Kootenay Lake Fertilization Program. A list of the 2008 participants and their primary function is shown in Table 1.1.

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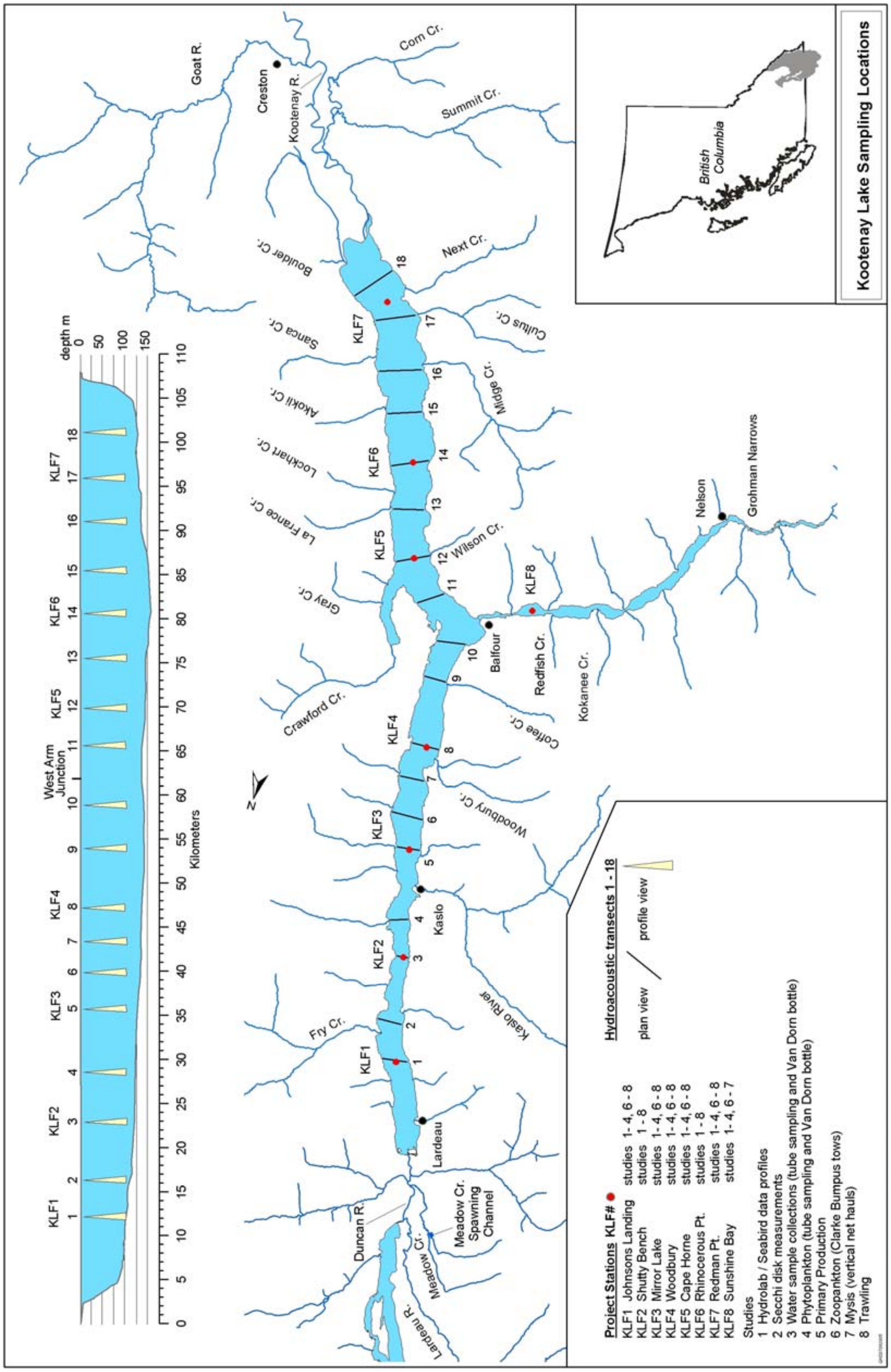

Figure 1.1. Kootenay Lake, British Columbia, sampling station sites.

Table 1.1 Listing of 2008 Kootenay Lake project focus, personnel and affiliation.

Contribution	**Personnel**	**Affiliation**
Project co-ordination, management and scientific liaison	Eva Schindler	Ministry of Environment[3]
Fertilizer schedule, loading	Eva Schindler Ken Ashley Wilf Doering	Ministry of Environment[3] BC Institute of Technology Agrium, Kamloops
Fertilizer application	George Veale – North Arm Western Pacific Marine – South Arm	G. Veale Holdings Ltd. Western Pacific Marine, Balfour
Physical limnology, water chemistry, phytoplankton, zooplankton, mysid sampling	Don Miller Eva Schindler Marley Bassett	Kootenay Wildlife Services Ltd. Ministry of Environment[3] Ministry of Environment[3]
Physical limnology, water sampling data analysis	Eva Schindler Marley Bassett	Ministry of Environment[3] Ministry of Environment[3]
Primary production sampling	Eva Schindler Les Fleck Greg Andrusak Maggie Squires Marley Bassett	Ministry of Environment[3] Crystal Springs Consulting Redfish Consulting Ltd. Ministry of Environment Ministry of Environment[3]
Primary productivity analysis	Shannon Harris	Ministry of Environment
Chlorophyll a analysis	Emma-Jane Johnson Shannon Harris	Ministry of Environment Ministry of Environment
Phytoplankton sample analysis	Dr. Frances Pick Paul Hamilton Linda Ley Dr. John Stockner	University of Ottawa Canadian Museum of Nature Canadian Museum of Nature Eco-Logic Ltd.
Limnology, phytoplankton and primary production report	Eva Schindler Shannon Harris Marley Bassett	Ministry of Environment[3] Ministry of Environment Ministry of Environment[3]
Zooplankton and mysid Sample analysis and report	Dr. Lidija Vidmanic	Limno-Lab Ltd.
Kokanee acoustic sampling	Dale Sebastian George Scholten Don Miller	Ministry of Environment[3] Ministry of Environment[3] Kootenay Wildlife Services Ltd
Kokanee trawling	Don Miller George Scholten Dale Sebastian	Kootenay Wildlife Services Ltd. Ministry of Environment[3] Ministry of Environment[3]
Meadow Creek fry kokanee enumeration	John Bell Murray Pearson	Ministry of Environment[3] Ministry of Environment[3]
Meadow Creek adult kokanee enumeration	John Bell Murray Pearson	Ministry of Environment[3] Ministry of Environment[3]
South Arm tributary adult kokanee enumeration	Les Fleck	Crystal Springs Contracting

Table 1.1. (continued)

South Arm kokanee eyed egg plants	Les Fleck Jeff Burrows Jordan Knox John Bell Marley Bassett Gary Munro Murray Pearson Eva Schindler Colin Spence Jessica Spencer Johnny Manson Steve Arndt Tracy Jensen Aaron Wolf Graham Nessman	Crystal Springs Contracting Ministry of Environment[3] Crystal Springs Contracting Ministry of Environment[3] Ministry of Environment[3] Ministry of Environment[3] Ministry of Environment[3] Ministry of Environment[3] Ministry of Environment[3] Ministry of Environment[3] BC Conservation Corps FWCP Freshwater Fisheries Society, BC Freshwater Fisheries Society, BC Freshwater Fisheries Society, BC
Kokanee and rainbow trout analysis and reports	Dale Sebastian David Johner Harvey Andrusak Greg Andrusak	Ministry of Environment[1] British Columbia Conservation Foundation Redfish Consulting Ltd. Redfish Consulting Ltd.
Regional support, logistics	Jeff Burrows	Ministry of Environment[3]
FWCP Technical Committee	Jeff Burrows Dale Sebastian David Wilson James Baxter Louise Porto	Ministry of Environment[3] Ministry of Environment[3] BC Hydro BC Hydro Fisheries and Oceans Canada
FWCP Steering Committee	Wayne Stetski Ted Down Kevin Conlin Doug Johnson Bruce MacDonald Grant Trower Greg Mustard Gerry Thompson Joe Nicholas Keith Louis Chief Fabian Alexis	Ministry of Environment[3] Ministry of Environment[3] BC Hydro BC Hydro Fisheries and Oceans Canada Public Representative Public Representative Public Representative First Nations Representative First Nations Representative First Nations Representative
FWCP Policy Committee	Al Martin Rebecca Reid David Facey	Ministry of Environment, Victoria[1] Fisheries and Oceans Canada BC Hydro, Burnaby
Administration	Ed Hill John Krebs James Baxter Beth Woodbridge Sue Ireland Charlie Holderman Deborah McNicol Anne Reichert CSD[2]	FWCP[1] FWCP[1] FWCP[1] FWCP[1] Kootenai Tribe of Idaho Kootenai Tribe of Idaho British Columbia Conservation Foundation Ministry of Environment Ministry of Environment

Table 1.1 (continued)

Editorial Comments	Eva Schindler Dr. Ken Ashley	Ministry of Environment[3] BC Institute of Technology

[1] Fish and Wildlife Compensation Program – Columbia Basin

[2] Corporate Services Division

[3] Ministry of Forests, Lands and Natural Resource Operations

Table 1.2 Sampling activities – Kootenay Lake, 2008.

Parameter sampled	**Sampling frequency**	**Sampling technique**
Temperature, dissolved oxygen, conductivity	Monthly, April to November	SeaBird profile from surface to bottom at stations KLF 1-8.
Transparency	Monthly, April to November	Secchi disk (without viewing chamber) at stations KLF 1-8.
Water chemistry Turbidity, specific conductivity., pH, silica, alkalinity and nutrients (TP, TDP, SRP, NO_3+NO_2,) TOC, TIC Total metals	Monthly, April to November	(a) Integrated sampling tube at 0 – 20m KLF 1-8 plus a bottle sample 5 m off the bottom at stations KLF1-8 (bottom sample collected May to October at stations KLF 1-7). (c) June and September samples at 0 – 20 m integrated KLF 1 - 8 and 5 m off the bottom at stations KLF 1-7.
Discrete N and P (NO_3^- + NO_2^-), SRP, TDP, and TP.	Monthly, June to September	Bottle samples at 2 m, 5 m, 10 m, 15 m and 20 m at stations KLF 2, 4, 6 and 7.
Chlorophyll *a (not corrected for phaeophytin)*	Monthly, April to November Monthly, June to September	Integrated sampling tube 0–20 m at station KLF 1-8. Discrete samples at 2 m, 5 m, 10 m, 15m and 20 m at stations KLF 2, 4, 6 and 7.
Phytoplankton	Monthly, April to November	Integrated sampling tube at 0–20 m at stations, KLF 1-8.
Discrete phytoplankton	Monthly, June to September	Bottle samples at 2 m, 5 m, 10 m, 15 m and 20 m at stations KLF 2, 4, 6 and 7.
Primary Production	Monthly, June to September	Sampled at stations KLF 2 and 6.
Macrozooplankton	Monthly, April to November	3 oblique Clarke-Bumpus net hauls (- 3 minutes each) from 40–0m at stations KLF 1-8 (150 μm net mesh).
Mysids	Monthly, April to November	3 replicate hauls with mysid net, two deep (to 1 m off the bottom) and one shallow (25 m) at stations KLF 1-8.
Kokanee acoustic sampling	2 surveys – July and September	Standard MoE Simrad and Biosonics hydroacoustic procedures at 18 transects.
Kokanee trawling	July and September trawl series	Standard MoE trawl series using oblique hauls at 18 transects.
Adult kokanee enumeration	Fall spawning period at Meadow Creek, the Lardeau River, and selected	Standard MoE, Region 4 procedures.

	South Arm tributaries to Kootenay Lake	
Kokanee fry enumeration	Spring monitoring at Meadow Creek Spawning Channel	Standard MoE, Region 4 procedures.

CHAPTER 2

FERTILIZER LOADING IN KOOTENAY LAKE, YEAR 17 (NORTH ARM) AND YEAR 5 (SOUTH ARM) (2008)

by

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and

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Fertilizer type

North Arm

An agricultural grade liquid fertilizer blend of ammonium polyphosphate (10-34-0, N-P_2O_5-K_2O; % by weight) and urea-ammonium nitrate (28-0-0, N-P_2O_5-K_2O; % by weight) (the fertilizer was contracted to Agrium) was used for the fertilization experiment in the North Arm of Kootenay Lake. The total weight of fertilizer applied in 2008 was 45.8 tonnes of phosphorus and 241.6 tonnes of nitrogen. Applications started on April 20 and continued weekly until September 7, a period of 21 weeks (Table 2.1, Figure 2.1). The nitrogen to phosphorus (N:P) ratio (weight:weight) of the fertilizer varied throughout the season, with a range from 0.67:1 in the spring to 10.8 in the late summer (Table 2.1, Fig. 2.1). The amounts of phosphorus and nitrogen added from 1992 to 2008 are listed in Table 2.2.

South Arm

In 2003, an analysis of the nutrient gradient in Kootenay Lake was conducted which compared the North Arm with the South Arm. The results indicated there was no North-South phosphorus gradient, but a decreasing nitrogen concentration gradient was detected from the North Arm to the South Arm. Therefore, as part of the adaptive management process, a decision was made to add nitrogen only to the South Arm during 2004, and these N only treatments have continued to the current year. In 2008, 264.6 tonnes of agricultural grade liquid urea-ammonium nitrate (28-0-0, N-P_2O_5-K_2O; % by weight) was added to the South Arm once per week from June 4th to September 3rd in 2008, a period 14 weeks in total (Table 2.3).

Fertilizer application

North Arm

Nitrogen and phosphorus nutrients were applied to the North Arm using a tug and barge, as in all previous years. The barge was fitted with two tanks capable of carrying a total of 76 tonnes of fertilizer. Applications for the North Arm occurred at weekly intervals. Fertilizer was pumped through a flow meter before being discharged at the stern into the propeller wash (Ashley et al. 1999). The fertilizer is required to be diluted approx. 10,000 to 1 with the prop wash as it is significantly heavier than water and the mixing ensures the nutrients remain available in the photic zone of the lake. The area of application in the North Arm was between two kilometres north of transect 1 and four kilometres south of transect 2, a distance of 10 km (see Fig. 1.1 in Chapter 1 of this report).

South Arm

The nitrogen and phosphorus nutrients for the South Arm experiment were dispensed from the Western Pacific Marine/Ministry of Transportation and Highways MV Balfour ferry in 2008. Two fertilizer trucks, each carrying 35 tonnes of fertilizer, would drive on to the ferry and the nutrients were dispensed into the lake via two dispensing diffusers located at the stern of the vessel which discharged into the propeller wash to ensure proper mixing. The area of application in the South Arm was between transects 12 and 15, a distance of 12.5 km (see Fig. 1.1 in Chapter 1 of this report). The method of application of fertilizer in the South Arm was similar to the North Arm where the load was distributed equally with one half released on the departing trip and one half on the return trip. On September 3rd, only half of the planned nitrogen was added due to biological conditions in the lake.

Seasonal loading and timing

North Arm

The loading and timing of nutrient additions in the North Arm were designed to simulate the loading during spring freshet (pre-dam) conditions. Weekly loading rates of phosphorus decreased during the summer while nitrogen loading rates increased. This loading schedule was conducted as in previous years to adaptively manage for biological nitrogen uptake and consumption in the water column as the season progressed (Table 2.1, Figs. 2.2 and 2.3). The total additions by year from 1992 to 2008 are documented in Table 2.2.

South Arm

Nitrogen additions to the South Arm of Kootenay Lake were maintained at a constant rate each week (Table 2.3, Fig. 2.4) .The total load of fertilizer distributed in 2008 in the South Arm was 264.6 tonnes of nitrogen. In previous years the following loads were added to the South Arm; in 2004, 124 tonnes of nitrogen was added, in 2005, 234 tonnes, in 2006, 257 tonnes was added and in 2007 245 tonnes was added.

Acknowledgements

The Fish and Wildlife Compensation Program – Columbia Basin provided funding for the North Arm project and the Kootenai Tribe of Idaho kindly provided complete funding for the South Arm project. Thanks to G. Veale Holdings Ltd for fertilizer dispensing in the North Arm and Western Pacific Marine (MV Balfour ferry) for dispensing in the South Arm. Thanks to Greg Andrusak of Redfish Consulting Ltd. and Les Fleck of Crystal Springs Contracting for assisting with dispensing for the South Arm project. Thanks to Lenora and Wilf Doering at Agrium, Kamloops and 5771 Holdings Ltd. for their contribution to the efficiency of fertilizer deliveries.

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Table 2.1. Kootenay Lake North Arm nutrient loading of fertilizer during 2008 – liquid ammonium polyphosphate (10-34-0) and liquid urea-ammonium nitrate (28-0-0).

Week	Date	Phosphorus			Nitrogen			N:P ratio wt:wt[2]
		Load mg/m^2	Amount kgs	10-34-0 Tonnes[1]	Load mg/m^2	Amount Kgs	28-0-0 Tonnes[1]	
1	Apr 20	7.5	1,307	8.8	5.1	880	0.0	0.67
2	Apr 27	7.5	1,307	8.8	5.1	880	0.0	0.67
3	May 04	12.8	1,227	15.0	8.6	1,500	0.0	0.67
4	May 11	16.2	2,821	19.0	10.9	1,900	0.0	0.67
5	May 18	28.9	5,018	33.8	87.6	15,207	42.2	3.0
6	May 25	15.4	2,672	18.0	46.7	8,100	22.5	3.0
7	June 01	19.2	3,326	22.4	58.1	10,080	28.0	3.0
8	June 08	17.9	3,103	20.9	80.2	13,920	42.3	4.5
9	June 15	14.2	2,465	16.6	63.2	10,970	33.2	4.5
10	June 22	12.8	2,227	15.0	79.7	13,834	44.0	6.2
11	June 29	13.7	2,376	16.0	96.3	16,720	54.0	7.0
12	July 06	0	0	0	0	0	0	
13	July 13	13.7	2,376	16.0	96.2	16,709	54.0	7.0
14	July 20	6.8	1,188	8.0	52.9	9,189	30.0	7.7
15	July 27	13.7	2,376	16.0	96.3	16,720	54.0	7.0
16	Aug 03	9.4	1,633	11.0	101.6	17,648	59.1	10.8
17	Aug 10	9.4	1,633	11.0	101.6	17,648	59.1	10.8
18	Aug 17	9.4	1,633	11.0	101.6	17,676	59.2	10.8
19	Aug 24	9.4	1,633	11.0	101.6	17,648	59.1	10.8
20	Aug 31	12.8	2,227	15.0	98.9	17,180	56.0	7.7
21	Sept 07	12.8	2,227	15.0	98.9	17,180	56.0	7.7

[1] Tonnes refers to the weight of 10-34-0 and 28-0-0 fertilizer added. [2] The N:P ratio refers to the ratio of the fertilizer.

Table 2.2. Total tonnes of phosphorus and nitrogen dispensed into the North Arm of Kootenay Lake from liquid agricultural fertilizer, 1992 to 2008.

Year	Phosphorus Tonnes	Nitrogen Tonnes
1992 – 1996	47.1	206.7
1997	29.5	111.6
1998	22.9	92.9
1999	22.9	92.9
2000	29.5	111.6
2001	47.1	206.7
2002	47.1	206.7
2003	47.1	240.8
2004	37.6	243.5
2005	44.1	246.9
2006	44.7	248.4
2007	46.2	246.9
2008	45.8	242

Table 2.3. Kootenay Lake South Arm nutrient loading of fertilizer during 2008 - liquid urea ammonium nitrate (28-0-0).

Week	Date	Nitrogen		Fertilizer
		Load mg/m^2	Amount Kgs	28-0-0 Tonnes[1]
1	June 04	85.9	19,600	70.0
2	June 11	85.9	19,600	70.0
3	June 18	85.9	19,600	70.0
4	June 25	85.9	19,600	70.0
5	July 02	85.9	19,600	70.0
6	July 09	85.9	19,600	70.0
7	July 16	85.9	19,600	70.0
8	July 23	85.9	19,600	70.0
9	July 30	85.9	19,600	70.0
10	August 06	85.9	19,600	70.0
11	August 13	85.9	19,600	70.0
12	August 20	85.9	19,600	70.0
13	August 27	85.9	19,600	70.0
14	September 03	43.0	9,800	35.0

[1] Tonnes refers to the weight of 28-0-0 fertilizer added.

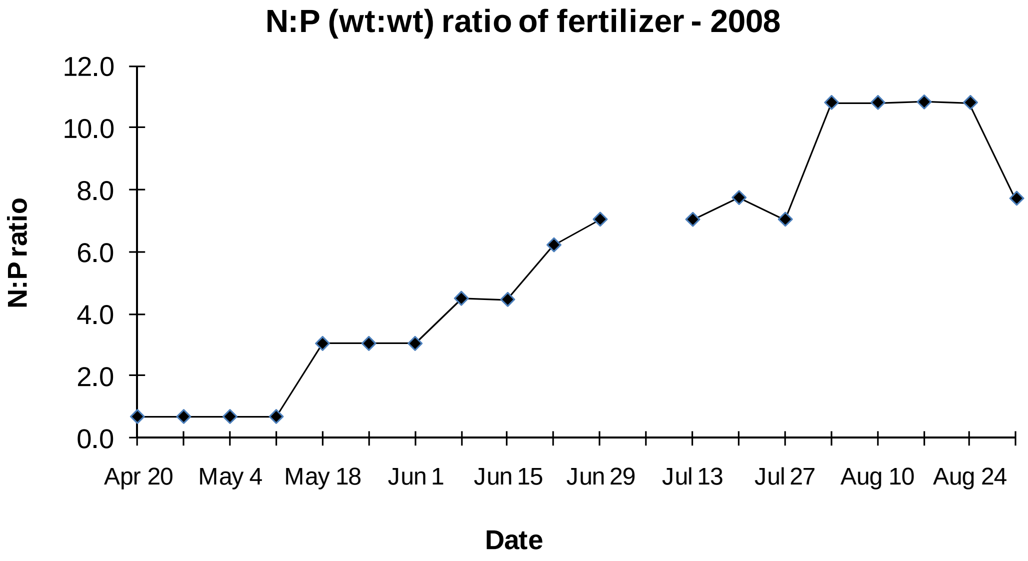

Figure 2.1. Nitrogen:phosphorus ratios (weight:weight) of fertilizer additions to the North Arm, April through September 2008.

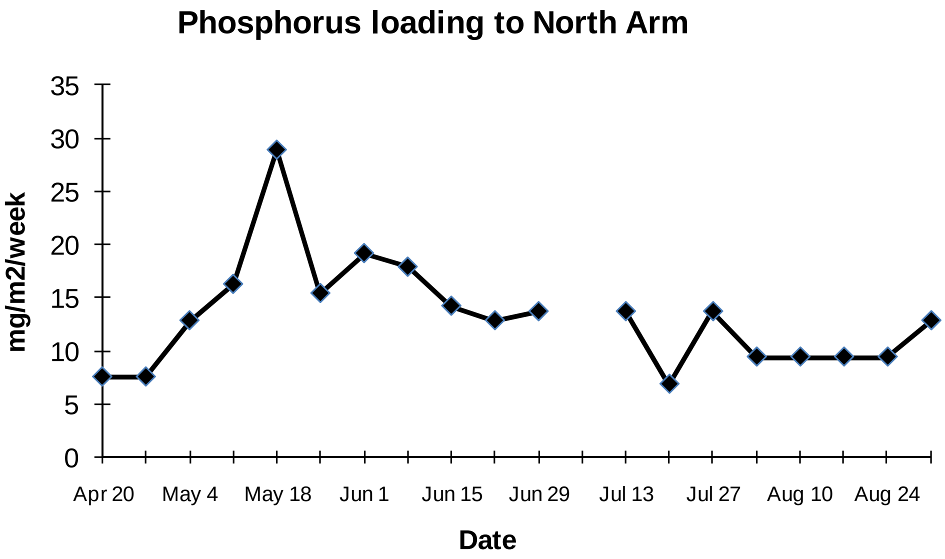

Figure 2.2. Weekly phosphorus inputs from fertilizer to the North Arm, April through September, 2008.

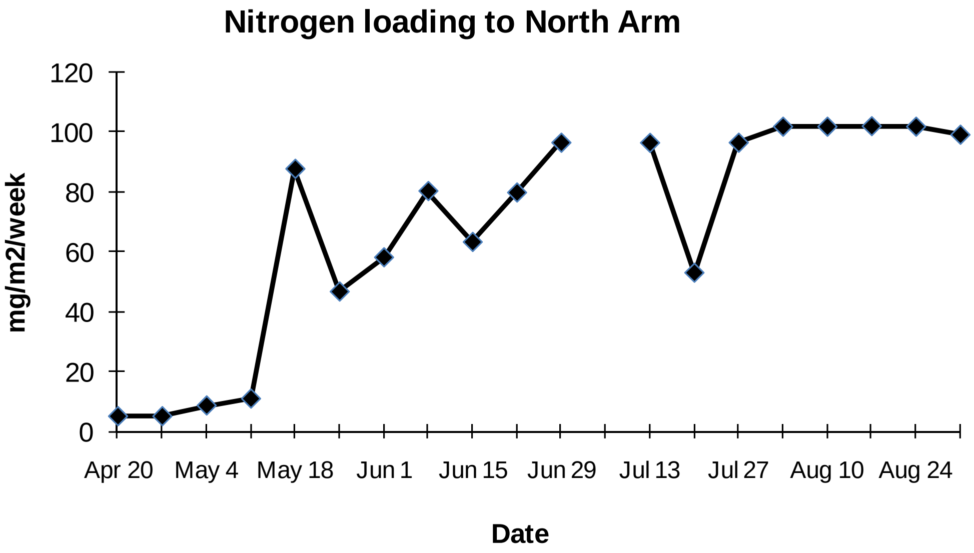

Figure 2.3. Weekly nitrogen inputs from fertilizer to the North Arm, April through September, 2008.

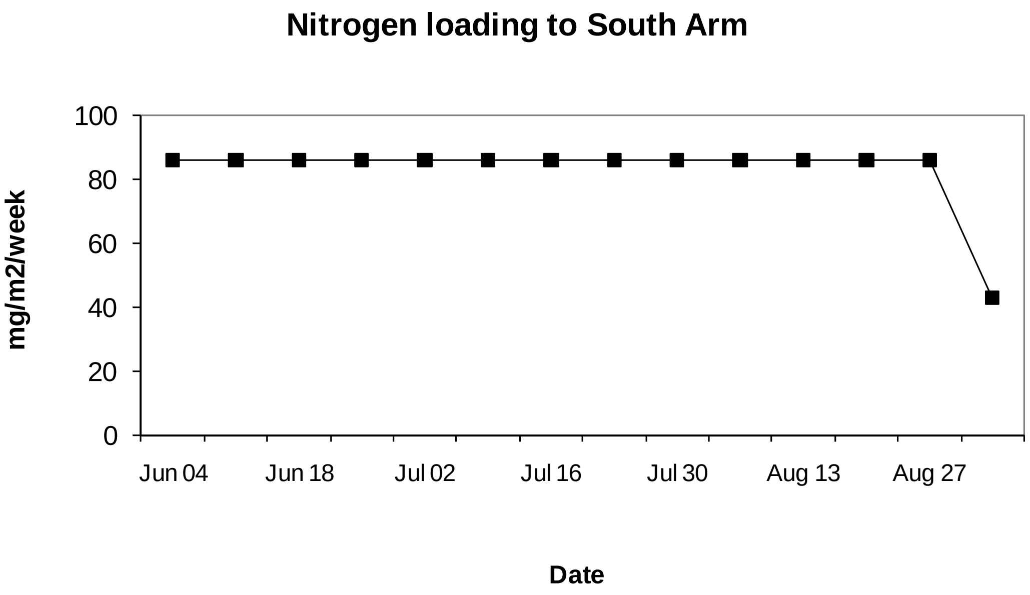

Figure 2.4. Weekly nitrogen inputs from fertilizer to the South Arm, April through September, 2008.

CHAPTER 3

PHYSICAL AND CHEMICAL LIMNOLOGY AND PHYTOPLANKTON OF KOOTENAY LAKE IN RESPONSE TO NUTRIENT ADDITION, YEAR 17 (NORTH ARM) AND YEAR 5 (SOUTH ARM) (2008)

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Introduction

Carefully monitored additions of limiting nutrients were used as a restoration technique for reversing oligotrophication (Ney 1996) of the Kootenay Lake ecosystem. Nutrient losses, resulting from upstream hydro-electric impoundment in the late 1960s and early 1970s, caused Kootenay Lake to shift from oligtotrophic to ultra-oligotrophic which triggered a decline of the keystone species, kokanee (*Oncorhynchus nerka*).

Nutrient additions have been used in British Columbia, Alaska, Idaho and Sweden as a technique for rebuilding depressed sockeye, kokanee and other salmonids in lakes and reservoirs. (Stockner and MacIssac 1996, Ashley et al. 1999, Mazumder and Edmundson 2002, Pieters et al. 2003a, b, Perrin et al. 2006, Rydin et al. 2008).

The strategy of the nutrient restoration program was to use a 'bottom up' approach to rebuild depressed kokanee and rainbow trout (*Oncorhynchus mykiss*) populations (Ashley et al. 1997). Nitrogen and phosphorus, in the form of liquid agricultural grade fertilizer (N; as 28-0-0, urea ammonium nitrate, N-P_2O_5-K_2O) (P; as 10-34-0, ammonium polyphophate) have been added annually to the North Arm of Kootenay Lake from mid-April through mid-September since 1992 (see Chapter 2 in this report). Nutrient additions of nitrogen only (as 28-0-0) commenced in the South Arm in 2004.

Phytoplankton consist of a diverse community of free-floating algae classified into a few major algal groups. The composition of the taxonomic community in the ecosystem is affected by each groups differing physiological requirements, and the heterogeneous physical, chemical and biological properties in a lake. Community structure and composition affect the transfer of energy from one trophic level to another and is important for biological success in aquatic ecosystems (Horne and Goldman, 1980).

Successful recruitment of fish depends partly on sufficient food supply (Beauchamp, 2004) and on food quality (Danielsdotter et al. 2007). Earlier work has shown that the preferred food source for kokanee is *Daphnia spp.*, a herbivorous zooplankton species (Thompson, 1999), which in turn mainly ingest nanoplankton, phytoplankton that range in size from 2.0-20.0 μm. Oligotrophic conditions tend to favor the growth of smaller sized phytoplankton (picoplankton, 0.2-2.0 um) due to their high nutrient uptake and growth rates (Stockner, 1987). During light applications of nutrients, the picoplankton fraction respond first, but at an increased nutrient load, there is a shift to a higher contribution by the nanoplankton and microplankton fractions (Stockner, 1987). Microplankton are considered inedible by zooplankton. Given that the community composition and the size structure of phytoplankton can quickly change with the application of nutrients, the trophic levels need to be closely monitored, as it can affect the transfer of food through the food web and directly influence the recovery of kokanee.

This report summarizes the physical and chemical limnology and phytoplankton data collected on the North, South and West arms of Kootenay Lake in 2008. Data from previous years can be found in previous annual reports (Schindler et al. 2006, 2007a, b, 2009, 2010).

Methods

Physical and chemical data were collected at pre-established Kootenay Lake Fertilization (KLF) sampling sites simultaneously with the collection of phytoplankton samples (Chapter 1, Figure 1.1). Monthly sampling was conducted from April to November at eight stations – four in the North Arm, three in the South Arm and one in the West Arm (KLF 1-8) (Table 3.1) (Fig 1.1 in Chapter 1).

Table 3.1. Kootenay Lake Nutrient Restoration 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

Physical Limnology

Temperature and oxygen profiles were obtained using a SeaBird, SBE 19-plus profiler. At all stations, the profiler logged information every 10 centimeters from the surface to 5 m off the bottom. The SeaBird also recorded oxygen, specific conductance and turbidity. These data are not shown in graphs or tables but are mentioned in the text. Conductivity and turbidity were analyzed by the water chemistry lab, and these data are graphed. Water transparency was measured at each station using a standard 20-cm Secchi disk without a viewing chamber.

Chemical Limnology

Water samples were collected at stations KLF 1-8 from April through November using a 2.54-cm (inside diameter) tube sampler to collect an integrated water sample from 0-20 m. A Van Dorn bottle was used to collect hypolimnetic water samples (5 m off the bottom) at stations KLF 1-4 and KLF 5-7 from May to October (Table 3.1). Water samples were placed in coolers on icepacks and shipped within 24 h of collection to Maxxam Analytics, Inc. in Burnaby, B.C. Samples were analyzed for turbidity, pH, conductivity, total phosphorus (TP), total dissolved phosphorus (TDP), orthophosphate (OP), total nitrogen, nitrate and nitrite, silica, alkalinity and total organic carbon (TOC). Chlorophyll *a* (Chl *a*) was analyzed by the Ministry of Environment, University of British Columbia. Prior to shipping, Chl *a* samples were prepared by filtering a portion of the integrated water sample through a filter with 0.45 µm pore size.

The integrated depth was changed from 30 m in previous years to 20 m as 20 m is more representative of the epilimnetic layer in Kootenay Lake. The 30-m depth used (up to and including 2003) occasionally penetrated the thermocline at times during the summer months and was therefore not fully representative of the epilimnetic layer. The integrated sample to 20 m is the same as the depth range used to collect integrated samples for phytoplankton taxonomy. Previous years' phytoplankton samples were collected to a depth of 20 m.

Additional water samples were taken at discrete depths in the epilimnion using a Van Dorn sampling bottle from June to September at stations KLF 2, 4, 6, and 7. Samples were obtained from depths of 2, 5, 10, 15, and 20 m for analysis of OP, TP, TDP, DIN, and Chl *a*.

Phytoplankton

Water samples were collected at stations KLF 1-8 from April through November using a 2.54-cm (inside diameter) tube sampler to collect an integrated water sample from 0-20 m. Water samples were collected using a Van Dorn bottle at stations KLF 2, 4, 6 and 7 from June through September at depths of 2, 5, 10, 15 and 20m at each station. Samples were preserved Lugol's iodine solution and stored in the dark prior to processing.

Laboratory Analysis

Phytoplankton Enumeration – Integrated samples

Subsamples of integrated water column samples were preserved for phytoplankton analysis using Lugol's iodine solution. Enumerations were made on settled material (Utermöhl 1938, Lund et al. 1958), using a Leitz Dialux 22 light microscope. 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 (from F. Pick et al. 2010).

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).

Total biomass was further separated into seven main divisions: Cyanobacteria, Chlorophyta, Chrysophyta, Cryptophyta, Bacillariophytes and Pyrrhophyta

Phytoplankton Enumeration – Discrete samples

Phytoplankton enumeration was typically performed within 15 days of receiving the samples. Prior to quantitative enumeration, the samples were gently shaken for 60 seconds and allowed to settle in a 25 mL settling chamber for a minimum of 6-8 hours. Counts were done using a Carl Zeiss inverted phase-contrast plankton microscope. Initially, several random fields (5-10) were examined at low power (250x magnification) for large microplankton (20-200 µm), including colonial diatoms, dinoflagellates and filamentous blue-greens. A second step involved counting all cells at high power (1,560x magnification) within a single random transect that was 10-15 mm long. This high magnification permitted quantitative enumeration of minute (<2µm) autotrophic picoplankton sized cells (0.2-2.0 µm, Cyanophyceae), and small nanoflagellates (2.0-20.0 µm Chrysophyceae and Cryptophyceae). In total, about 175-225 cells were enumerated from each sample to ensure statistical accuracy (Lund et al. 1958). Taxonomic identifications were performed using the keys of Prescott (1978) and Canter-Lund and Lund (1995). The phytoplankton species and biomass list used for the computation of population and class biomass estimates for Kootenay Lake in 2008 appears in Appendix 1 (from Stockner 2007; in Schindler et al. 2007).

Results and Discussion

Physical Limnology

Temperature

The main body of Kootenay Lake (stations KLF 1-7) begins warming in May with a strong thermocline developing by July and a maximum surface temperature occurring in August (Figs 3.1-3.7).

The shallow, riverine West Arm of Kootenay Lake is different from the main basin of the lake, with physical and chemical limnology similar to that of the epilimnion of the main lake (Daley et al. 1981). From April to June and September to November, temperatures were fairly uniform from the surface to the bottom depth (Table 3.2).

A maximum surface temperature of 20.4ºC was recorded in August at station KLF 7 in the South Arm. The maximum surface temperature in the North Arm was 18.0ºC in August at station KLF 3. During the same time, hypolimnetic temperatures remained 4-6ºC throughout the year. There were issues with the SeaBird logging information correctly in July and August; therefore a maximum temperature for 2008 is not available.

Table 3.2. Seasonal mean (± 1 standard deviation), maximum, and minimum temperatures in the West Arm (KLF 8) taken at 0-35 m depths, 2008.

Month	Mean	+SD	Maximum	Minimum
April	4.5	0.17	5.2	4.4
May	5.7	0.11	7.3	5.7
June	8.7	0.15	9.3	8.6
September	15.0	0.29	16.5	14.5
October	13.6	0.32	13.8	9.3
November	10.4	0.01	10.4	10.4

Spatial and temporal differences in stratification between the North and the South arms exist due to variation in temperature and discharge regimes from the Duncan/Lardeau rivers in the north and Kootenay River in the south which are regulated by upstream hydroelectric dams and reservoirs. Surface inflows are probably the most important sources affecting water quality conditions of this large lake system (Northcote et al. 1999). The Kootenay and Duncan rivers comprise 56% and 21% of the total inflow to Kootenay Lake, respectively (Binsted and Ashley 2006). Other differences in the thermal structure of the North and South arms are also caused by many complex interactions of surface-driven processes (wind and heat exchange) and internal wave dynamics within Kootenay Lake (Northcote et al. 1999).

Dissolved Oxygen

Results of oxygen profiles were similar to previous years. Kootenay Lake is well oxygenated from the surface to the bottom depths at each station (data on file at the Ministry of Environment). Nutrient enrichment has had no detectable effect on the concentration of hypolimnetic oxygen in Kootenay Lake.

Secchi Depth

In 2008, Secchi depths varied seasonally from summer to winter from 0.91 m to 11.9 m in the North Arm, 2.4 m to 13.4 m in the South Arm, and 2.4 m to 11.6 m in the West Arm (Fig 3.8). Similar to past years, Secchi disc measurements at all stations on Kootenay Lake in 2008 indicated a typical seasonal pattern of decreasing transparency associated with the spring phytoplankton bloom, followed by increasing transparency as photosynthesis decreases by late summer and fall. In early July, the North Arm experienced higher turbidity due to increased sediment loads from the Lardeau River (Fig. 3.10) The reduction in Secchi depth was therefore due to turbidity from inflowing water rather than phytoplankton biomass increases.

Since 1992, average Secchi depths decreased in transparency to 1997 and have shown an increased trend to 2008 (Fig 3.9). During some years, the confidence intervals had a wider range which is indicative of more pronounced seasonal trends in transparency.

Turbidity

Results at stations KLF 1 to KLF 4 in the North Arm in 2008 indicated a general increase from April to July and then a decline through the summer and into the fall (Fig 3.10). The peak in July coincided with a turbid event from a tributary to the Lardeau River - the lake became turbid due to increased particulate matter entering the lake from the inflowing glacially turbid Duncan River. This trend coincided with the seasonal trend of Secchi depth measurements in the North Arm (Fig. 3.8). Turbidity at stations KLF 5 to KLF 7 in the South Arm had a similar trend to the North Arm with the exception that peak turbidity occurred in June. The results at station KLF 8 in the West Arm followed a similar trend to the South Arm.

Averages from 1992 through 2008 ranged from 0.23 to 0.77 NTU in the North Arm and 0.22 to 1.04 NTU in the South Arm (Fig. 3.11). The greatest variation in confidence intervals occurred in 1997 and 2002.

Conductivity

Conductivity or specific conductance is a measure of resistance of a solution to electrical flow (Wetzel 2001). Results from integrated 0-20 m samples ranged between 130-170 µS/cm in the North Arm, between 140 – 180 µS/cm in the South Arm, and between 140 – 170 µS/cm in the West Arm in 2008 (Figure 3.12).

Average specific conductance from 1992 through 2008 varied from 131 – 169 µS/cm in the North Arm and 149 – 188 µS/cm in the South Arm (Fig. 3.13). Conductivity in the South Arm was higher than the North Arm; this is consistent to observations reported in Northcote et al. (1999) and Daley et al. (1981). The differences between the North and South arms are attributed to the surficial geology of the two major drainage basins that flow into Kootenay Lake.

Chemical Limnology

Integrated Sampling 0-20 m

Phosphorus

Total phosphorus (TP) samples, taken at 0-20 m ranged between 2 - 15 µg/L in the North Arm, 2 - 8 µg/L in the South Arm, and 2 - 10 µg/L in the West Arm (Figure 3.14). (The detection limit for phosphorus analyses is 2 µg/L – some of the results were at the detection limit). The result of 15 µg/L in the North Arm at station KLF 3 in May may be an outlier as the other values were between 4 - 10 µg/L. Peak total phosphorus occurred in May at all stations. Seasonal variation in the results was similar amongst the North, South and West arms of the lake.

The average total phosphorus in Kootenay Lake ranged between 2.7 - 14 µg/L from 1992 to 2008 (Fig. 3.15) indicative of an oligotrophic to oligo-mesotrophic system (Wetzel 2001). The peak concentration occurred in 1997 when turbidity was also high and discharge from the Kootenay River was also higher than average (Binsted and Ashley 2006). Total phosphorus has gradually declined in both the North and South arms of Kootenay Lake since the peak in 1997. A detailed overview of phosphorus inputs to Kootenay Lake from tributaries is described in Binsted and Ashley (2006).

Total dissolved phosphorus (TDP) ranged between 2 - 10 µg/L in the North Arm, 2 - 6 µg/L in the South Arm, and 3 - 7 µg/L in the West Arm (Fig 3.16). The North and South arms had similar trends in seasonal TDP with the peak concentration occurring in May. The trend of higher TDP results in the spring in the North Arm is likely a result of the phosphorus additions from fertilizer (see Chapter 2 for detailed nutrient additions).

The average total dissolved phosphorus ranged between 2.2 and 6.7 µg/L from 1992 to 2008 (Fig. 3.17). The peak years occurred in 1996 and 2007 in the North Arm and 1996, 1997 and 2007 in the South Arm. The South Arm results coincide with higher phosphorus inputs from the Kootenai/y River in 1996 and 1997 (Fig. 3.18). The North Arm results do not coincide with inputs from the Duncan River (Fig. 3.19).

Nitrogen

In fresh water, complex biochemical processes utilize nitrogen in many forms consisting of dissolved molecular N_2, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, and organic nitrogen. A major source of nitrogen in lakes is the nitrate in precipitation in their watersheds (Horne and Goldman, 1994). Nitrate is the most abundant form of inorganic nitrogen in lakes (Horne and Goldman, 1994). Total nitrogen is comprised of dissolved inorganic forms (i.e., nitrate, nitrite and ammonia) and particulate nitrogen (mainly organic).

Total nitrogen (TN) ranged between 90 - 240 µg/L in the North Arm, 70 – 280 µg/L in the South Arm and 70 - 200 µg/L in the West Arm (Fig. 3.20). The trend of TN decreased from spring to summer and then increased again during the fall. This is due to the dissolved inorganic nitrogen component declining from spring to summer (see the next section in this report).

Average TN values were 156 - 239 µg/L in the North Arm and 143 - 213 µg/L in the South Arm (Fig. 3.21). The highest TN value occurred in 2001 in the North Arm and in 2000 in the South Arm. There was a trend in declining TN after the peaks in 2000 and 2001; this coincides with declining dissolved inorganic nitrogen.

Dissolved inorganic nitrogen (DIN), consists of nitrite, nitrate and ammonia. Nitrate and ammonia are the forms of nitrogen most readily available to phytoplankton (Wetzel 2001). Ammonia is generally at the minimum detection limit of 5 µg/L in Kootenay Lake. Ammonia was not analyzed in 2008; therefore the dissolved inorganic nitrogen is represented by the nitrate and nitrite data. Dissolved inorganic nitrogen comparisons from 1992 to 2008 are discussed below.

Nitrate and nitrite nitrogen concentrations ranged between 40 – 170 µg/L in the North Arm, 39 – 168 µg/L in the South Arm, and 18 – 151 µg/L in the West Arm (Fig 3.22). The lowest concentrations occurred in July or August depending on the station (Fig. 3.22). The decline from spring to summer is due to increased photosynthetic activity and increased phytoplankton biomass.

The range of average DIN concentrations have been 62 - 140 µg/L in the North Arm and 62 - 130 µg/L in the South Arm since 1992 (Fig. 3.23). The lowest average concentration occurred in 1995 while the highest result reported in 2000.

Silica

Silica (dissolved) is an integral structural component in diatomaceous algae and is considered a major factor influencing algal production in many lakes (Wetzel 2001). Silica can be considered a limiting factor in diatom production when its availability is low.

Dissolved reactive silica ranged between 2.8 – 7.5 mg/L in the North Arm and 2.9 – 7.5 mg/L in the South Arm and 3.1 – 7.2 mg/L in the West Arm (Fig 3.24). Declining silica concentrations from spring to summer and increasing by fall were observed for all three arms of Kootenay Lake in 2008. This trend coincides with the trend of bacillariophytes; the highest biomass occurred in August where they would utilize the most silica for growth, thereby decreasing the silica in the water column.

Since 1992, average annual silica concentrations on Kootenay Lake varied between 3.2 - 5.5 in the North Arm and 4.0 - 6.1 mg/L in the South Arm (Fig. 3.25).

pH and Alkalinity

In 2008, pH in Kootenay Lake indicated slightly alkaline conditions, ranging from 7.8 – 8.2 in the North Arm, 7.9 to 8.3 in the South Arm and 7.9 to 8.1 in the West Arm.

Alkalinity is the buffering capacity of lake water (i.e., the sum of the titratable bases) to resist pH changes and involves the inorganic carbon components in most fresh waters (Wetzel 2001). Alkalinity ranged between 53 - 69 mg $CaCO_3$/L in the North Arm, 60 – 77 mg $CaCO_3$/L in the South Arm, and 57 - 71 mg $CaCO_3$/L in the West Arm (Fig 3.26). Alkalinity decreased from April to July and then increased to November in the North Arm while in the South and West arms alkalinity decreased through June and started to increase through November.

Since 1992, the average alkalinity varied between 58 - 65 mg $CaCO_3$/L in the North Arm and 65 – 74 mg $CaCO_3$/L in the South Arm (Fig. 3.27). The South Arm has remained more alkaline compared to the North Arm, most likely as a result of the geology of the Kootenay River basin.

Total Organic Carbon

Total organic carbon (TOC) includes both dissolved and particulate organic carbon (Wetzel 2001). Dissolved carbon dioxide and bicarbonate (both forms of inorganic carbon) are the major sources of inorganic carbon for photosynthesis in freshwater systems. Utilization of inorganic carbon provides the foundation for much of the organic productivity in an ecosystem.

Total organic carbon ranged between 0.5 – 5.9 mg/L in the North Arm, 0.7 – 3.6 mg/L in the South Arm, and 0.9 - 3.6 mg/L in the West Arm (Fig. 3.28). The North Arm results peaked in July, decreased through September and increased in early October. The South Arm TOC also peaked in July, except for the result from station KLF 5 which peaked in June, and results declined through the remainder of the sampling season. The TOC in the West Arm (KLF 8) was similar through the sampling season with a peak in early October.

Since 1997, TOC averaged 1.0 - 1.6 mg/L in the North Arm and 1.2 – 1.9 mg/L in the South Arm (Fig. 3.29). These values are consistent with oligotrophic ecosystems (Wetzel 2001). The values suggest that the lake does not receive large allochthonous organic inputs or produce large amounts of autochthonous organic carbon.

Chlorophyll a

Chlorophyll *a* (Chl *a*), a photosynthetic pigment, is a primary characteristic of all photosynthetic algae. Concentrations of this pigment are often associated with a lake's algal biomass and are representative of its overall standing stock biomass.

Chlorophyll *a* ranged between 0.4 and 2.8 µg/L in the North Arm, 0.1 and 2.4 µg/L in the South Arm, and 0.6 to 2.1 µg/L in the West Arm in 2008 (Fig. 3.30). Over the sampling season, chlorophyll *a* peaked in August in the North Arm and in July and August in the South Arm.

Average chlorophyll *a* ranged between 0.9 and 3.6 ug/L in the North Arm and 1.0 to 3.5 in the South Arm during the 1992 to 2008 period (Fig. 3.31). The lowest concentration occurred in 2008 in both arms and the highest occurred in 1996 and 2002 in the North Arm and South Arm respectively.

Discrete Sampling

Total Dissolved Phosphorus

Total dissolved phosphorus concentrations were similar between the North and South Arms except in June. Results from KLF 2 were higher (peaks of 5 and 4 µg/L at 5 and 10 meters, respectively) than the other stations (Fig. 3.32).

Dissolved Inorganic Nitrogen

Nitrate and nitrite contribute to the majority of dissolved inorganic nitrogen – ammonia is generally at the minimum detection limit of 5 µg/L in Kootenay Lake. Ammonia was not analyzed in 2008; therefore the dissolved inorganic nitrogen is represented by the nitrate and nitrite data. Nitrate and nitrite was highest in June, declined in July and August and then increased again in September at all stations except at KLF 7 where the peak nitrate and nitrite concentrations occurred in July (Fig. 3.33). The decrease in nitrate and nitrite over the season is indicative of nitrogen uptake by phytoplankton. The minimum concentration of nitrate was 16, 17 and 19 µg/L at depths of 2, 5 and 10 meters, respectively in July at station KLF 7. A nitrate concentration of 20 µg/L or less is considered to be limiting for phytoplankton (Wetzel, 2001, Ashley and Stockner, 2003). The concentration of nitrate was greater than 20 µg/L at the other three stations throughout the season.

Nitrogen to phosphorus ratios (dissolved fractions) (weight:weight) generally were higher than 10:1 throughout the season (Fig. 3.34). A ratio of 10:1 is considered to be nitrogen limiting for phytoplankton growth (Horne and Goldman, 1994). The ratios were less than 10:1 at station KLF 7 in July at depths of 2, 5 and 10 meters. By August the ratios increased to 19:1, indicative of P limitation The N:P ratios were higher in the North Arm than the South Arm during July and August. The lower N:P ratios in the South Arm further supports the rationale to only add nitrogen to the South Arm (details of nutrient additions are in Chapter 2).

Chlorophyll a

Chlorophyll *a* in discrete profiles ranged from 0.2 to 2.6 ug/L in the North Arm and 0.2 to 2.8 ug/L in the South Arm (Fig. 3.35). The highest concentrations occurred in August at all stations. These results correspond with the phytoplankton data.

Hypolimnion samples

Turbidity

Turbidity results ranged from 0.2 to 0.7 NTU in the North Arm and 0.2 to 0.5 in the South Arm (Fig. 3.36). The highest turbidity occurred in May.

Conductivity

Specific conductance ranged from 170 to 195 µS/cm in the North Arm and 190 to 200 µS/cm in the South Arm (data on file at MoE, Nelson).

Phosphorus

Total phosphorus (TP) ranged from 3 – 13 µg/L in the North Arm and 3 – 12 µg/L in the South Arm (Fig. 3.37). The peak concentrations occurred in May at most stations; the peak occurred in July at station KLF 1 and August at station KLF 7. Total dissolved phosphorus followed a similar seasonal pattern with concentrations ranging between 2 – 7 µg/L and 2 - 11 µg/L in the North and South arms respectively with the peak occurring in May.

Silica

Silica results ranged from 5.3 – 7.6 mg/L in the North Arm and 5.4 - 8.8 mg/L in the South Arm (Fig. 3.38). There was no seasonal pattern of silica as was noted in the epilimnetic samples (Fig. 3.24) This is due to algal photosynthesis not occurring in the hypolimnion.

Alkalinity

Alkalinity ranged from 72 – 80 mg Ca CO_3/L in the North Arm and 77 – 88 mg Ca CO_3/L in the South Arm (Fig. 3.39). There was no seasonal pattern as observed in the integrated samples collected from the epilimnion (Fig. 3.26).

Phytoplankton results

Integrated samples

Phytoplankton biomass from 0-20 m integrated samples were dominated by chryso/cryptophytes in the spring (April to June) and bacillariophytes from July onward. Peak biomass occurred at all stations in August except at station KLF 8 (West Arm) where the peak occurred in July (Fig. 3.40). The high biomass in August was dominated by *Cyclotella* sp., *Asterionella formosa*, *Fragilaria crotonensis* and *Tabellaria* sp.

Spatial and temporal variation in phytoplankton is usually uneven in lakes and can be affected by various factors including zooplankton grazing (Horne and Goldman 1994). There is statistical significance temporally for total biomass in 2008 (ANOVA p = <0.0001). To test the variability between sampling dates, monthly comparisons of whole lake total biomass were run using a students t-test. Significant differences (P<0.0001) were observed between August and April, August and November, August and October, August and May, August and June, July and April, July and November, July and October, July and May, July and June. These results indicate the importance of ensuring there is adequate monitoring from April through the fall. Seasonal variation of total biomass was tested by comparing the spring, summer and fall data. A significant difference (p<0.0001) between seasons was observed using ANOVA.

Discrete samples

North Arm – stations KLF 2 and KLF 4

Phytoplankton community composition was similar at both stations except in July where the biovolume of chryso/cryptophytes and bacillariophytes (diatoms) was higher at all depths at stations KLF 4 (Fig. 3.41). The higher biovolume of the chryso/cryptophytes was due to a bloom of *Mallomonas sp*. (edible species for macrozooplankton) and the higher biovolume of diatoms was due to a bloom of *Asterionella formosa* (inedible species for macrozooplankton). Peak biomass occurred in August at both stations with bacillariophytes contributing the highest percentage to the total (average of 65% and 66% at stations KLF 2 and KLF 4, respectively). The dominant species was *Fragilaria crotonensis*, an inedible species for zooplankton.

The seasonal pattern was dominated by chryso/cryptophytes in June, followed by bacillariophytes being the dominant group of phytoplankton in July, August and September. Macrozooplankton have higher biomass during these months (see Chapter 4 in this report), therefore the decrease in chryso/cryptophytes (the group considered most nutritious for zooplankton) could be attributable to a zooplankton grazing effect. In June, the chryso/cryptophytes accounted for 45% and 57 % of the overall biovolume at stations KLF 2 and KLF 4, respectively. During July, the contribution was 26% and 22%, in August, 13% (at both stations) and in September 27% and 20% respectively.

South Arm – stations KLF 6 and KLF 7

Phytoplankton community composition was similar amongst months except in June where chryso/cryptophytes were dominant at station KLF 6 and bacillariophytes were dominant at station KLF 7 (Fig. 3.42). Peak biovolume occurred in August at both stations with bacillariophytes contributing the highest percentage to the total (average of

82% and 85% at stations KLF 6 and KLF 7, respectively). At station KLF 6, *Fragilaria crotonensis* and *Tabellaria fenestrata* were the dominant species and at station KLF 7 *Tabellaria fenestrata* was the dominant species. In June, the chryso/cryptophytes accounted for 49% and 24 % of the overall biovolume at stations KLF 6 and KLF 7, respectively. During July, the contribution was 31% and 39%, in August, 6% and 8.5% and in September 28% and 30% respectively. The decrease in contribution of chryso/cryptophytes to overall biovolume could be attributed to a grazing effect of macrozooplankton.

Comparisons to other years - phytoplankton

Integrated samples

The annual average phytoplankton biomass from 1992 to 2008 ranged from 282 mg/m^3 to 2,267 mg/m^3 in the North Arm with the maximum occurring in 1997 (Fig. 3.43). The annual average phytoplankton biomass from 1992 to 2008 ranged from 286 mg/m^3 to 1,198 mg/m^3 in the South Arm with the maximum occurring in 1997 (Fig. 3.43). From 1992 to 2003, the averages amongst the North and South Arms varied greater than 2004 through 2008. From 1992 to 2003, only the North Arm was fertilized while in 2004 through 2008, both the North and South Arms were fertilized.

When using the statistics program JMP (SAS software) to analyze the data, the following was observed. On average, the differences between the north and south arms in the period 1992 to 2003 when using a one way ANOVA (F=37.8; p=<0.0001), there is a statistically significant difference between the two arms, with the North Arm having a larger annual average phytoplankton biomass. This is the period when only the North Arm was fertilized. During the years 2004 to 2008 (both the North and South Arms were fertilized), the one way ANOVA (F=0.0427; p=0.8365), the annual average of phytoplankton biomass in the North and South arms was not statistically different.

Discrete samples

The average phytoplankton abundance in the North Arm averaged over the five discrete depths and over the four month collection period was lower at station KLF 2 in 2008 compared to the 2005 to 2007 results. Abundance at station KLF 4 was similar. The average at stations KLF 6 was similar to previous years while the average at station KLF 7 was the highest since 2004 (Table 3.3). Biovolume follows a similar trend except the highest biovolume occurred in 2005.

Table 3.3. Average abundance and biovolumes from vertical profiles for Kootenay Lake in 2004 - 2008. Value was calculated as the mean of the five discrete depths over the 4 month collection period. Shading represents stations in the North Arm.

	Abundance (cells/mL)				
Station	**2004**	**2005**	**2006**	**2007**	**2008**
KLF 1	6205	6375	-	-	
KLF 2	4721	6062	6009	5925	5031
KLF 3	4846	5094	-	-	
KLF 4	5150	6003	-	5821	6068
KLF 5	4666	5684	-	-	
KLF 6	5021	5040	5300	4759	5204
KLF 7	3741	5255	4219	3856	5866
	Biovolume (mm^3/L)				
	2004	**2005**	**2006**	**2007**	**2008**
KLF 1	0.88	1.17	-	-	
KLF 2	0.75	1.15	1.11	1.02	0.59
KLF 3	0.69	1.01	-	-	
KLF 4	0.65	0.96	-	0.93	0.75
KLF 5	0.74	0.95	-	-	
KLF 6	0.80	0.85	1.04	0.78	0.72
KLF 7	0.60	0.91	0.73	0.62	0.83

Conclusion

The results of the 2008 nutrient enrichment, and the long term data from 1992 through 2008 indicate that Kootenay Lake is oligotrophic to oligo-mesotrophic based on nutrient and chlorophyll *a* concentrations. The discrete-depth sampling in 2008 indicated that the lake was not inorganic nitrogen limited except at one station in the South Arm in July.

Adaptively managing the weekly nutrient loading rates in 2008 resulted in N:P ratios favourable for phytoplankton growing conditions. Phytoplankton species composition is key for good zooplankton growth, especially *Daphnia*, the preferred prey item for kokanee. The edible fraction of phytoplankton provided an acceptable food base for herbivorous zooplankton (see Chapter 4 for details).

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SeaBird profiles at stations KLF 1, 3, 5 and 8 and all of the discrete depth profiles. The KTOI also provided funding for the discrete phytoplankton sampling and analysis at stations KLF 2, 4, 6 and 7. Thanks to Dr. Frances Pick of the University of Ottawa and Paul Hamilton and Linda Ley of the Canadian Museum of Nature, Ottawa for phytoplankton analysis of all integrated samples from stations KLF 1 – 8. Thanks to Dr. John Stockner of Eco-Logic Ltd, Vancouver for analysis of all discrete profile phytoplankton samples from stations KLF 2, 4 6 and 7. Thanks to Dr. Ken Ashley for reviewing this report.

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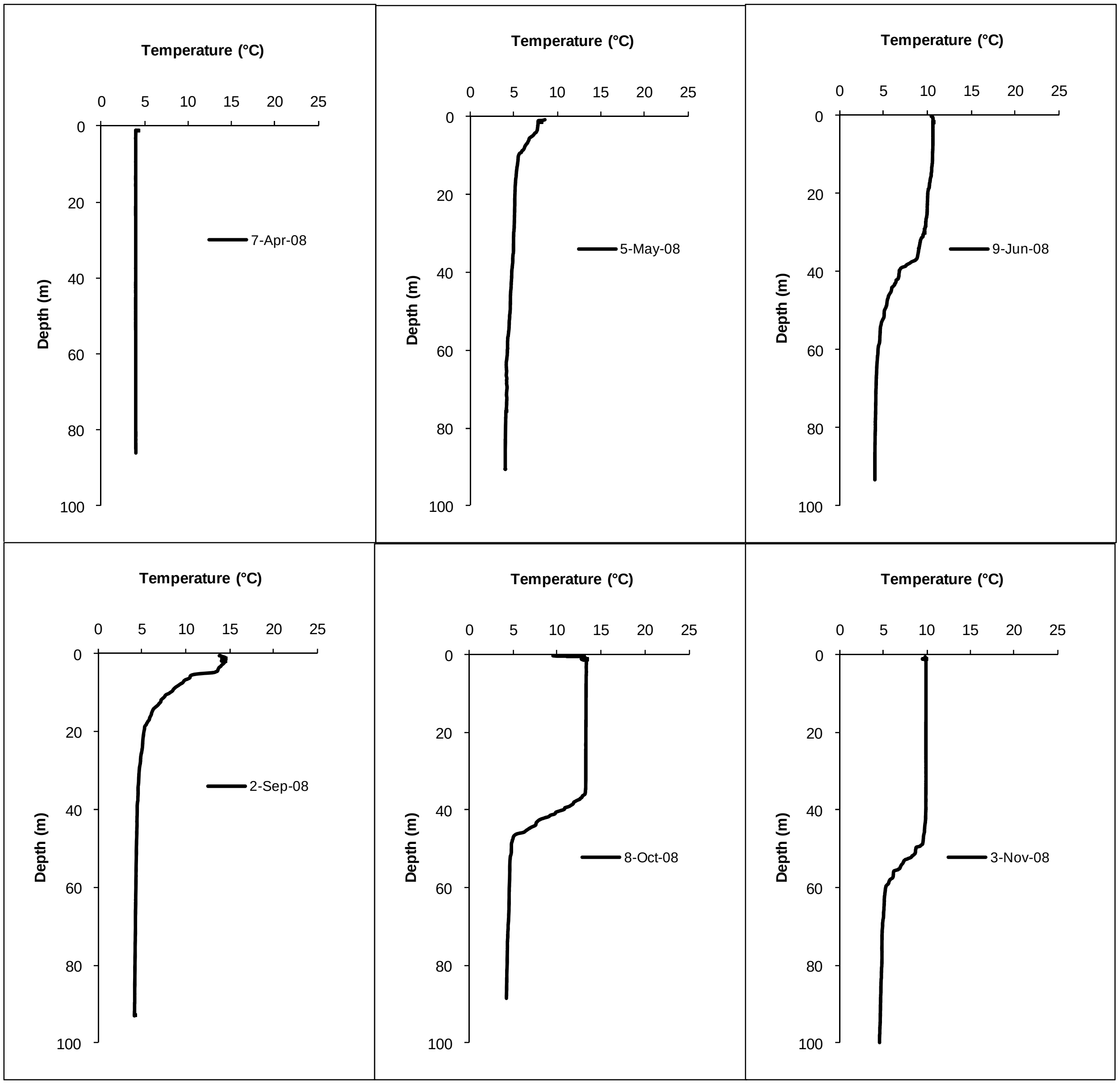


Figure 3.1. Temperature profiles from station KLF 1, April to June and September to November 2008.

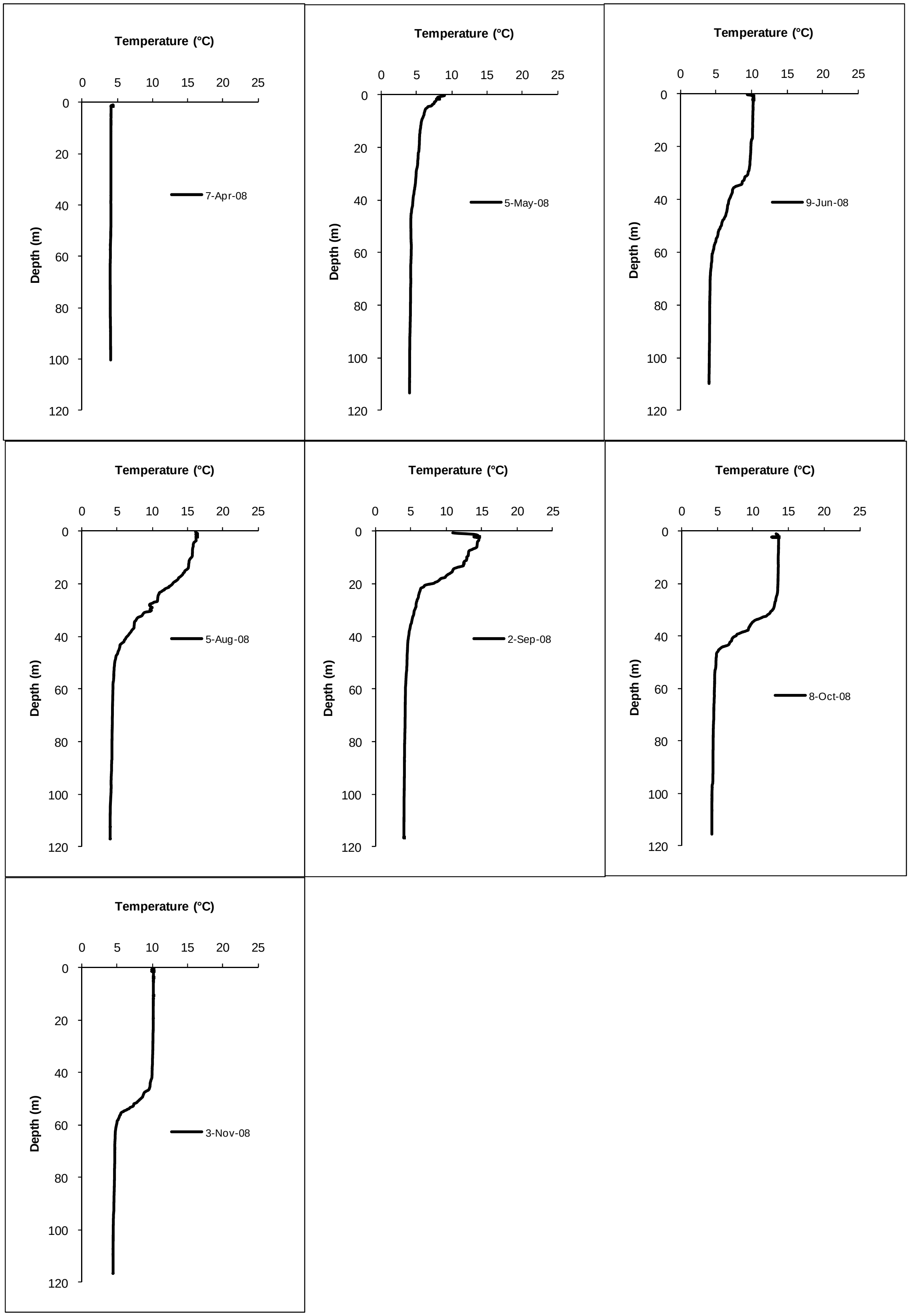


Figure 3.2. Temperature profiles from station KLF 2, April to June and August to November, 2008.

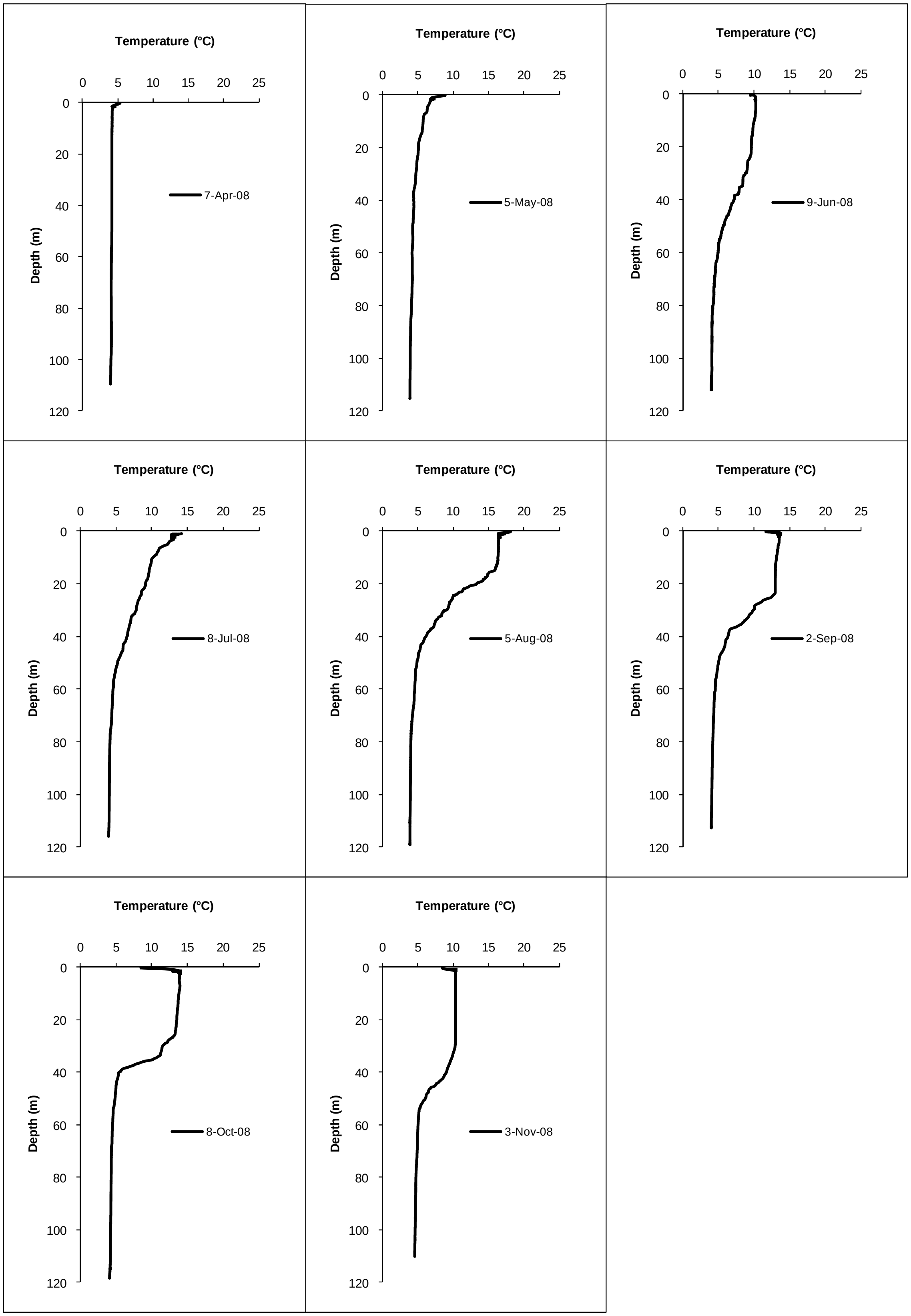


Figure 3.3. Temperature profiles from station KLF 3, April to November, 2008.

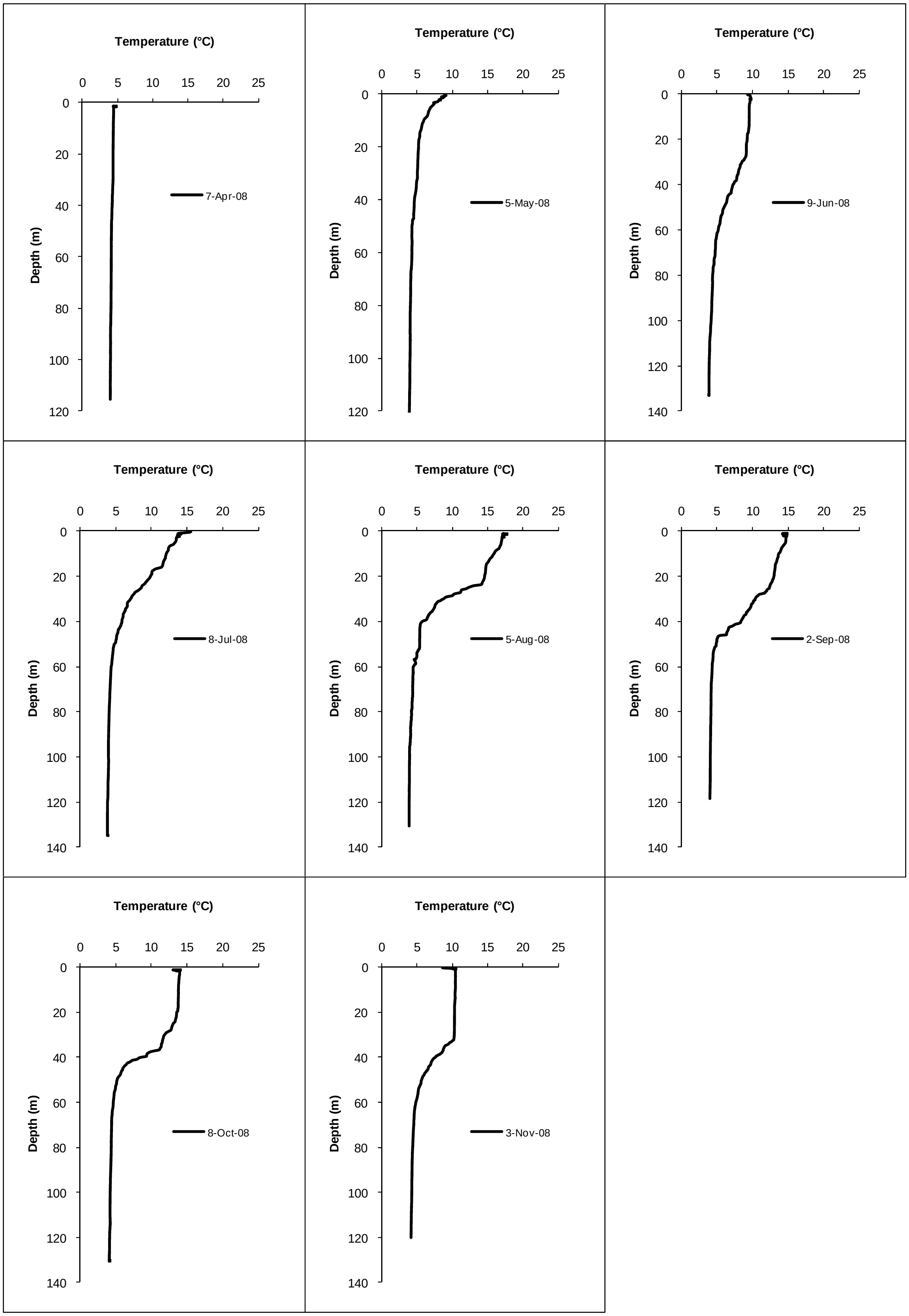


Figure 3.4. Temperature profiles from station KLF 4, April to November, 2008.

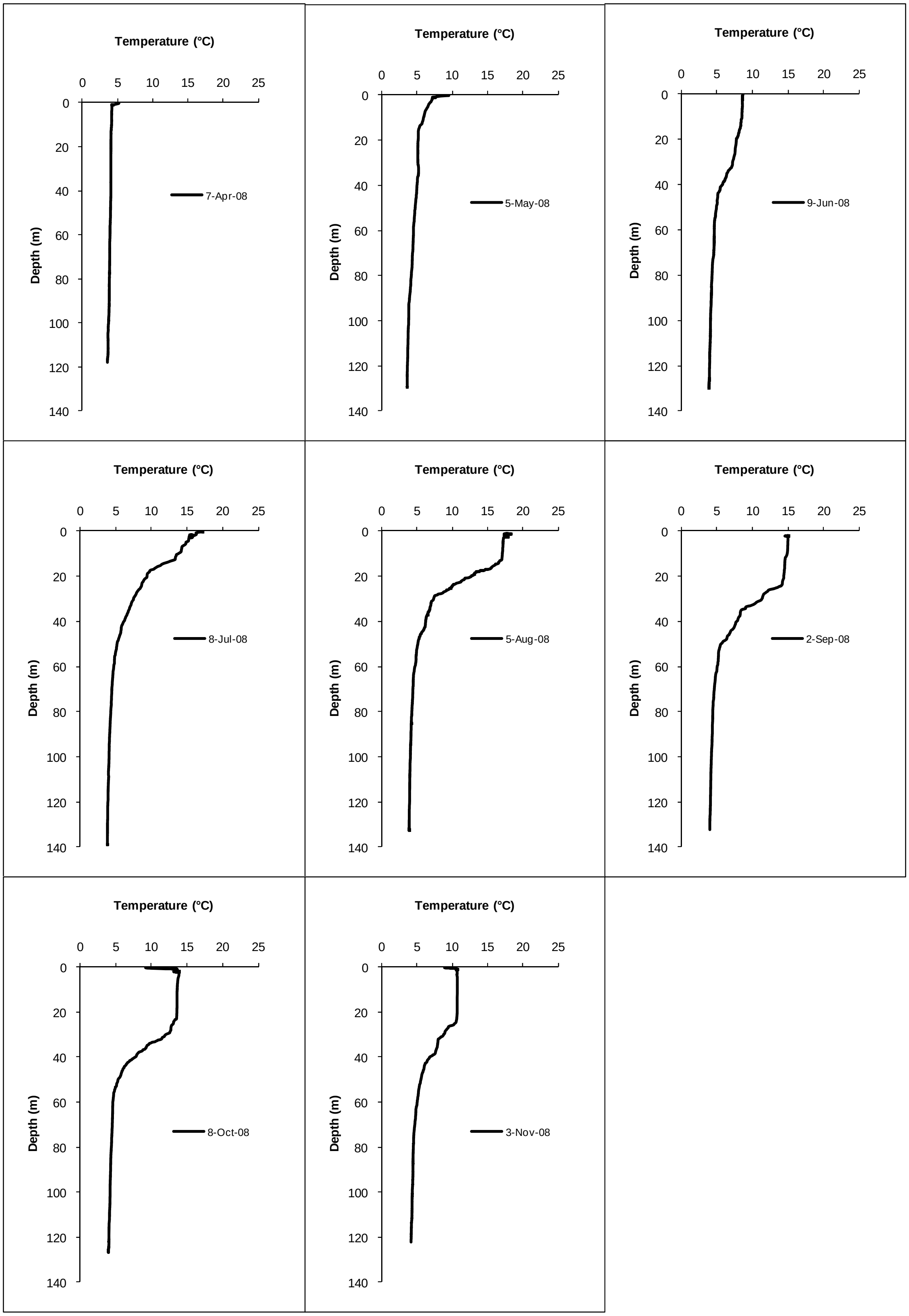


Figure 3.5. Temperature profiles from station KLF 5, April to November, 2008.

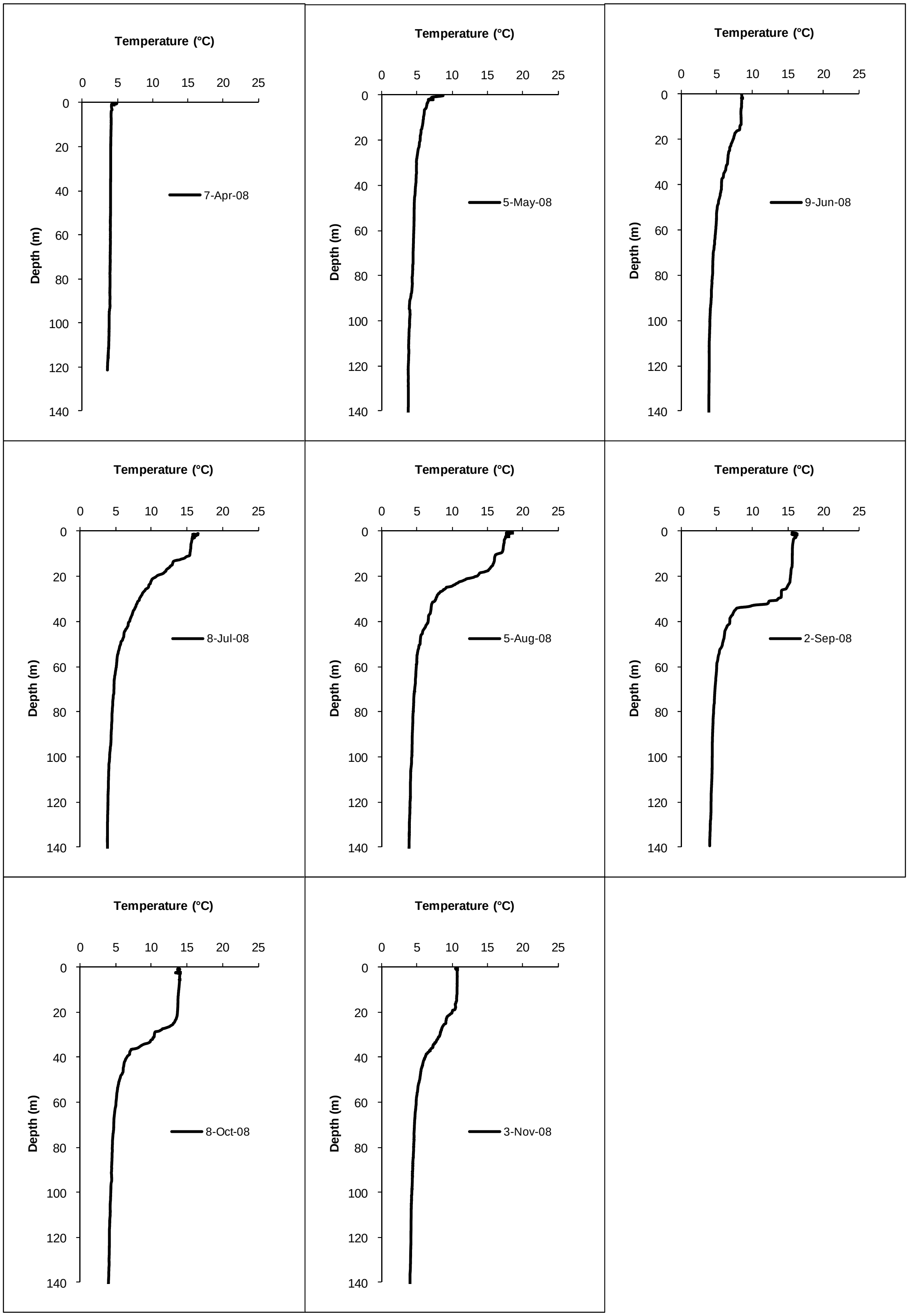


Figure 3.6. Temperature profiles from station KLF 6, April to November, 2008.

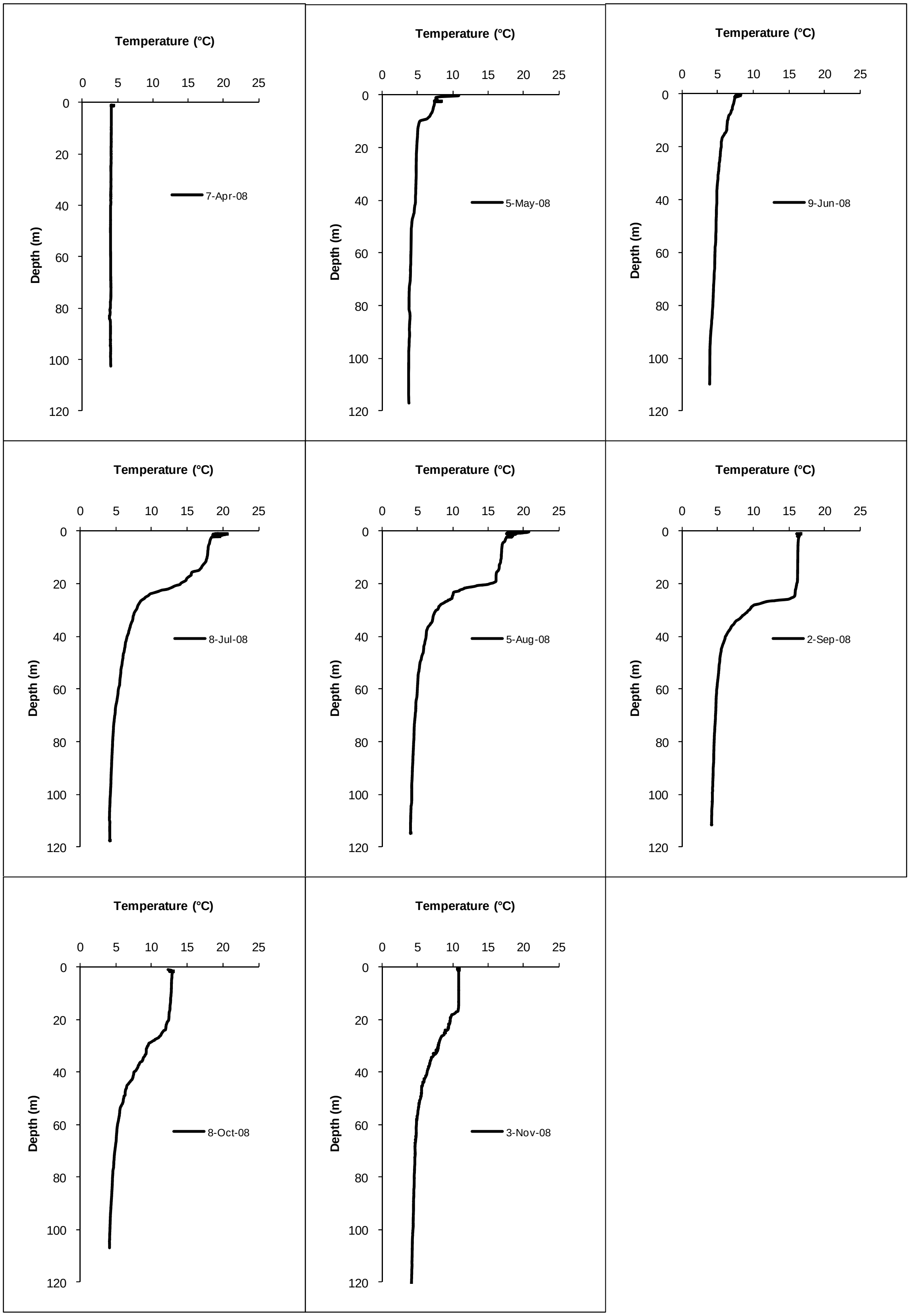


Figure 3.7. Temperature profiles from station KLF 7, April to November, 2008.

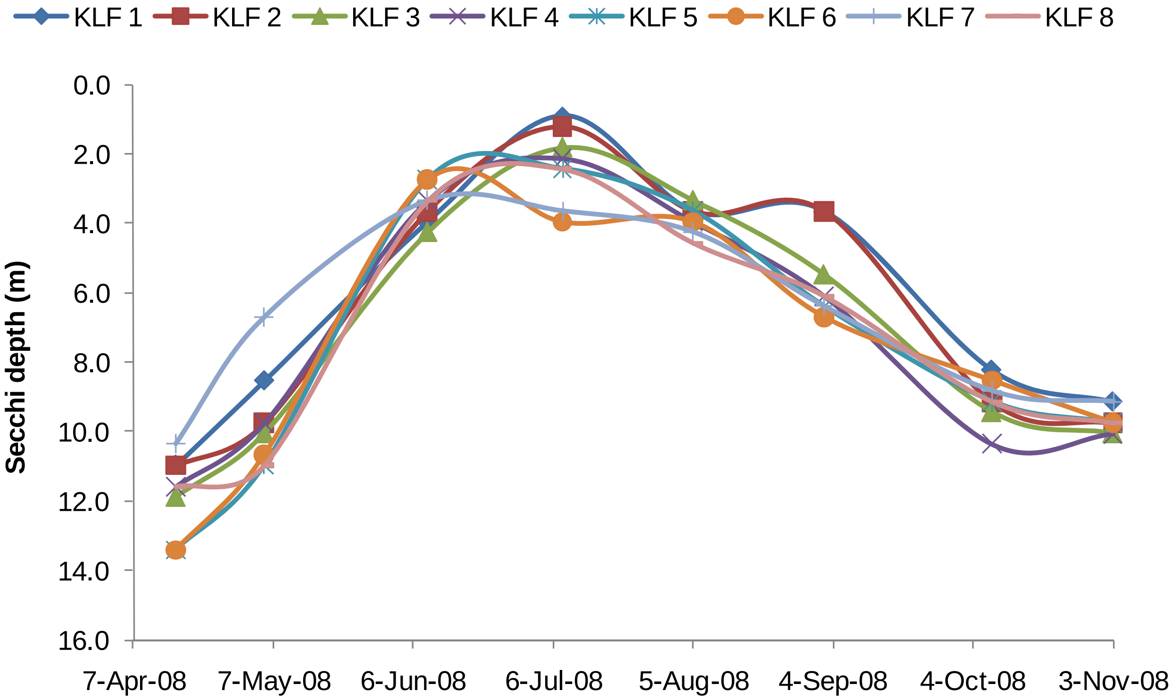


Figure 3.8. Seasonal Secchi depth measurements, April to November, 2008, KLF 1 – 8.

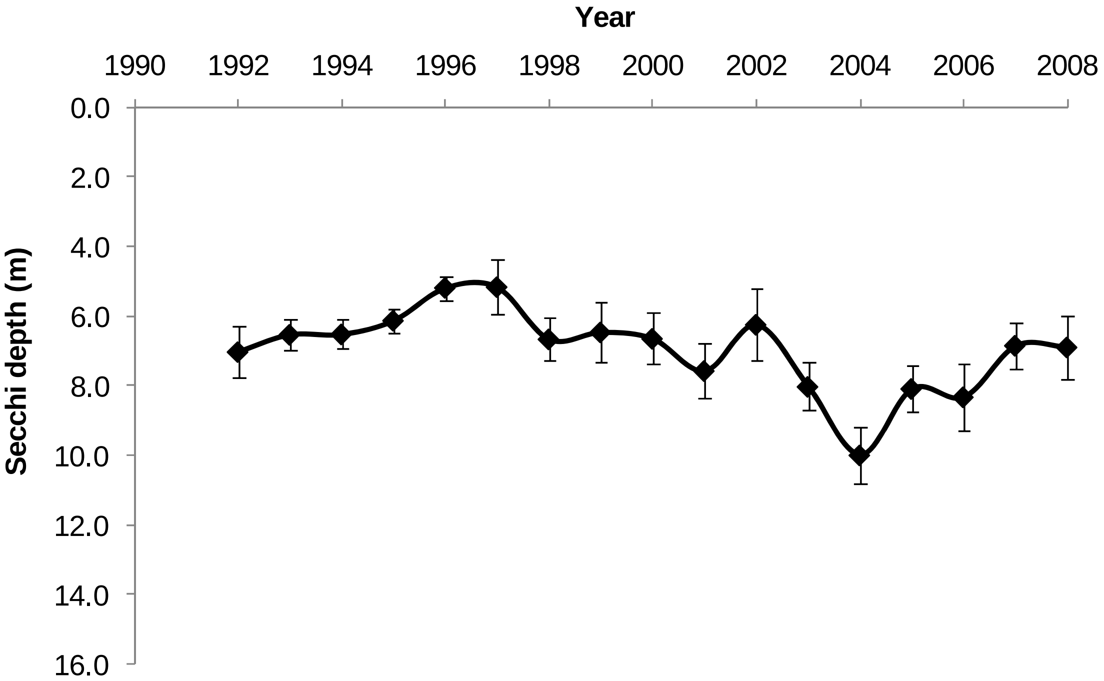
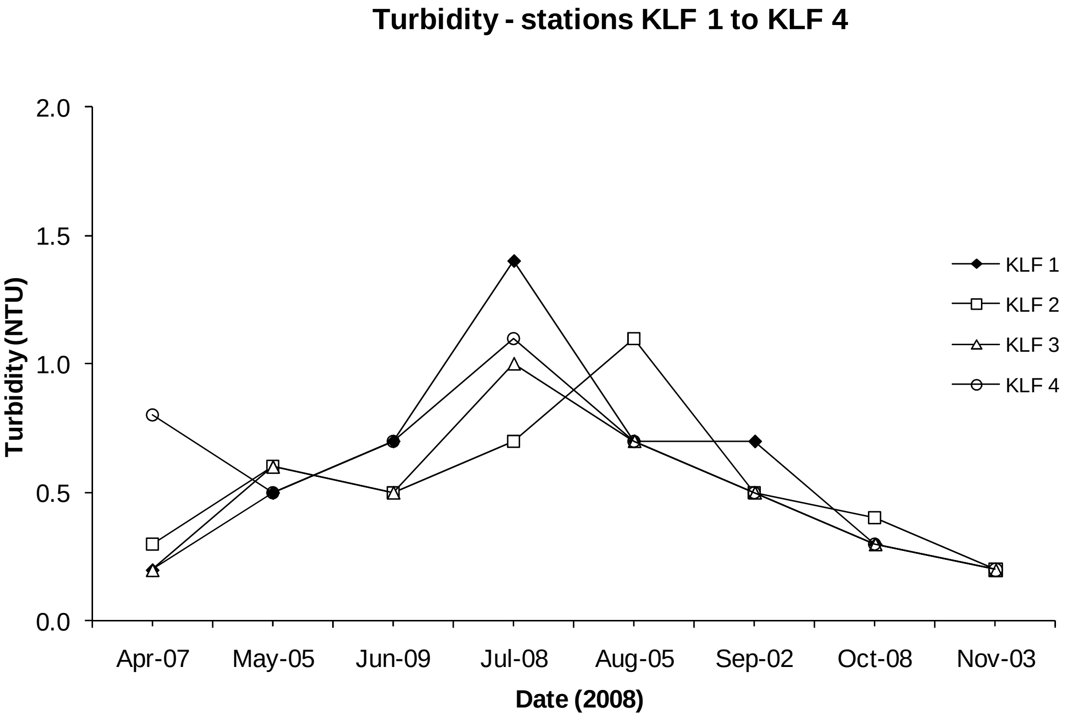


Figure 3.9. Average annual (April to October/November) Secchi depth measurements and 95% confidence intervals, Kootenay Lake, 1992 to 2008.



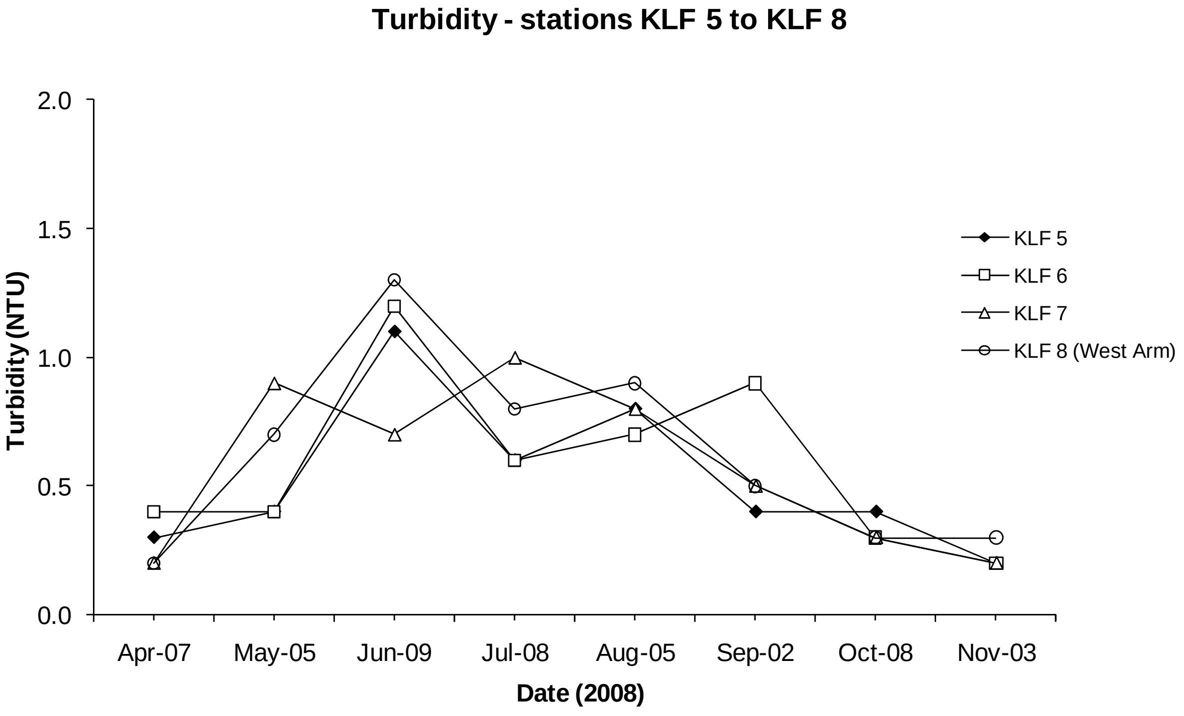
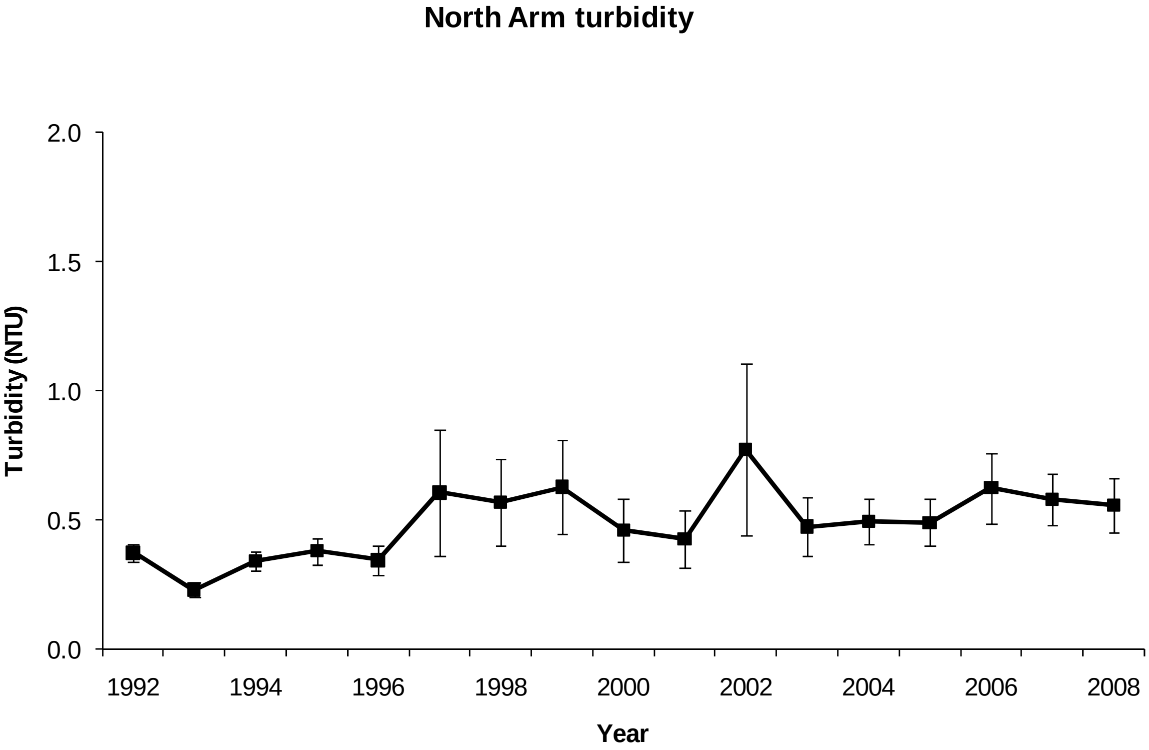


Figure 3.10. Turbidity measurements from integrated samples, 0-20 m, stations KLF 1 – 8, April to November, 2008.



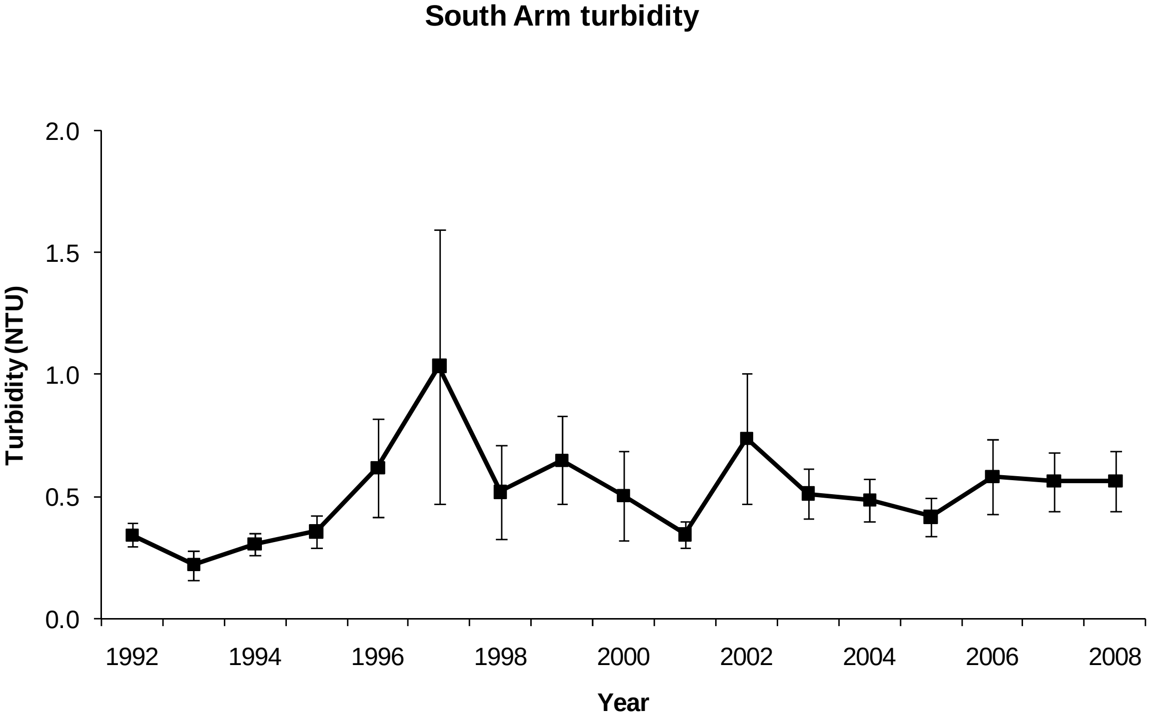
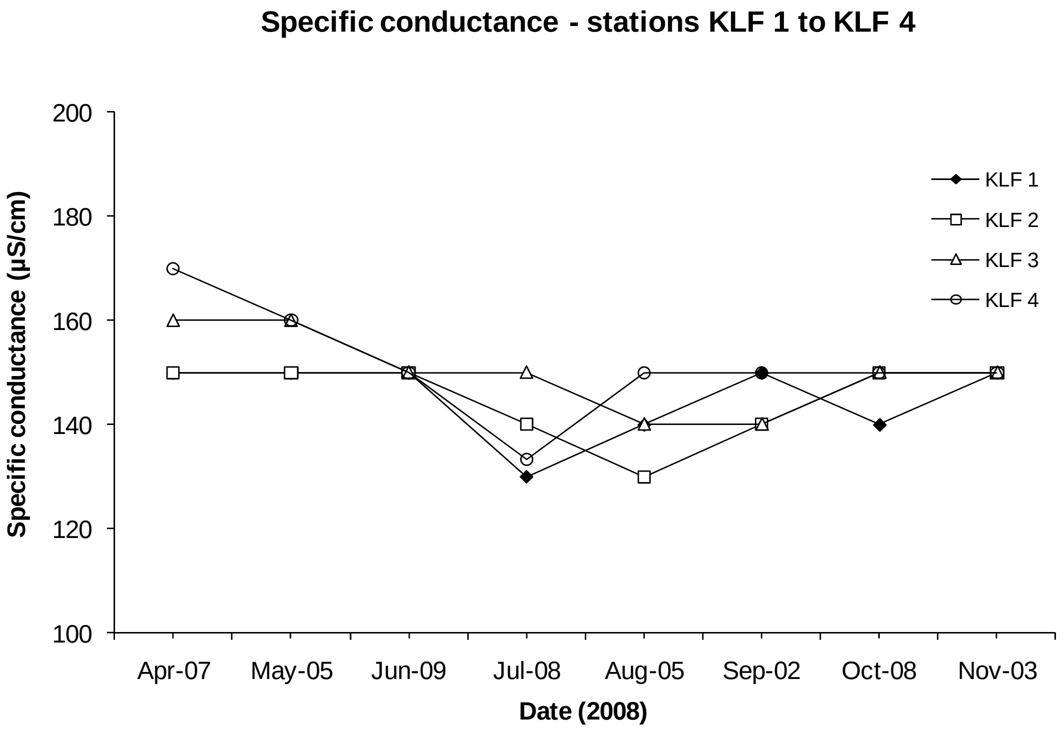


Figure 3.11. Average annual turbidity measurements and 95% confidence intervals Kootenay Lake, North and South arms (April to October/November), 1992 to 2008.



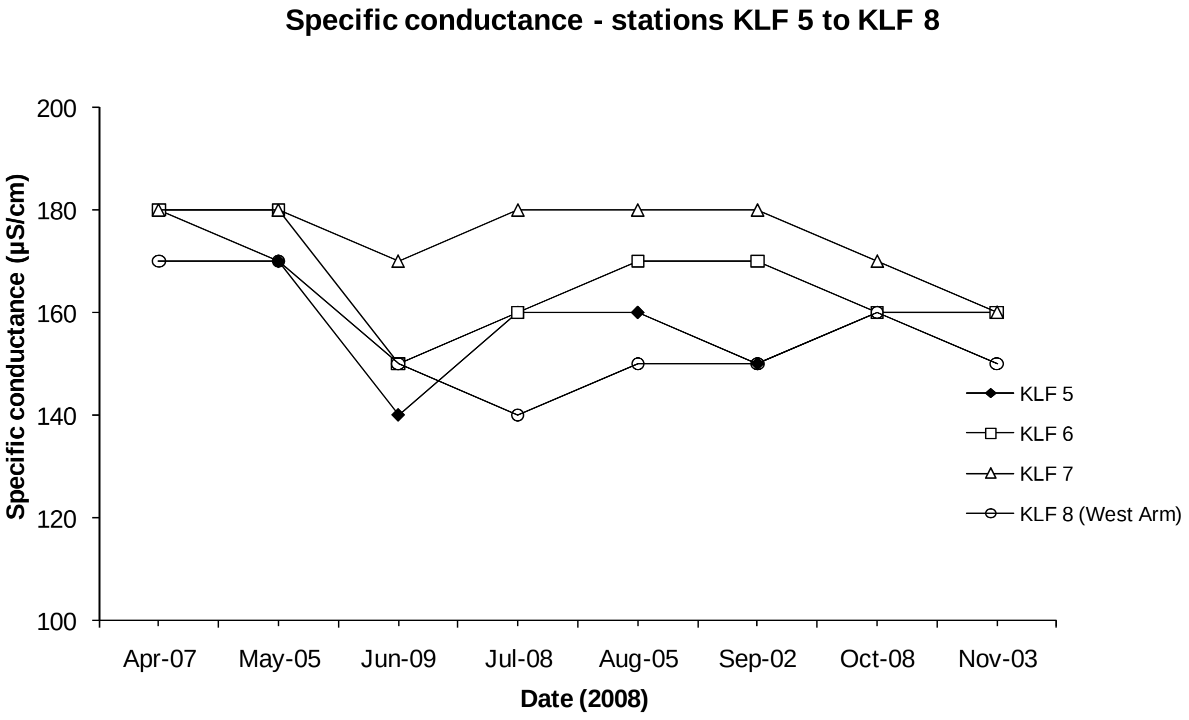
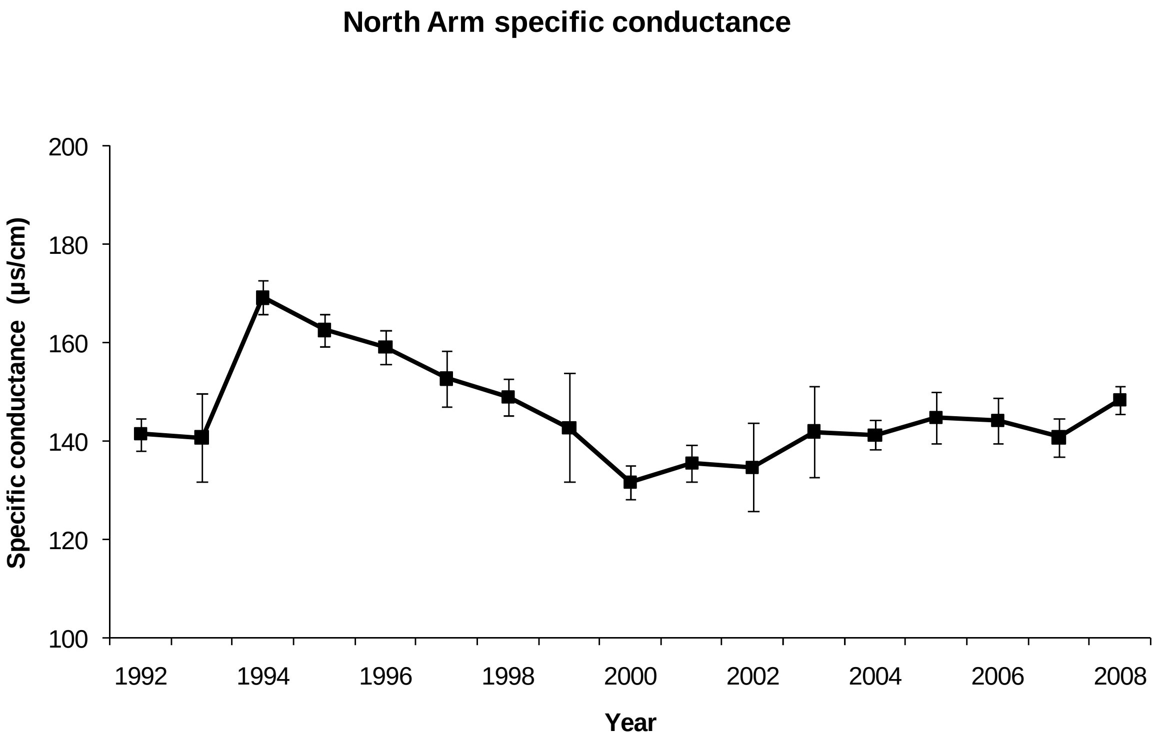
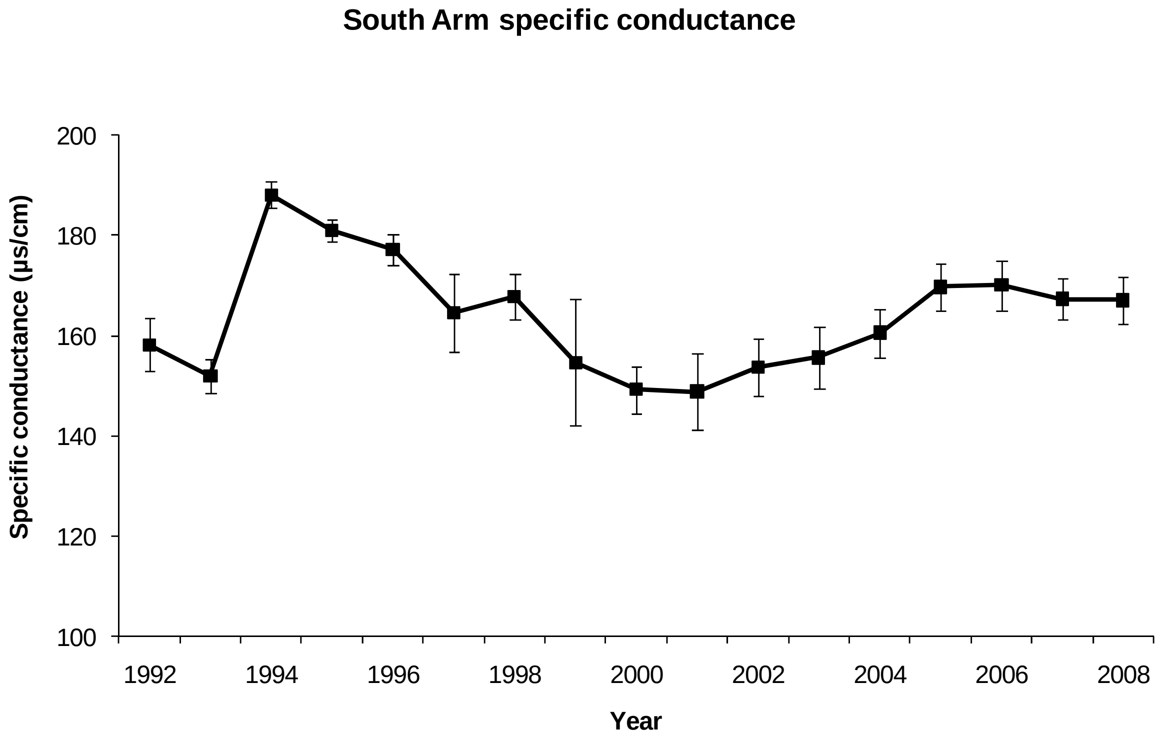


Figure 3.12. Specific conductance from integrated samples, 0-20 m, stations KLF 1 – 8, April to November, 2008.

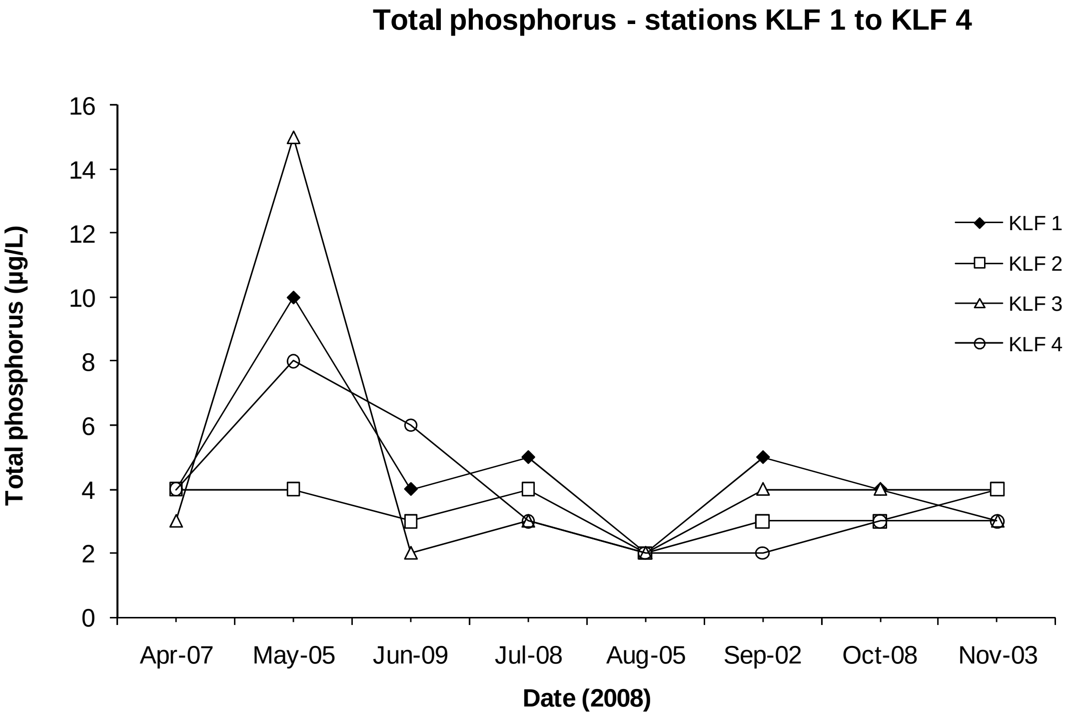


North Arm specific conductance

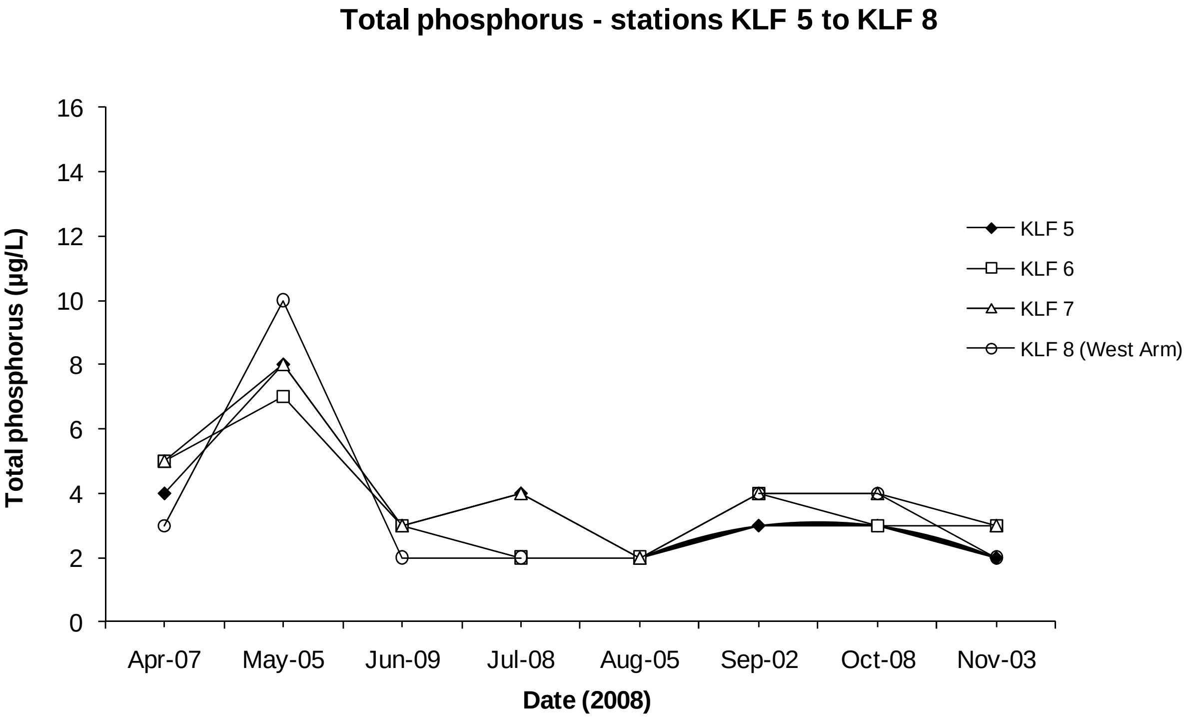


South Arm specific conductance

Figure 3.13. Average annual specific conductance measurements and 95% confidence intervals, Kootenay Lake, North and South arms (April to October/November), 1992 to 2008.

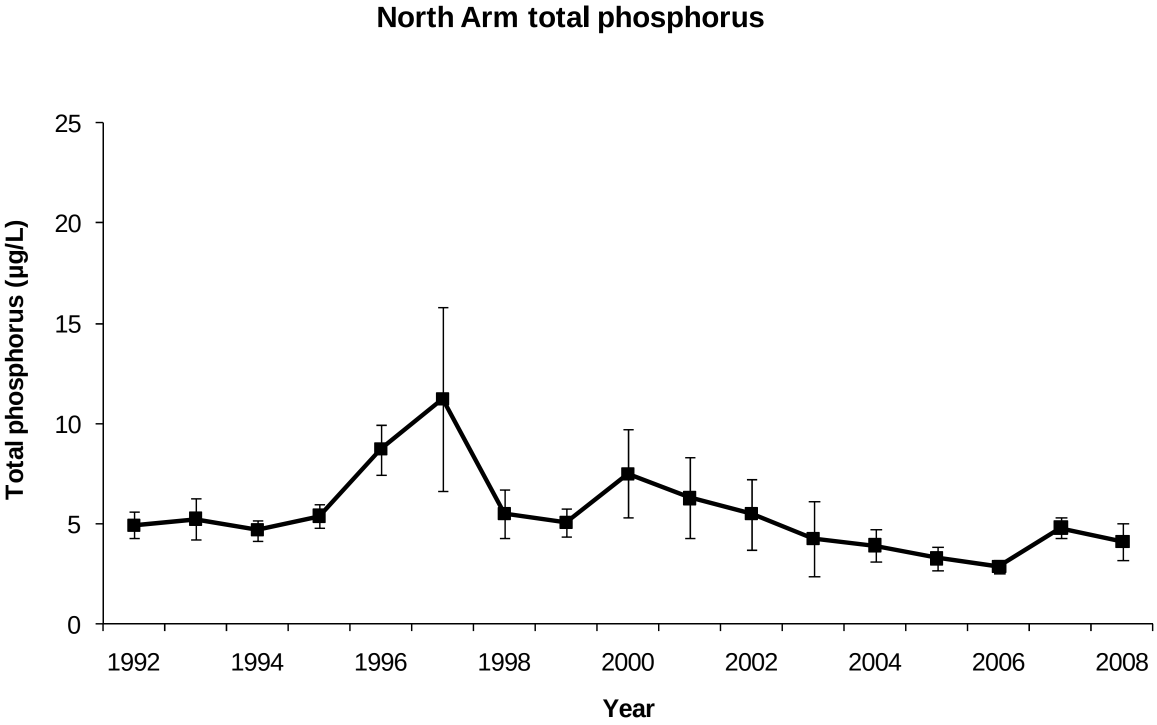


Total phosphorus - stations KLF 1 to KLF 4



Total phosphorus - stations KLF 5 to KLF 8

Figure 3.14. Total phosphorus concentrations from integrated samples, 0-20 m, stations KLF 1 – 8, April to November, 2008.


North Arm total phosphorus

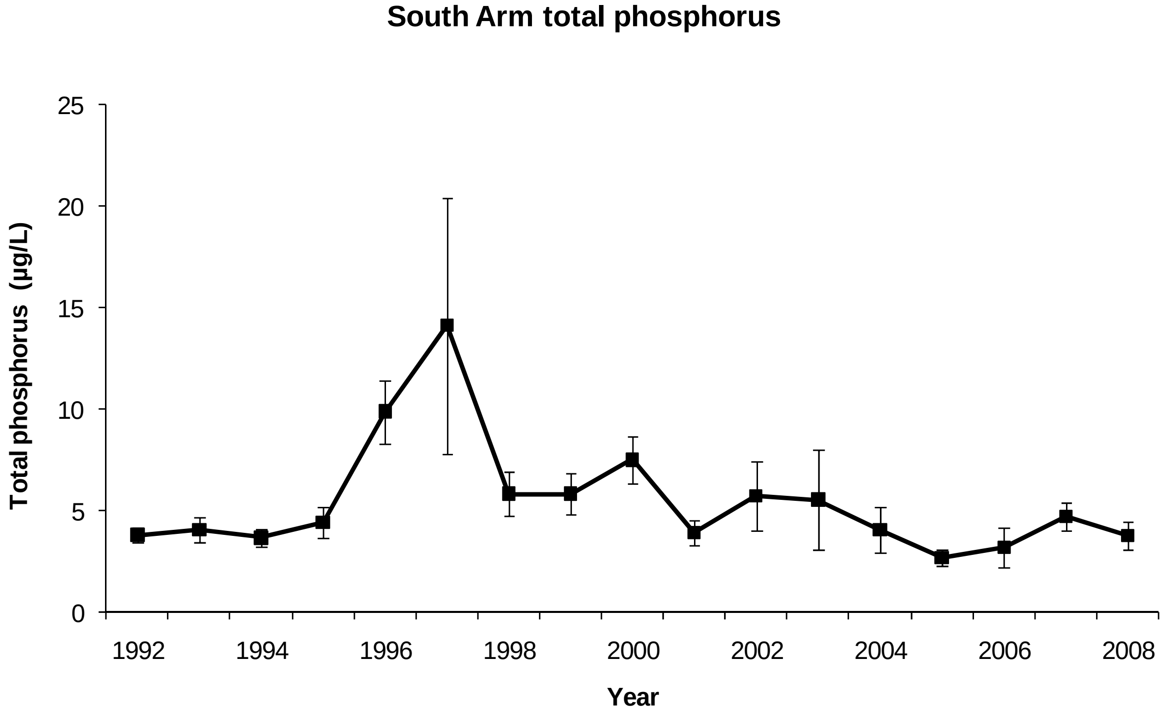

South Arm total phosphorus

Figure 3.15. Average total phosphorus concentrations and 95% confidence intervals, Kootenay Lake, North and South arms (April to October/November), 1992 to 2008.

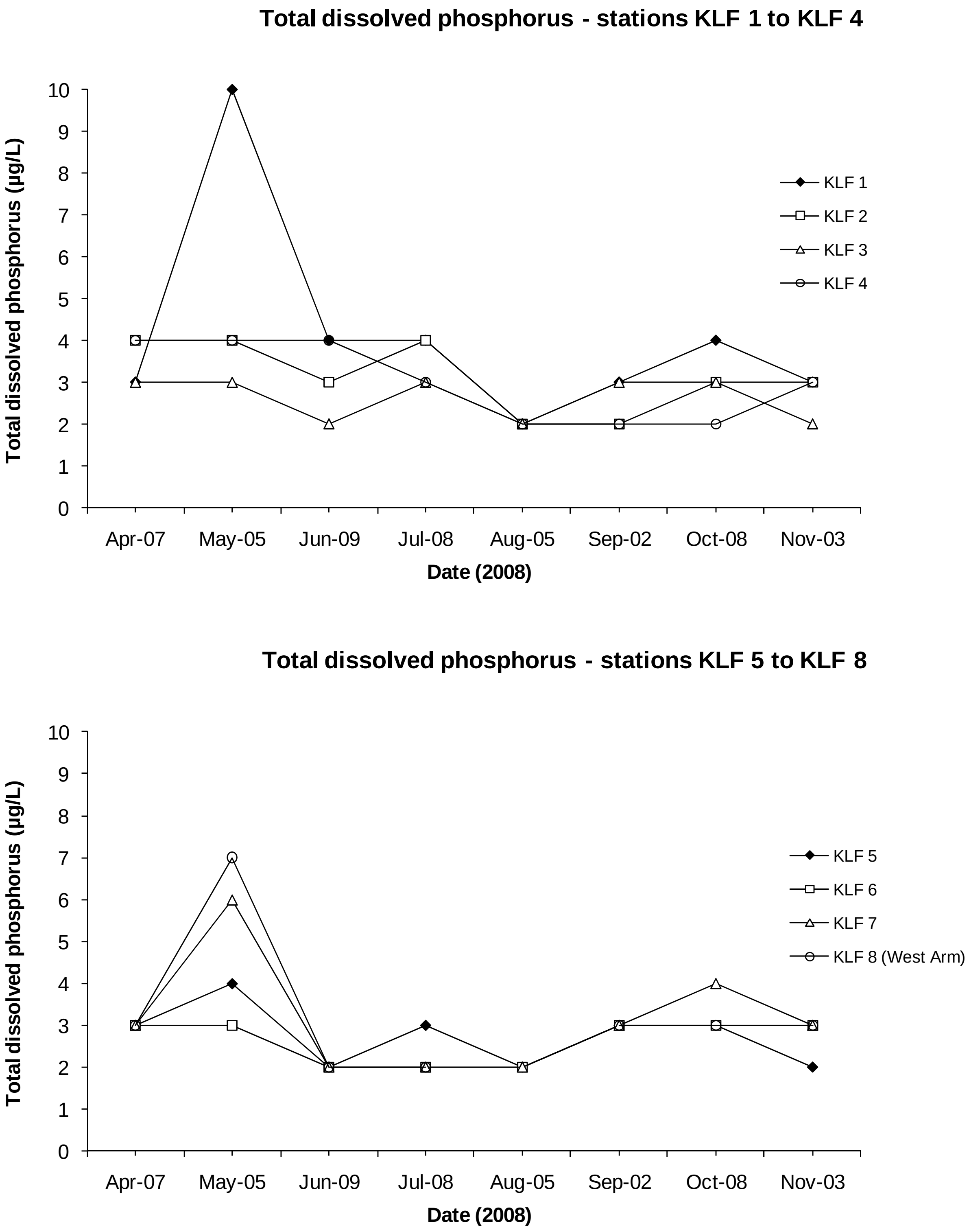
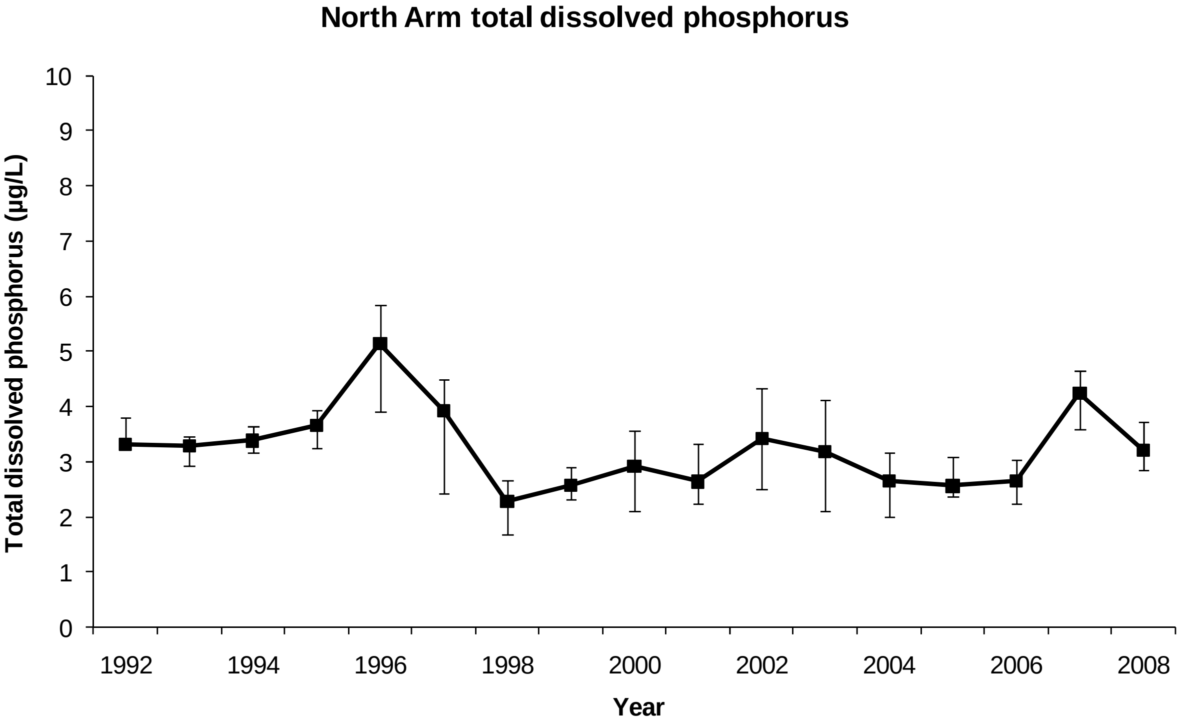


Figure 3.16. Total dissolved phosphorus concentrations from integrated samples, 0-20 m, stations KLF 1 – 8, April to November, 2008.



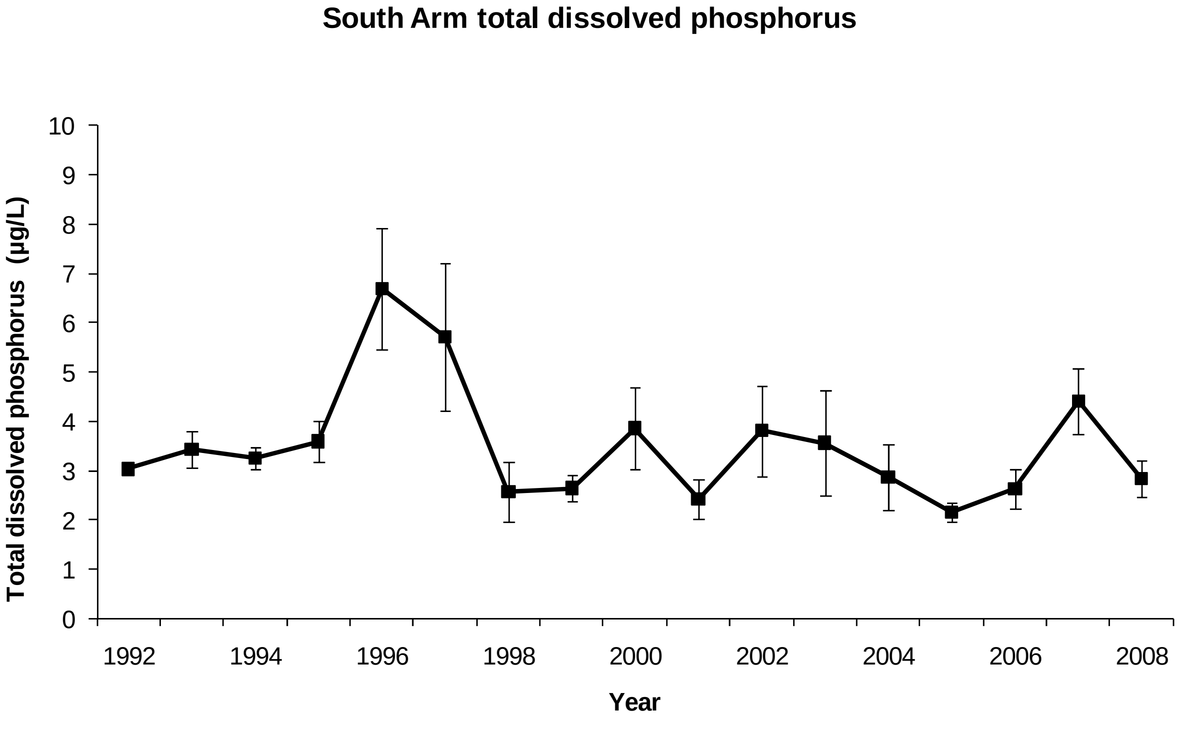


Figure 3.17. Average total dissolved phosphorus concentrations and 95% confidence intervals, Kootenay Lake, North and South arms (April to October/November), 1992 to 2008.

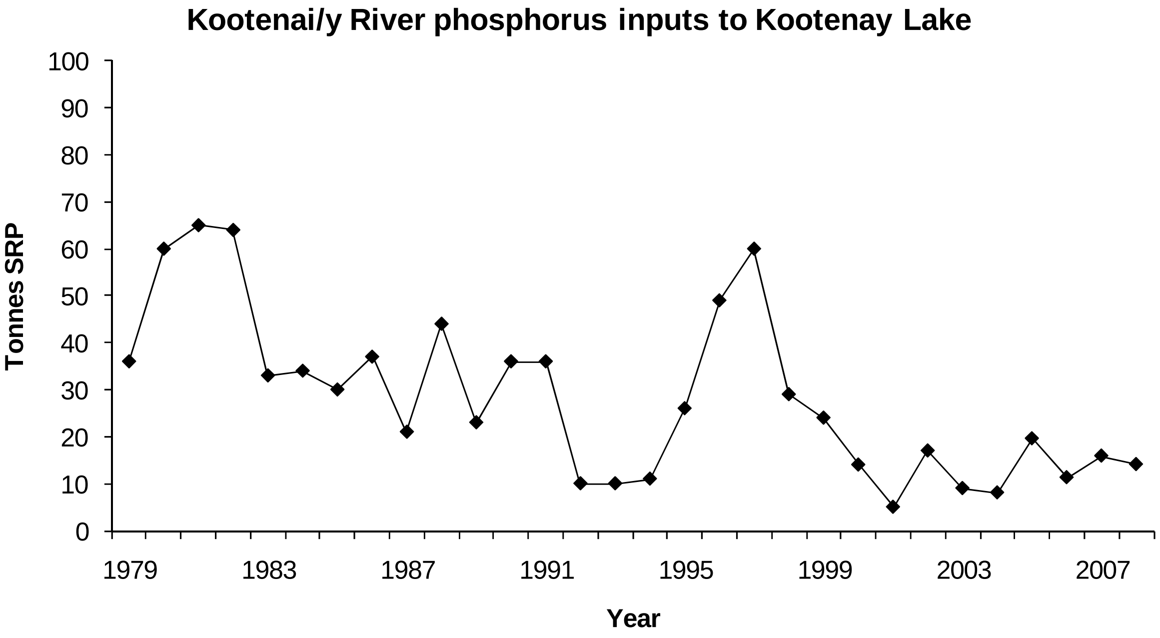


Figure 3.18. Phosphorus inputs from the Kootenai/y River to the South Arm of Kootenay Lake, 1979 to 2008.

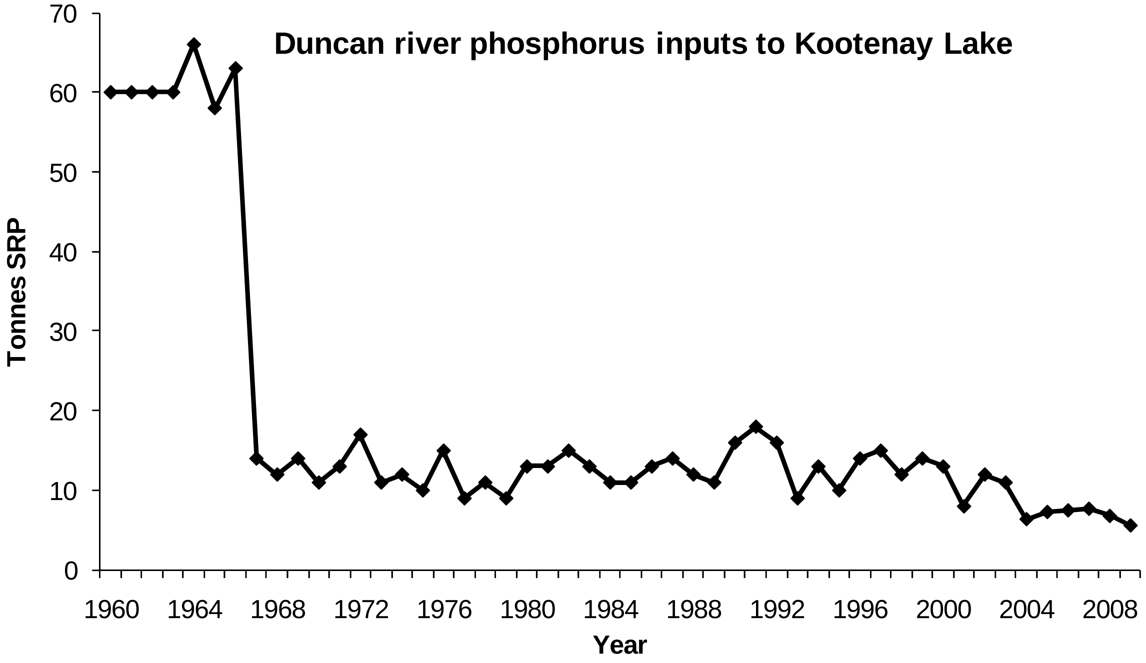
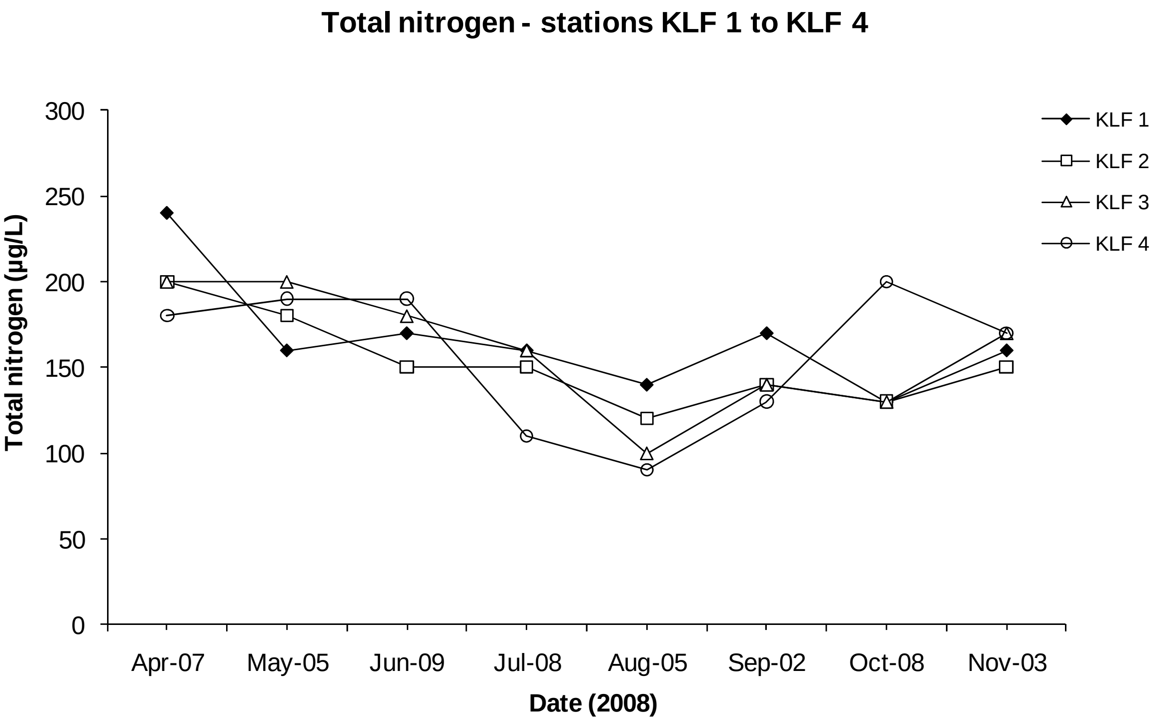


Figure 3.19. Phosphorus inputs from the Duncan River to the North Arm of Kootenay Lake, 1960 to 2008. Note: construction of Duncan Dam occurred in 1967.



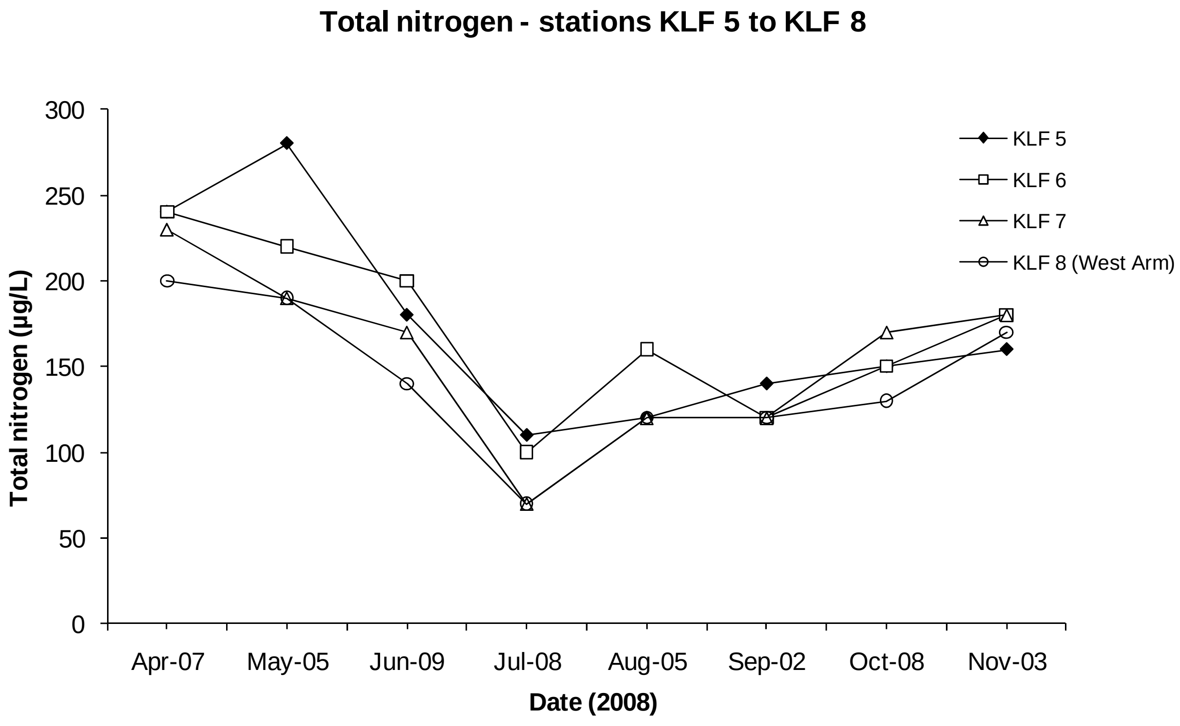
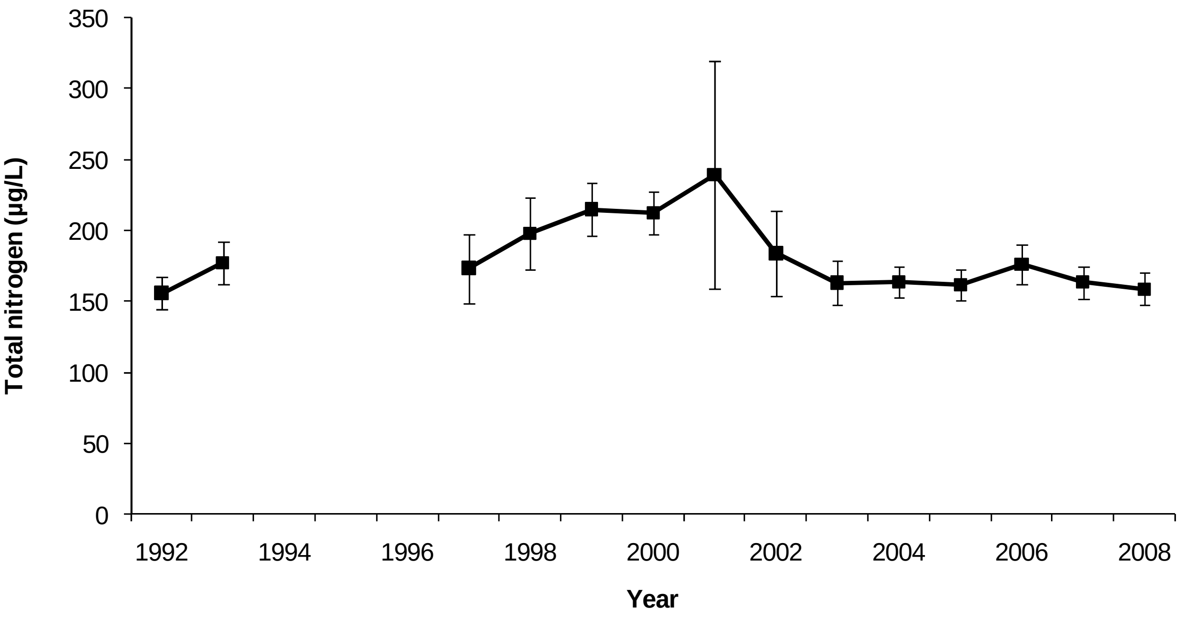


Figure 3.20. Total nitrogen concentrations from integrated samples, 0-20 m, stations KLF 1 – 8, April to November, 2008.

North Arm total nitrogen



South Arm total nitrogen

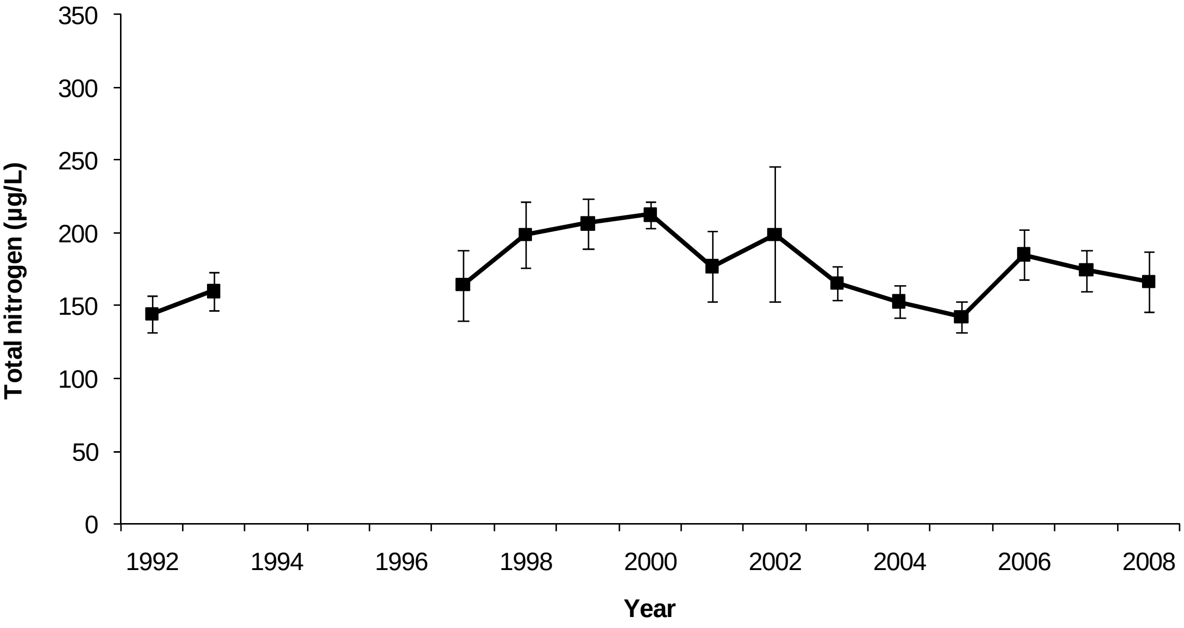
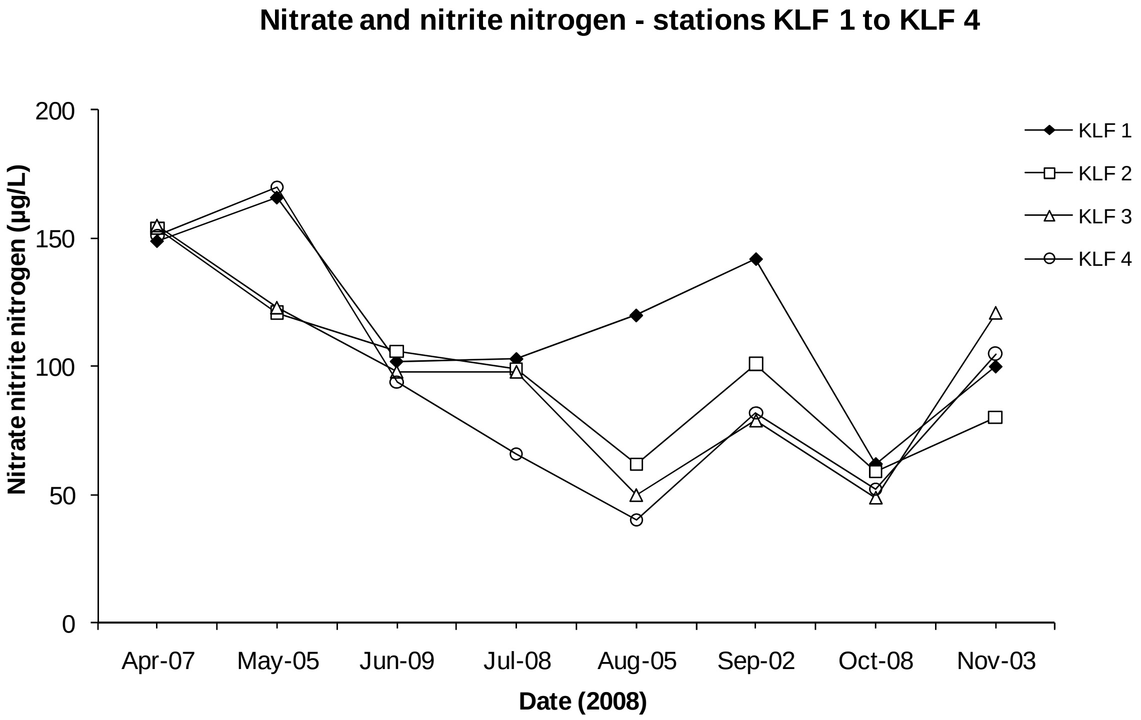


Figure 3.21. Average total nitrogen concentrations and 95% confidence intervals, Kootenay Lake, North and South arms (April to October/November), 1992, 1993 and 1997 to 2008.



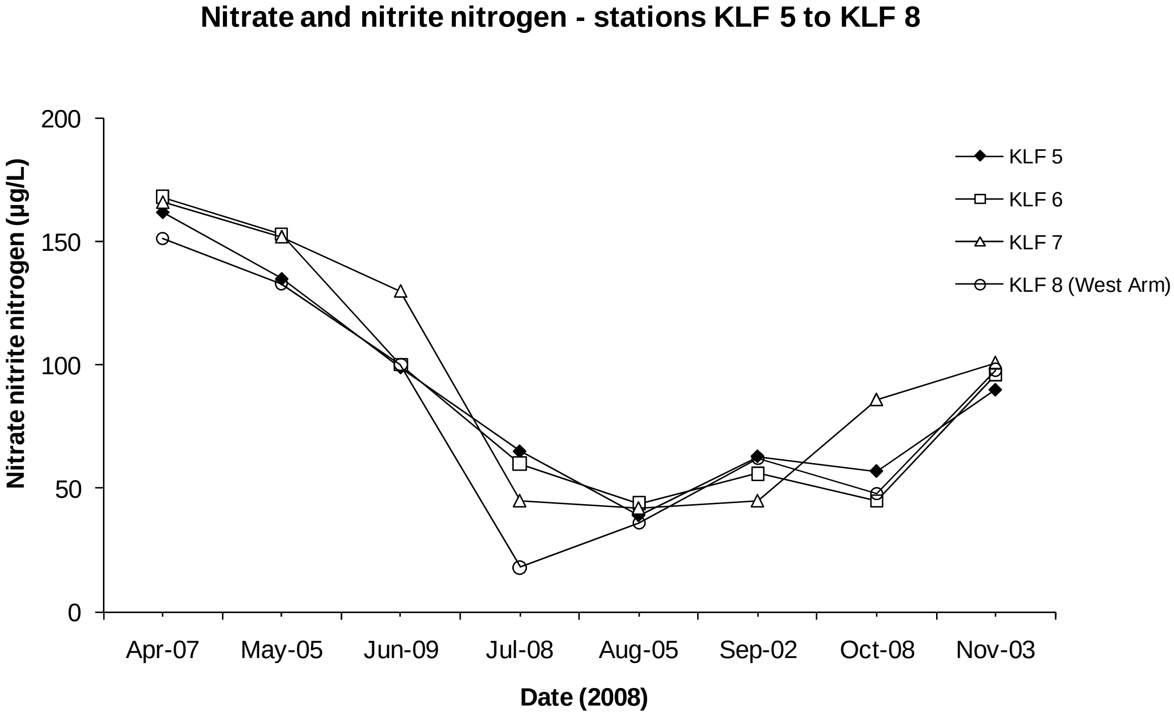
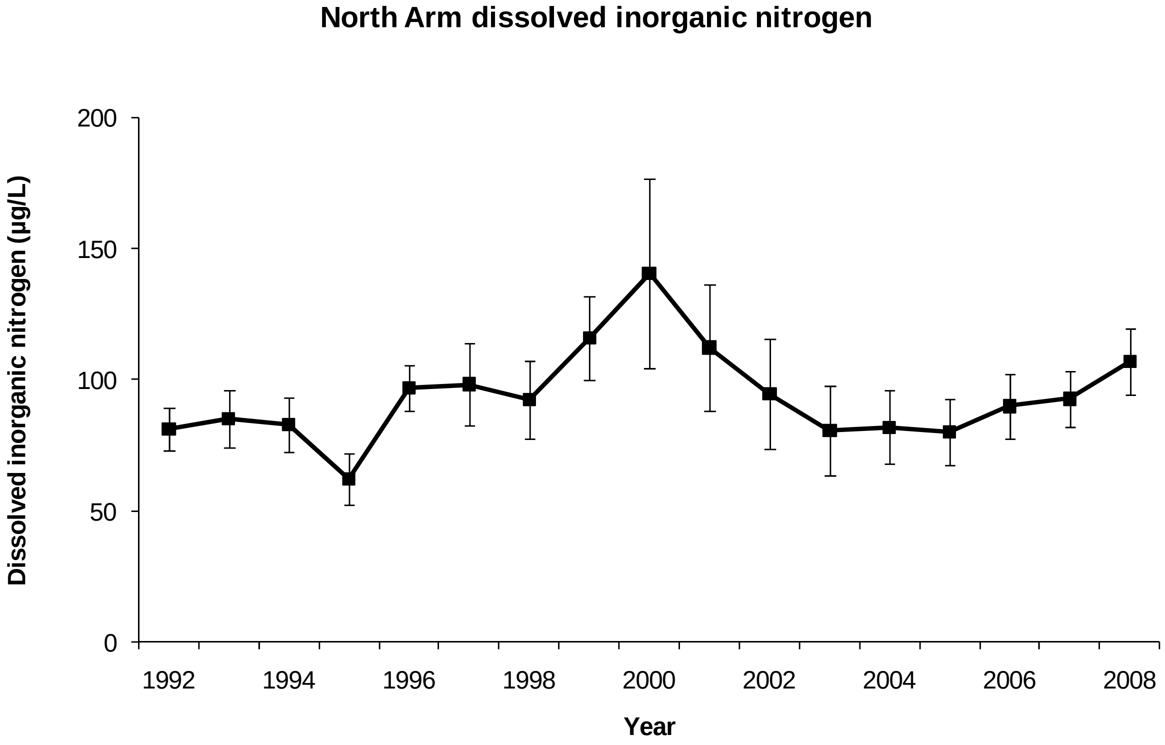


Figure 3.22. Nitrate and nitrite nitrogen concentrations from integrated samples, 0-20 m, stations KLF 1 – 8, April to November, 2008.



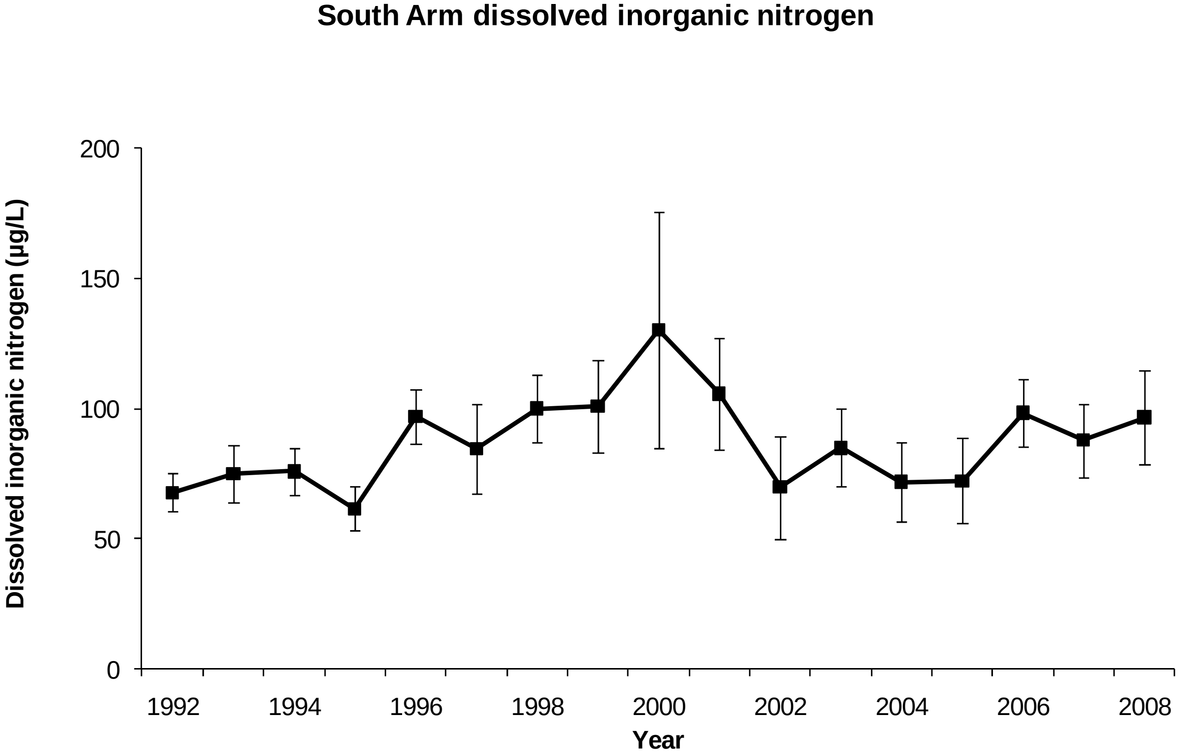


Figure 3.23. Average dissolved inorganic nitrogen concentrations and 95% confidence intervals, Kootenay Lake, North and South arms (April to October/November), 1992 to 2008.

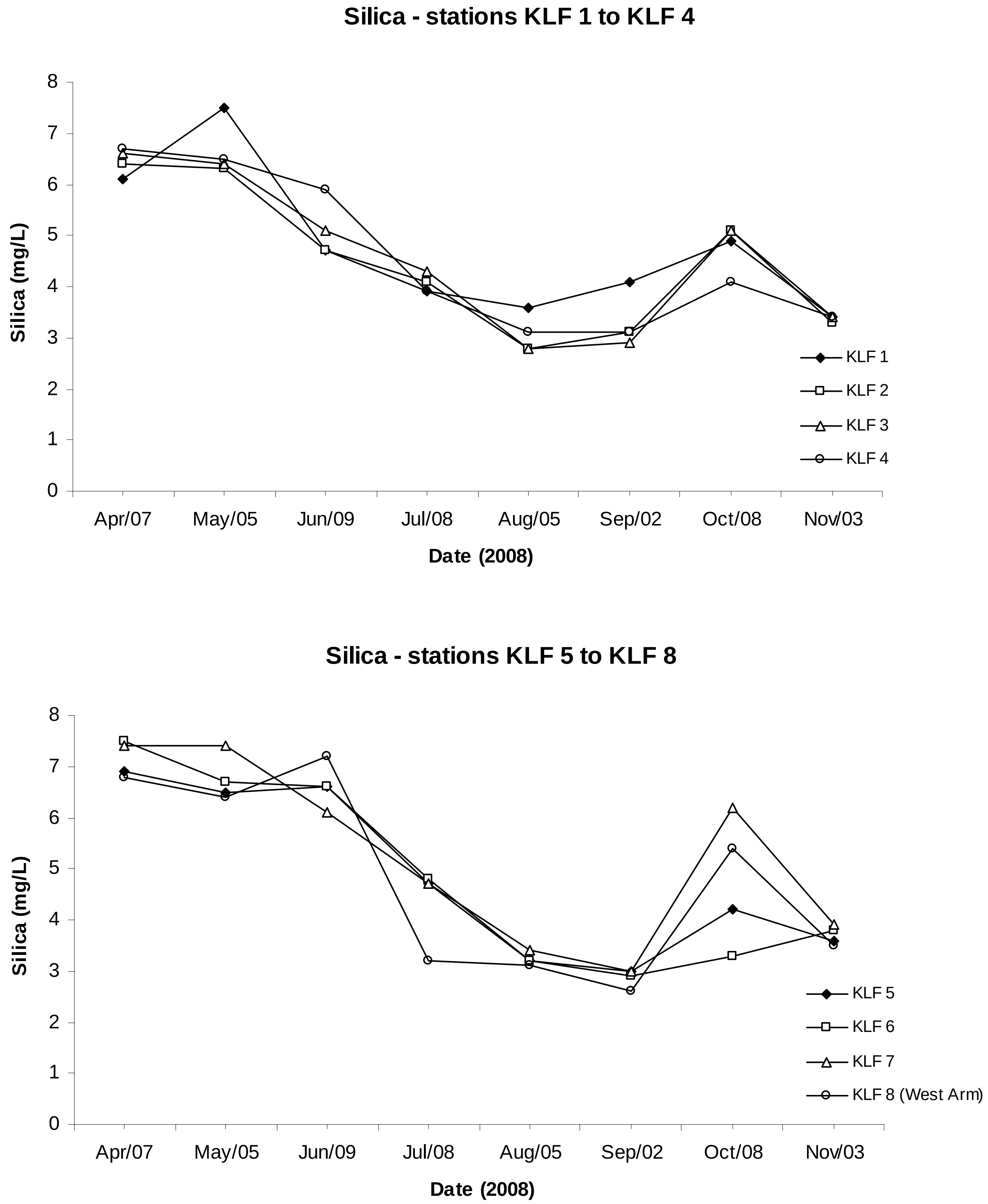


Figure 3.24. Silica concentrations from integrated samples, 0-20 m, stations KLF 1 – 8, April to November, 2008.

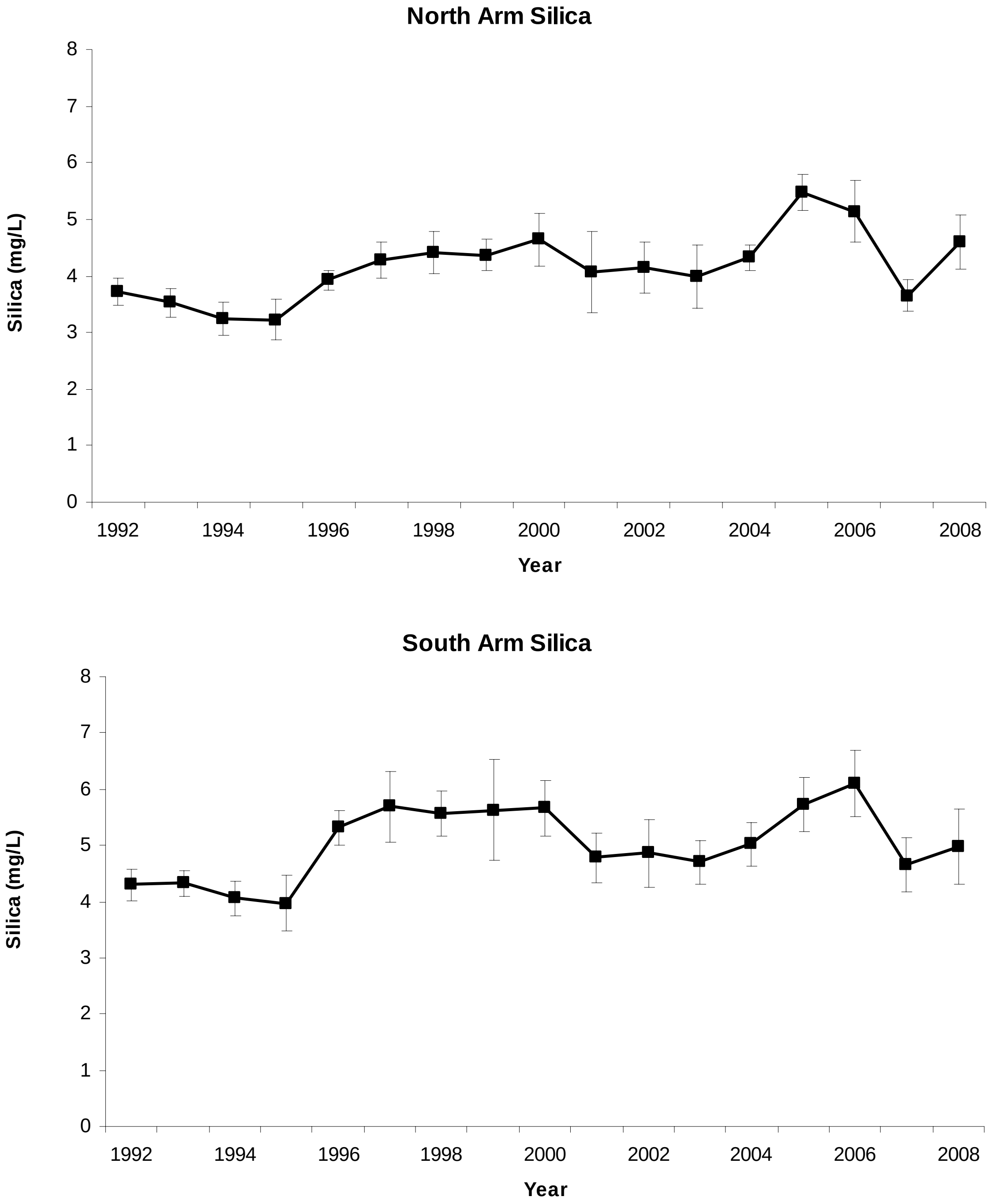
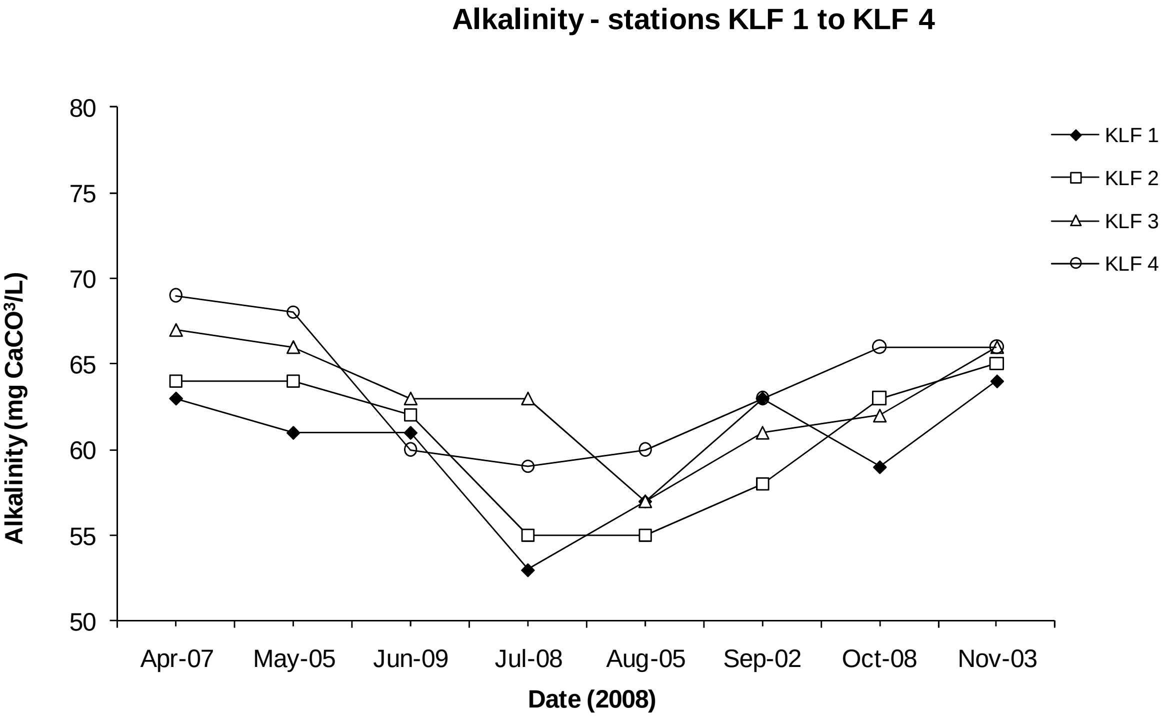


Figure 3.25. Average silica concentrations and 95% confidence intervals, Kootenay Lake, North and South arms (April to October/November), 1992 to 2008.



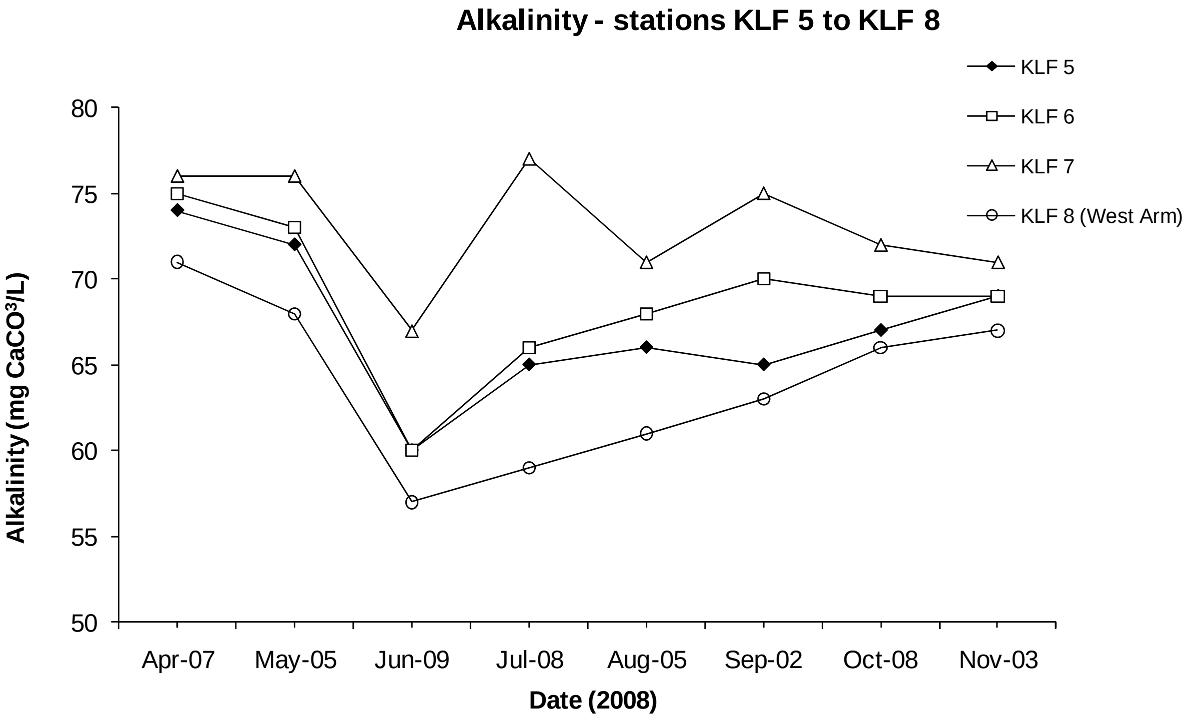
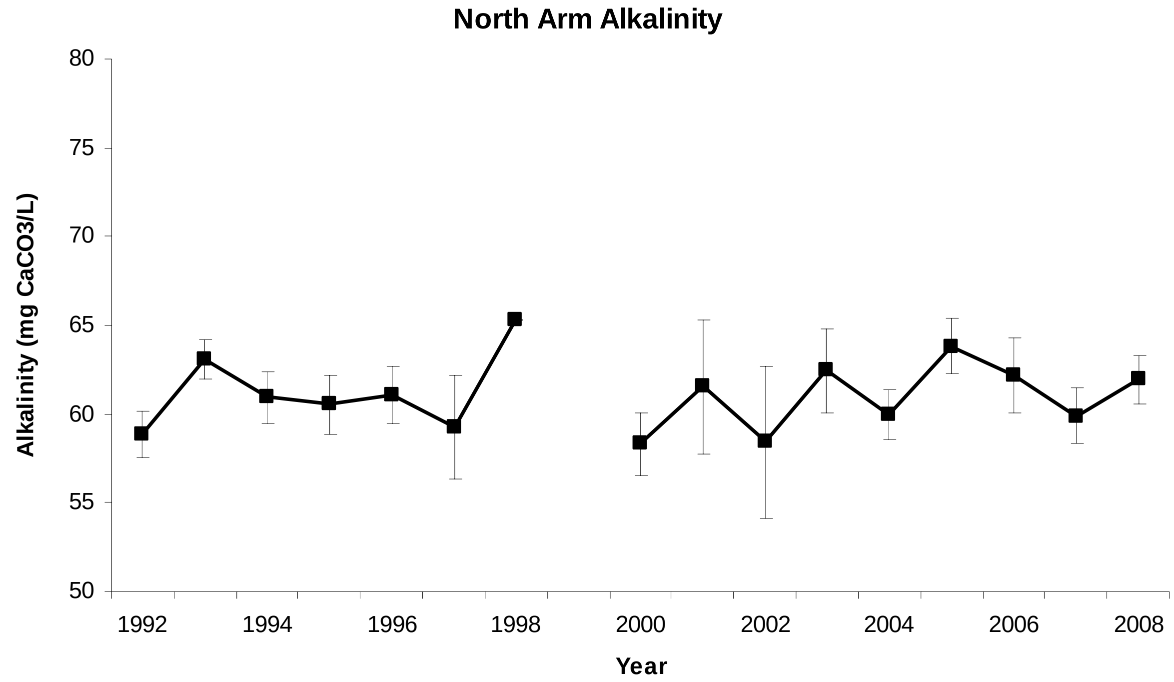


Figure 3.26. Alkalinity concentrations from integrated samples, 0-20 m, stations KLF 1 – 8, April to November, 2008.



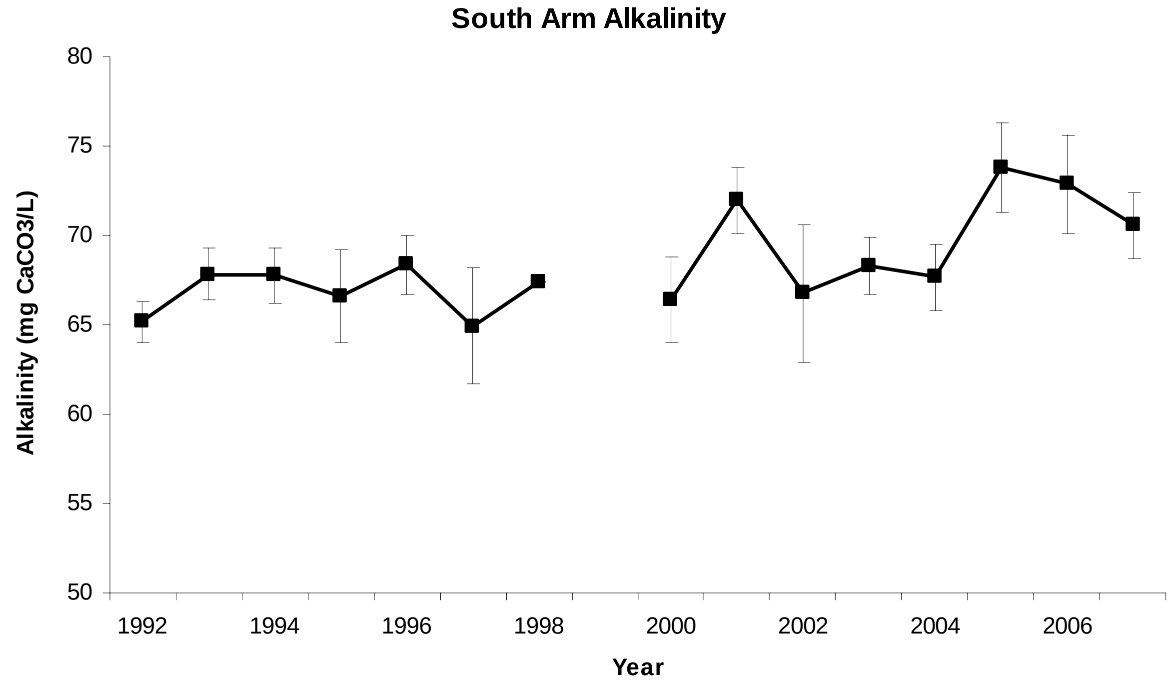
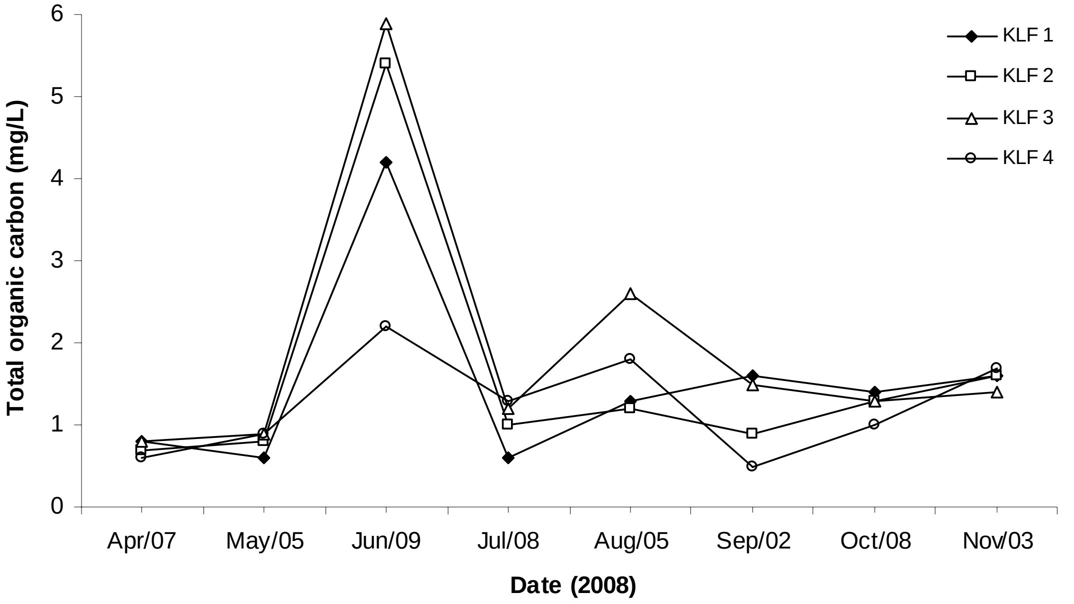


Figure 3.27. Average alkalinity concentrations and 95% confidence intervals, Kootenay Lake, North and South arms (April to October/November), 1992 to 2008. Note: there was not sufficient data collected in 1998 to calculate the confidence interval.

Total organic carbon - stations KLF 1 to KLF 4



Total organic carbon - stations KLF 5 to KLF 8

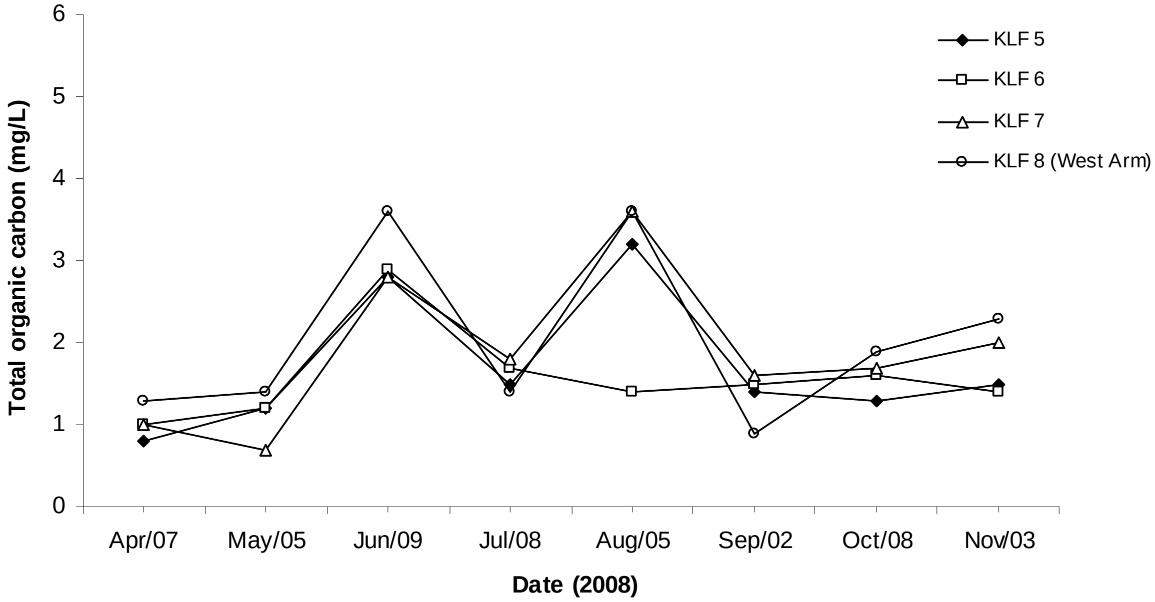
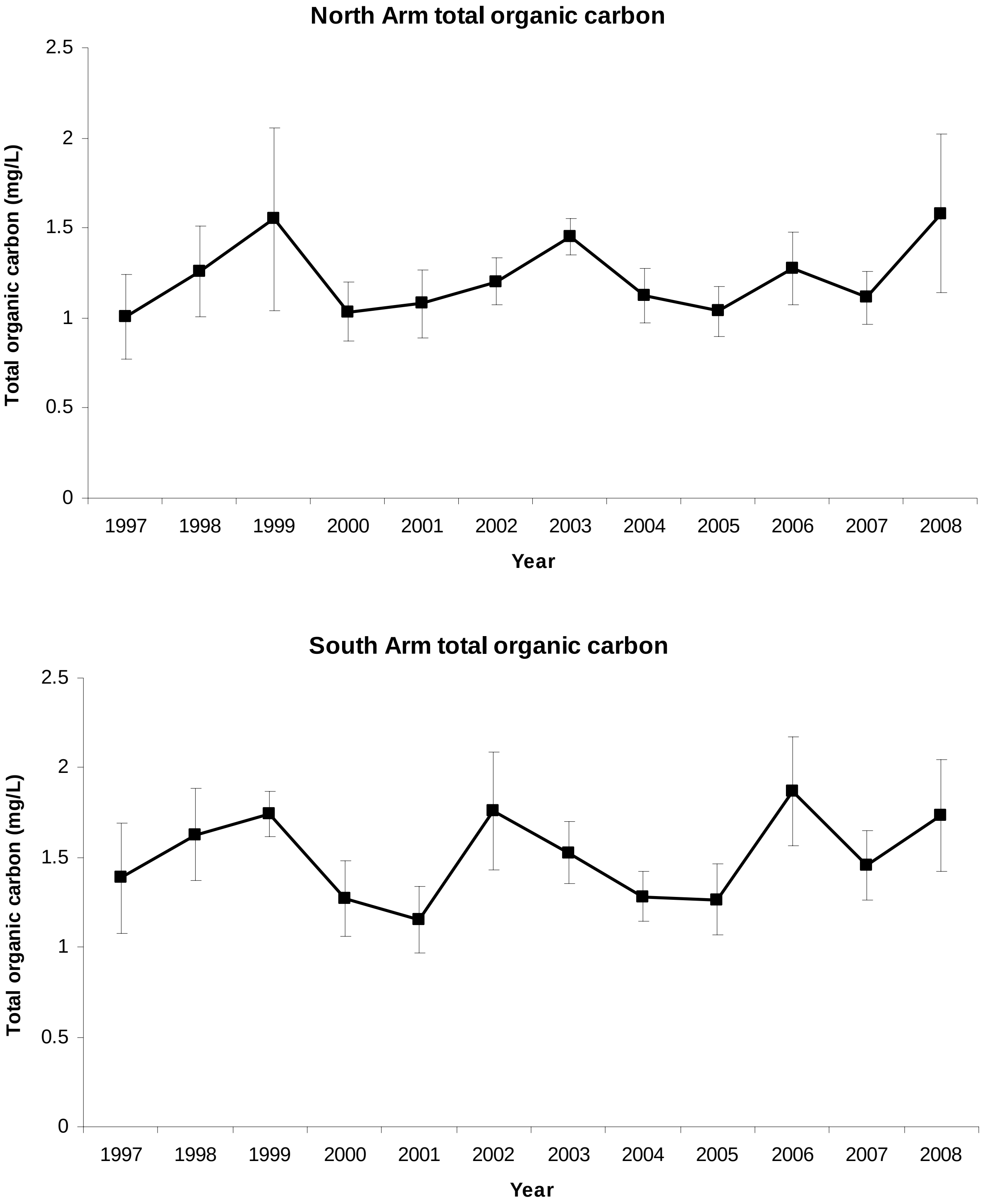
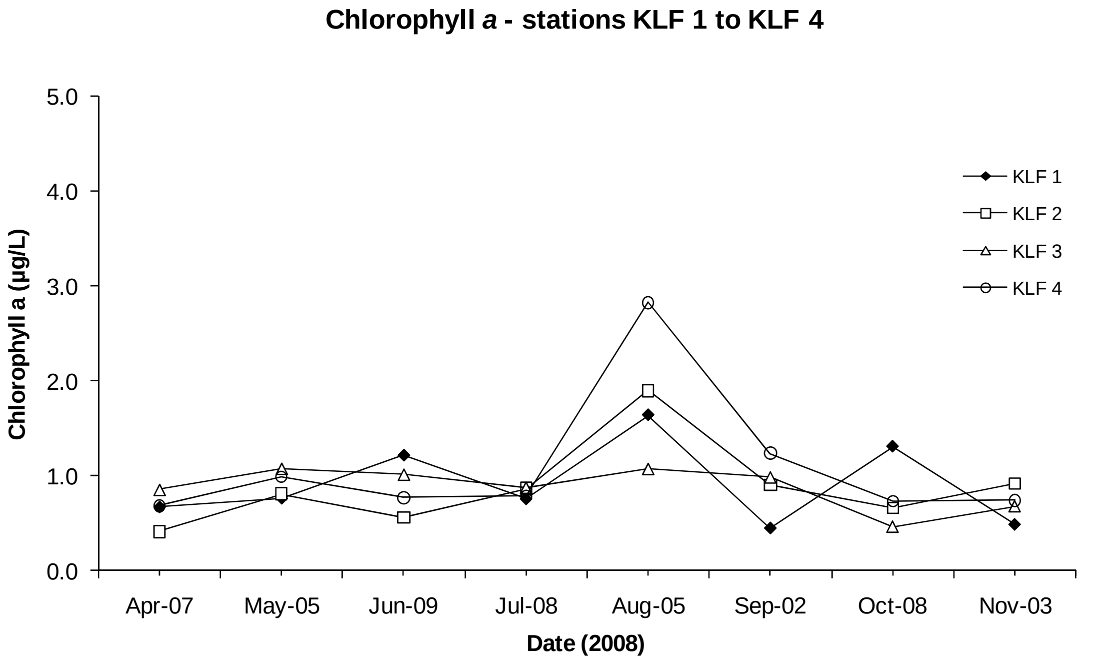


Figure 3.28. Total organic carbon concentrations from integrated samples, 0-20 m, stations KLF 1 – 8, April to November, 2008.


North Arm total organic carbon

South Arm total organic carbon

Figure 3.29. Average total organic carbon concentrations and 95% confidence intervals, Kootenay Lake, North and South arms (April to October/November), 1997 to 2008.



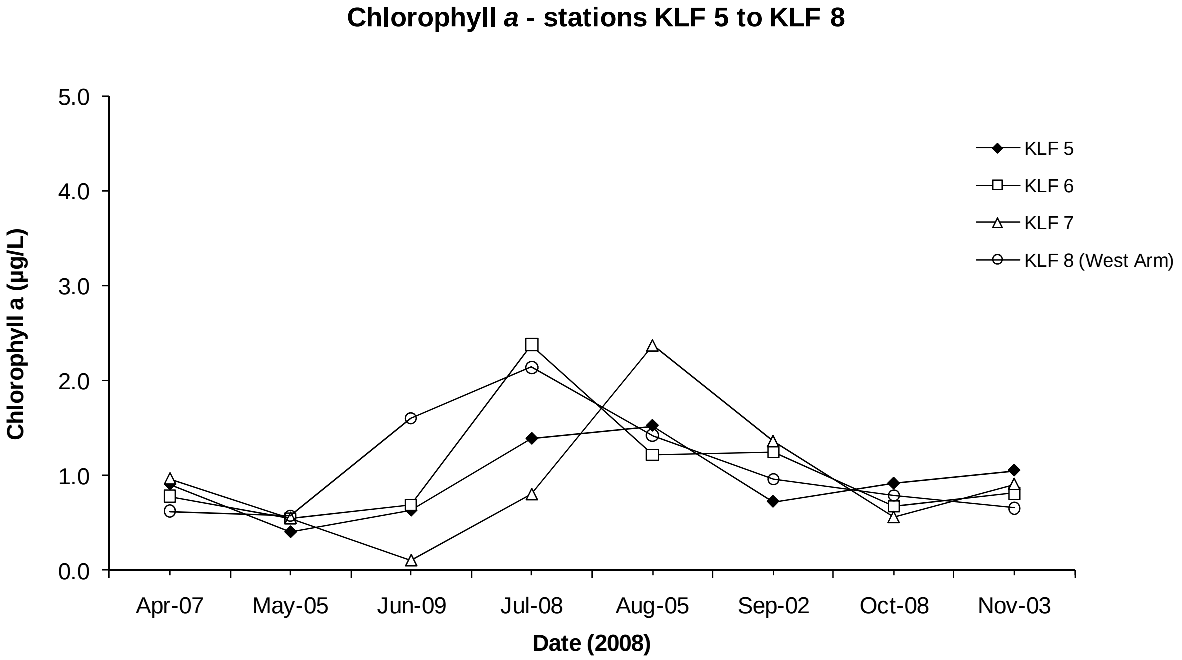
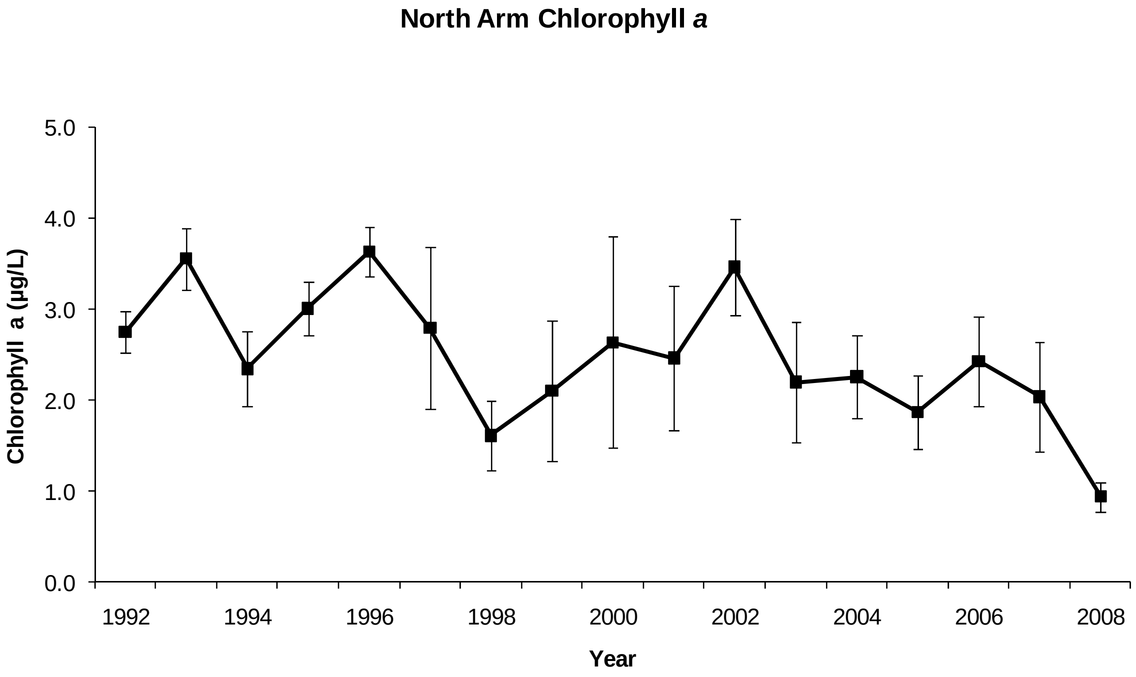


Figure 3.30. Chlorophyll *a* concentrations from integrated samples, 0-20 m, stations KLF 1 – 8, April to November, 2008.



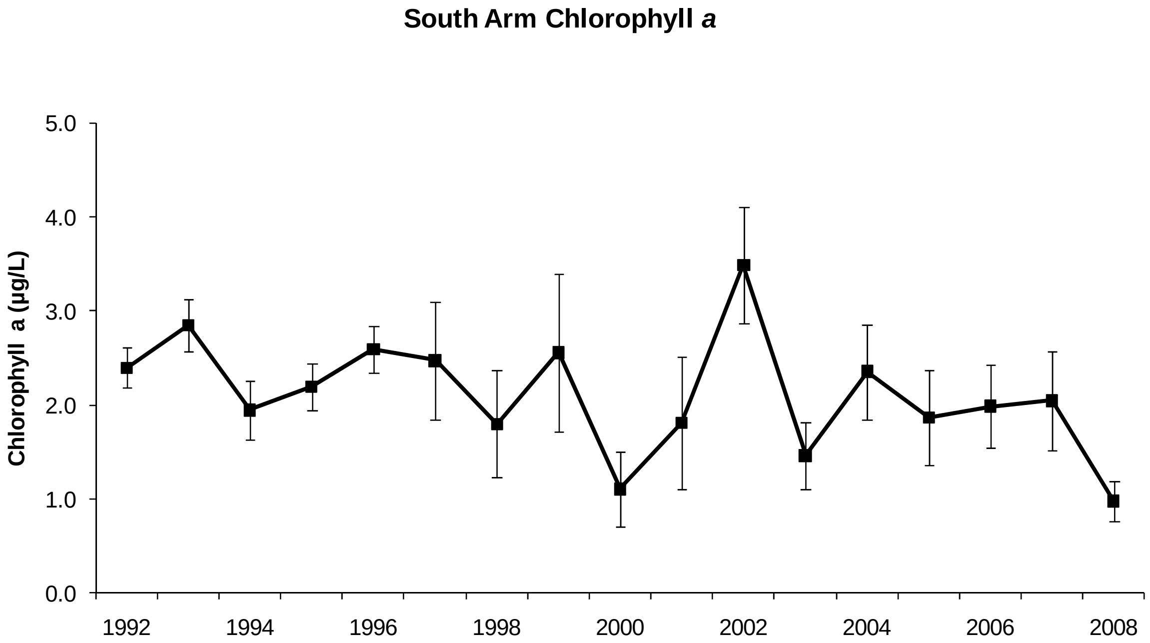


Figure 3.31. Average chlorophyll *a* concentrations and 95% confidence intervals, Kootenay Lake, North and South arms (April to October/November), 1997 to 2008.

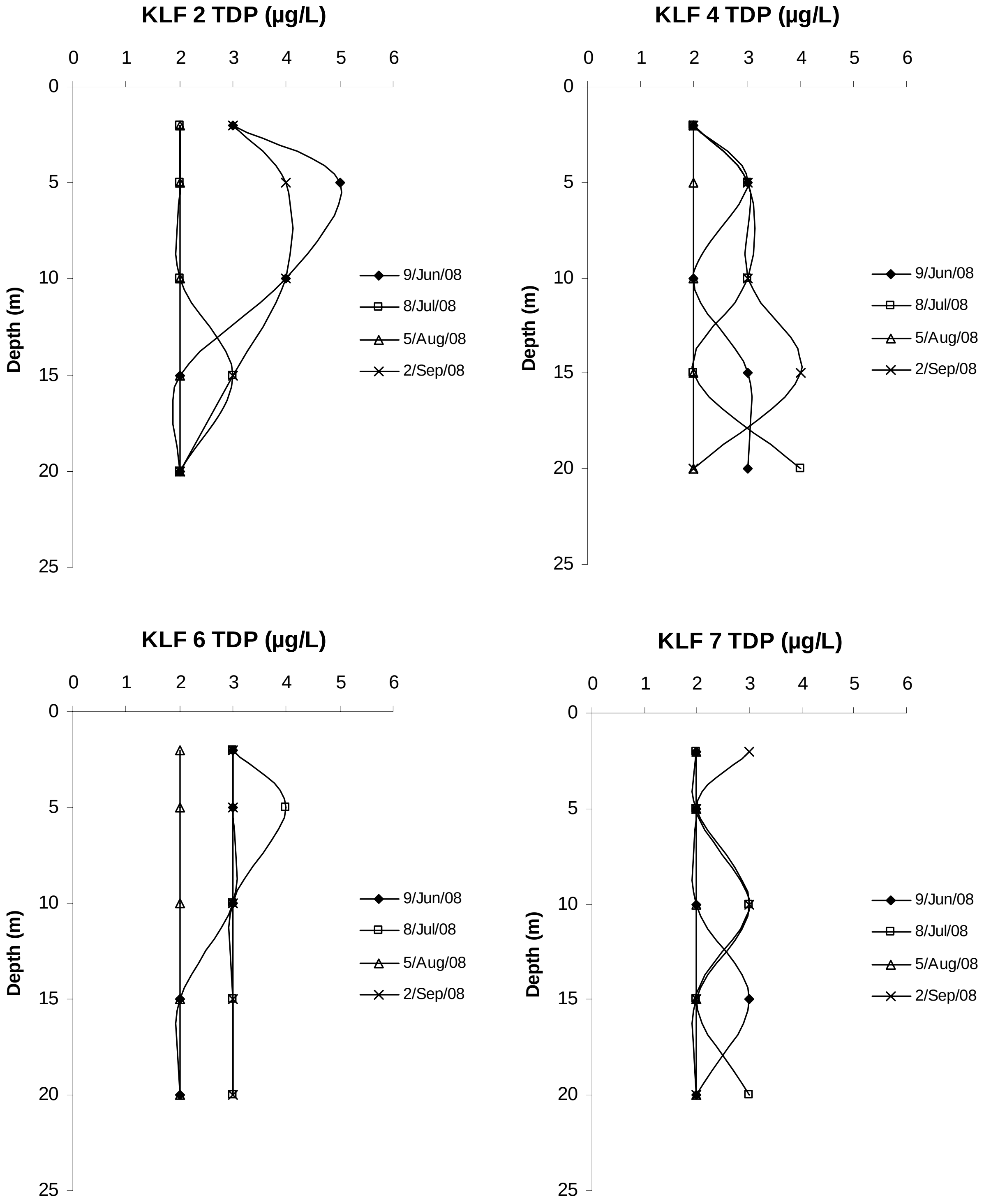


Figure 3.32. Total dissolved phosphorus concentrations, discrete depth profiles, stations KLF 2, 4, 6 and 7, June to September 2008.

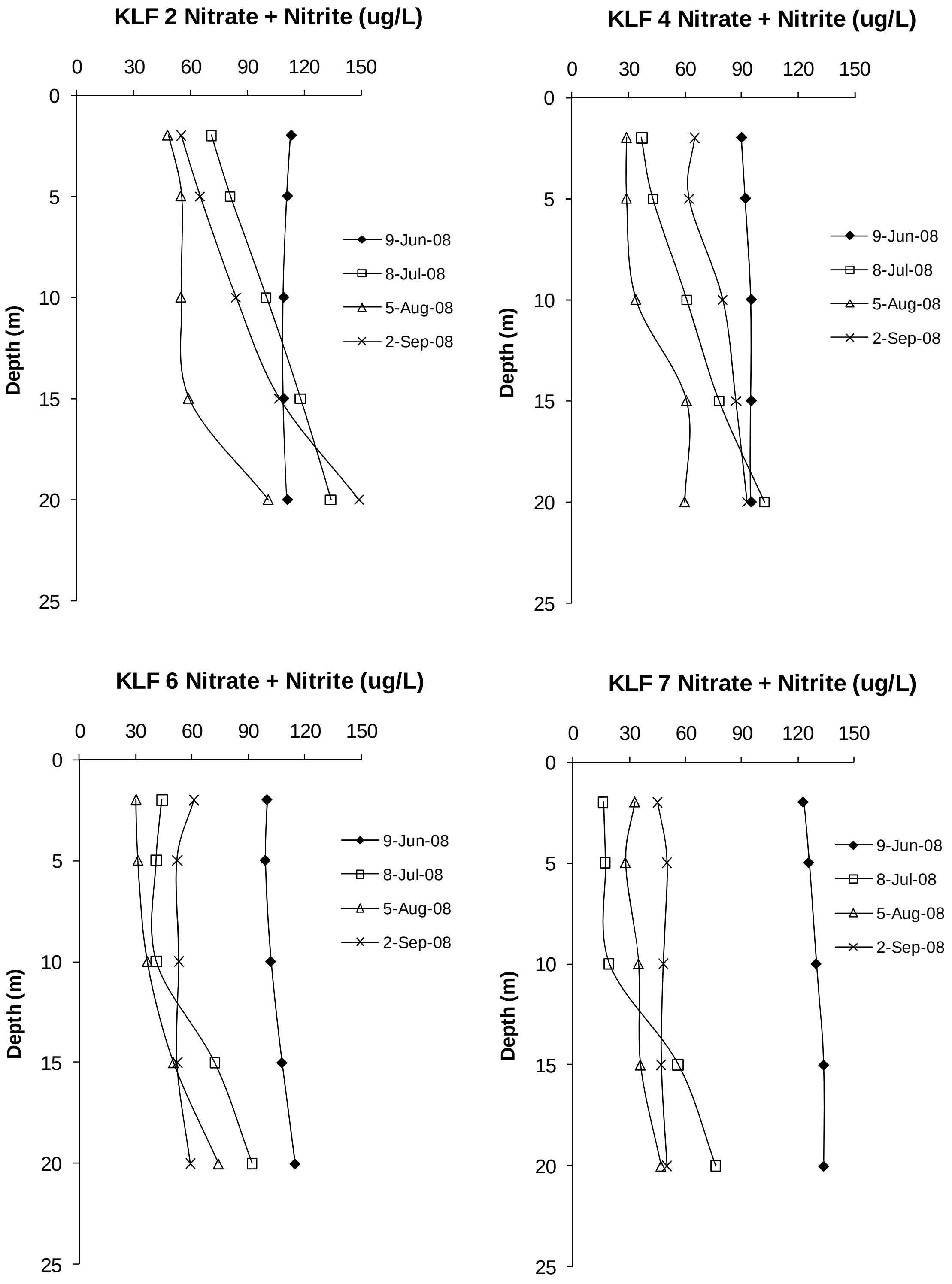


Figure 3.33. Nitrate and nitrite concentrations, discrete depth profiles, stations KLF 2, 4, 6 and 7, June to September 2008.

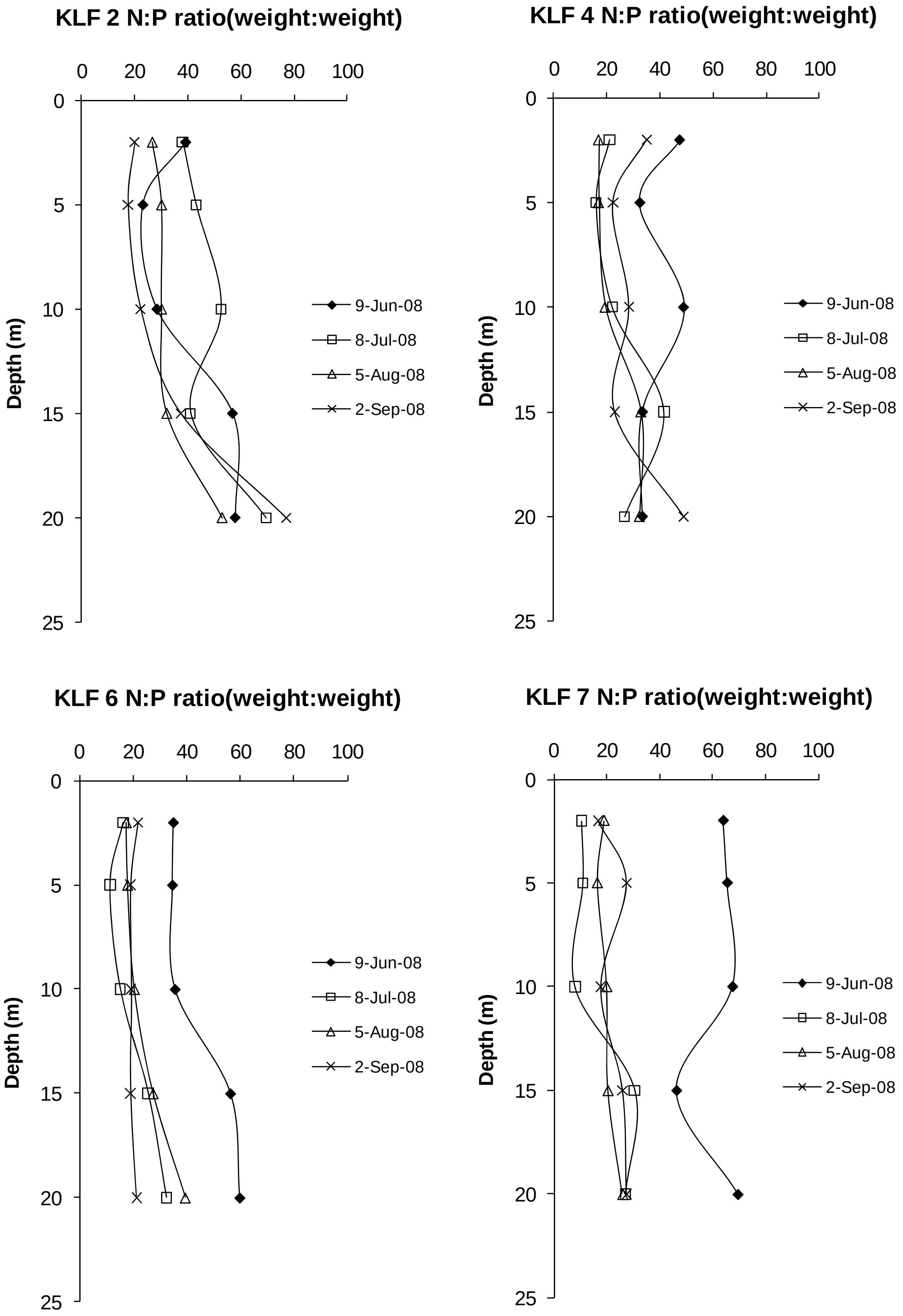


Figure 3.34. Nitrogen:phosphorus ratios (weight:weight), discrete depth profiles, stations KLF 2, 4, 6 and 7, June to September 2008.

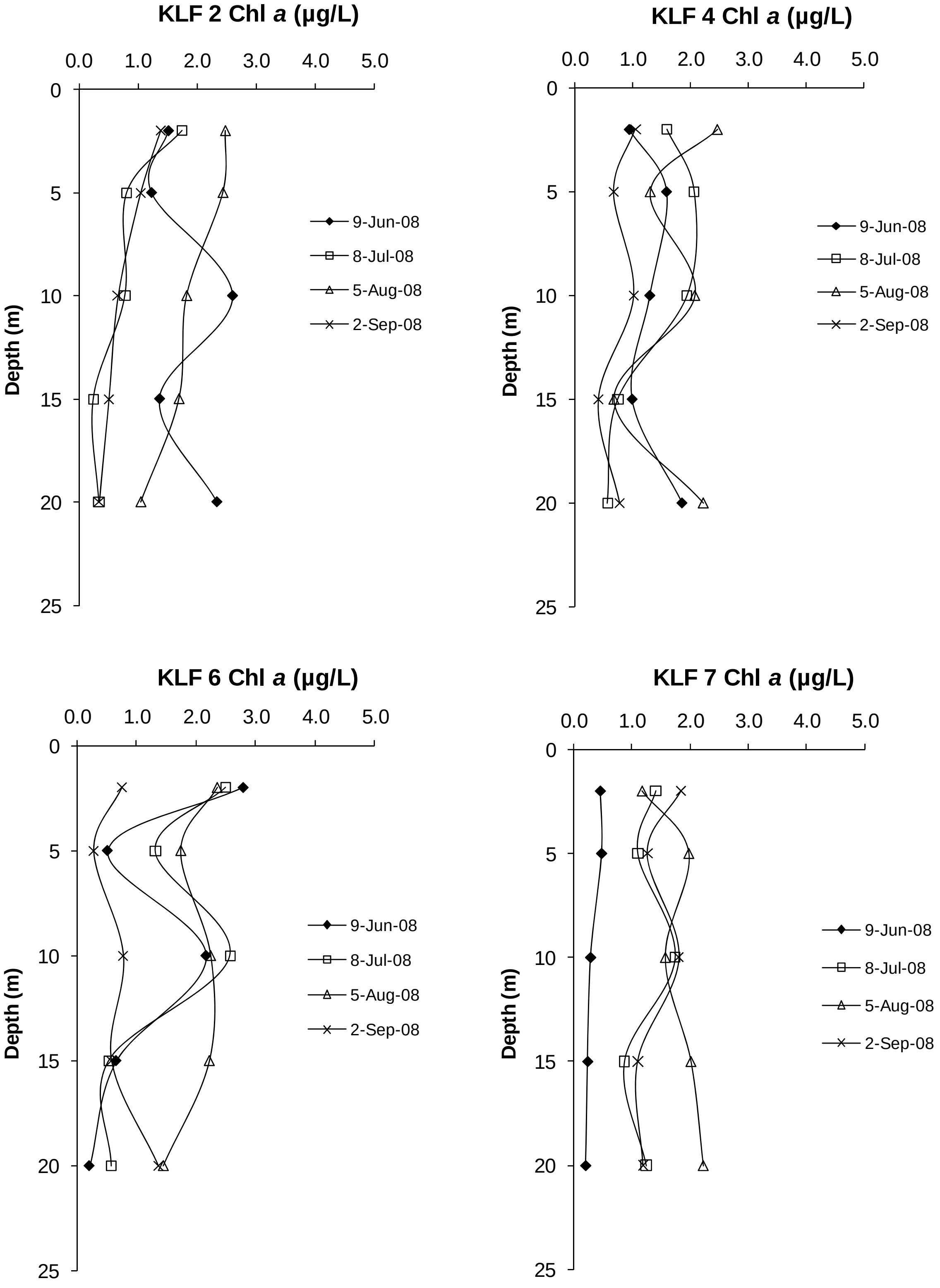
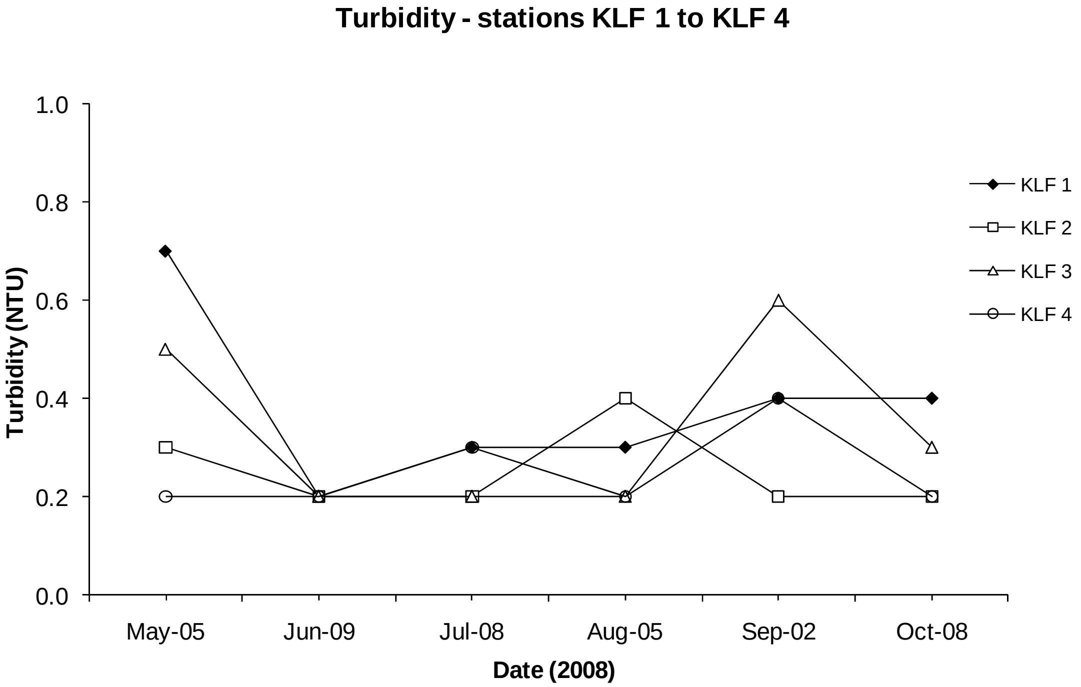


Figure 3.35. Chlorophyll *a* concentrations, discrete depth profiles, stations KLF 2, 4, 6 and 7, June to September 2008.



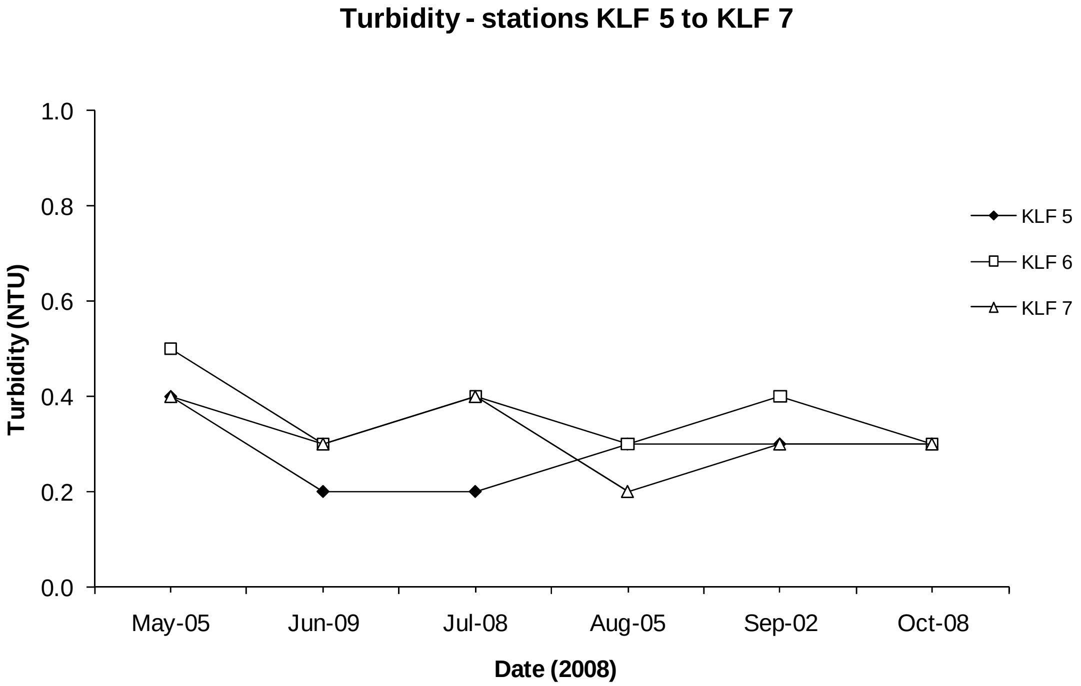
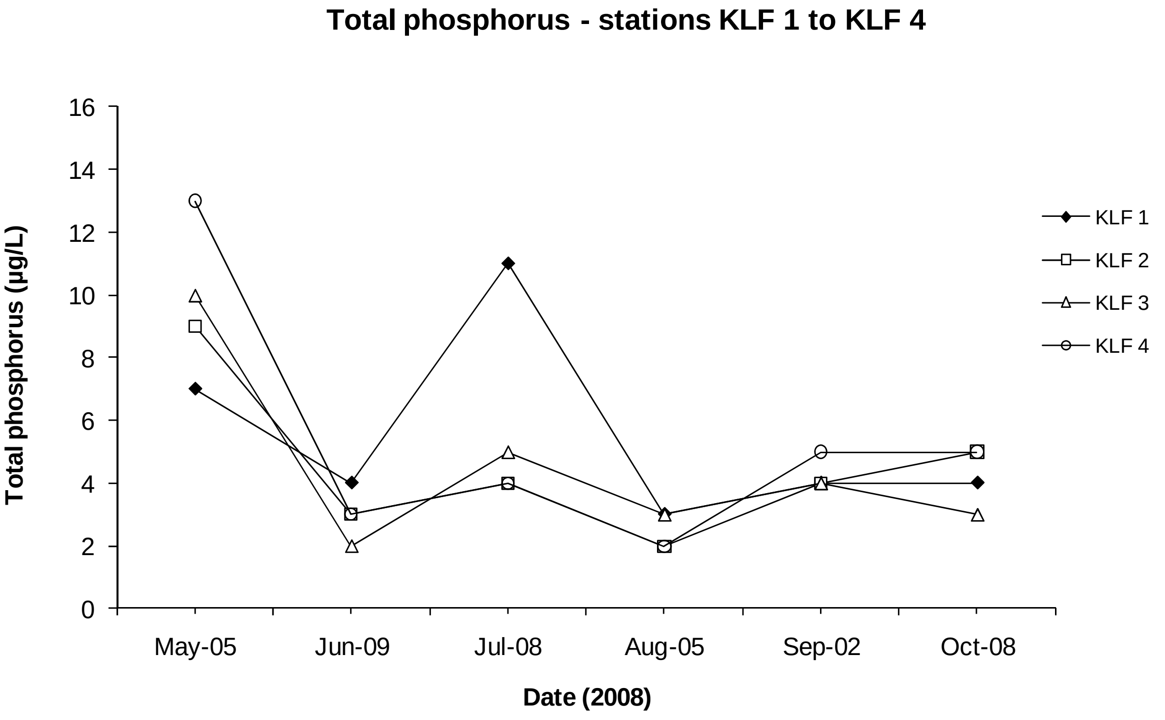


Figure 3.36. Turbidity results from discrete hypolimnion samples stations KLF 1 – 7, May to October, 2008.



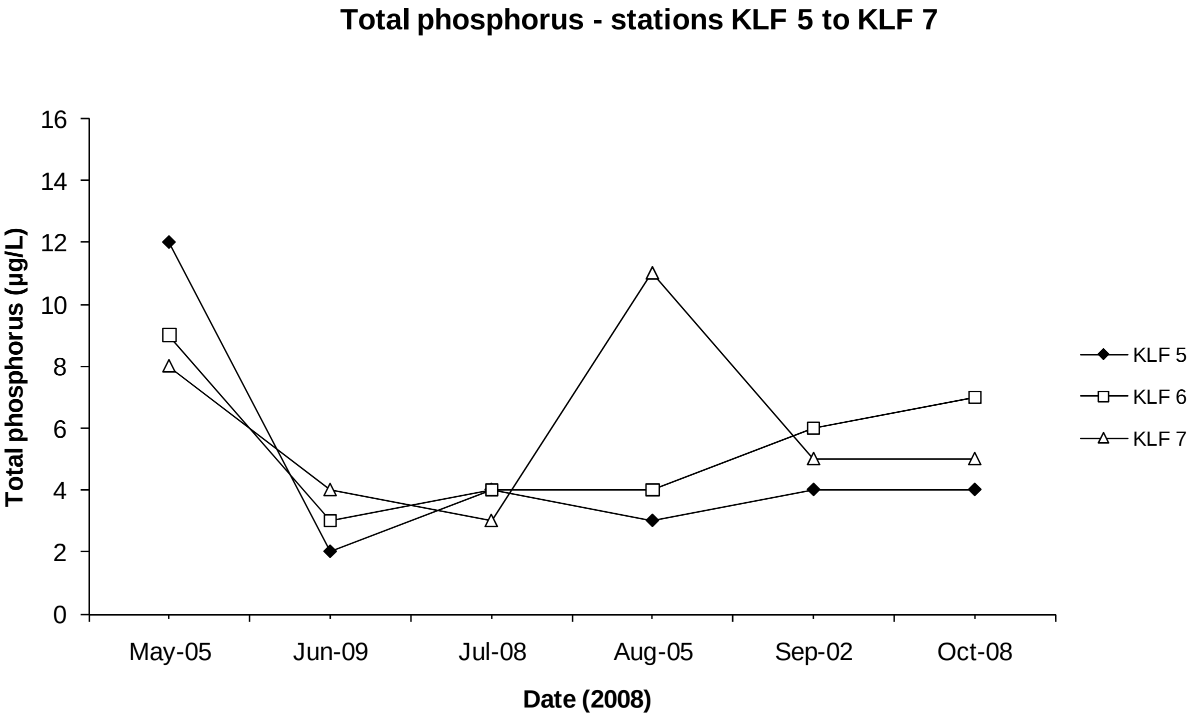


Figure 3.37. Total phosphorus results from discrete hypolimnion samples stations KLF 1 – 7, May to October, 2008.

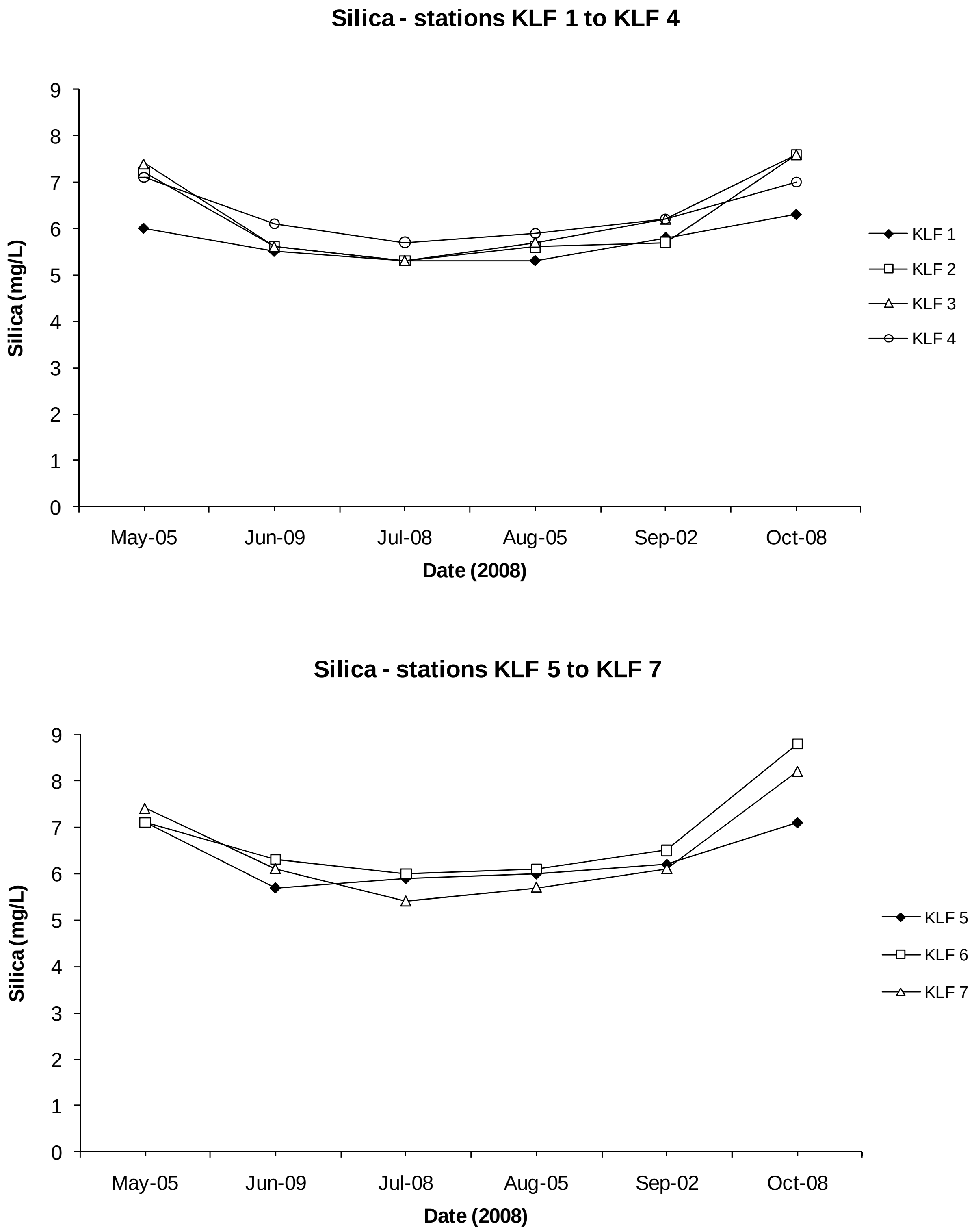


Figure 3.38. Silica results from discrete hypolimnion samples stations KLF 1 – 7, May to October, 2008.

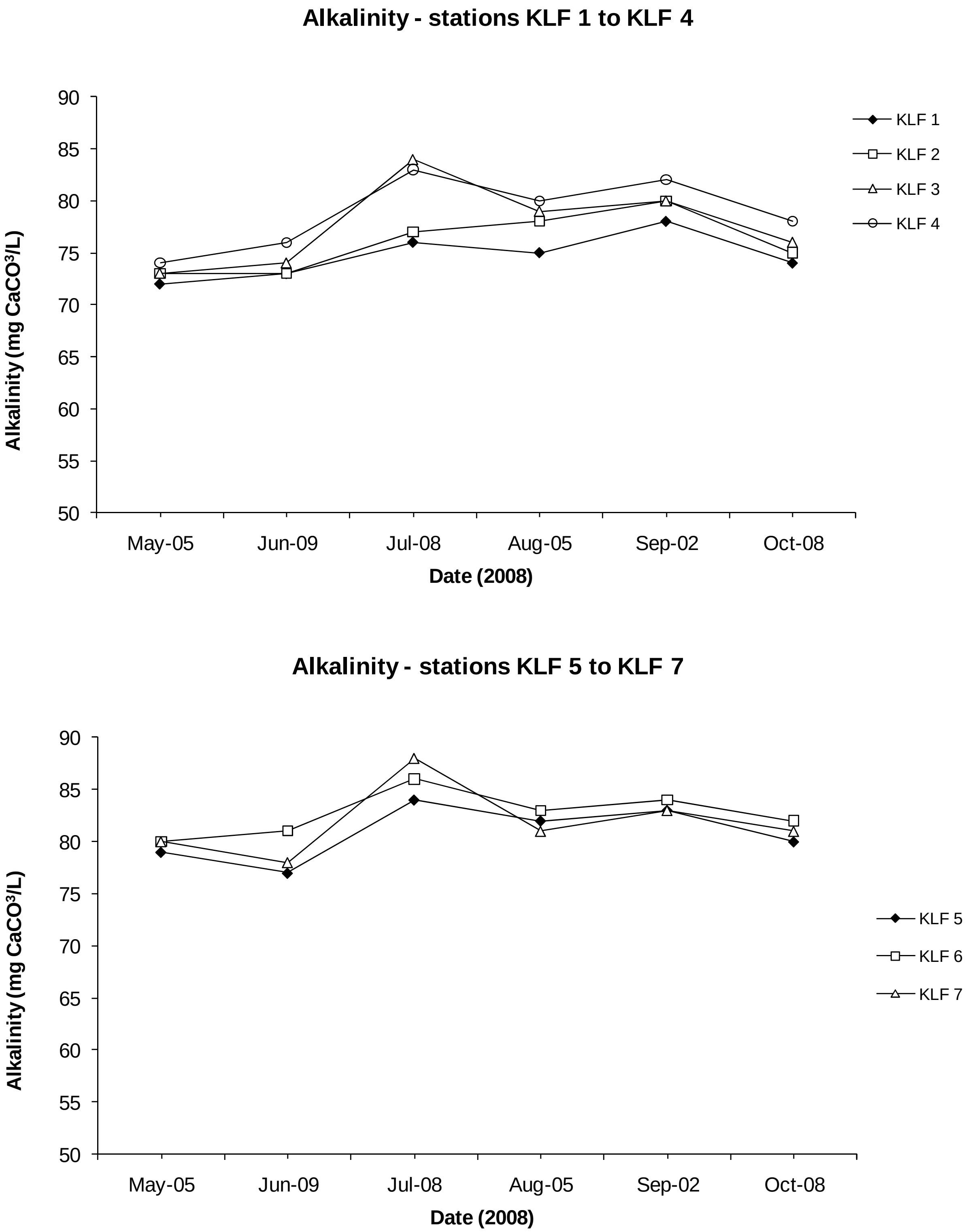


Figure 3.39. Alkalinity results from discrete hypolimnion samples stations KLF 1 – 7, May to October, 2008.

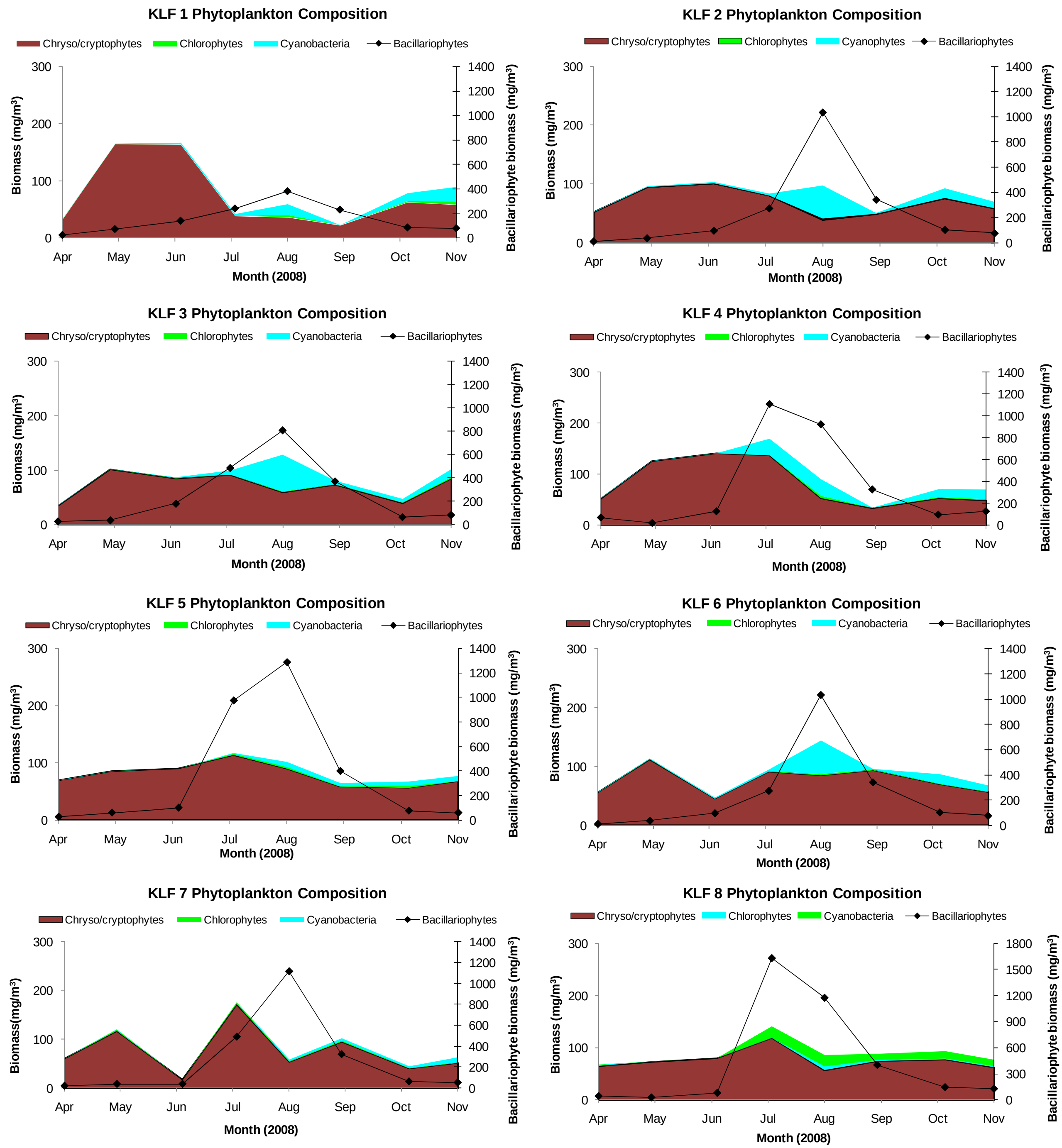


Figure 3.40. Phytoplankton biomass from 0 – 20 m integrated samples, stations KLF 1 – 8, April to November, 2008. Note: bacillariophyte axis different for station KLF 8.

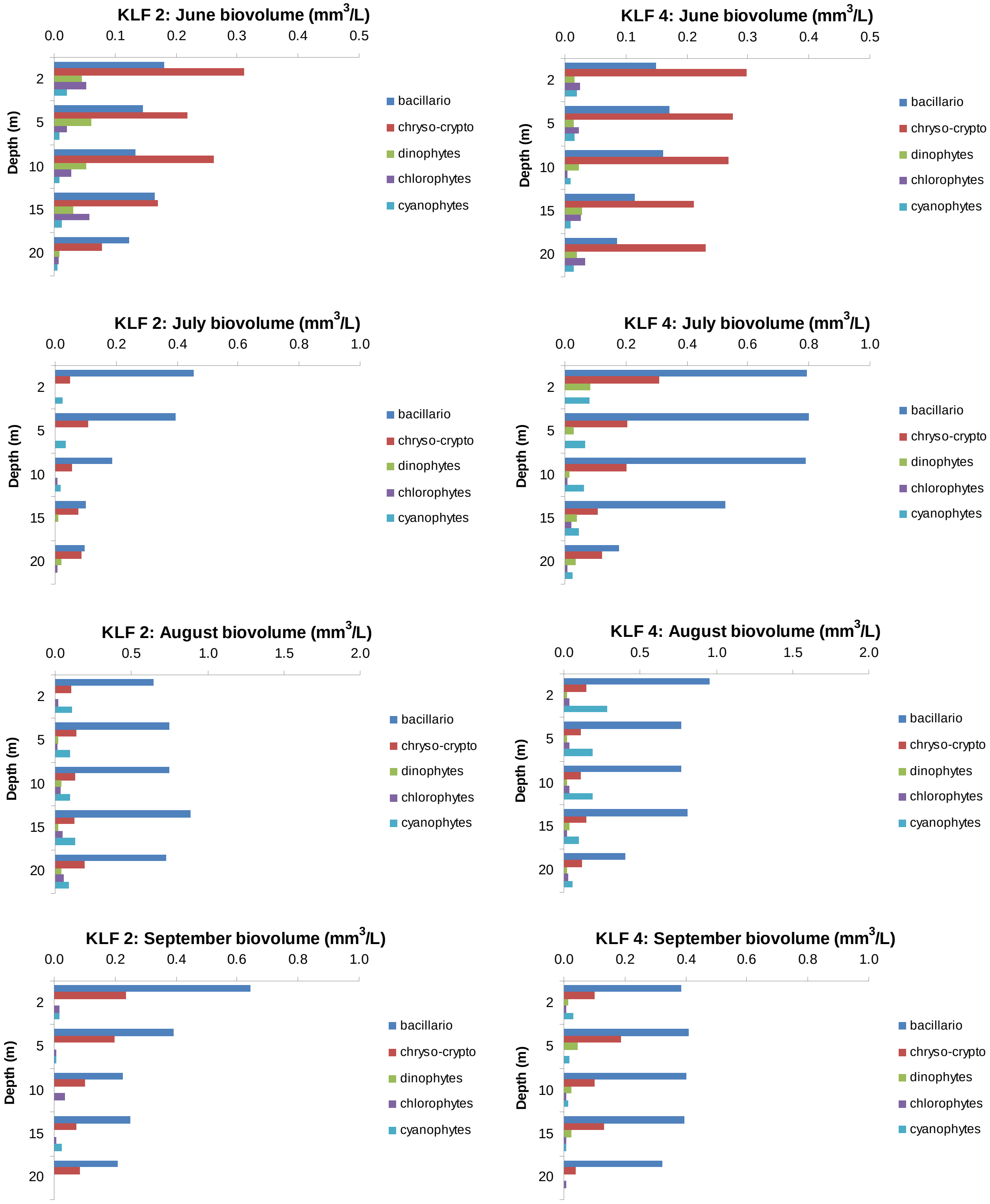


Figure 3.41. Phytoplankton biovolume from discrete depth samples, stations KLF 2 and KLF 4, June to September, 2008.

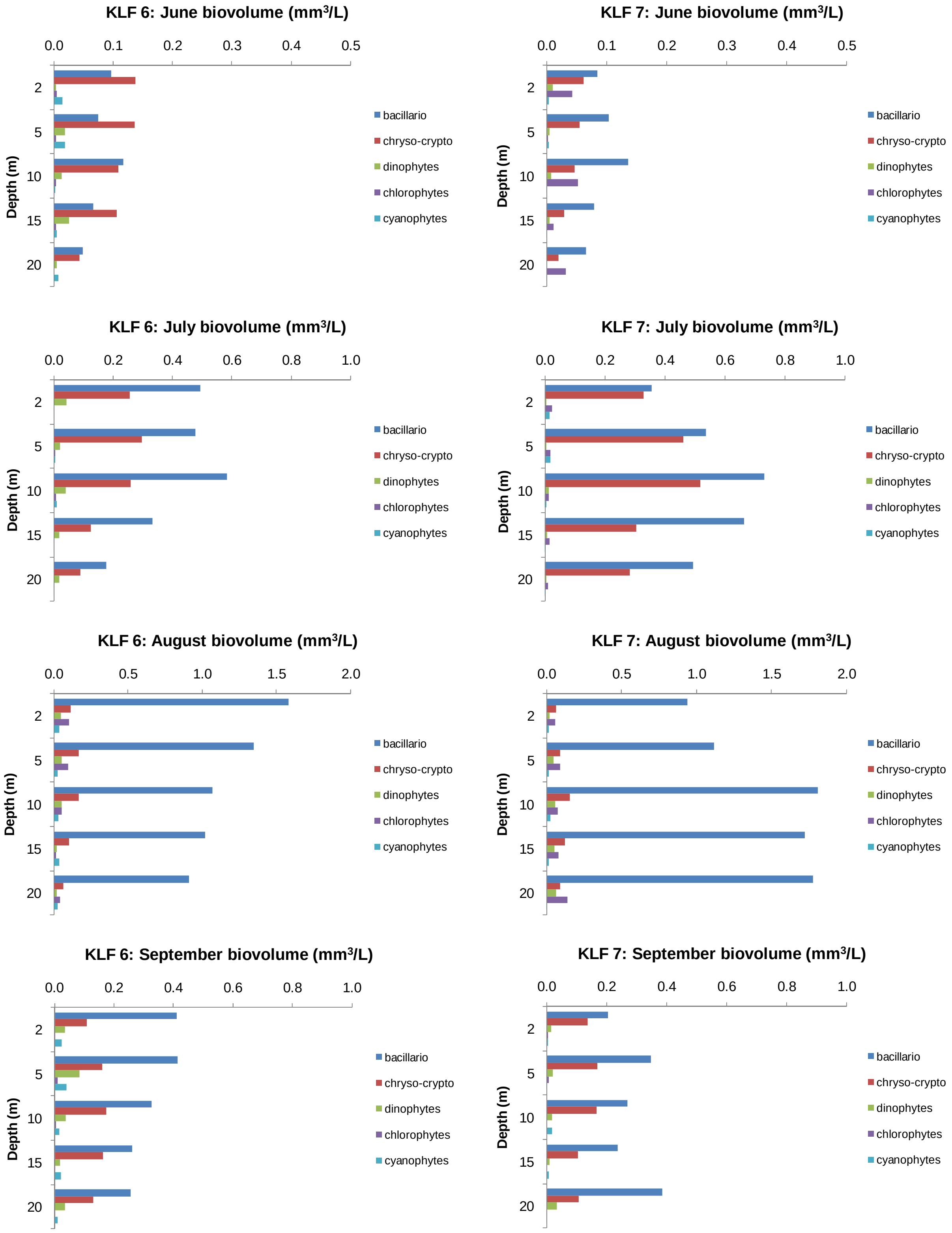


Figure 3.42. Phytoplankton biovolume from discrete depth samples, stations KLF 6 and KLF 7, June to September, 2008.

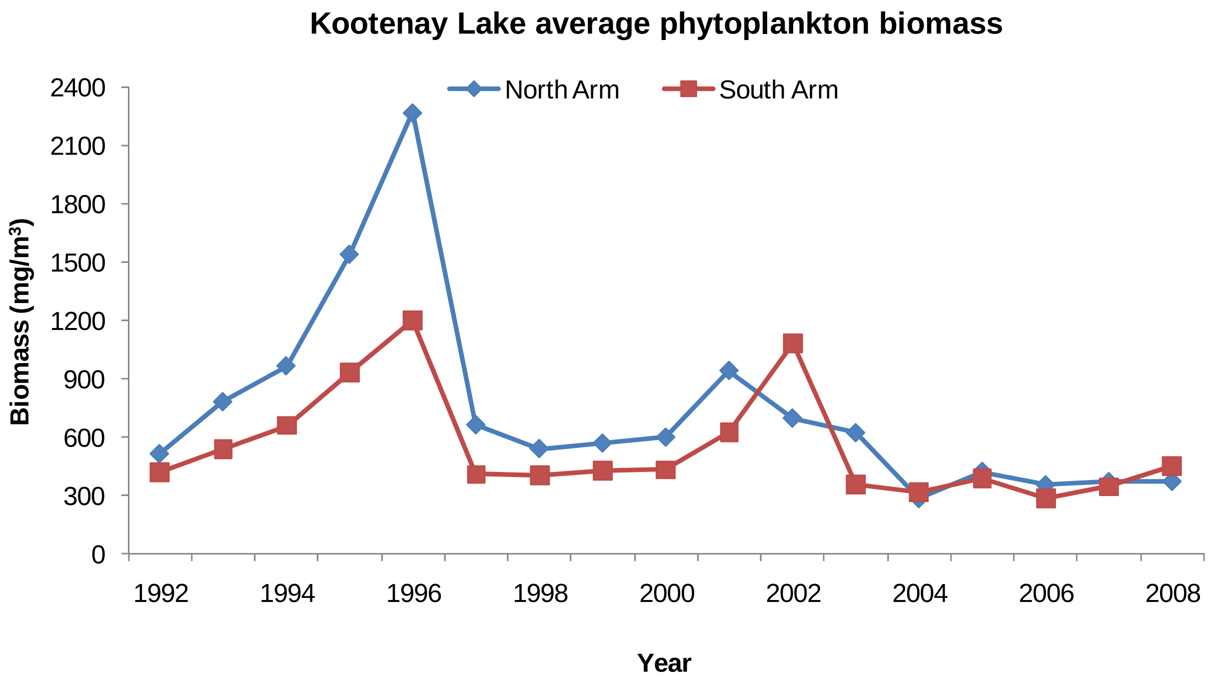


Figure 3.43. Annual average phytoplankton biomass from integrated samples, 0-20m, 1992 to 2008.

CHAPTER 4

ZOOPLANKTON AND *MYSIS DILUVIANA* RESPONSE TO NUTRIENT ADDITION IN KOOTENAY LAKE – 2008

by

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Introduction

Nutrient additions to Kootenay Lake began in 1992 in the North Arm, in an effort to restore the lake's productivity to pre-dam levels. Kokanee salmon (*Oncorhynchus nerka*) abundance had declined to a historical low in 1991 as a result of nutrients being trapped upstream from hydroelectric development. There was a concern that the stock might collapse and sport fish such as Gerrard rainbow trout (*Oncorhynchus mykiss)* and bull trout (*Salvelinus confluentus)* would decrease significantly, as kokanee are their main food source. 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*. *Mysis relicta* was introduced into Kootenay Lake in 1949 (this species is now renamed *Mysis diluviana*) (Audzijonyte and Vainola, 2005). The release of mysids interfered with established food webs and affected benthic, phytoplankton, zooplankton, and fish communities.

During the first five years of the program (1992 – 1996), 47.1 tonnes of phosphorus and 206.7 tonnes of nitrogen were added in the form of liquid fertilizer to Kootenay Lake (see Chapter 2 in this report for details). After four years of decreased nutrient addition (1997–2000), fertilizer loading was increased from 2001 onward to a similar level used during the first five years (1992–1996).

Fertilization of the South Arm commenced in 2004 and has continued through 2008. The fertilizer was dispensed between stations KLF 5 and KLF 6 (see Chapter 2 for details).

The study of zooplankton and mysids in Kootenay Lake started in 1992 as part of a multidisciplinary project to restore kokanee stocks by experimental fertilization of the lake’s North Arm. This report will focus on results from 1997 through 2008. Previous years’ data are described in Ashley et al. 1996 and 1997, and in Thompson 1999.

Methods

Zooplankton

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 (see Fig 1.1 in Chapter 1 of this report). From 1997 onward, zooplankton was sampled monthly from April through October at four stations: KLF 2, 4, 6, and 7. In 2003, a station in the West Arm was established (KLF 8) and samples were collected monthly from August to November. Samples were also collected from stations KLF 1, 3, and 5 during the same months. From 2004 onward samples were collected from April through November at all stations.

In 2008, samples were collected from April 09th to November 06th, using a Clarke-Bumpus sampler. At each of the stations (KLF 1–8), three replicate oblique tows were made. The net had 153-µm mesh and was raised from a depth of 40 m to 0 m, at a boat speed of 1 m/s. 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 sampling seasons in a flume at the Civil Engineering Department at the University of British Columbia.

Zooplankton samples were rinsed from the dolphin bucket through a 100-μm filter to remove excess lake water and were 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 length of up to 30 organisms of each species was 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 an empirical length-weight regression from McCauley (1984). The number of eggs carried by gravid females and the length of these individuals were recorded for use in fecundity estimates.

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).

Mysis diluviana

Samples of mysids from Kootenay Lake were collected monthly from January to December from 1997 to 2004, February to December in 2005, February to November in 2006 and from April to November in 2007 and 2008 at eight stations (KLF 1–4 in the North Arm, KLF 5–7 in the South Arm and station KLF 8 in the West Arm). Sampling was done at night, around the time of the new moon when logistically possible, 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 mesh. Two hauls were made in deep water (0.5 nautical miles from both west and east of lake centre) and one haul was made in shallow water near either the west or east shore. The West Arm station has a maximum depth of 35 m, therefore two samples were collected from this depth and one from 25 m. 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 and were then preserved in 100% denaturated alcohol (85% ethanol, 15% methanol).

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. Samples were analyzed for density, biomass, life history stage, and maturity. Mysids were counted and had their life history stage and maturity identified. Nine life history stages were identified: 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) (Reynolds and DeGraeve 1972). The body length (tip of rostrum to base of telson) of up to 30 individuals of each stage and maturity was measured, for use in biomass calculations, using a mouse cursor on a live television image of each organism. Lengths were converted to biomass (mg dry weight) using an empirical length-weight regression (Smokorowski 1998).

Results

Species Present

Twenty 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 cladocerans *Daphnia galeata mendotae* and *Bosmina longirostris* being the most numerous.

During the study period, four calanoid copepod species, *Epischura nevadensis* (Lillj.), *Leptodiaptomus ashlandi* (Marsh), *Leptodiaptomus pribilofensis* (Juday and Muttkowski) and *Leptodiaptomus sicilisi* (Forbes), were identified in samples from Kootenay Lake (Table 4.1). Only one cyclopoid copepod species, *Diacyclops bicuspidatus thomasi* (Forbes), was identified during the same time period.

Fifteen cladoceran species were present in Kootenay Lake during the study period (Table 7.1). Seven species were present in samples in all twelve 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 brachiurum* (Liéven). Other rare species such as *Scapholeberis mucronata* (O.F.M.), *Polyphemus pediculus* (L.), *Chydorus sphaericus* (O.F.M.), *Sida cristallina* (O.F.M.), *Alona affinis* (Leydig), *Acroperus harpae* (Baird), and *Graptoleberis testudinaria* (Fischer) were observed sporadically. *Daphnia* spp. were not identified to species for density counts in any of the study years.

In all twelve 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 *D. brachiurum*, *Daphnia* spp., and *B. longirostris* were common in all study years.

Table 4.1. List of zooplankton species identified in Kootenay Lake, 1997–2008.

	97	98	99	00	01	02	03	04	05	06	07	08
Cladocera												
Alona sp.		+						+		+		+
Alona affinis								+		+	+	+
Acroperus harpae								+				+
Bosmina longirostris	+	+	+	+	+	+	+	+	+	+	+	+
Ceriodaphnia reticulata	+	+	+	+	+	+	+	+	+	+	+	+
Chydorus sphaericus		+	+	+			+	+	+	+	+	+
Daphnia galeata mendotae	+	+	+	+	+	+	+	+	+	+	+	+
Daphnia pulex	+	+	+	+	+	+	+	+	+	+	+	+
Daphnia longispina	+	+	+	+	+	+	+	+	+	+	+	+
Diaphanosoma brachiurum	+	+	+	+	+	+	+	+	+	+	+	+
Graptoleberis testudinaria								+				
Leptodora kindti	+	+	+	+	+	+	+	+	+	+	+	+
Polyphemus pediculus	+	+									+	
Scapholeberis mucronata	+		+	+						+		
Sida cristallina			+								+	
Copepoda												
Diacyclops bicuspidatus	+	+	+	+	+	+	+	+	+	+	+	+
Epischura nevadensis	+	+	+	+	+	+	+	+	+	+	+	+
Leptodiaptomus ashlandi	+	+	+	+	+	+	+	+	+	+	+	+
Leptodiaptomus pribilofensis										+	+	
Leptodiaptomus sicilis						+		+				

Density and Biomass

Zooplankton densities during the period of nutrient addition (1992–2008) have been consistently higher than during the period from 1973 to 1991, with the exception of some years such as 1972 and in the period from 1983 to 1985 (Fig. 4.1). The zooplankton populations in Kootenay Lake show a diverse species assemblage, with relatively steady population density in 2008 compared to the previous year. The zooplankton community in 2008 was composed of 91% copepods, 4% *Daphnia* spp., and 5% cladocerans other than *Daphnia* spp. in the North Arm (Fig. 4.2). The proportion of cladocerans (including *Daphnia* spp.) varied from about 4–16% from 1997 to 2008, except in 2001 when cladocerans composed of 27% of the zooplankton community. The South Arm population in the 2008 sampling season was similar to the North Arm and was comprised of 93% copepods, 3% *Daphnia* spp., and 4% cladocerans other than *Daphnia* spp. The proportion of cladocerans (including *Daphnia* spp.) over the course of the study varied from 5% to 18% from 1997 to 2008.

Kootenay Lake zooplankton density is numerically dominated by copepods, which include calanoids and cyclopoids. Both of these groups are widely distributed at the surface waters, are primarily planktonic, and are important components in food webs. During the study period 1997–2003 and in 2007 and 2008, cyclopoids dominated the copepod community. During the summer and late fall in 2004, during the entire season in 2005 and in the summer of 2006 calanoids were numerically dominant in both the North and South arms of Kootenay Lake (Figs. 4.3 and 4.4). Copepods were the most abundant zooplankton at each station from 1997 to 2008. They dominated during the entire sampling season, with populations peaking in July-August. In 2008, copepod density peaked in June to September at stations in the North Arm, and in July in South and West Arms. The largest copepod population was in the West Arm at station KLF 8 in July 2008 and averaged 62.04 individuals/L (Fig. 4.4). Cladocerans were occasionally captured at the beginning of the sampling season in April and May, but significant populations did not develop until August in each study year (Table 4.2, Fig. 4.5).

Zooplankton density in the North Arm fluctuated from year to year during the study period (Fig. 4.5). The fertilizer load in 2001 was increased to the 1992 to 1996 levels, and zooplankton density increased in the following two years. Zooplankton abundance from 2001 to 2003 was the highest observed during the fertilization experiment and was higher than abundance observed in the early 1980s (Fig. 4.1). During the next two years, 2004 and 2005, the zooplankton density decreased, followed by an increase in 2006, with similar results in 2007. In 2008 the seasonal average zooplankton abundance in the North Arm increased slightly to 27.09 individuals/L from 23.92 individuals/L in 2007. The *Daphnia* spp. density from 1997 to 2005 was less than 1 individual/L in the North Arm, except in 2001 with 1.17 individuals/L and in 2003 with 2.22 individuals/L. In 2006 and 2007 the annual average density of *Daphnia* increased to over 1.5 individuals/L, while in 2008 it decreased again to 0.96 individuals/L (Fig. 4.6). The density of other cladocerans varied during the course of the study with the highest values in 2001 at 7.96 individuals/L. In 2008, the seasonal average abundance of cladocerans other than *Daphnia* was 1.44 individuals/L.

Zooplankton density during the twelve years studied was lower in the South Arm than in the North Arm, except in 1997, 2004, and 2007 (Fig. 4.5). In the South Arm, the total zooplankton density increased from 2001 to 2003 compared to the 1997 to 2000 period. The 1997 to 2000 period was the time when North Arm fertilizer additions decreased (see Chapter 2). In 2004 and 2005 a decrease of total zooplankton occurred in the South Arm followed by a slight increase in 2006 and 2007 and a decrease in 2008. A similar pattern of density fluctuation of Copepoda and other Cladocera occurred during the study period (Fig. 4.5c). *Daphnia* spp. density fluctuated in each successive year of the study. In 2008, the seasonal average density of zooplankton in the South Arm was 21.54 individuals/L, copepods dominated with 19.98 individuals/L, while the density of *Daphnia* and other cladocera was 0.77 individuals/L and 0.79 individuals/L respectively (Fig 4.5a, Fig 4.6).

In 2008, the total zooplankton density and densities of copepods in the West Arm increased while *Daphnia* and Cladocera other than *Daphnia* decreased compared to the previous year. The seasonal average density (April to November) of zooplankton in the West Arm was 23.34 individuals/L (Fig. 4.5a). The zooplankton community in 2008 was composed of 91% copepods, 3% *Daphnia* spp., and 6% cladocerans other than *Daphnia* spp (Fig. 4.2).

Zooplankton biomass had similar trends in both the North and South arms of Kootenay Lake. From 1997 to 2008, biomass varied with the highest values recorded in 2003 in all three arms (Fig. 4.7a). A similar trend was observed for copepod biomass and *Daphnia* biomass in the North Arm. During 1997 – 2000 and 2004 – 2005, biomass was higher in the South Arm than in the North Arm for all categories except copepods (Fig. 4.7b, 4.7c, Fig. 4.8). During 2001 to 2003 and 2006 to 2008, biomass was higher in the North Arm than in the South Arm. Cladocerans other than *Daphnia* had the highest biomass in 2001 in both the North and South Arms. In 2008, biomass of total zooplankton and *Daphnia* decreased in both the North and South arms compared to the 2007 results. Biomass of Copepods and cladocerans other than *Daphnia* in the North Arm increased while in the South Arm the biomass decreased during the same time period. The peak in *Daphnia* biomass in the North Arm occurred in 2003 with 40.92 μg/L, while in the South Arm *Daphnia* biomass reached its peak in 2006 with 35.42 μg/L (Fig. 4.8). In the North Arm, *Daphnia* spp. comprised 11% to 49% of the total zooplankton biomass from 1997 to 2008. During the same period, *Daphnia* spp. varied from 12% to 48 % of the total zooplankton biomass in the South Arm (Fig. 4.9). In 2008 *Daphnia* biomass comprised 25% and 27% of the total zooplankton biomass in the North and South Arm respectively.

During 2008, total zooplankton biomass decreased in the West Arm as well as the biomass of *Daphnia* and other Cladocera, while copepod biomass increased. The highest seasonal average biomass of total zooplankton, copepods and cladocerans other than *Daphnia* in the West Arm occurred in 2003, while the highest *Daphnia* biomass occurred in 2006. In 2008 the seasonal average biomass of zooplankton in the West Arm decreased from 57.20 μg/L in 2007 to 46.47 μg/L (Fig. 4.7a). *Daphnia* biomass decreased significantly from 26.29 μg/L in 2007 to 9.63 μg/L in 2008 (Fig. 6.8). The kokanee spawning escapement has increased in 2008 from the numbers in 2006 and 2007; therefore a potential grazing effect of kokanee on zooplankton could have occurred. From 2003 to 2008 the proportion of copepod biomass varied from 33-75%, cladocerans other than *Daphnia* comprised 3-10% and *Daphnia* comprised 21-64% of the total zooplankton biomass. In 2008 copepods comprised 75%, *Daphnia* spp. 21% and cladocerans other than *Daphnia* spp. 4% of the total the zooplankton biomass (Fig. 4.9).

Seasonal and Along-Lake Patterns

In 2008, copepods were the predominant form of zooplankton, cladocerans were present throughout the sampling period and *Daphnia* spp. was observed from July to November. The seasonal development of zooplankton density did not differ between the North and South arms of Kootenay Lake in 2008. Total zooplankton density increased from the spring to the summer and decreased in the fall. Copepod density dominated during the entire season, except in September where *Daphnia* dominated the biomass in all three basins. Cladoceran abundance was low and the peak occurred in September in the North Arm and in August in the South and West arms. *Daphnia* spp. density peaked in September in the North and South Arms, and in August in the West Arm of Kootenay Lake.

During 2008, peak total zooplankton densities occurred in July in the South and West Arms with 54.61 and 63.20 individuals/L respectively, and in September in the North Arm with 42.34 individuals/L (Table 4.2). The peak total zooplankton biomass occurred in July at 104.43 μg/L in the West Arm, and in September in the North and South Arm at 148.38 μg/L and 117.70 μg/L respectively. The peak *Daphnia* spp. biomass also occurred in September in all three basins with

87.83 µg/L in the North Arm, 72.49 µg/L in the South Arm and 43.32 µg/L in the West Arm (Table 4.2). During the September peak, *Daphnia* spp. comprised a small proportion of zooplankton density. The large body size of the adults resulted in peak *Daphnia* biomass of 59%, 61%, and 51% of the total biomass in the North, South, and West arms respectively.

During 1997, 2006 and 2007, *Daphnia* spp. started to appear as early as May, which was earlier than other years. In those years *Daphnia* was the most numerous in August. Conversely, 2004 was a late-season year, where *Daphnia* spp. began to appear in August and reached its peak in October. In other years *Daphnia* usually started to appear in July, with the peak occurring in August-September.

During the twelve years of the study, peaks in density occurred at approximately the same time in the North and South arms. Similarly, biomass peaks in the North and South arms tended to coincide, or only be a month apart. At times, there was a one to two month delay between the density and the biomass peaks. This delay was due to the increase in *Daphnia* and other cladoceran densities following the copepod density peak, in addition to the large body size of individual cladocerans.

Table 4.2. Monthly average density and biomass of zooplankton in the North, South and West arms of Kootenay Lake in 2008. Density is in units of individuals/L, and biomass is in units of µg/L.

Density		**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**
North Arm	Copepoda	4.76	6.67	33.93	33.81	31.81	29.66	31.12	25.76
	Daphnia	0.00	0.00	0.00	0.00	0.77	5.90	0.97	0.04
	Other Cladocera*	0.03	0.02	0.08	0.11	3.90	6.78	0.46	0.13
	Total Zooplankton	4.78	6.69	34.01	33.92	36.48	42.34	32.56	25.93
South Arm	Copepoda	4.18	10.85	11.90	53.90	22.28	21.00	20.68	15.03
	Daphnia	0.00	0.00	0.00	0.03	1.70	4.14	0.27	0.00
	Other Cladocera*	0.01	0.01	0.14	0.69	3.37	1.84	0.29	0.02
	Total Zooplankton	4.19	10.86	12.04	54.61	27.35	26.98	21.24	15.05
West Arm	Copepoda	2.42	7.65	12.98	62.04	25.82	18.79	15.14	25.36
	Daphnia	0.00	0.00	0.00	0.00	2.75	2.55	0.18	0.21
	Other Cladocera*	0.01	0.00	0.15	1.16	6.76	2.42	0.16	0.16
	Total Zooplankton	2.43	7.65	13.12	63.20	35.33	23.77	15.47	25.72

Biomass		**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**
North Arm	Copepoda	9.98	12.75	43.44	60.50	56.54	52.44	42.63	38.74
	Daphnia	0.00	0.00	0.00	0.00	11.20	87.83	11.45	0.50
	Other Cladocera**	0.03	0.05	0.12	0.19	7.15	8.12	1.34	0.50
	Total Zooplankton	10.01	12.80	43.56	60.69	74.89	148.38	55.42	39.74
South Arm	Copepoda	7.71	20.00	21.03	78.68	42.56	41.23	31.55	26.26
	Daphnia	0.00	0.00	0.00	0.11	28.77	72.49	4.86	0.00
	Other Cladocera**	0.01	0.02	0.22	0.97	5.00	3.99	1.00	0.10
	Total Zooplankton	7.72	20.01	21.25	79.76	76.33	117.70	37.42	26.35
West Arm	Copepoda	4.96	11.25	18.98	103.29	44.14	36.73	20.84	38.00
	Daphnia	0.00	0.00	0.00	0.00	29.37	43.32	2.37	1.95
	Other Cladocera**	0.01	0.00	0.20	1.15	9.60	4.00	0.49	1.10
	Total Zooplankton	4.97	11.25	19.19	104.43	83.11	84.05	23.71	41.05

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

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

The maximum zooplankton density in 2008 occurred in September, in the main body of Kootenay Lake at station KLF 1, averaging 67.24 individuals/L, and in July in the West Arm averaging 63.20 individuals/L (Fig. 4.10 and 4.11). Copepod densities peaked in June-July at most stations. The peak copepod density in the main body of the lake occurred in July at station KLF 6 with 60.08 individuals/L. The peak density in the West Arm also occurred in July with 62.04 individuals/L (Fig. 4.11). The peak copepod biomass was also in July with 100.84 µg/L at station KLF 7 and 103.29 µg/L in West Arm at station at KLF 8. Cladocerans were occasionally captured in April-May (when sampling began), with significant populations developing in August-September (Figs. 4.10 and 4.11). The peak density of Cladocera other then *Daphnia* in the main body of the lake occurred in September at station KLF 1 with 12.48 individuals/L, while the peak biomass occurred in August at station KLF 4 with 14.97 µg/L.

Peak *Daphnia* densities along the lake were generally 5-21% of the total zooplankton density. The maximum seasonal density in the main body of the lake was in September at station KLF 4, at 10.36 individuals/L, while in the West Arm the peak density occurred in August at 2.75 individuals/L. The maximum *Daphnia* biomass in the main body of the lake was observed at station KLF 4 at 180.80 µg/L in September. The maximum *Daphnia* biomass in the West Arm was 43.32 µg/L, also recorded in September (Figs. 4.12 and 4.13). In each sampling year, the biomass trend along the main body of the lake was largely driven by the development of *Daphnia* spp., from August onward. *Daphnia* comprise 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).

Zooplankton Fecundity

Fecundity of the four most common zooplankton species, *L ashlandi*, *D. bicuspidatus thomasi*, *Daphnia spp*., and *B. longirostris*, were studied. Copepods *L. ashlandi* and *D. bicuspidatus thomasi* develop from fertilized eggs that are carried by the females in egg sacs (one egg sac Calanoida - *Leptodiaptomus*; two egg sacs Cyclopoida - *Diacyclops*). Copepod eggs hatch into small free-swimming larvae that develop by molting through a number of subsequent larval stages. Clutch size, number of eggs and time required to complete juvenile stages depends on different environmental conditions, food availability, and predation. During a period of unfavourable conditions, resting eggs are produced. These eggs sink to the bottom where they undergo a period of diapause. In contrast to copepods, cladocerans *Daphnia spp*., and *B. longirostris* reproduce by parthenogenesis during a greater part of the season. The eggs are deposited into a brood pouch at the dorsal to the body bounded by the carapace. The eggs develop in the brood pouch and hatch as a small form of parents. The number of molts and the number of eggs released in the brood pouch are affected by different environmental factors such as temperature, food availability, lipid reserves accumulated in their body, predation, competition etc. With unfavourable conditions (lower temperature, lower food availability short photoperiod), the production of parthenogenesis eggs decline and production of one or few resting eggs increases. Fertilised resting eggs are enclosed in the brood pouch and the surrounding carapace thickens. Resting eggs can withstand severe conditions, and under favourable conditions parthenogenesis females hatch and continue the life cycle.

L. ashlandi females were gravid throughout the sampling period in 2008 (Fig. 4.14). The proportion of females that were gravid was highly variable. This trend occurred in previous years, and was always below 0.4. From April to November 2008, the proportion of gravid females averaged 0.11 in the North Arm, 0.15 in the South Arm, and 0.16 in the West Arm (App. 4.1, Fig. 4.15). From 1997 to 2002 and in 2007, females in the South Arm carried more eggs than in the North Arm, while from 2003 to 2006 and in 2008 the pattern changed and females from the North Arm had more eggs than those from the South Arm (App. 4.1). In 2008 *L. ashlandi* females carried an average of 12.86, 12.06, and 12.20 eggs per gravid female in the North, South and West arms respectively. The number of eggs ranged from 6 to 22 per gravid female (App. 4.1, Fig. 4.15). The number of eggs per water volume averaged 1.38 eggs/L in the North Arm, 2.04 eggs/L in the South Arm, and 1.32 eggs/L in the West Arm. The number of eggs per capita averaged 0.19, 0.29, and 0.17 eggs/individual in the North, South, and West arms respectively.

Fecundity data of *D. bicuspidatus thomasi* varied throughout the study period. The proportion of gravid females *D. bicuspidatus thomasi* in 2008 ranged from 0 to 0.5 (Fig. 4.14). From April to November, the proportion of gravid females averaged 0.12 in the North Arm, 0.18 in the South Arm, and 0.10 in the West Arm (App. 4.1, Fig. 4.15). The seasonal average number of eggs per gravid female was 15.08, 16.52, and 14.31 in the North, South and West arms respectively. The number of eggs per gravid female ranged from 7 to 38 eggs. During the sampling season, the number of eggs per litre of water averaged 1.95, 2.74 and 2.08 eggs/L, while the number of eggs per capita averaged 0.22, 0.53 and 0.30 eggs/individual in the North, South, and West arms respectively.

Gravid females of *Daphnia* spp. were observed in samples from August to October in 2008. The proportion of gravid *Daphnia* spp. ranged from 0 to 0.39 in 2008 and averaged 0.11 in the North Arm, 0.18 in the South Arm and 0.07 in the West Arm (App. 4.1, Fig. 4.16). The proportion of gravid females was similar level to 2007 results. The seasonal average fecundity in 2008 was 2.61, 2.29 and 2.47 eggs per gravid female in the North, South, and West arms respectively, with a range of 1–6 eggs per gravid female. During the sampling season, the number of eggs per litre of water averaged 0.16, 0.22 and 0.21 (Fig. 4.17), while the number of eggs per capita averaged 0.36, 0.45 and 0.17 in the North, South, and West arms respectively. Fecundity was higher in the main body of the lake than in the West Arm during the 2008 sampling season.

Gravid females of *B. longirostris* were observed from April to November in 2008 (Fig. 4.16). The proportion of gravid females averaged 0.28, 0.32 and 0.16 in the North, South, and West arms respectively in 2008. The seasonal averages were 1.79, 1.52 and 2.0 eggs per gravid female in the North, South, and West arms respectively. The number of eggs per gravid female ranged from 1 to 3 eggs (App. 4.1, Fig. 4.17). During the sampling season, the number of eggs per litre of water averaged 0.37, 0.21 and 0.36, while the number of eggs per capita averaged 0.56, 0.45 and 0.34 in the North, South, and West arms respectively.

Comparison to other lakes

Total average density and biomass and *Daphnia spp*. average density and biomass varied during 1997–2008 (Fig. 6.5). Seasonal average zooplankton density in Kootenay Lake was higher than in either of the Arrow basins during each year of the study, except in 2000 and 2004 when zooplankton density in Lower Arrow was similar to Kootenay Lake results (Fig. 4.18) (Schindler et al. 2006, 2007, 2009, 2010). Total biomass in Kootenay Lake was less than the biomass in Lower Arrow during each year from 1998 to 2000 and less than the biomass in Upper Arrow only in 1999 (Fig. 4.19). From 2001 to 2008, the fertilizer load in Kootenay Lake was increased from the loads added during 1997 to 2000, causing zooplankton biomass to increase. From 2001 to 2003 zooplankton biomass was higher in Kootenay Lake than in both basins of Arrow Lakes Reservoir. From 2004 to 2006 the biomass in all three Kootenay arms was similar to biomass results in Lower Arrow and two to four fold higher then in Upper Arrow. In 2007 zooplankton biomass in the main body of Kootenay Lake was double than in Lower Arrow and almost six times higher than in Upper Arrow, while zooplankton biomass in the West Arm was similar to results in Upper and Lower Arrow. In 2008 zooplankton biomass in all three arms of Kootenay

Lake was lower than in Lower Arrow and higher than in Upper Arrow. *Daphnia* biomass in the main body of Kootenay Lake was approximately 1.5 fold less than in Upper Arrow and approximately 3.5 fold lower than in Lower Arrow, while in the West Arm the difference was even more pronounced (Fig. 4.19). These differences are due to the fluctuation in the proportion of *Daphnia spp*. in total zooplankton density and biomass in these lakes (Fig. 4.20). Since individual *Daphnia* have a higher biomass than individuals of most other zooplankton species in these systems, it results in an increase of zooplankton biomass. The variation in *Daphnia* biomass between Kootenay Lake and Arrow Lakes Reservoir can also be explained by the variation in abundance in kokanee. Kokanee populations in Kootenay Lake have increased from 2005 to 2008, coinciding with the decrease in *Daphnia* biomass (see Chapter 5 in this report). Kokanee abundance in Kootenay Lake is also higher than in Arrow Lakes Reservoir – the grazing effect of kokanee on zooplankton would therefore be potentially less in Arrow than in Kootenay (Schindler et al 2009, 2010).

Seasonal average zooplankton density and biomass in Kootenay Lake was higher than in Alouette Lake during the study period, except in 2006 and 2008 when zooplankton and *Daphnia* biomass in Alouette Lake exceeded biomass values in the Kootenay Lake (Figs. 6.18, 6.19). In 2004 and 2007 biomass of both total zooplankton and *Daphnia* in Alouette Lake was the lowest over the years studied. *Daphnia* did not appear in the lake during the entire season, therefore explaining the low biomass (Harris et al. 2007). In 2005, 2006 and 2008 the *Daphnia* population in Alouette Lake increased, comprising of 56-65% of the total zooplankton biomass (Fig. 6.20). *Daphnia* density and biomass in Alouette Lake in 2006 and 2008 were higher than in the main body of Kootenay Lake with similar results in the West Arm of Kootenay Lake.

The highest percentage of *Daphnia* density and biomass in total zooplankton in Arrow Lakes Reservoir exceeded those values in other lakes in the period from 1997 to 1999, while in the period from 2000 to 2008 the proportion of *Daphnia* density and biomass varied from lake to lake. In 2008 the proportion of *Daphnia* density and biomass in Kootenay Lake was the lowest among the studied lakes (Fig. 4.20).

Mysis diluviana

Abundance and Biomass

Seasonal average mysid densities during the nutrient addition period (1992 through 2008) were well below the values observed in the late 1970s and the mid-1980s (Fig. 4.21). The values observed during this period may have arisen due to sampling frequency and the methods used. Samples were collected less regularly than during the current study, and the plankton net used to collect samples had a finer mesh (Crozier and Duncan 1984). From 1992 to 2004, sampling of mysids began in January and continued until December, so all annual average values represent twelve-months. In 2005, samples were not collected in February; therefore annual average values represent eleven-months. In 2006 samples were collected for ten months, between February and November, and in 2007 and 2008 for eight months from April to November. Mysid densities varied between 100 and 200 individuals/m^2. Higher densities were found only in 1992, the first year of nutrient additions and in 2001, when nutrients were increased to a similar level used during the first five years of the program (1992–1996) (Fig. 4.21) (see Chapter 2 for details of nutrient additions).

The annual average of mysid densities at deep stations was higher in the South Arm than in the North Arm in 1993, 1994, 2001, 2002, 2007 and 2008. In other years mysids were more abundant in the North Arm, except in 2004 when average mysid density was similar in the North and South arms of the lake. In the West Arm, the mysid population was significantly less than in either the North or South arms where samples were collected for an entire season, 2004 - 2008 (Fig. 4.22). The West Arm station has a maximum depth of 35 m. The samples comprised of only juveniles which tend to be distributed in the deep and shallow sites of the lake. Mature mysids tend to be distributed at the deep sites only.

M. diluviana is a cold water species. In stratified lakes its populations are restricted to the hypolimnion where the water temperature is <15°C (Wetzel 2001). During the day mysids stay just above the sediment of the hypolimnion of the lake. During the night with the decrease in light intensity, they migrate to the upper layers of the hypolimnion where temperatures are still below 15°C. This species rarely migrates into warmer surface water.

Samples collected at pelagic stations tended to have higher densities than near-shore samples. From 1999 to 2008, mysid densities at shallow sites in both the North and South arms were generally below 300 individuals/m^2 throughout the year (Fig. 4.23). At deep sites from July to October, densities were greater than 300 individuals/m^2 in five of the ten years (1999, 2000, 2001, 2004, and 2005) and less than 300 individuals/m^2 during the other five years (2002, 2003, 2006, 2007, and 2008). From 1999 to 2008, mysid densities were higher at deep stations in the North Arm, except in 2001, 2002, 2007 and 2008 when densities were higher in the South Arm. During this same period, mysid densities at the shallow stations were similar in both the North and South arms, except in 1999 when the density in the North Arm exceeded the number of mysids in the South Arm, and in 2000 and 2008 when densities in the South Arm were greater than in the North Arm (Fig. 4.23).

Peak monthly values at shallow sites were usually recorded in June-July, mainly due to a higher number of juveniles (Figs. 4.24 and 4.25). At deep sites, there were usually two density peaks during the year, the first in May-June and the second in August-October, mainly due to a higher density of immature males and females (Figs. 4.26 and 4.27)**.** In 2008, the mysid density increased at deep sites in both arms from the previous year. At the near shore stations an increase in mysid density occurred in the South Arm, and a decrease was observed in the North Arm. In 2008, the highest seasonal mysid abundance at a deep site was in July at station KLF 5 in the South Arm, at 465 individuals/m^2 (mainly juveniles) (Fig. 4.27). The highest seasonal abundance of mysids at a shallow site was also in July at station KLF 5, at 265 individuals/m^2 (mainly juveniles) (Fig. 4.25).

During 1999–2008, average mysid biomass was generally below 2,500 mg/m^2 at deep sites at all stations (Fig. 4.28). The average biomass was generally below 1,000 mg/m^2 at shallow sites. Biomass was low in winter and spring, increased in summer and fall, and began to decline in December. From 1999 to 2001, mysid biomass frequently exceeded 2,000 mg/m^2 from August to November. At the shallow sites, high peaks in biomass occasionally occurred; where results exceeded 3,000 mg/m^2 at station KLF 5 in July 2000, 4,400 mg/m^2 at station KLF 1 and 2,300 mg/m^2 at station KLF 5 in June 2002 (Figs. 4.29 and 4.30). Biomass was higher at deep stations than at shallow stations, because of the greater proportion of older (and therefore larger) individuals. In 2008, similar to previous years, biomass was generally higher at the deep sites. The highest biomass at deep sites in 2008 was in August at 3,815 mg/m^2 (mainly immature males and females) at station KLF 2. The highest biomass at shallow sites was in September at 904 mg/m^2 (mainly immature males and females) at station KLF 7.

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, therefore during the summer and fall, immature males and females dominate 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 comprised of slightly more females than males. The timing of progression through the developmental stages at the shallow sites in 2008 was similar to previous years (Figs. 4.24 and 4.25). From April to June, juveniles dominated the distribution. From July to September, the number of immature males and females increased, and from September to November, very few individuals of any stage were observed.

Density of developmental stages of *M. relicta* at deep sites is shown in Figs. 4.26 and 4.27. From April to June in 2008, juveniles, immature males and immature females were consistently present, similar to results from previous years. From July to September, the proportion of immature males and females increased as juvenile individuals grew into the immature stage. From September to November immature and mature individuals were common.

Comparison to other lakes

Annual average density of mysids in the North Arm of Kootenay Lake was consistently higher than the density observed in Arrow Lakes Reservoir from 1997 to 2000 (Fig. 4.33). Mysid density in the South Arm varied with results similar to Arrow Lakes Reservoir (Schindler 2006, 2007, 2009, 2010). From 2002 onward, mysid density in both the North and South arms of Kootenay Lake were lower than in Upper Arrow, and similar or higher than in Lower Arrow.

Mysid biomass in Kootenay Lake was higher than in Arrow Lakes Reservoir from 1999 to 2002 (Fig. 4.33). In 2003, mysid density and biomass in Upper Arrow was twofold higher than Kootenay Lake. From 2004 to 2007 mysid biomass in Arrow Lakes Reservoir was similar or lower than in Kootenay Lake. In 2008 mysid density in Lower Arrow was higher than in Kootenay Lake. At the same time mysid biomass in Lower Arrow was similar to the biomass in the North and South arms of Kootenay Lake, since smaller individuals of immature males and females and juveniles made up the majority of the mysid population of Lower Arrow. Mysid density and biomass in Upper Arrow was lower than the North and South arms of Kootenay Lake. In Okanagan Lake experimental trawl fishing for mysids began in 1998, with two companies receiving test fishery permits to harvest mysids starting in 2000. Mysid fishing effort has been focused on high-density areas. Mysid density and biomass in Okanagan Lake, were higher than in Kootenay Lake during the entire study period, except in 1999 when mysid density in the North Arm of Kootenay Lake was higher, and in 2008 when the density in both the North and South arms of Kootenay Lake was higher than in the Okanagan Lake. Seasonal average biomass in Okanagan Lake from 1999 to 2008 exceeded those values in Kootenay Lake two to three times, and in 2004 exceeded the values five times (Andrusak et al. 2008). Generally, annual average biomass in Kootenay Lake varied between 500 and 1,500 mg/m^2, while in Okanagan Lake, the annual average biomass ranged between 1,500 and 4,000 mg/m^2 (Fig. 4.33). Despite a decrease of both mysid density and biomass in 2008, Okanagan Lake continues to offer the greatest potential for high levels of mysid harvest.

Discussion

Addition of nutrients in Kootenay Lake was reduced from 1997 to 2000, relative to the 1992 to 1996 period, but was increased again from 2001 onward. In 1999 and 2000 climatic conditions, changes in algal composition and in *Mysis diluviana* and kokanee abundance made conditions favourable for *Daphnia* spp. and other cladocerans in Kootenay Lake. These factors, and the increase of fertilizer to the North Arm, may have made conditions more favourable in 2001. A bloom of small cladocerans in 2001 was a first response to the increase of the nutrient load, and in the following years, their density varied but at a lower result than during 2001. These changes have likely been due to a combination of nutrient load, predation, and climatic changes. The decline in the proportion of cladocerans in 2002 may have been due to a decrease in the biomass of edible phytoplankton (nanoplankton, 2–22 μm). As a result, zooplankton biomass may have declined and not been high enough to keep pace with the grazing pressure imposed by the higher number of kokanee in the lake. The edible phytoplankton in 2003 increased in the fertilized North Arm of the lake, which was mirrored by increased zooplankton biomass, especially *Daphnia* biomass which increased more than two-fold. In 2003 zooplankton density and biomass were the highest measured during the study period, followed by a significant decrease in 2004 and 2005 in all three arms of Kootenay Lake.

Nutrient additions to the South Arm commenced in 2004 and have continued through 2008. In 2004 and 2005, phytoplankton biomass in Kootenay Lake was the lowest recorded in the North Arm since 1992. The nutrient addition did not appear to enhance phytoplankton biomass in those years, which could be a reason for the substantial decrease in *Daphnia* as well as in other zooplankton abundance and biomass. In 2006 conditions were more favourable for *Daphnia*, causing an increase of density and biomass in comparison to previous years. In 2007 and 2008 zooplankton density was similar to 2006; however, *Daphnia* density decreased causing a decrease of zooplankton biomass in each of the three arms of Kootenay Lake. The density and biomass of zooplankton, and particularly *Daphnia* represent what remains after they have been grazed by two major zooplankton predators in the lake, mysids and kokanee, whose density increased in 2007 and 2008.

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 lake. Kokanee in Kootenay Lake preferentially select the largest zooplankton, and the average zooplankton size in the diet samples was larger than the average size in the zooplankton samples (Thompson 1999). *Mysis diluviana* preys upon all sizes of *Daphnia* spp. and does not appear to preferentially select larger individuals.

Kootenay Lake is at the more productive end of oligotrophic lakes. Total zooplankton biomass and biomass of copepods, cladocerans, and *Daphnia* were relatively stable in Kootenay Lake during the period of decreased nutrient loads, 1997 to 2000. With the increased nutrient load in 2001, the zooplankton biomass in Kootenay Lake increased significantly, exceeding the biomass in Arrow Lakes Reservoir. The same trend continued through 2003, followed by a biomass decrease in 2004 and 2005, with results similar to Lower Arrow but still significantly higher than the zooplankton biomass in Upper Arrow. In 2006, biomass of all categories in Kootenay Lake was similar to values in Lower Arrow. Although total zooplankton biomass and *Daphnia* biomass in Kootenay Lake decreased slightly in 2007 in comparison to 2006, those values were higher than results in Arrow Lakes Reservoir, where the *Daphnia* population did not develop during the season causing a sharp decrease of zooplankton biomass.

Total zooplankton density in Kootenay Lake during the 2008 season was higher than in Arrow Lakes Reservoir and Alouette Lake. *Daphnia* density and biomass as well as biomass of total zooplankton were lower than in Arrow Lakes Reservoir or Alouette Reservoir. Zooplankton is subjected to a number of different factors of the aquatic environment, among them the most influential being predation. A possible explanation for the lower *Daphnia* density and biomass in Kootenay Lake in the past, in comparison to Arrow Lakes Reservoir, is that in previous years there was higher predation pressure on zooplankton by greater mysid and kokanee densities in Kootenay Lake. Kootenay Lake contained approximately twice the density of *M. diluviana* as Arrow Lakes Reservoir did between 1997 and 1999. Not ignoring other possible influences, changes in zooplankton (particularly cladocerans) in recent years were caused by a suite of environmental factors, food availability and predation pressure. Environmental factors are never constant and they continually interact causing that the plankton habitat never reaches an equilibrium for which a single species is favoured.

During the study period from 1997 to 2001, mysid densities at deep stations gradually increased. During the following two years (2002 to 2003), a sharp decrease occurred and from 2004 through 2008, an increased trend was recorded. Average mysid density was higher in the South Arm than in the North Arm in 2001, 2002, 2007 and 2008. During the period 1995 to 2000 and again in 2005 and 2006, the density was higher in the North Arm. In 2004, the average mysid density did not differ in the two basins. During the season, densities increased in the summer and declined in the winter. Mysid density and biomass were higher at the deep sites than at shallow near-shore sites with near-shore samples containing mainly juveniles and immature males and females, while mature and breeding males and females were rare.

In comparison to other oligotrophic lakes in British Columbia, Kootenay Lake in the early 80’s had a substantial mysid population. Since 1992, when the nutrient restoration program commenced, mysid densities have increased, with results similar to that of more productive years of the late 1970s and early 1980s. From 1993 onward, mysid data indicate that Kootenay Lake has been more productive than Arrow Lakes Reservoir, even with the commencement of nutrient additions to Arrow Lakes Reservoir in 1999. In 2002 and 2003, mysid densities in Kootenay Lake decreased and were lower than in Arrow Lakes Reservoir. Fluctuations in mysid population from 2004 onward shifted the density and biomass in Kootenay Lake again to numbers similar to Arrow Lakes Reservoir. Compared to Okanagan Lake, mysid densities and biomass were substantially lower in Kootenay Lake despite the increased nutrient load to Kootenay Lake in 2001 and the commencement of South Arm nutrient additions in 2004.

In oligotrophic systems, such as in Kootenay Lake, predation can play an important role in regulating food web structure, particularly through its influence on available food. The presence of kokanee and mysids, as main zooplankton predators, and changes in any of the environmental conditions, can influence the survival of individual zooplankton species, such as *Daphnia*, and the population growth in the zooplankton community. As grazers in the middle of the food web, the zooplankton community is affected both by predation and by nutrient dynamics. 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. Consequently, the present state of zooplankton, and particularly *Daphnia*, consist of what remains after they have been grazed by predators. In addition to predation, other factors such as changes in the availability of edible algae may affect zooplankton biomass. Contrary to the previous years, zooplankton densities and biomass in 2001–2008 followed the nutrient gradient with higher values in the fertilized sections of Kootenay Lake. It seems that favourable growing conditions prevailed over predation by kokanee and *M. relicta* and allowed increased productivity and a stable zooplankton community in the lake.

Acknowledgements

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Appendix 4.1. Fecundity data for *L. ashlandi, D. bicuspidatus thomasi, Daphnia spp.* and *B. longirostris* in the North, South and West arms of Kootenay Lake in 1997–2008. Values are seasonal averages, calculated for samples collected April-October 1997–2002 and April-November 2003 and 2008.

L. ashlandi	Basin	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Proportion of Gravid Females	North	0.16	0.12	0.11	0.13	0.13	0.18	0.21	0.13	0.10	0.19	0.15	0.11
	South	0.19	0.14	0.16	0.18	0.15	0.11	0.09	0.15	0.12	0.17	0.15	0.15
	West							0.12	0.18	0.23	0.19	0.18	0.16
# Eggs per Gravid Female	North	13.83	13.21	17.78	14.71	13.33	10.16	11.91	13.68	11.59	13.56	15.82	12.86
	South	14.53	12.49	18.56	16.90	13.97	11.96	10.56	11.16	9.92	12.32	16.23	12.06
	West							10.31	9.86	10.04	14.21	13.31	12.20
# Eggs per Litre	North	1.04	1.34	1.08	0.77	3.61	1.96	2.74	2.31	1.15	3.39	1.83	1.38
	South	2.22	1.65	1.13	2.19	3.42	1.08	1.85	1.74	0.91	3.33	1.76	2.04
	West							1.2	1.35	1.32	2.83	0.94	1.32
# Eggs per Capita	North	0.29	0.24	0.23	0.25	0.31	0.15	0.3	0.19	0.17	0.31	0.32	0.19
	South	0.46	0.26	0.23	0.45	0.24	0.12	0.12	0.25	0.14	0.24	0.23	0.29
	West							0.2	0.11	0.25	0.28	0.23	0.17

D. bicuspidatus	Basin	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Proportion of Gravid Females	North	0.28	0.09	0.12	0.11	0.12	0.13	0.14	0.14	0.16	0.16	0.16	0.12
	South	0.26	0.16	0.16	0.13	0.13	0.20	0.15	0.13	0.19	0.16	0.16	0.18
	West							0.15	0.12	0.15	0.18	0.12	0.10
# Eggs per Gravid Female	North	11.66	14.86	14.93	13.34	13.15	12.93	12.04	15.39	14.52	15.44	18.00	15.08
	South	12.28	16.41	16.70	13.42	14.55	14.02	12.1	13.39	15.67	14.47	17.54	16.52
	West							12.12	14.02	16.13	15.89	16.91	14.31
# Eggs per Litre	North	2.72	2.55	2.64	3.72	2.41	3.96	4.97	3.06	1.65	3.59	4.62	1.95
	South	2.77	2.11	4.55	2.81	3.27	2.89	2.19	3.72	2.36	2.43	3.39	2.74
	West							3.66	3.41	1.65	1.98	2.60	2.08
# Eggs per Capita	North	0.42	0.28	0.35	0.36	0.32	0.34	0.27	0.33	0.28	0.49	0.45	0.22
	South	0.47	0.39	0.57	0.38	0.47	0.53	0.26	0.36	0.76	0.39	0.47	0.53
	West							0.22	0.3	0.61	0.54	0.54	0.30

Daphnia spp.	Basin	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Proportion of Gravid Females	North	0.17	0.17	0.29	0.02	0.07	0.22	0.2	0.34	0.16	0.12	0.14	0.11
	South	0.12	0.22	0.16	0.04	0.09	0.18	0.21	0.23	0.16	0.15	0.17	0.18
	West							0.23	0.26	0.06	0.19	0.04	0.07
# Eggs per Gravid Female	North	2.19	2.17	2.71	1.75	1.71	2.78	2.61	2.98	2.43	2.28	2.49	2.61
	South	2.24	2.41	2.42	2.24	1.83	2.14	2.1	2.93	2.58	2.30	2.46	2.29
	West							3.18	2.96	2.28	2.62	1.81	2.47
# Eggs per Litre	North	0.1	0.37	0.11	0.02	0.17	0.49	0.95	0.24	0.14	0.53	0.42	0.16
	South	0.15	0.48	0.07	0.11	0.14	0.28	0.52	0.14	0.15	0.40	0.50	0.22
	West							0.69	0.72	0.18	0.74	0.11	0.21

# Eggs per Capita	North	0.41	0.36	1.05	0.04	0.13	0.78	0.55	1.19	0.37	0.28	0.40	0.36
	South	0.26	0.71	0.6	0.14	0.17	0.48	0.47	0.68	0.50	0.44	0.48	0.45
	West							1.34	0.73	0.16	0.67	0.08	0.17

B. longirostris	Basin	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Proportion of Gravid Females	North	0.27	0.30	0.15	0.18	0.16	0.16	0.36	0.27	0.26	0.25	0.18	0.28
	South	0.20	0.28	0.31	0.09	0.15	0.28	0.24	0.26	0.18	0.21	0.25	0.32
	West							0.24	0.14	0.09	0.34	0.14	0.16
# Eggs per Gravid Female	North	2.43	3.26	2.25	1.75	1.52	1.52	1.92	2.53	2.39	1.75	1.93	1.79
	South	2.14	2.50	2.13	1.56	1.45	1.67	1.56	1.94	1.69	1.53	1.72	1.52
	West							1.33	1.86	1.14	1.52	1.73	2.00
# Eggs per Litre	North	0.17	0.48	0.02	0.02	0.22	0.14	1.15	0.4	0.39	0.37	0.33	0.37
	South	0.39	0.20	0.10	0.06	0.15	0.15	0.9	0.15	0.33	0.24	0.18	0.21
	West							0.82	0.45	0.10	0.46	0.67	0.36
# Eggs per Capita	North	0.57	1.02	0.31	0.27	0.29	0.25	0.72	0.78	0.65	0.45	0.36	0.56
	South	0.47	0.70	0.62	0.14	0.26	0.41	0.37	0.21	0.26	0.35	0.56	0.45
	West							0.32	0.27	0.10	0.52	0.26	0.34

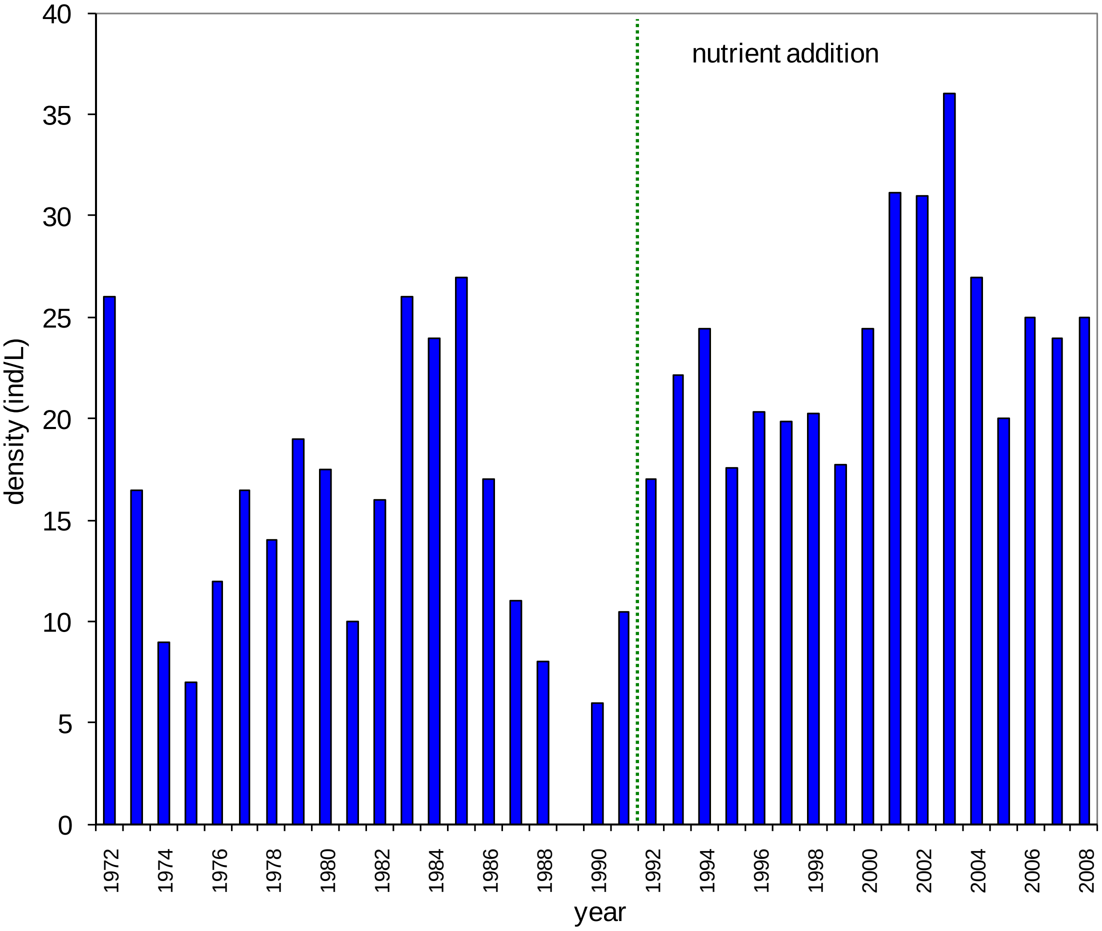


Figure 4.1 Kootenay Lake zooplankton density, 1972 – 2008. Note: 1972 – 1990 represents a mid-lake station near current station KLF 5. The 1992 to 2008 data is calculated as a whole lake average.

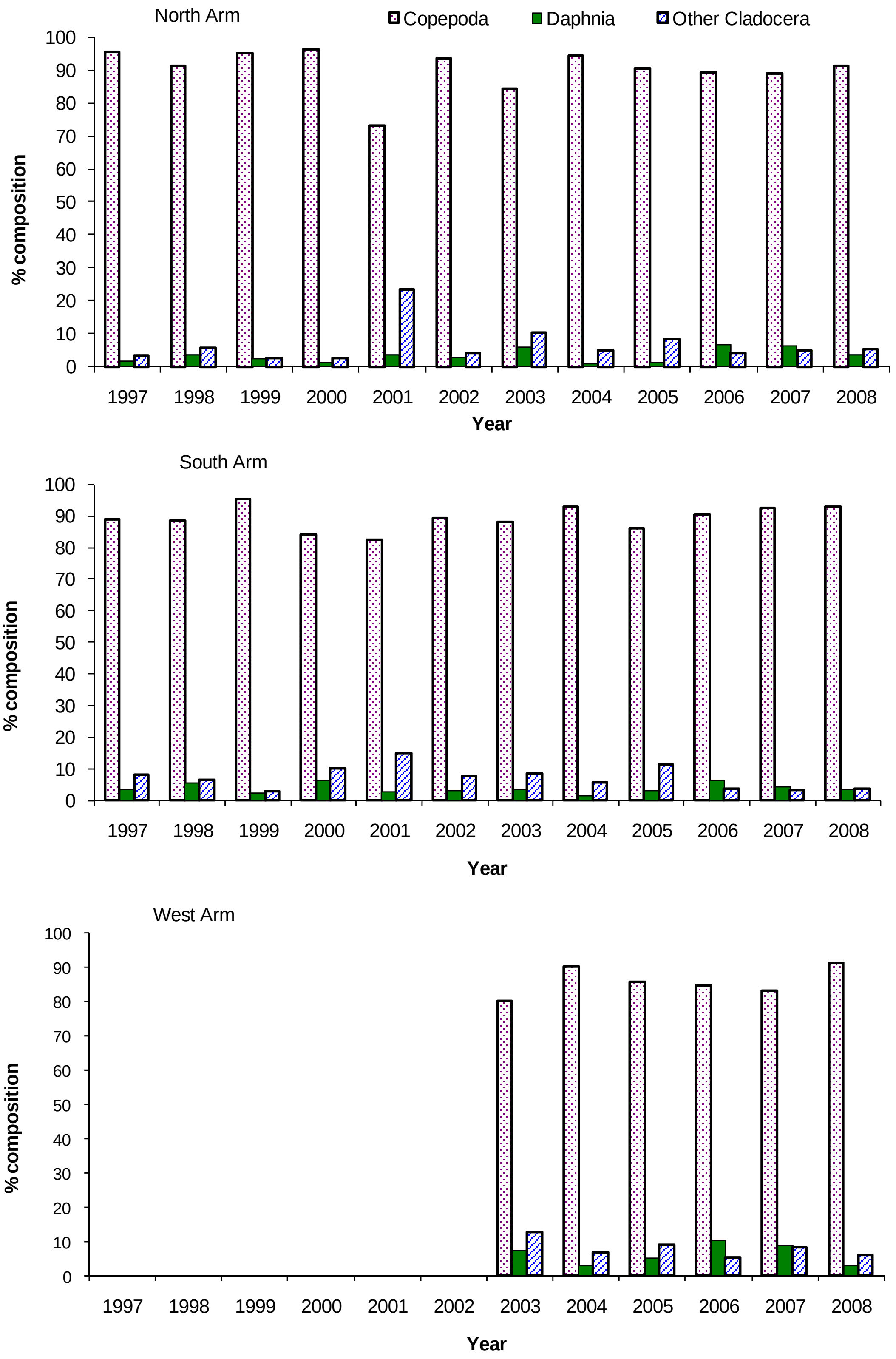


Figure 4.2. Seasonal composition of zooplankton as a percentage of density in the North and South arms, 1997 to 2008 and West Arm, 2003 to 2008.

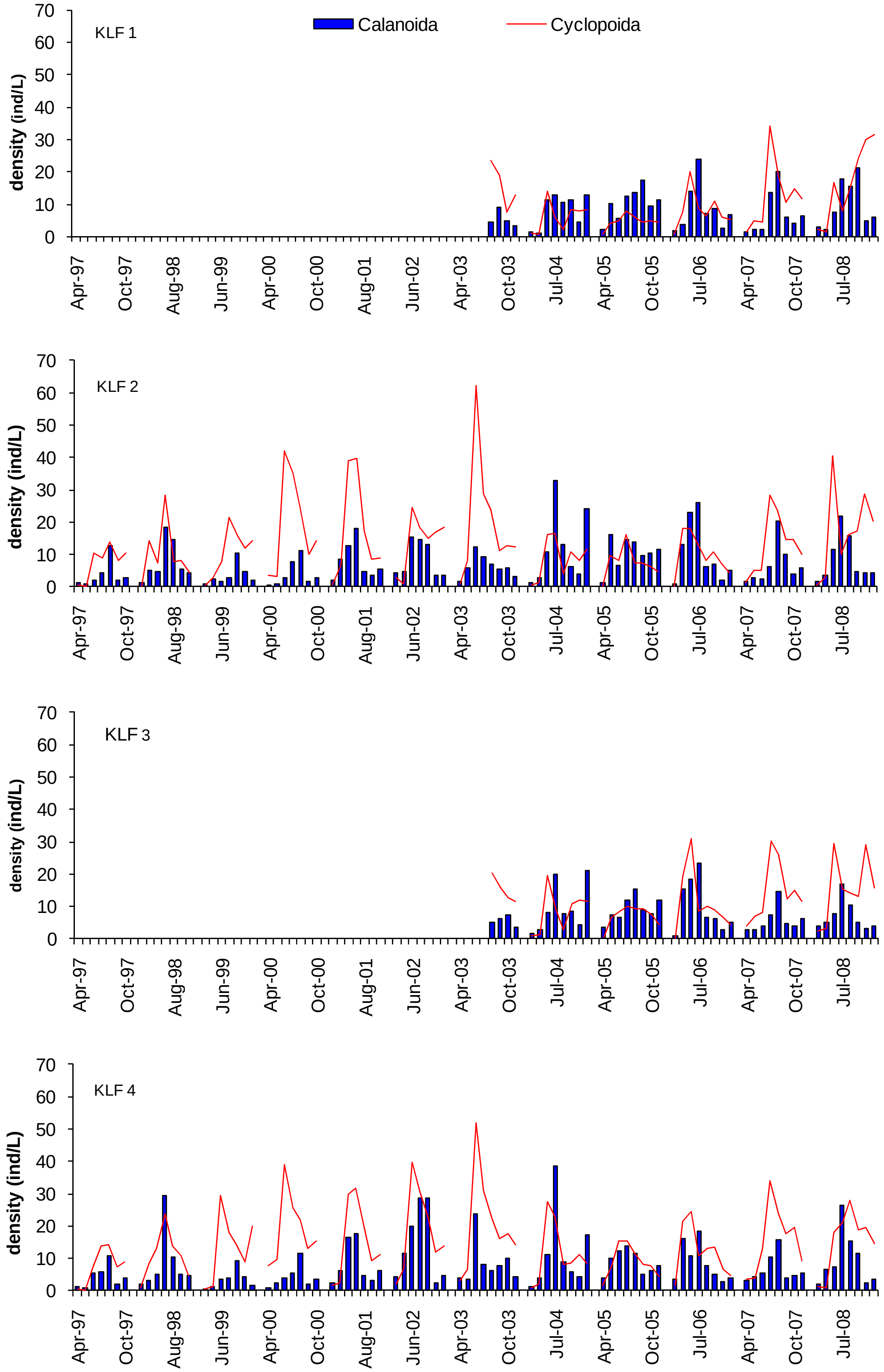


Figure 4.3. Density of cylcopoid and calanoid zooplankton, Kootenay Lake stations KLF 1 to KLF 4, 1997 to 2008.

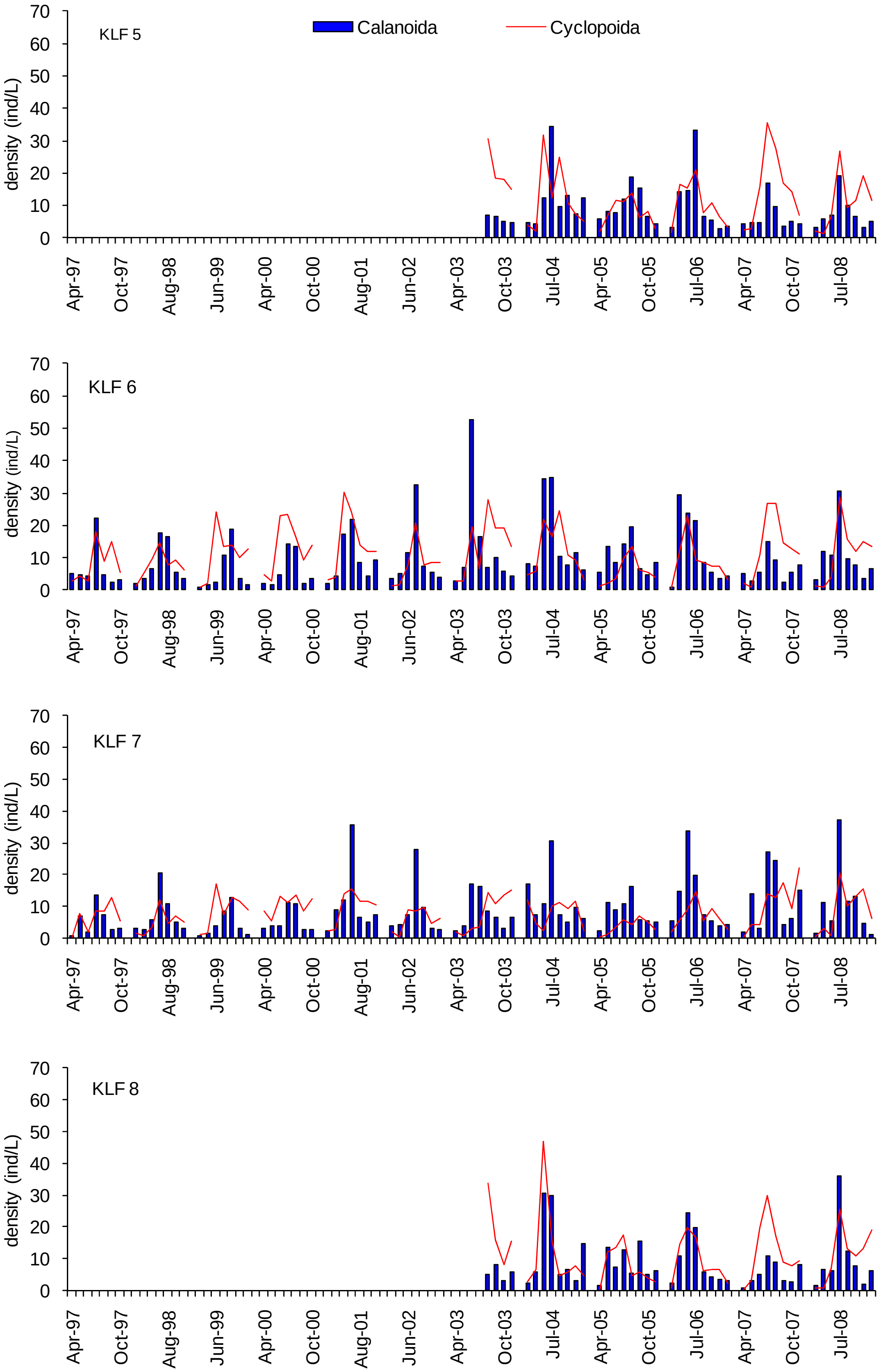
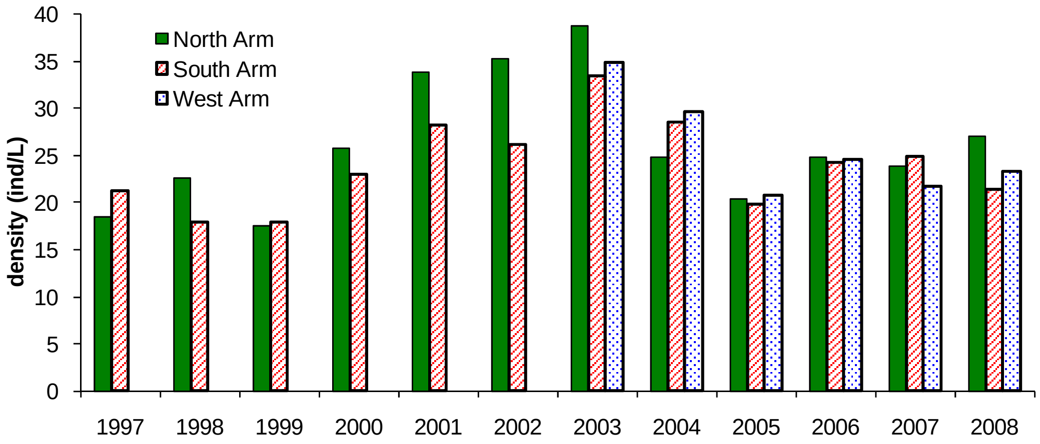
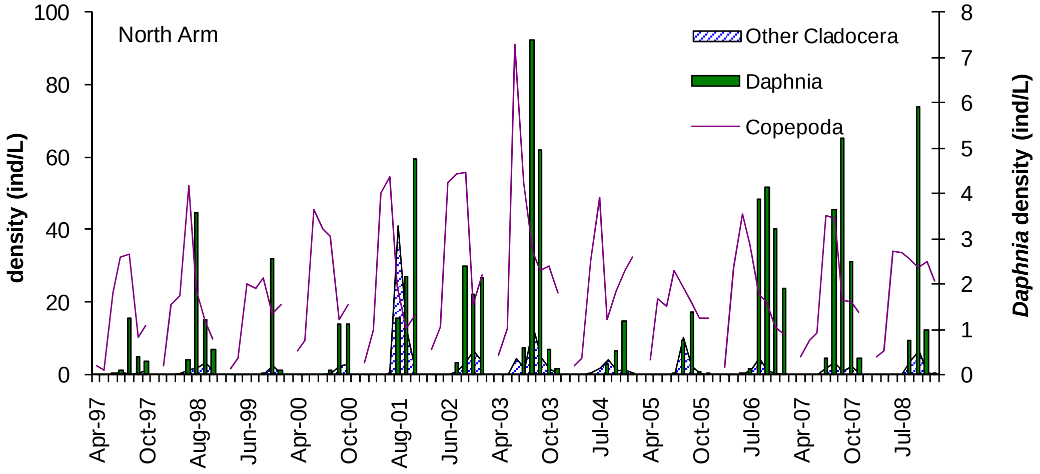


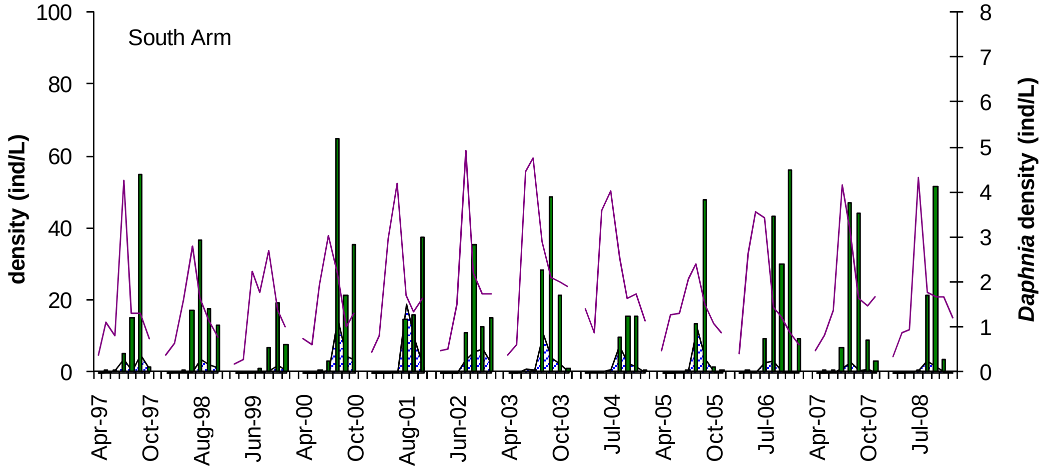
Figure 4.4. Density of cylcopoid and calanoid zooplankton, Kootenay Lake stations KLF 5 to KLF 7, 1997 to 2008 and KLF 7 August 2003 to 2008.



a) Seasonal average density of total zooplankton in the North, South, and West arms.



b) Seasonal density of zooplankton in the North Arm of Kootenay Lake, 1997-2008.



c) Seasonal density of zooplankton in the North Arm of Kootenay Lake, 1997-2008.

Figure 4.5. Zooplankton density in Kootenay Lake, 1997 to 2008.

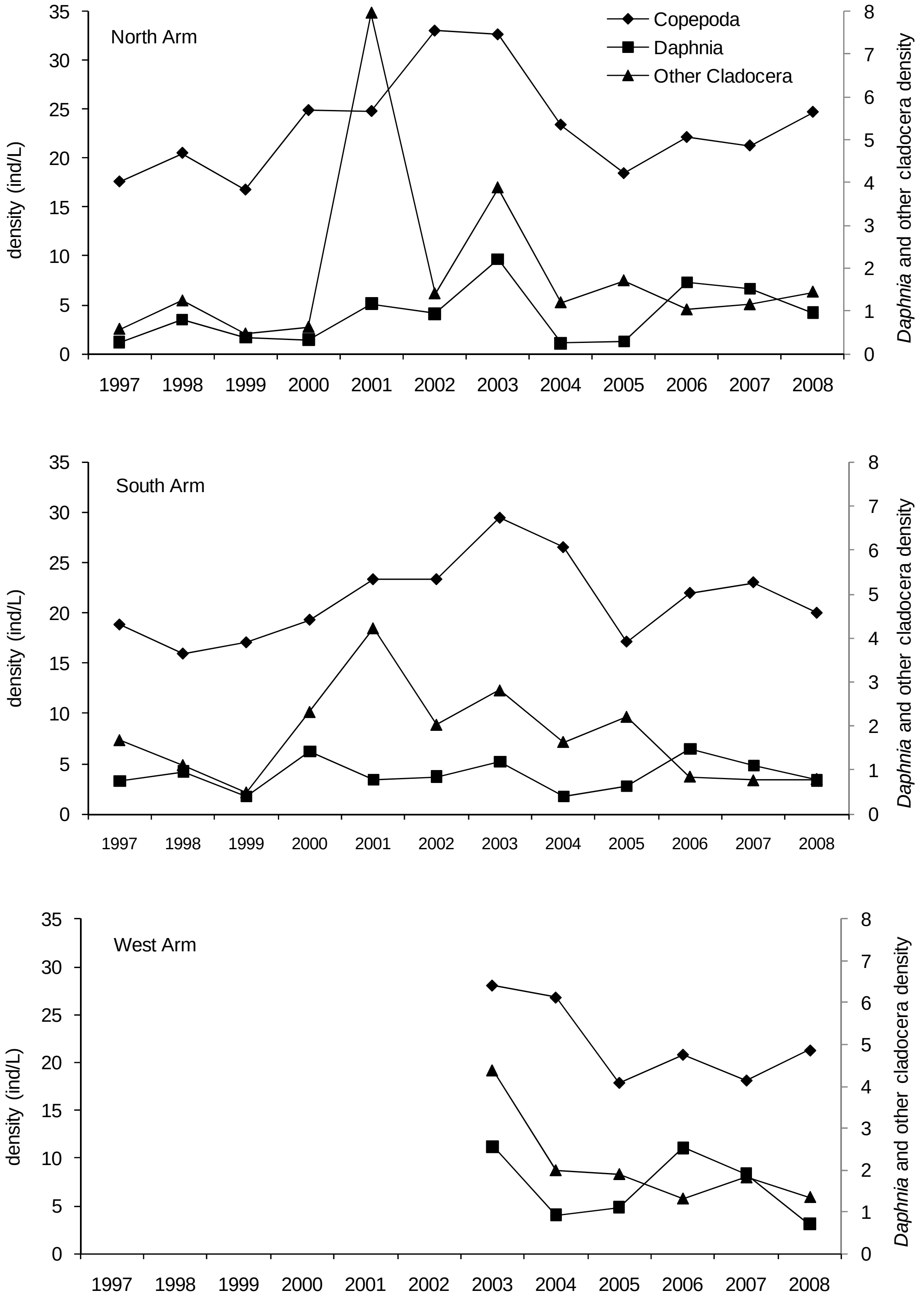
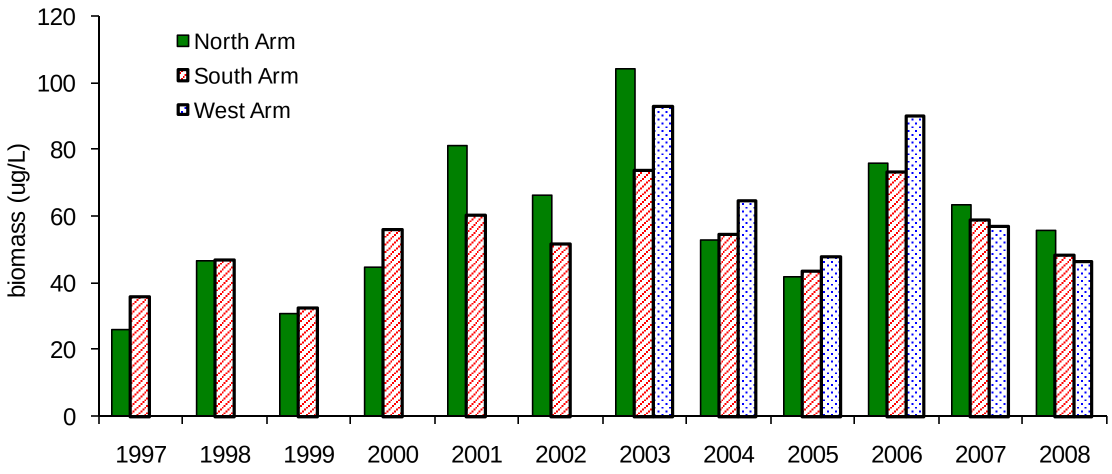
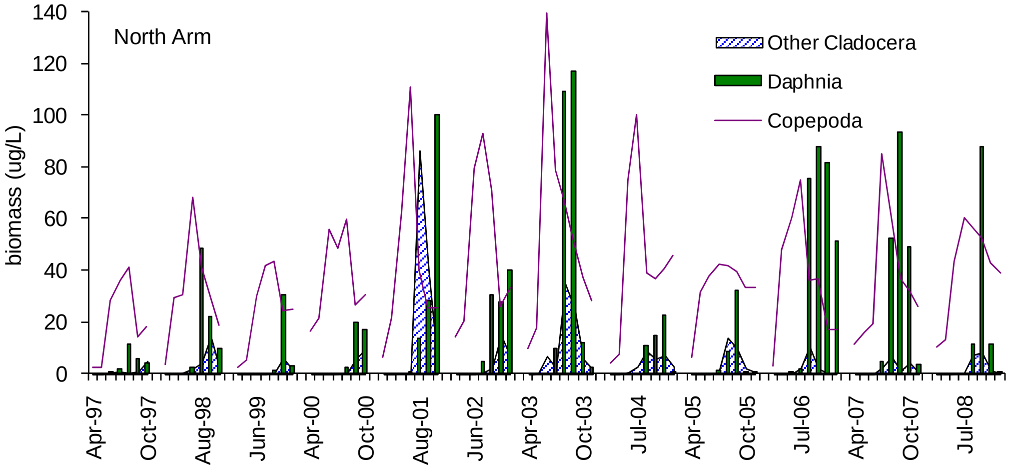


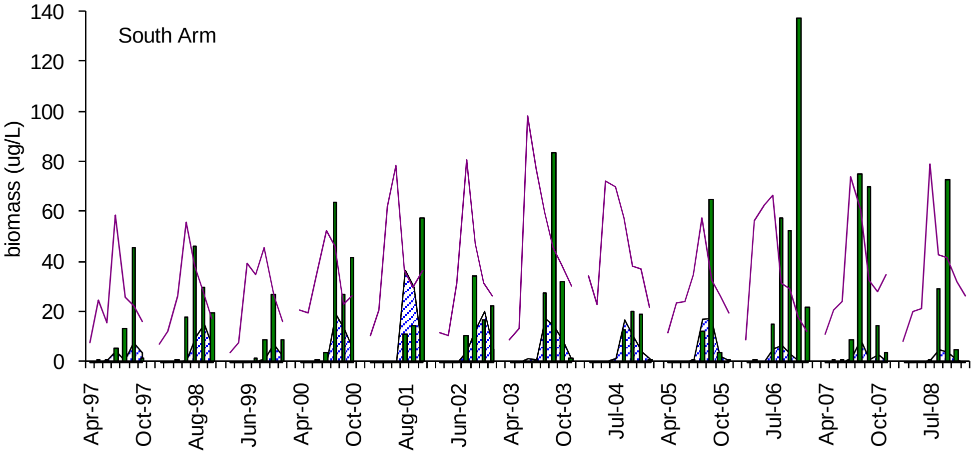
Figure 4.6. Seasonal average zooplankton density in Kootenay Lake, 1997 – 2008. Note: West Arm data is from 2003 – 2008.



a) Seasonal average biomass in Kootenay Lake, North, South and west arms, 1997 – 2008.



b) Seasonal biomass in zooplankton in the North Arm, Kootenay Lake, 1997 to 2008.



c) Seasonal biomass in zooplankton in the South Arm, Kootenay Lake, 1997 to 2008.

Figure 4.7. Zooplankton biomass, Kootenay Lake, 1997 to 2008.

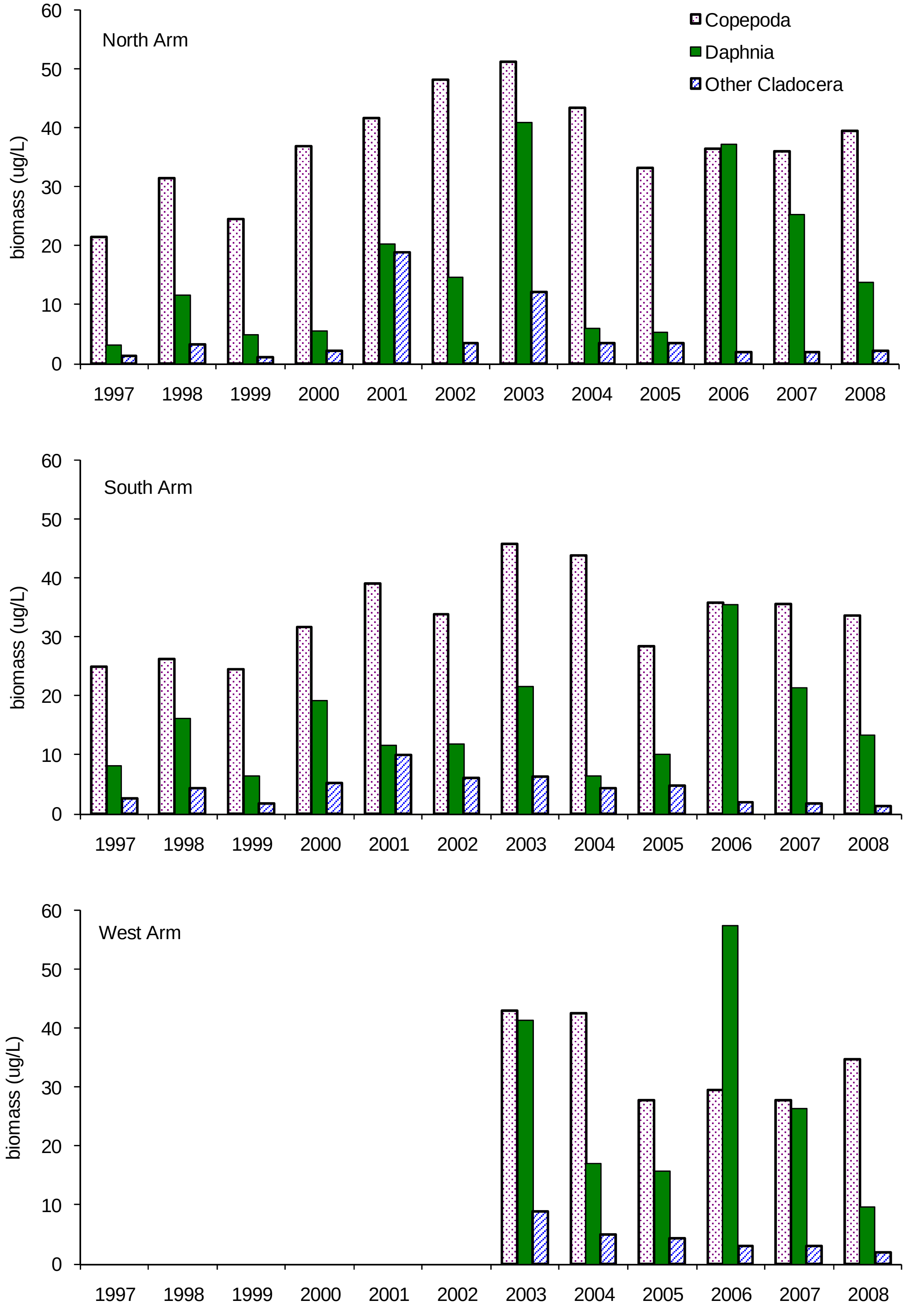


Figure 4.8. Seasonal average zooplankton biomass, Kootenay Lake, 1997 to 2008.

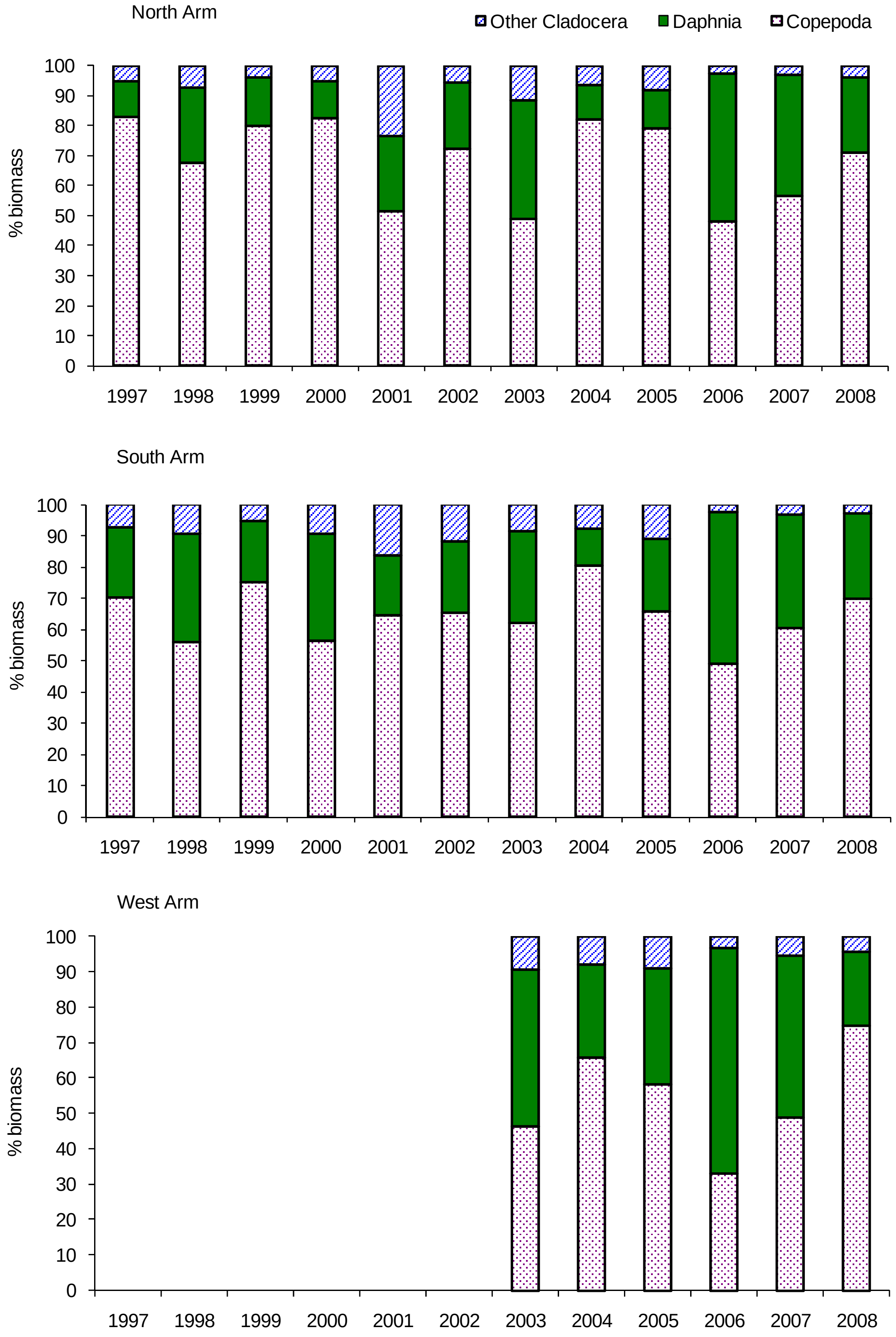


Figure 4.9. Seasonal composition of zooplankton as a percentage of average biomass in Kootenay Lake, North and South arms, 1997 - 2008 and West arm, 2003 – 2008.

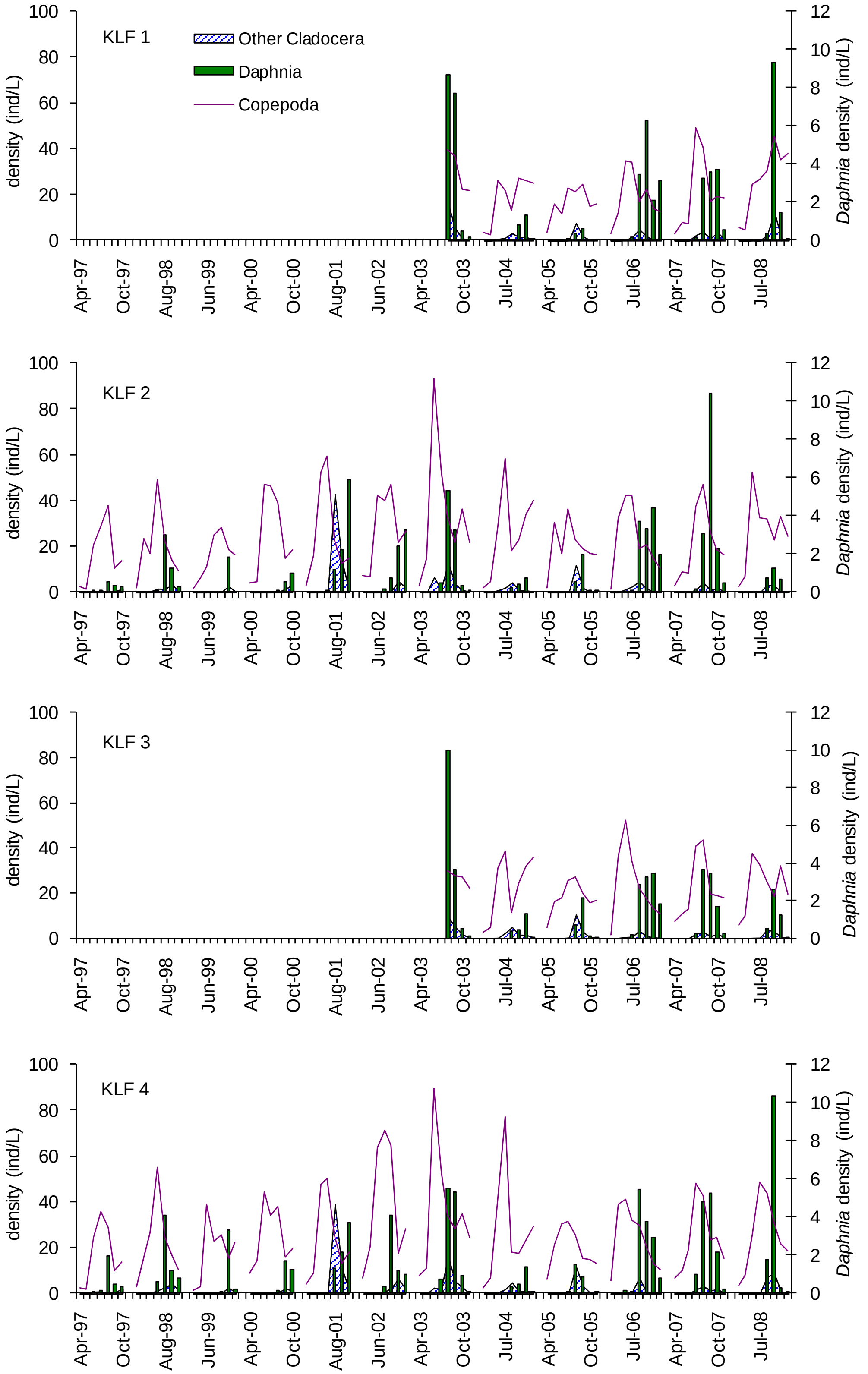


Figure 4.10. Seasonal density of zooplankton stations KLF 1 to KLF 4, Kootenay Lake, 1997 to 2008.

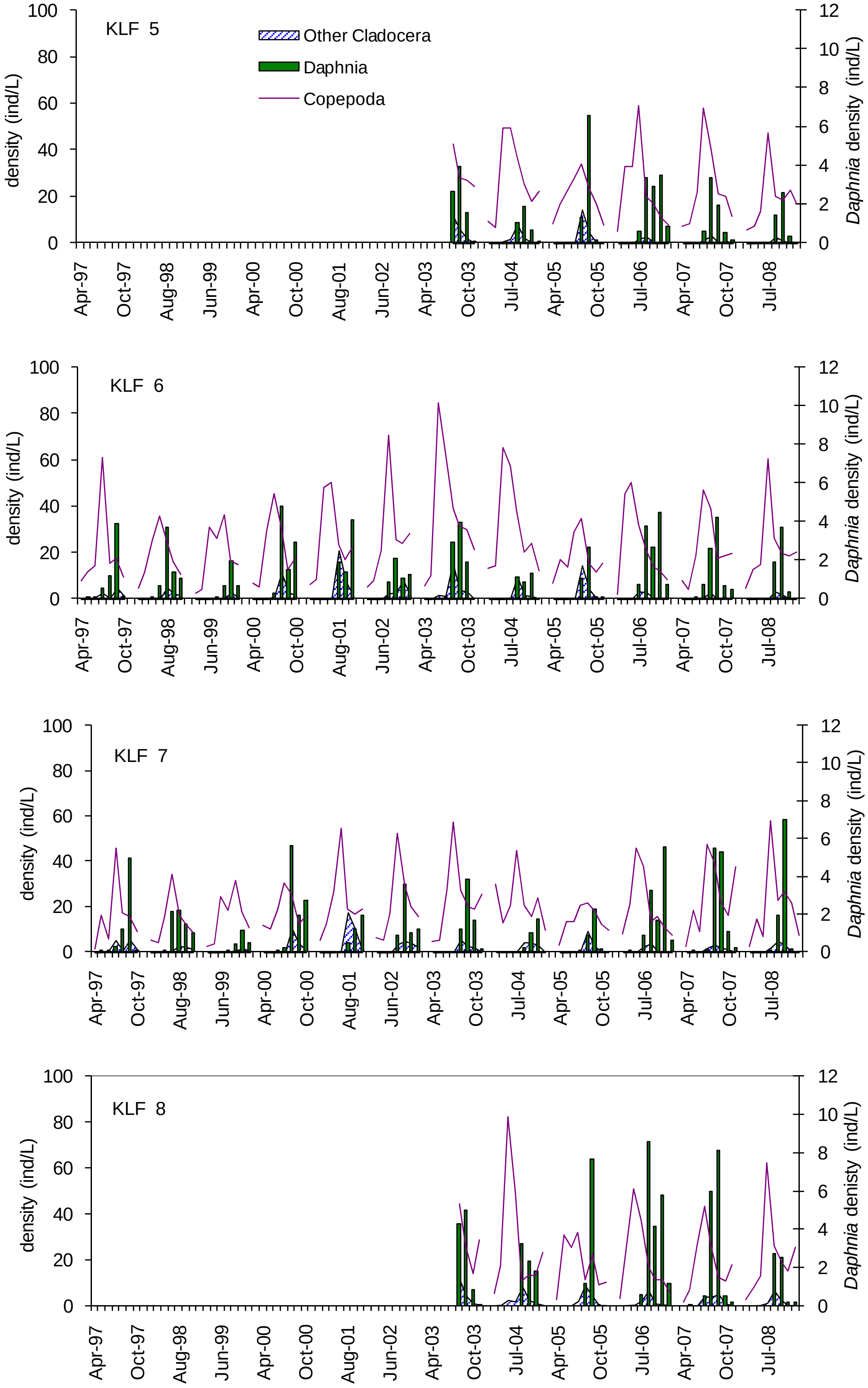


Figure 4.11. Seasonal density of zooplankton stations KLF 5 to KLF 7, 1997 – 2008 and KLF 8, 2003 – 2008.

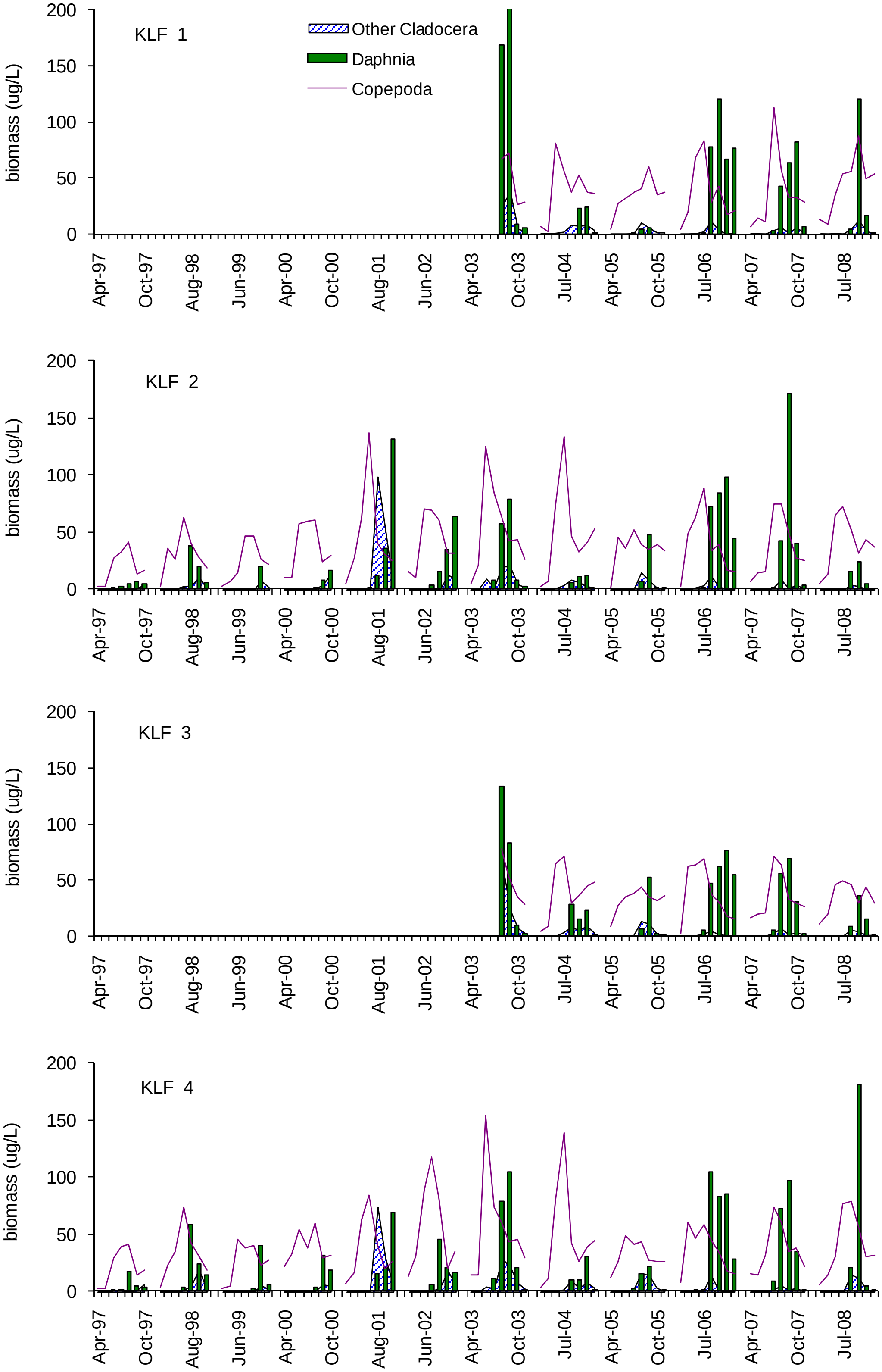


Figure 4.12. Seasonal biomass of zooplankton stations KLF 1 to KLF 4, Kootenay Lake, 1997 - 2008.

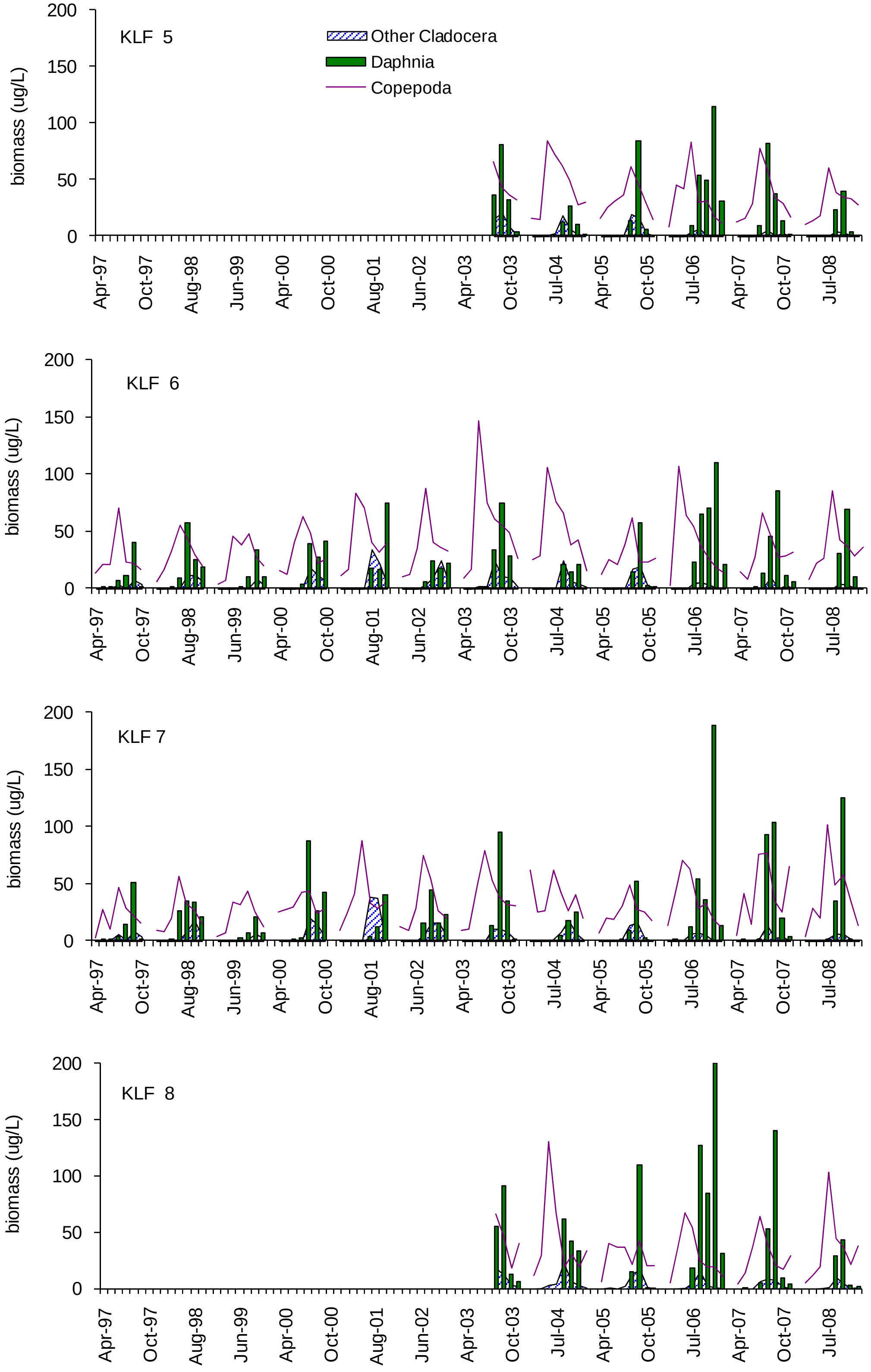


Figure 4.13. Seasonal biomass of zooplankton stations KLF 5 to KLF 7, 1997 – 2008 and KLF 8, 2003 – 2008.

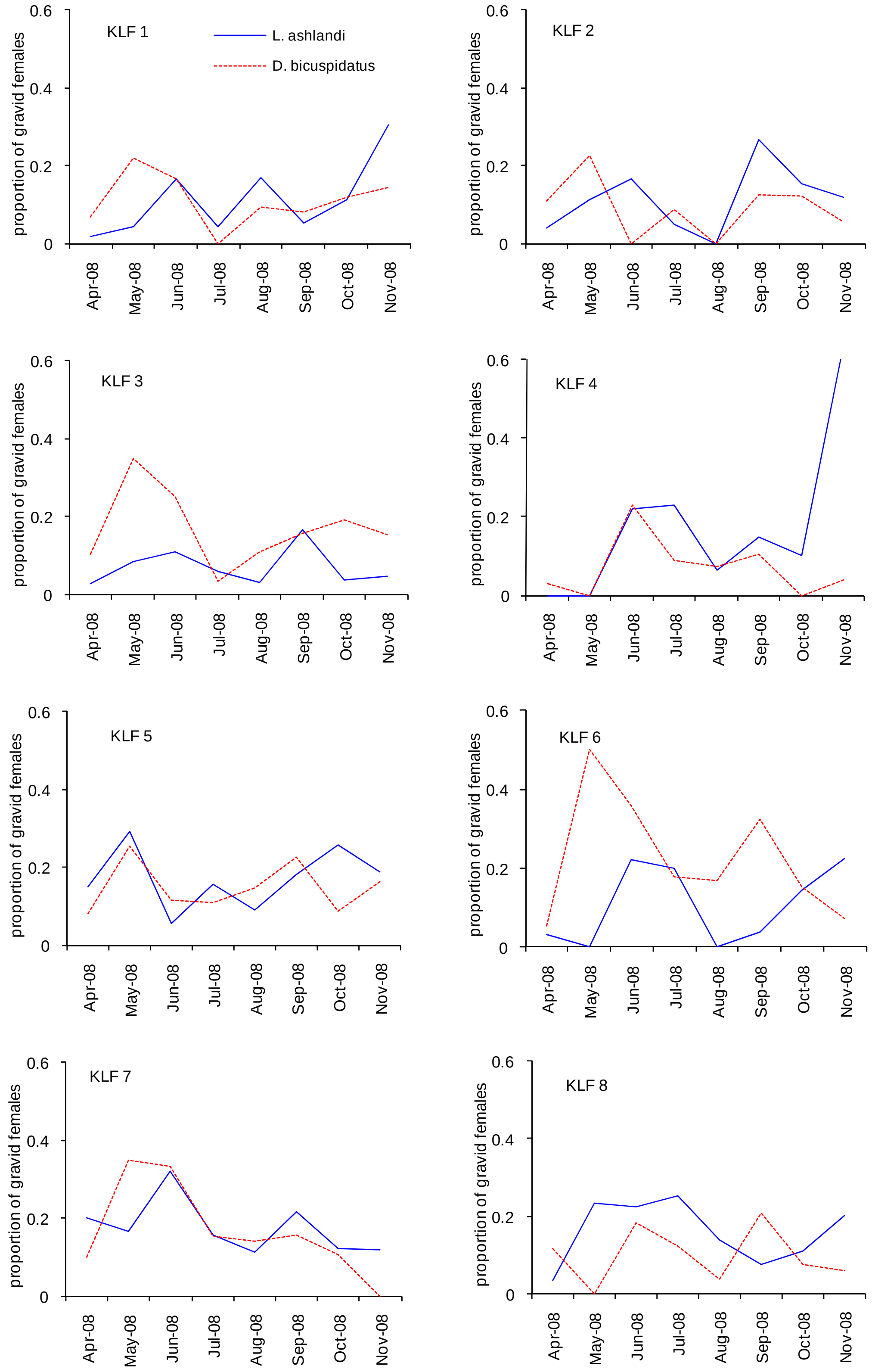


Figure 4.14. Proportion of gravid females of two species of Copepods in Kootenay Lake, stations KLF 1 to KLF 8 April - November 2008.

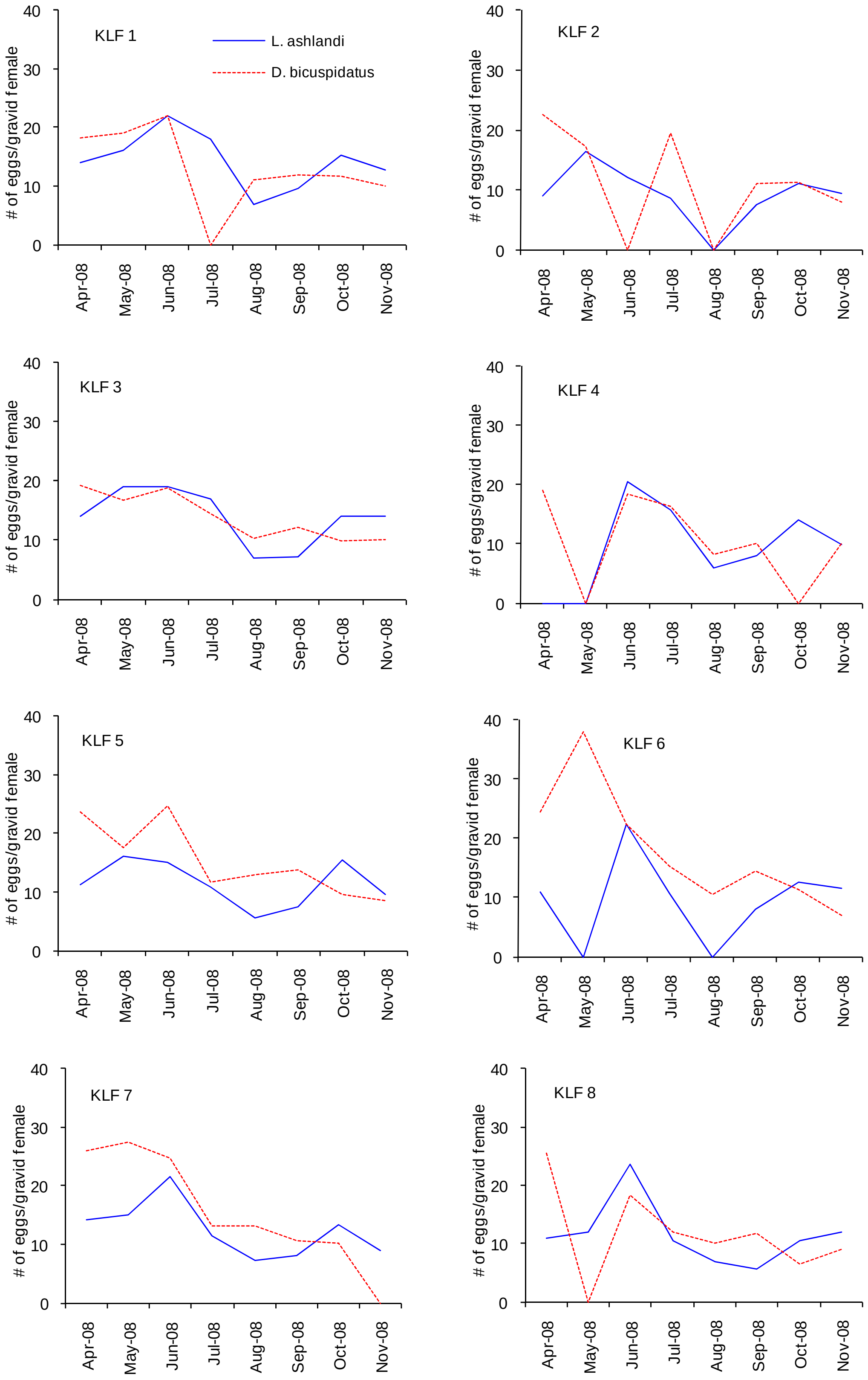


Figure 4.15. Number of eggs per gravid female, in two species of Copepods, Kootenay Lake, stations KLF 1 to KLF 8 April - November 2008.

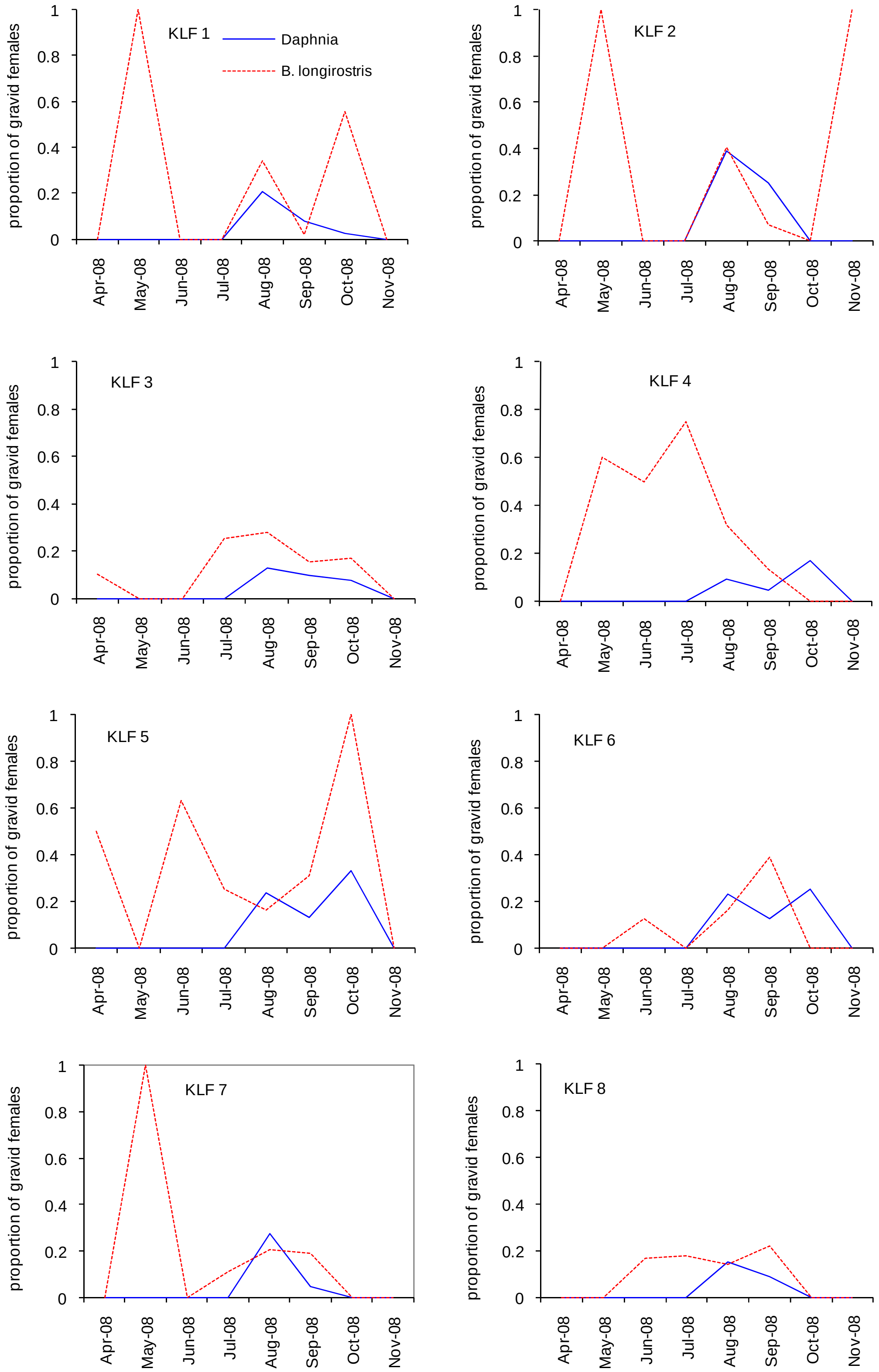


Figure 4.16. Proportion of gravid females in two species of Cladocera, Kootenay Lake, stations KLF 1 to KLF 8, April - November 2008.

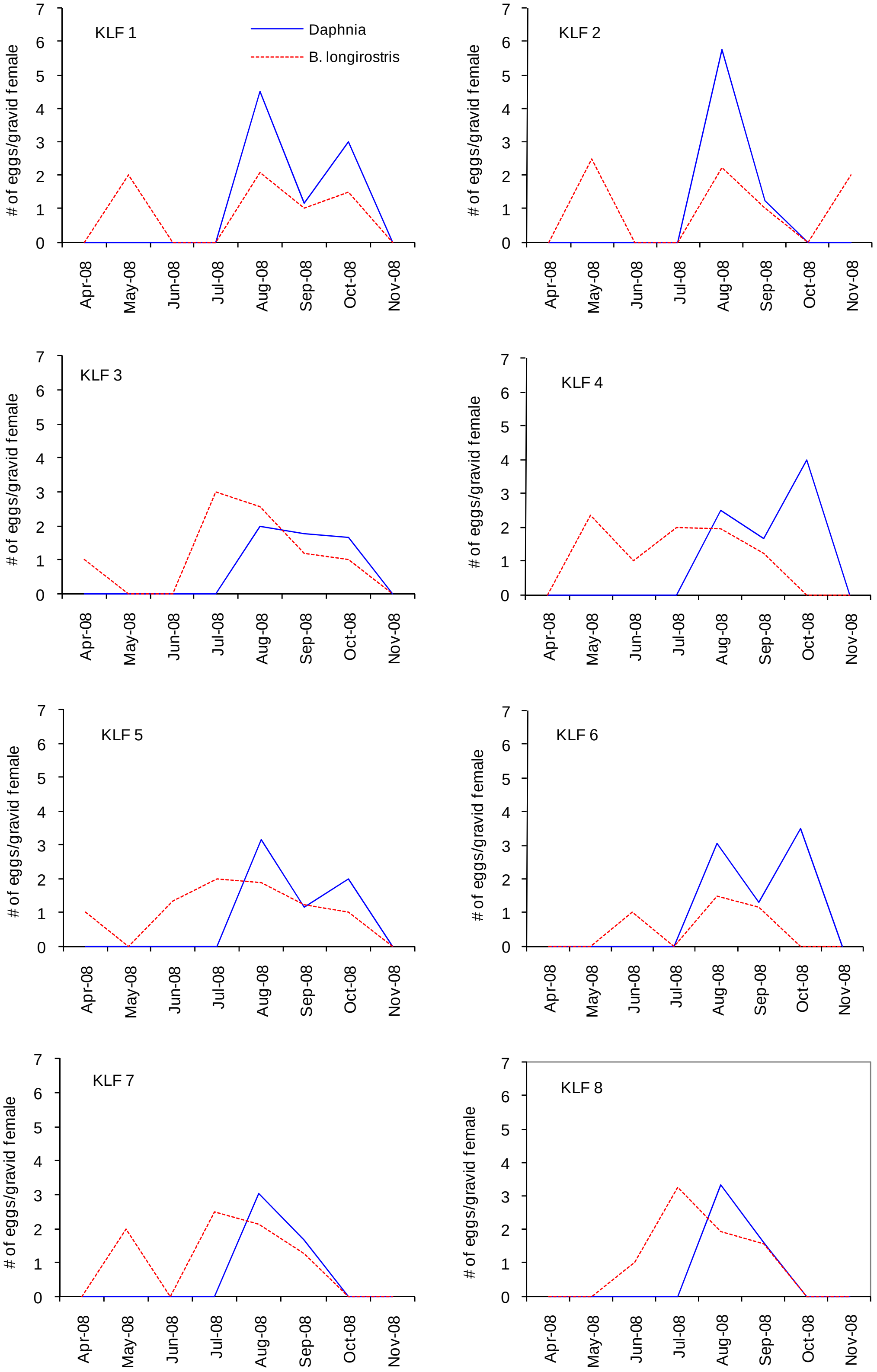


Figure 4.17. Number of eggs per gravid female in two species of Cladocera, Kootenay Lake, stations KLF 1 to KLF 8, April - November 2008.

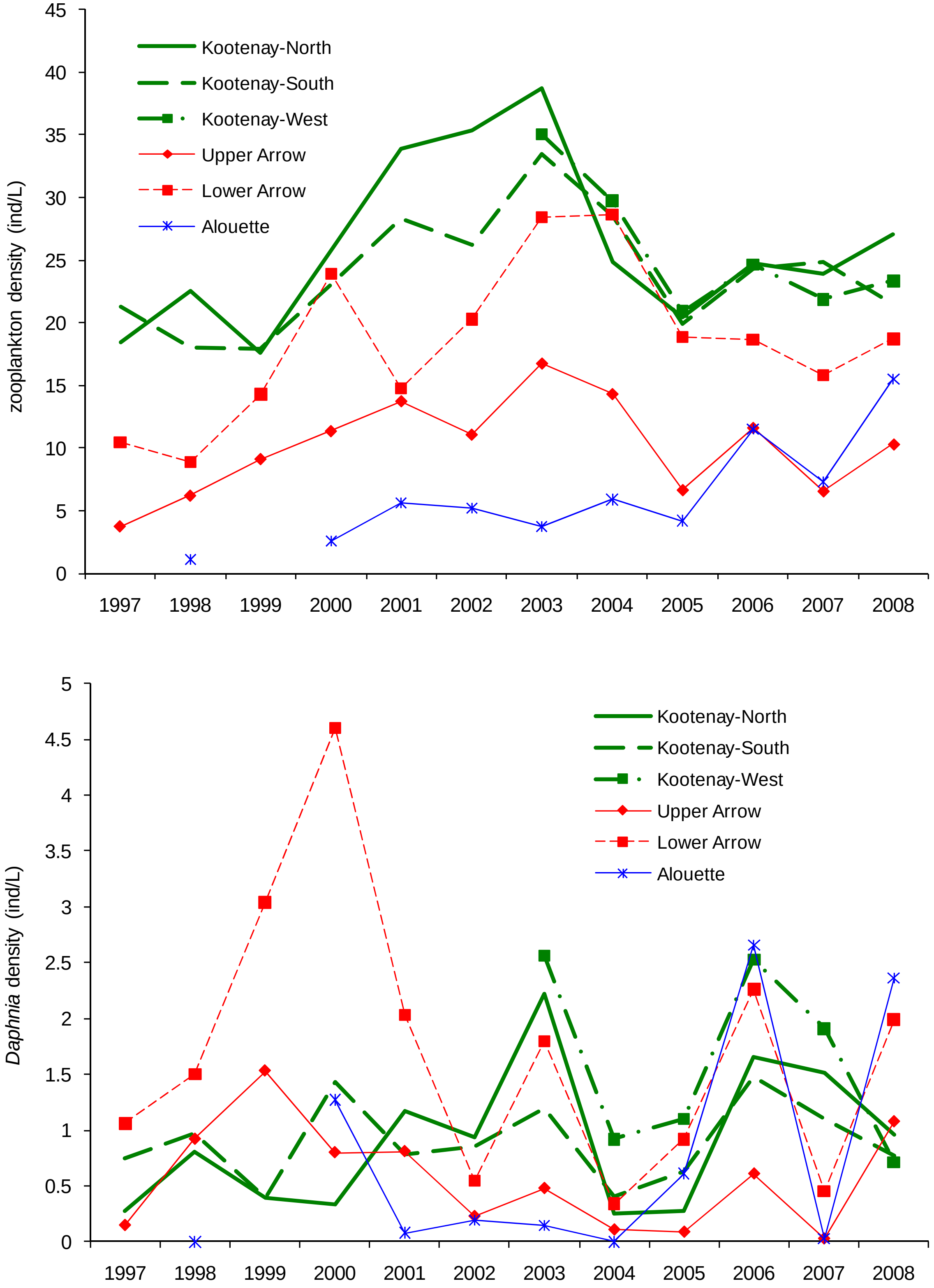
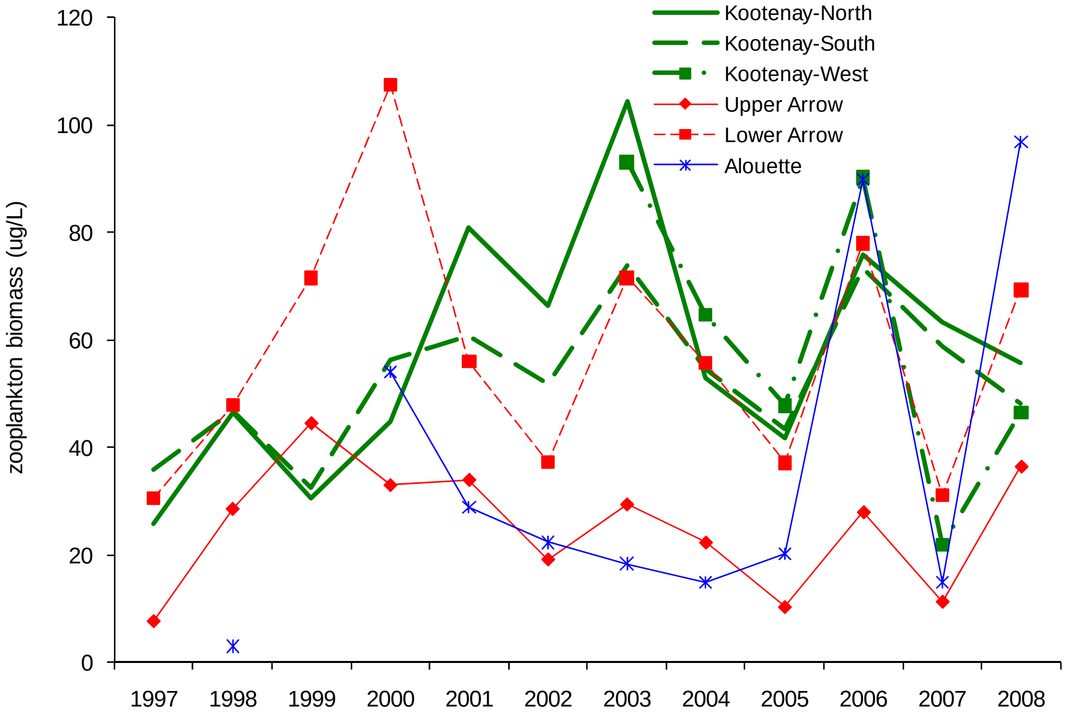


Figure 4.18. Seasonal average density (top) and *Daphnia* density (bottom) in some British Columbia Lakes, 1997 - 2008.



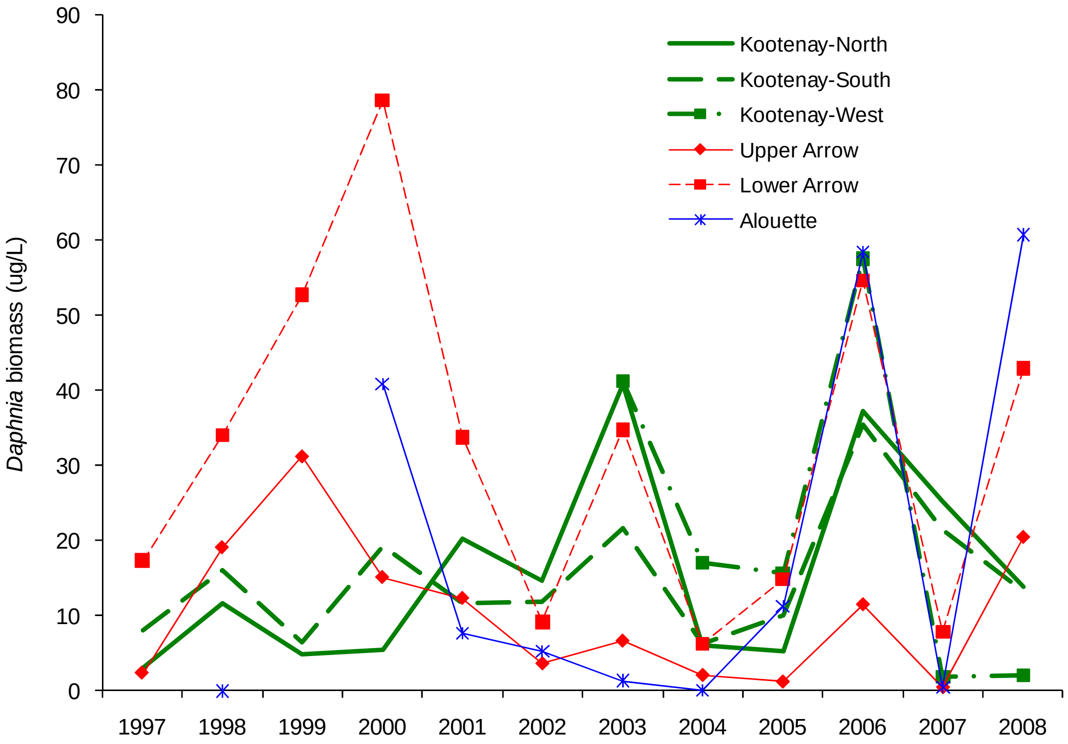


Figure 4.19. Seasonal average biomass (top) and *Daphnia* biomass (bottom) in some British Columbia Lakes, 1997 - 2008.

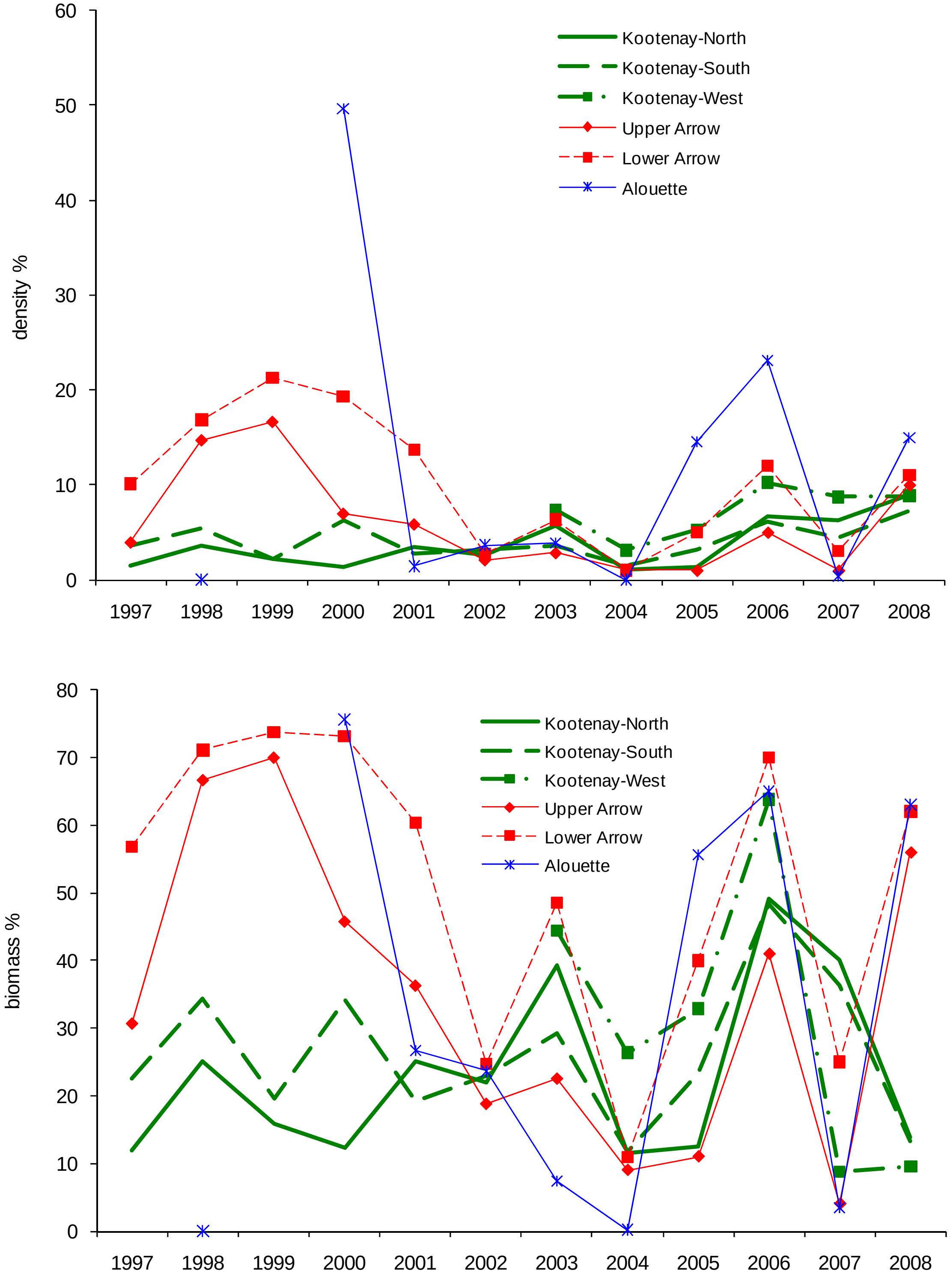


Figure 4.20. *Daphnia* density (top) and biomass (bottom) as a percentage of total zooplankton density and biomass in some British Columbia Lakes, 1997 - 2008.

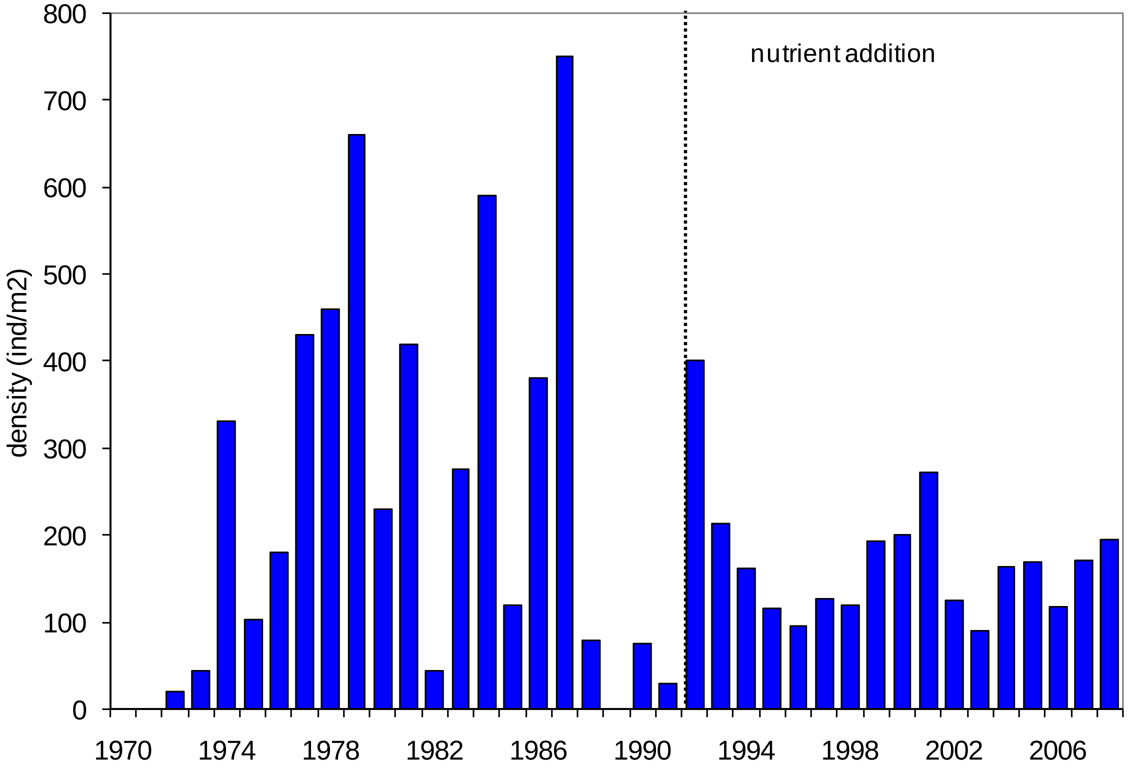
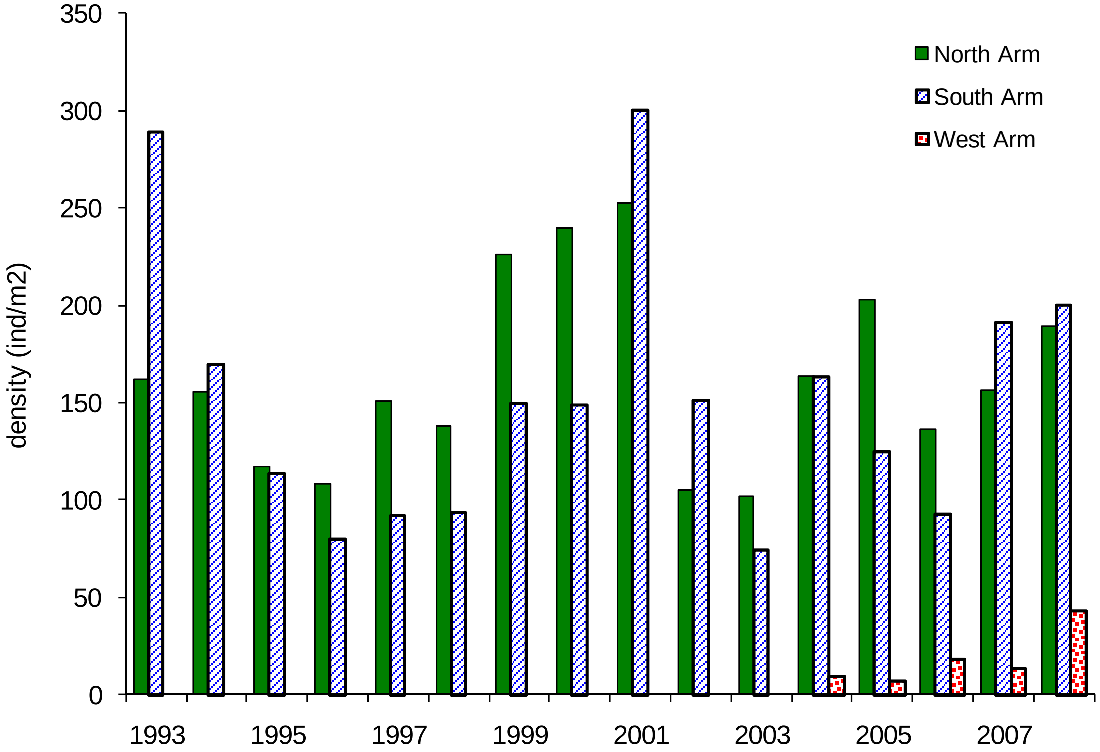


Figure 4.21. Annual average density of *Mysis* in Kootenay Lake, 1972 - 2008.



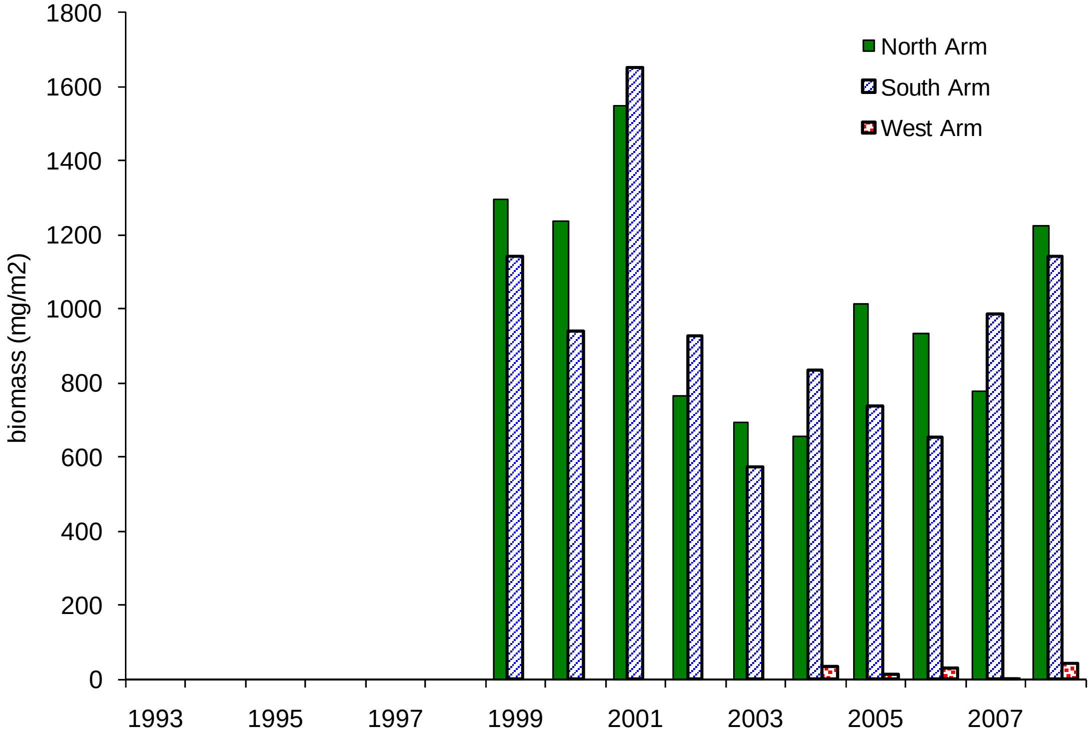


Figure 4.22. Annual average density (top) and biomass (bottom) of *Mysis* in the North and south arms of Kootenay Lake, 1992 to 2008 and the West Arm 2004 - 2008.

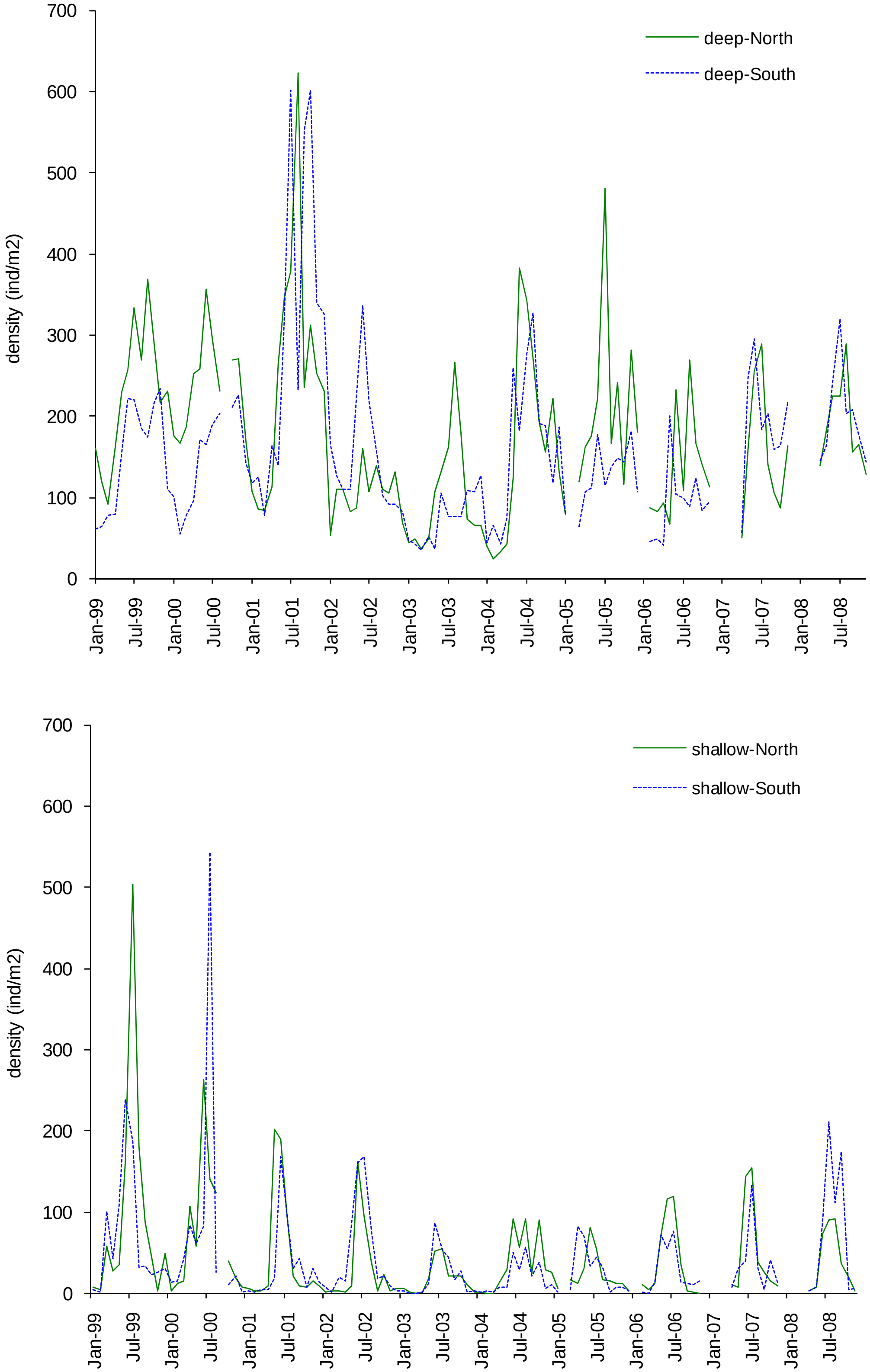


Figure 4.23. Seasonal average density of *Mysis* at pelagic and near shore stations in Kootenay Lake, 1999 - 2008.

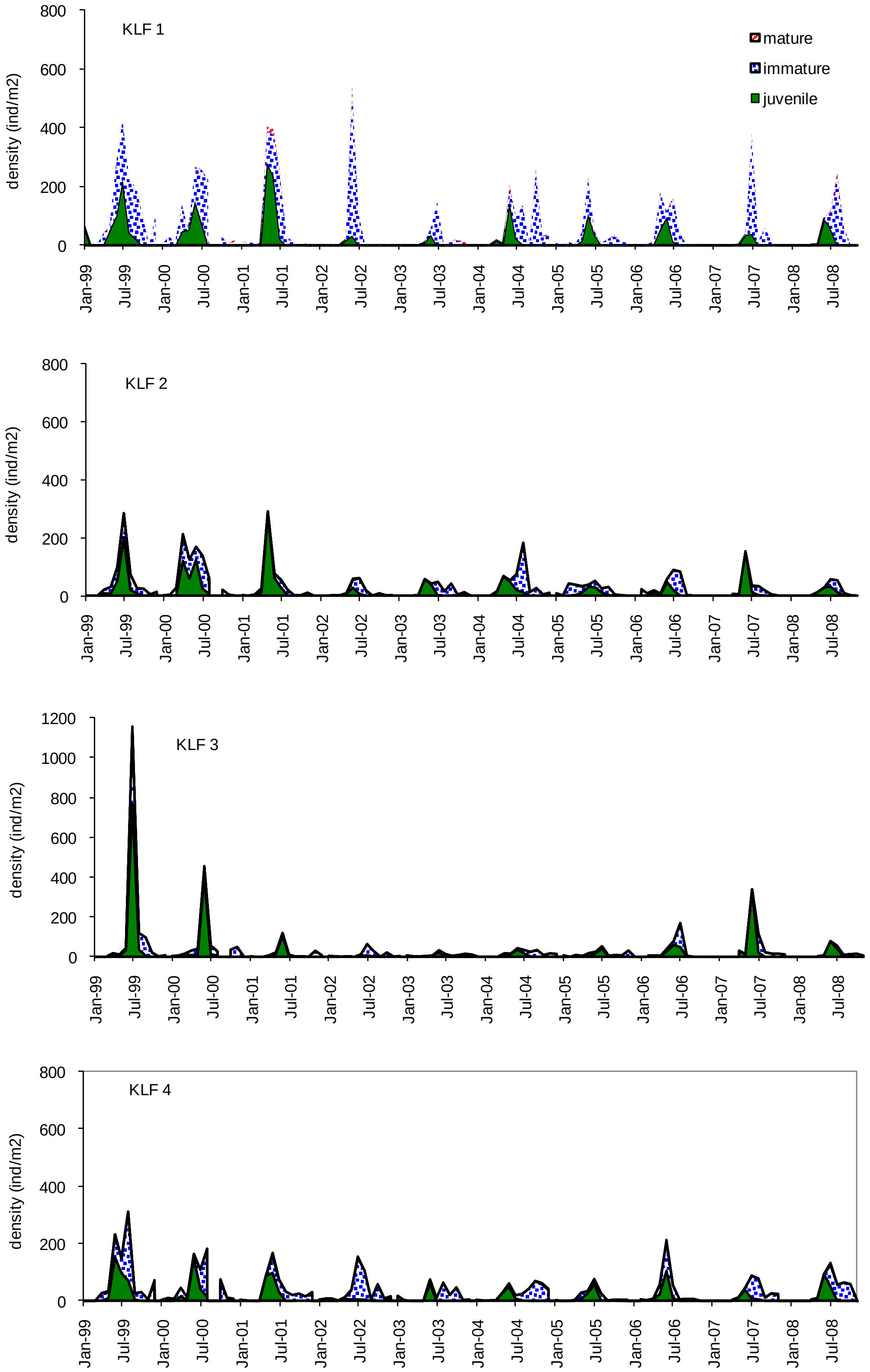


Figure 4.24. Seasonal density of developmental stages of *Mysis* at near shore sites, stations KLF 1 to KLF 4, Kootenay Lake, 1999 - 2008.

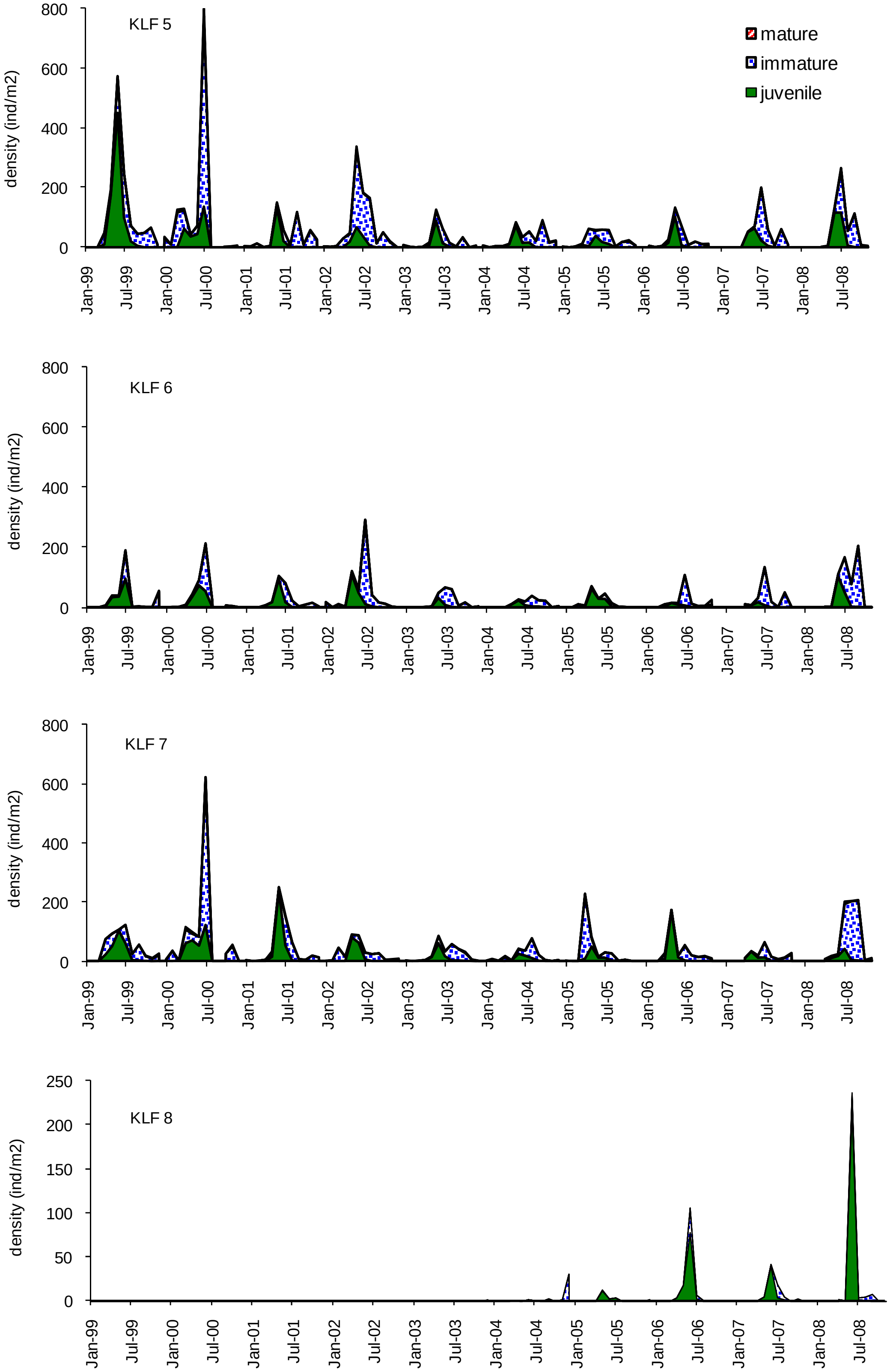


Figure 4.25. Seasonal density of developmental stages of *Mysis* at near shore sites, stations KLF 5 to KLF 8, Kootenay Lake, 1999 - 2008.

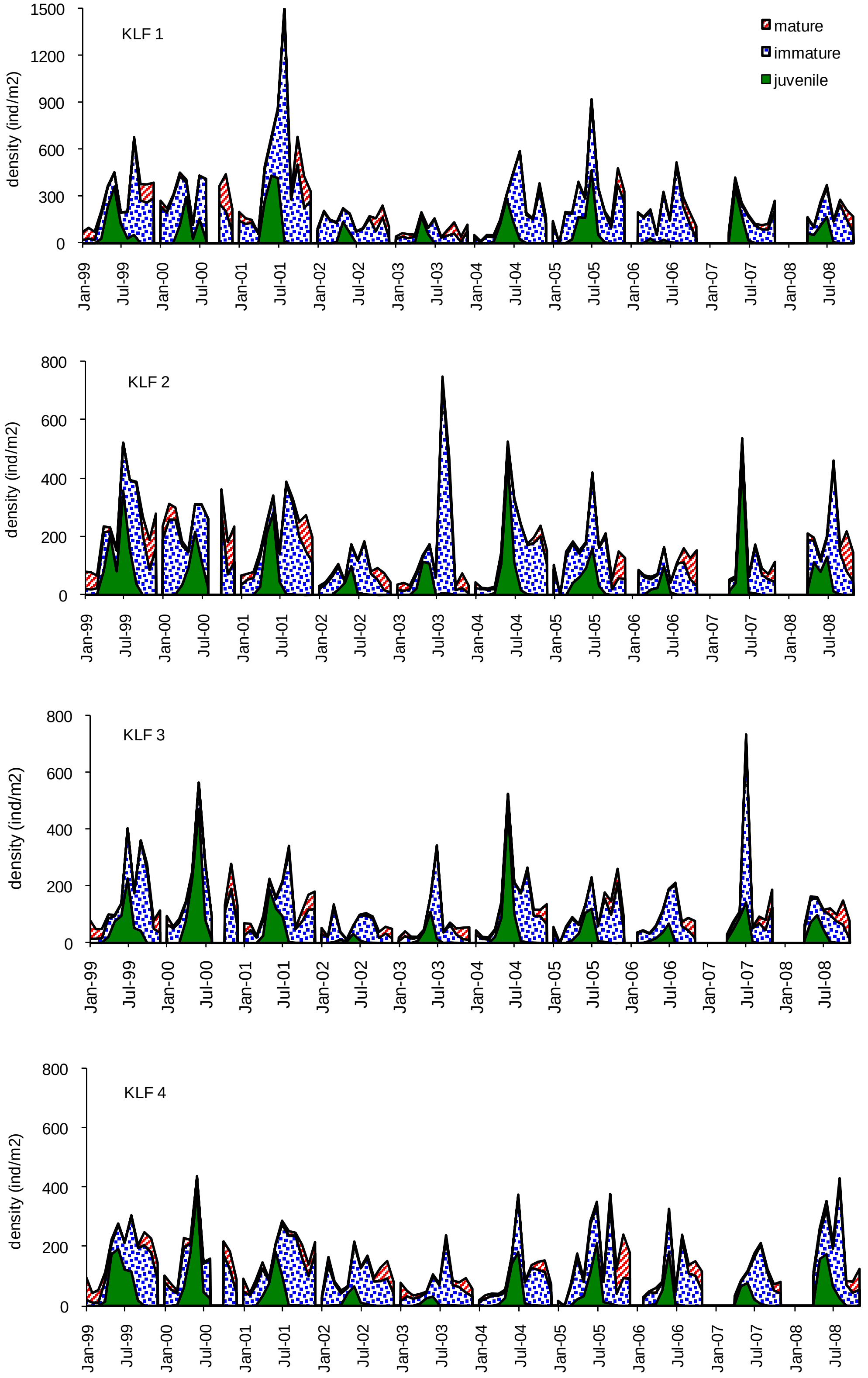


Figure 4.26. Seasonal density of developmental stages of *Mysis* at deep sites, stations KLF 1 to KLF 4, Kootenay Lake, 1999 - 2008.

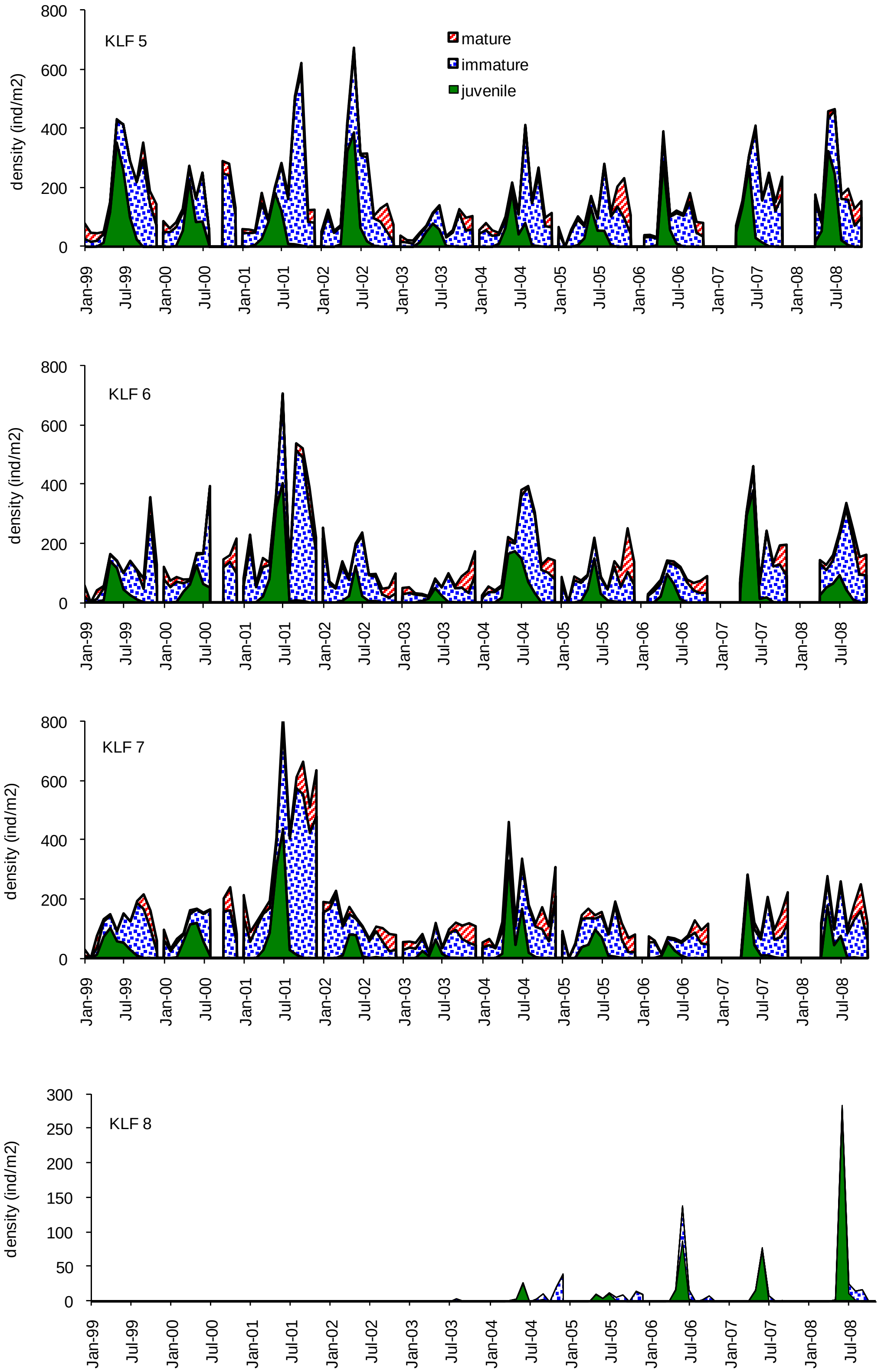
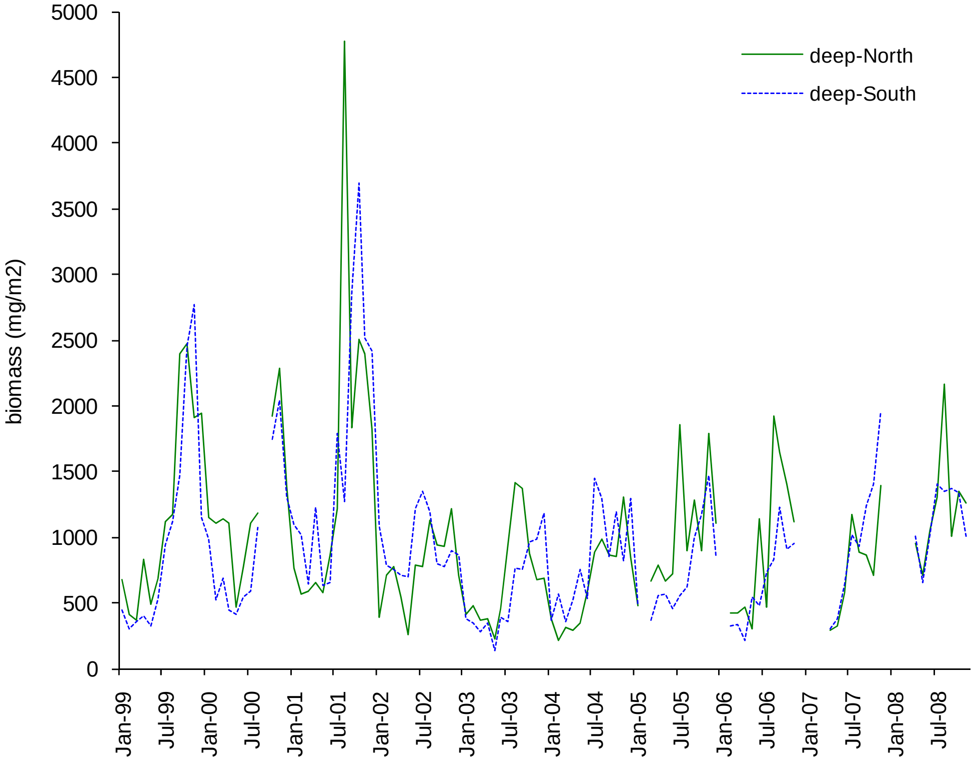


Figure 4.27. Seasonal density of developmental stages of *Mysis* at near shore sites, stations KLF 5 to KLF 8, Kootenay Lake, 1999 - 2008.



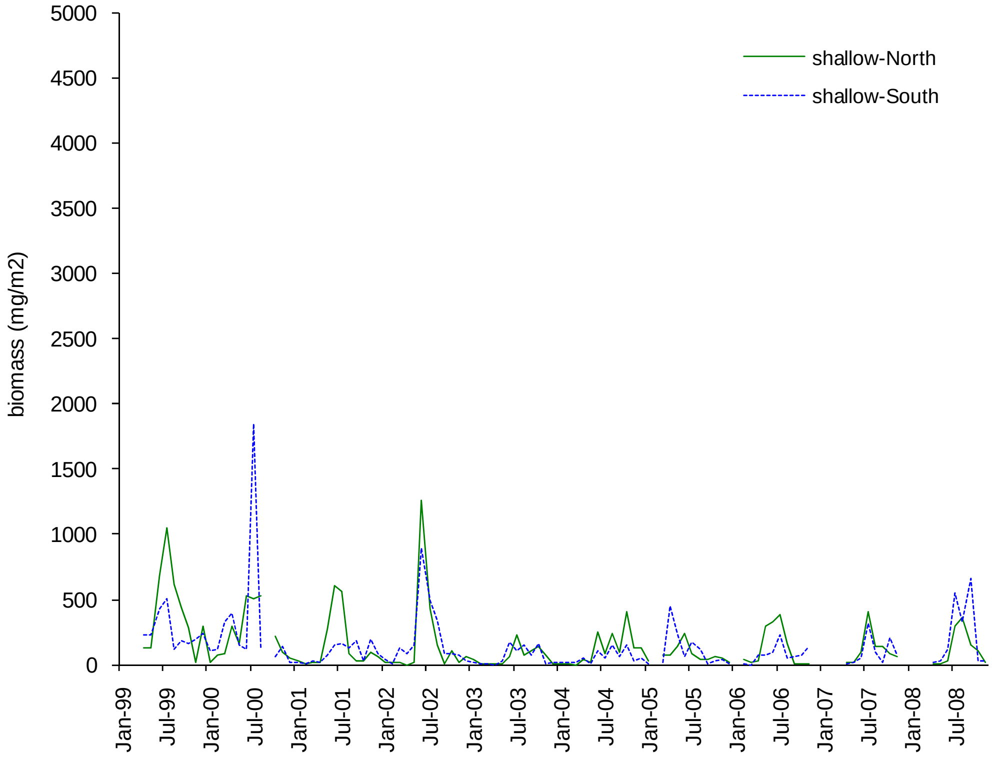


Figure 4.28. Seasonal average of *Mysis* at pelagic and near shore sites, Kootenay Lake, 1999 - 2008.

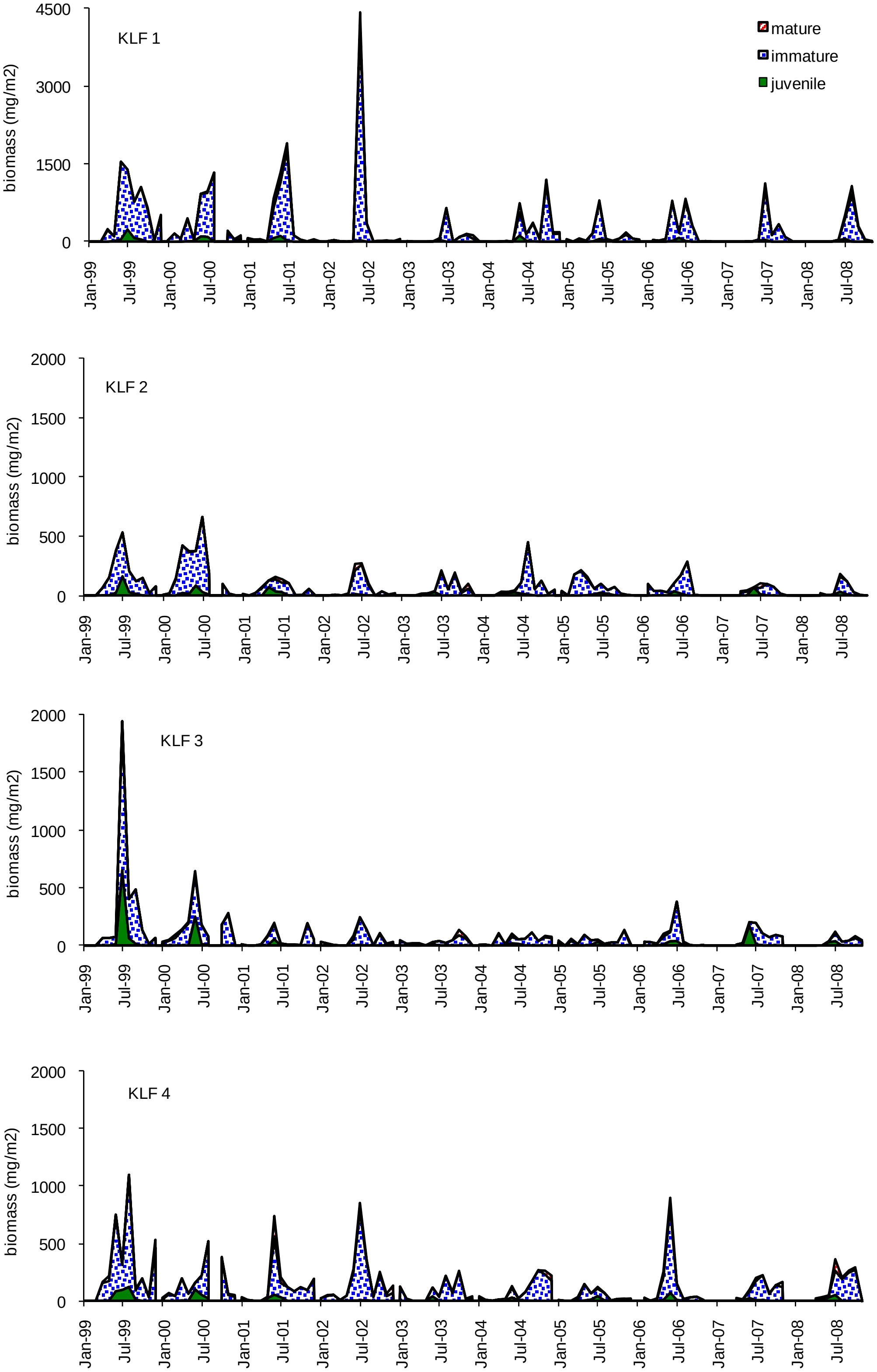


Figure 4.29. Biomass of developmental stages of *Mysis* at near shore sites, stations KLF 1 to KLF 4, Kootenay Lake, 1999 - 2008.

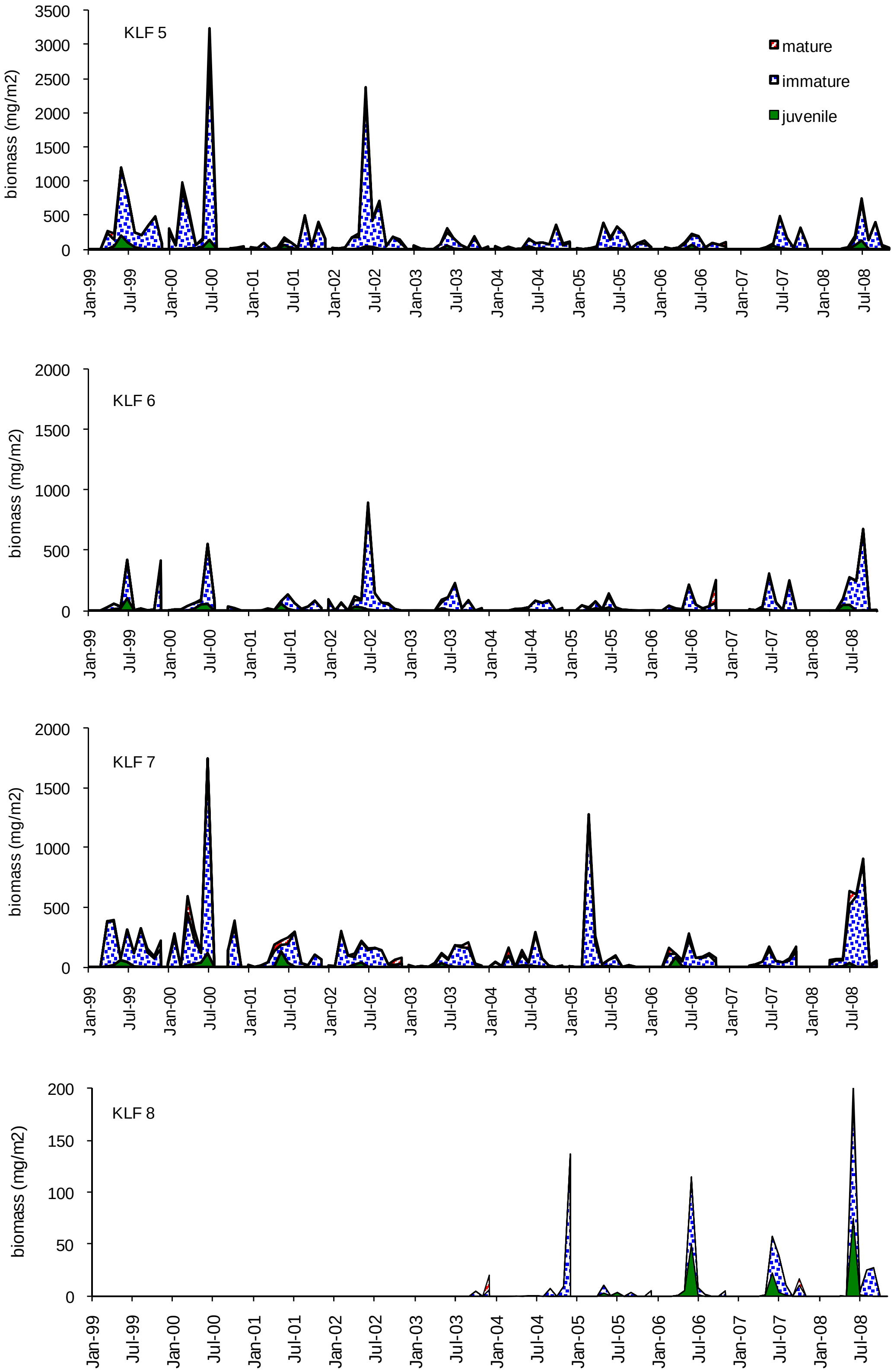


Figure 4.30. Biomass of developmental stages of *Mysis* at near shore sites, stations KLF 5 to KLF 8, Kootenay Lake, 1999 - 2008.

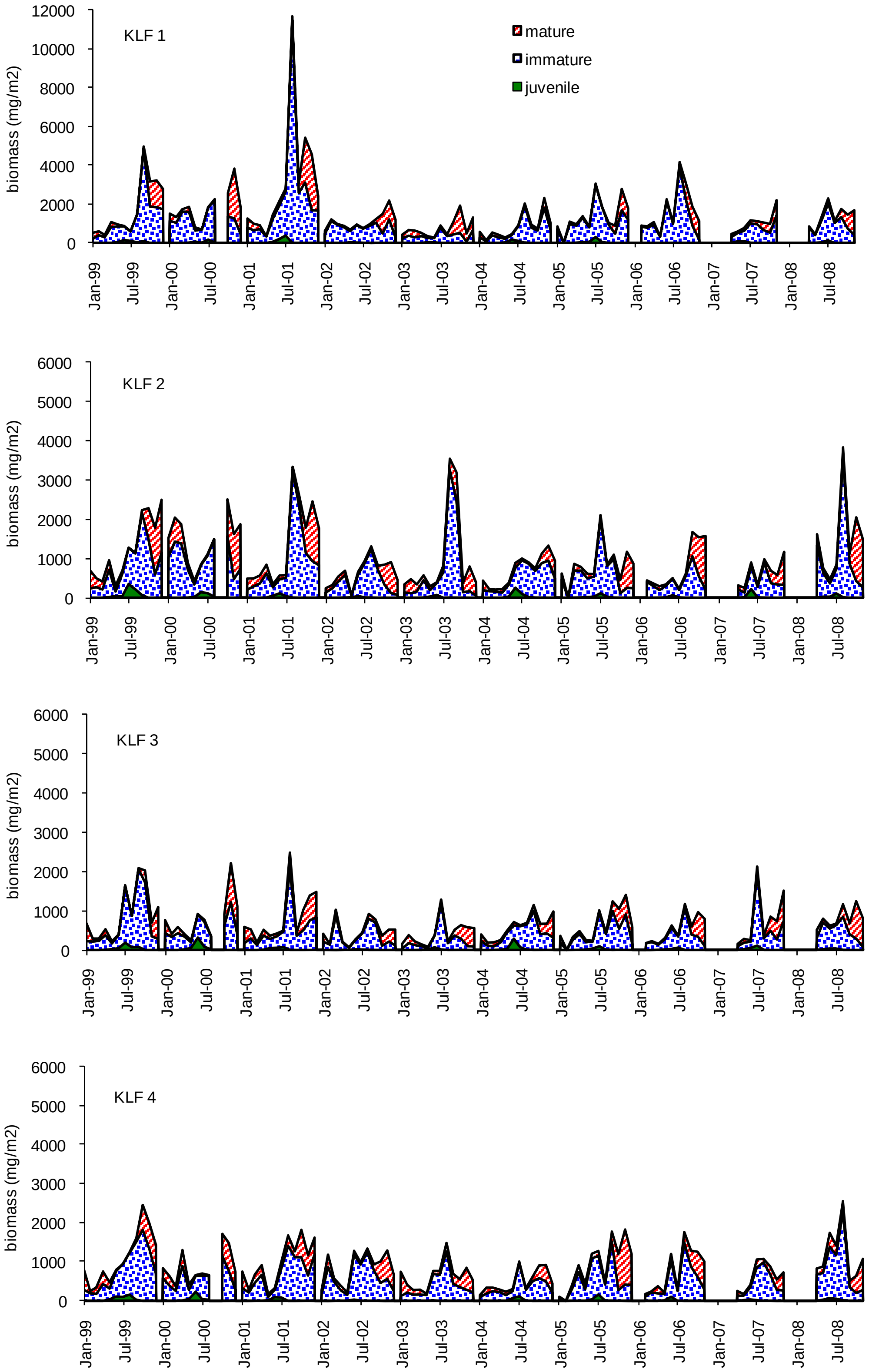


Figure 4.31. Biomass of developmental stages of *Mysis* at deep sites, stations KLF 1 to KLF 4, Kootenay Lake, 1999 - 2008.

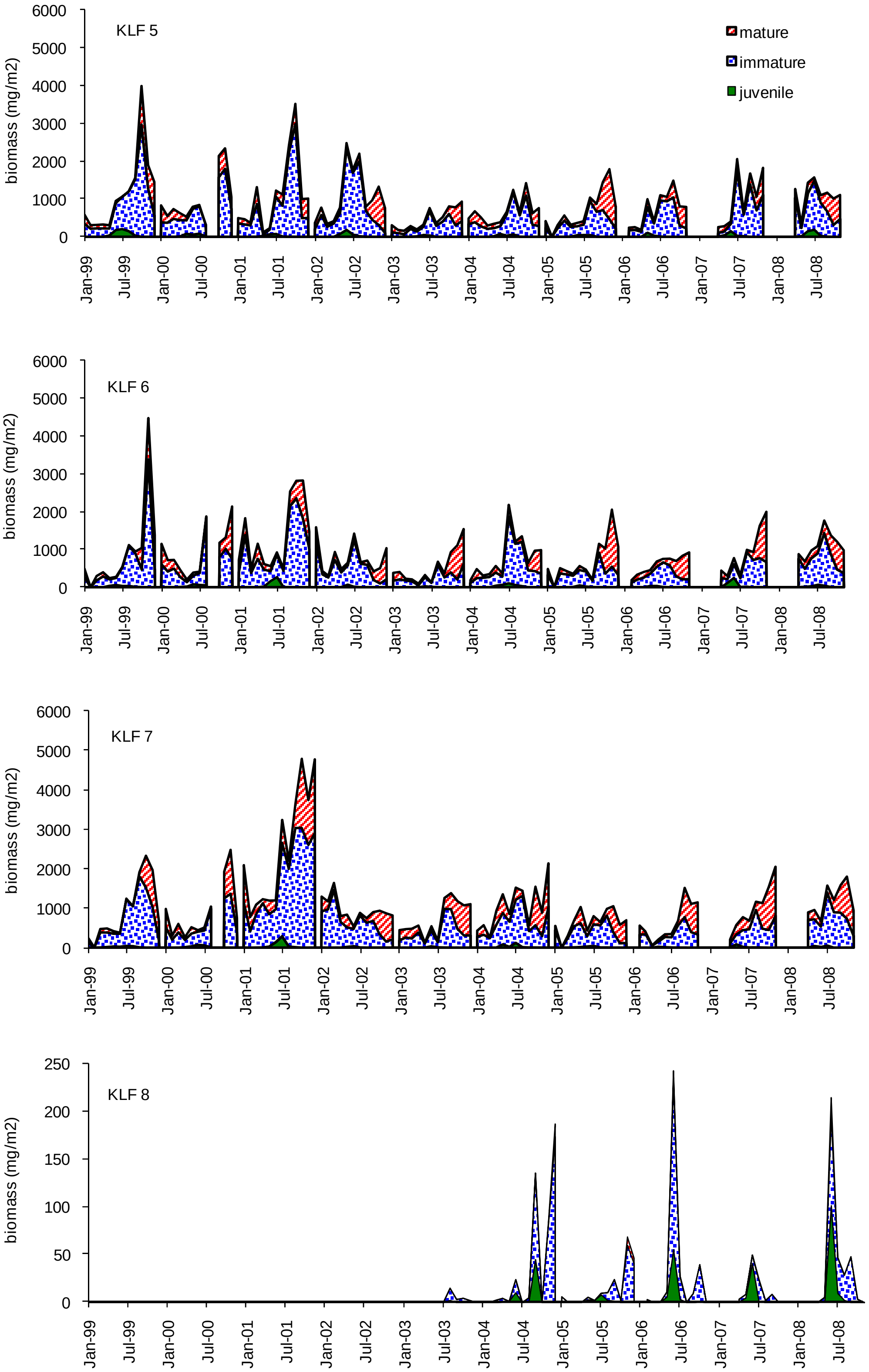


Figure 4.32. Biomass of developmental stages of *Mysis* at deep sites, stations KLF 5 to KLF 8, Kootenay Lake, 1999 - 2008.

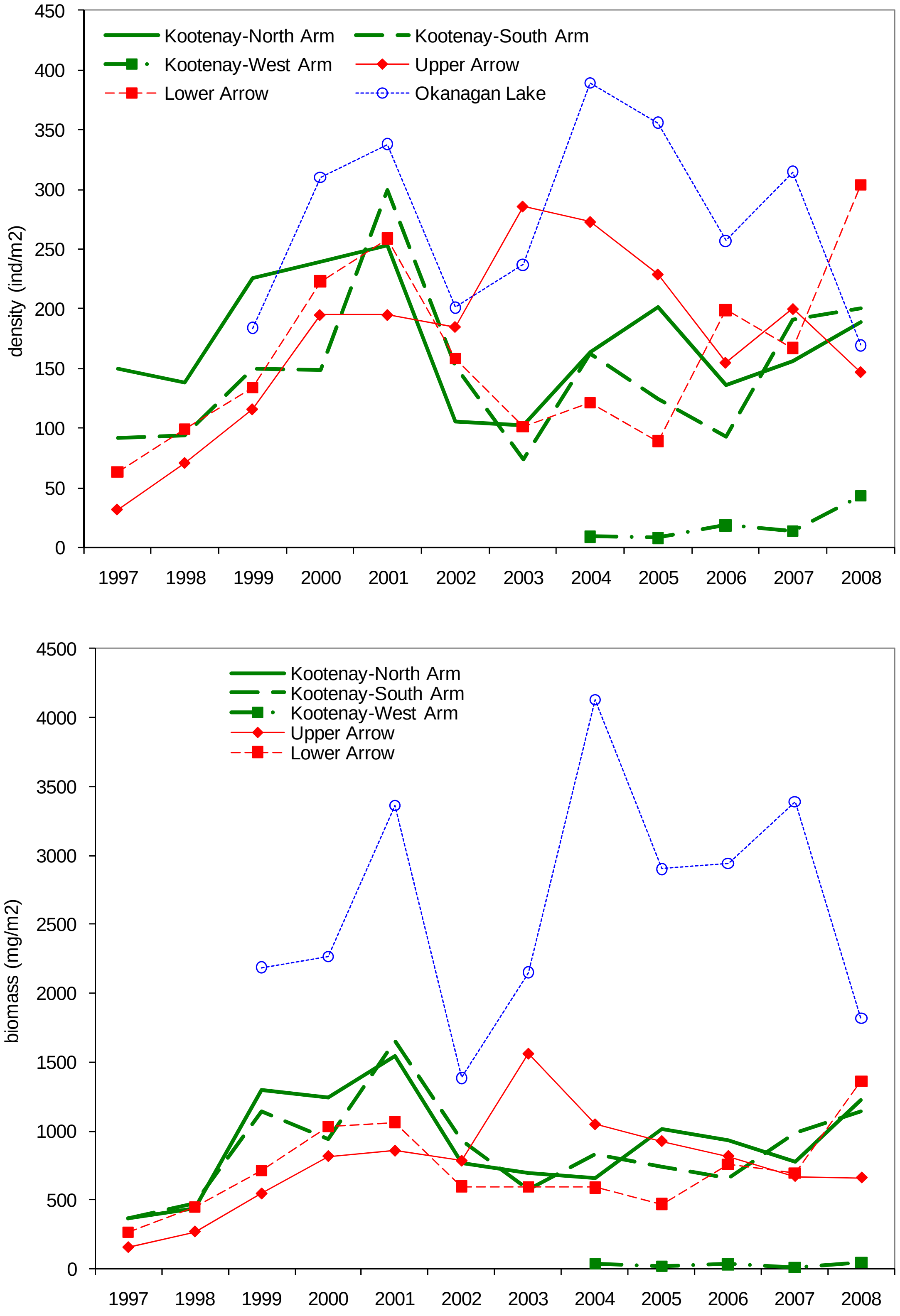


Figure 4.33. Annual average density (top) and biomass (bottom) of *Mysis* in some British Columbia lakes, 1999 – 2008.

CHAPTER 5

KOKANEE RESPONSES TO NORTH ARM (Year 17) AND SOUTH ARM (Year 5) KOOTENAY LAKE EXPERIMENTAL NUTRIENT ADDITIONS (2008)

by

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Introduction

Kokanee (*Oncorhynchus nerka*) are a keystone species in Kootenay Lake since they are the most abundant fish species in pelagic habitat and provide a primary food source for large piscivores including Gerrard rainbow trout, bull trout, sturgeon, and burbot. It follows then that piscivores should thrive if kokanee abundance is sustained at a high level. As the dominant planktivore, kokanee rely almost entirely on zooplankton and are therefore one of the main benefactors of increased productivity through nutrient additions. A positive response in kokanee abundance and biomass provides credible evidence that additional carbon produced from increased primary productivity is transferred through the food web to fish. Tracking the status of kokanee has therefore been a key component of the fertilization monitoring program. Kokanee status is assessed through a number of metrics including their distribution, size abundance and biomass in the lake and numbers and size of mature fish returning to spawn.

Meadow Creek and the Lardeau River are the primary spawning systems for main lake kokanee. Spawner abundance has been tracked in these systems since the early 1960s, likely making them the most studied kokanee population in British Columbia. Meadow Creek escapements provide an index of abundance for the main lake population. Since 1967 the escapements have tracked major ecological changes that have taken place in Kootenay Lake, thus the spawning channel data is critically important in monitoring the effects of lake fertilization. Estimates of fry production are used to evaluate egg to fry survival in the channel as well as fry to adult survival in the lake. Meadow Creek has also been the primary source for kokanee egg collection in BC for nearly a century (Northcote 1973). Meadow Creek kokanee eggs and fry have been planted in many systems throughout BC, including egg and fry plants in streams tributary to the South Arm of Kootenay Lake (Sebastian et al. 2010).

The annual hydroacoustic and trawl surveys have also provide key monitoring data since 1988 for tracking kokanee status through in-lake estimates of their abundance, size, age structure and biomass. The relative distribution of kokanee generally indicates where the most productive rearing habitat for kokanee occurs at the time of the survey and provides further insight into how nutrient additions affect kokanee.

Background

Fisheries research on Kootenay Lake dates back to the early 1950s, when a great deal of the work was undertaken due to the sport fisheries for Gerrard rainbow trout, bull trout and kokanee that have been some of the most popular found anywhere in the interior of British Columbia. Over the years, the limnology of Kootenay Lake has been studied in considerable detail and the status of North Arm kokanee has been well documented long before lake fertilization began. Since the North Arm nutrient experiment began in 1992 there has been a comprehensive monitoring program aimed at measuring trophic level responses to lake fertilization (see Ashley et al. 1997; Ashley et al. *in:* Murphy and Munawar 1999; Ashley et al. 1999; Thompson 1999; Wright 2002; Schindler et al. 2007, 2009a, 2010). The experiments' primary objective was to restore the nutrient concentrations in the North Arm to pre-dam conditions because upstream reservoirs were serving as nutrient sinks (Larkin 1998; Ashley et al. 1999). The initial response of North Arm kokanee to lake fertilization was very positive. Kokanee escapements to the North Arm's Lardeau River and Meadow Creek systems have once again surpassed 1 million. There was a deliberate reduction in fertilizer loading from 1997–2000 to test the hypothesis that it was nutrient additions that had increased kokanee numbers through a bottom-up effect. Kokanee numbers declined in concert with reduced nutrient loading (Schindler et al. 2009a) and this enabled fisheries managers to increase the loading rate starting in 2001. Results of the Kootenay Lake (North Arm) experimental fertilization have been documented in a number of technical reports and other publications (e.g., Ashley et al. 1997; Wright et al. 2002; Schindler et al. 2007, 2009a, 2010). A parallel program of nutrient addition to the nearby Upper Arrow Reservoir began in 1999 (Pieters et al. 2000, 2003, Schindler et al. 2009b, 2010b) and provides the opportunity for some comparisons between these two large experimental programs.

Despite the success experienced with the North Arm project there have been no obvious benefits to west arm kokanee (Redfish Consulting Ltd. 2002). Furthermore, South Arm kokanee, once considered a morphologically and genetically distinct stock (Vernon 1957) have been virtually extirpated from their natal spawning tributaries over the past three decades. Historically, the South Arm tributaries supported only modest numbers of spawning kokanee (Vernon 1957; Andrusak and Brown 1987) but this stock also began a precipitous decline in the late 1970s concurrent with declining lake productivity (Andrusak and Fleck 2007). Kokanee from Kootenay Lake that spawn in Northern Idaho streams also underwent complete collapse (Ericksen et al. 2009).

In the early 2000s Idaho and BC collaborated on a plan to restore South Arm kokanee numbers. This effort to improve South Arm productivity was coordinated and integrated through a Sub-basin Plan designed to restore impacted fish species with particular emphasis on kokanee in Kootenay Lake and the Kootenai/y River (Idaho) (Anders et al. 2004). The partnership included cooperation with various agencies in Canada and the United States including: Kootenai Tribe of Idaho (KTOI); Bonneville Power Administration (BPA); British Columbia Ministry of Environment (MOE); and, Idaho State Fish and Game (IDFG). Commencing in August 2004, nutrient additions comparable to the North Arm project were undertaken on the South Arm to increase lake productivity and restore South Arm kokanee.

A third nutrient addition experiment in the Kootenay watersheds began in 2005 in Northern Idaho. Small quantities of ammonium polyphosphate have been added during the growing season to the Kootenai River at Bonners Ferry in an effort to restore river productivity lost due to impoundment by the Libby Dam and Kookanusa Reservoir. A comprehensive monitoring program has been established by the KTOI and ISFG and to date lower trophic level responses have been positive (P. Anders, Cramer Fish Sciences Moscow Idaho pers. comm.). The river fertilization is worth noting as it may benefit the survival, growth and contribution of kokanee entrained at Libby Dam into the South Arm of Kootenay Lake.

In order to restore South Arm kokanee it was necessary to “jump start” their numbers using eyed-egg plants in streams. Egg plants using Meadow Creek stock began in South Arm streams in BC during the fall of 2005. The Kootenai Tribe of Idaho began kokanee eyed-egg plants (also Meadow Creek stock) in Idaho tributaries as early as 1997, but far more intensively during the last five years (Sebastian et al. 2010; Ericksen et al. 2009).

Anders et al. (2007) recently assessed kokanee populations currently in existence in the Kootenay/ai drainage by analyzing microsatellite samples obtained from spawners from Montana, Idaho and BC. Two distinct groups (populations) of kokanee were identified: Koocanusa Reservoir kokanee were distinct from those in Kootenay Lake and River. Within the Kootenay Lake group the North Arm were distinct from West and South Arm stream spawners. The influence of using Meadow Creek stock for the egg plants is most likely to change the genetics of the South Arm stock.

Some stream restoration work has recently been undertaken in Kootenai River tributaries (in Idaho) in an effort to improve spawning and rearing habitat. Habitat restoration activities have been initiated on three streams to date: Trout, Parker and Long Canyon Creeks. These streams were prioritized for habitat enhancement activities based on potential water and riparian resource problems, as well as KTOI cultural significance and landowner interest. Habitat restoration activities have primarily focused on improving grazing management (i.e. rest, rotation, temporary fencing, off stream watering options) and re-establishing native plant species within the riparian zone (Ericksen et al. 2009). Some stream restoration projects in BC have also been identified by Andrusak et al. (2004).

Annual kokanee escapement estimates to South Arm BC and Idaho tributaries should provide important measures for assessing the response of kokanee to the addition of nutrients in the South Arm as well as the success of egg plants. These results can be compared to the much longer term kokanee data set from Meadow Creek. Early summer hydroacoustic surveys will assist in monitoring the fry recruitment levels to the South Arm prior to North Arm fry arriving.

As mentioned previously, trophic level responses to nutrient additions are being monitored on a long term basis and annual reporting is provided (see technical series by Schindler et al. 2007; 2009a, 2010a). Kokanee, and to a lesser extent Gerrard rainbow trout, are being monitored as part of this comprehensive evaluation program. This report documents results of the North and South Arm kokanee responses to 17 years (1992–2008) and five years (2004 - 2008) respectively of consecutive nutrient addition, with emphasis on kokanee responses to different nutrient loadings. The specific objectives of this report are:

1. to summarize and interpret kokanee hydroacoustic and trawl data from surveys in July and September, 2008;
2. to summarize and interpret North and South Arm kokanee escapement data;
3. to demonstrate the apparent response of kokanee to various levels of experimental nutrient additions since 1992 (North Arm) and since 2004 for the South Arm.

Site Description

A general site description of Kootenay Lake is presented in Chapter 1 of this report. Figure 1.1 shows the location of hydroacoustic transects (1-18) and trawl stations (KLF1-KLF7). The boundary between the North and South Arms can be described as a straight line between Pilot Point on the East side of Kootenay Lake and the lake outlet at Balfour. In the North Arm flows are dominated by the Lardeau/Duncan system. Smaller systems also important for spawning are Fry Creek, Campbell Creek and Powder Creek on the north east side and Coffee Creek, Woodbury, Cooper Creek and Kaslo River on the west side.

In addition to the Kootenai/y River, primary streams flowing into the South Arm in BC include the Goat River, Boulder Creek, Akokli Creek, Sanca Creek, Lockhart Creek, Grey Creek, and Crawford Creek on the east side and Boundary, Corn, Summit, Next, Cultus, and Midge creeks on the west side of the lake (Fig. 5.1). The focus of kokanee work in northern Idaho tributary streams flowing into the Kootenai/y River include: Boundary, Fisher, Smith, Parker, Long Canyon, Ball, Trout, and Myrtle creeks (Fig. 5.1).

Methods

Kokanee Escapement Estimates

The numbers of kokanee spawners in Meadow Creek and the Lardeau River have been estimated for over forty years. The methods have changed very little over this period thus providing consistent time series information. Since the mid-1960s, kokanee escapements to Meadow Creek have been determined by manually counting fish moving upstream into the channel using a permanent fish fence located at the lower end of the channel. At the peak of spawner migration, visual estimates are also made of kokanee numbers in Meadow Creek downstream of the channel. In years of high spawner numbers, some fish are passed upstream of the channel using 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 1966–1998 as part of an evaluation of the channel’s performance.

Methods used to conduct visual estimates of kokanee in lower Meadow Creek, Lardeau River, and Arrow Lakes Reservoir tributaries are described in detail by Redfish Consulting Ltd. (1999) and Sebastian et al. (2000). Due to the high cost of enumerating the Lardeau River via helicopter, a single peak count estimate is conducted that is intended to provide only an order of magnitude estimate useful for understanding population trends. This estimate is supported by several days of visual ground truthing estimates and the peak of spawning is reasonably well known based on the daily count information of nearby Meadow Creek. None-the-less this data is not accurate enough to provide information for population estimates.

South Arm spawning streams are assessed by experienced fisheries personnel who walk each stream and visually count spawning kokanee. The surveys occur weekly extending from late August to the end of September. The index streams include Crawford, Grey, Lockhart, LaFrance, Akokli, Boulder, Goat River and Summit Creek. At the same time the Kootenai Tribe of Idaho (KTOI) staff conducted kokanee spawner surveys on six northern Idaho tributaries to the Kootenai/y River. Similar to methods used in BC, the Idaho surveys were also conducted from mid August to early October but the frequency of surveys in the past were often much less owing to few if any fish being observed.

Kokanee Eyed-egg Plants

All of the streams selected for eyed-egg plants were known to have historically supported spawning populations (see Ericksen et al. 2009). Sites within streams were chosen primarily based on accessibility and habitat suitability; i.e. sites with low gradient, stable sites with natural gravels that can be utilized by kokanee spawners. As well, site specific "redds" were developed based on likelihoods of adequate over-wintering water levels and velocities determined by experienced biologists and technicians.

Redds were developed by excavating the stream substrate as deep as 0.5m and ~.75m x 1.5 m in area. Size (area) of redds varied depending on ease of excavation. A 5 cm flexible PVC pipe was laid on the floor of the excavated area with one end at the downstream end of the excavated area and the other end protruding out of the water at the upstream end of the excavation. The pipe was then held in place with nearby large rocks (~ 5-15 cm) with smaller gravels (< 3cm) then place on top of the larger rocks and pipe to the level of the stream bed. Most redds that were supplemented with small gravels that were screened to reduce the amount of fines and sediment.

Kokanee eggs were usually developed at a hatchery to the eyed stage then transported to the redd sites for placement. The number of eggs placed within a redd varied from 20,000 per red to 48,000 per red depending on the tributary. This was done by pouring the eggs in water into the protruding pipe. As the pipe fills with eggs it was gradually pulled from the redd allowing the eggs to flow out the open end and disperse within the placed gravel. On occasions when eggs "leaked" out of the red, small gravel and fines were placed to hold the eggs within the redd.

An alternate method was used to plant about half the eggs in the South Arm Kootenay Lake tributaries in 2008. Tubes were filled with 30,000 to 35, 000 eyed eggs per tube and were placed in a trench in the substrate and covered with gravel (E. Schindler, Ministry of Environment, Nelson, BC, personal communication). The number of eyed eggs planted using the two methods for each tributary are documented in Table 5.5.

Trawl and Hydroacoustic Sampling

Complete night-time surveys of the limnetic habitat in Kootenay Lake were conducted during the new moon phase in both July and September 2008. Since 1985 both hydroacoustic and trawl surveys have been carried out concurrently each fall during the new moon period using consistent methods (Schindler et al. 2010a). With the South Arm Fertilization beginning in 2004, additional acoustic and trawl monitoring was done during the early summer period. The survey timing ranged from mid-June to mid-July depending on when the new moon period occurred (Table 5.1). The intent of early sampling was to get a snapshot of fish distribution and abundance early in the growth season while the North and South Arm fry populations are still segregated. Early sampling provides an index of South Arm fry abundance as well as some size information which can be compared with the North Arm population (for all ages).

Table 5.1. Dates of early summer acoustic and trawl sampling, trawl location and number of trawls conducted

Year	Month	Dates	Trawl location (number of trawls)	
			North Arm	**South Arm**
2004	June	13-16	Birchdale (1)	Rhino Point (3)
2005	July	8-10	Shutty (1), Woodbury (3)	Midge Cr(3)
2006	June	26-28	Shutty (2), Woodbury (2)	Rhino Pt (3),Redman Pt (3)
2007	July	4-7	Birchdale (1)	Redman Point(3)
2008	July	5-6	Shutty (1)	Redman Point (1)

Trawl

Mid-water trawl samples provide species verification for the acoustic survey, indices of kokanee abundance, age structure, size-at-age, and the proportion of mature fish in the catch. Fall surveys consist of three stepped-oblique trawls at each of six stations (see Chapter 1; Fig. 1.1) to capture a representative sample of fish from each depth strata where fish were observed on the echosounder. The net was fished for 8 minutes at consecutive 5-m depth layers, targeting fish from 20–45-m depth (i.e. five layers). Trawl gear used consisted of an opening and closing 5 x 5 m beam trawl, holding a 20 m long net of graduated mesh size (6 to 92 mm stretched), towed at 0.80-0.95 $m \cdot s^{-1}$. The trawl net depth was initially calibrated against boat speed and cable length with a Notus net depth sensor system after which depths were estimated by cable length. A Global Positioning System (GPS) was used to estimate distances traveled for calculating sampled volumes.

Trawling strategy was different for the early season sampling due to a lack of fry in the South Arm and the short nights and very limited sampling times available. Consequently, the focus of early season trawling was to catch some fry for comparing fry size between North and South Arms early in the season prior to the stocks mixing. The net was typically towed for one hour covering up to three 5 m depth layers but largely directed at depths where highest concentrations of fry were found on the echosounder. If fry were not captured in three one hour directed trawls, no further sampling was done (i.e., it was concluded that trawling would not likely be successful at other locations in the South Arm where acoustic densities were even lower).

Captured fish were kept on ice until they were processed the following morning. Species composition, fork length, weight, distinguishing marks (e.g., fin clips), scale code, and stage of maturity were recorded. Scales were taken from fish >75 mm for aging. Fish lengths from fall sampling were adjusted to an October 1 standard using empirical growth data from Rieman and Myers (1992) in Appendix 5.1

Hydroacoustics

Acoustic survey data were collected at 18 transect locations evenly spaced along the length of the main lake, including both North and South Arms (see Chapter 1, Fig. 1.1). In 2008, survey data were obtained using a Simrad model EY500 120 KHz split beam system. Prior to 2008, survey data were collected using a Simrad model EY200P 70 kHz single beam sounder; this equipment was retired in 2008. Detailed methods for hydroacoustic data collection and analysis from the EY200P sounder collected to 2007 are described by Schindler et al. (2010a). The Simrad EY500 system was calibrated in the field at the beginning of the survey following the procedure described by the manufacturer. The transducer was towed on a planer alongside the boat at a depth of 1 m, and data were collected continuously along survey lines at 4-6 $pings^{\cdot}s^{-1}$ while cruising at ~2 $m^{\cdot}s^{-1}$. Navigation was by radar, GPS, and a 1:75,000 Canadian Hydrographics bathymetric chart. Split beam data for 2008 was analyzed using Sonar 5 post processing software version 5.9.8 described by Balk and Lindem (2008). Habitat was stratified by 5 m depth layers from 3-50 meters, and then further stratified into relatively homogeneous zones using density depth contour plots. Stratum areas for each transect and depth layer were derived from reservoir bathymetry. A Monte Carlo Simulation procedure was used to combine all strata and develop maximum likelihood estimates (MLE) and statistical bounds for the combined zones using 30,000 iterations. Monte Carlo simulations were run for both the entire fish population and for fish larger than fry size (>85mm or -46dB).

Fish size distributions were estimated by the split beam method as described by Simmonds and MacLennan (2005). The fish densities in $number \cdot ha^{-1}$ for each transect and depth strata were output in 38 1-decibel (dB) size groups from -61 to -24 dB using Sonar 5 software and compiled on an Excel spreadsheet. Each density by transect, depth and size group was then expanded by the estimated area of habitat at depth to develop a size specific population estimate for the reservoir. Echosounder specifications and field settings are presented in Appendix 5.2 and acoustic size classes and fork length equivalents in Appendix 5.3.

Kokanee Biomass

Biomass estimates for pelagic habitat were determined from acoustic abundance proportioned into age groups based on both trawl and acoustic surveys. Where trawl catches of older fish were deemed too low to be statistically valid, proportions of age 1+ and 2+ fish were estimated directly from acoustic split beam size distributions assuming both field calibration and Love’s (1977) “Dorsal Aspect” formula were reliable. Spawner biomass was estimated by applying the average weight of spawners measured at Meadow Creek spawning channel to the total estimated number of spawners from all tributaries. For years where no weights were available, individual weights were estimated from a length weight relation derived from previous Meadow Creek data on file (MOE). This number was then divided by the surface area of “pelagic habitat” to determine a biomass density ($kg^{\cdot}ha^{-1}$). See Appendix 5.6 for biomass calculations and results.

Results

2008 Kokanee Escapements

North Arm

After two consecutive years of very low spawner returns at Meadow Creek, the 2008 escapement increased by ~2.5 times to 940,000 fish (Fig. 5.2). This number of spawners was slightly lower than the 2004 estimate of ~1.1 million but a considerable improvement over the 2006 and 2007 returns of <400,000 fish. Similarly, the 2008 Lardeau River escapement of 409,000 in 2008 was ~3 times higher than the two previous years and was the largest return in the last nine years (Fig. 5.3). Both Meadow Creek and the Lardeau River experienced similar increases over the previous two years.

South Arm

In sharp contrast to the ~ 1.35 million kokanee in the Lardeau-Meadow Creek system in 2008 there were hardly any kokanee spawners in the South Arm streams (Table 5.2) or in the northern tributaries of the Kootenai River in Idaho (Table 5.3). Only eight fish were observed in 8 index spawning streams in BC in 2008. Results from the Idaho streams were more encouraging as 1276 spawners were counted in 2008. This is the first count to exceed 1000 since 1981. Restoration efforts continue in an effort to rebuild the spawning populations through kokanee eyed egg plants. These egg plants were initiated as early as 1997 in Idaho with substantially increased numbers starting in 2003 (Table 5.4). It is

Table 5.2. Kokanee spawner counts in BC South Arm tributaries during 1990s and 2000s. Historical data can be found in Ericksen et al. (2009).

Year	Crawford	Gray	La France	Lock-hart	Akokli	Sanca	Boulder	Midge	Goat River	Summit	Cultus	Combined
1992						6	3		20	30		59
1993												
1994	2	0	0	0	100	4	0	0	0	0	0	106
1995	0	0	0	0	0	0	0	0	0	0	0	0
1996	40	30	20	20	200	0	0	50	4	0	50	414
1997	0	100	3	1	150	7	0	0	0	0		261
1998	0	5	0	0	50	2	0	5	2	0		64
1999	0	20	2	0	20	2	0	0	0	0		44
2000	0	2	0	0	20	0	1		0	0		23
2001	0	8	0	0	6	0	0	33	0	0		47
2002	0	10	0	0	5	0	0		0	0		15
2003	5	35	0	0	151	8	0	0	2	1		202
2004	0	8	0	0	8	0	0	0	0	0	0	16
2005	0	0	0	0	1	0	0		0	0		1
2006	0	9	0	0	2	0	0		0	1		12
2007	8	40	0	3	4	0	0		0	0	100	155
2008	0	6	2	0	0	0	0		0	0		8

believed the increased spawner numbers in 2007 and again in 2008 were the initial returns from the eyed egg plants (Ericksen et al. 2009). If these fish are spawning as age 3+ then initial returns to BC streams should occur in 2009 since the most recent egg plants didn’t begin until 2005 (Table 5.5).

Table 5.3. Kokanee spawner counts in Northern Idaho streams.

Year	Boundary	Smith	Long Canyon	Parker	Trout	Myrtle	Ball	Combined
1980	2,000	2,000	2,000	500	100	0	0	6,600
1981	1,100	600	1,600	350	50	50	50	3,800
1982-92	No records							
1993	0	NS	17	47	0	0	NS	64
1994-95	No records							
1996	0	0	0	0	0	0	NS	0
1997	0	0	3	0	0	NS	NS	3
1998	8	0	0	0	0	NS	NS	8
1999	38	0	0	0	0	NS	NS	38
2000	17	NS	30	7	0	NS	NS	54
2001	31	NS	25	0	7	NS	NS	63
2002	0	30	NS	30	0	NS	NS	60
2003	0	NS	40	55	0	0	NS	95
2004	9	NS	11	1	5	0	NS	26
2005	0	NS	0	3	0	0	NS	3
2006	0	NS	6	5	0	0	NS	11
2007	NS	200	150	10	325	2	100	787
2008	0	215	0	62	535	9	455	1,276

Table 5.4. Number of kokanee eyed egg plants in Idaho tributaries 1997-2008. Data from Ericksen et al. 2009.

Year	Idaho tributaries								
	Boundary	Long Canyon	Parker	Trout (S. fork)	Trout (N. fork)	Ball	Myrtle	Fisher	Combined
1997		100,000							100,000
1998		100,000	100,000	100,000					300,000
1999		200,000	150,000	150,000					500,000
2000		no egg plants						0	
2001		no egg plants						0	
2002		no egg plants						0	
2003		417,000	417,000	417,000	50,000		200,000		1,501,000
2004		500,000	500,000	587,500	325,000		587,500	500,000	3,000,000
2005		420,000	420,000	420,000	200,000		420,000	420,000	2,300,000
2006		100,000			25,000			25,000	150,000
2007		625,000	300,000	425,000	93,000		150,000	150,000	1,743,000
2008	1,000,000	500,000	50,000	325,000	200,000	325,000		100,000	2,500,000

Table 5.5. Number of kokanee eyed egg plants in BC South Arm of Kootenay Lake streams 2005-2008.

	British Columbia tributaries								
Year	**Akokli**	**Boulder**	**Crawford**	**Cultus**	**Goat R.**	**LaFrance**	**Lockhart**	**Summit**	**Combined**
2005		200,000	300,000		1,000,000			500,000	2,000,000
2006		175,000						210,000	385,000
2007		150,000	300,000		1,100,000				1,550,000
2008a		90,000	120,000		828,000			80,000	1,118,000
2008b		240,000	180,000		700,000			240,000	1,360,000

a Eggs planted in the gravel using a flexible PVC pipe (method used from 2005 to 2007)
b Eggs placed in tubes and then buried in the gravel (additional method)

Spawner Size and Fecundity

Kokanee spawners returning to Meadow Creek are typically quite small compared with many other lakes. Their mean size has been remarkably consistent over four decades (n=40 years), falling within a narrow size range from 19.5–28.2 cm with the mean size of females (22.3 cm) slightly smaller than of males (22.6 cm). Mean size of 2008 males (25.9 cm) was slightly larger than the females (25.4 cm). Both were somewhat smaller than the record setting sizes recorded in 2007 when mean male size was 28.2 and female mean size was 27.7 cm. Overall spawner size in 2008 was substantially larger than the long term average. Mean sizes for the last three years were much larger than any previous years except 1993, one year after fertilization commenced (Fig. 5.4). The 2008 fecundity was 379 eggs/female or 30% higher than the long term average of 265 eggs/female. There are no recent kokanee spawner biological data for either the Lardeau River or any of the South Arm streams.

Meadow Creek Kokanee Fry Production

Fry production from Meadow Creek in the spring of 2008 was ~25.4 million, with the spawning channel continuing to contribute the vast majority (97% in 2008) of the total production from Meadow Creek. Fry production in 2008 was considerably higher than the previous two years and third highest on record (Fig. 5.5). Since nutrient additions began in 1992, total fry production out of Meadow Creek has increased substantially with all but three years exceeding 15 million fry. During the 1980s the total numbers averaged 8.7 million and seldom exceeded 12 million (Fig. 5.5). Higher levels of fry production from the channel in the last decade reflect a combination of a) improved channel performance due to channel renovations and b) higher egg deposition resulting from increased escapement levels and/or increased growth and fecundity (Fig. 5.4 & 5.5). Greater numbers of spawners, hence higher egg deposition, should eventually result in an asymptotic relationship between fry produced and egg deposition; i.e., at some point greater egg deposition will not translate into increased numbers of fry due to redd superimposition from crowded spawning conditions. A scatter plot of fry production vs. egg deposition shows a linear relationship suggesting that the maximum production level for fry has not been exceeded in Meadow Creek Spawning Channel (Fig. 5.6). Fisheries managers continue to load the channel as frequently as possible to determine optimum channel egg deposition.

Trawl Catch Data

Total catch, composition, and age distribution

Fall trawling surveys have been carried out on Kootenay Lake for more than twenty years, and the catch has always been > 99% kokanee (Schindler et al. 2010a). This re-affirms that virtually all fish in the limnetic zone recorded by the acoustic survey are kokanee. In recent years the majority of kokanee have been captured in the nutrient addition zone at the north end of the lake. Total fall 2008 kokanee catch was 1,217 and consisted of 96.1% age 0+, 3.5% age 1+, 0.4% age 2+, and no age 3+ fish captured (Table 5.6). Ageing of the 2008 spawners is discussed below.

Table 5.6. Kokanee catch statistics from 2008 spring and fall trawl surveys.

Survey time	Section	Station	Hauls	Age 0	age 1	age 2	Age 3	total
Spring	North Arm	2 Shutty Bench	1	105	23	2	0	130
Spring	South Arm	7 Redman Point	1	0	1	4	5	10
Spring	***Total lake***		***2***	***105***	***24***	***6***	***5***	***140***
				75%	*17.1%*	*4.3%*	*3.6%*	*100%*
Fall	North Arm	1 Johnson	3	34	1	0	0	35
Fall	North Arm	2 Shutty Bench	3	208	6	0	0	214
Fall	North Arm	4 Woodbury Cr	3	416	4	1	0	421
Fall	South Arm	5 Wilson Creek	3	204	28	4	0	236
Fall	South Arm	6 Rhinoceros Pt	2	172	3	0	0	175
Fall	South Arm	7 Redman Point	3	135	1	0	0	136
Fall	North Arm	total	9	658	11	1	0	670
Fall	North Arm	total	8	511	32	4	0	547
Fall	***Total lake***	***Total survey***	***17***	***1169***	***43***	***5***	***0***	***1217***
				96.1%	*3.5%*	*0.4%*	*0%*	*100%*

Length at age

The trawl catch data provided certainty for aging of juvenile fish and therefore estimates of mean length at age in 2008. Distinct modes with minimal overlap were evident for each age group and coincided well with scale interpretations. The 2008 fall catch data produced three modes, suggesting mean fork lengths of 54 mm, 134 mm and 186 mm for age 0+, 1+ and 2+ fish respectively (Fig 5.7, Table 5.7). There were no age 3+ fish represented in the trawl presumably as mature age 3+ fish had left the lake to spawn just prior to the fall trawling. Plotting the length frequency distribution of 660 Meadow Creek spawners on Figure 5.7 shows no overlap with the trawl fish while a single mode indicates that the majority of spawners are most likely age 3+ fish with a mean length of 257 mm. It is worth noting that the largest spawners on record (279 mm in 2007) followed the largest age 2+ fish on record at 221mm from the 2006 trawling. The 2008 spawners were slightly smaller [257 mm, n=660] than the record sized spawners of 2007, but were still the largest recorded since 1993 (Fig. 5.8). The much smaller sized age 2+ in

2008 suggests that 2009 spawners will be considerably smaller than the previous two years.

Table 5.7. Size statistics from trawl captured kokanee during July and September surveys in 2008.

Survey time	Basin	Station	age 0	age 1	age 2	age 3
July 2008	North Arm	Ave. length (mm)	34	90	168	n/a
		Length range (mm)	26-51	72-106	155-181	n/a
		Standard deviation	3.6	8.5	18.8	n/a
		Sample size (n)	105	23	2	0
	South Arm	Ave. length (mm)	n/a	96	180	242
		Length range (mm)	n/a	n/a	169-189	229-266
		Standard deviation	n/a	n/a	10.0	14.2
		Sample size (n)	0	1	4	5
	Both Arms - total ave. length (mm)		*34*	*90*	*176*	*242*

Survey time	Basin	Station	age 0	age 1	age 2	age 3
Sept 2008	North Arm	Ave. length (mm)	53	126	194	n/a
		Length range (mm)	36-87	99-148	n/a	n/a
		Standard deviation	5.6	14.4	n/a	n/a
		Sample size (n)	658	11	1	0
	South Arm	Ave. length (mm)	56	137	184	n/a
		Length range (mm)	42-74	100-154	163-196	n/a
		Standard deviation	4.2	13.7	14.8	n/a
		Sample size (n)	511	32	4	0
	Both Arms - total ave. length (mm)		*54*	*134*	*186*	

When South Arm fertilization began, early summer hydroacoustic and trawl surveys were added to the annual monitoring program to better understand what changes (if any), occurred due to South Arm nutrient additions. The 2008 summer hydroacoustic survey results indicate that small numbers of kokanee fry were present at the southern end of the lake, however; there were too few to catch with trawling. Since South Arm fry catches were too low most years to make statistical comparisons with North Arm fry, their slightly larger size was best shown by a cumulative length frequency distribution combining trawl catches from all years (Fig. 5.9). Interestingly, there were more age 1+ than fry captured in the South Arm during the early season trawling. In terms of relative abundance, the South Arm fry catches were more similar to age 2+ catches. Meanwhile, the North Arm catches were dominated by age 0+ fish all years. It was hoped that the early summer trawl component of the survey would assist in determining if there were significant size differences in fry produced in the South Arm compared with those fry that migrated from the North Arm. It is of interest to note that mean size of South Arm fish captured in fall 2008 was larger for all age groups with meaningful sample sizes (0+ & 1+) than those same age groups caught in the North Arm (Table 5.7).

Age-at-maturity

The trawl caught kokanee provide good insight into age of spawners since three modes are usually present, and the spawners are typically larger than the largest age 2+ fish captured in the trawl (Fig. 5.7). Mean size of age 2+ from the 2006 trawl sample were much larger than average and this cohort grew to a record size in 2007 and would appear to be primarily age 3+ spawners with some smaller 2+ spawners present. This data supports some limited otolith age analysis from fifty spawners (n=50) that indicated most fish in 2007 were again age 3+ (58%) with some ages 2+ (32%) and few age 4+ (10%) also contributing to the 2007 spawning population (Schindler et al. 2010a). Length frequency distribution of the 2007 spawners certainly suggests multiple ages contributed to the spawning population whereas the 2008 population appears to be represented by one mode and virtually all one age group (Fig. 5.10). A small sample of otoliths in 2008 (n=30) indicated that the smallest fish (i.e. <230mm) were age 2+ while the large majority (>230mm) were age 3+. The small sample of otoliths suggested about ~20% age 2+, however, when compared with the length frequency from a much larger sample it would appear that the proportion of fish <230mm likely to be age 2+ was only about 3%. It is also worth noting that according to the Casselmen rating system, only 8 of the 30 otoliths in 2008 had ratings of 6 or higher for all features indicating good reliability and that otoliths from younger fish (i.e. 2+) tend to be easier to interpret so score higher more often than older fish. It is recommended that the sample size be increased to 50 otoliths from 30 for Meadow Creek kokanee.

Hydroacoustic Abundance Estimates and trends

Nighttime surveys of the limnetic zone of the main lake have been conducted in a standardized manner since 1991 and comparable manual echo counts date back to 1985. In fall 2008 the maximum likelihood estimate (MLE) for kokanee abundance all ages in pelagic habitat was 26.9 million (24.2 to 29.6). Although a 3.5 million increase over the 2007 and 4.8 million increase over 2006, the 2008 increase was not statistically significant over the two previous years or the 17-year average of 23.1 million (19.1-27.0) since nutrient addition began (Fig. 5.11). The age 1-3+ component in 2008 was estimated at 4.27 million (3.59 to 4.98). This represented a slight decline over the 5.49 million in 2007 (Fig. 5.12) but was also within the bounds of the 16 year average of 6.2 million (4.6-7.7) for age 1-3+ fish in Kootenay Lake. Complete fall kokanee density and abundance statistics are provided in Appendix 5.4 & 5.5.

Hydroacoustic surveys in the late 1980s and early 1990s indicated total numbers of ~6-13 million (Fig. 5.11). Within two years of lake fertilization there was a sizeable increase in total numbers to ~35 million kokanee by 1994. This increase was mainly due to rapid growth at the onset of fertilization (i.e., a classic density-growth response to favourable in-lake conditions), which resulted in a peak of both fecundity and total egg deposition in 1993 (Fig. 5.4). Most of the numerical increase in 1994 was observed in age 0+ fish, although ages 1–3+ fish had also increased slightly. Meadow Creek fry production remained high for three consecutive years [i.e., 1994–1996, Fig. 5.5] which led to increased numbers of ages 1–3+ fish after two years (i.e., 1996–1998) (Fig. 5.12). The higher numbers of ages 1–3+ fish correlate with a three-year period of lower growth and lower fecundity, suggesting that a combination of increased competition from ages 1–3+ fish and decreased nutrient additions in the late 1990s led to smaller adults and reduced fry production (Figs. 5.4, 5.5, 5.12). Reduced numbers of fry during 1997–2000 were followed by lower numbers of ages 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 consistent with a period of rapid growth and increase in spawner size and fecundity (Figs. 5.4, 5.8).

Kokanee abundance increased substantially from 2001–2002 ranging from 25–35 million (Fig. 5.11). These increases were most likely due to the combined result of increased fry production (Fig. 5.5) and improved rearing conditions from increased nutrient additions that began in 2001. In 2004 and 2005 estimated numbers decreased to ~ 16 million but this decrease was followed by three consecutive years of increased abundance with the 2008 estimate exceeding 25 million. The 2008 fry estimate represents the third highest since fertilization began. The reason(s) for the lower estimates in 2004 and 2005 is not obvious since Meadow Creek fry production remained high. The spawning channel produces the majority of fry for the North Arm and there is a good relationship between the fall fry acoustic estimates and Meadow Creek production (Fig. 5.13). This relationship (R^2=0.80) suggests that fry survival rates over the summer period have been quite consistent from year to year (1990-2008). Two years (2000 and 2005 estimates) were obvious outliers and were not included in the regression model. For these years the data suggests poor survival during the summer, a major departure from other years. The most recent years (2006-2008) data again demonstrated a similar relationship of late summer fry abundance to Meadow Creek fry production (Fig. 5.13).

Distribution in the lake

In-lake distributions of kokanee in response to lake fertilization show some interesting trends. Prior to fertilization, kokanee densities in the South Arm tended to be higher during late summer than in the North Arm (Fig. 5.14). During the first eight years of fertilization, North Arm densities were higher than in the South Arm presumably indicating that fertilization had changed the rearing conditions for kokanee. Commencing in 2000 this trend reversed under reduced fertilizer loadings (Fig. 5.11) but resumed in 2001 as fertilizer loading was increased. In 2002 and 2003 the densities were higher in the South Arm. It is interesting that during the second decline in kokanee abundance which occurred in 2005 and 2006, only the South Arm densities declined. With continued addition of nutrients to the North Arm, densities there remained fairly high.

During 2006 - 2008 the North Arm densities remained high and South Arm densities caught up. The similar densities in the two arms of the lake during the last two years may indicate that fertilizer being added to the South Arm as well as the North Arm may be affecting kokanee distribution and relative abundance.

The addition of early summer surveys over the past five years has provided insight into seasonal fry distribution. In early summer, fry have typically been highly skewed to the north end since the majority are produced in Meadow Creek and the Lardeau River at the north end of the lake. By the end of summer the fry tend to disburse more evenly throughout the lake as illustrated by comparing July and September fry distributions in 2007 and 2008 (Fig. 5.15). With the exception of 2005, the age 1-3+ fish densities were higher in the South Arm by late summer from 2004-2008. The September 2005 pattern was unusual with all age groups highly concentrated at the north end of the lake and was more typical of early season fish distributions (Fig. 5.15, upper panel). This unusual concentration of kokanee remaining in the North Arm fertilization zone into the fall was also observed in 1993 and again in 2001. In both instances this change was observed following an increase in nutrient levels with the start of fertilization in 1992 and the increase in levels in 2001 over the previous three years.

South Arm fry population

One of the reasons for early season hydroacoustic sampling was to estimate fry numbers in the South Arm prior to the North Arm fry arriving. Fry abundance in the South Arm ranged from 1.4 - 3.8 million during 2004-2008 (Table 5.8). Statistical bounds on the fry component of the South Arm however were fairly wide, particularly in 2004, indicating the estimates have low precision. This is not surprising, given the extremely low densities and patchy distribution of South Arm fry early in the summer and the limited number of transects (n=7). It appears that survey timing may be fairly critical for these estimates. If sampling was done too early (i.e. June), fry were still aggregated near the South end and near the surface or at other locations contributing to the recruitment. If the sampling was too late, there is an increased likelihood of including fish that have emigrated from the North Arm. There are a number of reasons that precision is low in the early season fry estimates. Their small size makes them more difficult to separate from *Mysis* and the difference between fry and age 1+ size at that time of year may not be large enough to produce a clear separation between fry and older fish. By contrast, the huge numbers of fry compared with small numbers of age 1+ fish in the North Arm make a visible cut-off on acoustic distributions more obvious. Unfortunately, with the current lack of precision, it is not possible to demonstrate any changes in the South Arm fry production. The numbers do however, indicate that fry levels in the South Arm are higher than what would be expected from the egg plants, suggesting there must be other significant sources of fry production to this area. The earliest season distributions may provide some clues as to their origin. The aggregation at Transect 18 would support the notion that entrainment from Kookanusa Reservoir may be provided significant recruitment (some years).

Table 5.8. Comparison of early and late summer fry estimates for the South Arm of Kootenay Lake during 2004-2008.

Year	**Dates**	**Fry MLE (with bounds)**[1] In millions
2004	June 13-16	3.85 (0.76 - 6.75)
2005	July 8-10	1.41 (0.90 – 1.95)
2006	June 26-28	2.39 (0.67 – 3.98)
2007	July 4-7	3.12 (1.61 – 4.49)
2008	July 5-6	2.37 (0.84 – 3.92)

1. MLE – Maximum likelihood estimate

Another slight aggregation in the middle of the South Arm at transects 14 and 15 may indicate the presence of some local stream production or some limited shoal spawning in that vicinity which is not supported by the our current knowledge of spawner distribution and stream counts.

Kokanee Biomass Estimates

Total kokanee biomass in the lake can be estimated using the mean weights and numbers determined from trawl and hydroacoustic surveys (see Appendix 5.6 for details). Prior to fertilization (1985-1991) the average kokanee biomass density was ~3.5 kg$\cdot$ha^{-1} in the lake (not including spawners). Since fertilization (1992-2008) the kokanee biomass densities has increased to an average of ~ 9.6 kg$\cdot$ha^{-1}, close to a three-fold increase (Fig. 5.16; Appendix 5.6c). Spawner biomass was calculated by applying average weights from Meadow Creek Spawning Channel to the combined escapement from Meadow Creek and Lardeau River. Spawner biomass averaged 1.8 kg$\cdot$ha^{-1} prior to treatment and has averaged 3.6 kg$\cdot$ha^{-1} or approximately double since nutrient additions (Appendix 5.6c). Because of survey timing (i.e. acoustic surveys occur once spawners have left the lake) the in-lake and spawner biomass can be summed to estimate total kokanee biomass. The before and after treatment average total biomass was estimated at 5.3 and 13.2 kg$\cdot$ha^{-1} respectively (Appendix 5.6c).

The extremely low number of age 2+ fish captured in the 2008 trawl surveys has led to an unusually low estimate for proportion of age 2+ fish suggesting a total abundance of only 445,100 age 2+ fish. This apparent lack of age 2+ sized fish did not show up in the acoustic size distributions so it is most likely that both the numbers and total biomass of age 2+ fish reported for 2008 has been under estimated based on trawl proportions. This can be verified in next year's report by comparing the estimates of 2+ fish in the lake with the estimated number of 3+ fish returning to spawn in 2009. If trawl biases in 2008 are found to be unacceptable then some further refinements to the methods and assumptions for estimating biomass will need to be made. Possibly more reliance on acoustic size distributions would produce more reliable estimates of age structure and in particular the abundance of age 2+ fish.

Fry-to-Adult Survival Rates

There are a number of trend indicators that can be used to determine the response of nutrient addition on the lakes' kokanee population. Although the most convincing data is the biomass estimates shown in Figure 5.16, fry-to-adult survival rates can also provide insight into conditions in the lake. High survival rates usually following a period of low fish abundance in the lake while low survival rates suggest either high in-lake abundance or unproductive growing conditions in the lake. Estimates of fry-to-adult survival rates have been determined using long-term data from Meadow Creek. There are some limitations on this methodology due to accuracy of the data such as fry estimates but also adult counts, particularly below the spawning channel in Meadow Creek. However, it is felt that such estimates are useful because the data have been collected in a consistent manner using the same methods over a long period of time. It is therefore acknowledged that these estimates may not be accurate but consistency in data collection allows for adequate trend information. The assumptions include:

- one dominant age at spawning (i.e., age 3+);
- minimal harvest that does not appreciably influence escapement levels;
- predation is constant;

- natural stream egg-to-fry production of 5–10% used for fry estimates above and below the Meadow Creek spawning channel.

Age data from the trawl samples and spawners support the assumption that the majority of fish mature at age 3+. Therefore, fry-to-adult survival rates have been estimated on the basis of age 3+ at time of spawning. Even if these fish spawned as a mix of ages such as in 2007 or at a different dominant age (e.g., at age 2+), the long-term trend of calculated fry-to-adult survival rates would illustrate a similar pattern even though a few specific years may not be accurately represented (Schindler et al. 2010a). Note: in Arrow Lakes Reservoir, the age at maturity was more variable than in Kootenay so a more refined approach was required to get reliable estimates of fry to adult survival. This approach could also be applied to Kootenay in future.

The most recent spawners returning in 2007 and 2008 were primarily the progeny of parents from the 2003 and 2004 spawning years. In 2003, an estimated 0.86 million spawners returned to Meadow Creek and deposited ~57 million eggs in the system which produced ~15.7 million fry. These fry returned as 0.39 million spawners; therefore, the fry-to-adult survival for this cohort (2003–2007 cycle) was only 2.5% (Fig. 5.17). In contrast the 2004 spawners were far greater in number (>1.0 million), produced 26.3 million fry and most returned four years later as 0.94 million spawners resulting in a 3.6% survival rate. Spawner returns in 2006 and 2007 were lower than expected. This may be linked to the unusual kokanee distribution during the summer of 2005 when crowding into the North Arm nutrient addition zone may have resulted in higher than average predation.

In Kootenay Lake, the fry to adult survival does not have a strong relationship to overall fry production levels as observed for the nutrient addition period in Arrow Lakes Reservoir (Sebastian et al in Schindler et al. 2010b) (Fig. 5.18). There are clearly factors other than kokanee density affecting survival rates in Kootenay Lake. However, in general, the average survival rate of ~6.5% in the four years prior to fertilization during a period of low abundance in the lake were higer than the survival rates of < 4% during the 2000s when kokanee abundance has been high. The average survival rate since fertilization began was ~5%, while some historic data from the 1970s indicate the survival rate may have been much higher at ~12% during the eutrophication period.

Recruit-Spawner Relationship

The relationship between parents and offspring over a number of generations provides some valuable insights into how kokanee respond to large-scale changes in productivity. A generalized stock-recruitment relationship can be generated from the Meadow Creek spawning channel data based on 37 years of relatively consistent enumeration. This analysis again assumes that the dominant age of spawners has been 3+ and that the sport catch has been minimal. Escapements to Meadow Creek from 2004-2006 exceeded their parental numbers thus replacement levels have been > 1.0 (Fig. 5.19). In 2007 and 2008 the recruits did not equal parental numbers indicating a declining population. This is similar to the results during the 2000–2003 escapement years (i.e., fewer recruits than spawning parents). In both these instances the lower than expected adult returns can be traced back to lower than average fry numbers in the late summer three years previous (Fig. 5.12, 5.18).

The trend in the recruit-spawner relationship for the Lardeau River for years when data are available (data on file, MOE, Nelson BC) follow a similar pattern to that noted for Meadow Creek. The Lardeau River data interpretation is based on a single count and is subject to many sources of error. Nonetheless the Lardeau data tracks Meadow Creek data as can be seen in Figure 5.18. Since nutrient additions began, replacement levels were achieved in all years except those that grew in the lake when nutrient additions were deliberately reduced (1997-2000). Similar to Meadow Creek recruit numbers in 2007 did not equal their parental numbers however in 2008 Lardeau recruits did exceed their parental numbers whereas Meadow Creek recruits did not.

Discussion

Major changes to Kootenay Lakes' productivity have been the subject of a number of publications over the last four decades. A series of investigators including Northcote (1973), Daley et al. (1981), and Ashley et al. *in* Murphy and Munawar (1999) and Schindler et al. (2009a; 2010a) have all described various impacts to the lake that have been reflected in fish production. During the last half century there have been four significant perturbations affecting lake productivity: eutrophication during the 1960s, oligotrophication during the 1970s, ultra-oligotrophication during the 1980s followed by a return to productive oligotrophy since 1992 i.e., the nutrient addition era. This report provides several lines of evidence that lake fertilization since 1992 has increased the abundance and biomass of main lake North Arm kokanee by a minimum of twofold. It is too early to determine if South Arm kokanee have benefitted but some of the 2008 results were encouraging.

Escapements

The long term monitoring of North Arm kokanee spawner numbers at Meadow Creek and Lardeau River combined with some South Arm tributary spawner data has been invaluable in determining the success of Kootenay Lake fertilization. North Arm of Kootenay Lake nutrient additions have now been underway for seventeen years and South Arm for the last five years that combined have evolved into a highly successful restoration program. The long-term and continuous escapement and fry production estimates from Meadow Creek provide the opportunity to evaluate numerical and biological responses of kokanee to nutrient addition. Since 1967 the spawner returns to Meadow Creek have ranged from 0.2 to 1.4 million fish (Fig. 5.2). After nutrient additions commenced in 1992 there was evidence that kokanee were responding positively. Total in-lake abundance increased from ~10 million to ~35 million from 1992–1994. By 1996, escapements to Meadow Creek exceeded one million, a level not experienced since the late 1970s. There was a decrease in spawner numbers in the early 2000s followed by three years of escapements close to one million (2003-2005) and then numbers < 0.5 million in 2006 and 2007. In 2008 the escapement increased to nearly one million. The increases during 2003-2005 were anticipated based on high fry production from Meadow Creek during the early 2000s and from the 2002 to 2004 hydroacoustic surveys that indicated high abundance of age 1–3+ fish (Fig. 5.12). Low in-lake abundance estimates in 2004 and 2005, and particularly for the age 1-3+ group in 2005 foreshadowed the lower escapements in 2006 and 2007. The 2006 and 2007 surveys indicated strong 0+ cohorts and some improvement in the age 1-3+ and these data correctly foreshadowed increased spawner numbers in 2008. The Lardeau River escapements have also shown large fluctuations historically of 0.1 to 3.0 million since 1964. Escapements averaging 0.2 million during the 2000s however have remained lower than historic levels which averaged 0.6 million (pre-1980's). In 2008 however the estimate of 0.41 million was the highest since 1999. Growing conditions have greatly improved during the last two decades therefore it is most likely that lower Lardeau River egg-to-fry survival rates account for the lack of significant increased escapements compared to Meadow Creek.

South Arm fertilization commenced in late 2004 in a joint effort by the BC Ministry of Environment, the Kootenai Tribe of Idaho (KTOI), Bonneville Power Administration (BPA) and Idaho State Fish and Game to restore South Arm kokanee spawners. This work had been planned for a number of years as described by Anders et al. (2004). Key strategies include: increasing lake productivity through nutrient additions, extensive kokanee eyed egg plants and stream restoration activities to improve kokanee spawning habitat. Unlike the initial response of increased numbers of kokanee to the 1992-1996 fertilization experiment in the North Arm (Ashley et al. 1997) and Arrow Lakes Reservoir (Schindler et al. 2010b) there has been little evidence that five years of South Arm fertilization has resulted in similar increases in kokanee spawner numbers to South Arm streams. This is not surprising since few if any South Arm fish exist and those that do persist are vastly outnumbered by the millions of fry and juvenile fish of Meadow Creek origin. Realistically it should not be expected to see any immediate kokanee response to South Arm fertilization since there has been virtually no spawners in BC's South Arm tributaries for well over two decades (Andrusak and Sebastian 2009). Appreciable numbers of eyed eggs were only planted in these streams starting in 2005 therefore earliest returns from these introductions wouldn't occur until 2008 or later.

There is some evidence that the eyed egg plants have been successful in Idaho as spawner numbers increased in 2007 and 2008 well beyond any counted in the previous twenty five years (Erickson et al. 2009). However, there is still some uncertainty even with these encouraging returns since it is possible that juvenile kokanee entrained at Libby Dam may be the source of these recent spawner returns. The unusual high numbers of age 0+ detected during the September 2008 acoustic survey (Fig. 5.12) only adds to this uncertainty. Whilst the evidence is inconclusive that South Arm kokanee have increased due to South Arm fertilization, the monitoring results of lower trophic levels indicate South Arm productivity has improved since fertilization began as evidenced through increases in phytoplankton and zooplankton biomass (see Chapters 3 and 4 in this report).

Meadow Creek Fry Production

The Meadow Creek spawning channel represents the engine that drives the entire lake ecosystem. It produces by far the majority of kokanee fry for the lake, supports the largest number of spawners and is the primary egg collection site for the province that include those eggs planted in the South Arm and Idaho streams. Fry production estimates at this spawning channel provides an outstanding long term data set that indicates from the late 1960s through to the early 1990s annual production ranged from 1.4-15 million and averaged ~5 million fry annually (Fig. 5.5). No monitoring occurred from 1979-1984 but thereafter fry production was determined to be especially low in the late 1980s ranging from approximately 2.3–7.4 million. Major channel renovations in the late 1980s improved channel performance (Redfish Consulting Ltd. 1999) resulting in increased fry production of 7–30 million in the 1990s and 2000s. In the last 10 years production has ranged from ~13-25 million. In concert with improved channel performance was the commencement of lake fertilization that initially resulted in improved in-lake kokanee growth and survival. The relationship between egg deposition and fry production shown in Figure 5.6 is linear (R^2=0.76) suggesting that maximum fry production has yet to be achieved since maximum egg deposition has not yet been defined. Experimentation with spawner numbers in the channel should continue toward defining the optimum number of fish that should be permitted to spawn in the channel to achieve maximum fry production.

South Arm Fry production

Comparison of the longitudinal kokanee density distributions between early summer and fall surveys in Figure 5.15 indicate that abundant North Arm fry aggregated in the vicinity of the North Arm fertilization zone (i.e. acoustic transects 1-4) during July had typically moved southward and redistributed themselves over the entire lake including in the South Arm over the summer period (i.e. prior to fall assessment). The origin of the early summer South Arm fry remains in doubt. Although their slightly larger size supports the argument that they are not likely to be from Meadow Creek, the numbers captured by trawling were too low to confirm any statistically significant differences with North Arm fry. It is most likely that these are comprised of a few progeny from South Arm tributaries combined with entrained kokanee from Koocanusa Reservoir. The larger size may be attributable to reportedly good rearing conditions in the fertilized Kootenai River although this remains speculative. Attempts to quantify South Arm fry numbers early in the season using acoustic surveys has been challenging. Acoustic fry densities were typically low and highly variable between depth layers and transects. This “patchy” fry distribution and low number of transects (n=7) has led to fairly poor precision of these estimates. Increasing the number of transects is not an option, since the short nights in early July combined with unsettled weather conditions make the current level of sampling difficult to maintain. Despite the low precision, the estimates of 1.4-3.8 million fry for the South Arm does indicate a significant source of fry that cannot be explained through current adult spawner counts and fry from egg plants in South Arm tributaries, so does support the notion of significant recruitment through entrainment from Koocanusa.

Other problems with early season fry assessment include the potential for interference from abundant *Mysis* shrimp due to the small size of fry in July, and the lack of distinct size modes between fry and older fish due to their low numbers. Recently acquired software enables higher resolution of size separation (e.g. assessment by 1dB size increments compared with 3dB increments used previously) and will assist in fine tuning both the upper size cut-off between fry and older kokanee and the lower end cut-off between fry and *Mysis* shrimp. In addition, the new software has improved capability for editing out “noise” and partitioning transects to increase the sample size. It is hoped that these improvements will lead to better precision in the early season fry abundance estimates and improve our ability to detect changes.

Since 2005 the mean size of Meadow Creek spawners has been increasing with a slight decrease in 2008 however it is recognized that this has been a whole lake density dependent growth response by North Arm kokanee rather than a response that can be attributed to South Arm fertilization. In-lake abundance, particularly during 2004 and 2005, was comparatively low (Fig. 5.11) when growing conditions were evidently good, and resulted in size increases for age 1-3+ fish similar to what occurred during initial years of North Arm fertilization. Arguably growing conditions in the South Arm have improved since 2004 due to nutrient additions but there is no clear evidence that the observed size increases from 2004-2007 were due solely to South Arm fertilization. In-lake abundance is again increasing thus size in 2009 and 2010 should decline.

Fall acoustics data for the last three years indicated that greater numbers of kokanee were present in the South Arm compared to the North Arm. Presumably this meant good growing conditions existed thus attracting fish to move into the south basin. While this movement could be interpreted to be a response to South Arm fertilization it should be noted that such southern movements have been observed a number of times prior to 2005 (data on file MoE Victoria BC). i.e. southward movement cannot be attributed to South Arm fertilization alone.

Biological Responses to Lake Fertilization

Some complex changes in Kootenay Lake kokanee size and numbers have occurred over the last three decades largely as a result of responses to varying levels of nutrient input. Prior to nutrient additions, numbers of kokanee, mean size, and fecundity had all declined (Figs. 5.2, 5.4, 5.11). These downward changes triggered the fertilization experiment as it was quite evident that decreased lake productivity predicted by Daley et al. (1981) was real and threatened the entire ecosystem, especially kokanee and their large predators (Ashley et al. 1997). Shortly after nutrient addition began, the mid-1990s kokanee numbers increased as well as their mean size and fecundity. There is little doubt these changes occurred due to low numbers of kokanee in the lake growing in an enriched system; by the late 1990s, spawner numbers were again >1 million. Mean size and fecundities then decreased from 1996–1999 suggesting a density-growth response due to large numbers of fish produced by the 1992–1996 spawners. With spawner numbers falling during 2000-2003, fecundity and spawner length increased; spawner numbers declined despite good fry production levels primarily due to decreased fertilizer loads from 1997–2000. During all these changes to Meadow Creek kokanee there continued to be no response by South Arm kokanee. i.e. no spawners.

Spawner size and fecundity had declined from 2003-2005 reflecting a density-growth response as the age 1-3+ population increased following a return to full nutrient loading levels starting in 2001. The acoustic data however shows an unexpected decrease in late summer fry populations in 2004 and 2005 despite average fry production from Meadow Creek in 2004 followed by relatively high fry production in 2005. This suggests that fry survival over the summer was lower than average, particularly in 2005 which was considered an outlier. Potential causes of low fry survival in 2005 are discussed below under the subheading "*In-lake abundance and biomass*". Meadow Creek fry production during the last three years has been average or better and the relation between fry production at Meadow Creek and late summer fry has returned to the more typical relationship (see Fig. 5.13). The increased fish size and fecundity observed in the 1990s and 2000s has been expected to decline and stabilize close to the long-term average as the abundance of kokanee reaches lake carrying capacity. While this prediction is still held, it is evident that some in-lake survival problems at least during 2004 and 2005 have caused a delay in reaching a more stable state. An increase in total in-lake abundance over the last three years should lead to larger returns of smaller sized kokanee over the next few years, similar to the response observed in the mid 1990s.

Variations in age at maturity have occurred during lake fertilization due to density dependent growth responses as lake productivity has fluctuated. The most common age of North Arm kokanee spawners has been age 3+ (Vernon 1957). As the lake became less productive in the 1980s Martin (1984) reaffirmed that most North Arm kokanee spawn at age 3+. However, once fertilization began Thompson (1999) observed a shift in age-at-maturity of Meadow Creek fish during 1993–1996. She confirmed the dominant age-at-maturity remained age 3+ from 1989–1992 but also found that 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 significant changes to lake productivity that occurred at the time these cohorts were growing in the lake. Increased growth can result in a shift to earlier maturation. Conversely during a period of declining lake growing conditions, such as occurred prior to fertilization and to a lesser extent during reduced fertilization combined with high in-lake abundance in 1997-98, it is not surprising that kokanee shifted back to entirely age 3+ at maturity. In Buck Lake (California) where kokanee numbers increased and growth decreased, size at maturity decreased followed by delay in maturation from age 2+ to age 3+ (Grover 2005).

The accelerated growth and earlier age of maturation noted by Thompson (1999) in the early 1990s was likely due to a combination of low kokanee densities and initial high growth in response to lake fertilization. Similar conditions occurred again in 2001 when nutrient additions were restored and the number of age 1-3+ kokanee was low. This again led to a mix of age 2+ and 3+ spawners returning in 2001 and 2002. By 2003-04 the age of Meadow Creek kokanee was determined to be age 3+. With an unexpected decline in abundance and biomass during 2004 - 2006 growth increased in 2005-2007 resulting again in some fish returning at age 2+ in 2006 and 2007. As in-lake abundance continued to increase during 2007-2008 the size of Meadow Creek spawners has begun to decrease. Based on the length frequency of trawl caught fish and length frequency and limited otolith analyses of the spawners it appears most 2008 spawners were again age 3+.

Mean size-at-age of trawl caught kokanee provide an excellent record of how each age group has responded to fertilization and variation in loading rates. Ashley et al. (1997) initially pointed out that growth of fry and 1+ fish had not changed appreciably since the fertilization experiment began. This remains the case for fry with little size variation evident before and after fertilization (Fig. 5.8). Age 1+ kokanee mean size also does not show any real change before and after fertilization but variation in their size is evident and there appears to be density dependent growth some years. Lake nutrient addition and variations in nutrient loading rates have positively impacted size and growth of the 2+ and 3+ fish. Generally, when the number of age 1-3+ fish increased, the mean length of age 2+ fish declined. Spawner sizes most often followed the trend in age 2+ size but a year following. For example, the acoustic data for 2004 and 2005 confirmed lower abundance of fry which translated to lower numbers of age 1-3+ fish in 2005-06. The average size of age 2+ fish reached a peak in 2006 and the age 3+ spawners in 2007 were the largest on record at 279 mm. The 2006 and 2007 abundance data foreshadows larger escapements in 2008 and 2009 of smaller spawners. These changes did occur in 2008. The trawl and acoustics data combined with spawner size data demonstrates that ages 2+ and 3+ fish in terms of growth appear to benefit the most from fertilization.

Crude estimates of fry-to-adult survival rates have been calculated for Meadow Creek kokanee to provide supporting evidence and a greater understanding of how kokanee have responded to lake fertilization. Derived Meadow Creek fry-to-adult survival rates were comparatively high during the early 1970s. 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 (Northcote 1973; Daley et al. 1981). A major perturbation occurred when the Duncan Dam became operational in 1967 blocking very large numbers of spawning kokanee (>1 million, Bull 1965), resulting in limited spawning success. At that time the lake would have been highly productive (Northcote 1973) but it likely received only one half the former numbers of kokanee fry due to the loss of Duncan River kokanee production. In addition, the Meadow Creek spawning channel did not produce large numbers of fry during its initial years of operation [late 1960s and 1970s]. These conditions likely account for the estimated high fry-to-adult survival rates during that era. No fry production estimates were made during most of the 1980s, but low in-lake survival rates were probably prevalent by the late 1980s and early 1990s as evidenced by declining escapements reflecting the period of reduced nutrient levels (Daley et al. 1981; Ashley et al. 1997). With nutrient addition starting in 1992 higher survival rates were evident (1992-1994) followed by decreasing rates through to 2002. High fry-to-adult survival rates usually occur during a period of low abundance in the lake with good growing conditions e.g. an abundance of food due to fertilization. It is also possible to have high survival rates with an abundance of kokanee under good growing conditions. This is the ideal scenario but seldom achieved or sustained. Low survival rates suggest either high in-lake abundance plus favorable food conditions or in many ultra-oligotrophic cases low in-lake abundance and unproductive growing conditions. Low survival rates are often followed by increased kokanee abundance if lake growing conditions are favorable.

Since 1995 comparatively low survival rates generally reflect good growing conditions and moderate to high abundance of kokanee owing to lake fertilization. If an objective of lake fertilization is to achieve high spawner returns, then lower fry-to-adult survivals are an expected and desirable outcome. For example the high survival rate calculated for 1994 was a result of fewer fish in the lake during 1989-1992, especially 1991. The lower rates from 2000-2002 were the result of greater spawner numbers during 1996-1999. The 2006 and 2007 survival rates represent the lowest rates in three decades following high spawner escapements and fairly high fry production from 2003-2005. The 2008 survival rate did increase but still remained below the long term average. It is speculated that if growing conditions remain favorable these low rates should be reflected in higher spawner numbers in 2009 and 2010.

The lake productivity changes that have occurred over the last half century appear to track reasonably well with the North Arm kokanee recruit/spawner relationship. Through most of the 1970s, replacement levels (recruits at least equal to parental numbers) were achieved when the lake was in a highly productive state but the spawning channel was producing comparatively low fry numbers, certainly less than the production lost due to Duncan Dam. During this period, all of the kokanee cycles (four year) replaced themselves. The end of the 1970s through to the late 1980s was a period when replacement levels were not attained, probably for two very different reasons. First, 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 (Binsted and Ashley 2006). Second, spawning channel production was slowly increasing but total in-lake abundance was in decline due to loss of Duncan River production. Meadow Creek kokanee continued to grow reasonably well at average size but fairly low fecundity. For a short period of time Meadow Creek kokanee production increased even though lake productivity was declining and there were a few cycles in the mid 1980s that actually replaced themselves despite declining lake productivity. By the late 1980s and early 1990s the lake had become extremely unproductive and escapement levels fell to record lows with four successive kokanee cycles failing to replace themselves. With nutrient addition starting in 1992 there has been a fairly rapid recovery of kokanee with recruits exceeding parental numbers for two consecutive cycles (1992–1999). Deliberate reduction of nutrient loading resulted in low escapements from 2000-2002 with the recruits< parental numbers. The recruit:spawner ratios for Meadow Creek from 2001–2003 were the lowest recorded since 1989, with the 2002 return the lowest on record since fertilization began (Figs.5.2, 5.18). With full nutrient loading resumed in 2001 the in-lake abundance estimates increased by 2001 and 2002. Escapements increased from 2003-2005 with replacement levels exceptionally high. The unexplained decline in fry and subsequent age 1-3+ during 2004 and 2005 resulted in the 2002-2006 cycle barely replacing itself and the 2003-2007 cycle fell below replacement. The 2004-2008 cycle improved but recruits were still lower than parental numbers. The Lardeau River 2004-2008 cycle did however improve and exceeded the replacement level.

In-Lake Abundance and Biomass

Initially North Arm kokanee responded very rapidly to nutrient addition, especially ages 2 and 3s. Increased lake productivity during the mid 1990s combined with low in-lake numbers, resulted in better growth , a doubling of average fecundity that resulted in record numbers of fall fry (>30 million) by 1994. Fry-to-adult survival increased from about 5% to > 10% by 1994, and then declined to <3% by 2002, followed by higher survival from 2003-2005 before decreasing to < 4% by 2008 (Fig. 5.17). As the number of spawners peaked in the late1990s, spawner size, fecundity, and fry-to-adult survival rates all declined, indicating a strong density-dependent response. The adaptive management adjustment of reducing the experimental nutrient load from 1997 to 2000 had an equally but opposite impact on kokanee abundance as the whole lake population declined to near pre-fertilization levels from 2000 to 2002 (Figs. 5.11, 5.12). As the fertilizer loadings were increased back to the 1992-1996 rates in-lake abundance again increased. During this time the fry-to-adult survival rates increased for two years since in-lake abundance was low(er) leading to a recovering of the in-lake population. Unfortunately an unexplained decline in fry survival and numbers in 2004 and 2005 translated to a decrease in spawner numbers in 2006 and 2007 before an improvement in numbers in 2008.

Throughout the fertilization period there have been some anomalies with the kokanee data that don't reflect "text book" bottom up trophic responses. Total kokanee abundance in 2004 (Figs. 5.11, 5.12) based on the acoustics survey was much lower than expected at about 16 million, and was only partly attributed to lower fry production from Meadow Creek in spring 2004 (Fig. 5.5). The relationship between acoustic late summer fry abundance and Meadow Creek fry production has been quite strong (Fig. 5.13; R^2=0.80). At that time the 2004 data were not considered unusual and could possibly be attributed to delayed density-dependence mortality (or inter-cohort density-dependence mortality) which has been proposed as the cause of sockeye cyclical patterns of dominance (Myers et al. 1997, Ricker 1997, Myers 2001). Levy and Wood (1992) referred to "brood interactions" which cause reduced survival in year class(es) that follow the dominant line. The most likely mechanism for this reduction is competition for food, in which the stronger year class consumes sufficient prey and impacts the following year class. However when the 2005 acoustics data also indicated very poor summer survival of fry, despite good fry production, the 2005 data point was definitely considered a significant outlier (Schindler et al. 2007). Despite no obvious change in phytoplankton or zooplankton in 2005, almost 25 million fry produced from Meadow Creek were reduced to only half by the end of the summer, a far greater mortality than expected based on the relationship between Meadow Creek fry and fall fry estimates from hydroacoustic surveys. Interestingly, the longitudinal distribution of fry in 2005 determined by the acoustic survey in September (Fig. 5.15) was very unusual, with the majority of fry remaining in the northern end. i.e. no typical movement to the southern part. It is possible that these high fry densities in a small portion of the lake were subjected to unusually high predator mortality. Two other years, 1993 and 2001 (data on file) also showed similar aggregations of kokanee fry in the North Arm fertilization zone into the fall, and both occurred when populations were building in response to a change in nutrient regimes. The difference was that 1993 and 2001 showed average or higher fry survival over the summer period. It is possible that a top down impact accounts for these anomalies thus it is important in future to assess predator population size and diet. Since 2005 acoustic surveys estimated increased fry numbers and there was again a good relationship between fry produced and the fall estimate (Fig. 5.13). The 2004 and 2005 anomalies are difficult to explain but the impact of such lower than expected fall fry numbers appear to have resulted in some compensatory growth and survival as evidenced by early maturation of age 2+ fish in 2007. Based on length frequency data it appears age of the 2008 spawners has reverted back to dominance of age 3+ as the in-lake abundance has increased.

Estimation of kokanee biomass before and after lake fertilization provides the most convincing evidence of successful bottom up transfer of nutrients. There has been nearly a threefold increase in kokanee fall biomass or standing crop (measured in the lake) from 3.5 $kg{\cdot}ha^{-1}$ to 9.5 $kg{\cdot}ha^{-1}$ since fertilization began. The biomass of kokanee spawners which had left the lake just prior to fall acoustic estimates should also be included in order to estimate the maximum standing crop for each year. The increase may have been even greater were it not for the deliberate reduction in loading rates in the late 1990s which resulted in lower biomass estimates for at least two years (2000 and 2001). The biomass estimates in 2005 and 2006 decreased to 10-12 $kg{\cdot}ha^{-1}$ due to lower numbers of age 1-3+ fish following two lower fry survival years in 2004 and 2005. Biomass increased to 15.3 $kg{\cdot}ha^{-1}$ in 2007 but declined slightly in 2008 to 11.5 $kg{\cdot}ha^{-1}$. There has been no incremental increase in biomass since South Arm fertilization began most likely because so few South Arm kokanee contribute to the overall numbers.

Piscivore Response

The reliance by the top predators-Gerrard rainbow trout (and bull trout) - on kokanee is well known (Andrusak and Parkinson 1984), and for this reason, the nutrient restoration program has been aimed at increasing kokanee numbers to ensure conservation of these top predators. Andrusak and Andrusak (2006) reported that the condition and growth of sport-caught rainbow trout in 2004 had vastly improved compared to data analyzed from the 1960s and 1980s. Spawner counts in the Lardeau River at Gerrard BC for the last four years have been well above the 41-year average (data on file, MOE, Nelson BC). However anglers reported a substantial decline in large size rainbow catch in 2007 and 2008 with an overall decrease in size (KLRT data on file MoE Nelson). At the same time anglers also report an upturn in catch and success rates of smaller rainbow trout and bull trout, with this opinion supported by the annual Kootenay Lake angler survey results (data on file, MOE, Nelson BC). Growth rates and age-at-maturity of Gerrards require close examination.

Given all of the recent changes described here, it is quite possible that the predator populations have increased to the point where they are imposing heavy predation on the kokanee, especially the older kokanee, and that predation now regulates kokanee abundance as much as lake productivity. This “top down” effect by predators has been described by a number of authors (Carpenter et al. 2001, Hyatt et al. 2004, Perrin et al. 2006) and may partly explain why the acoustic data shows slightly lower estimates in recent years during lake fertilization despite high fry production levels from Meadow Creek. All of the above reinforces the need to continue to monitor all trophic levels including the highly valued piscivores.

Summary

The wealth of information gathered on Kootenay Lake over the course of the nutrient addition project points to a highly successful program. Kokanee biomass has increased, spawners have once again reached near record numbers, mysid numbers have remained constant if not slightly lower and there is growing evidence that Gerrard rainbow trout and bull trout are benefiting. Further, beneficial results due to fertilization of the South Arm should become more evident in the near future and the monitoring work should prove to be invaluable in determining how successful this restoration work has been.

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Don Miller and staff of Kootenay Wildlife Services Ltd conducted trawling and biological sampling while hydroacoustic surveys were conducted by George Scholten and David Johner of MOE, Victoria. Scale analyses were done by at MOE's Abbotsford Lab by Emma Jane Johnson and spawner otolith analyses were done by Carol Lidstone of Birkenhead Scale Analyses, Lone Butte, BC.

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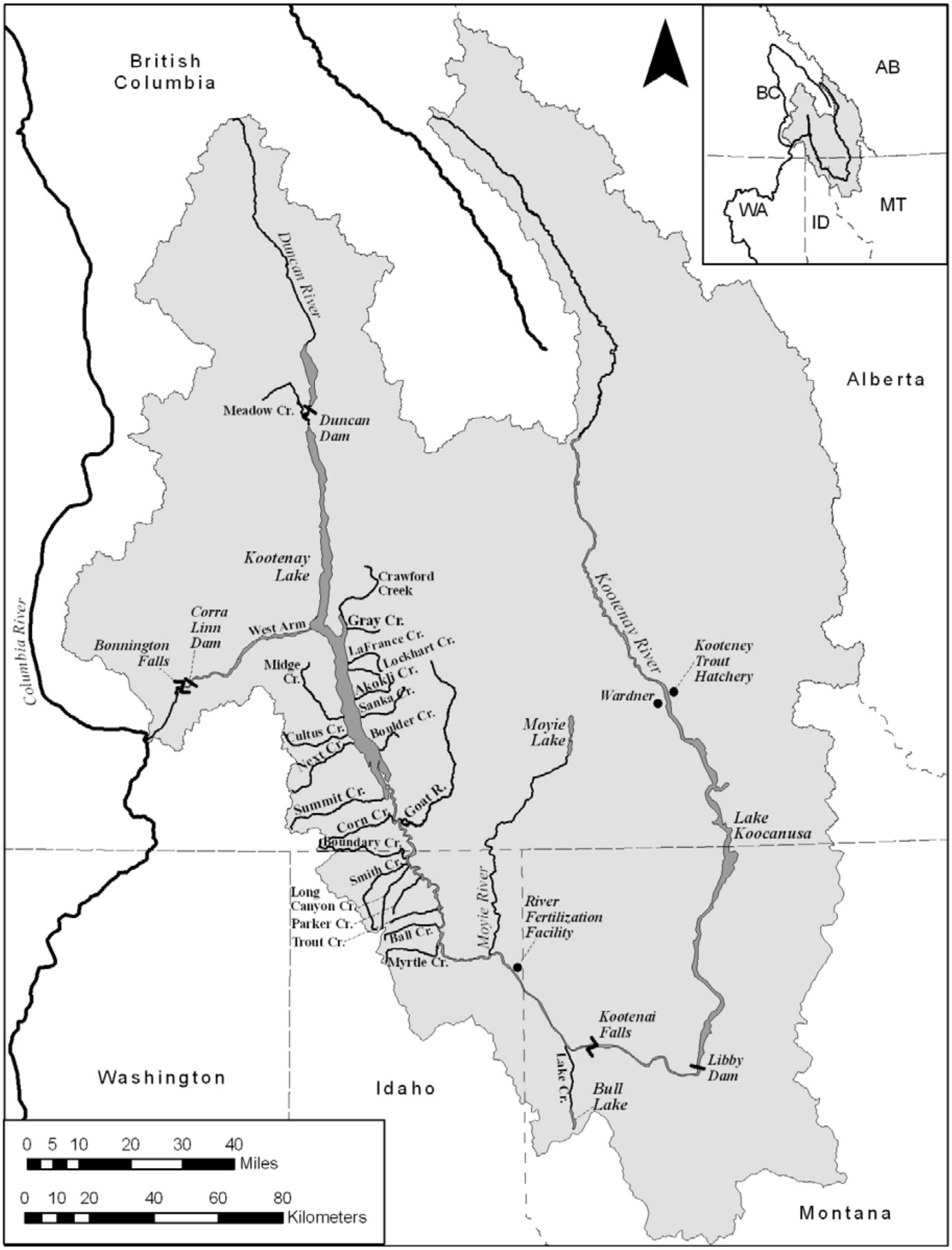


Figure 5.1. Map of the Kootenay River Basin in British Columbia, Montana, and Idaho showing South Arm tributaries (adopted from Ericksen et al. 2009).

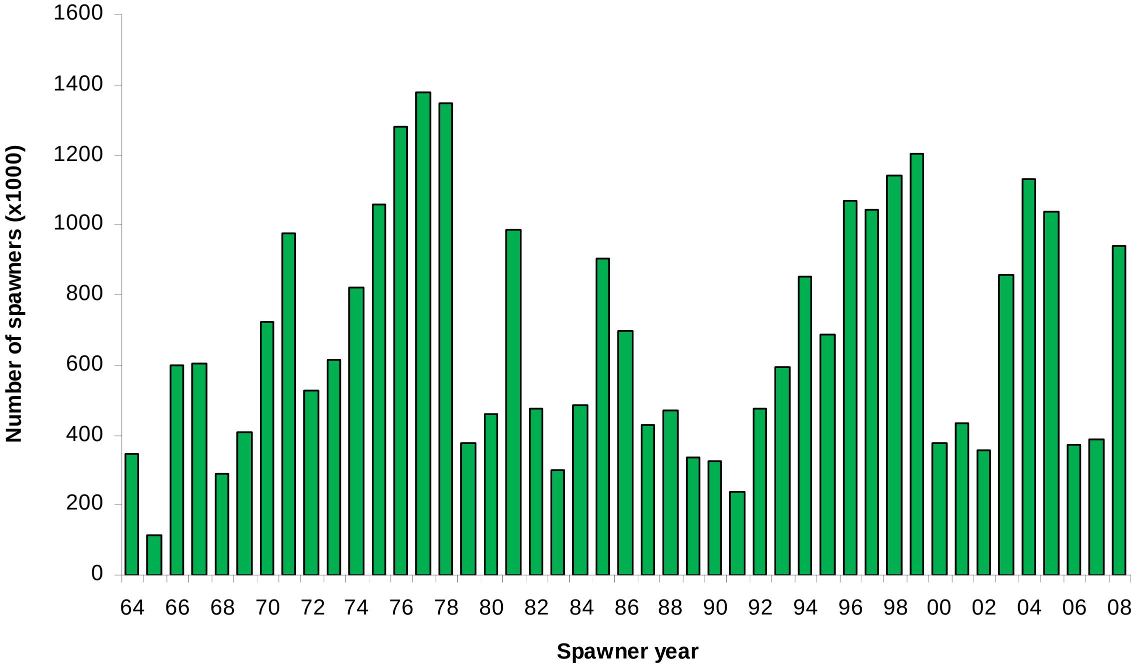


Figure 5.2 North Arm of Kootenay Lake kokanee escapements to Meadow Creek 1964-2008. (Note: 1964-1968 data from Acara 1970 unpubl. MS).

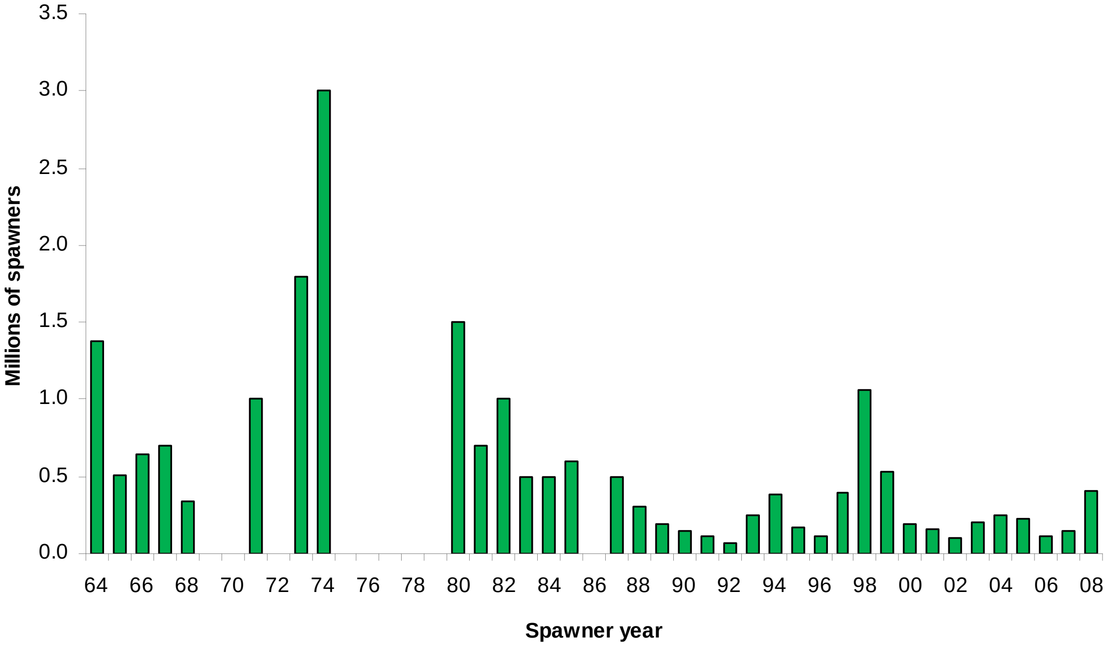


Figure 5.3 North Arm of Kootenay Lake kokanee escapements to Lardeau River for the years surveys were conducted 1964-2008. (Note: 1964-68 data from Acara 1970 unpubl. MS).

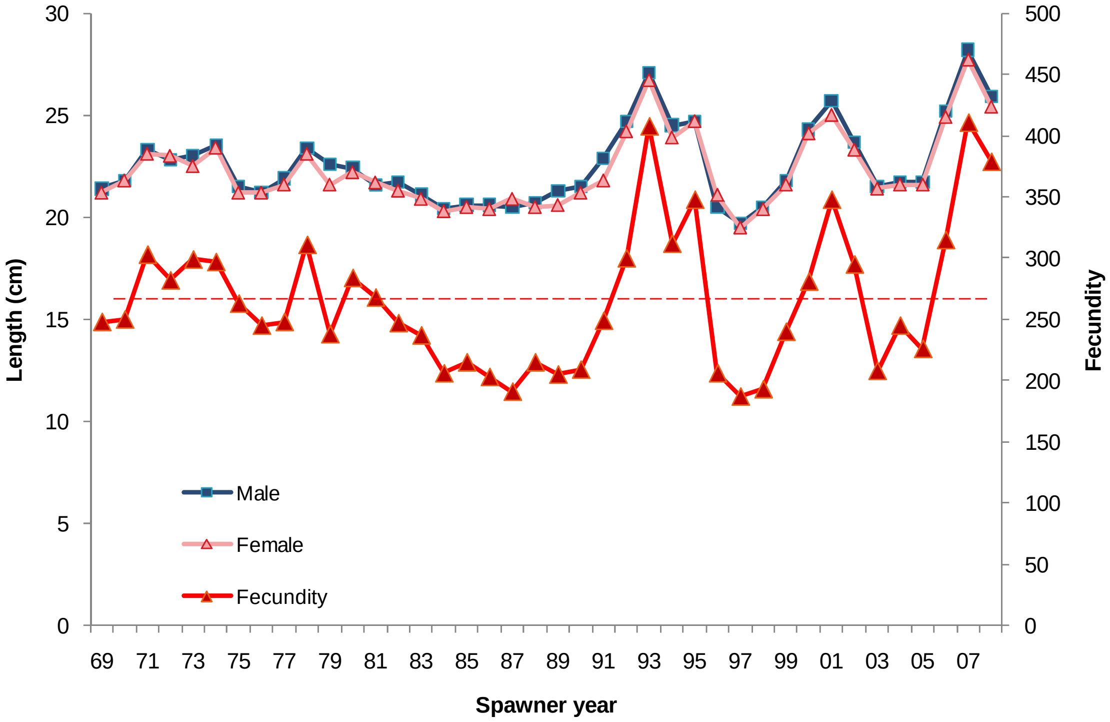


Figure 5.4 Mean length of Meadow Creek female and male kokanee spawners and mean fecundity, 1969-2008. Dotted line illustrates average fecundity of 265 eggs per female.

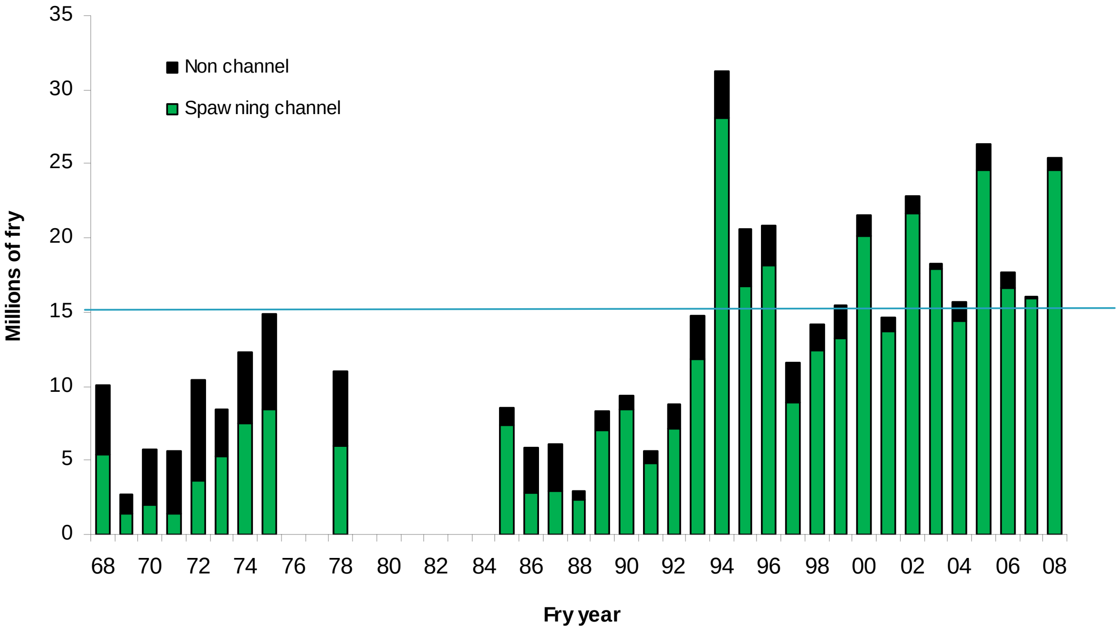


Figure 5.5 Meadow Creek kokanee fry production from the spawning channel and areas upstream and downstream of the channel 1968-2008. No data 1976-1984 except for 1978.

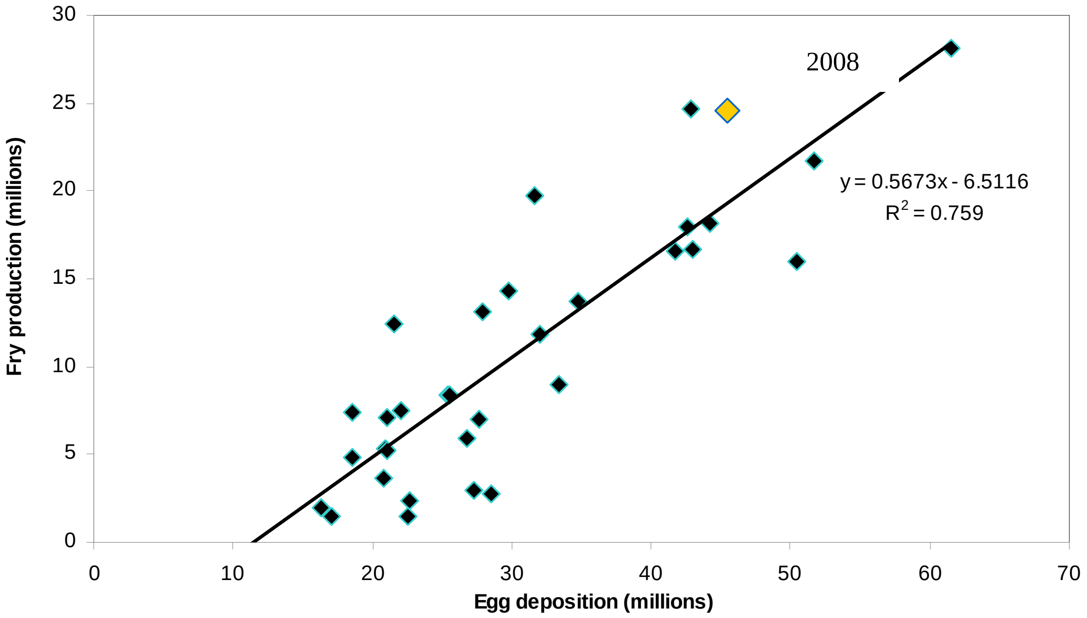
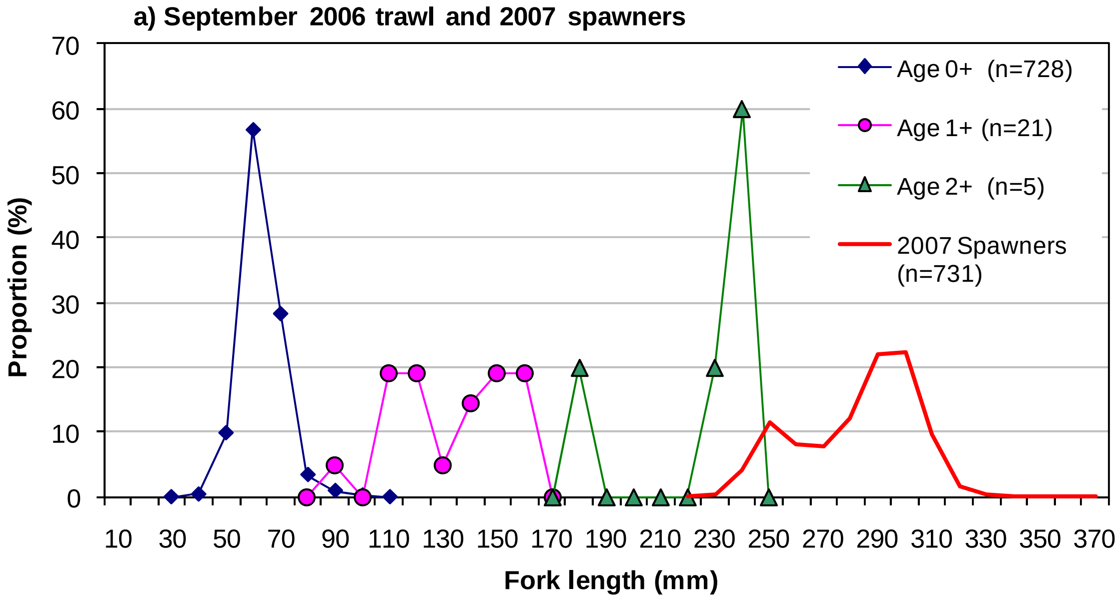


Figure 5.6 Scatter plot of Meadow Creek spawning channel egg deposition vs. fry production for years where data available 1968-2008.



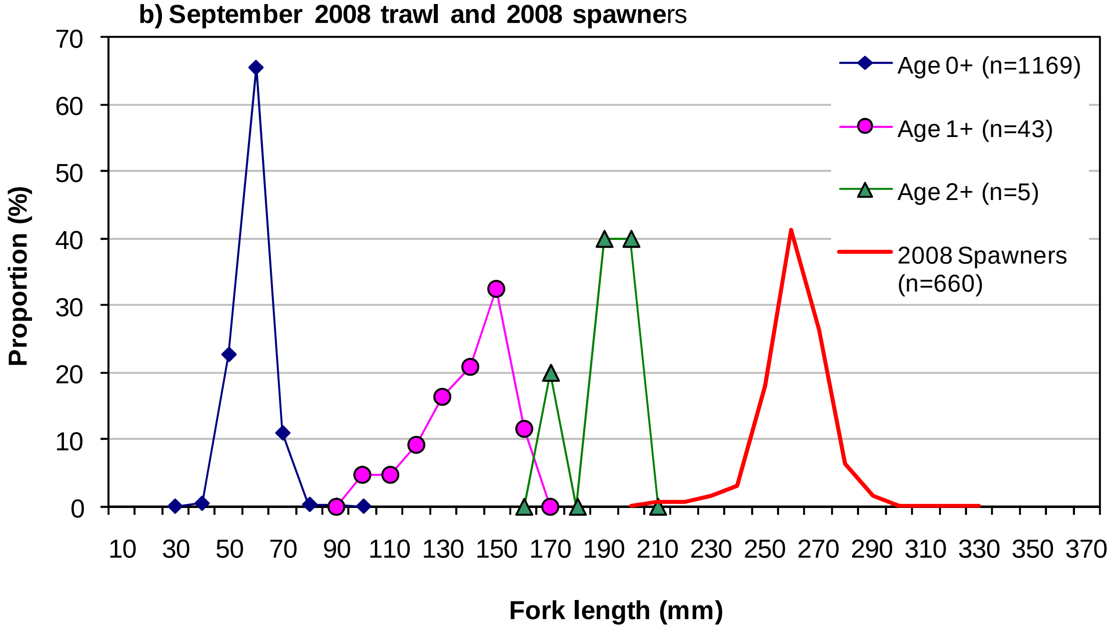


Figure 5.7 Kokanee length frequency distribution by age for a) 2006 trawl captured kokanee with 2007 Meadow Creek spawners and b) 2008 trawl captured kokanee with Meadow Creek 2008 spawners.

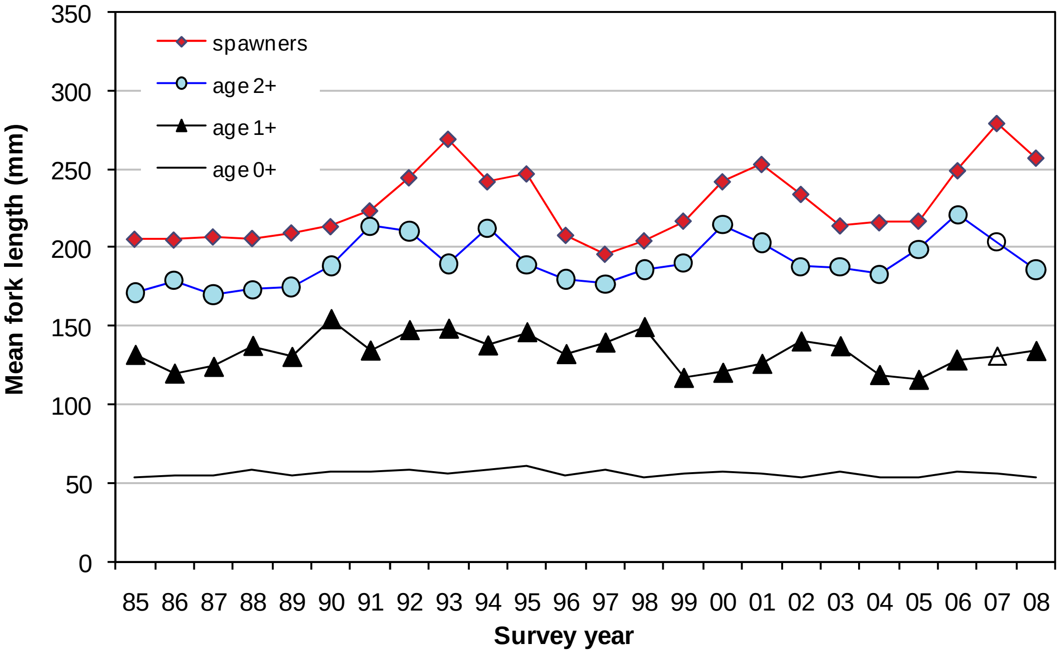


Figure 5.8 Trends in mean length-at-age for trawl captured Kootenay Lake kokanee 1985-2008. Mean size of spawners are lengths obtained from Meadow Creek kokanee.

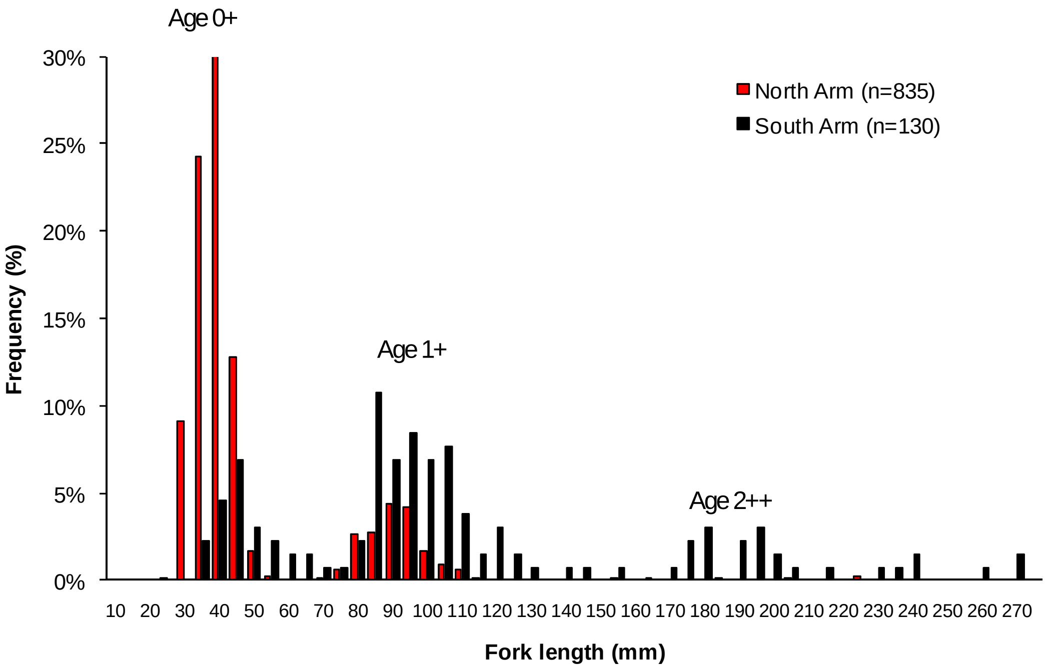
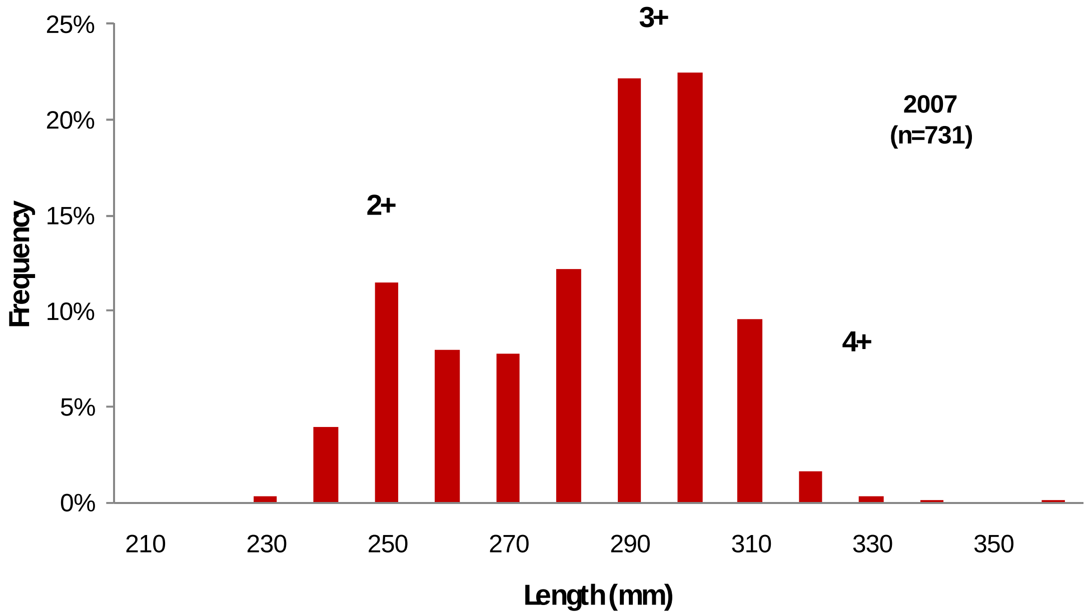


Figure 5.9 Comparison in North and South Arm kokanee length distributions based on early summer trawl sampling (2004-2008) showing a difference in fry size between North and South Arms.



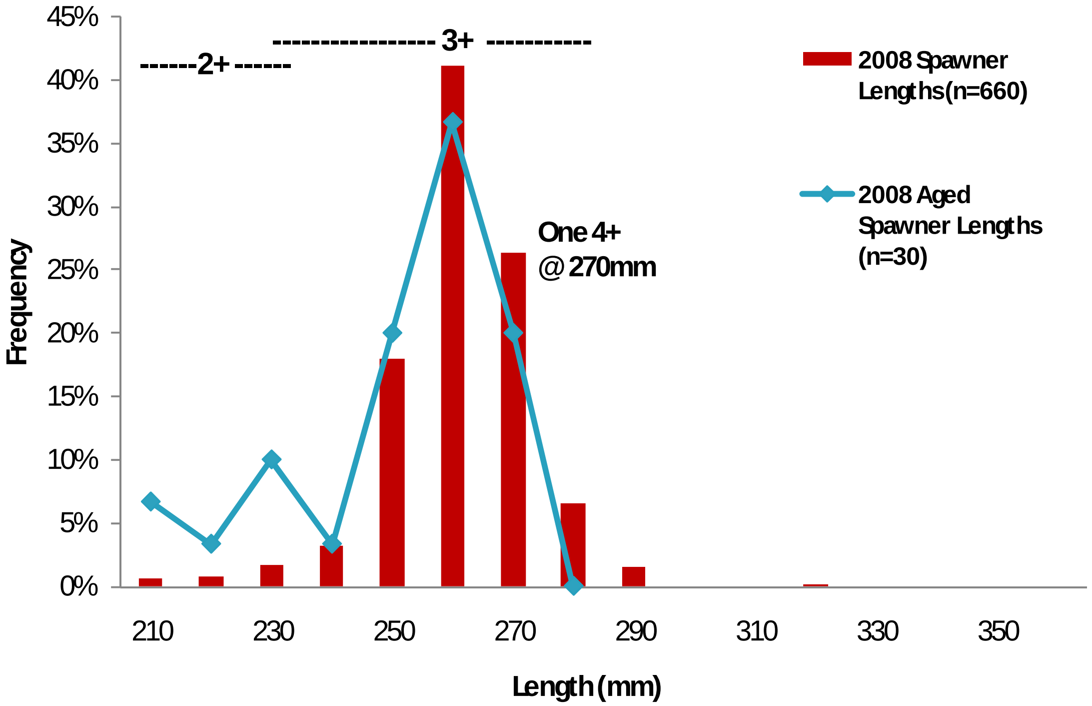


Figure 5.10 Percent length frequency of Meadow Creek kokanee for 2007 and 2008.

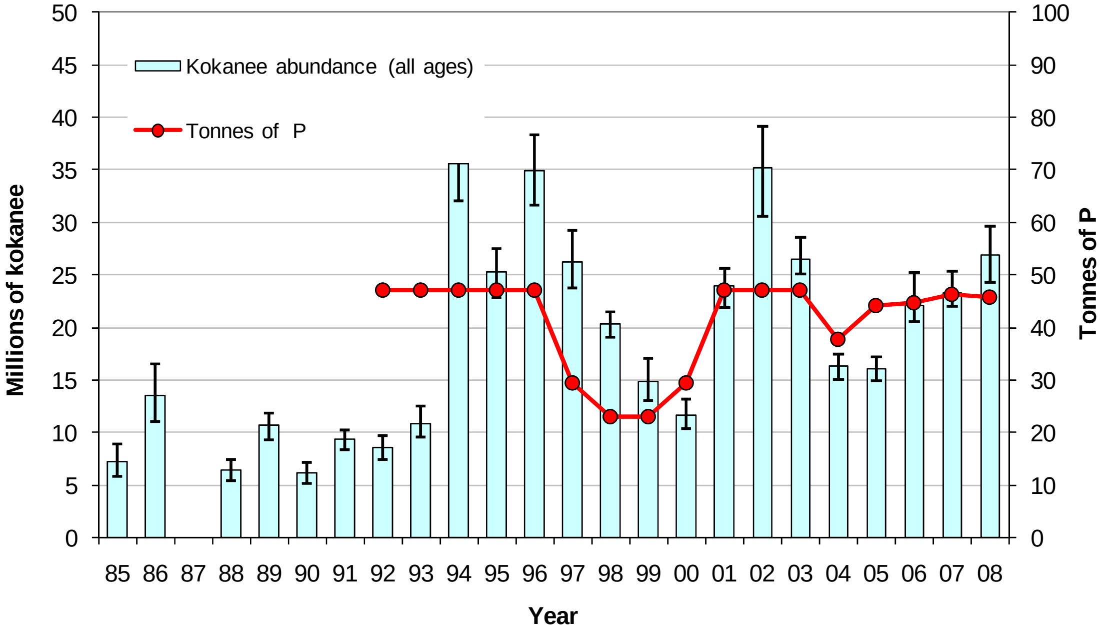


Figure 5.11 Response of in-lake kokanee abundance (all ages) to nutrient additions 1992-2008.

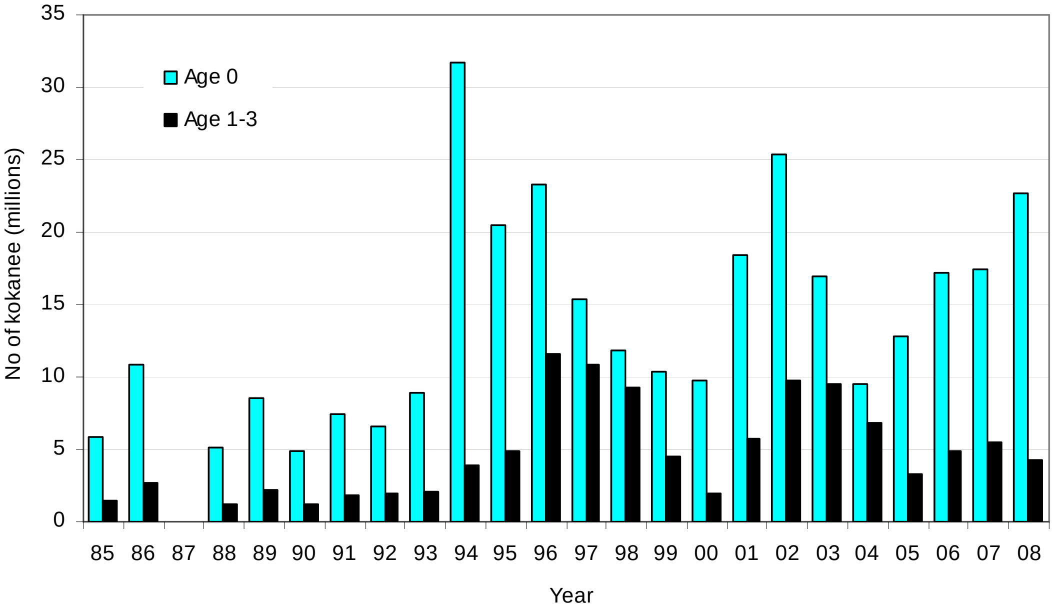


Figure 5.12 Trends in age 0+ and age1-3+ kokanee abundance in Kootenay Lake based on hydroacoustic surveys 1985-2008.

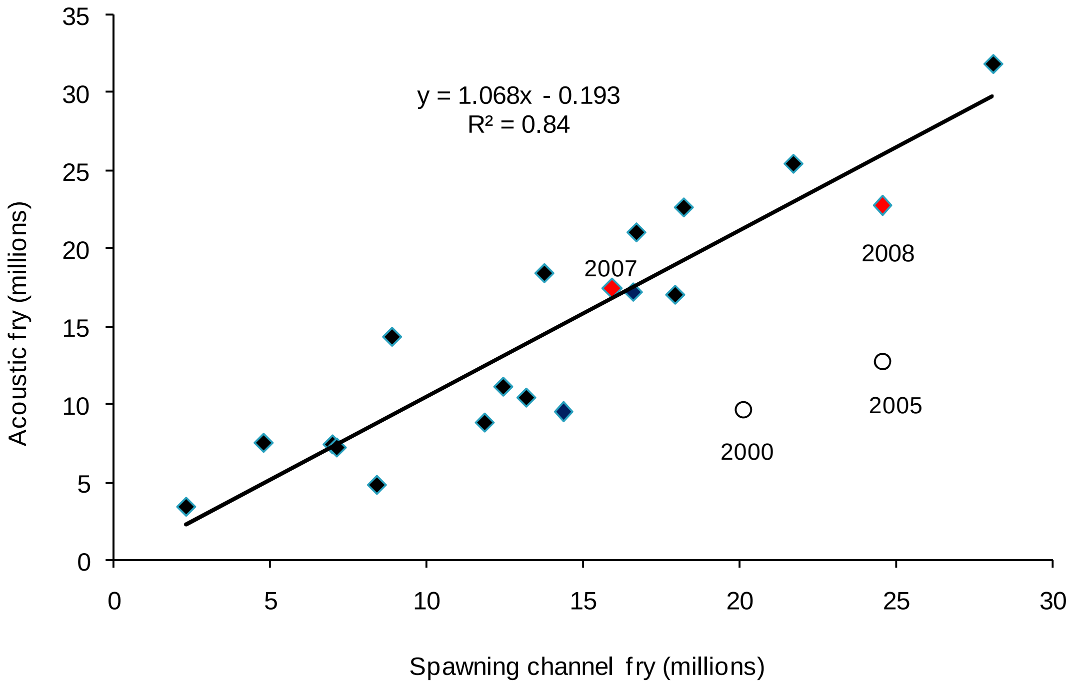


Figure 5.13 Relationship between numbers of kokanee fry produced from the Meadow Creek spawning channel and estimated numbers of fry (1988-2008) from fall hydroacoustic surveys. Note: Years 2000 and 2005 removed as considered outliers.

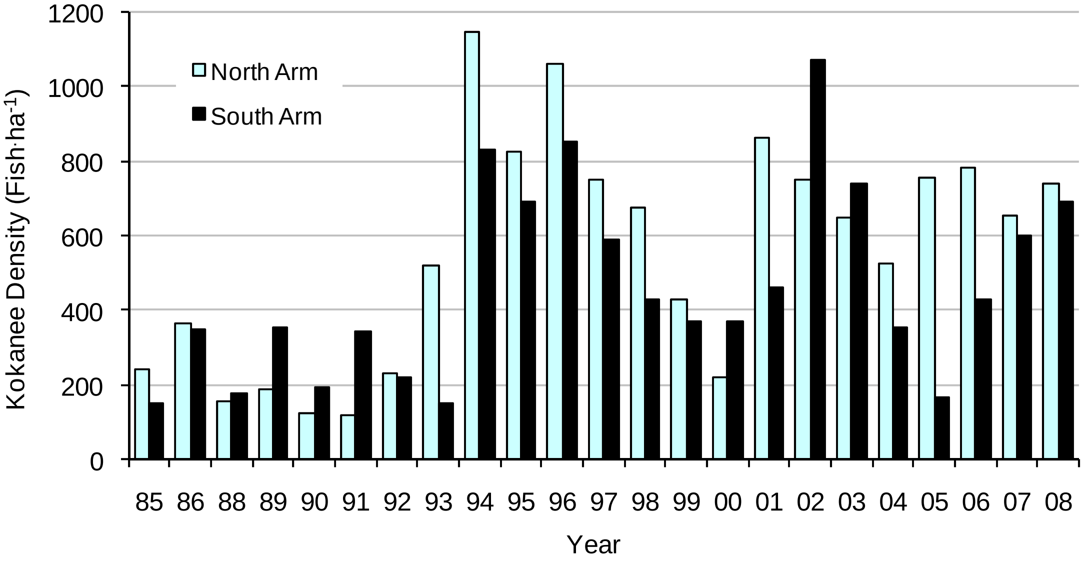


Figure 5.14 Comparison of kokanee density in North and South Arms based on acoustic surveys, 1985-2008.

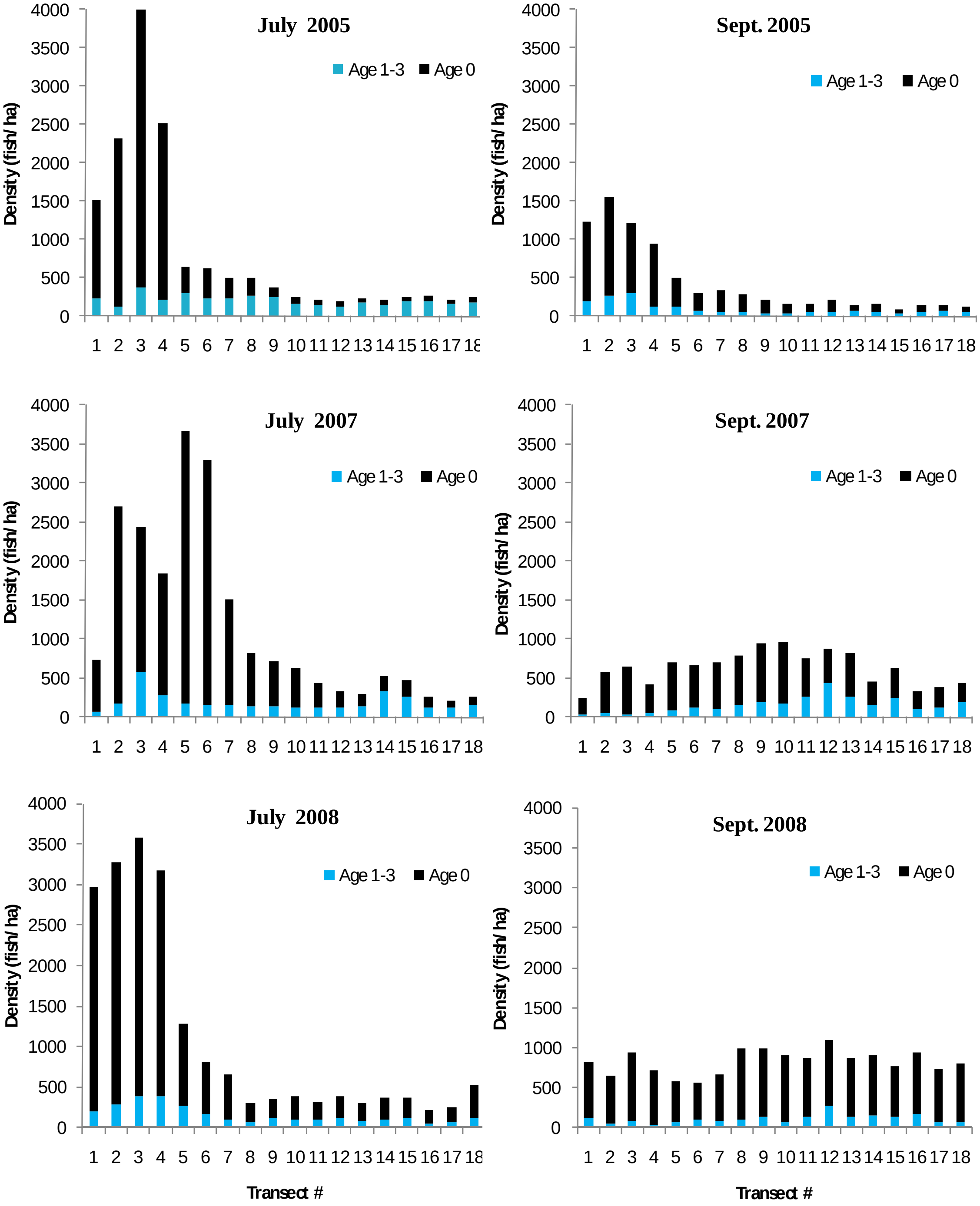


Figure 5.15 Longitudinal density distributions for age 0+ and age 1-3+ kokanee in Kootenay Lake during July and September 2005, 2007 and 2008. Note: Transects are in order from North to South with #1-10 representing North Arm and #11-18 representing South Arm.

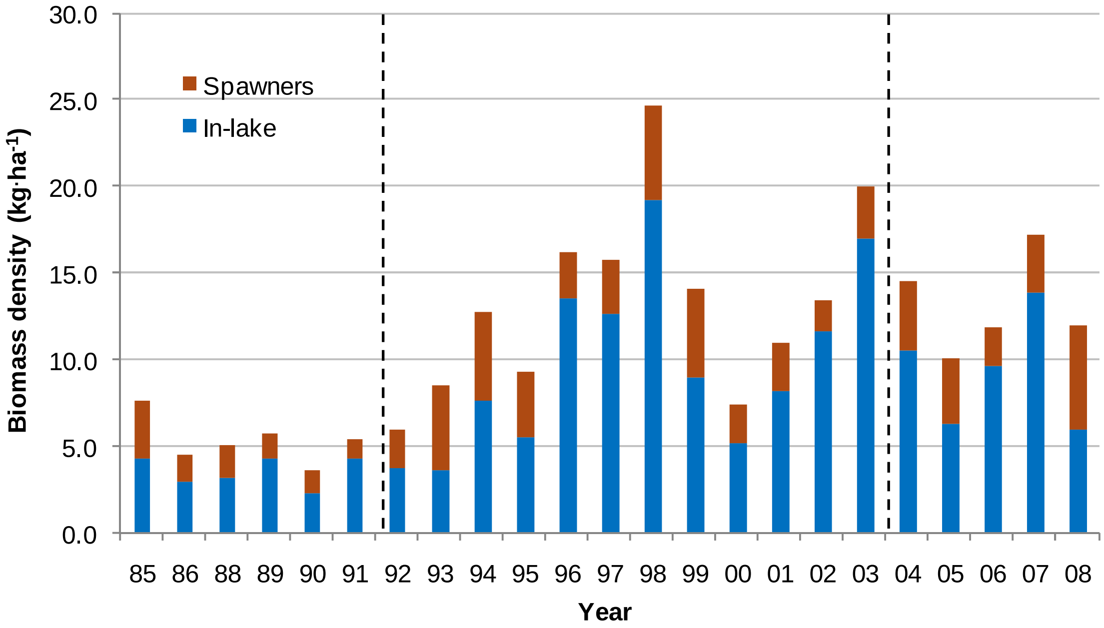


Figure 5.16 Trends in biomass density (kg·ha^{-1}) for Kootenay Lake based on acoustic and trawl surveys 1985-2008. The dotted lines indicate commencement of nutrient additions to the North Arm in 1992 and South Arm in 2004.

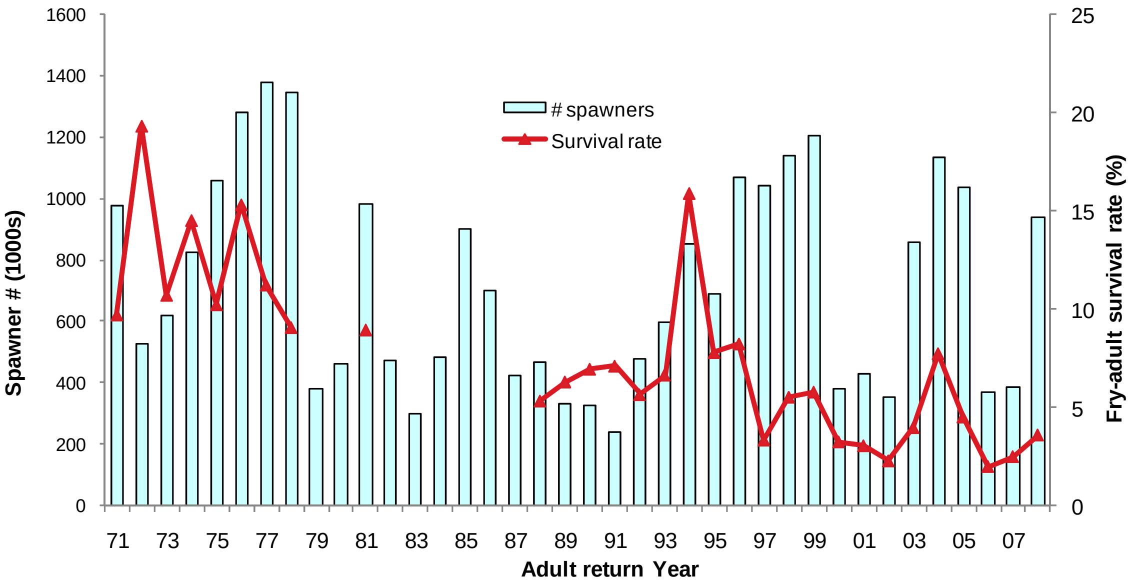


Figure 5.17 Kokanee fry to adult survival rate based on Meadow Creek data. Number of spawners illustrated to emphasize that low survival rates are usually followed by higher escapement levels.

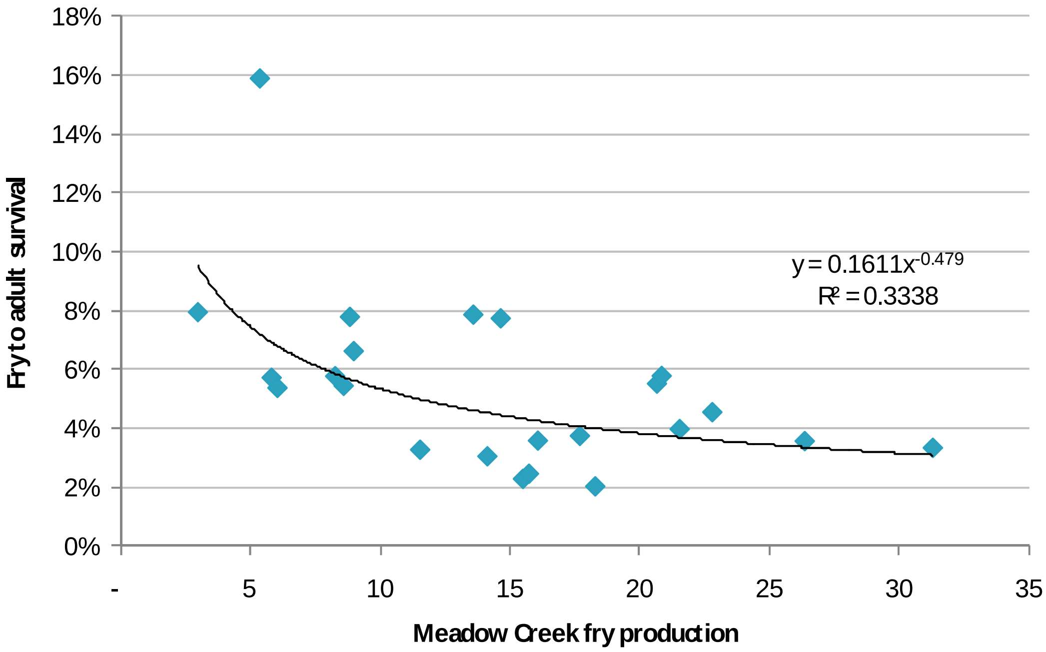


Figure 5.18 Relation of fry survival and fry production levels based on Meadow Creek data.

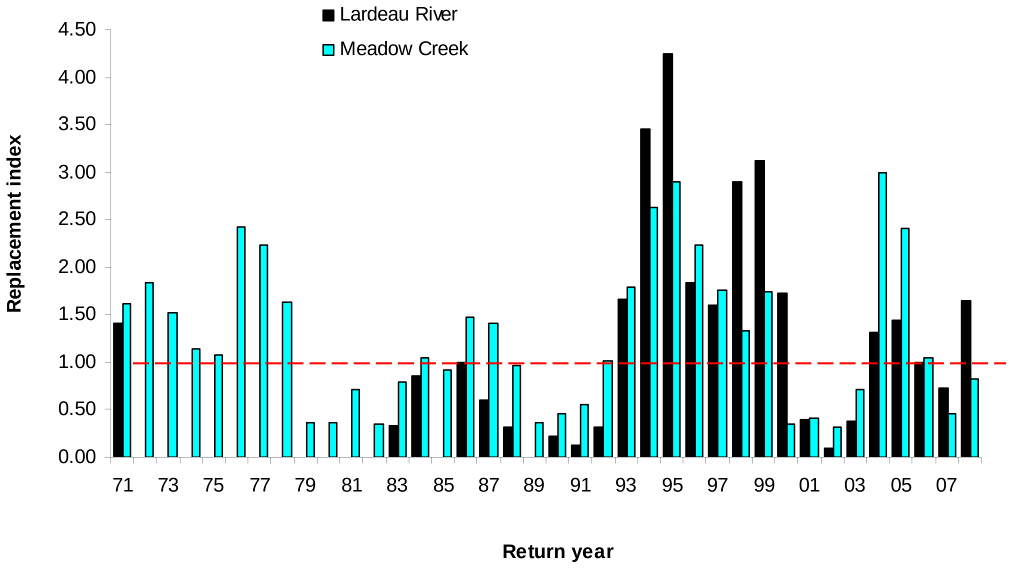


Figure 5.19 Recruit-spawner relationships for Lardeau River and Meadow Creek (1971-2008). Dotted line indicates replacement level of 1.0.

APPENDIX 5.1. Kokanee length correction factors for Kootenay Lake**.** Correction factors for >180-mm fish and for 100–180-mm fish are from Rieman and Myers (1992). Correction factors for <100-mm fish were derived from Okanagan Lake trawl samples collected during 1988–93.

Date	>180 mm	100–180 mm	<100 mm
1-Sep	1.025	1.064	1.090
2-Sep	1.023	1.061	1.087
3-Sep	1.021	1.058	1.084
4-Sep	1.020	1.056	1.081
5-Sep	1.018	1.053	1.078
6-Sep	1.016	1.050	1.075
7-Sep	1.014	1.047	1.072
8-Sep	1.012	1.044	1.069
9-Sep	1.011	1.042	1.066
10-Sep	1.009	1.039	1.063
11-Sep	1.007	1.036	1.060
12-Sep	1.005	1.033	1.057
13-Sep	1.003	1.030	1.054
14-Sep	1.002	1.028	1.051
15-Sep	1.000	1.025	1.048
16-Sep	1.000	1.023	1.045
17-Sep	1.000	1.022	1.042
18-Sep	1.000	1.020	1.039
19-Sep	1.000	1.018	1.036
20-Sep	1.000	1.017	1.033
21-Sep	1.000	1.015	1.030
22-Sep	1.000	1.013	1.027
23-Sep	1.000	1.011	1.024
24-Sep	1.000	1.010	1.021
25-Sep	1.000	1.008	1.018
26-Sep	1.000	1.006	1.015
27-Sep	1.000	1.005	1.012
28-Sep	1.000	1.003	1.009
29-Sep	1.000	1.001	1.006
30-Sep	1.000	1.000	1.003
1-Oct	1.000	1.000	1.000
2-Oct	1.000	1.000	0.997
3-Oct	1.000	1.000	0.994
4-Oct	1.000	1.000	0.991
5-Oct	1.000	1.000	0.988
6-Oct	1.000	1.000	0.985
7-Oct	1.000	1.000	0.982
8-Oct	1.000	1.000	0.979
9-Oct	1.000	1.000	0.976
10-Oct	1.000	1.000	0.973
11-Oct	1.000	1.000	0.970
12-Oct	1.000	1.000	0.967
13-Oct	1.000	1.000	0.964
14-Oct	1.000	1.000	0.961
15-Oct	1.000	1.000	0.958
16-Oct	1.000	1.000	0.955
17-Oct	1.000	1.000	0.952
18-Oct	1.000	1.000	0.949
19-Oct	1.000	1.000	0.946
20-Oct	1.000	1.000	0.943
21-Oct	1.000	1.000	0.940
22-Oct	1.000	1.000	0.936
23-Oct	1.000	1.000	0.933
24-Oct	1.000	1.000	0.930
25-Oct	1.000	1.000	0.927
26-Oct	1.000	1.000	0.924
27-Oct	1.000	1.000	0.921
28-Oct	1.000	1.000	0.918
29-Oct	1.000	1.000	0.915
30-Oct	1.000	1.000	0.912
31-Oct	1.000	1.000	0.909
1-Nov	1.000	1.000	0.906
2-Nov	1.000	1.000	0.903
3-Nov	1.000	1.000	0.900
4-Nov	1.000	1.000	0.897
5-Nov	1.000	1.000	0.894
6-Nov	1.000	1.000	0.891
7-Nov	1.000	1.000	0.888
8-Nov	1.000	1.000	0.885
9-Nov	1.000	1.000	0.882
10-Nov	1.000	1.000	0.879
11-Nov	1.000	1.000	0.876

APPENDIX 5.2. Equipment and data processing specifications.

Echosounder Specifications and Field Settings

Description	SIMRAD EY500
transducer	Split beam 120 kHz
nominal beam angle	7.0 degree
depth of face deployment	1.0 m, tow foil, vertical, mobile
pulse width	1.0 ms
ping rate	1 – 3 $p \cdot sec^{-1}$
time varied gain	40 log r
data collection threshold	-70dB
range collected	0 -100 meters
power	63W
gain	26.1dB
data storage	computer hard disk

Data Processing Specifications

Description		
120kHz Split Beam		Sonar5 version 5.9.8
Time varied gain		40 log r
TS min threshold (dB)		-70
TS max threshold (dB)		-24
Single Echo detector	:SED threshold	-70 dB min, -24 dB max, (reported from -61 to -24dB)
	:Min. echo length	0.60
	:Max echo length	1.60
	:Max phase deviation	0.6
Range processed		3 – 50 m

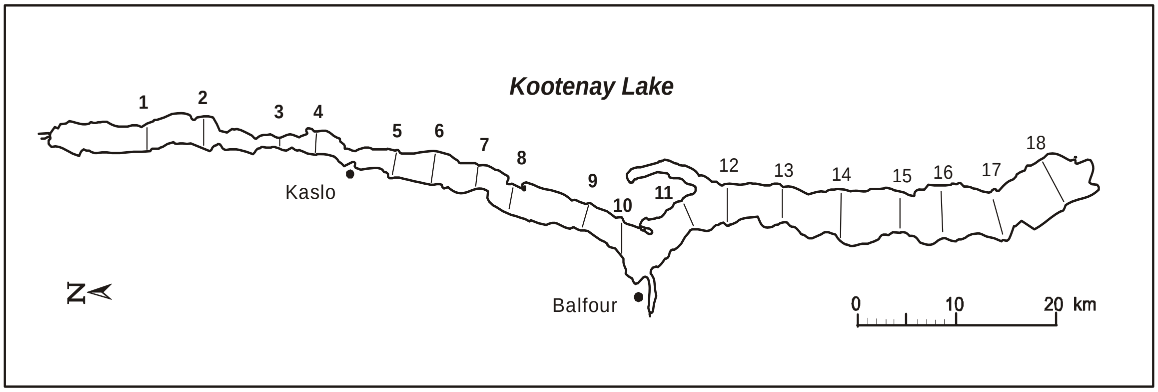
APPENDIX 5.3. Love's (1977) empirical relation of fish length to acoustic target strength.

Aspect Dorsal: TS = 19.1 $\log_{10}$ (L) – 0.9 $\log_{10}$ (F^1) – 62
Where: TS=target strength in decibels (dB), L=length in cm and F=frequency in KHz=120 KHz

Target strength	Fish length range (mm)		Target strength	Fish length range (mm)	
(dB)	Min	Max	(dB)	Min	Max
-26	961		-44	110	123
-27	852	960	-45	97	109
-28	755	851	-46	86	96
-29	669	754	-47	76	85
-30	593	668	-48	68	75
-31	526	592	-49	60	67
-32	466	525	-50	53	59
-33	413	465	-51	47	52
-34	366	412	-52	42	46
-35	325	365	-53	37	41
-36	288	324	-54	33	36
-37	255	287	-55	29	32
-38	226	254	-56	26	28
-39	201	225	-57	23	25
-40	178	200	-58	20	22
-41	158	177	-59	18	19
-42	140	157	-60	16	17
-43	124	139	-61	14	15
			-62	13	13

APPENDIX 5.4. Transect fish densities (number·ha^{-1}) in Kootenay Lake in 2008.

Transect Number	July 2008			Sept. 2008		
	All Ages	Age 0+	Age 1-3+	All Ages	Age 0+	Age 1-3+
1	2774	2574	200	707	594	113
2	2984	2701	284	600	545	55
3	3202	2821	380	872	796	76
4	2777	2385	392	690	659	31
5	1023	763	260	522	460	62
6	643	484	159	464	371	93
7	550	444	106	581	502	78
8	244	181	63	883	782	101
9	249	141	108	850	716	134
10	291	196	94	835	761	74
11	227	130	97	750	623	127
12	261	144	117	827	555	272
13	205	116	89	738	599	139
14	270	165	105	763	616	146
15	243	119	123	640	503	137
16	156	104	52	761	590	171
17	184	124	60	668	597	71
18	400	277	123	737	677	59



APPENDIX 5.5. Maximum likelihood population estimates and bounds for (a) all ages of kokanee and (b) ages 1-3 kokanee in Kootenay Lake in September 2008.

a) Statistics for kokanee of all ages (>–61 dB) in two zones (Zone 1=TR 1-3; Zone 2=TR 4-18)

Zone	Depth	N	Density	Std. Error	Area	Stratum Pop.	Statistic[1]	Abundance
1	3-5	3	6.9	3.5	5320	36708		
1	5-10	3	11.1	6.3	5320	59052		
1	10-15	3	45.4	21.8	5320	241528		
1	15-20	3	227.6	81.5	5320	1210832		
1	20-25	3	274.2	102.9	5267	1444157		
1	25-30	3	103.8	51.8	5211	540931	LB=	24,227,000
1	30-35	3	30.9	15.3	5138	158777	**MLE=**	26,917.000
1	35-40	3	15.3	5.6	5052	77289	UB=	29,631,000
1	40-45	3	5.7	2.1	4965	28299		
1	45-50	3	5.4	3.2	4878	26341		
2	3-5	15	0.9	0.6	32880	29592		
2	5-10	15	8.6	3.0	32880	282768		
2	10-15	15	10.0	4.8	32880	328800		
2	15-20	15	25.4	9.3	32880	835152		
2	20-25	15	128.3	18.5	32649	4188908		
2	25-30	15	284.3	19.2	32431	9220014		
2	30-35	15	172.0	16.8	32132	5526756		
2	35-40	15	61.8	12.1	31852	1968436		
2	40-45	15	17.3	4.4	31632	547227		
2	45-50	15	5.3	1.1	31406	166451		

[1] MLE = maximum likelihood estimate, LB = lower bound, and UB = upper bound

b) Statistics for age 1-3+ kokanee (>–45 dB) in three zones (Zone 1=TR 1-3, Zone 2=TR 4-10, Zone 3=TR 11-18)

Zone	Depth	N	Density	Std. Error	Area	Stratum Pop.	Statistic[1]	Abundance
1	5-10	3	1.0	1.0	5320	5496		
1	10-15	3	0.9	0.9	5320	4985		
1	15-20	3	10.5	5.5	5320	55775		
1	20-25	3	36.1	14.5	5267	190163		
1	25-30	3	22.1	6.6	5211	115029		
1	30-35	3	7.8	4.6	5138	40304		
1	35-40	3	1.4	0.6	5052	6916		
1	40-45	3	0.6	0.4	4965	3149		
1	45-50	3	0.8	0.8	4878	3963		
2	10-15	7	0.3	0.2	11420	3818	LB=	3,591,000
2	15-20	7	0.6	0.3	11420	6359	MLE=	4,273,000
2	20-25	7	1.7	0.4	11308	19647	UB=	4,979,000
2	25-30	7	18.8	1.7	11210	211290		
2	30-35	7	44.8	8.2	11086	496299		
2	35-40	7	13.9	4.7	10963	152309		
2	40-45	7	1.2	0.5	10859	12502		
2	45-50	7	0.6	0.3	10751	6618		
3	5-10	8	1.6	1.1	21460	33808		
3	10-15	8	2.2	0.9	21460	47298		
3	15-20	8	1.2	0.4	21460	25478		
3	20-25	8	3.3	0.6	21341	70936		
3	25-30	8	25.7	3.3	21221	545804		
3	30-35	8	61.1	8.4	21046	1284986		
3	35-40	8	34.3	11.9	20888	716518		
3	40-45	8	9.0	2.9	20773	187641		
3	45-50	8	2.0	0.8	20655	41762		

[1] MLE = maximum likelihood estimate, LB = lower bound, and UB = upper bound

APPENDIX 5.6. Preliminary estimates of kokanee biomass for Kootenay Lake

a) Estimated number of fish at each age based on acoustic abundance, trawl proportions and mean weights by year and age from trawl samples

	Estimated number of fish				**Mean weight (g)**			
Year	**Age 0+**	**Age 1+**	**Age 2+**	**Age 3+**	**Age 0+**	**Age 1+**	**Age 2+**	**Age 3+**
1985	3,630,000	1,334,103	2,016,667	279,231	1.6	24.9	53.5	66.0
1986	11,603,512	648,799	1,023,105	224,584	1.9	17.9	60.4	69.3
1988	3,400,660	1,685,283	1,294,057	-	2.2	26.6	52.2	
1989	7,423,643	1,368,605	1,700,388	207,364	1.6	25.5	59.9	68.3
1990	4,808,922	732,788	480,892	137,398	2.2	39.9	75.4	89.2
1991	7,479,751	930,124	775,104	155,021	2.1	29.7	127.9	130.8
1992	7,212,801	390,618	908,413	18,168	2.1	36.3	120.6	180.9
1993	8,790,000	1,218,451	460,634	430,915	1.5	36.5	76.4	108.9
1994	31,780,000	2,510,286	1,287,886	21,829	2.0	31.0	114.1	134.0
1995	21,000,000	3,721,029	572,466	6,505	2.0	34.2	74.4	138.4
1996	22,600,000	6,181,282	5,956,053	162,665	1.4	21.4	57.2	62.8
1997	14,270,000	5,807,355	5,840,165	262,479	1.7	25.0	50.5	77.4
1998	8,400,000	2,248,680	8,012,903	538,416	1.4	36.8	73.4	97.4
1999	10,360,000	2,050,323	2,489,677	-	2.1	33.3	101.4	
2000	9,690,000	636,667	1,273,333	-	2.0	32.2	123.0	
2001	18,380,000	4,967,368	752,632	-	2.4	35.9	119.2	
2002	25,430,000	9,091,528	542,778	135,694	1.8	37.0	84.9	111.4
2003	17,049,000	5,263,848	4,187,152	-	3.4	39.9	90.9	
2004	9,450,000	3,692,578	2,782,813	374,609	2.5	23.1	90.6	109.3
2005	12,830,000	1,703,125	1,021,875	545,000	1.7	18.7	110.8	137.7
2006	17,230,000	3,933,462	936,538	-	3.3	35.8	183.4	
2007[1]	*17,859,000*	*3,736,000*	*1,401,000*	*350,000*	*3.3*	*35.8*	*183.4*	*235.0*
2008	22,643,800	3,827,896	445,104	-	2.3	35.5	93.6	

1. Note no trawling in 2007; applied approximate proportion by age from two previous years to the age 1 2 and 3 fish. Based on density, the growth was likely similar to 2006 so applied 2006 mean weights by age. Estimates are italicized. The mean weight of age 3 was assumed to be the same as mean weight of spawners in 2007.

b) Calculation of in-lake biomass (metric tons) and biomass density (kg·ha^{-1}) of kokanee in Kootenay Lake.

	Biomass (metric tonnes)					**Biomass Density (kg·ha^{-1})**				
Year	**Age 0+**	**Age 1+**	**Age 2+**	**Age 3+**	**Total**	**Age 0+**	**Age1+**	**Age2+**	**Age 3+**	**Total**
1985	6	33	108	18	165	0.16	0.87	2.82	0.48	4.3
1986	22	12	62	16	111	0.58	0.30	1.62	0.41	2.9
1988	7	45	68	-	120	0.19	1.18	1.77	-	3.1
1989	12	35	102	14	163	0.31	0.91	2.67	0.37	4.3
1990	11	29	36	12	88	0.28	0.76	0.95	0.32	2.3
1991	16	28	99	20	163	0.42	0.72	2.59	0.53	4.3
1992	15	14	110	3	142	0.40	0.37	2.87	0.09	3.7
1993	14	44	35	47	140	0.35	1.16	0.92	1.23	3.7
1994	64	78	147	3	291	1.66	2.04	3.85	0.08	7.6
1995	41	127	43	1	212	1.07	3.33	1.11	0.02	5.5
1996	32	132	341	10	515	0.83	3.46	8.92	0.27	13.5
1997	24	145	295	20	485	0.64	3.80	7.72	0.53	12.7
1998	12	83	588	52	735	0.31	2.17	15.40	1.37	19.2
1999	22	68	252	-	343	0.57	1.79	6.61	-	9.0
2000	19	21	157	-	196	0.50	0.54	4.10	-	5.1
2001	44	178	90	-	312	1.15	4.67	2.35	-	8.2
2002	47	336	46	15	444	1.22	8.81	1.21	0.40	11.6
2003	57	210	381	-	648	1.50	5.50	9.96	-	17.0
2004	24	85	252	41	402	0.62	2.23	6.60	1.07	10.5
2005	21	32	113	75	242	0.56	0.83	2.96	1.96	6.3
2006	56	141	172	-	369	1.47	3.69	4.50	-	9.7
2007[1]	*58*	*134*	*257*	*82*	*531*	*1.52*	*3.50*	*6.73*	*2.15*	*13.9*
2008	53	136	42	-	230	1.38	3.56	1.09	-	6.0
Pre	12	30	79	13	135	0.3	0.8	2.1	0.4	3.5
Fert	35	116	195	21	367	0.9	3.0	5.1	0.5	9.6

1. Note 2007 biomass estimates are based on assumptions from table above

c) Calculation of kokanee spawner biomass (metric tons) and biomass density ($kg \cdot ha^{-1}$) in Kootenay Lake. Note: bottom rows compare average biomass during pre-fertilization (1985-91) and fertilization years (1991-2008).

Year	**Total Spawners (no)**	**Mean Weight (g)**	**Spawner Biomass (tonnes)**	**Spawners** ($kg \cdot ha^{-1}$)	**Inlake** ($kg \cdot ha^{-1}$)	**Total** ($kg \cdot ha^{-1}$)
1985	1,501,100	85.0	127.6	3.3	4.3	7.6
1986	697,600	89.0	62.1	1.6	2.9	4.5
1988	767,900	96.5	74.1	1.9	3.1	5.1
1989	523,000	106.7	55.8	1.4	4.3	5.7
1990	475,000	107.1	50.9	1.3	2.3	3.6
1991	347,100	125.7	43.6	1.1	4.3	5.4
1992	547,200	158.5	86.7	2.3	3.7	6.0
1993	845,000	218.2	184.4	4.8	3.7	8.5
1994	1,233,000	158.2	195.1	5.1	7.6	12.7
1995	858,000	166.7	143.0	3.7	5.5	9.3
1996	1,178,000	89.4	105.4	2.8	13.5	16.3
1997	1,444,200	81.8	118.1	3.1	12.7	15.8
1998	2,200,000	94.9	208.7	5.5	19.2	24.7
1999	1,734,700	112.6	195.3	5.1	9.0	14.1
2000	567,000	156.2	88.6	2.3	5.1	7.5
2001	591,300	184.0	108.8	2.8	8.2	11.0
2002	464,000	143.5	66.6	1.7	11.6	13.4
2003	1,056,100	108.2	114.3	3.0	17.0	20.0
2004	1,382,600	111.6	154.4	4.0	10.5	14.5
2005	1,266,708	112.0	141.9	3.7	6.3	10.0
2006	481,000	*180.0*	86.6	2.3	9.7	11.9
2007[1]	533,700	235.6	125.7	3.3	*13.9*	*17.2*
2008	1,348,600	168.0	226.6	5.9	6.0	12.0
Pre	718,617	101.7	69.0	1.8	3.5	5.3
Fert	1,043,053	145.8	138.2	3.6	9.6	13.2

1. In-lake biomass assumptions outlined in tables above.