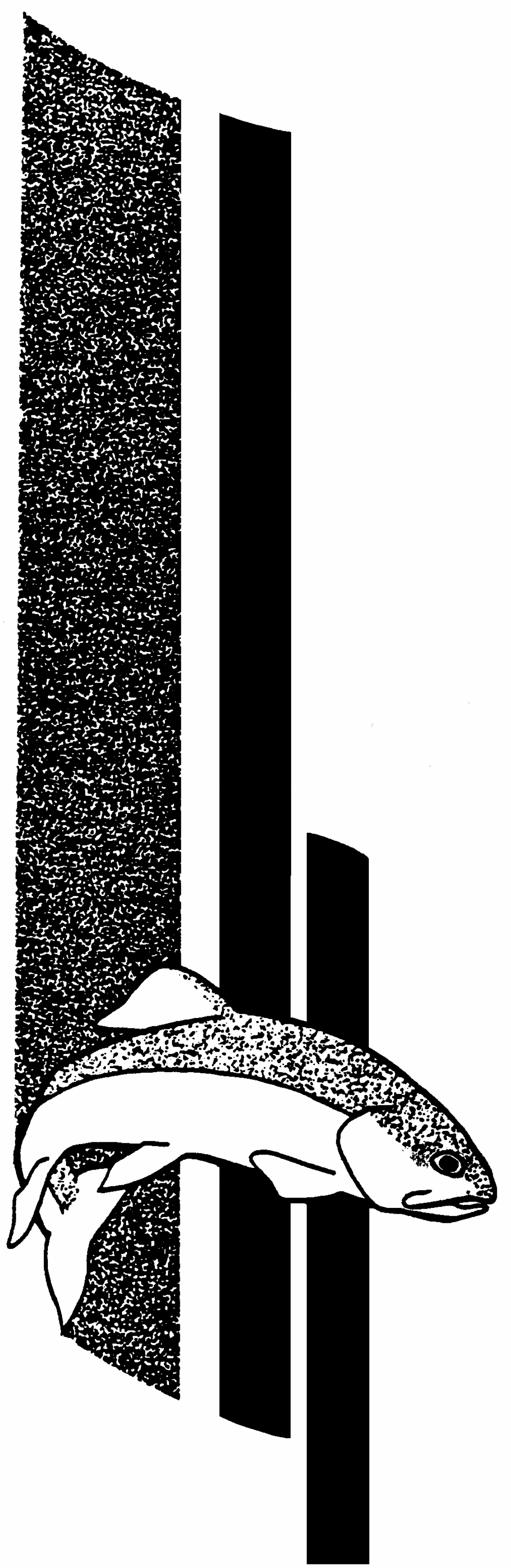

KOOTENAY LAKE NUTRIENT RESTORATION PROGRAM, YEAR 16 (NORTH ARM) AND YEAR 4 (SOUTH ARM) (2007) REPORT

by

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Environmental Stewardship - Fish and Wildlife
Ministry of Environment
Province of British Columbia

Major Funding by

Fish and Wildlife Compensation Program - Columbia Basin

and

Kootenai Tribe of Idaho

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FISH & WILDLIFE COMPENSATION PROGRAM COLUMBIA BASIN BC hydro Fisheries and Oceans Canada Pêches et Océans Canada

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

BRITISH COLUMBIA Ministry of Environment

The ministry's vision is a clean, healthy and naturally diverse environment.

Northwest Power and Conservation Council BONNEVILLE POWER ADMINISTRATION

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

EXECUTIVE SUMMARY

This report summarizes results from the sixteenth year (2007) of nutrient additions to the North Arm of Kootenay Lake and four years of nutrient additions to the South Arm. These 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 experiment is to restore kokanee (*Oncorhynchus nerka*) populations, which are the main food source for Gerrard rainbow trout (*Oncorhynchus mykiss*) and bull trout (*Salvelinus confluentus*).

Nutrients added were in the form of agricultural grade liquid fertilizer (10-34-0, ammonium polyphosphate (phosphorus, P) and 28-0-0, urea ammonium nitrate (nitrogen, N). The total amount added to the North Arm in 2007 was 46.2 tonnes of P and 246.9 tonnes of N while in the South Arm 245 tonnes of nitrogen were added but zero P.

Kootenay Lake has an area of 395 km^2, a maximum depth of 150 m, a mean depth of 94 m, and a water renewal time of approximately two years. The lake is warm monomictic generally mixing from late fall to early spring and stratifying during the summer. Surface water temperatures were warmest in August at 20^o C and 22^o C in the North Arm and South Arm, respectively.

The concentration of oxygen in vertical profiles were similar to previous years with the lake being well oxygenated from the surface to the bottom depths at all stations. Similar to past years, Secchi disc measurements at all stations in 2007 indicated a typical seasonal pattern of decreasing depths associated with increased phytoplankton biomass, followed by increasing depths as the algae biomass gradually diminished in the fall.

The concentrations of total phosphorus (TP) ranged from 2 - 10 µg/L and tended to decrease as summer advanced in the North Arm, whereas it was uniform in the South Arm with a peak in September at one station. Over the sampling season dissolved inorganic nitrogen (DIN) concentrations decreased, with the decline corresponding to nitrate (the dominant component of DIN) being utilized by phytoplankton during summer stratification.

Owing to the importance of epilimnetic nitrate that is required for optimal N:P ratios and to ensure growth of edible phytoplankton, discrete epilimnetic water sampling was undertaken in 2007 to more accurately monitor changes in euphotic zone nitrate concentrations. As expected, there was a seasonal decline in nitrate concentrations, thus supporting the strategy of increasing the nitrogen loading in both arms. These in-season adjustments emphasize the need for an adaptive management approach to ensure the nitrogen to phosphorus (N:P) (dissolved fraction) ratio does not decrease below 15:1 (weight:weight) during the fertilizer application period.

Phytoplankton composition determined from integrated samples (0-20m) was dominated by diatoms, followed by cryptophytes and chrysophytes. In 2007, the contribution of

cryptophytes to total biomass was greater in the North Arm than in the South Arm (31% vs. 18%); a higher contribution than in 2006.

Phytoplankton in the discrete depth samples (2, 5, 10, 15 and 20 m) was dominated by chryso-cryptophytes in June and then shifted to bacillariophytes being dominant from July through September, a trend similar to other years. There were no large blue-green (cyanobacteria) populations in 2007. The trend of chyrso-cryptophytes being dominant in the spring and decreasing in the summer and fall months coincides with the increase in *Daphnia spp*. biomass, indicating that grazing on the phytoplankton is likely occurring.

Depth integrated ^{14}C primary production rates ranged from oligotrophic to mesotrophic conditions (50 to 430 mg $C/m^2/d$) with seasonal and interannual variability. The contribution of nanoplankton (i.e., 2 to 20 u cell diameter) to total productivity ranged from 25% in 2006 to 47% in 2007. Results in 2004 and 2005 ranged between 39% and 46%. Nanoplankton production is considered the size class preferred by *Daphnia spp.* which in turn is the main food source for kokanee.

In 2007, seasonal average zooplankton abundance and biomass in the main body of the lake slightly decreased compared to 2006. Total zooplankton density and densities of copepods and *Daphnia* in the West Arm decreased while Cladocera other than *Daphnia spp.* increased compared to 2006. Zooplankton density was numerically dominated by copepods and biomass was dominated by *Daphnia spp*.

The annual average mysid biomass data at deep stations indicated that the North Arm of Kootenay Lake supported slightly less biomass than the South Arm in 2007. Mysid densities increased through the summer and decreased into fall. The mean whole lake values remain within pre-nutrient addition densities.

Kokanee escapement to the Meadow Creek spawning channel slightly increased in 2007 to approximately 386,000 spawners compared to 371,000 in 2006. The Lardeau River escapement increased from 2006 with 100,000 spawners to approximately 147,000 spawners. Similar to the last decade, kokanee spawner numbers in the South Arm tributaries remained virtually at zero.

The mean size of female and male kokanee from Meadow Creek was the largest on record (28.2 cm and 27.7 cm, respectively); the long term average has been 22.4 cm. Fecundity increased in 2007 with an average of 411 eggs per female. The increased kokanee size in 2007 is believed to reflect a density dependent growth response owing to good growing conditions.

Spring hydroacoustic survey estimates indicated very low densities of kokanee in the South Arm with highest densities at the northerly stations where most of the fry are produced. The relationship between the number of fry produced from Meadow Creek and the number of fry estimated in the fall hydroacoustic survey were similar, a trend that has occurred during most study years. By the fall, the distribution of kokanee fry was fairly uniform throughout the lake, as observed in previous years. Fall hydroacoustic estimates for all age groups increased to approximately 23 million kokanee in 2007 thus foreshadowing increased spawner numbers in the near future.

The results of the 2007 nutrient additions indicate that the trophic level response has been positive. Nutrient additions to the North and South arms have resulted in sufficient phytoplankton composition and biomass suitable for *Daphnia spp.* growth. Pelagic kokanee numbers size and biomass increased; all indicative of successful trophic level transfer to planktivores, and indicative of a positive response to our closely monitored seasonal applications of limiting macronutrients.

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CHAPTER 1

INTRODUCTION

TROPHIC LEVEL RESPONSES TO NORTH ARM (Year 16) AND SOUTH ARM (YEAR 4) KOOTENAY LAKE NUTRIENT ADDITIONS - 2007

by

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Introduction

Hydro developments on the Canadian portion of the Columbia River system have had irreversible impacts to the fish communities of the former Arrow, Duncan and Kootenay lakes. Daley et al. (1981) and Ashley et al. (1997) reviewed the impacts of upstream reservoirs on Kootenay Lake while Stockner (2003) and Pieters et al. (*in* Stockner 2003) discuss changes that have occurred to the Arrow Lakes. One overriding impact has been significant declines in lake productivity due to newly formed upstream reservoirs that retained key nutrients that previously contributed to downstream systems productivity (Stockner 2003; Perrin et al. 2006). Recently Matzinger et al. (2007) have also described an additional productivity impact to the Arrow Lakes Reservoir due to weekly hydraulic alterations to the inflows Arrow Lakes system. To address the productivity decline large scale lake fertilization programs have been initiated on both Kootenay Lake and Arrow Lakes Reservoir. For sixteen years Kootenay Lake has been the focus of experimental nutrient additions in a long-term effort to offset the impact of ultra-oligotrophication (Schindler et al. 2006, 2007 a, b). This report describes trophic level responses to the sixteenth year of nutrient additions to the North Arm of Kootenay Lake and four years of results from nutrient additions to the South Arm.

During the course of four decades of dam construction on the Columbia and Kootenay rivers there have been no formal assessments of impacts to fish and wildlife, even for the most recent dam constructed in the early 1980s at Revelstoke BC. As a consequence the real losses to fish and wildlife will never be fully understood although efforts are currently underway to better quantify the losses (J. Thorley Fisheries Biologist, Poisson Consulting Ltd. Nelson BC 2007 pers. comm.). Almost three decades ago Daley et al. (1981) identified that nutrient impoverishment in Kootenay Lake was the result of key nutrient uptake 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 all too apparent by the late 1980s. Kokanee (*Oncorhynchus nerka*) numbers fell at an alarming rate and by 1991 there were < 0.25 million adults compared to numbers typically > 1 million. Experimental fertilization commenced on the North Arm in 1992 in an effort to reverse the kokanee decline. This bottom-up approach to increasing fish production assumed that each trophic level would respond to nutrient addition therefore to understand the response (s) each trophic level had to be monitored annually. In this report the 2007 trophic level responses to nutrient additions in two widely separated parts of the lake are compared with previous years' results.

Impetus for adding nutrients to the lake was prompted by concern for the Gerrard rainbow trout (*Oncorhynchus mykiss*) which are the primary focus of the economically valuable Kootenay Lake sport fishery. These trout can reach trophy sizes of ~10-14 kg due to their highly piscivorous foraging behavior on kokanee (Andrusak and Parkinson 1984). Fertilization of the lake was aimed at ensuring the sustainability of these top predators 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 is actually aimed at the entire fish community in Kootenay Lake, not solely kokanee and rainbow trout. The 1992 strategy that was implemented to the North Arm of Kootenay Lake was simple: add nutrients (P and N) equal to pre-impoundment levels 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. The North Arm fertilization program is funded by the Fish and Wildlife Compensation Program – Columbia Basin and Ministry of Environment.

Despite successful restoration of North Arm kokanee the number of spawners in South Arm streams continued to decline and by the early 2000s there were virtually none observed (Andrusak 2007). At the same time Kootenay Lake kokanee that spawn in northern Idaho streams were also virtually non-existent. In an attempt to reverse this situation 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 attempt to restore South Arm kokanee abundance (Anders et al. 2003). This project began late in 2004 and has been fully implemented for the entire growing seasons since then.

The IDFG and KTOI are also committed to restoring Kootenai River productivity in Idaho and Montana. This river has also become nutrient poor due to their uptake in the Koocanusa Reservoir located upstream at Libby, Montana (BPA 2005). 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 (Slaney et al. 2003 in Stockner 2003; Ashley and Stockner 2003 in Stockner 2003). After extensive reviews (BPA 2005) and public hearings the KTOI was permitted in 2005 by the USA Environmental Protection Agency (EPA) to add liquid nitrogen and phosphorous to the Kootenai River for up to five years to replace lost nutrients (S. Ireland, Project Manager, KTOI, Bonners Ferry, Idaho, pers. comm. 2007). Results of this work 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, located in southeastern British Columbia, is the major system that collects Kootenay River flows that ultimately enter the upper Columbia River. (Fig. 1.1). It lies in a north-south direction between the Selkirk and Purcell Mountain ranges. 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, at Balfour, BC, is 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 shallow basins interconnected by narrow riverine sections. The West Arm of Kootenay Lake flows in a westerly direction becoming 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), Ashley et al. (1999), and Northcote et al. (1999).

Background

Over the last century Kootenay Lake has experienced a number of major perturbations that have resulted in numerous scientific investigations dating back to the late 1940s. Initially Dr. P.A. Larkin and some of his students conducted a general limnological investigation on Kootenay Lake in the late 1940s (Larkin 1950). This pioneer work provided some excellent baseline data that has been particularly useful in understanding the lake prior to the eutrophication that began in the early 1950s (Northcote 1973). Larkin was also responsible for introduction of the opossum shrimp *Mysis relicta* into Kootenay Lake in 1949 that resulted in a major ecological impact due to their competition for zooplankton with kokanee (Northcote 1991). The 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 outlet of the lake (Sparrow et al. 1964). As it turned out these trout utilize mysids on a very limited basis (Andrusak and Parkinson 1984). Contrary to the intention of improving the fish populations in the lake it is widely viewed today that this introduction has been detrimental especially to kokanee since mysids 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; Ashley et al. 1997; Walters et al. 1991), but the larger issue of decreased lake productivity overshadows the mysid impact (Daley et al. 1981).

In an unexpected turn of events West Arm kokanee 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 caught up in the 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 an exceptionally large size, 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).

One of Dr. Larkin's students (E.H. Vernon) studied Kootenay Lake kokanee and determined there were three races of kokanee that reside in the lake (Vernon 1957). T.G. Northcote was another of Dr. Larkin's students and Northcote has published several papers that documented limnological changes in Kootenay Lake (Northcote 1972, 1991; Northcote et. al. 1999). Northcote (1973) provided an excellent summary of the early anthropogenic impacts on Kootenay Lake and chronicles eutrophication of the lake. 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).

The Cominco Ltd. fertilizer plant located on the St. Mary River at Kimberley, BC, during the 1950s to the early 1970s discharged tonnes of fertilizer into the St. Mary's River that flows into the Kootenay River and then 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). 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 historically high levels but no estimates of escapement 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.

With Kootenay Lake moving towards eutrophication by the early 1970s public pressure and governments forced Cominco to control their fertilizer discharge. Pollution abatement was well in hand by 1973, which coincided with completion of the Libby Dam. The level of impact of these two events was unforeseen. However, the federal government was prompted to launch a major limnological investigation in the mid 1970s led by Dr. Ralph Daley of Environment Canada, Inland Waters Directorate. A multi-disciplinary team investigated the physical and chemical limnology from 1976-1979 and their study concluded that cessation of phosphorous 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 decline in productivity through to the 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. Kokanee escapements to Meadow Creek reflected these changes all too well. In general the late 1960s and early 1970s was a period of high kokanee abundance (provide range) followed by the 1980s when the lake experienced oligotrophication and kokanee numbers began to decline until record lows of < 0.25 million were recorded in 1990 and 1991. At the same time the South Arm kokanee population had virtually disappeared.

Duncan Dam, constructed 12 km upstream of the north end of the lake was completed in 1967. It resulted in eliminating 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, a 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). A little known fact about Kootenay Lake research was that at the time of the construction of Duncan Dam, a major research program was funded by BC Hydro. This work was directed toward kokanee population assessments at Meadow Creek and the Lardeau River, and toward in-lake kokanee population estimates. Considerable limnological sampling was conducted from 1965-1970. Unfortunately, there was little documentation of this work other than the kokanee assessment work at Meadow Creek and the zooplankton assessment by Zyblut (1970). The Meadow Creek spawning channel was built in 1967 as partial compensation for construction of the Duncan Dam. A very good data base has been established since 1967 on Meadow Creek kokanee spawner numbers, size, fecundity and fry production.

Hydroelectric development has resulted in an irreversible impact on Kootenay Lake's fish habitat. The two major inflowing systems – Kootenay/i 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. Recently, an assessment of impact of lake level drawdown on spawning West Arm kokanee has revealed problems related to egg desiccation and stranding (Andrusak and Andrusak 2007).

The majority of the lake's inflow originates in the upper Kootenay River watershed that starts in the East Kootenay and flows south 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. The Libby Dam was built on the Kootenay River in the mid 1970s 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. upstream reservoirs trap more nutrients now than the natural lake conditions that existed before the 1950s. Nutrients stripped out of the system by the Koocanusa Reservoir behind the Libby Dam are the most likely cause of reduced river productivity in the Idaho portion of the river and this has prompted the major restoration program involving nutrient additions (Holderman and Hardy 2004; BPA 2005). Recent work in the early 2000s in Idaho has also revealed major problems with burbot and sturgeon spawning success as a result of the Libby Dam altering the hydrological regime of the Kootenay River (Paul Anders, Cramer Fish Scientists University of Idaho pers. comm. 2007).

It was quite apparent by 1990 that lake productivity had decreased to the level where 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.

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. In response to these dire circumstances and public concern the provincial government organized a workshop held 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 contemplated. A Kootenay Lake Fertilization Response Model was developed to understand what would happen if the lake was fertilized to pre-impoundment and pre-cultural enrichment levels (Walters et al. 1991). The model predicted that fertilization would unlikely be successful and that mysids, not kokanee, would be the most likely beneficiaries. Walters and Martell (2004) 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 virtually all the public supported experimenting with 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 (Hyatt and Stockner 1985; Stockner and MacIsaac 1996) and, the literature was fairly supportive 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 and in Alaska has proven quite successful (Stockner 2003; Hyatt et al. 2004, Mazumder and Edmundson 2002).

Strong public support for North Arm experimental fertilization and supportive literature convinced provincial fisheries managers to proceed with a five year program despite the model's prediction. 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 reported in a series of technical reports (Ashley et al. 1999; Wright et al. 2002a, b; Schindler et al. 2006, 2007 a, b) with the response by North Arm kokanee increasing from low numbers documented in the 1990s. 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).

Despite apparent success in restoring North Arm kokanee numbers the experiment had its critics who argued that there was no control hence it could not be stated with absolute certainty that the kokanee recovery was due solely to nutrient addition. Thus the experiment was modified by reducing the nutrient loading from 1997-2000 by nearly 50% to determine if fertilization was the primary reason for the striking increase in kokanee numbers. The results of reduced fertilizer loadings were swift and equally dramatic. 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. As a consequence the fertilizer-loading rate was increased in 2001 to the original 1992 level. Once again kokanee numbers increased in 2003 and 2004 to ~ 1 million. The biological responses to Kootenay Lake fertilization have been documented in a series of technical reports similar to this one as well as some in more formal publications (Ashley et al. 1997; Ashley et al. in Murphy and Munawar 1999).

Kootenay Lake was highly productive during the 1960s and early 1970s due to cultural eutrophication that was directly attributable to the uncontrolled release of huge quantities of phosphorus from Cominco’s plant on the St. Mary River (Northcote 1973; Daley et al. 1981). At this time the lake arguably supported a highly productive sport fishery that was the most intensive inland sport fishery in the province having an estimated net worth of $5.8 million (Pearse and Laub 1969). Exceptionally large kokanee and burbot in the West Arm 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. While most of the fishing was directed at kokanee and burbot that concentrated at the lake’s outlet 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 persists to this day. Rainbow trout fishing occurs year round with most fishing gear comprised of surface trolled plugs or bucktail flies that mimic kokanee. The fishery was closely monitored for several decades until the 1990s with the most recent catch statistics summarized by Andrusak (1987) and Redfish Consulting Ltd. (2007). It is believed that the exploitation rate for these trout is very high (e.g., 63% - Andrusak 1981). Until recently the only known spawning area for these unique-sized trout is at the outlet area of Trout Lake where the Lardeau River forms and then flows south into Kootenay Lake after joining the Duncan River. For this reason 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).

In recent years a number of large trout have also been observed spawning just downstream of the Duncan Dam. Numbers of fish are difficult to determine but it appears there may be 50-100 (L. Porto, DFO Habitat Biologist, Nelson, BC, pers. comm., 2007). Research is underway to determine their origin since they may be Gerrard rainbow trout that have been induced to spawn due to warm(er) water releases from the Duncan Dam. Alternatively these fish may be remnants of the original Duncan River spawning run that were thought to have disappeared after the dam was completed.

The lake supports at least two other 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 is comprised of 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 this decrease attributed to the change in lake productivity. 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 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 and spoons but usually at much greater depths. These fish occasionally exceed 7 kg 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 (2007) employed a combination of redd counts and a resistivity counter on the Kaslo River to estimate ~ 900 spawners. Based on these two estimates and the large number of streams that also support adfluvial forms it is quite evident that Kootenay Lake supports large numbers of bull trout compared to rainbow trout numbers.

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 time anglers. The West Arm kokanee population was the centre of attention during the 1970s when the lake was highly productive. 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.

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 (C. Spence, Fisheries Biologist, BC Ministry of Environment, Nelson, BC, pers. comm. 2007).

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 five 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., 2007).

This report summarizes results of the 2007 monitoring program that tracks trophic level responses to experimental fertilization of the North Arm and South Arm of Kootenay Lake.

Objective of the Kootenay Lake Experimental Fertilization 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 (prior to dams and the effects from the fertilizer plant). The primary goal of this fertilization program has been to ensure 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 Environment 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 2007 Kootenay Lake Fertilization Program. A list of the 2007 participants and their primary function is shown in Table 1.1.

Acknowledgements

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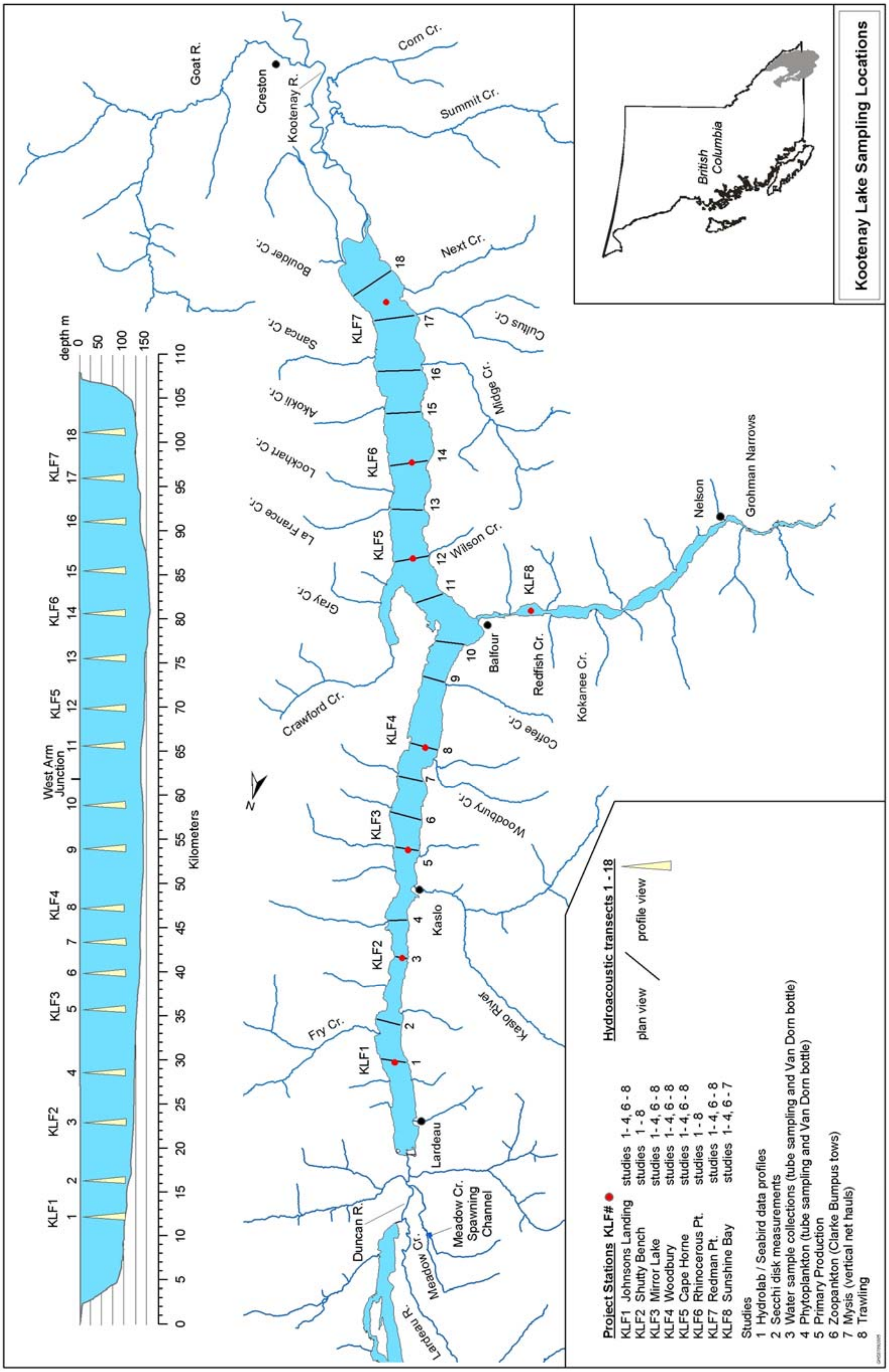

Figure 1.1. Kootenay Lake, British Columbia, sampling stations sites.

Table 1.1. Kootenay Lake participants, activities and affiliation for 2007 studies.

Contribution	**Personnel**	**Affiliation**
Project co-ordination and scientific liaison	Eva Schindler	Ministry of Environment
Fertilizer schedule, loading	Eva Schindler	Ministry of Environment
Fertilizer application	George Veale Western Pacific Marine	G. Veale Holdings Ltd. Western Pacific Marine
Physical limnology, water chemistry, phytoplankton, zooplankton, mysid sampling	Don Miller Mike Lindsay Eva Schindler Marley Bassett	Kootenay Wildlife Services Ltd. Ministry of Environment Ministry of Environment Ministry of Environment
Physical limnology, water sampling analysis	Greg Andrusak Eva Schindler Marley Bassett	Redfish Consulting Ltd. Ministry of Environment Ministry of Environment
Primary production sampling	Shannon Harris Les Fleck Greg Andrusak Marley Bassett	Ministry of Environment Crystal Springs Consulting Redfish Consulting Ltd. Ministry of Environment
Primary productivity analysis	Shannon Harris	Ministry of Environment
Phytoplankton analysis and ecology	Dr. Frances Pick Linda Ley Paul Hamilton Dr. John Stockner Eva Schindler	Biology Department, University of Ottawa Canadian Museum of Nature Canadian Museum of Nature Eco-Logic Ltd. Ministry of Environment
Zooplankton and mysid analysis and biology	Dr. Lidija Vidmanic	Limno-Lab Ltd.
Kokanee acoustic sampling	Dale Sebastian George Scholten Don Miller	Ministry of Environment Ministry of Environment Kootenay Wildlife Services Ltd
Kokanee trawling	Don Miller George Scholten Dale Sebastian	Kootenay Wildlife Services Ltd. Ministry of Environment Ministry of Environment
Meadow Creek fry kokanee enumeration	John Bell Murray Pearson	Ministry of Environment Ministry of Environment
Meadow Creek adult kokanee enumeration	John Bell Murray Pearson	Ministry of Environment Ministry of Environment
Kokanee analysis	Dale Sebastian Harvey Andrusak David Johner Patricia Woodruff	Ministry of Environment Redfish Consulting Ltd. British Columbia Conservation Foundation British Columbia Conservation Foundation

Table 1.1. (continued)

South Arm kokanee eyed egg plants	Jeff Burrows Les Fleck Jordan Knox Marley Bassett Eva Schindler Gary Munro Mickey McDonald Traci Jensen Laird Siemens Greg Andrusak	Ministry of Environment Crystal Springs Contracting Crystal Springs Contracting Ministry of Environment Ministry of Environment Ministry of Environment Freshwater Fisheries Society of BC Freshwater Fisheries Society of BC Freshwater Fisheries Society of BC Redfish Consulting Ltd.
South Arm tributary adult kokanee enumeration	Les Fleck	Crystal Springs Contracting
Regional support	Jeff Burrows	Ministry of Environment
FWCP Technical Committee	Jeff Burrows Dale Sebastian David Wilson Trevor Oussoren Louise Porto	Ministry of Environment Ministry of Environment BC Hydro BC Hydro Fisheries and Oceans Canada
FWCP Steering Committee	Wayne Stetski Ted Down Kevin Conlin Maureen DeHaan Bruce MacDonald Richard Spilker Greg Mustard Joe Nicholas Byron Louis	Ministry of Environment Ministry of Environment BC Hydro BC Hydro Fisheries and Oceans Canada Public Representative Public Representative First Nations Respresentative First Nations Representative
Administration	Ed Hill James Baxter Beth Woodbridge Sue Ireland Charlie Holderman Deborah McNicol Corporate Services Division	FWCP[1] FWCP[1] FWCP[1] Kootenai Tribe of Idaho Kootenai Tribe of Idaho British Columbia Conservation Foundation Ministry of Environment
Editorial comments	Eva Schindler Harvey Andrusak Dr. Ken Ashley	Ministry of Environment Redfish Consulting Ltd BC Institute of Technology

[1] Fish and Wildlife Compensation Program – Columbia Basin

Table 1.2 Sampling activities – Kootenay Lake, 2007.

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, NH_3) 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^-), ammonia, 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 streams tributary to Kootenay Lake	Standard MoE, Region 4 procedures.
Kokanee fry enumeration	Spring monitoring at Meadow Creek Spawning Channel	Standard MoE, Region 4 procedures.

CHAPTER 2

FERTILIZER LOADING IN KOOTENAY LAKE, YEAR 16 (NORTH ARM) AND YEAR 4 (SOUTH ARM) (2007)

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) was used for the fertilization experiment in the North Arm of Kootenay Lake. The total quantity of added fertilizer in 2007 was 46.2 tonnes of phosphorus and 246.9 tonnes of nitrogen. 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 10.7 in the late summer (Table 2.1). The amounts phosphorus and nitrogen added from 1992 to 2007 are listed in Table 2.2.

South Arm

In 2003, an analysis of the nutrient gradient had compared the North Arm with the South Arm. The results indicated that there was no phosphorus gradient, but a decreasing nitrogen gradient was present from the North Arm to the South Arm. Therefore, a decision was made to add nitrogen only to the South Arm during 2004. Nitrogen alone has been added to the South Arm since 2004. An agricultural grade of 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 10th to September 9th in 2007 (Table 2.3).

Fertilizer application

North Arm

Nutrients were applied to the North Arm using a tug and barge, as in 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 of the tug into the prop wash from the propeller (Ashley et al. 1999). The fertilizer is required to mix in with the prop wash as it is significantly heavier than water – 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 nutrients for the South Arm experiment were dispensed from the Western Pacific Marine/Ministry of Transportation and Highways MV Balfour ferry in 2007. Two fertilizer trucks each carrying 35 tonnes of fertilizer drove on to the ferry and the nutrients were dispensed into the lake from the trucks via two dispensing bars located at the stern of the vessel and into the propeller wash of the ferry 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. Nitrogen was not added to the lake on August 1st due to the MV Balfour ferry requiring repair. On August 8th half of the planned nitrogen was added due to a fertilizer truck breaking down.

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 rates increased. This loading schedule was conducted as in previous years to adaptively manage for nitrogen consumption in the water column as the season progressed (Table 2.1, Fig 2.1). The total load of fertilizer distributed in 2007 in the North Arm was 46.2 tonnes of phosphorus and 246.9 tonnes of nitrogen.

South Arm

Nitrogen additions to the South Arm of Kootenay Lake were maintained at a similar rate each week (Table 2.3, Fig. 2.2). The total load of fertilizer distributed in 2007 in the South Arm was 245 tonnes of nitrogen (274 tonnes was initially planned). In previous years the following was added to the South Arm; in 2004, 124 tonnes of nitrogen was added, in 2005, 234 tonnes and in 2006, 257 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 and Les Fleck for assisting with dispensing for the South Arm project.

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Table 2.1. Kootenay Lake North Arm nutrient loading of fertilizer during 2007 – 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 22	7.5	1,307	8.8	5.1	880	0.0	0.67
2	Apr 29	7.5	1,307	8.8	5.1	880	0.0	0.67
3	May 06	12.8	1,227	15.0	8.6	1,500	0.0	0.67
4	May 13	16.2	2,821	19.0	10.9	1,900	0.0	0.67
5	May 20	18.7	3,252	21.9	56.4	9,792	27.2	3.0
6	May 27	22.5	3,905	26.3	68.0	11,814	32.8	3.0
7	June 03	22.5	3,905	26.3	68.0	11,814	32.8	3.0
8	June 10	18.7	3,252	21.9	84.5	14,678	44.6	4.5
9	June 17	15.0	2,598	17.5	67.6	11,746	35.7	4.5
10	June 24	12.8	2,220	15.0	79.6	13,829	44.0	6.2
11	July 01	13.7	2,376	16.0	103.6	17,980	58.5	7.6
12	July 08	13.7	2,376	16.0	103.6	17,980	58.5	7.6
13	July 15	6.8	1,188	8.0	51.8	8,990	29.2	7.6
14	July 22	13.7	2,376	16.0	103.6	17,980	58.5	7.6
15	July 29	9.5	1,648	11.1	101.3	17,596	58.9	10.7
16	Aug 05	9.8	1,707	11.5	100.2	17,390	58.0	10.2
17	Aug 12	9.4	1,633	11.0	99.9	17,340	58.0	10.6
18	Aug 19	9.4	1,633	11.0	99.9	17,340	58.0	10.6
19	Aug 26	12.8	2,227	15.0	102.1	17,734	58.0	8.0
20	Sept 02	12.8	2,227	15.0	102.1	17,7034	58.0	8.0

1 Tonnes refers to the amount of fertilizer added, for example 12.0 tonnes of 10-34-0 has 1,786 kg of phosphorus and 1,203 kg of nitrogen.
2 The N:P ratio refers to the ratio of the fertilizer.

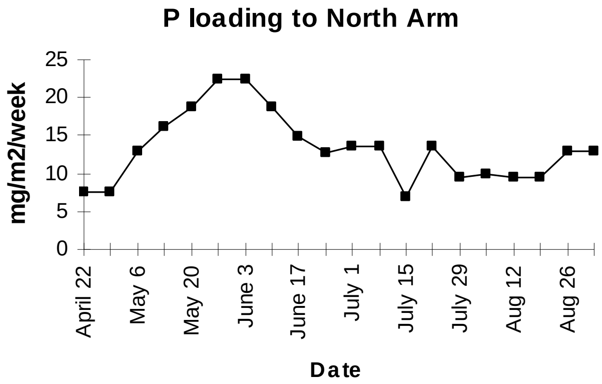
Table 2.2. Total tonnes of phosphorus and nitrogen dispensed into the North Arm of Kootenay Lake from liquid agricultural fertilizer, 1992 to 2007.

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

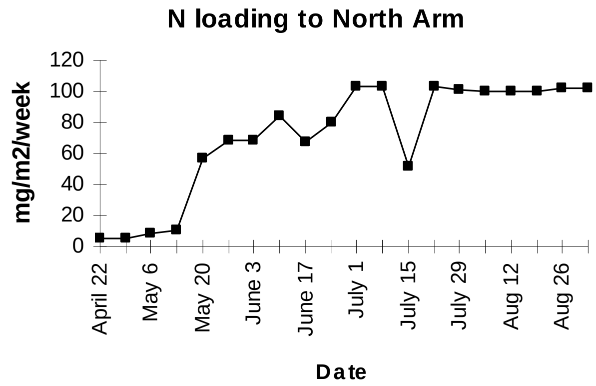
Table 2.3. Kootenay Lake South Arm nutrient loading of fertilizer during 2007 – liquid urea ammonium nitrate (28-0-0).

Week	Date	Nitrogen Load mg/m^2	Nitrogen Amount kgs	Fertilizer 28-0-0 Tonnes[1]
1	Jun 10	85.9	19,600	70.0
2	Jun 17	85.9	19,600	70.0
3	Jun 24	85.9	19,600	70.0
4	Jul 01	85.9	19,600	70.0
5	Jul 08	85.9	19,600	70.0
6	Jul 15	85.9	19,600	70.0
7	Jul 22	85.9	19,600	70.0
8	Jul 29	0	0	0
9	Aug 05	43.0	9,800	35.0
10	Aug 12	85.9	19,600	70.0
11	Aug 19	85.9	19,600	70.0
12	Aug 26	85.9	19,600	70.0
13	Sep 02	85.9	19,600	70.0
14	Sep 09	85.9	19,600	70.0

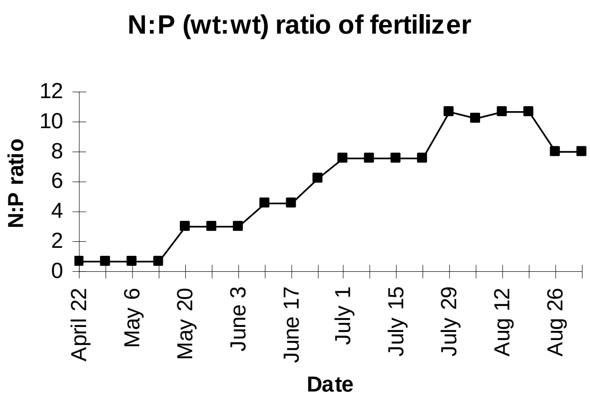
[1] Tonnes refers to the amount of fertilizer added.



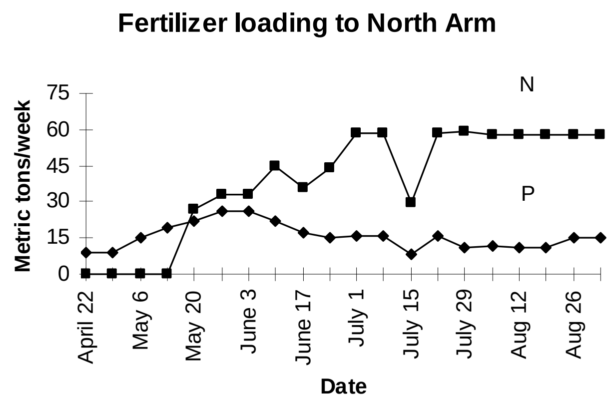
a)



b)

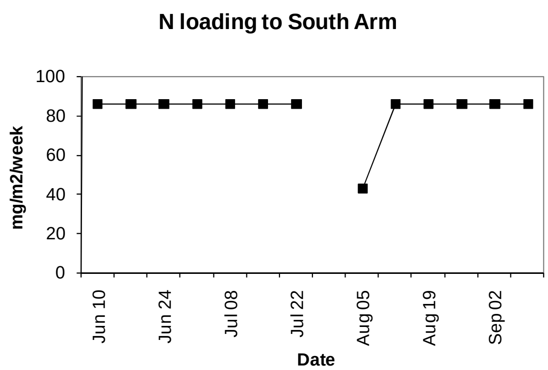


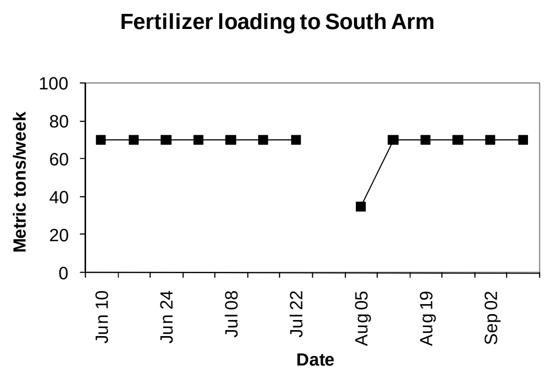
c)



d)

Figure 2.1. Kootenay Lake nutrient loading in 2007 with weekly distributions of: a) phosphorus loading to the North Arm, b) nitrogen loading to the North Arm, c) the N:P ratio (wt:wt) of fertilizer dispensed, and d) the combined nutrient loading of fertilizer in tonnes per week.





a) b)

Figure 2.2. Kootenay Lake South Arm nutrient loading in 2007 with weekly distributions of nitrogen to the South Arm, a) mg/m^2/week and b) tonnes of fertilizer per week.

CHAPTER 3

PHYSICAL AND CHEMICAL LIMNOLOGY OF KOOTENAY LAKE IN RESPONSE TO NUTRIENT ADDITION, YEAR 16 (NORTH ARM) AND YEAR 4 (SOUTH ARM) (2007)

by

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Introduction

Carefully monitored additions of limiting nutrients were used as a restoration technique for reversing oligotophication of the Kootenay Lake ecosystem. Prior to addition of limiting nutrients, Kootenay Lake was ultra-oligotrophic resulting from impoundment of naturally occurring nutrients due to the construction of upstream hydroelectric impoundments. Nutrient additions have been used in British Columbia, Alaska, Idaho and Sweden as a technique for rebuilding depressed sockeye and kokanee stocks 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).

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. Oligotrophication (Ney 1996), which triggered a decline of the keystone species, kokanee (*Oncorhynchus nerka*).

The strategy of the nutrient enrichment program was to use a ‘bottom up’ approach to rebuild depressed kokanee and rainbow trout (*Oncorhynchus mykiss*) populations in Kootenay Lake (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) (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.

This report summarizes the physical and chemical limnology data collected on the North, South and West arms of Kootenay Lake in 2007. Data from previous years can be found in previous Kootenay Lake Fertilization Experiment annual reports (Wright et al. 2002; Schindler et al. 2006, 2007a, b, 2009).

Methods

Physical and chemical data were collected at pre-established Kootenay Lake Fertilization (KLF) sampling sites simultaneously with the collection of phytoplankton and samples (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 centimetres 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 analysis was also conducted by the water chemistry lab, and these data are graphed. Water transparency was measured at each station using a standard 20-cm Secchi disk.

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 shipped within 24 h of collection to PSC Analytical Services (now 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, dissolved inorganic nitrogen (DIN), silica, alkalinity, total organic carbon (TOC), and chlorophyll a (Chl *a*). Prior to shipping to the lab, Chl *a* samples were prepared by filtering a portion of the integrated water sample through a filter with 0.45 µm pore size. At the lab, the filters were placed in centrifuge tubes with 90% buffered acetone and sonicated to rupture the algal cells and homogenize the filters. Chl a concentrations were then calculated from formulae using the absorbance of the supernatant at specific wavelengths.

The epilimnion integrated depth was changed from 30 m in previous years to 20 m because 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 representing the epilimnetic layer. The integrated sample to 20-m is the same as the depth 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 at the lab (as above) of OP, TP, TDP, DIN, and Chl *a*

In this report, average results of samples collected from integrated samples from the spring, summer, and fall of 1997 to 2007 are presented for the North Arm and the South Arm of Kootenay Lake. Detailed data and analysis for the 1997 to 2006 sampling seasons are available in previous annual reports. All data are on file at the BC Ministry of Environment office in Nelson, B.C.

Results and Discussion

Physical Limnology

Temperature

Kootenay Lake, a warm monomictic lake, is generally isothermal from early winter to early spring and stratified during the summer (Wetzel 2001). The main body of Kootenay Lake (stations KLF 1-7) begins warming in June with a strong thermocline developing by July (Figs 3.1-3.7). Fall turnover started in November with an initial deepening of the thermocline

The shallow, riverine West Arm of Kootenay Lake is quite 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 November, temperatures were fairly uniform from the surface to the bottom depth (Table 3.2).

A maximum surface temperature of 23.1ºC was recorded in August in the South Arm (KLF 7). The maximum surface temperature in the North Arm was 20.5ºC in August at stations KLF 3 and KLF 4. During the same time, hypolimnetic temperatures remained 4-6ºC throughout the year. The West Arm remained isothermal throughout the year, due to its riverine morphology with a maximum temperature of 19.3ºC was recorded in August in 2007 (Table 3.2).

Table 3.2. Seasonal mean (± standard deviation), maximum, and minimum temperatures in the West Arm (KLF 8) taken at 0-35 m depths, 2007.

Month	Mean	+SD	Maximum	Minimum
May	5.7	0.37	7.1	5.5
June	12.2	0.33	13.9	11.9
July	13.8	0.57	16.1	13.3
August	19.3	0.63	19.8	17.6
September	16.6	0.18	16.9	16.2
October	13.9	0.07	13.9	12.8
November	10.8	0.09	10.8	10.1

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). Moreover, 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 hypolimnetic oxygen concentrations.

Secchi Depth

In 2007, Secchi depths varied seasonally from summer to winter from 3.3 m to 14.0 m in the North Arm, 3.7 m to 9.5 m in the South Arm, and 3.7 m to 13.1 m in the West Arm (Fig 3.8). Secchi measurements evaluate the transparency of the water column to light, hence can serve as a general indicator of algal biomass (Wetzel 2001). Similar to past years, Secchi disc measurements at all stations on Kootenay Lake in 2007 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.

Since 1997, average Secchi depths have shown a gradual increase in transparency for the spring season in both the North and South arms (Table 3.3). On the other hand, average Secchi depths have remained relatively consistent throughout the summer since 1997.

Table 3.3. Average Secchi depth (m) in spring (April-June), summer (July-September), and fall (October-November) for the North and South arms of Kootenay Lake, 1997-2007*.

Year	North Arm **KLF 1-4			South Arm **KLF 5-7		
	Spring	Summer	Fall	Spring	Summer	Fall
1997	4.8	5.6	8.4	3.1	5.1	7.6
1998	6.6	7.6	6.7	5.2	7.5	7.5
1999	7.3	5.2	9.0	6.2	5.6	8.2
2000	6.4	6.0	7.3	6.4	6.5	9.6
2001	8.0	6.5	10.1	7.2	7.4	8.7
2002	9.4	5.8	7.9	6.6	5.5	4.7
2003	8.8	6.4	7.7	7.7	6.0	9.1
2004	8.9	6.4	7.8	7.8	7.0	9.3
2005	8.8	5.9	9.1	8.8	7.0	10.0
2006	9.6	5.6	10.9	7.8	6.6	11.3
2007	8.0	4.6	8.7	6.7	5.3	8.9

*Prior to 2003, fall data were for October only.
**Prior to 2004, North Arm data calculated from KLF 2 & 4, South Arm data calculated from KLF 6 & 7.

Turbidity

Turbidity is caused by suspended particles (e.g., fine particulate matter), plankton and other small organisms (Wetzel and Likens, 2000). Results in the North Arm in 2007 indicated a general increase from April to June and then a decline through the summer and into the fall (Fig 3.9). The peak in June coincides with the spring freshet – the lake became turbid due to increased particulate matter entering the lake from the inflowing glacially turbid Duncan River. The trend coincides with the seasonal trend of Secchi depth measurements in the North Arm (Fig. 3.8). Turbidity in the South Arm had a similar trend to the North Arm with one exception. At station KLF 7, the turbidity was high in April - this resulted from particulate matter entering the lake from the Kootenay River.

In the period 1997-2007, average turbidity values ranged from 0.29-0.99 NTU in the North Arm and 0.25-1.80 NTU in the South Arm (Table 3.4). The increase in turbidity in the spring of 1997 could be attributed to higher discharge from the Kootenay River (Fig. 3.32). The increase in turbidity during the spring months in the South Arm in 2006 and 2007 could be attributed to additional discharge entering the lake resulting from a change in Libby Dam operations.

Table 3.4. Average turbidity (NTU) from 0-20 m in spring (April-June), summer (July-September), and fall (October-November) for the North and South arms of Kootenay Lake, 1997-2007*.

Year	North Arm **KLF 1-4			South Arm **KLF 5-7		
	Spring	Summer	Fall	Spring	Summer	Fall
1997	0.65	0.65	0.36	1.80	0.66	0.43
1998	0.46	0.72	0.44	0.74	0.39	0.25
1999	0.61	0.72	0.39	0.83	0.57	0.36
2000	0.42	0.47	0.55	0.69	0.41	0.25
2001	0.29	0.60	0.35	0.29	0.40	0.36
2002	0.61	0.99	0.42	0.96	0.73	0.48
2003	0.35	0.62	0.41	0.50	0.66	0.42
2004	0.35	0.71	0.40	0.36	0.73	0.31
2005	0.48	0.63	0.27	0.37	0.59	0.27
2006	0.53	0.92	0.34	0.71	0.69	0.23
2007	0.59	0.70	0.39	0.73	0.56	0.32

*Prior to 2003, fall data were for October only and samples collected from 0-30 m.
**Prior to 2004, North Arm data calculated from KLF 2 & 4, South Arm data calculated from KLF 6 & 7.

Conductivity

Conductivity or specific conductance is a measure of resistance of a solution to electrical flow (Wetzel 2001). Results from integrated samples (0-20 m) ranged between 124-160 µS/cm in the North Arm, between 142-185 µS/cm in the South Arm, and between 147-168 µS/cm in the West Arm in 2007 (Figure 3.10).

In the period 1997-2007, average conductivity values ranged between 130-163 µS/cm in the North Arm and 130-183 µS/cm in the South Arm (Table 3.5). Conductivity in the South Arm was higher than the North Arm; this is consistent to that reported in Northcote et al. (1999) and Daley et al. (1981). The differences between the North and South arms are attributed to the specific geology of the two major basins that flow into Kootenay Lake. Note: in Schindler et al. 2007 and 2009, the average conductivity value in the spring of 2000 was listed as 92. After further review of the data, it was determined there was an outlier and this was not included in the calculation listed in this report.

Table 3.5. Average conductivity (µmhos/cm) from 0-20 m in spring (April-June), summer (July-September), and fall (October - November) for the North and South arms of Kootenay Lake, 1997-2007*.

Year	North Arm **KLF 1-4			South Arm **KLF 5-7		
	Spring	**Summer**	**Fall**	**Spring**	**Summer**	**Fall**
1997	163	143	152	165	162	173
1998	153	146	148	164	169	176
1999	163	135	106	183	144	130
2000	131	132	134	143	153	159
2001	135	137	134	140	152	167
2002	155	124	127	151	157	151
2003	154	135	127	159	153	153
2004	145	137	142	150	165	167
2005	153	131	154	163	172	178
2006	148	133	152	162	172	179
2007	146	130	147	168	164	172

*Prior to 2003, fall data were for October only and samples collected from 0-30m.
**Prior to 2004, North Arm data calculated from KLF 2 & 4, South Arm data calculated from KLF 6 & 7.

Chemical Limnology

Integrated Sampling 0-20 m

Phosphorus

Total phosphorus (TP) samples, taken at 0-20 m ranged between 3 - 9 µg/L in the North Arm, 2 - 11 µg/L in the South Arm, and 3 - 6 µg/L in the West Arm (Figure 3.11). The result of 11 µg/L in the South Arm at station KLF 5 in September could possibly be an outlier as the other South Arm concentrations were between 4 - 6 µg/L. Seasonal variation in the results was similar amongst the North, South and West arms of the lake.

The average TP in Kootenay Lake ranged between 2 - 22.2 µg/L from 1997 to 2007 (Table 3.6) indicative of an oligotrophic to oligo-mesotrophic system (Wetzel 2001). The peak concentration occurred in the spring of 1997 when turbidity was also high (Table 3.5) 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 over this 10 year period. The decline in total phosphorus in the South Arm coincides with a decrease in discharge from the Kootenay River. Binsted and Ashley (2006) have provided a detailed overview of discharge and phosphorus loadings to Kootenay Lake from these two major rivers.

Table 3.6. Average total phosphorus (TP; µg/L) from 0-20 m in spring (April-June), summer (July-September), and fall (October - November) for the North and South arms of Kootenay Lake, 1997-2007*.

Year	North Arm **KLF 1-4			South Arm **KLF 5-7		
	Spring	Summer	Fall	Spring	Summer	Fall
1997	14.0	10.5	5.0	22.2	8.8	6.0
1998	4.3	7.0	4.5	5.0	6.8	5.5
1999	4.8	5.5	4.5	6.2	5.3	6.5
2000	5.0	10.0	7.5	5.8	9.2	7.5
2001	7.7	6.0	3.0	3.5	4.8	2.5
2002	6.3	3.8	5.5	7.8	5.2	3.5
2003	3.5	5.0	7.8	4.3	4.5	4.0
2004	3.5	3.3	5.5	2.9	3.9	6.2
2005	4.4	3.0	2.0	3.1	2.8	2.0
2006	3.1	3.3	2.0	4.0	3.2	2.0
2007	5.8	4.4	3.9	5.2	5.0	3.7

*Prior to 2003, fall data were for October only and samples collected from 0-30m.
**Prior to 2004, North Arm data calculated from KLF 2 & 4, South Arm data calculated from KLF 6 & 7.

Total dissolved phosphorus (TDP) ranged between 3 - 7 µg/L in the North Arm, 2 - 9 µg/L in the South Arm, and 3 - 5 µg/L in the West Arm (Fig 3.12). The North and South arms had similar trends in seasonal TDP except for a result of 9 µg/L at station KLF 4 in April . The trend of higher TDP results in the spring, followed by a sharp decline is most likely associated with the rapid biological utilization of TDP coinciding with spring algal production in the epilimnion.

From 1997 to 2007, epilimnetic TDP ranged between 2 - 8 µg/L (Table 3.7). The result of 8 µg/L occurred in the spring of 1997; and coincided with a higher concentration of TP (Table 3.6). Results from 1998 to 2006 were similar, with a slight increase in 2007. Phosphorus concentrations are indicative of an oligotrophic ecosystem (Wetzel, 2001).

Table 3.7. Average total dissolved phosphorus (TDP; µg/L) from 0-20 m in spring (April-June), summer (July-September), and fall (October-November) for the North and South arms of Kootenay Lake, 1997-2007*.

Year	North Arm **KLF 1-4			South Arm **KLF 5-7		
	Spring	**Summer**	**Fall**	**Spring**	**Summer**	**Fall**
1997	4.3	3.5	4.0	8.0	4.3	3.0
1998	2.7	2.0	2.0	3.3	2.0	2.0
1999	2.8	2.3	2.5	3.0	2.3	2.5
2000	2.0	3.5	4.0	2.5	5.0	4.5
2001	3.5	2.0	2.0	2.2	2.7	2.5
2002	4.0	2.8	4.0	4.0	4.0	3.0
2003	2.8	2.5	3.5	3.2	3.3	4.8
2004	2.2	2.3	4.0	2.0	3.3	3.5
2005	2.8	2.1	3.0	2.2	2.2	2.0
2006	2.8	2.5	2.6	2.9	2.8	2.0
2007	4.8	4.0	3.8	5.4	4.0	3.5

*Prior to 2003, fall data were for October only and samples collected from 0-30m.
**Prior to 2004, North Arm data calculated from KLF 2 & 4, South Arm data calculated from KLF 6 & 7.

Nitrogen

The nitrogen cycle within freshwaters is highly complex and occurs through various forms of fixation, assimilation, and reduction (Wetzel 2001). In fresh water, complex biochemical processes utilize nitrogen in many forms consisting of dissolved molecular $N_{2,}$ ammonia nitrogen, nitrite, nitrate, 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.

Total nitrogen (TN) ranged between 100 - 230 µg/L in the North Arm, 130 - 250 µg/L in the South Arm and 120 - 240 µg/L in the West Arm (Fig. 3.13). 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 125 - 343 µg/L in the North Arm and 125 - 228 µg/L in the South Arm (Table 3.8). Spring TN values were higher than the summer and fall results. The highest recorded value was in the North Arm during the spring of 2001 and the lowest value recorded was during the fall of 2003.

Table 3.8. Average total nitrogen (TN; µg/L) from 0-20 m in spring (April-June), summer (July-September), and fall (October-November) for the North and South arms of Kootenay Lake, 1997-2007*.

Year	North Arm **KLF 1-4			South Arm **KLF 5-7		
	Spring	**Summer**	**Fall**	**Spring**	**Summer**	**Fall**
1997	218	143	130	212	130	125
1998	225	192	135	227	187	150
1999	220	190	275	228	180	220
2000	213			177		
2001	343	167	145	215	163	105
2002	200	177	175	210	180	235
2003	182	302	125	177	155	90
2004	192	148	148	168	128	168
2005	178	153	145	160	126	142
2006	219	142	164	224	151	176
2007	196	140	151	206	157	155

*Prior to 2003, fall data were for October only and samples collected from 0-30m.
**Prior to 2004, North Arm data calculated from KLF 2 & 4, South Arm data calculated from KLF 6 & 7.

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). Dissolved inorganic nitrogen (DIN) concentrations ranged between 38 - 152 µg/L in the North Arm, 41 - 171 µg/L in the South Arm, and 20 - 159 µg/L in the West Arm (Fig 3.14).

Similar to TN, all three arms indicated a similar trend of declining DIN from spring to fall followed by an increase in late fall. This pattern coincides with the seasonal growth of phytoplankton and biological utilization of nitrogen in the epilimnion.

The range of average DIN concentrations have been 35 - 157 µg/L in the North Arm and 32 - 145 µg/L in the South Arm since 1997 (Table 3.9). A general pattern of declining DIN concentrations from spring to summer within each year is evident. Importantly, this pattern coincides with the natural influx of nutrients associated with freshet conditions and the anthropogenic influx of nutrients from nutrient additions. Variability in the spring concentrations of DIN can be directly attributed to climatic influences such as precipitation and seasonal timing of the run-off.

Table 3.9. Average dissolved inorganic nitrogen (DIN; µg/L) from 0-20 m in spring (April-June), summer (July-September), and fall (October-November) for the North and South arms of Kootenay Lake, 1997-2007*.

Year	North Arm **KLF 1-4			South Arm **KLF 5-7		
	Spring	**Summer**	**Fall**	**Spring**	**Summer**	**Fall**
1997	118	89	70	113	64	62
1998	120	75	32	123	83	86
1999	147	94	90	130	80	77
2000	35	69	71	42	54	68
2001	157	82	69	145	83	57
2002	133	75	58	108	44	57
2003	108	50	67	114	71	63
2004	123	55	61	105	39	72
2005	109	51	81	107	32	80
2006	119	64	85	120	78	97
2007	119	65	95	113	58	94

*Prior to 2003, fall data were for October only and samples collected from 0-30m.
**Prior to 2004, North Arm data calculated from KLF 2 & 4, South Arm data calculated from KLF 6 & 7.

Silica

Silica is an integral structural component in diatomaceous algae and is considered a major factor influencing algal production in many lakes (Wetzel 2001). Moreover, silica can have a strong influence on the succession and productivity of algal communities in lakes and streams. As a result, silica can be considered a limiting factor in diatom production when its availability is low. Silica occurs primarily in two major forms: dissolved silicic acid and particulate silica.

Dissolved reactive silica ranged between 1.7 – 4.8 mg/L in the North Arm and 2.9 – 6.6 mg/L in the South Arm and 2.9 – 5.2 mg/L in the West Arm (Fig 3.15). Declining silica concentrations from spring to summer-fall were observed for all three arms of Kootenay Lake in 2007. This pattern is associated with the biological utilization of silica during the diatom bloom that generally peaks by late spring.

In general, silica tends to display little variation in natural waters around the world compared to other inorganic constituents (Wetzel 2001). Since 1997, silica concentrations on Kootenay Lake have tended to be slightly higher in the South Arm than in the North Arm and this trend continued in 2007.

Table 3.10. Average silica (mg/L) from 0-20 m in spring (April-June), summer (July-September), and fall (October-November) for the North and South arms of Kootenay Lake, 1997-2007*.

Year	North Arm **KLF 1-4			South Arm **KLF 5-7		
	Spring	**Summer**	**Fall**	**Spring**	**Summer**	**Fall**
1997	4.8	4.0	3.5	6.8	5.1	4.3
1998	4.9	4.2	3.5	6.3	5.3	4.7
1999	5.1	5.0	4.2	6.1	4.1	4.9
2000	5.4	4.4	3.3	6.4	5.4	4.3
2001	5.4	3.4	2.2	5.5	4.6	3.5
2002	5.2	3.5	4.0	6.0	4.2	4.7
2003	5.3	3.3	3.2	5.6	4.5	4.0
2004	4.9	4.2	3.7	5.7	4.6	4.8
2005	6.2	4.5	5.9	6.6	4.5	6.2
2006	6.6	4.3	4.1	7.4	5.8	4.7
2007	4.4	3.3	3.1	5.8	4.2	3.6

*Prior to 2003, fall data were for October only and samples collected from 0-30m.
**Prior to 2004, North Arm data calculated from KLF 2 & 4, South Arm data calculated from KLF 6 & 7.

pH and Alkalinity
In 2007, pH in Kootenay Lake indicated slightly alkaline conditions, ranging from 7.9 – 8.3 for all stations.

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 51.4 - 68 mg $CaCO_3$/L in the North Arm, 60.2 – 80.5 mg $CaCO_3$/L in the South Arm, and 62.2 - 70.8 mg $CaCO_3$/L in the West Arm (Fig 3.16). No distinct pattern was observed throughout the sampling period from April-November.

During 1997-2007, alkalinity has remained consistent, ranging from a low in 2002 (53 mg $CaCO_3$/L) in the North Arm to a high in the South Arm in 2006 (78 mg $CaCO_3$/L, Table 3.11). 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.

Table 3.11. Average alkalinity (mg $CaCO_3$/L) from 0-20 m in spring (April-June), summer (July-September), and fall (October-November) for the North and South arms of Kootenay Lake, 1997-2007*.

Year	North Arm **KLF 1-4			South Arm **KLF 5-7		
	Spring	**Summer**	**Fall**	**Spring**	**Summer**	**Fall**
1997	64	55	57	67	63	67
1998	65			67		
1999						
2000	62	58	57	63	66	70
2001		63	59		72	72
2002	68	53	58	66	67	69
2003	67	61	59	68	68	70
2004	63	58	59	66	68	70
2005	66	60	66	70	76	76
2006	63	59	65	69	74	78
2007	62	56	63	70	69	73

*Prior to 2003, fall data were for October only and samples collected from 0-30m.
**Prior to 2004, North Arm data calculated from KLF 2 & 4, South Arm data calculated from KLF 6 & 7.

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 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 - 2 mg/L in the North Arm, 0.7 - 2.8 mg/L in the South Arm, and 0.5 - 3.6 mg/L in the West Arm (Figure 3.17). 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 0.6 - 1.8 mg/L in the North Arm and 0.9 - 2.2 mg/L in the South Arm (Table 3.12). Although these values are at the low end of the range (TOC of 1 - 30 mg/L) in natural waters, they are consistent with oligotrophic systems (Wetzel 2001). The values suggest that the lake does not receive large allochthonous organic inputs or produce large amounts of autochthonous organic carbon.

Table 3.12. Average total organic carbon (TOC; mg/L) from 0-20 m in spring (April-June), summer (July-September), and fall (October-November) for the North and South arms of Kootenay Lake, 1997-2007*.

Year	North Arm **KLF 1-4			South Arm **KLF 5-7		
	Spring	Summer	Fall	Spring	Summer	Fall
1997	0.8	1.4	0.6	1.4	1.6	0.9
1998	1.1	1.5	1.2	1.5	1.8	1.5
1999	1.8	1.3	1.3	1.8	1.7	1.6
2000	1.0	1.1	1.1	1.3	1.3	1.2
2001	1.0	1.2	1.1	1.0	1.4	1.0
2002	1.2	1.2	1.2	1.6	1.9	1.6
2003	1.4	1.6	1.4	1.6	1.5	1.7
2004	1.1	1.1	1.3	1.2	1.5	1.2
2005	1.0	1.1	1.0	1.1	1.7	0.8
2006	1.2	1.1	1.7	1.7	2.2	1.7
2007	1.1	1.2	1.0	1.5	1.6	1.2

*Prior to 2003, fall data were for October only and samples collected from 0-30m.
**Prior to 2004, North Arm data calculated from KLF 2 & 4, South Arm data calculated from KLF 6 & 7.

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, and may be loosely correlated with productivity under some conditions. Importantly, chlorophyll concentrations are highly variable because of many dynamic physical and chemical processes within lake systems.

Chl *a* ranged between 0.5 - 5.5 µg/L in the North Arm, 0.6 - 4.3 µg/L in the South Arm, and 0.5 - 3.5 µg/L in the West Arm in 2007 (Figure 3.18). The peak in the North Arm occurred in July at station KLF 1 with a result of 5.5 µg/L. The peak in the South Arm occurred in July at station KLF 5 with a result of 4.3 µg/L. The peak in the West Arm occurred one month later with a result of 4 µg/L. Over the sampling season, Chl *a* increased each month until the peak was reached and then declined to the fall months. This trend coincides with the integrated phytoplankton results (see Fig 4.1 in Chapter 4 of this report).

From 1997 - 2007, average Chl *a* concentrations have ranged between 1 - 4.5 µg/L in the North Arm and 0.8 - 4.8 µg/L in the South Arm (Table 3.13). In the 1997 to 2000 period, Chl*a* was generally higher in the spring than the summer. This could be attributed to correspondence with the spring phytoplankton bloom and decreased nutrient loading. From 2001 onward, Chl *a* results generally were highest in the summer months; this coincides with higher nutrient loads added to the North Arm than the 1997 to 2000 period (see Chapter 2 for details). Summer chlorophyll *a* concentrations in the South Arm slightly increased during 2004 through 2007 compared to previous years, except in 2002. This slight increase could be attributed to the South Arm nutrient additions which commenced in 2004.

Table 3.13. Average chlorophyll *a* (Chl *a*; µg/L) from 0-20 m in spring (April-June), summer (July-September), and fall (October- November) for the North and South arms of Kootenay Lake, 1997-2007*.

Year	North Arm **KLF 1-4			South Arm **KLF 5-7		
	Spring	Summer	Fall	Spring	Summer	Fall
1997	4.1	1.7	2.2	2.4	1.9	4.3
1998	2.0	1.5	1.0	2.3	1.6	1.1
1999	2.6	1.8	1.6	3.5	1.7	2.1
2000	3.5	1.5	1.1	1.1	1.2	1.1
2001	2.8	2.6	1.1	2.2	1.7	0.8
2002	3.2	3.5	4.1	2.4	3.8	4.8
2003	1.6	3.2	1.7	1.2	1.8	1.4
2004	1.9	2.7	2.1	1.7	2.8	2.8
2005	1.8	2.4	1.1	1.5	2.7	1.2
2006	1.3	3.6	2.3	1.3	2.9	1.7
2007	1.4	4.5	1.6	1.8	3.5	1.4

*Prior to 2003, fall data were for October only and samples collected from 0-30m.
**Prior to 2004, North Arm data calculated from KLF 2 & 4, South Arm data calculated from KLF 6 & 7.

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 13 and 16 µg/L at 2 and 5 metres, respectively) than the other stations. North Arm results ranged between 2 and 9, (peak stations KLF 2, July at 10 m). South Arm results ranged between 3 and 7 µg/L. The peak result was in July at 5 m at station KLF 7 (Fig. 3.19).

Dissolved Inorganic Nitrogen

Nitrate and nitrite are the majority of the contribution to dissolved inorganic nitrogen – ammonia is generally at the minimum detection limit of 5 µg/L in Kootenay Lake. Ammonia was not analyzed in 2007; therefore the DIN 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. 3.20). The decrease in nitrate and nitrite over the season is indicative of nitrogen uptake by phytoplankton. Nitrate was limiting in August at all stations at depths of 2 and 5 metres. A nitrate concentration of 20 µg/L or less is considered to be limiting for phytoplankton (Wetzel, 2001, Ashley and Stockner, 2003).

Nitrogen to phosphorus ratios (dissolved fractions) (weight:weight) generally were higher than 10:1 throughout the season. 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 2 in June at depths of 2 and 5 metres and in July and August at depths of 2, 5, and 10 metres. Ratios were less than 10:1 at station KLF 4 in July and August at 2, 5 and 10 metres. In the South Arm ratios were less than 10:1 in July at stations KLF 6 and 7 at 2 metres, in August at 2, 5, 10 and 15 metres and in September at 2 and 5 metres. The lower N:P ratios in the South Arm further supports the rationale to only add nitrogen to the South Arm.

Chlorophyll a

Discrete depth chlorophyll *a* (Chl *a*) results were similar in the North and South arms. The range of results was 1- 5.3 µg/L and 0.9 to 4.8 µg/L in the North and South arms respectively. Peak Chl *a* occurred in July at stations KLF 4, 6 and 7. Peak biomass occurred in September at station KLF 2. The peak integrated phytoplankton biomass was also in July at stations KLF 4 and KLF 6 and in August at station KLF 7.

Hypolimnion samples

Turbidity ranged from 0.2 to 0.5 NTU and 0.2 to 0.6 NTU in the North and South arms respectively (Fig 3.23). There was no apparent seasonal trend in the North Arm but in the South Arm, turbidity was highest in May and then decreased as the summer advanced.

Conductivity was fairly uniform amongst sampling stations and months in the North Arm and the South Arm (Fig. 3.24).

Total dissolved phosphorus (TDP) and total phosphorus (TP) ranged between 2 – 7 µg/L in the North Arm and 2 – 6 µg/L in the South Arm (Figs. 3.25 and 3.26). Concentrations were highest in May, decreased in June and remained consistent from July to October.

Dissolved inorganic nitrogen (DIN) concentrations remained fairly consistent amongst stations in the North and South arms (Fig. 3.27). DIN in the hypolimnion was consistently higher than concentrations in the epilimnion. This is to be expected as photosynthetic activity occurs in the epilimnetic layer. Total nitrogen (TN) concentrations were higher than DIN and remained consistent amongst stations and dates in the North and South arm (Fig. 3.28).

Silica remained at similar concentrations throughout the sampling period. Concentrations ranged between 5.3 and 6.1 mg/L in the North Arm and 5.7 to 6.4 mg/L in the South Arm (Fig. 3.29).

Alkalinity was similar amongst stations and dates in both arms. The results ranged between 63 – 80 mg $CaCO_3$/L and 77 – 81 mg $CaCO_3$/L in the North Arm and South Arm, respectively.

Comparisons between years – Integrated epilimnion samples

Turbidity fluctuated over the years with the maximum turbidity occurring in the South Arm in 1997 (Fig. 3.31). This coincides with the Kootenay River having higher than average discharge in the same year (Fig. 3.32). Average spring turbidity correlated well with average spring discharge (Fig 3.33 and 3.34). A linear fit resulted in an r^2 of 0.68 and an ANOVA was statistically significant with $p<0.0001$.

Conductivity in both arms increased from 1992 to 1994 and then declined through 2000 where averages remained fairly uniform through 2007 (Fig. 3.35).

North Arm average total phosphorus concentrations varied from 4 - 5 µg/L from 1992 to 1995 and increased to 8 and 11 µg/L in 1996 and 1997, respectively (Fig. 3.37). In 1998 and 1999, the concentration decreased to 5.5 and 5 µg/L with a slight increase to 7.5 µg/L in 2000 (Fig. 3.37). From 2000 to 2007, concentrations have slightly declined. Since 2002, the average discharge from the Duncan River has also declined (Fig. 3.32). Total dissolved phosphorus in the North Arm remained uniform from 1992 to 1995 with a slight increase in 1996 and then has remained uniform from 1997 to 2007 (Fig. 3.36).

South Arm average total phosphorus varied from 3 to 4 µg/L from 1992 to 1995, increased to 10 and 14 µg/L in 1996 and 1997, respectively and then varied between 4 and 7.5 µg/L from 1998 to 2007 (Fig. 3.37). Total dissolved phosphorus illustrated a similar trend with concentrations ranging between 2.2 and 6.7 µg/L. The peaks in 1996 and 1997 coincided with peak average discharge from the Kootenai/y River (Fig. 3.32). The trend of phosphorus in the South Arm also coincides with the trend of tonnage of SRP (soluble reactive phosphorus) input from the Kootenai/y River. South Arm spring TP concentrations correlated well with spring average discharge (Fig. 3.38). A linear fit resulted in an r^2 of 0.55 and ANOVA was statistically significant with $p=0.001$.

Chlorophyll *a* (Chl *a*) concentrations ranged from 1.6 to 3.6 µg/L over the years. The highest concentration occurred in 1996, a year of high phosphorus input into Kootenay Lake from the Kootenai/y River (Fig 3.40). The lowest concentration occurred in 1998, one of the years of the reduced fertilizer additions to the North Arm (see Chapter 2 for details). The standard deviations were high due to the fact that there is a seasonal trend of Chl *a* (Fig. 3.18).

Dissolved inorganic nitrogen (DIN) ranged between 62 µg/L in 1995 to 140 µg/L in 2000. The DIN trend is seasonal (Fig 3.18); therefore the standard deviations are high. Typically, DIN is high in the spring and as photosynthetic activity increases in the summer, the nitrogen decreases as it is utilized by phytoplankton. The DIN concentration was lower in the South Arm than the North Arm for most years except in 1998, 2003 and 2006 (Fig. 3.41).

Average silica concentrations varied from 3.2 to 5.5 mg/L in the North Arm and 4.0 to 6.1 mg/L in the South Arm (Fig 3.42). The concentrations were well above 0.5 mg/L, which is the concentration considered to be limiting to diatom algae over the study period

(Wetzel 2001). Silica tended to be higher in the South Arm than the North Arm in most years.

Conclusion

The results of the 2007 nutrient enrichment, and the long term data from 1992 through 2007 were indicative that Kootenay Lake is now oligotrophic to oligo-mesotrophic based on nutrient and chlorophyll *a* concentrations.

In 2007, Kootenay Lake was phosphorus limited during the spring months and nitrogen limited in August at 2 and 5 metres in the epilimnion – this is an improvement from previous years where nitrogen limitation occurred in July and August at deeper depths within the epilimnion. This trend occurred in both arms – nitrogen only additions in the South Arm are recommended for future years. Long term total phosphorus results were similar between the North and South Arms, also indicative that phosphorus additions to the South Arm are not necessary. Silica concentrations were above the limitation required for the phytoplankton community.

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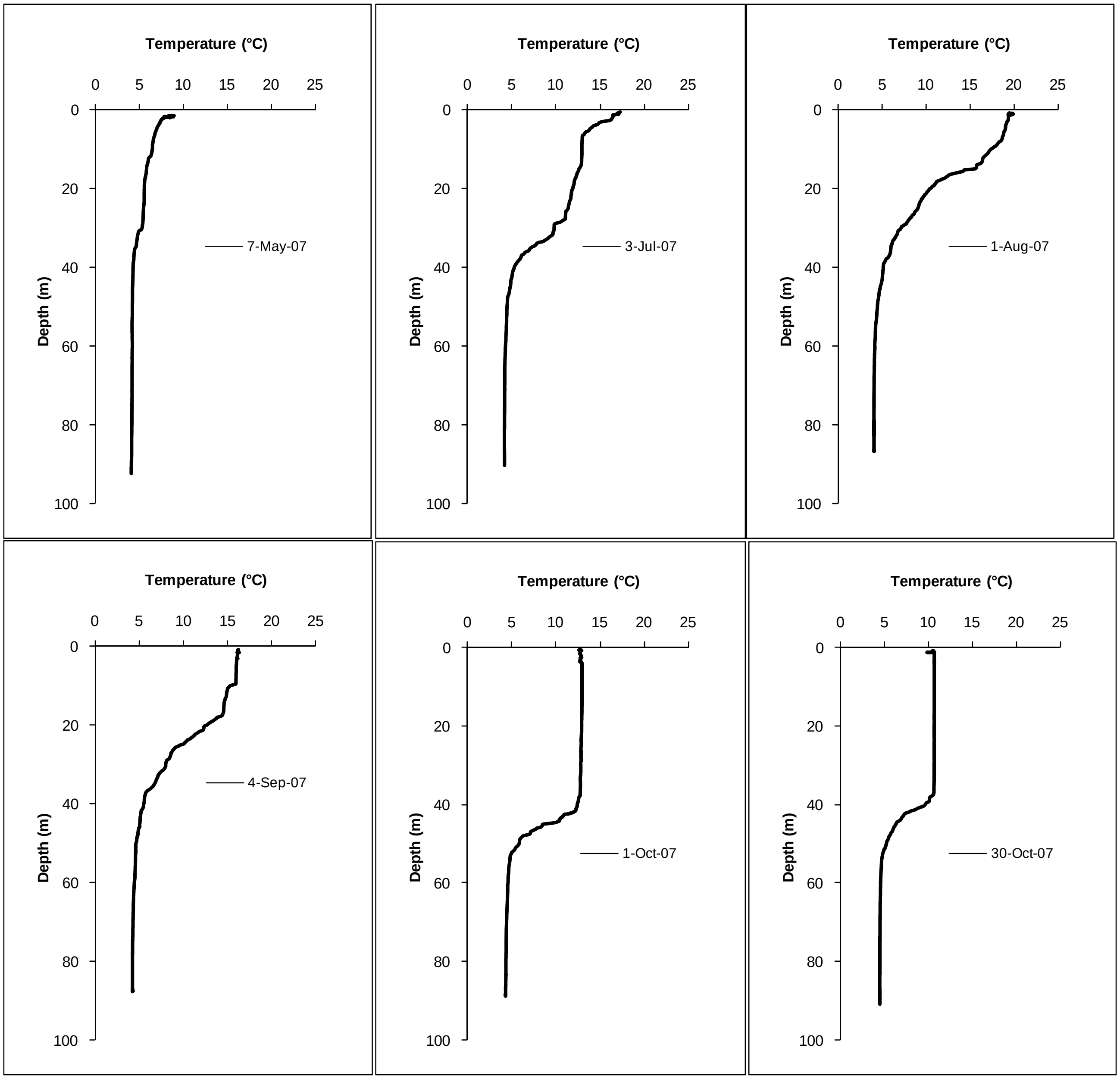


Figure 3.1. Temperature profiles, station KLF 1, May, July to November 2007.

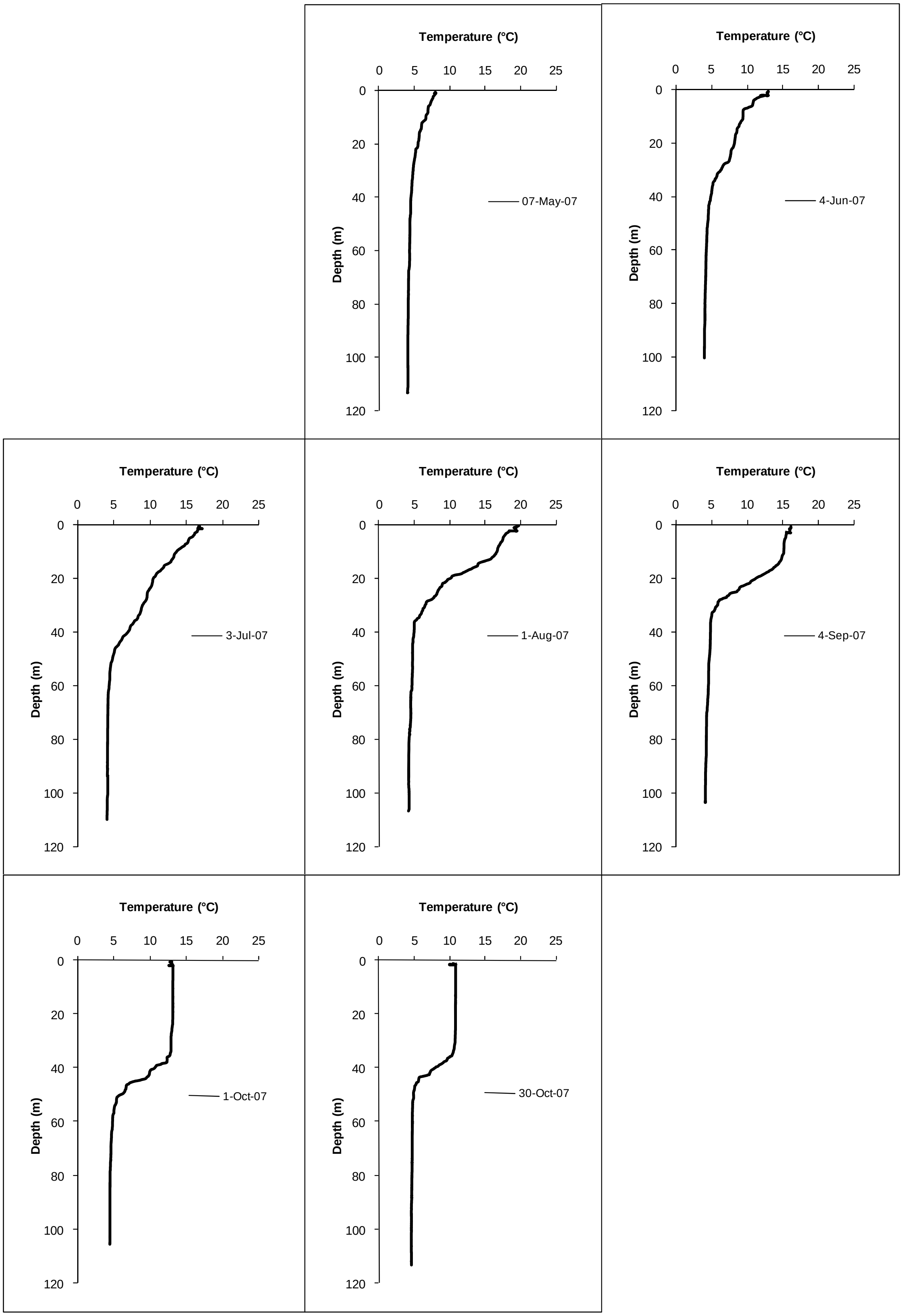


Figure 3.2. Temperature profiles, station KLF 2, May to November 2007.

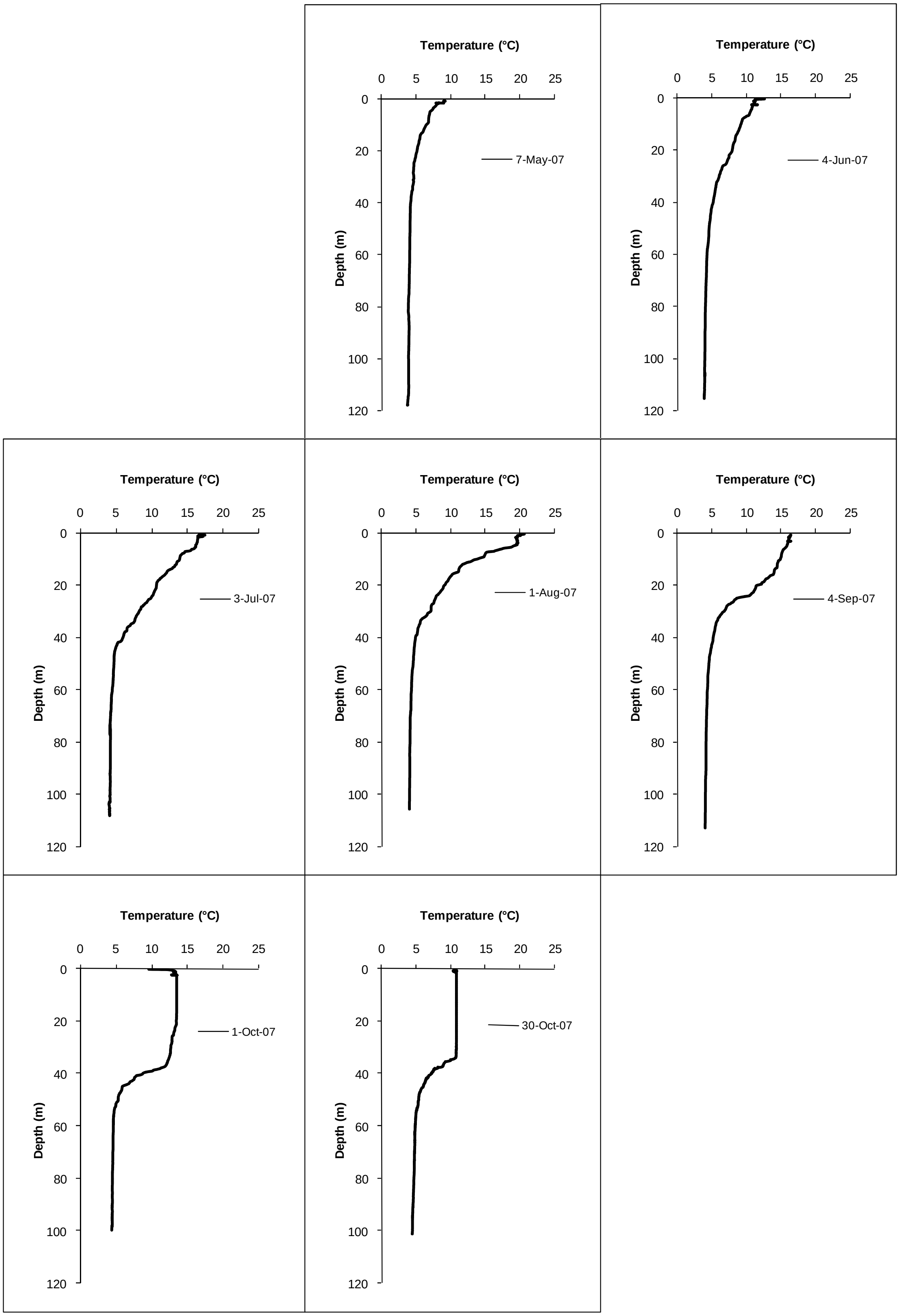


Figure 3.3. Temperature profiles, station KLF 3, May to November, 2007.

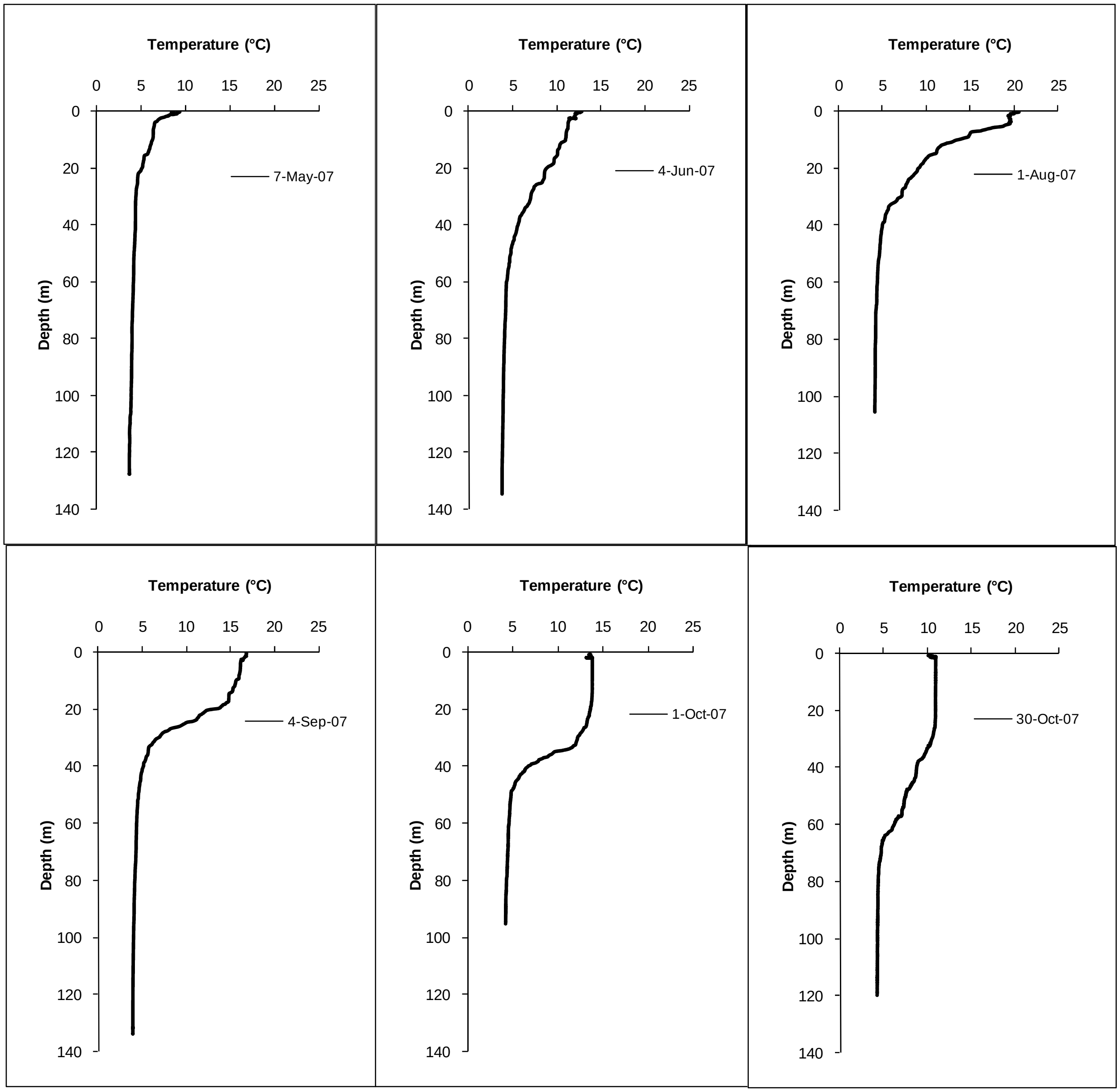


Figure 3.4. Temperature profiles, station KLF 4, May, June, August to November, 2007.

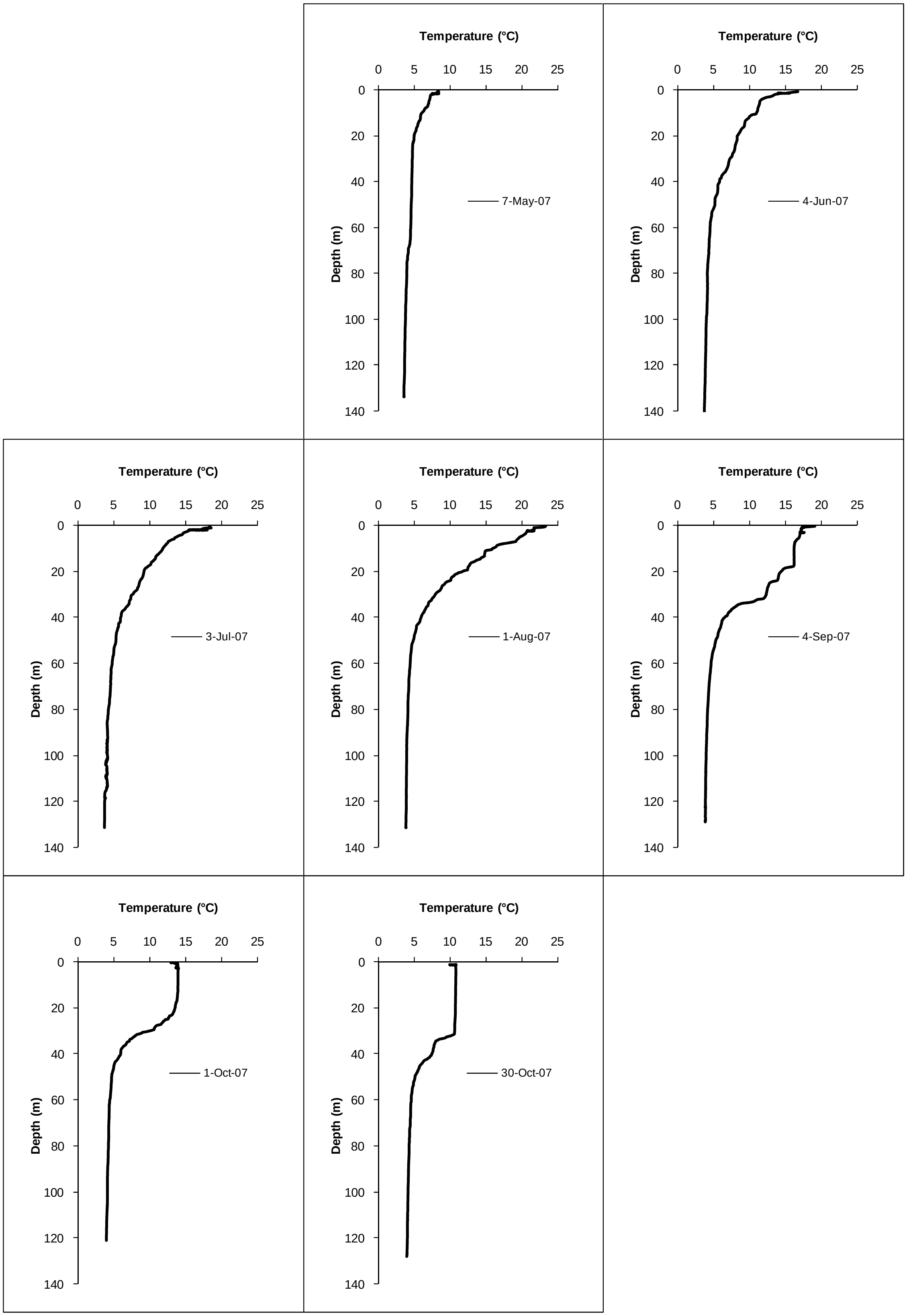


Figure 3.5. Temperature profiles, station KLF 5, May to November, 2007.

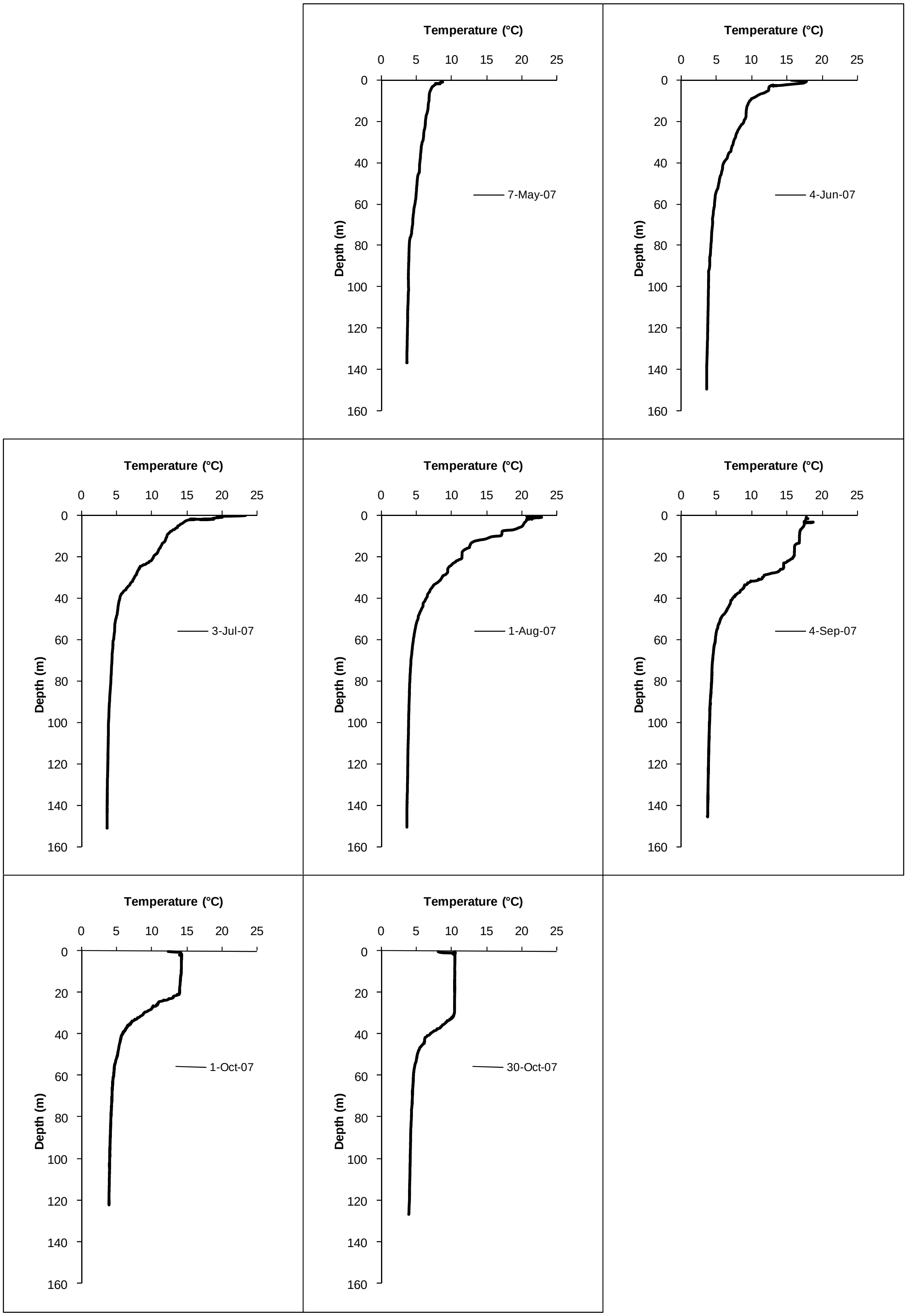


Figure 3.6. Temperature profiles, station KLF 6, May to November, 2007.

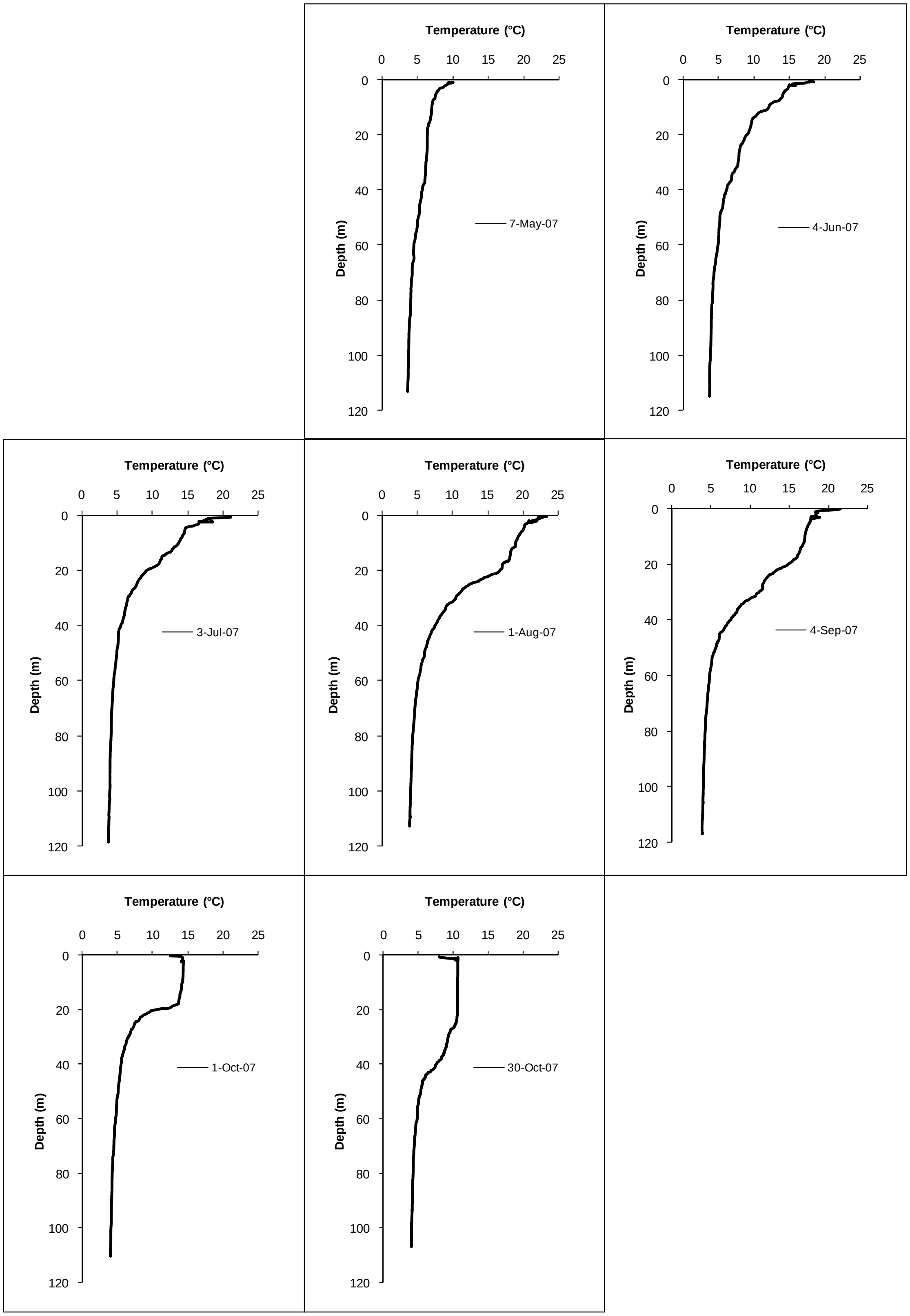


Figure 3.7. Temperature profiles, station KLF 7, May to November 2007.

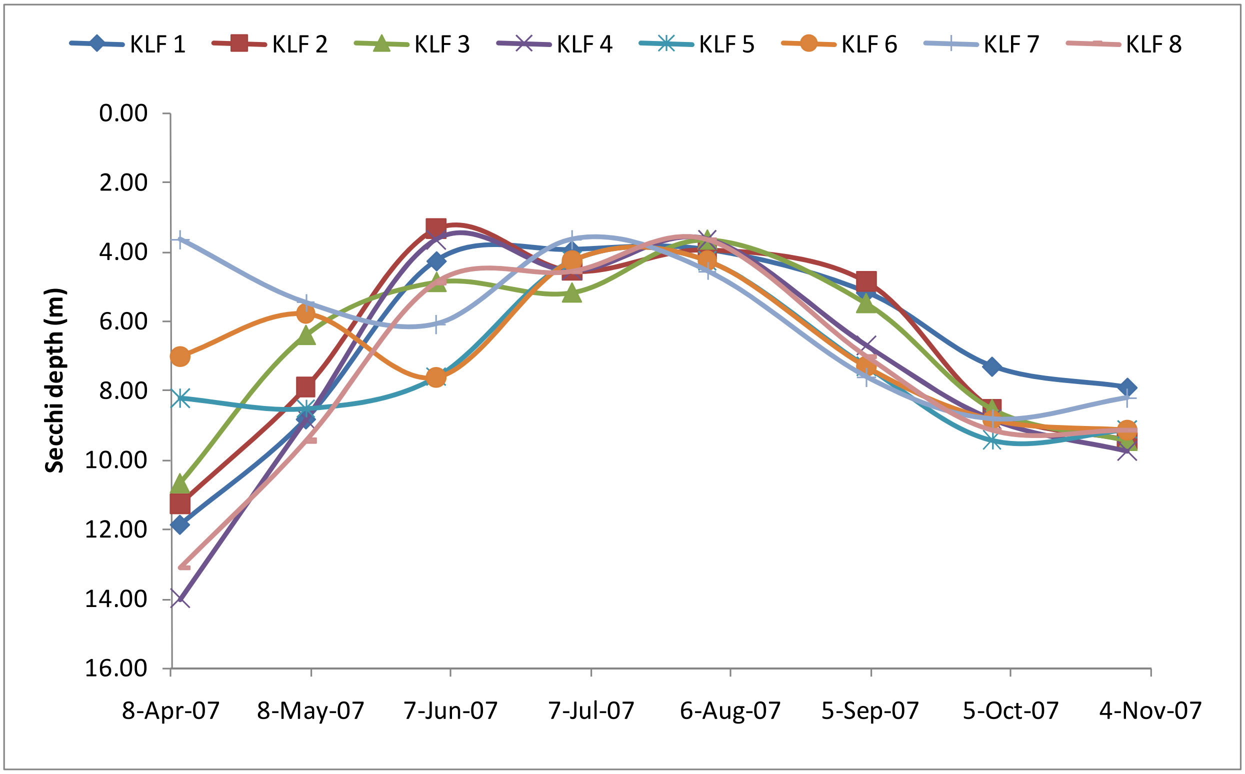


Figure 3.8. Secchi disk depth measurements at stations KLF 1-8 from April to November, 2007.

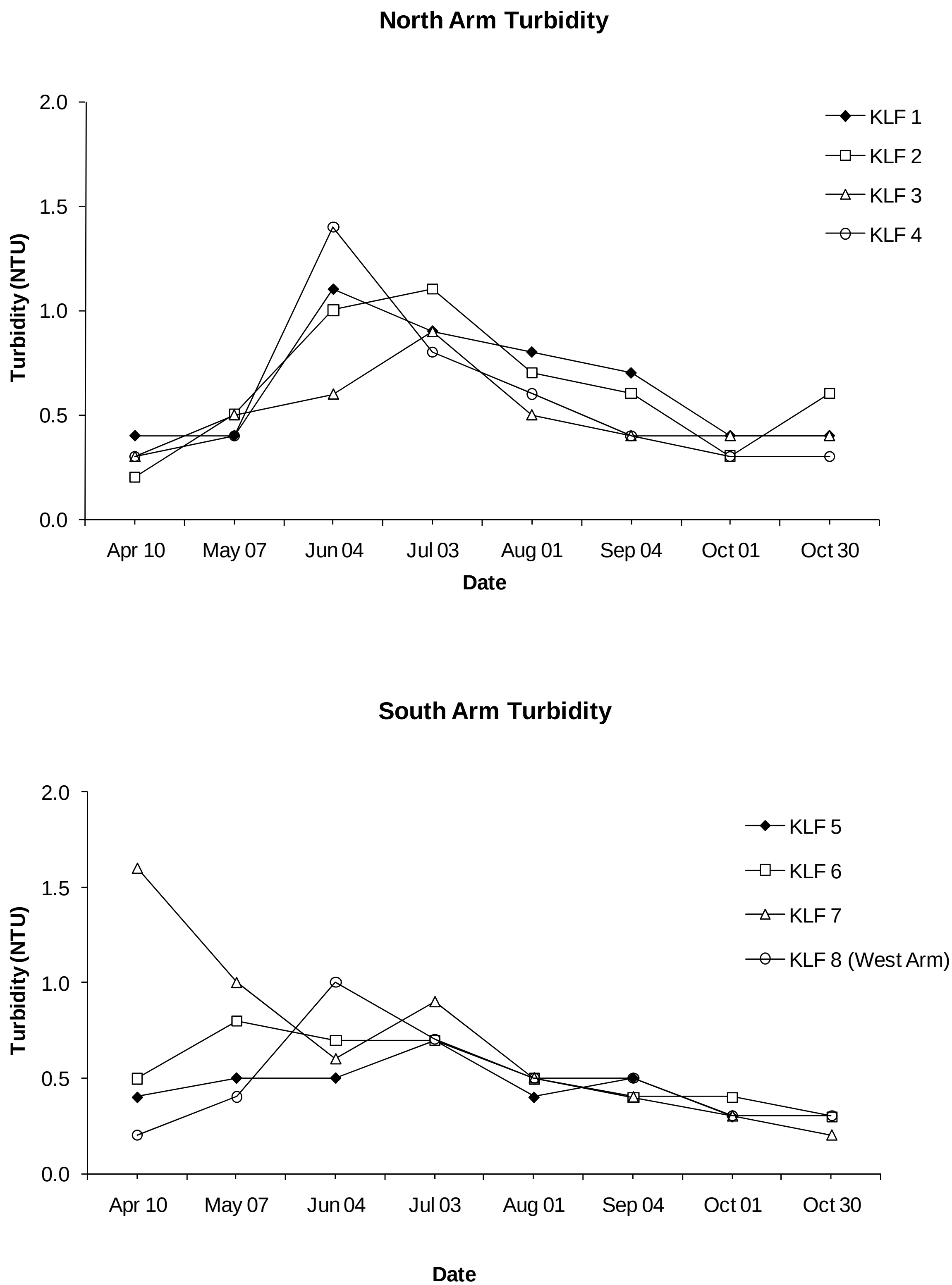
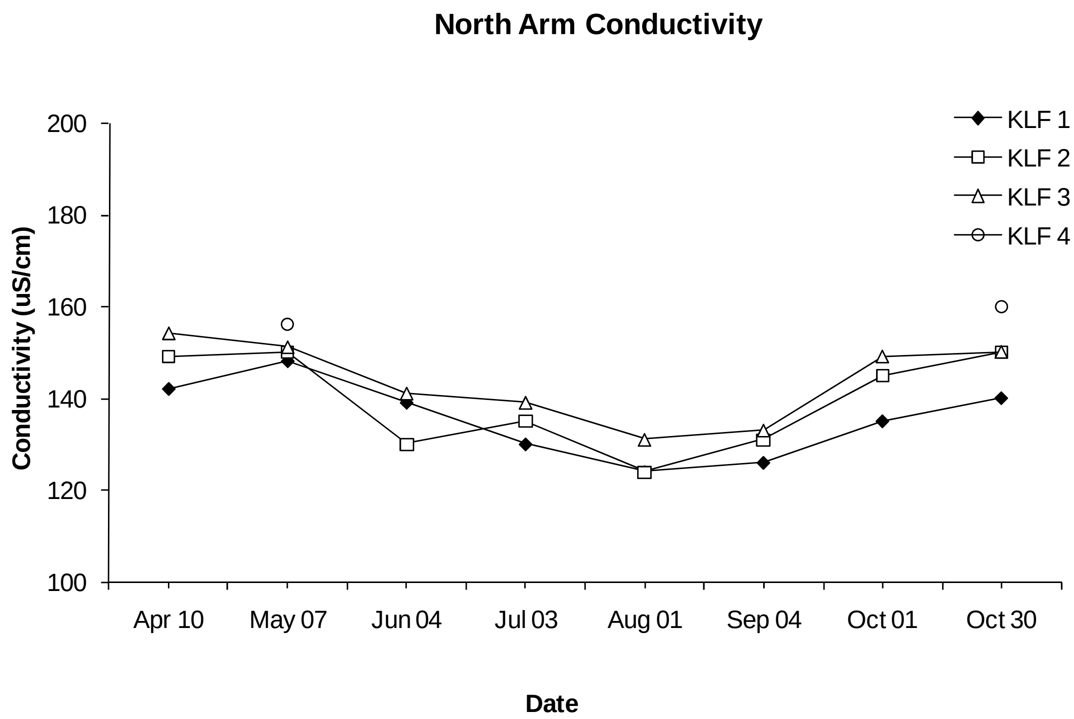


Figure 3.9. Turbidity in 0-20 m at stations KLF 1-8, April to November, 2007.



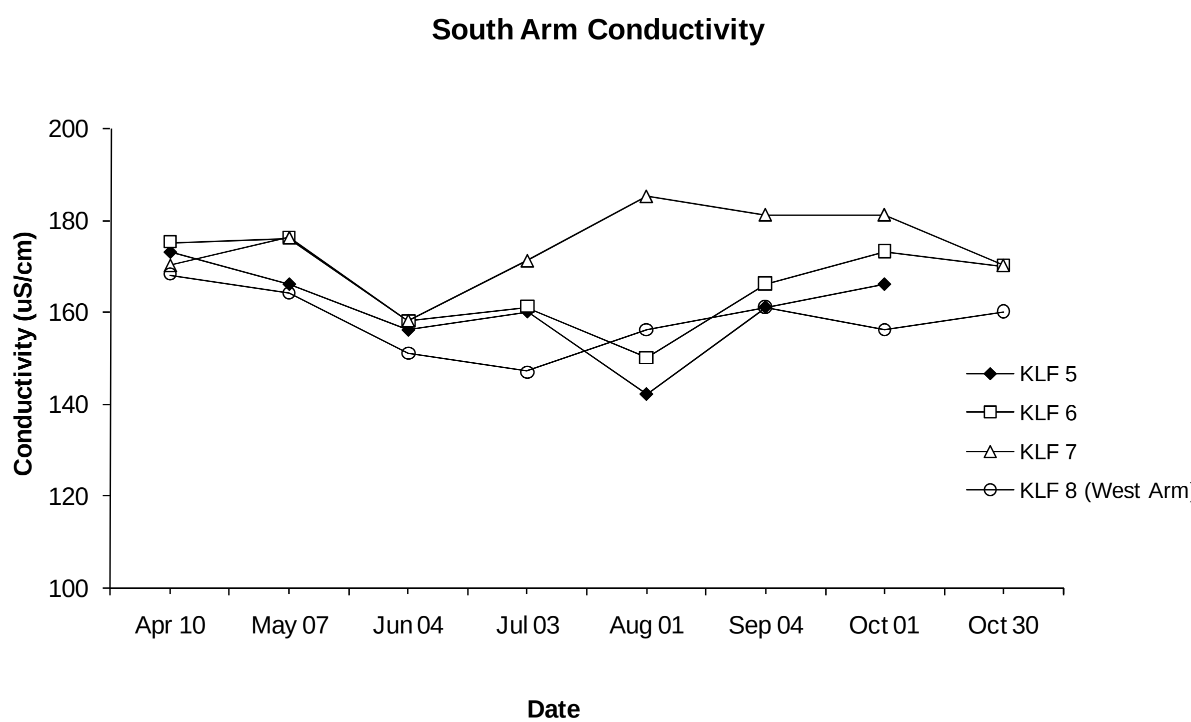
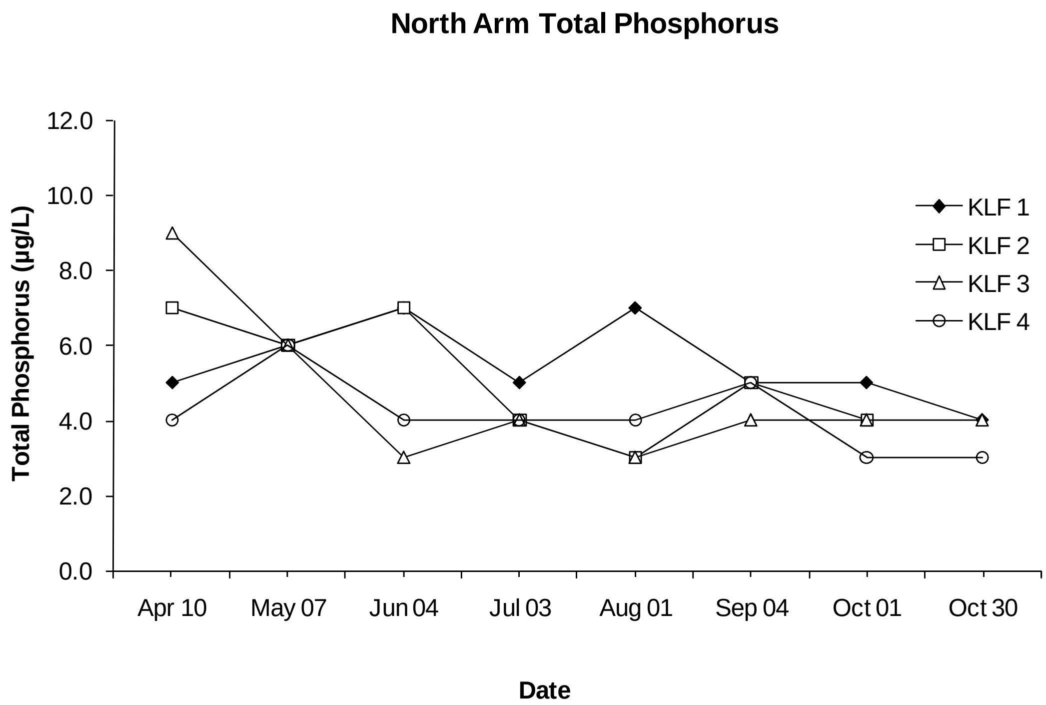


Figure 3.10. Conductivity in 0-20 m samples at stations KLF 1-8, April to November, 2007.



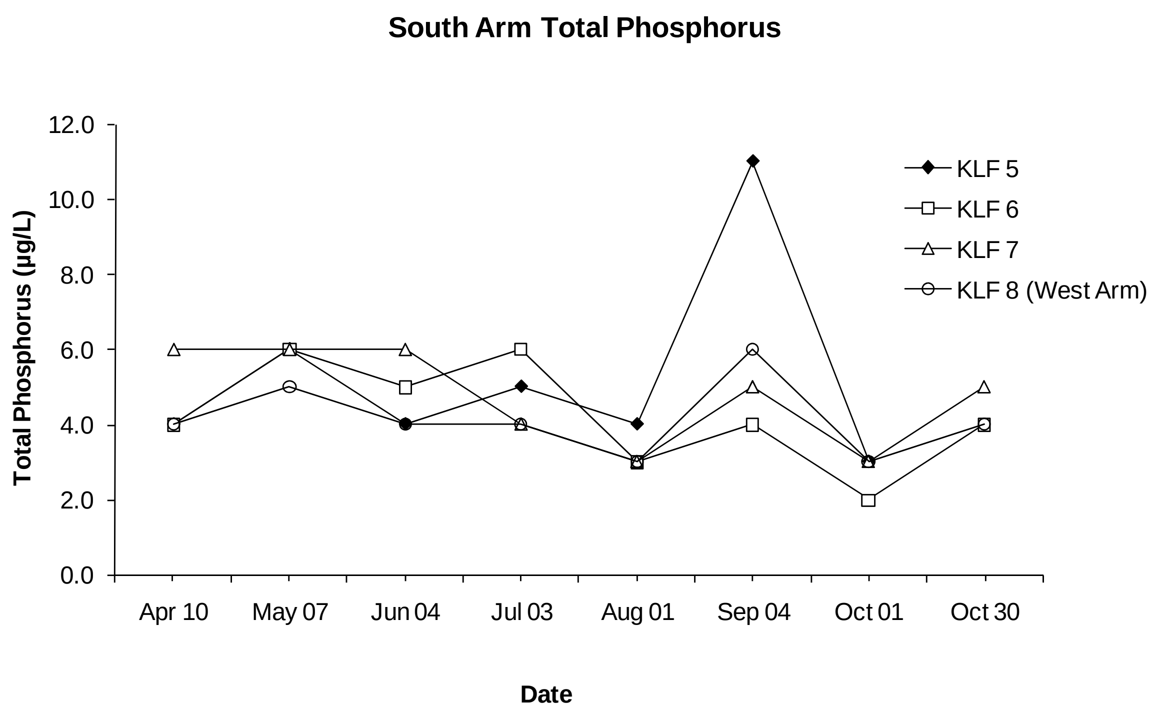
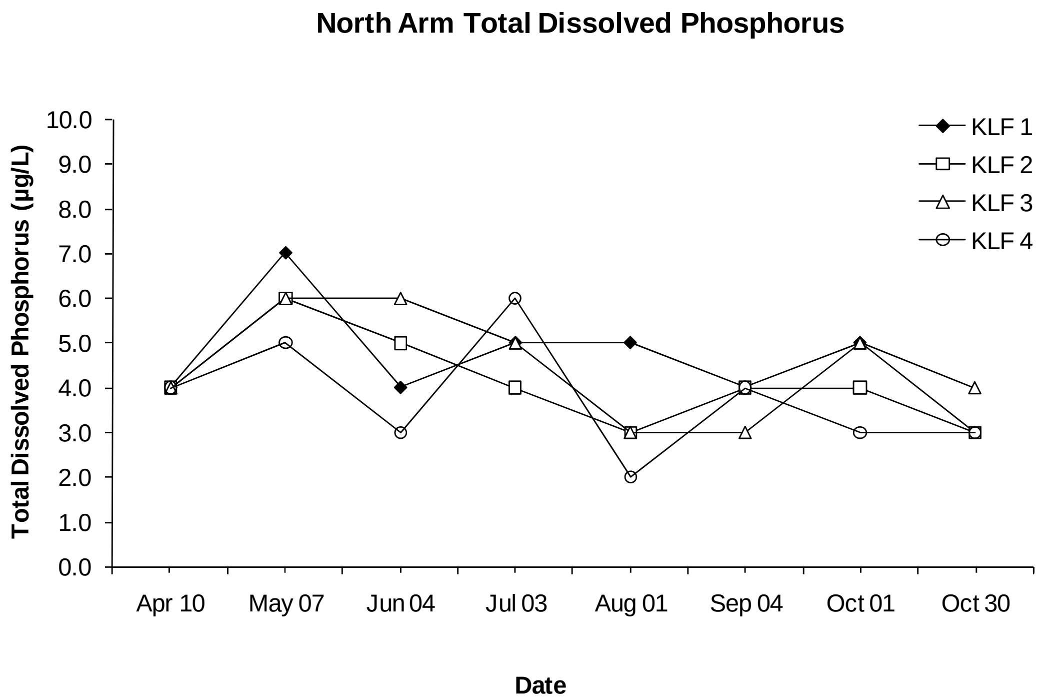


Figure 3.11. Total phosphorus in 0-20 m samples at stations KLF 1-8, April to November, 2007.



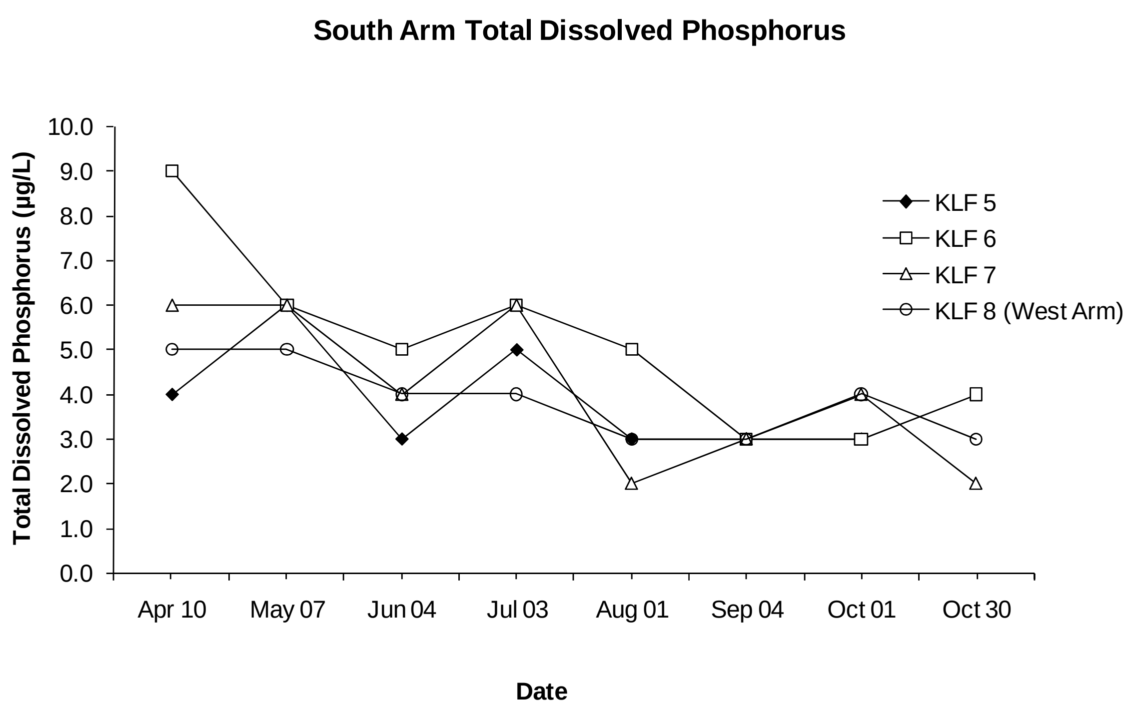
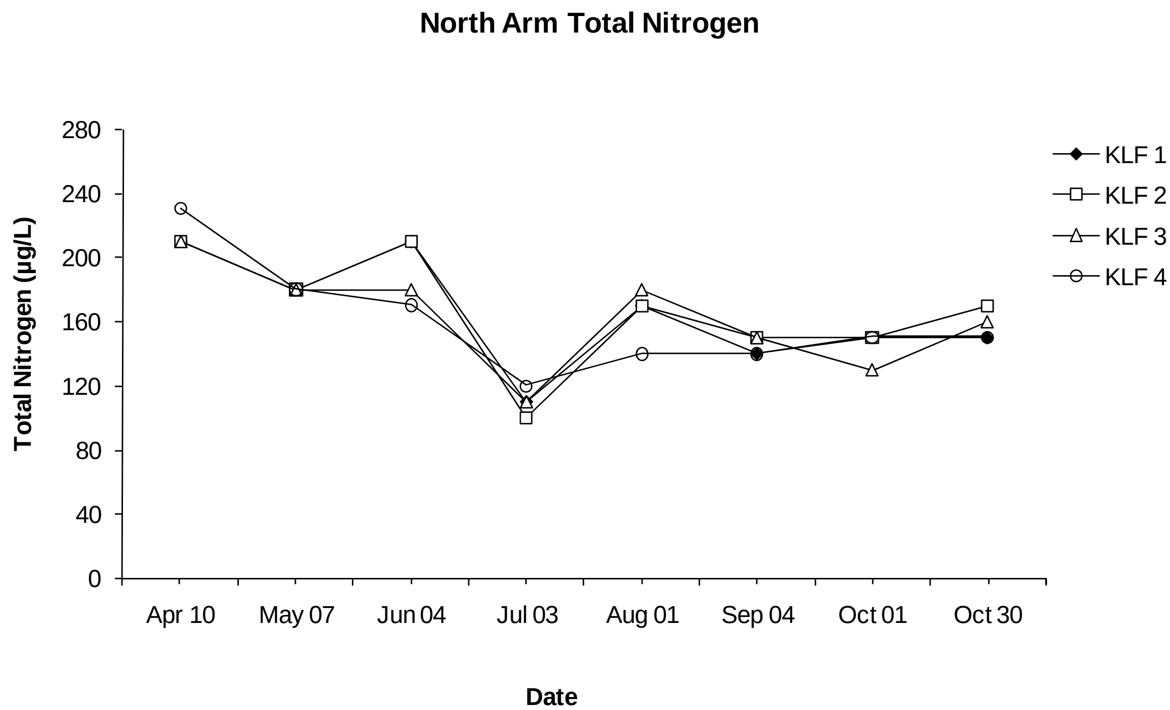


Figure 3.12. Total dissolved phosphorus in 0-20 m samples at stations KLF 1-8, April to November, 2007.



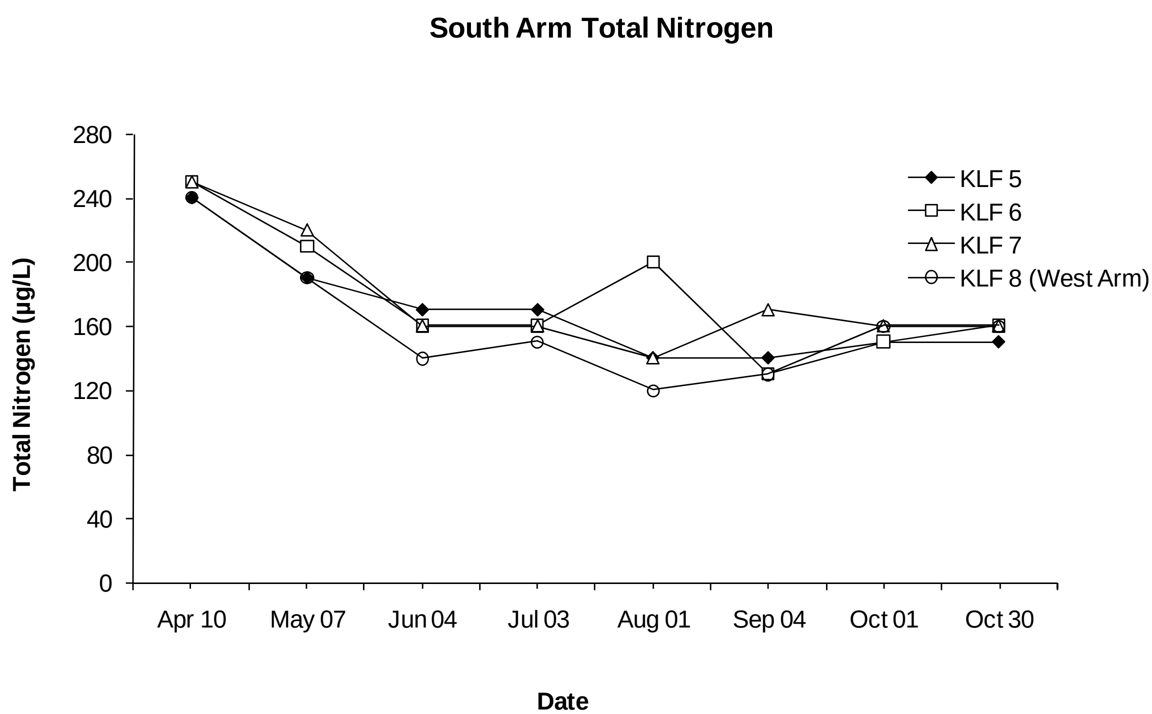
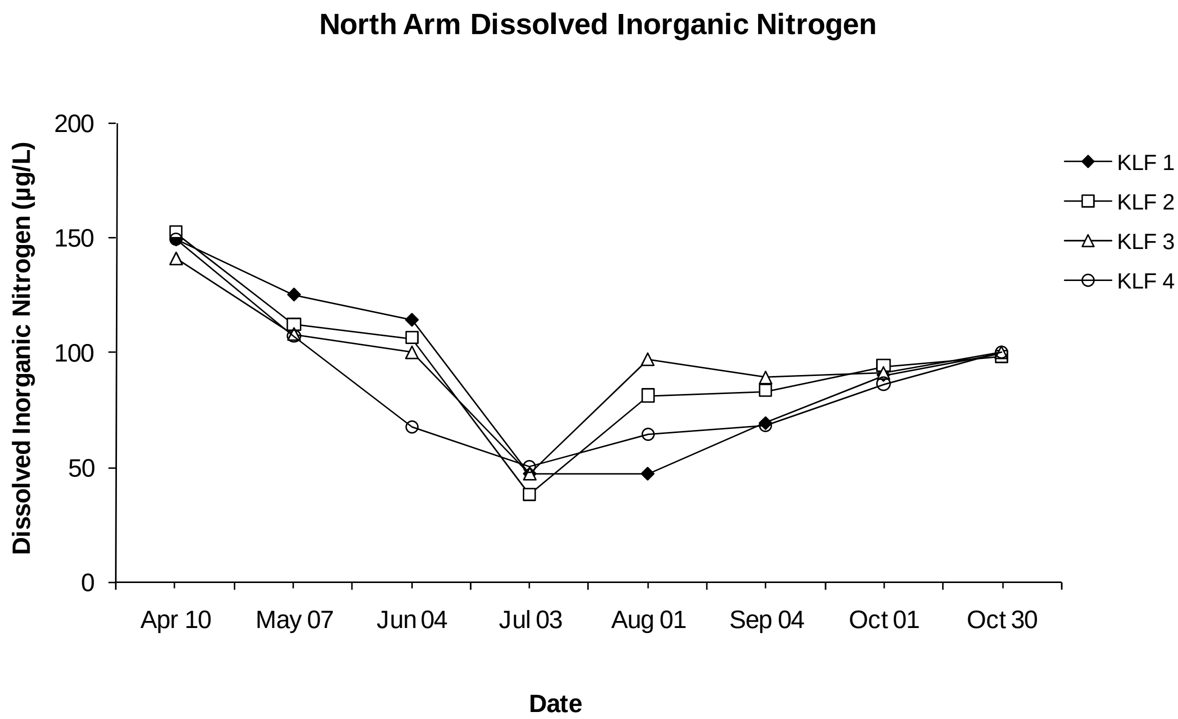


Figure 3.13. Total nitrogen in 0-20 m samples at stations KLF 1-8, April to November, 2007.



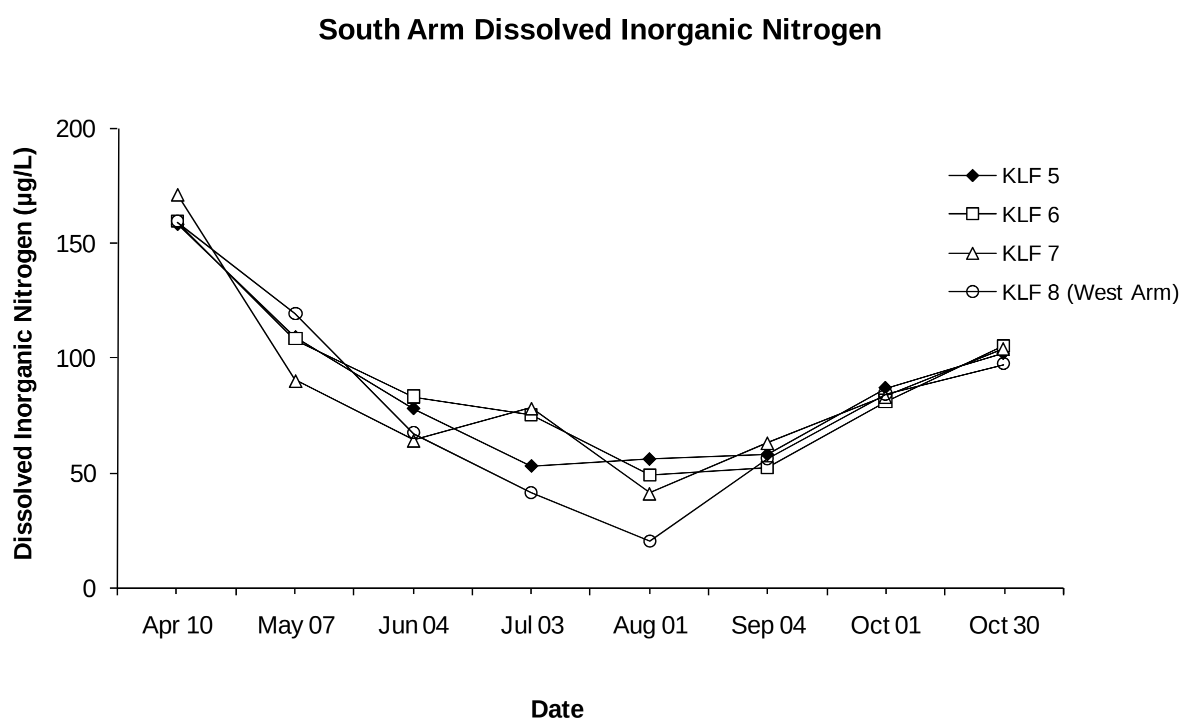
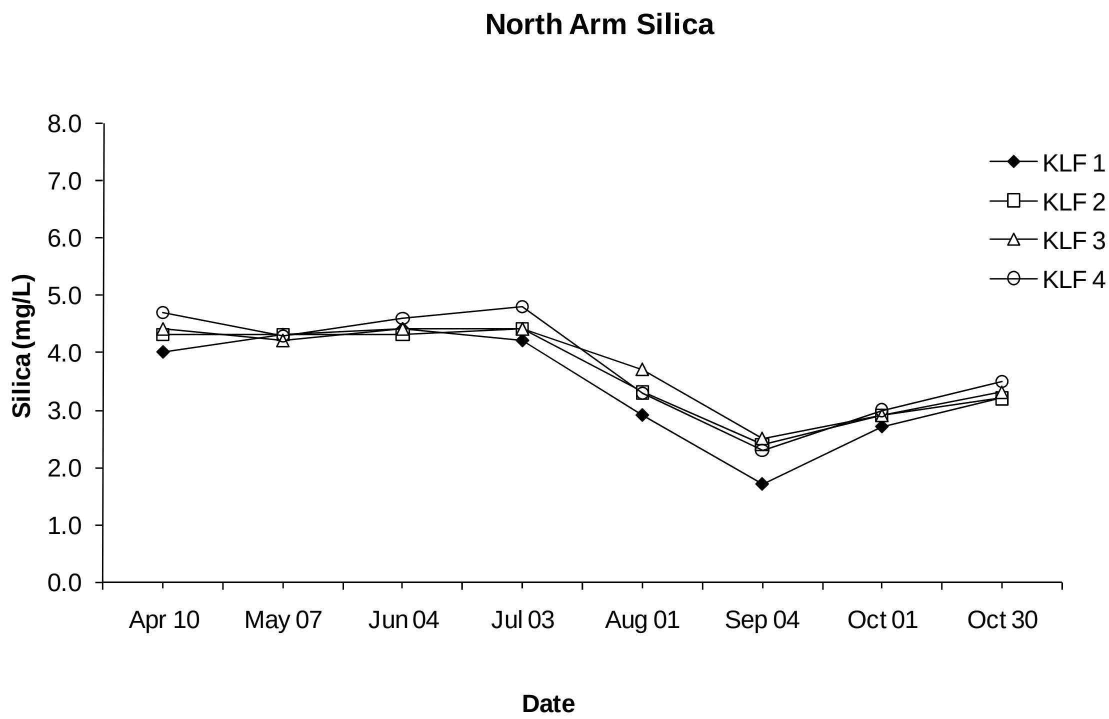


Figure 3.14. Dissolved inorganic nitrogen in 0-20 m samples at stations KLF 1-8, April to November, 2007.



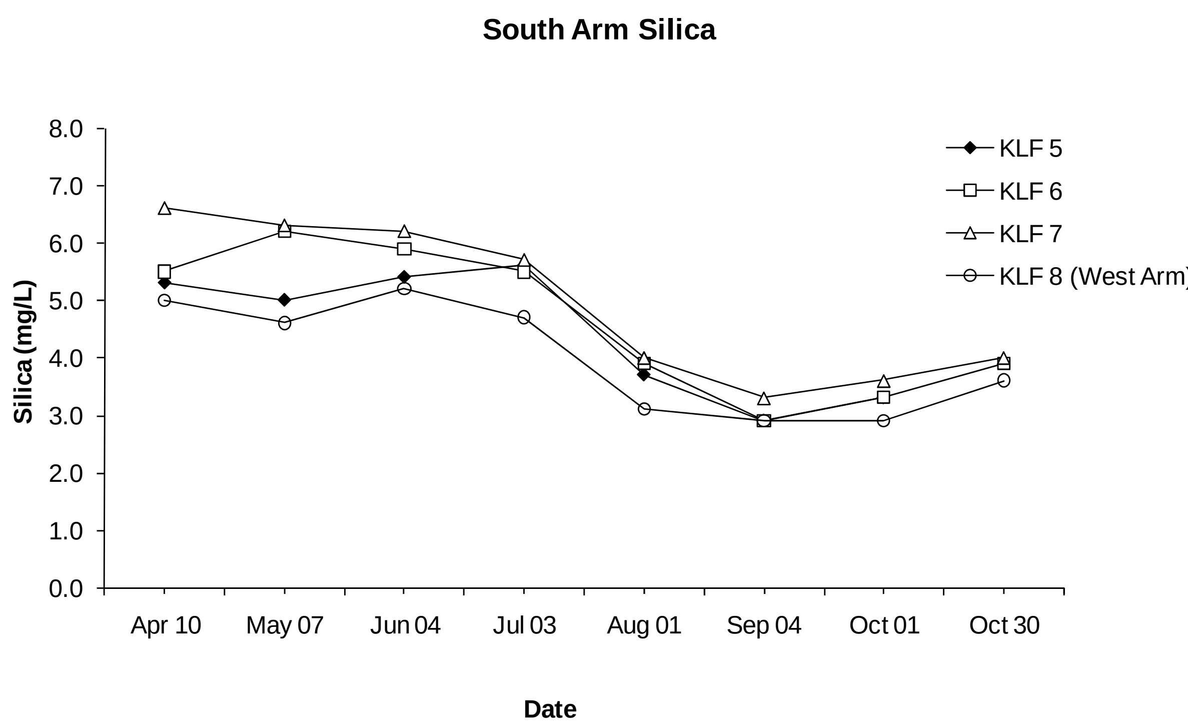


Figure 3.15. Silica in 0-20 m samples at stations KLF 1-8, April to November, 2007.

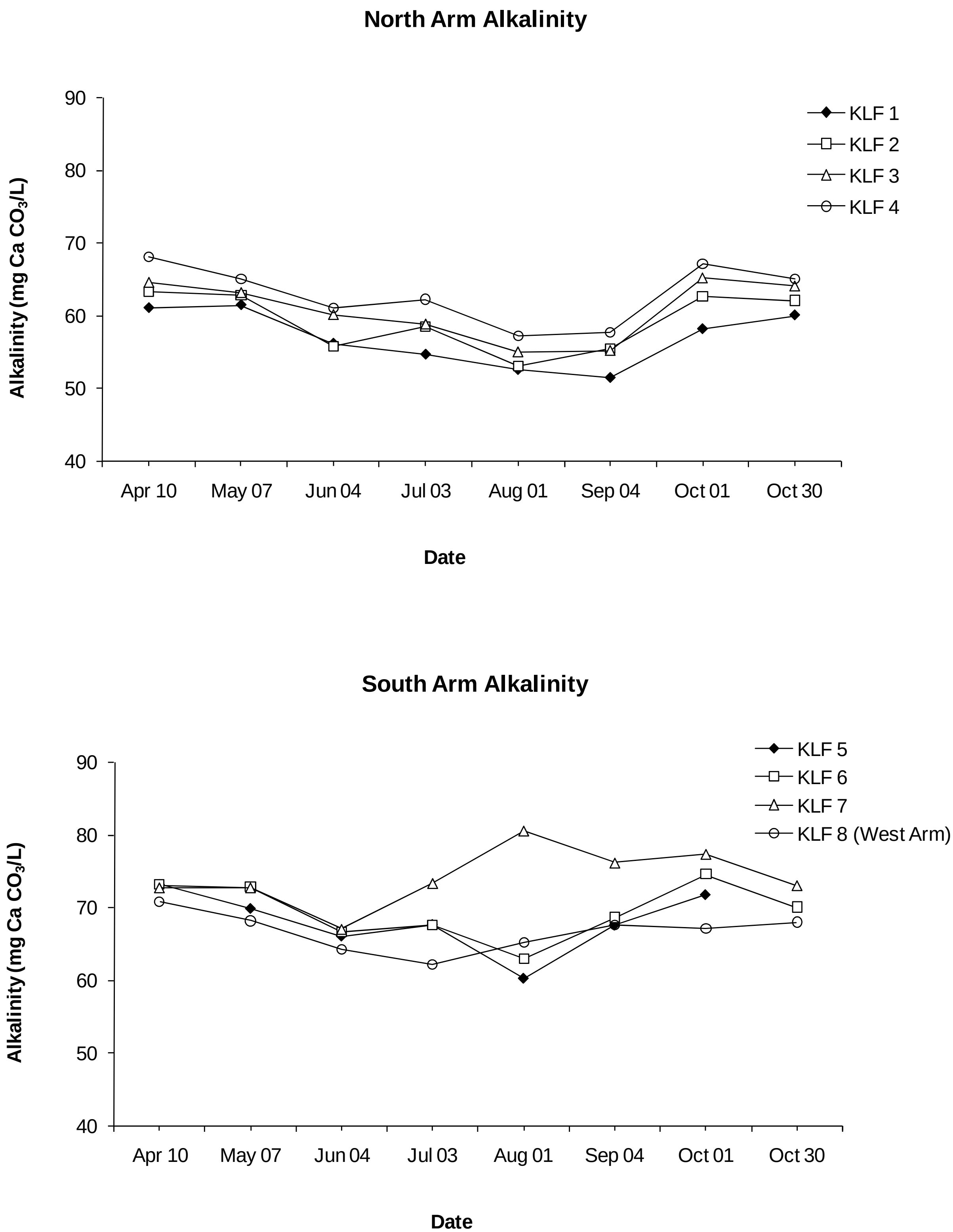
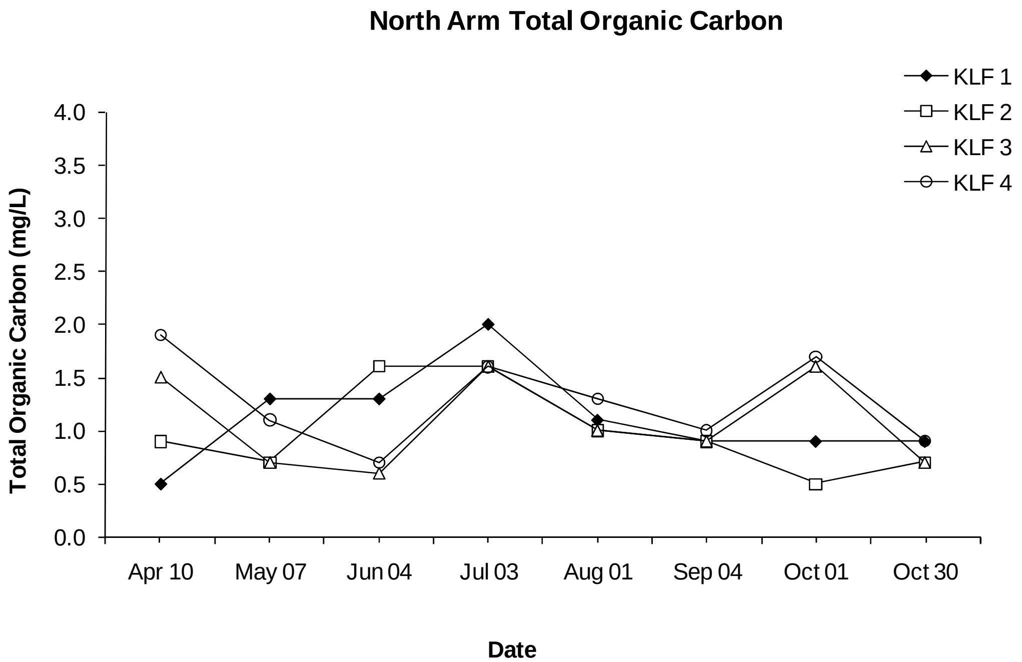


Figure 3.16. Alkalinity in 0-20 m samples at stations KLF 1-8, April to November, 2007.



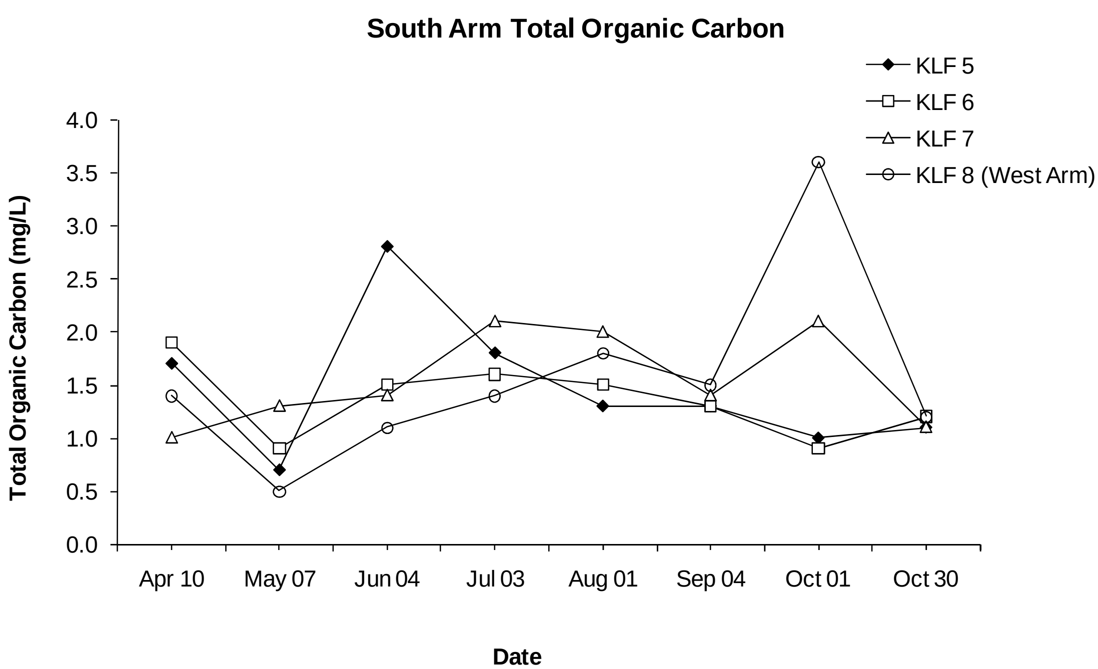
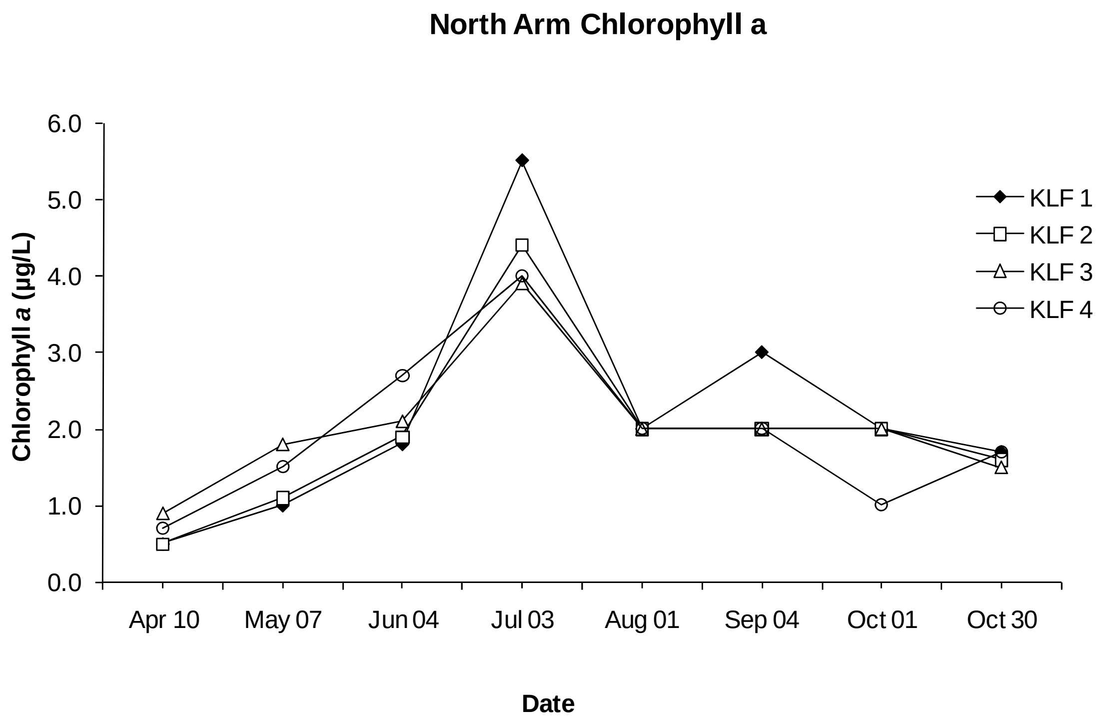


Figure 3.17. Total organic carbon in 0-20 m samples at stations KLF 1-8, April to November, 2007.



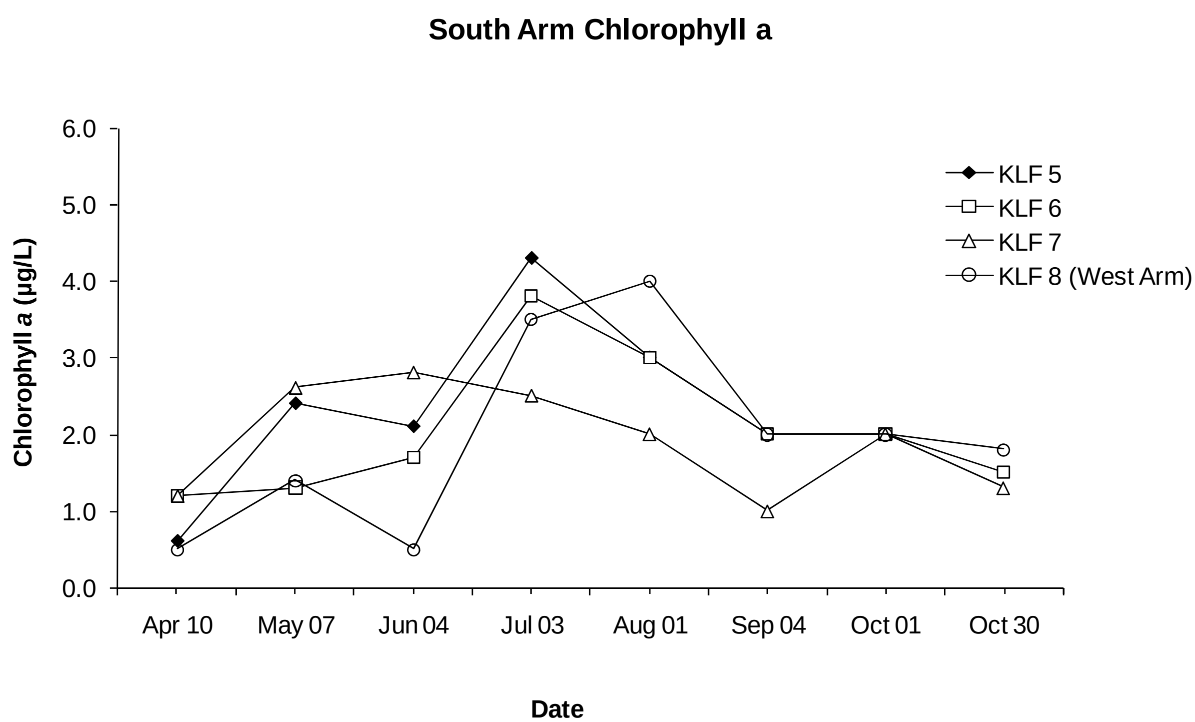


Figure 3.18. Chlorophyll *a* in 0-20 m samples at stations KLF 1-8, April to November, 2007.

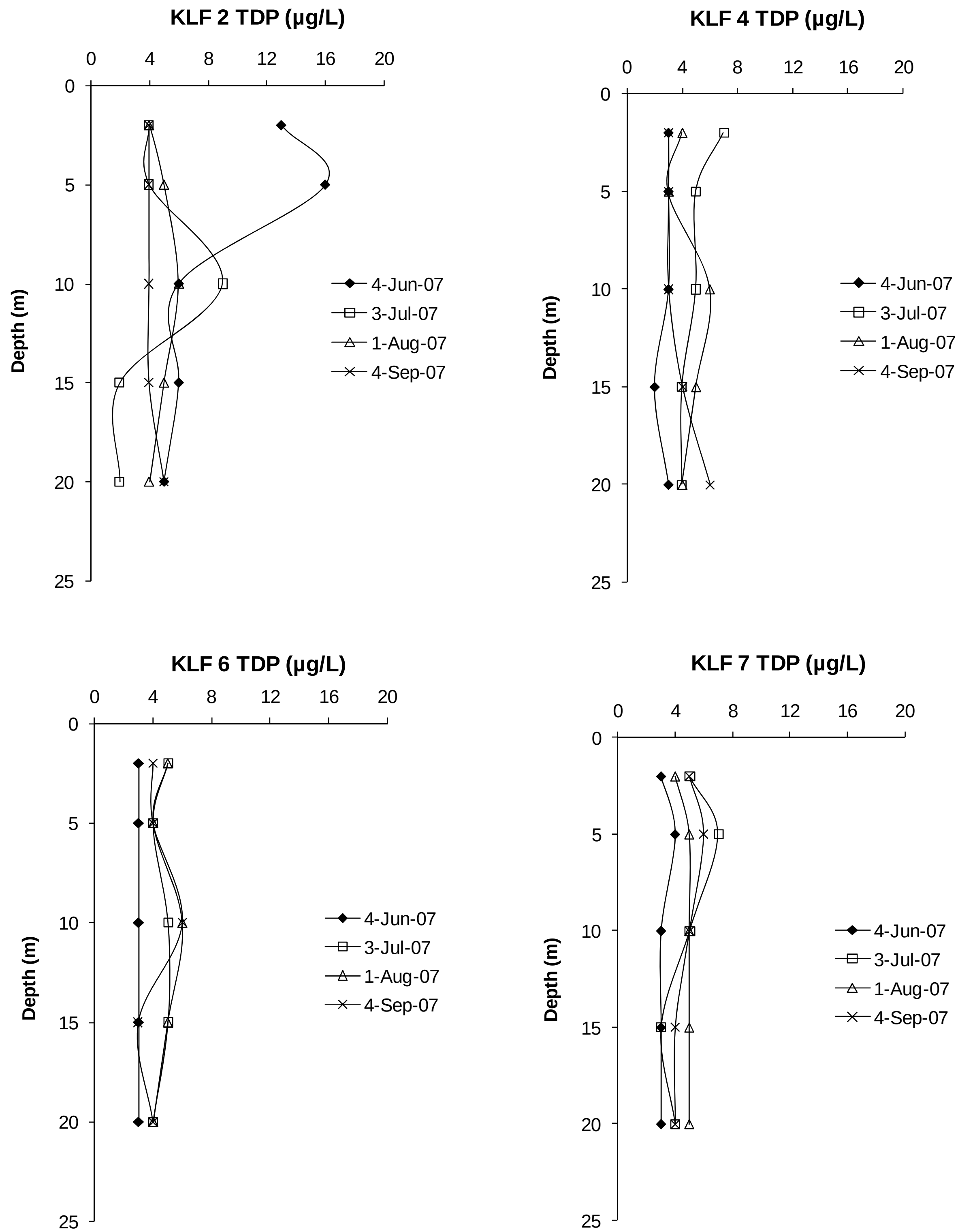


Figure 3.19. Discrete depth profiles of total dissolved phosphorus in the epilimnion at stations KLF 2, 4, 6 and 7, June to September 2007.

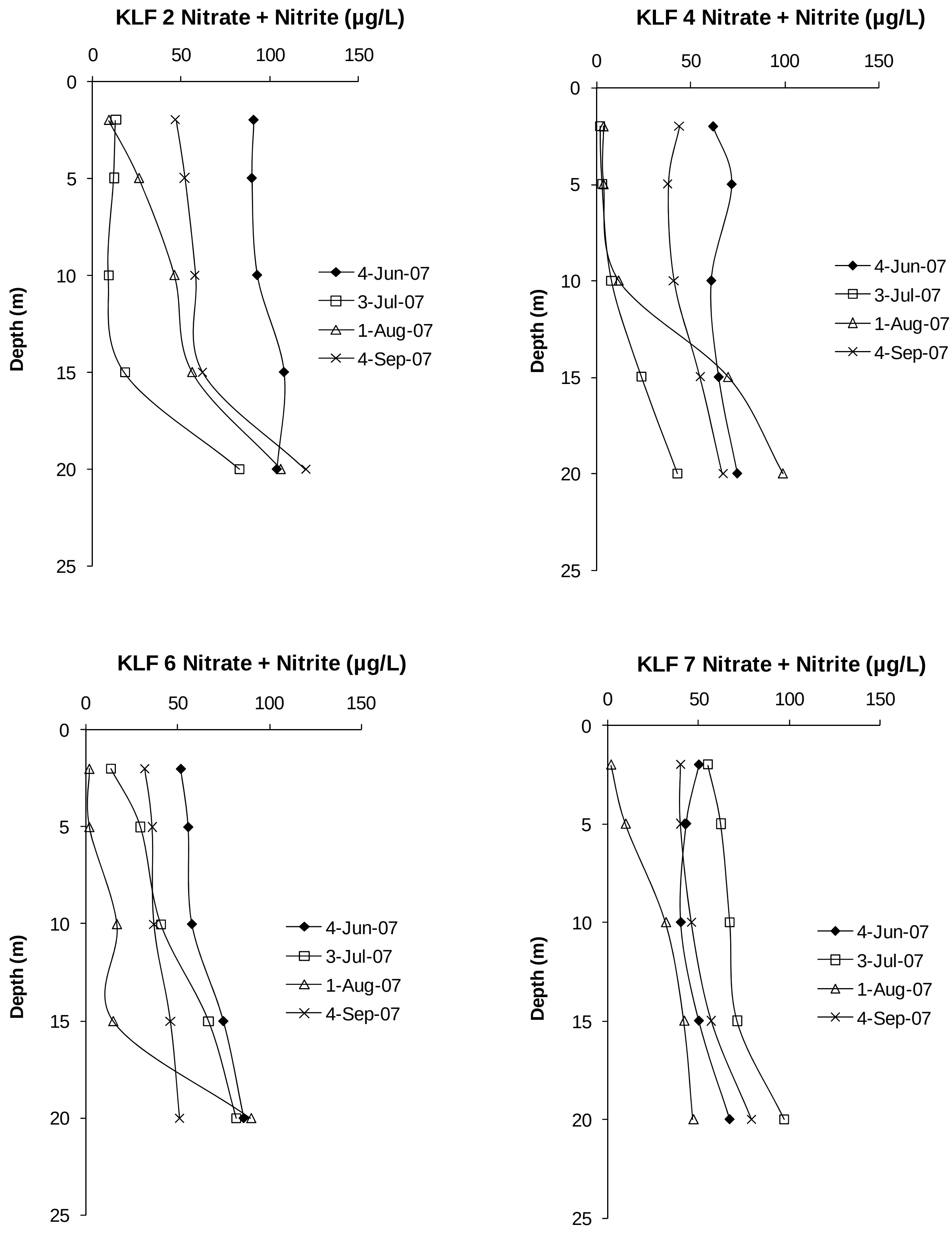


Figure 3.20. Discrete depth profiles of nitrate and nitrite in the epilimnion at stations KLF 2, 4, 6 and 7, June to September 2007.

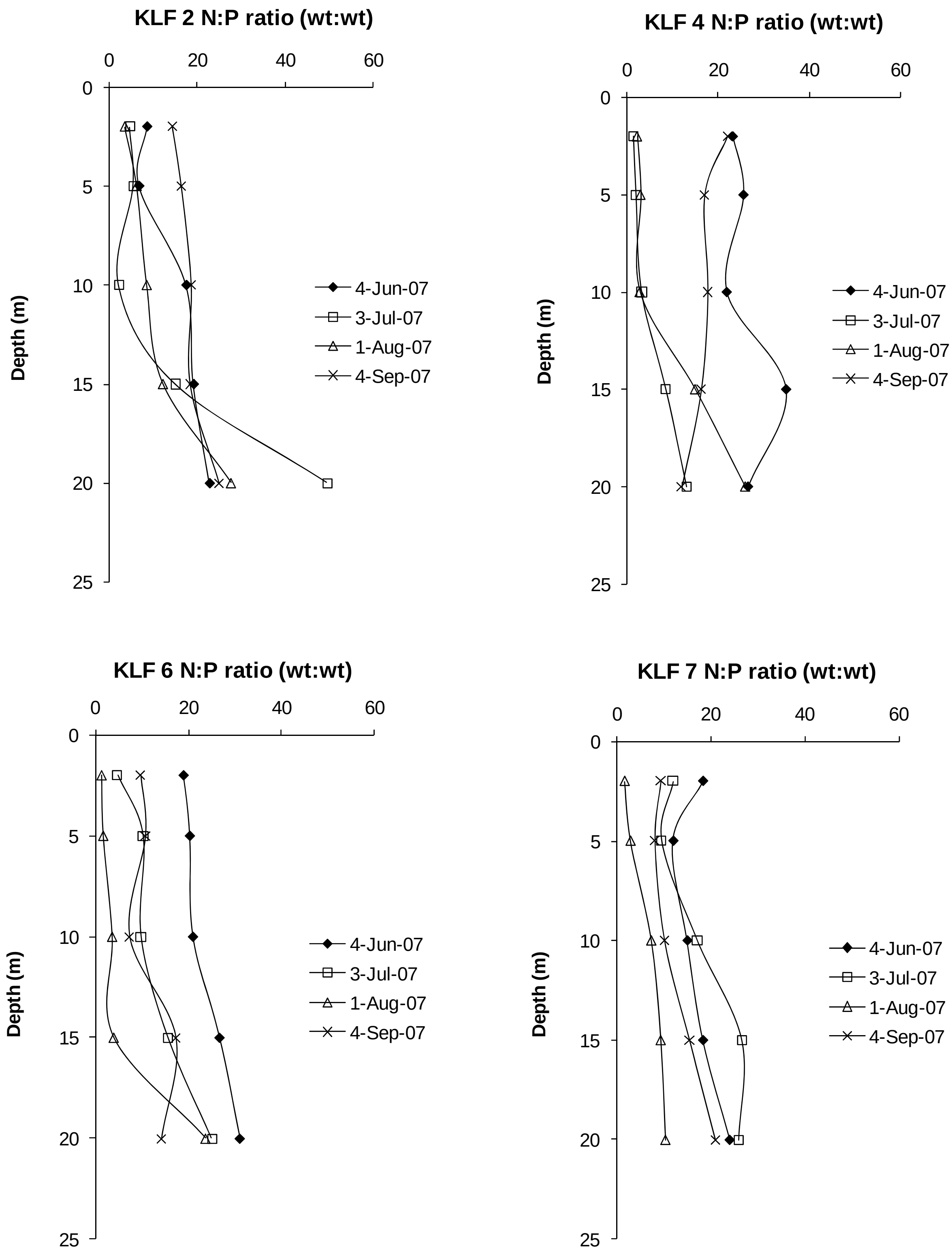


Figure 3.21. Discrete depth profiles of nitrogen:phosphorus ratios (weight:weight) in the epilimnion at stations KLF 2, 4, 6 and 7, June to September 2007.

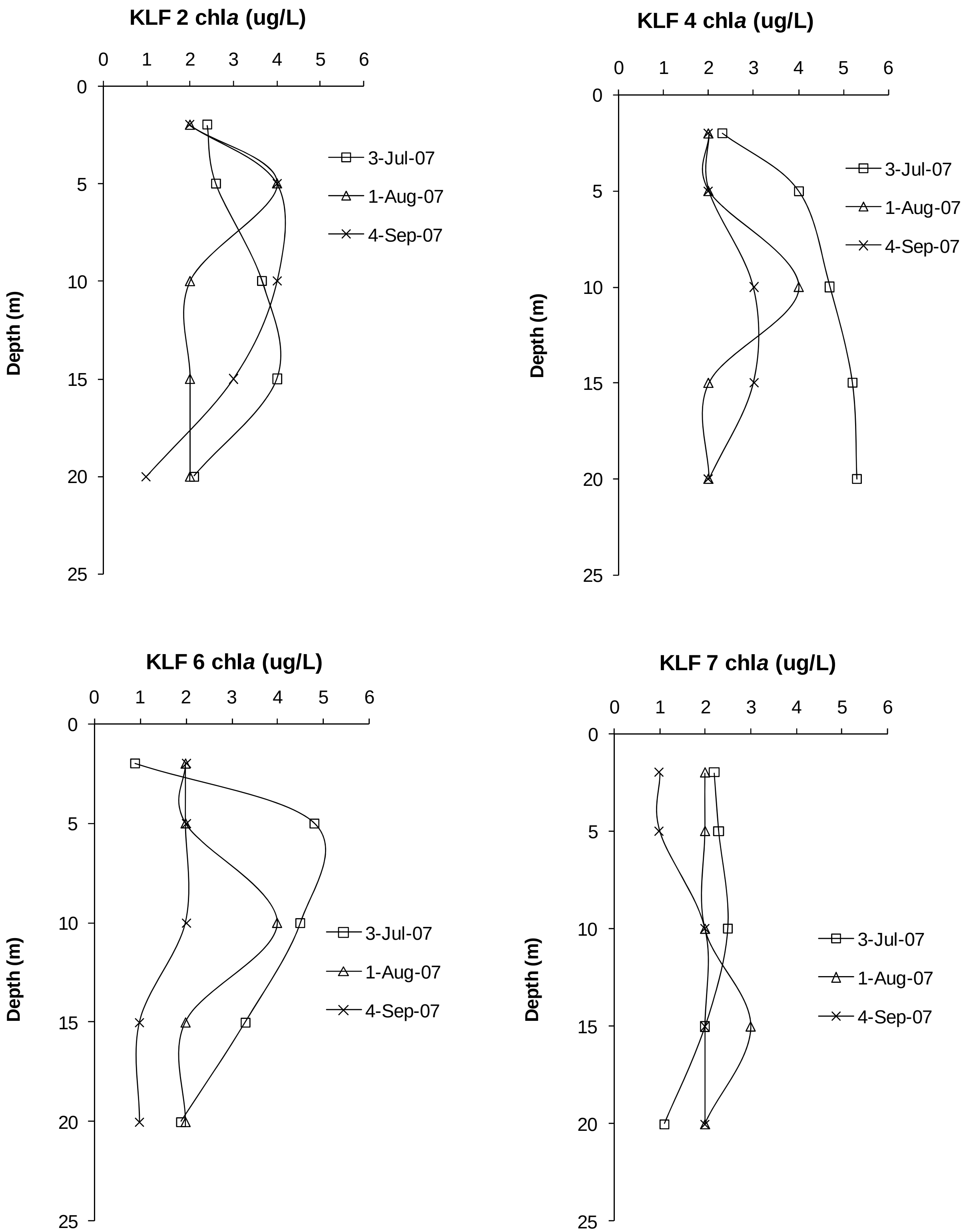
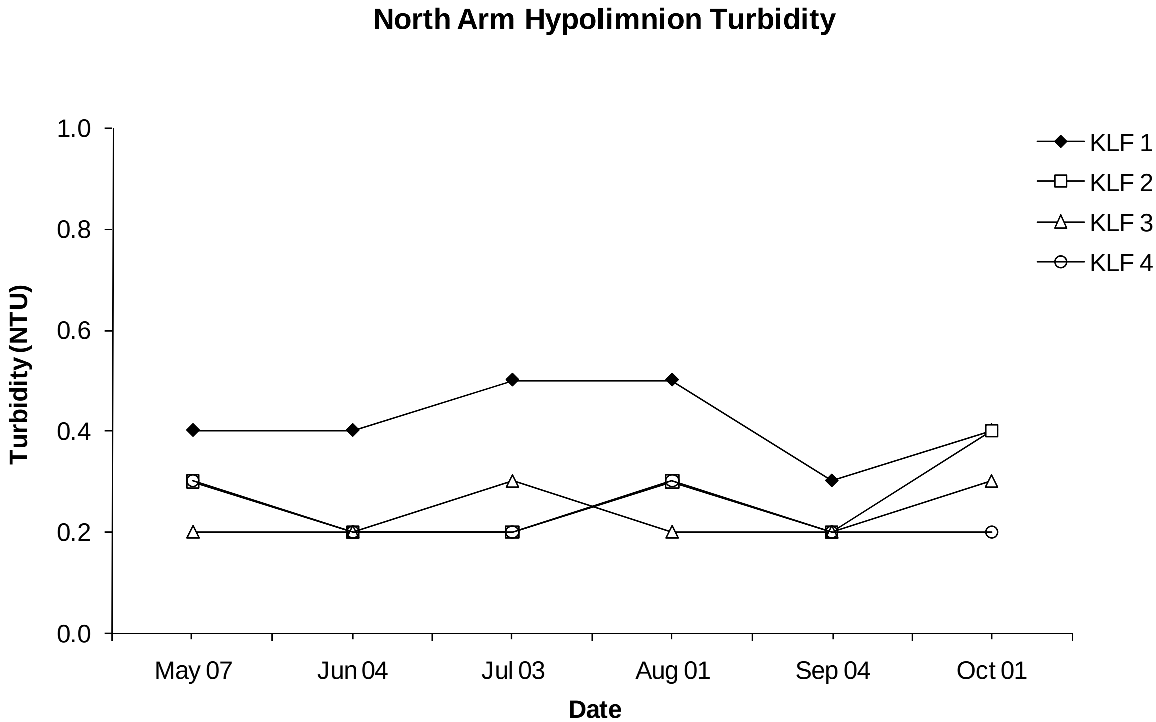


Figure 3.22. Discrete depth profiles of chlorophyll *a* in the epilimnion at stations KLF 2, 4, 6 and 7, June to September 2007.



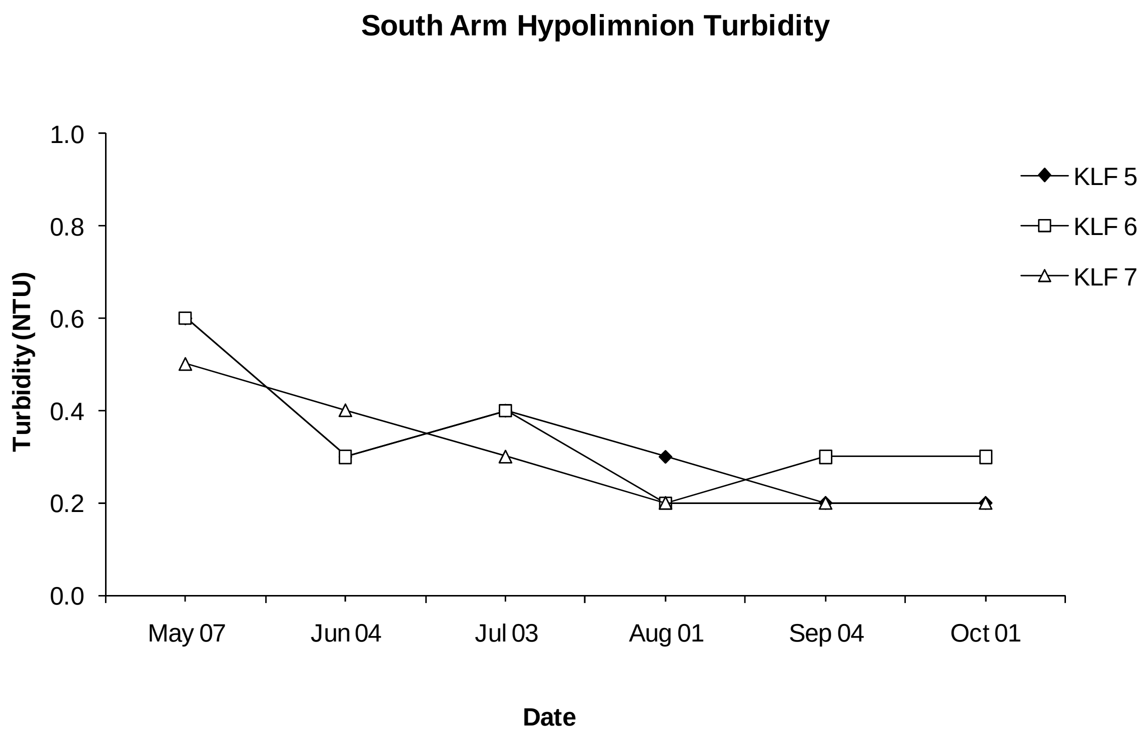
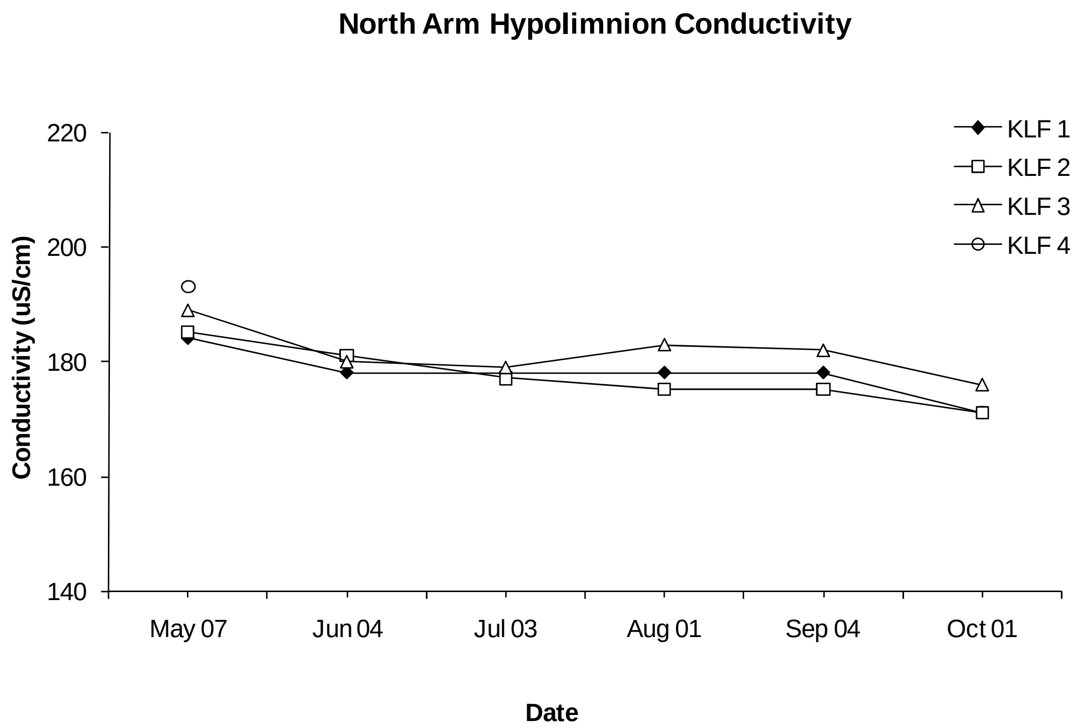


Figure 3.23. Turbidity in the hypolimnion at stations KLF 1-7, May to October, 2007.



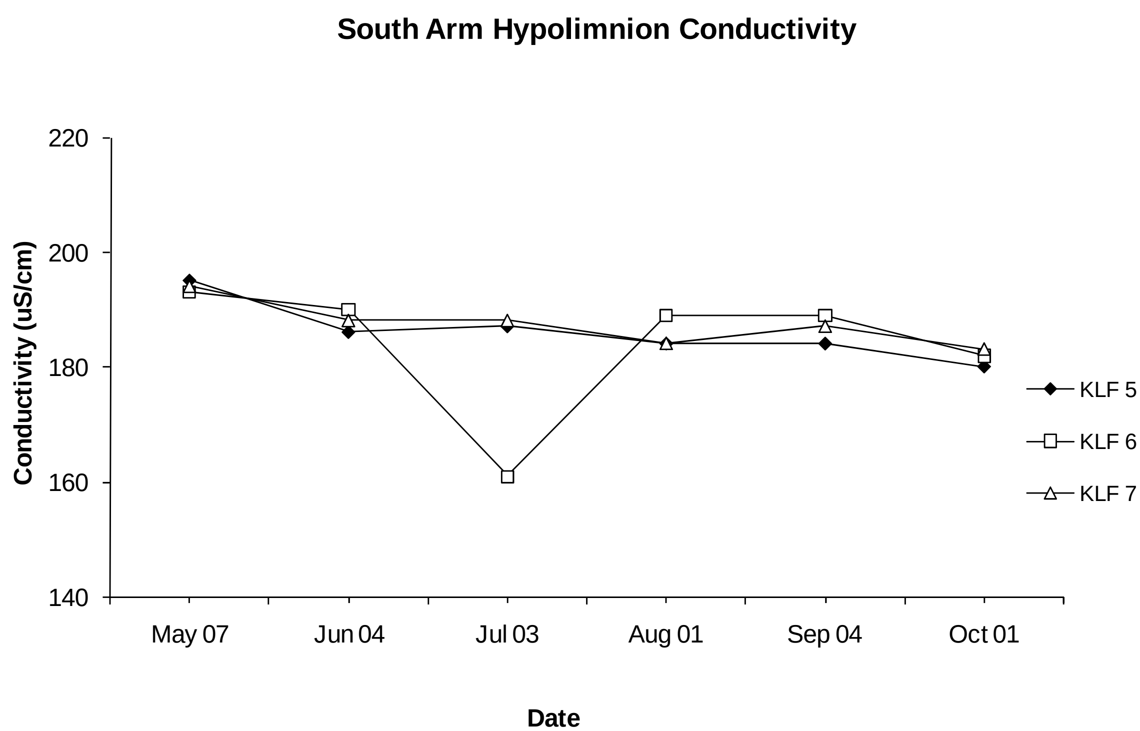
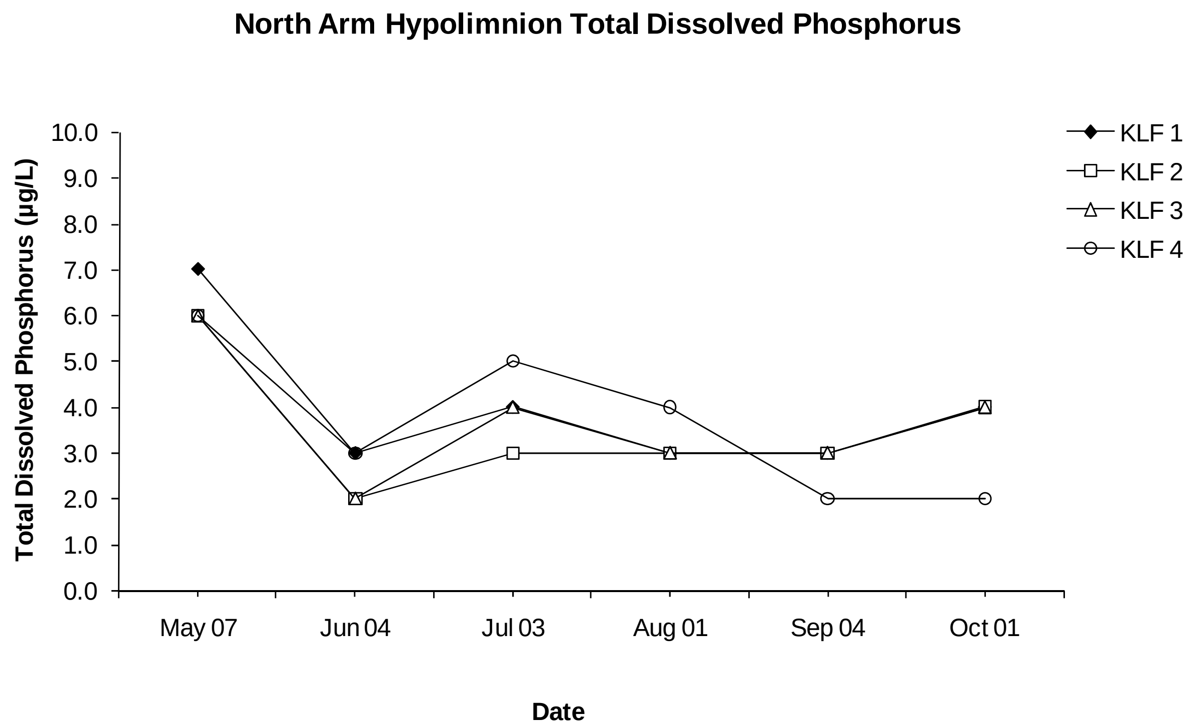


Figure 3.24. Conductivity results in the hypolimnion at stations KLF 1-7, May to October, 2007.



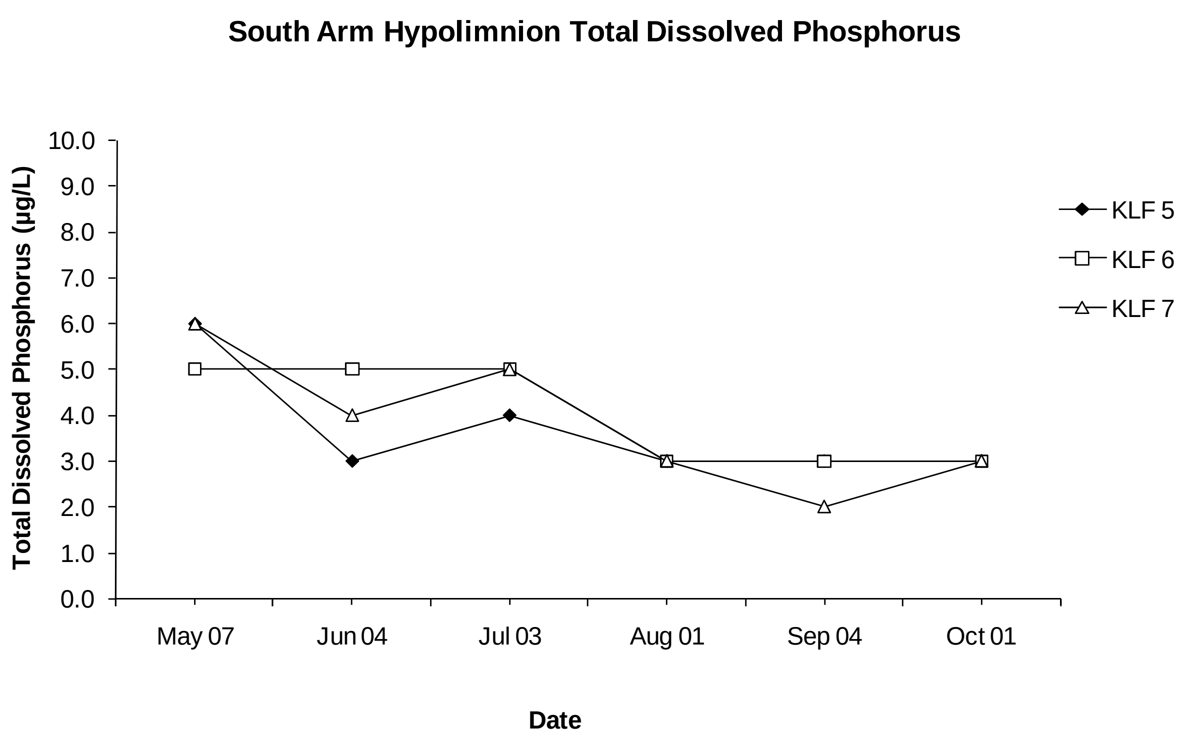
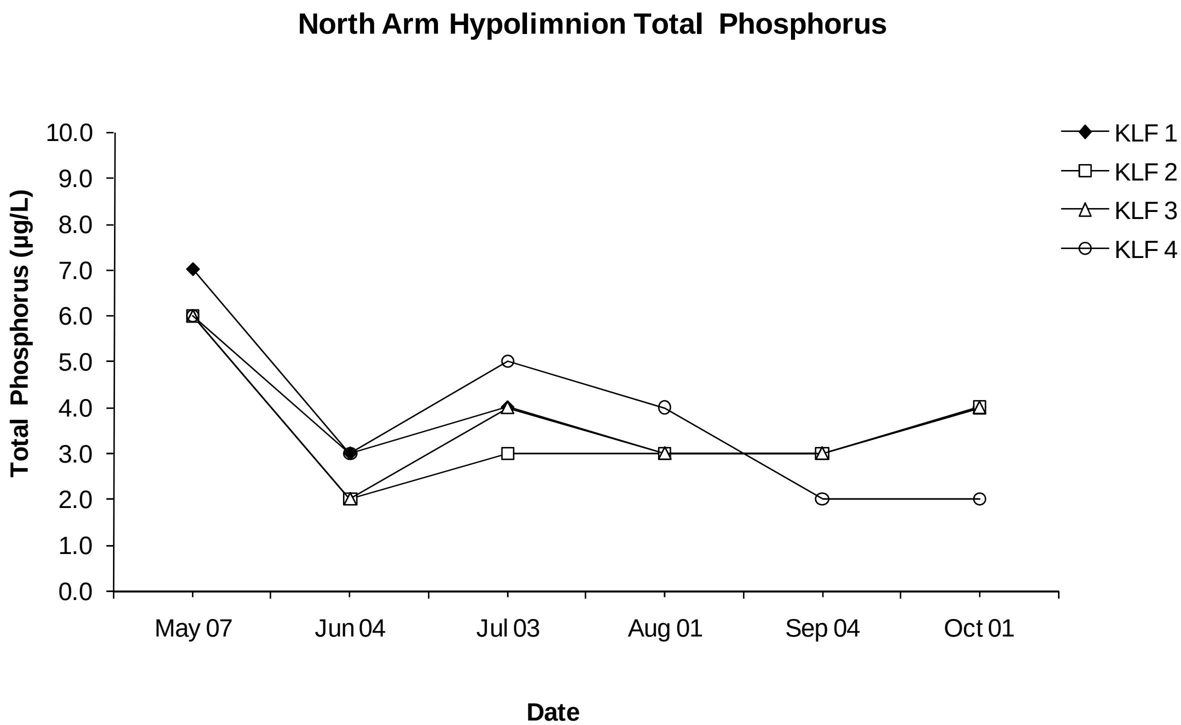


Figure 3.25. Total dissolved phosphorus in the hypolimnion at stations KLF 1-7, May to October, 2007.



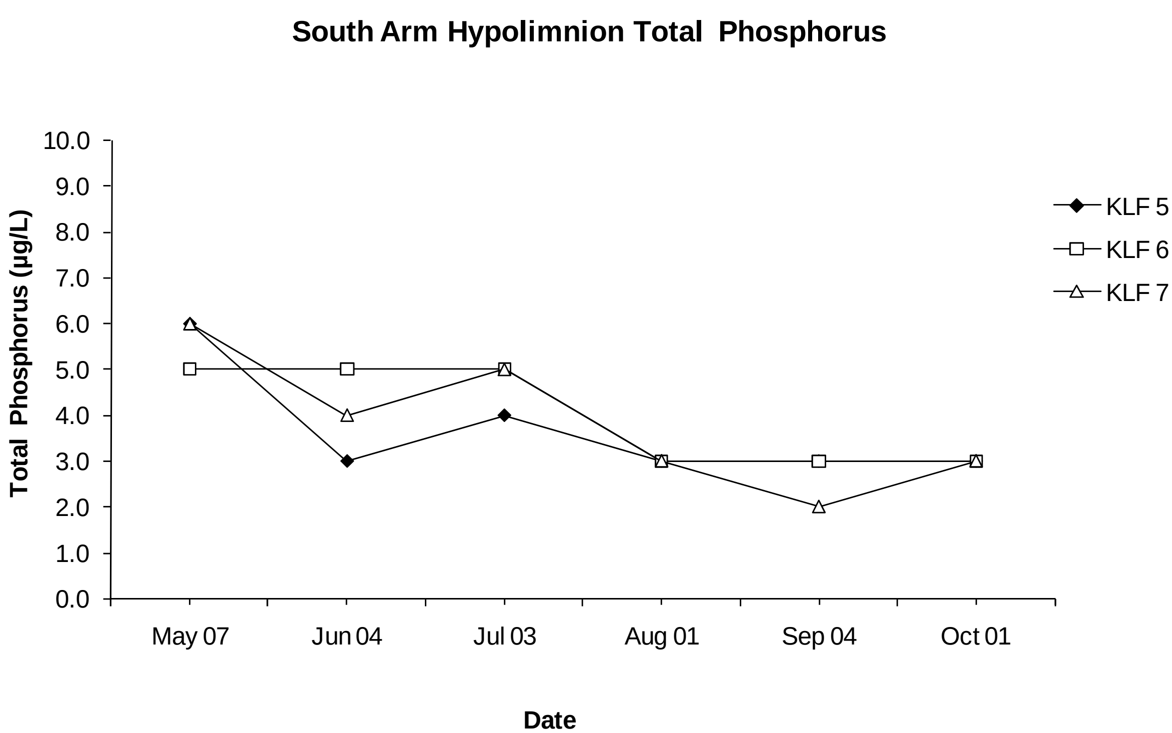
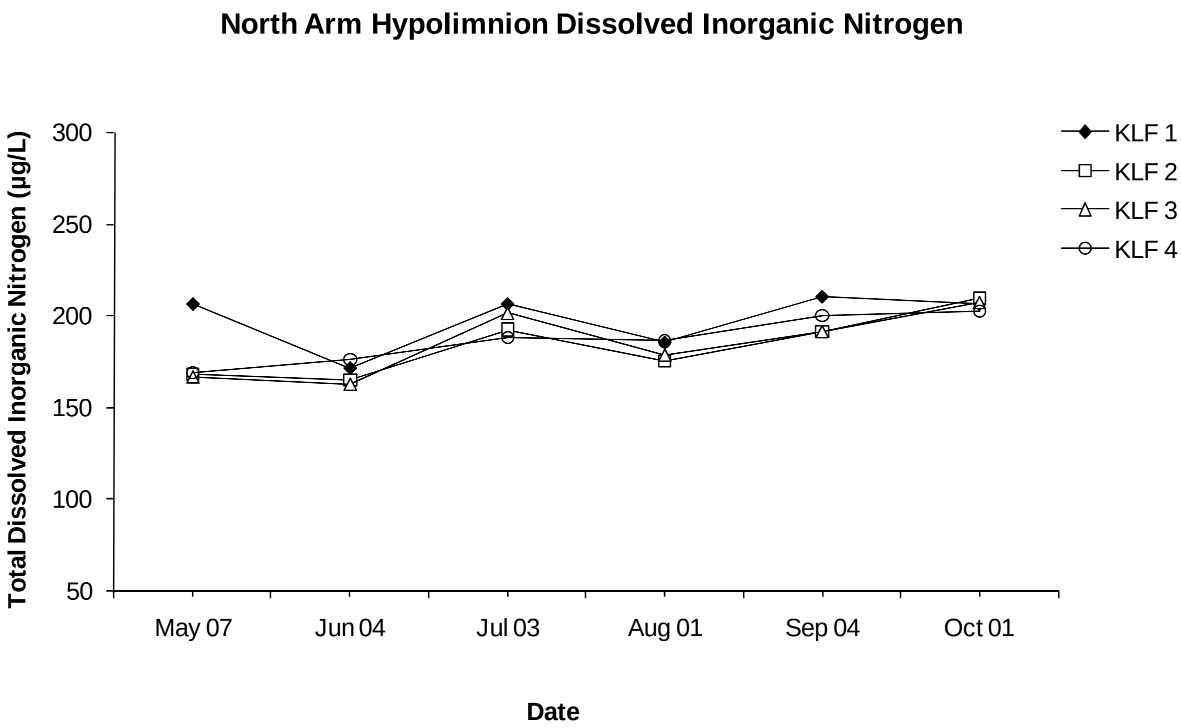


Figure 3.26. Total phosphorus in the hypolimnion at stations KLF 1-7, May to October, 2007.



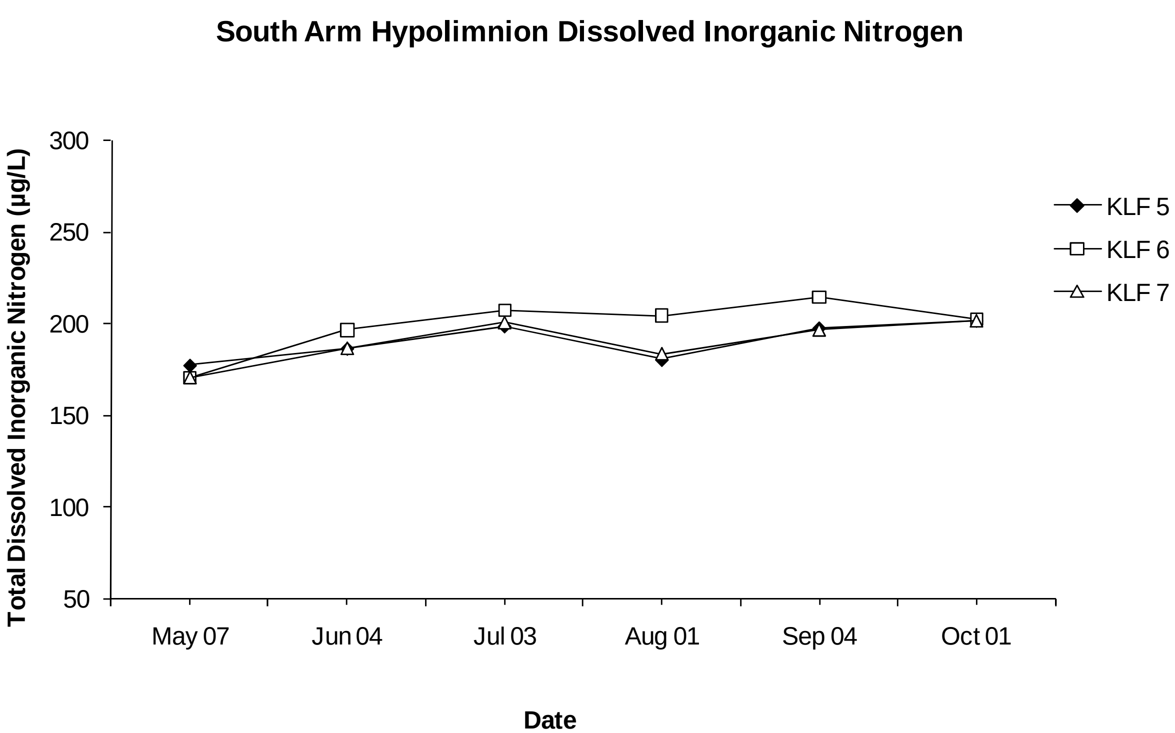
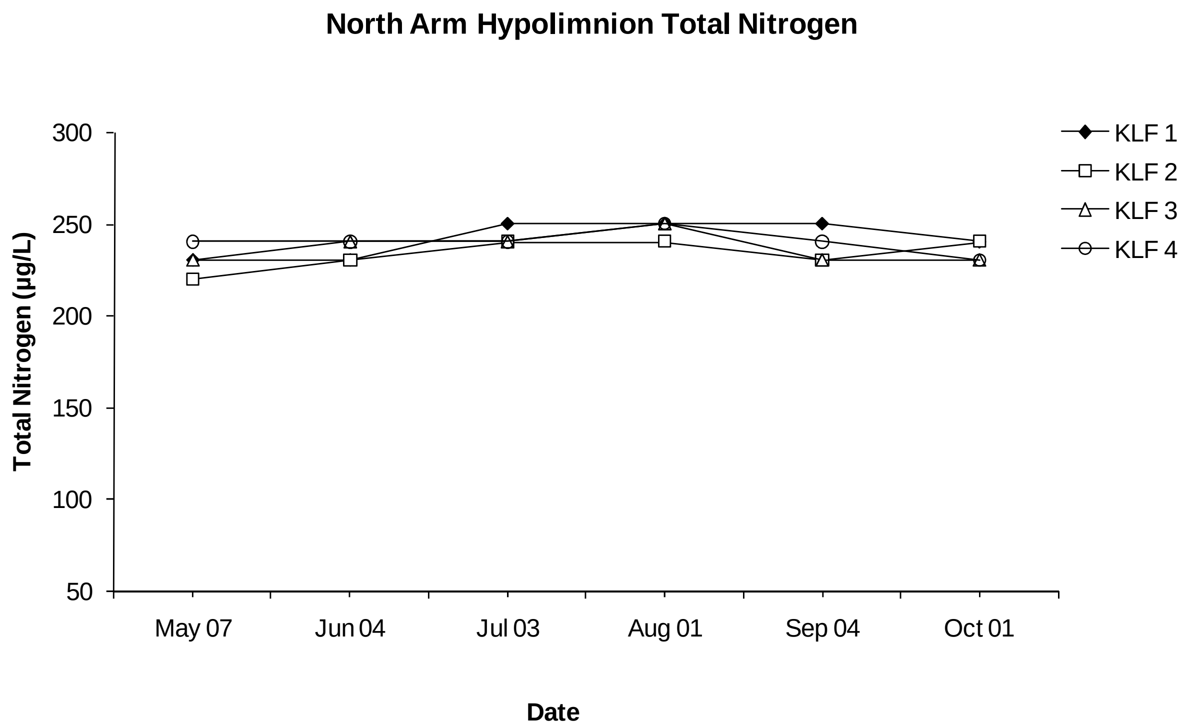


Figure 3.27. Dissolved inorganic nitrogen in the hypolimnion at stations KLF 1-7, May to October, 2007.



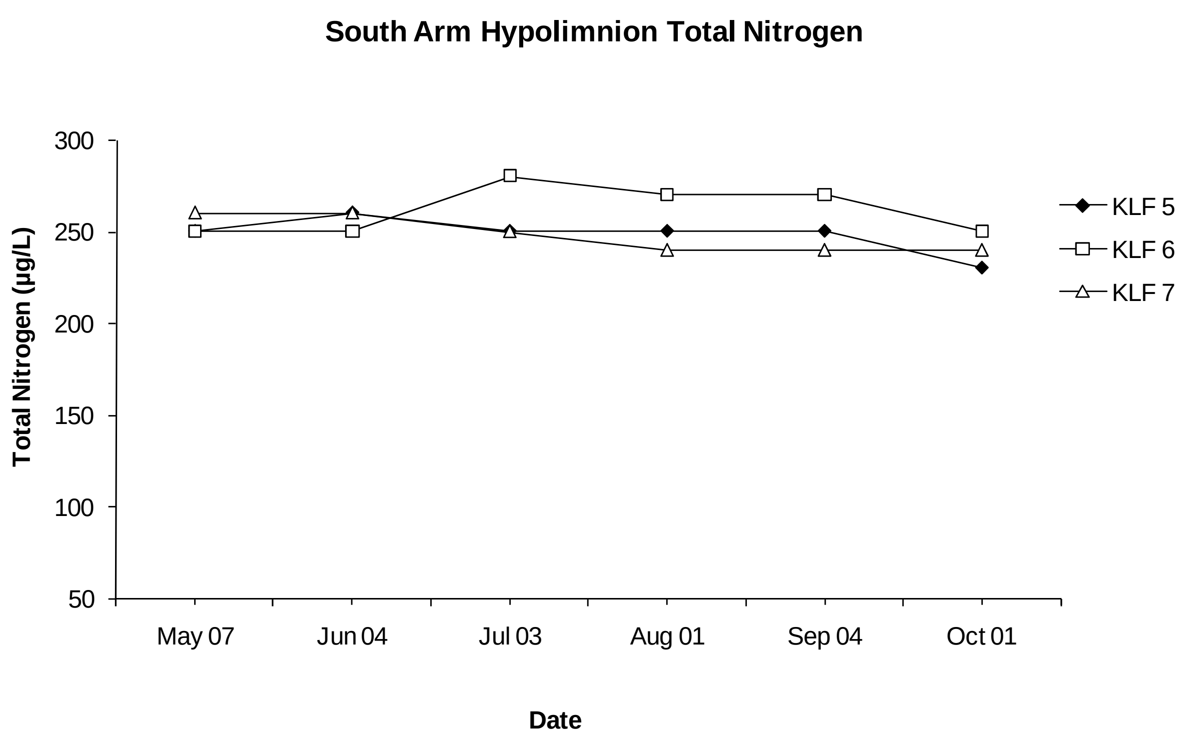
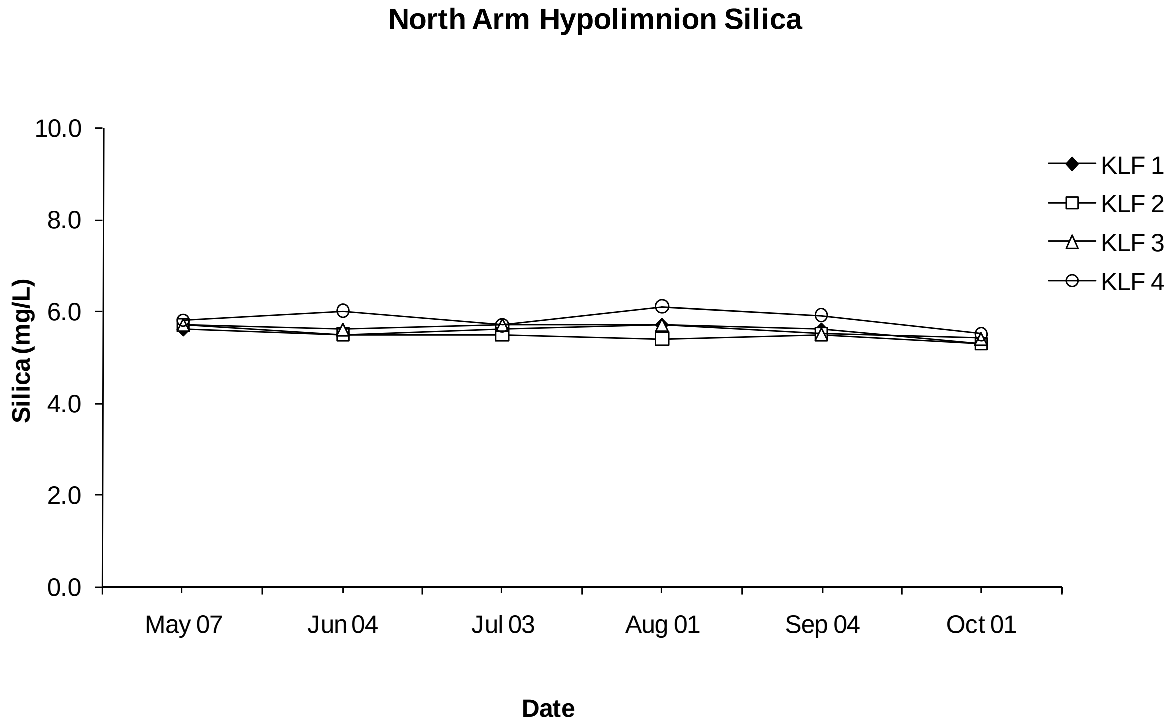


Figure 3.28. Total nitrogen in the hypolimnion at stations KLF 1-7, May to October, 2007.



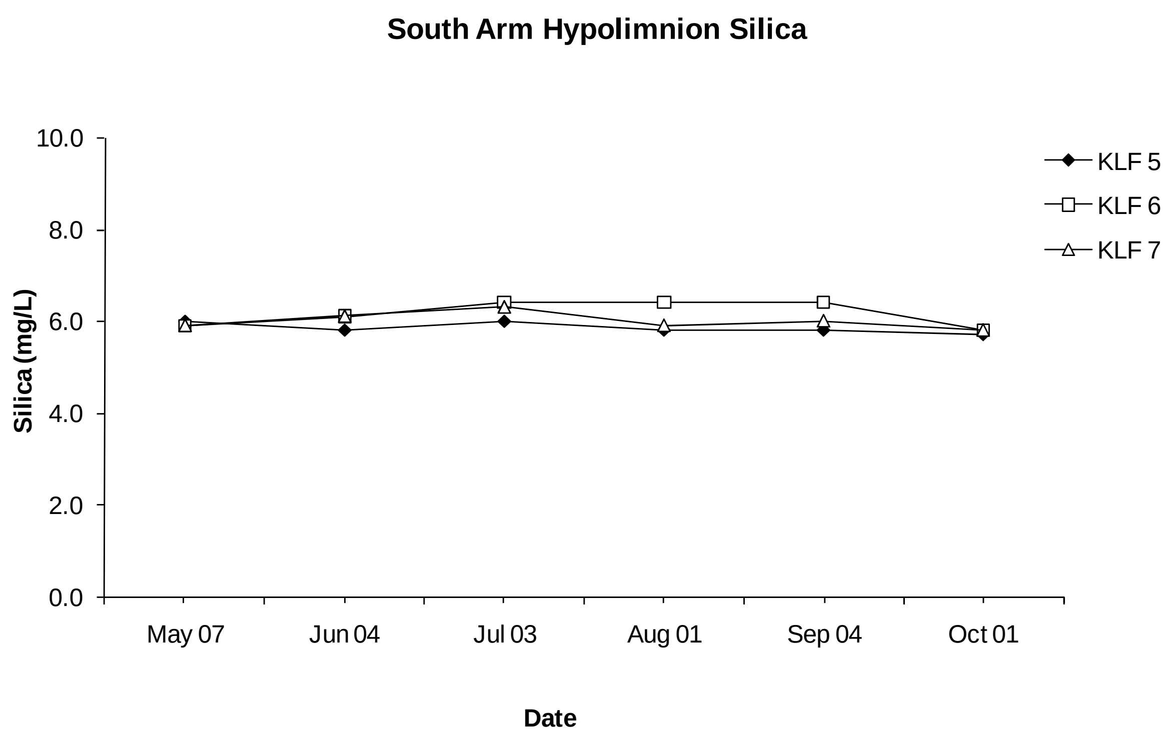
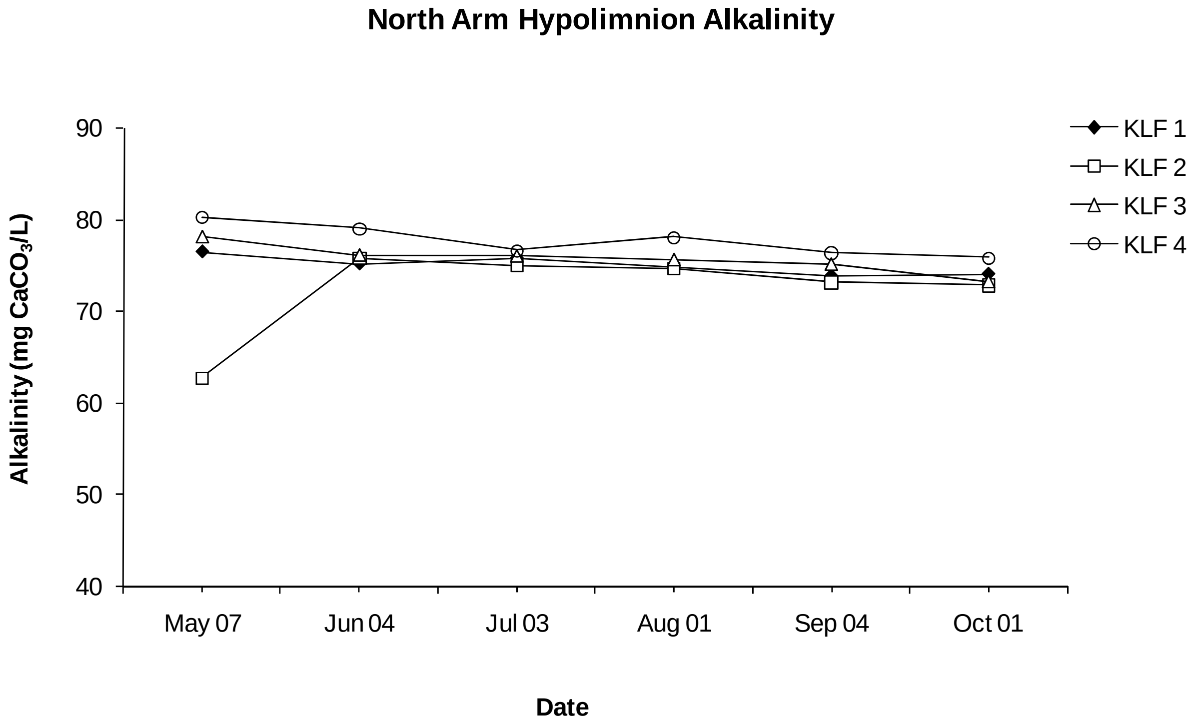


Figure 3.29. Silica in the hypolimnion at stations KLF 1-7, May to October, 2007.



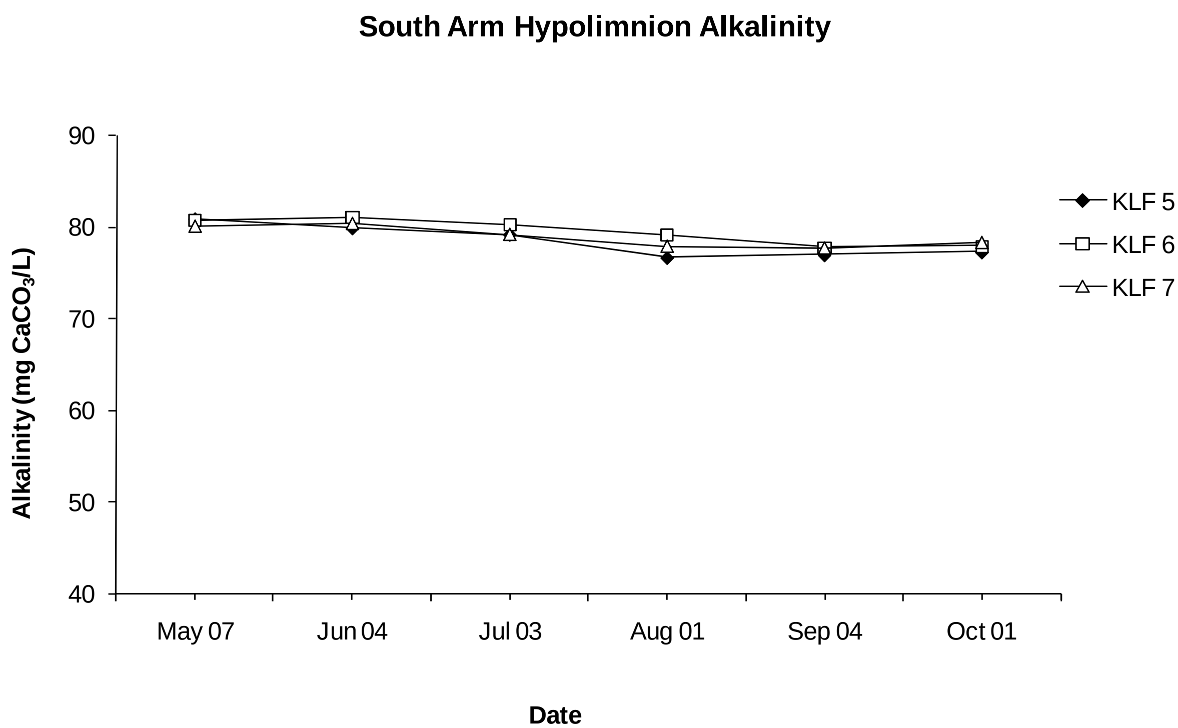
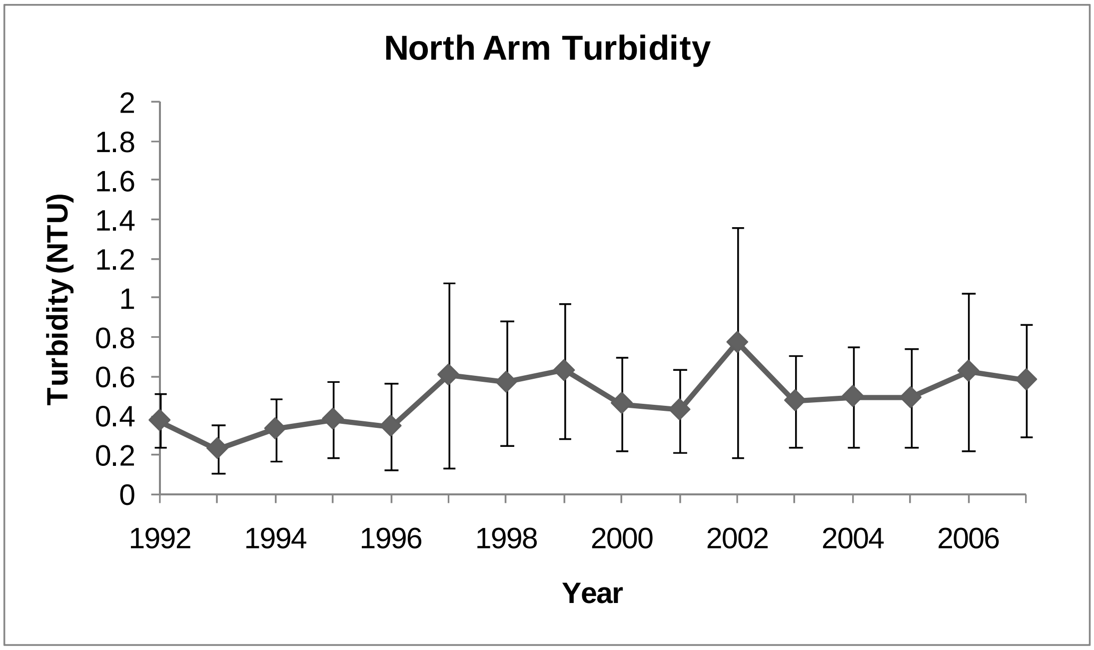


Figure 3.30 Alkalinity in the hypolimnion at stations KLF 1-7, May to October, 2007.



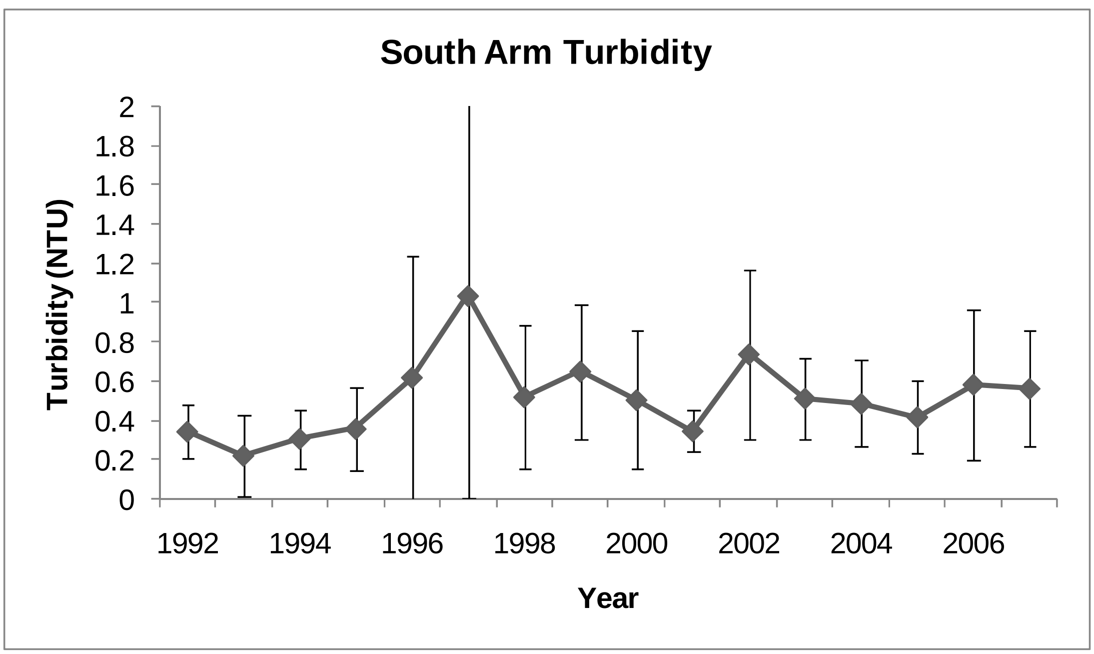
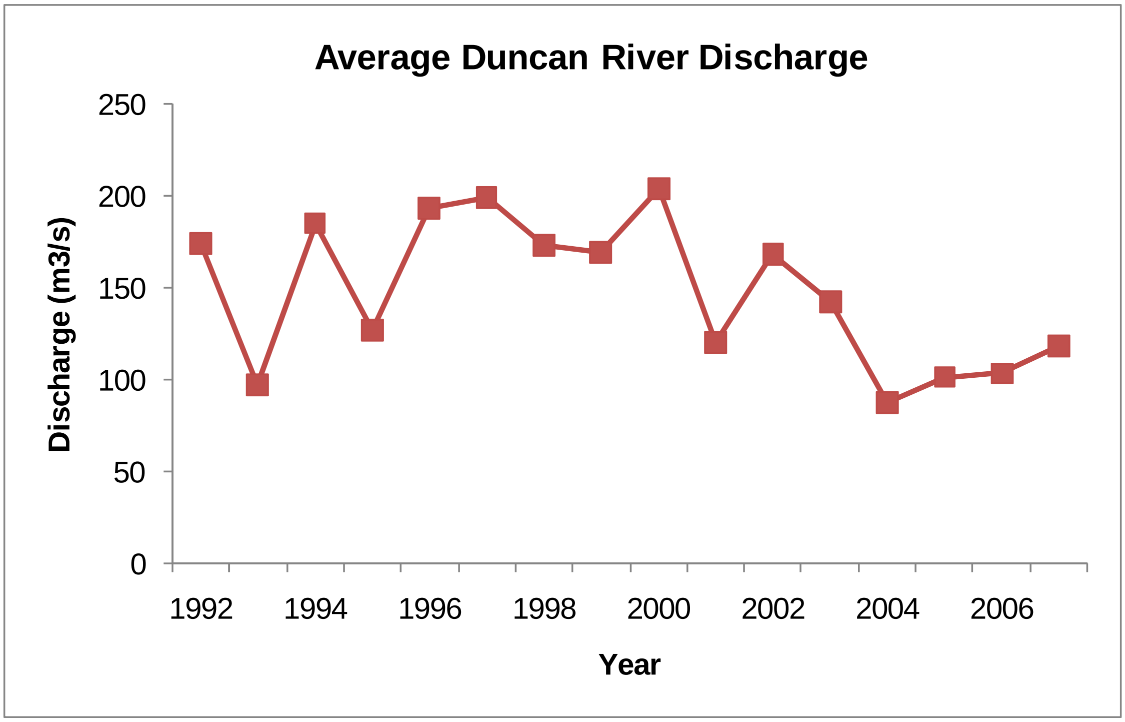


Figure 3.31. Average turbidity and standard deviations in the integrated epilimnion samples in Kootenay Lake, 1992 to 2007.



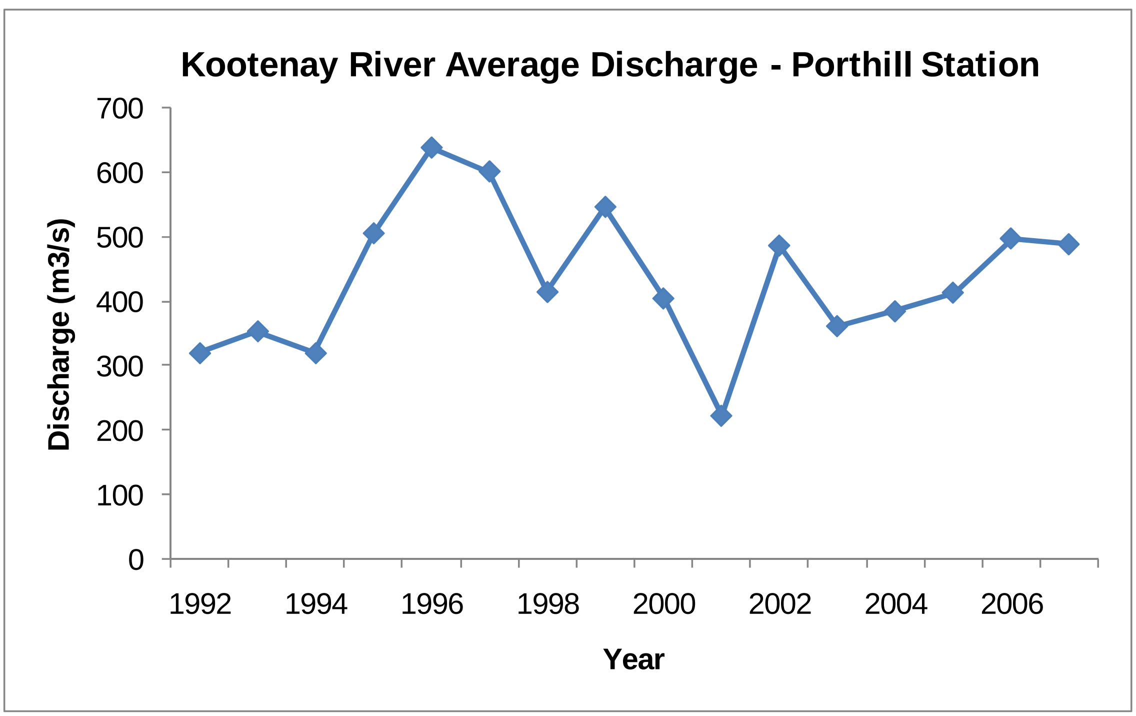


Figure 3.32. Average annual discharge from the Duncan and Kootenai/y rivers, 1992 to 2007.

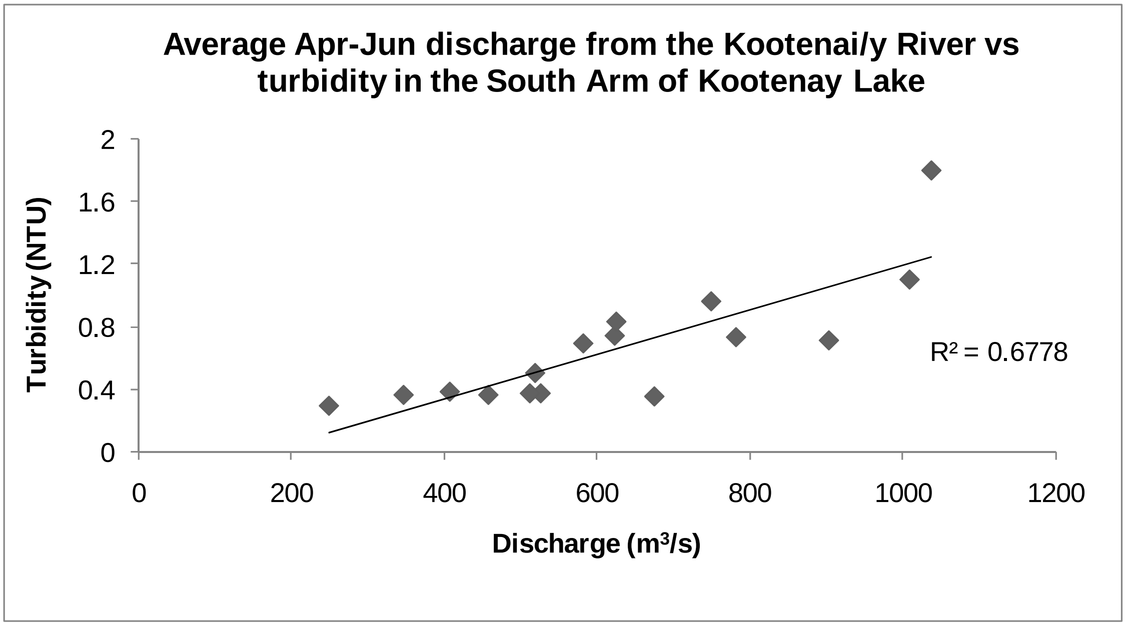


Figure 3.33 Average April to June discharge from the Kootenai/y River vs turbidity in the South Arm of Kootenay Lake; data was from 1992 to 2007.

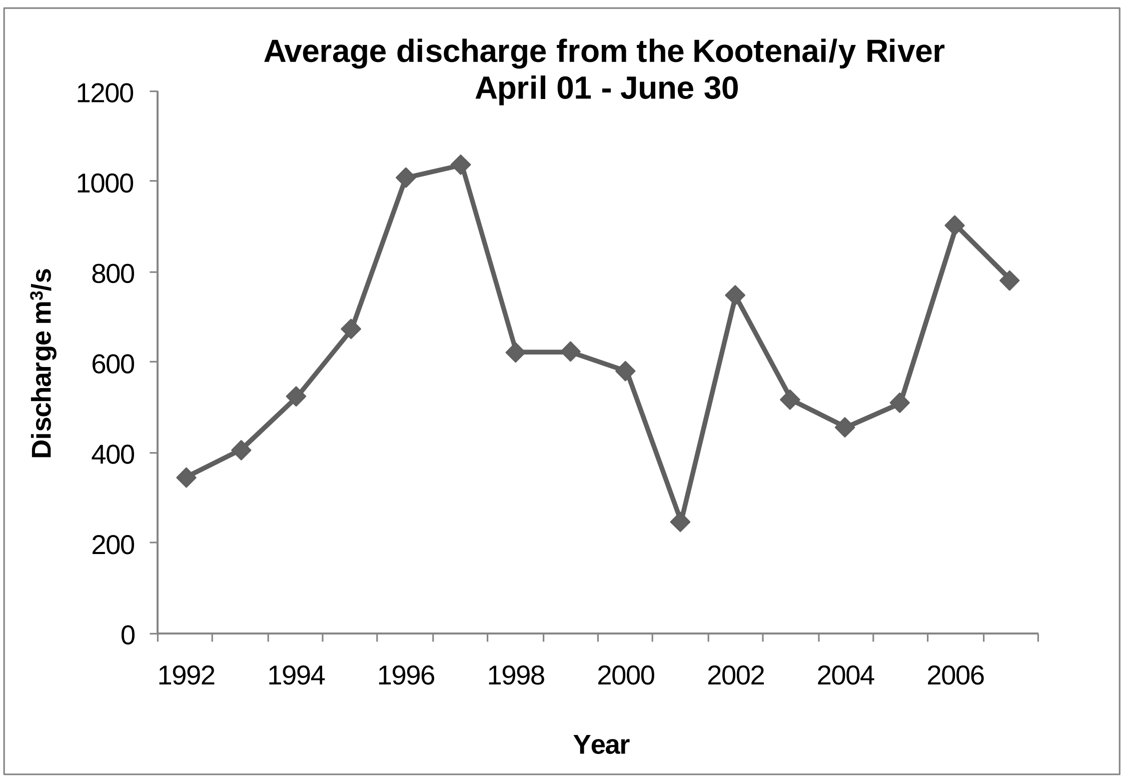
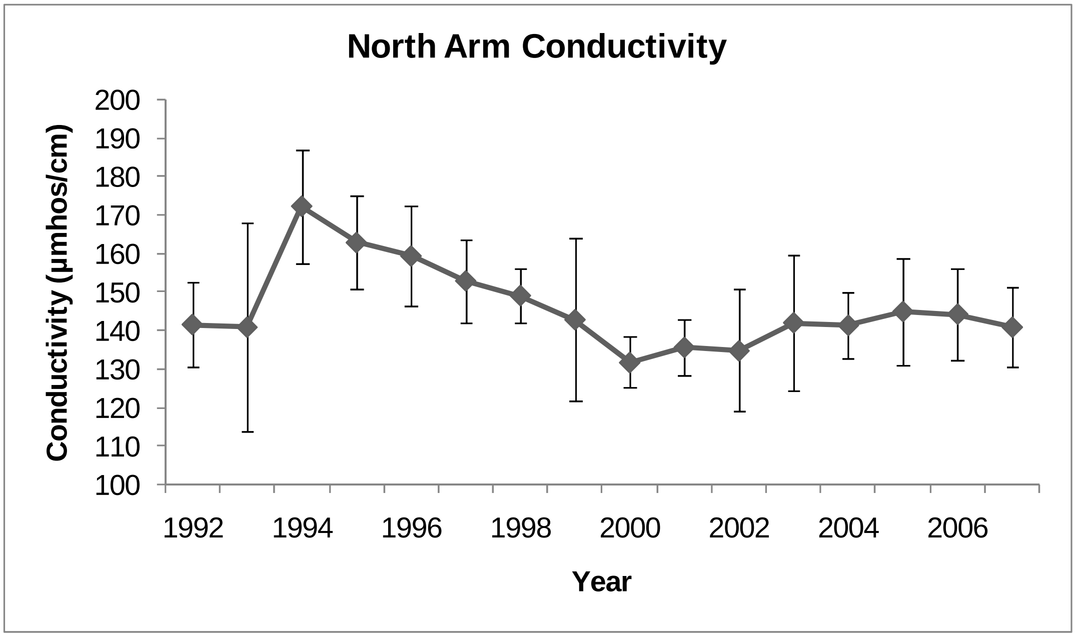


Figure 3.34. Average April to June discharge from the Kootenai/y River, 1992 to 2007.



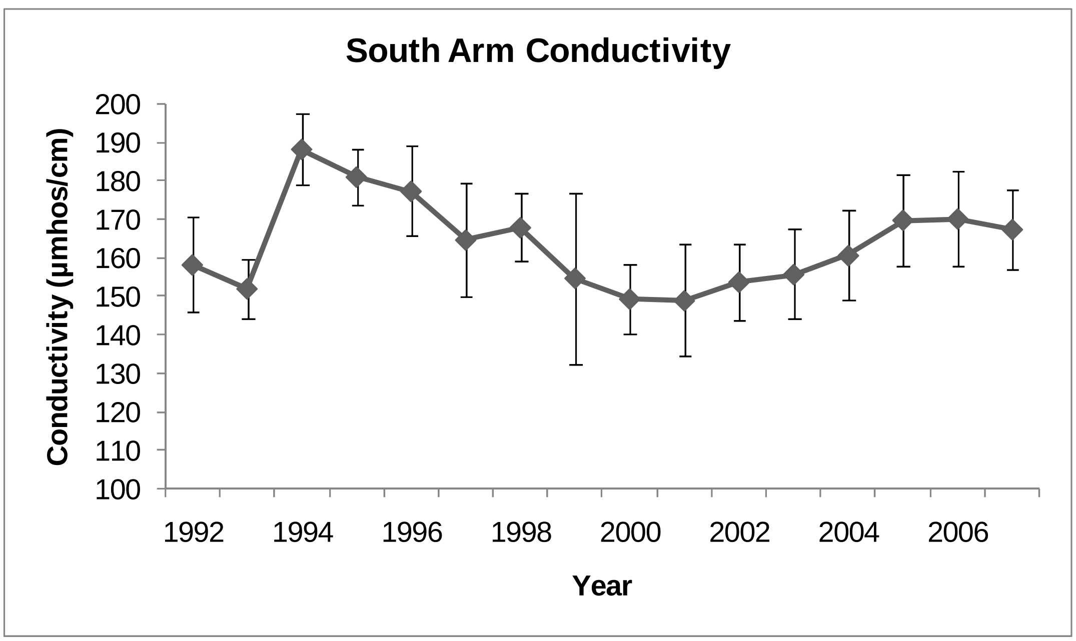
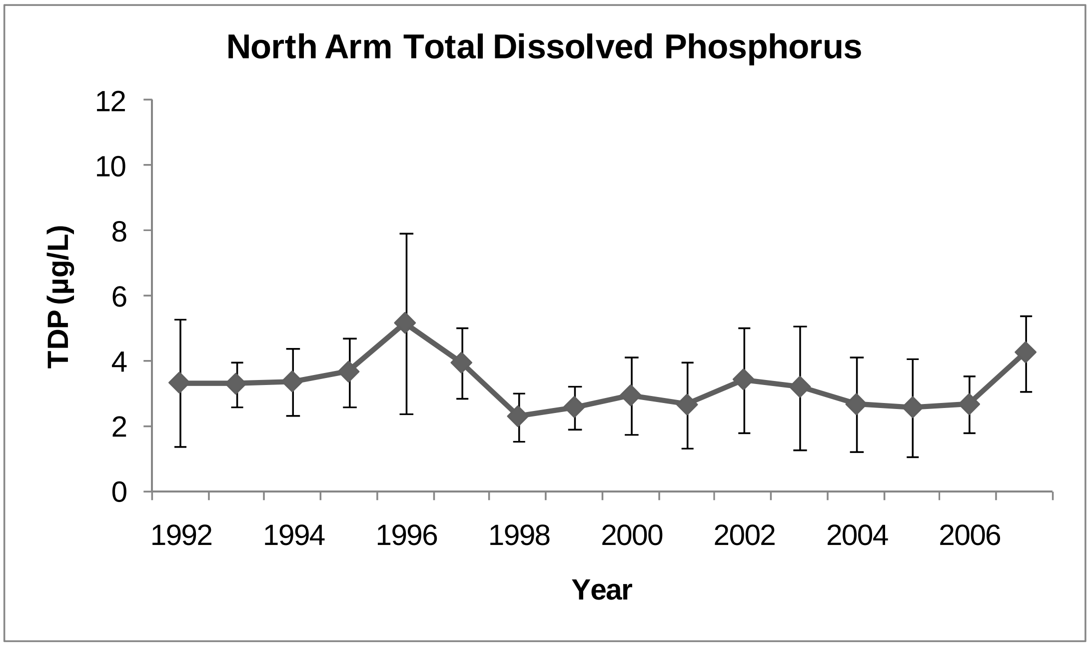


Figure 3.35. Average conductivity and standard deviations in the integrated epilimnion samples in Kootenay Lake, 1992 to 2007.



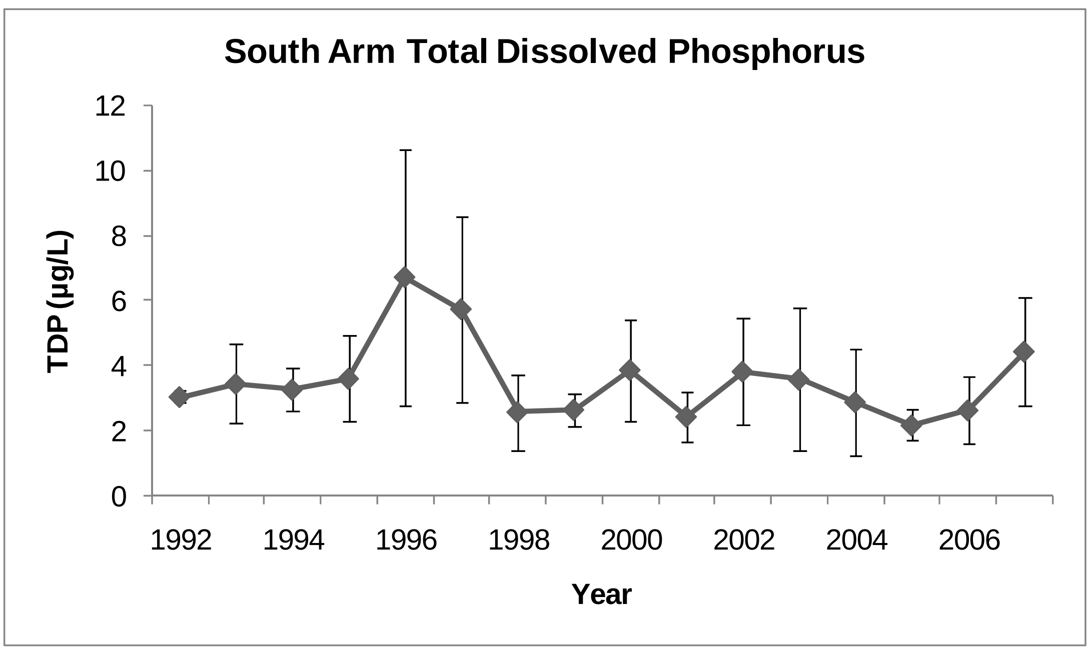


Figure 3.36. Average total dissolved phosphorus and standard deviations in the integrated epilimnion samples in Kootenay Lake, 1992 to 2007.

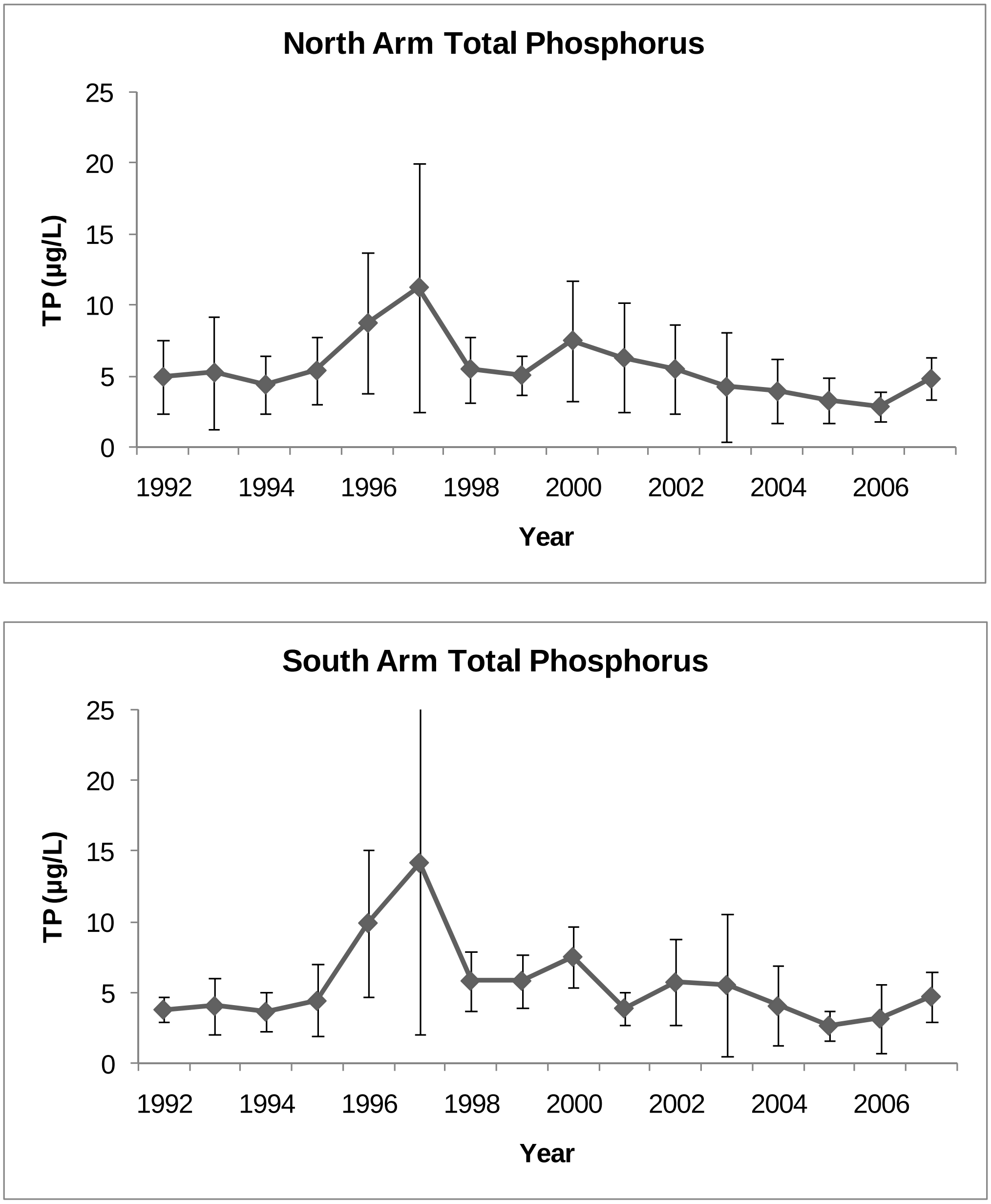


Figure 3.37. Average total phosphorus and standard deviations in the integrated epilimnion samples in Kootenay Lake, 1992 to 2007.

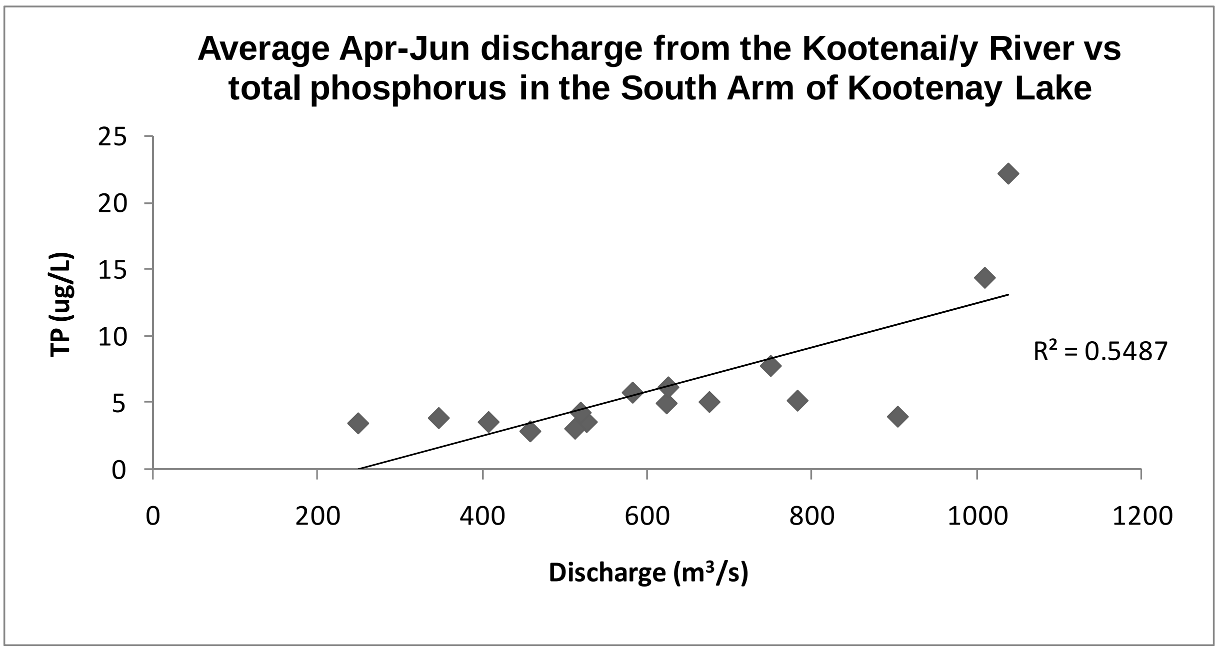


Figure 3.38. Average April to June discharge from the Kootenai/y River vs total phosphorus in the South Arm of Kootenay Lake; data was from 1992 to 2007.

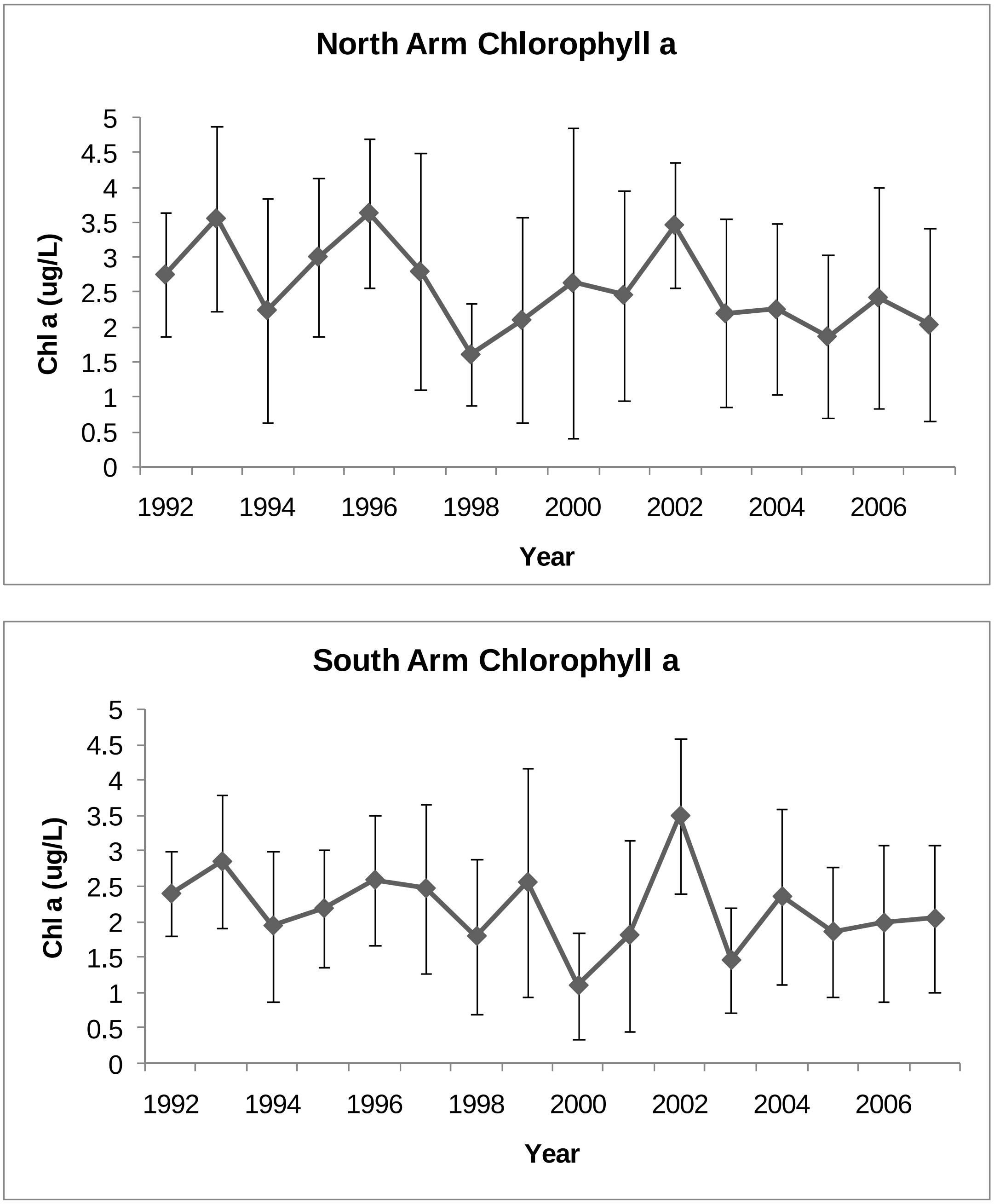


Figure 3.39. Average chlorophyll *a* and standard deviations in the integrated epilimnion samples in Kootenay Lake, 1992 to 2007.

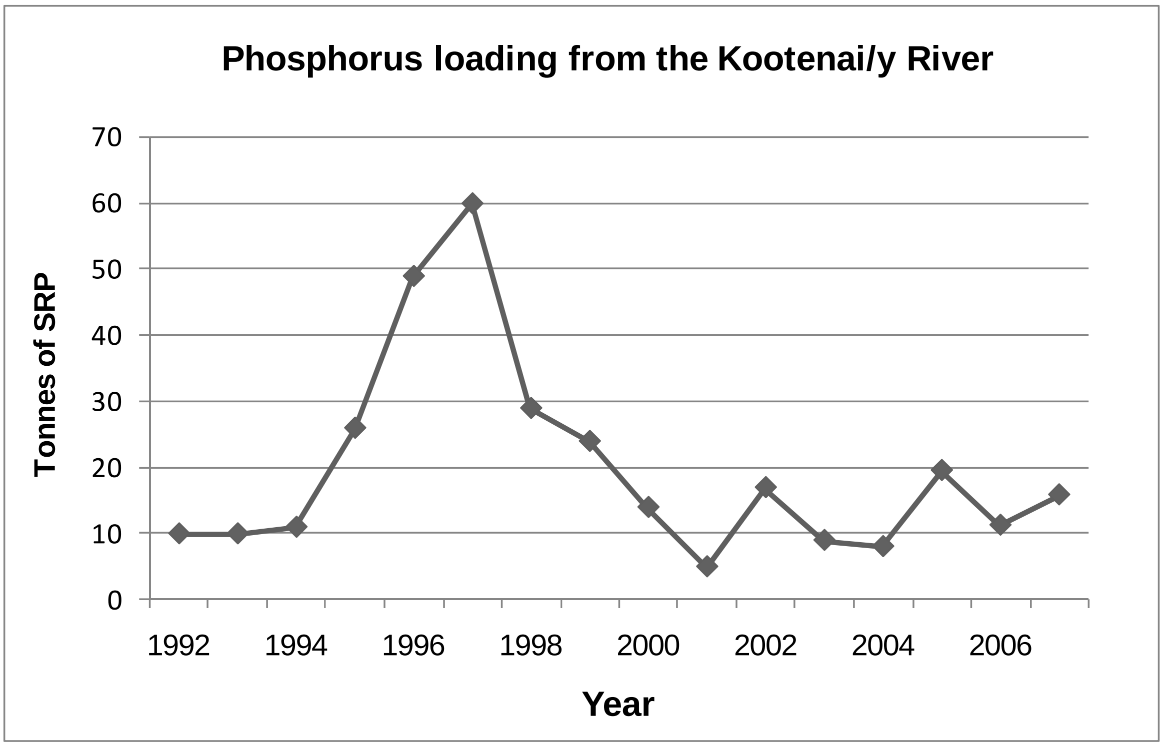
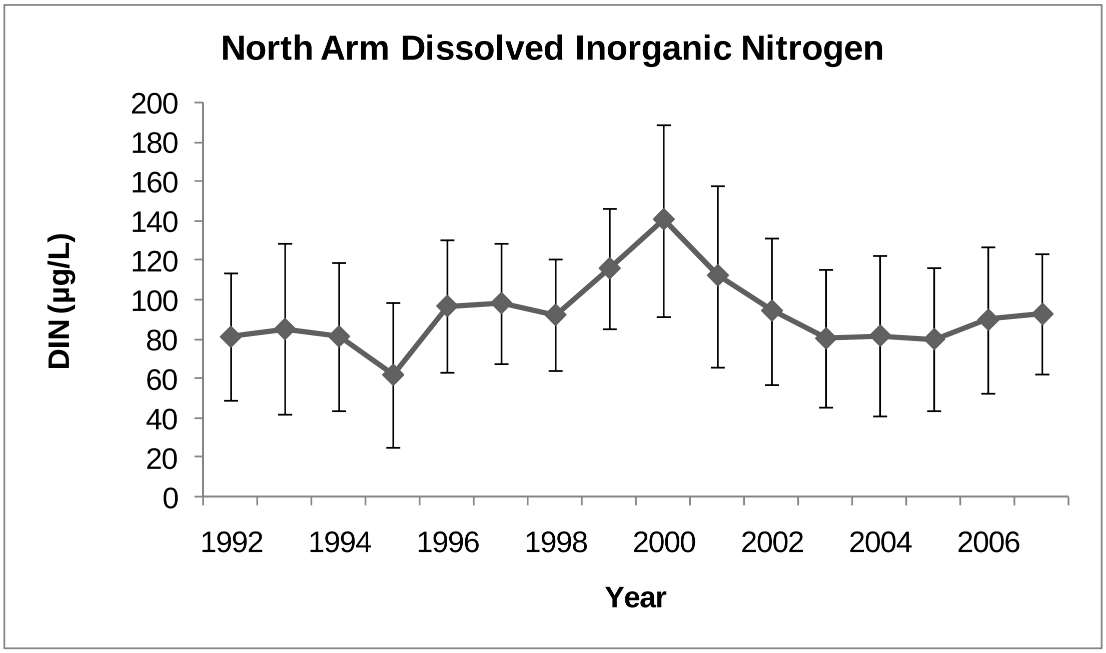


Figure 3.40. Annual soluble reactive phosphorus inputs to the South Arm of Kootenay Lake, 1992 to 2007.



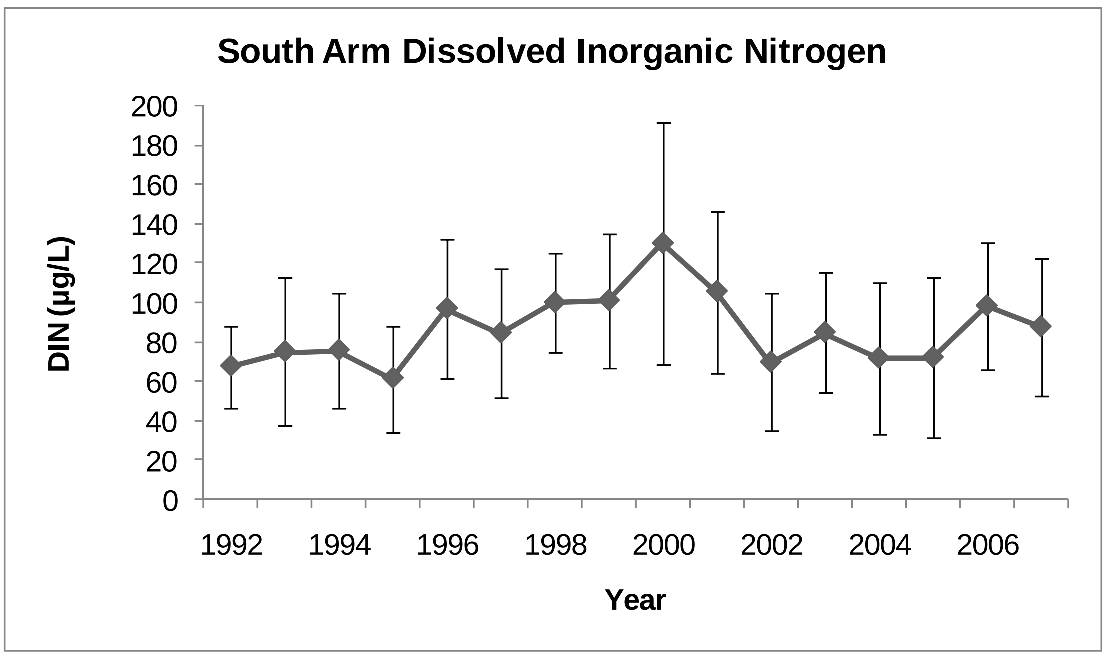
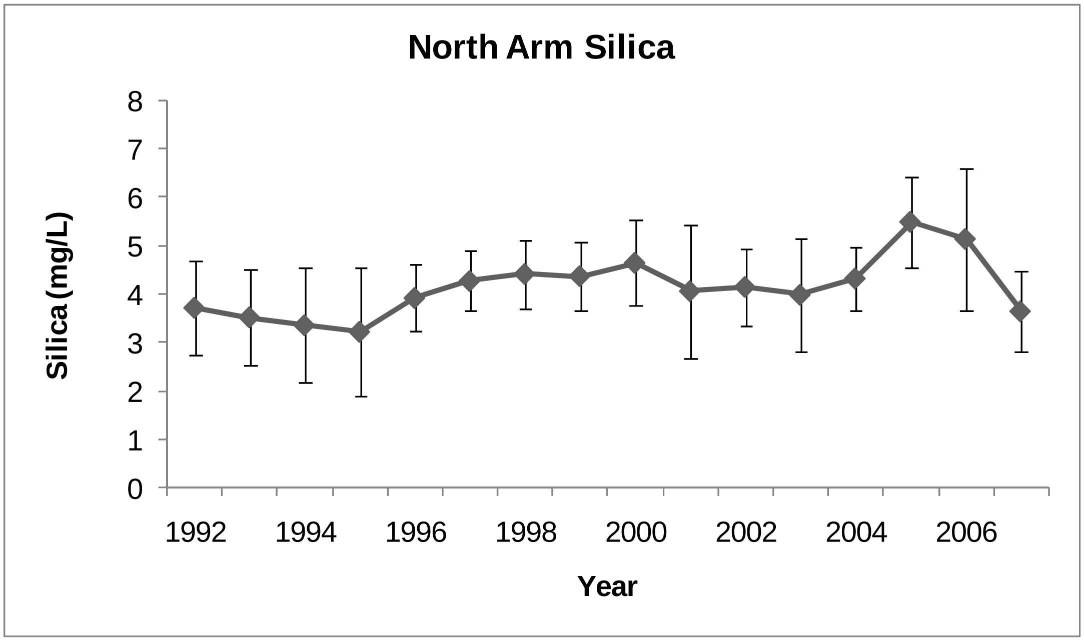


Figure 3.41. Average dissolved inorganic nitrogen and standard deviations in the integrated epilimnion samples in Kootenay Lake, 1992 to 2007.



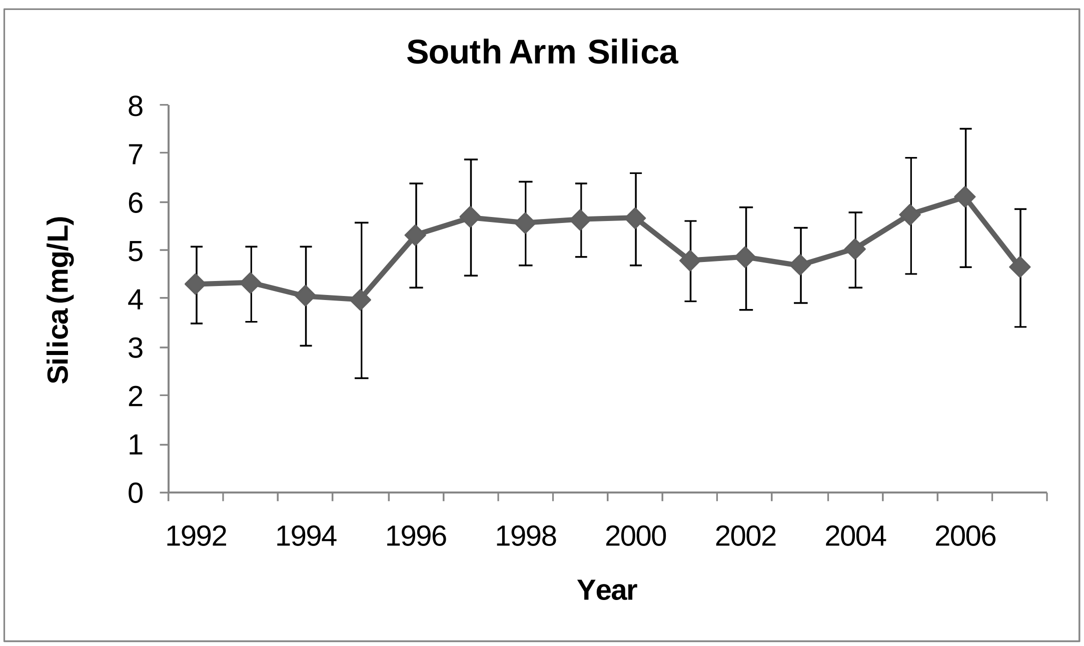


Figure 3.42. Average silica and standard deviations in the integrated epilimnion samples in Kootenay Lake, 1992 to 2007.

CHAPTER 4

PHYTOPLANKTON BIOMASS, COMPOSITION AND SIZE DISTRIBUTION OF KOOTENAY LAKE, BC FOLLOWING NUTRIENT ADDITIONS – YEAR 16 (NORTH ARM) AND YEAR 4 (SOUTH ARM) (2007)

by

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Introduction

Kootenay Lake, a large (390 km2) fjord lake in South-Eastern British Columbia, has been continuously fertilized since 1992 in an effort to rehabilitate declining populations of kokanee salmon (Oncorhynchus nerka) (Ashley et al. 1997, 1999). From 1992 to 1996 the fertilization treatment to the North Arm used 47.1 tonnes of agricultural grade phosphorus fertilizer from spring to early fall. A further five-year adaptive management period of experimental fertilization was initiated in 1997 to document trophic level responses to changing loading rates of nitrogen and phosphorus. In 1997, fertilizer loading was lowered to 29.5 tonnes of phosphorus and this load was further reduced to 22.9 tonnes of phosphorus in each year of 1998 and 1999. In the 9th year of fertilization (2000) the load was increased back to 29.5 tonnes of phosphorus as it was in 1997 and in the 10th – 12thyear (2003) the load was further increased back to 47.1 tonnes as during 1992-96. In 2004, 38 tonnes of phosphorus and 244 tonnes of nitrogen were added to the North Arm. In addition, in 2004, the South Arm was fertilized for the first time during August (Aug 1-Sept 10th) with a weekly addition of nitrogen (28-0-0). In 2005, the total load of fertilizer distributed in 2005 in the North Arm was 44.1 tonnes of phosphorus and 246.9 tonnes of nitrogen, dispensed weekly from April 24th to September 5th; N was added to the South Arm as an agricultural grade of 28-0-0 urea-ammonium nitrate formulation, twice per week from June 5th to September 5th (except weeks of July 17th, July 31st, and September 4th) for a total load similar to the North Arm (234 tonnes of N). In 2006, 44.6 tonnes of P and 248.4 tonnes of N were added to the North Arm and 257.3 tonnes of N to the South Arm. In 2006, nitrogen was added at weekly intervals and a similar regime was continued in 2007.

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

This report is an analysis of the changes, induced by fertilization, to the phytoplankton community of Kootenay Lake during 2007, the 16th year of fertilization in the North Arm and the fourth year of fertilization with N in the South Arm. The data from the 2007 sampling are presented with a comparison to 1992-2006 data. As in 2003 - 2006 in addition to the standard stations KLF 2, 4, 6 and 7, the stations KLF 1, 3, 5 and 8 (located in the West Arm of Kootenay, where water exits the lake) were also sampled.

Methods

Water samples were collected integrating a 0 - 20 m water column, in keeping with the historical sampling procedure, at 7 stations along the length of the North Arm and into the South Arm and at 1 station in the West Arm (station KLF 8). Collection dates for the samples enumerated from 2007 are given in Appendix I along with summary details of the number of transects examined, total species richness, total abundance and total biomass recorded. Samples were enumerated from each of the 8 stations, at one-month intervals, from April through the end of October 2007.

Subsamples of integrated 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.

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

Taxa were assigned to specific size classes based on the mean of their longest dimension. Accordingly, total biomass was partitioned into six size classes: the picoplankton (<2.1µm), the ultraplankton (>2-10 µm), the nanoplankton (10.1-20 µm), the microplankton (20.1-64 µm) and the net plankton (>64 µm). For the purposes of reporting here, nanoplankton are considered to encompass 2 – 20 µm in diameter cells (the more conventional definition of nanoplankton), which is considered the most edible fraction for zooplankton. In contrast the net plankton is considered the least edible size fraction. Picoplankton, which can be very abundant in oligotrophic BC lakes, is a size fraction difficult to enumerate accurately by conventional light microscopy and needs to be examined by epifluorescence microscopy.

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

A species list for all phytoplankton enumerated is given in Appendix II along with the codes used for these species; the list of "associated taxa" refers to algae observed in the samples but not present in the enumerated transects. The count sheets of the raw data are provided in Appendix III for each sample. Linda Ley conducted the enumerations using the same technique as in previous years using the same computer program (Hamilton 1990).

Results and Discussion

2007 Monthly transects

Total phytoplankton biomass was low in April with higher concentrations in the North Arm stations (KLF 1-4 average 0.12 g m^{-3}) compared to the South Arm stations (KLF 5-7 average 0.081g m^{-3}) (Fig. 4.1). Cryptophytes (*Cryptomonas* spp. and *Rhodomonas* renamed *Plagioselmus*) were dominant.

The low biomass in April was followed by a rise in biomass in May at all stations. The May rise in the North Arm was due to further increases in cryptophytes and the beginnings of significant pennate diatom biomass particularly of *Synedra* spp. Biomass continued to rise through early June most importantly in the North Arm due to further increases in cryptophytes and pennate diatoms namely *Synedra* spp. and some *Asterionella.*

In July algal biomass was highest at KLF 5 (as observed also in 2006) in the South Arm from increases in *Asterionella*, *Tabellaria*, some *Cryptomonas* and *Fragilaria.* Algal biomass was uniformly high across the lake in August when the pattern was one of highest biomass at KLF 1 (Fig. 4.1). During August *Fragilaria crotonensis* and *Asterionella* contributed about half the biomass in both arms of the lake

With the exception of high biomass at KLF1, biomass was lower in September along the lake as pennate diatom biomass was declining. Small centric diatoms contributed roughly equally with pennate diatoms to the total algal biomass. During October biomass was lower than in September and fairly similar along the lake. Biomass was higher in the fall than in the spring (Fig. 4.1).

Taxonomic composition at the division level

On average, diatoms (Bacillariophyta) dominated the biomass of Kootenay Lake comprising, depending on the station (63% for station KLF 2, 65% for KLF 6) of the total annual algal biomass (Fig. 4.2). As is typically observed in other years, large pennate diatoms tend to dominate the maximum biomass periods but in 2007 this occurred in July – August rather than the typical bloom period (mid to late June is usually when Kootenay Lake has a diatom maximum) but the peak diatom biomass may have been missed due to sampling early in the months of both June and July. Later in the summer a variety of centric species of the genus *Cyclotella* become more abundant but in 2007 as in 2006 they were rarely ever dominant in terms of biomass.

Following diatoms, the next most important division was the Cryptophyta followed by the Chrysophyta and finally Cyanobacteria or “others” (comprised of Chlorophyta and Pyrrhophyta) (Fig. 4.2). Cryptophyta were typically most dominant in the spring (April through June, Fig. 4.2). In fact cryptophyta were more important during spring and early summer in 2007 relative to previous years. In contrast to 2005 and 2006, the contribution of cryptophytes to total biomass was greater in the North Arm than in the South Arm (31% vs. 18%). Cryptophytes are considered the most nutritional algae for zooplankton growth along with chlorophytes so an increase in cryptophyte biomass should have positive impacts on zooplankton production. Alternatively the high cryptomonad biomass may reflect a lower grazing pressure or a change in phenology of major grazers in 2007.

Chrysophyta comprised the third major algal division in Kootenay Lake and chrysophyte biomass was slightly higher in the South Arm as well as the average annual (or summer) contribution of chrysophytes (5.7% vs. 3.8% in North Arm). Cyanobacterial biomass was negligible as in previous years.

Size distribution

Large pennate diatoms tend to dominate biomass in Kootenay probably as a result of significant deep vertical mixing and silica availability. As a result, the size distribution of algal biomass tends to be dominated by the larger fractions (Fig. 4.3). Netplankton with a maximum linear dimension greater than 64 µm was a significant fraction of the total biomass ranging from 35 to 42% on an annual basis depending on the station and varied from 1 to 54% seasonally. As such the effect of season tends to override the effect of station or fertilisation on the size distribution of biomass. In the North and South arms there was a large increase in net plankton in July and August (Fig. 4.3). The average contribution of netplankton to the total biomass was greater in the North Arm (33%) than in the South Arm during 2007 (24%) which is a lower contribution than that observed in 2006 and in most other years. Nanoplankton plankton biomass (2 – 20 µm) was higher in the South Arm in the spring (May and June) while the North Arm nanoplankton was higher in the summer (June, July, August) (Fig. 4.4).

Comparison with the previous years of fertilization

In the year 2007, the average biomass was only slightly higher in the North relative to the South Arm (Table 1). However, the summer biomass (June, July, August) was clearly higher in the N+P fertilized North Arm versus the N-fertilized South Arm (Fig. 4.5)

Considering the levels of fertilizer added to the North Arm in 2007, algal biomass was not as high as in previous years with similar fertilizer additions, or more significantly, the enhancement relative to the South Arm was not particularly high at 1.4 although higher that 2004-2006 (Table 4.1). The highest summer enhancement was recorded in 2001 at 3.04 (Table 4.1). While differences in the enhancement ratios could in part be due to the timing of sampling with respect to blooms, they may also reflect differences in the physical regime of the lake between years as there is a strong climate effect on the year to year variation in algal biomass (Fig. 4.5).

The addition of N to the South Arm did not result in a significant increase in summer biomass relative to the natural variation observed over the 10 years when the South Arm was not treated (2007 Stn 6 summer average 0.47 g m^{-3} vs. the average of 1993-2003 of 0.59 g m^{-3}). The fact that the North Arm biomass was on average higher points to the overall importance of P in limiting algal biomass in Kootenay Lake.

Acknowledgements

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Table 4.1. Biomass averages (mg.m^3) at station KLF 2in the North Arm and at station KLF 6 in the South Arm from 1992 – 2007. Enhancement is the effect of fertilization during the summer (ratio of Station KLF 2 over Station KLF 6) although starting in 2004 nitrogen has been added to the South Arm.

	Annual (Apr. - Oct.Nov.) (n = 7 - 14)		Summer (Jun. - Aug.) (n = 3 - 6)		Summer Enhancement
	Stn 2	Stn 6	Stn 2	Stn 6	Ratio
1992	445	359	534	473	1.13
1993	658	364	1091	455	2.40
1994	900	477	1183	557	2.12
1995	1366	800	1556	945	1.65
1996	1867	813	2483	1040	2.39
1997	626	337	1081	519	2.08
1998	436	323	516	462	1.12
1999	405	340	501	397	1.26
2000	500	316	419	395	1.06
2001	1011	438	1016	334	3.04
2002	572	875	881	1085	0.82
2003	509	276	720	340	2.12
2004	217	287	224	336	0.67
2005	439	429	624	469	1.33
2006	464	317	589	469	1.26
2007	361	309	664	473	1.40

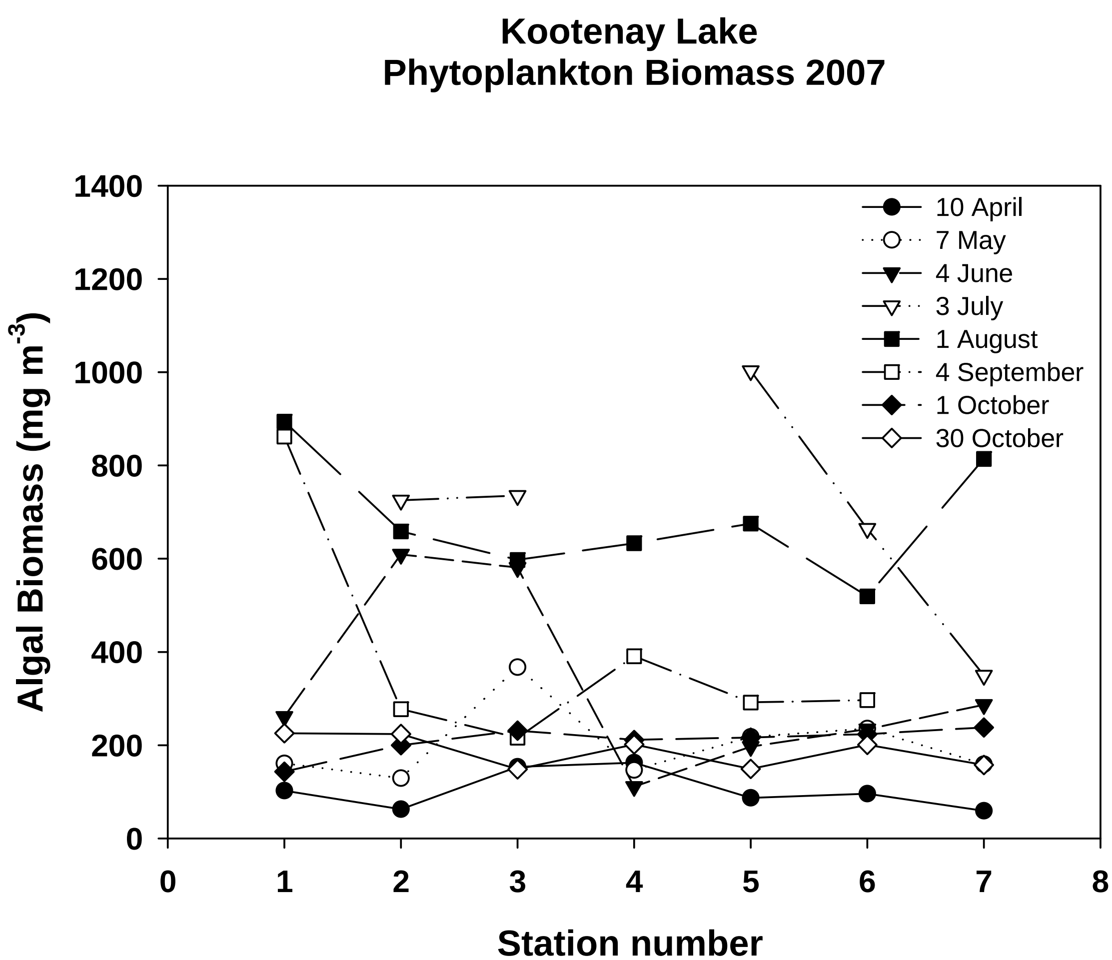

Figure 4.1. Total algal biomass, along the North South transect of Kootenay Lake, from April through November of 2007 Stations KLF 1 through KLF 7. KLF 8, an additional station in the West Arm, is not represented.

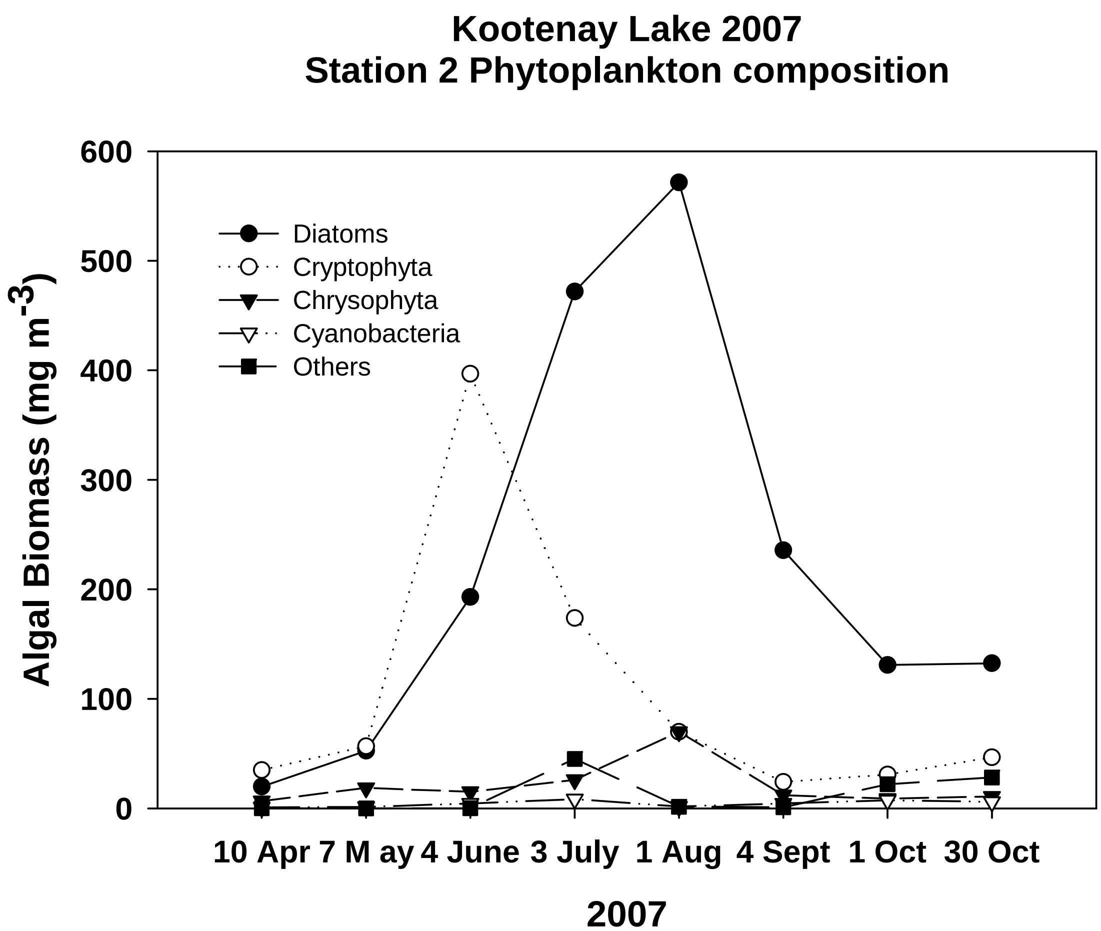

Figure 4.2a Seasonal algal biomass by algal division, for Station 2 North Arm in 2007. Lines correspond to divisions as indicated in the legend. “Others” correspond to chlorophytes and occasional pyrrhophytes (dinoflagellates).

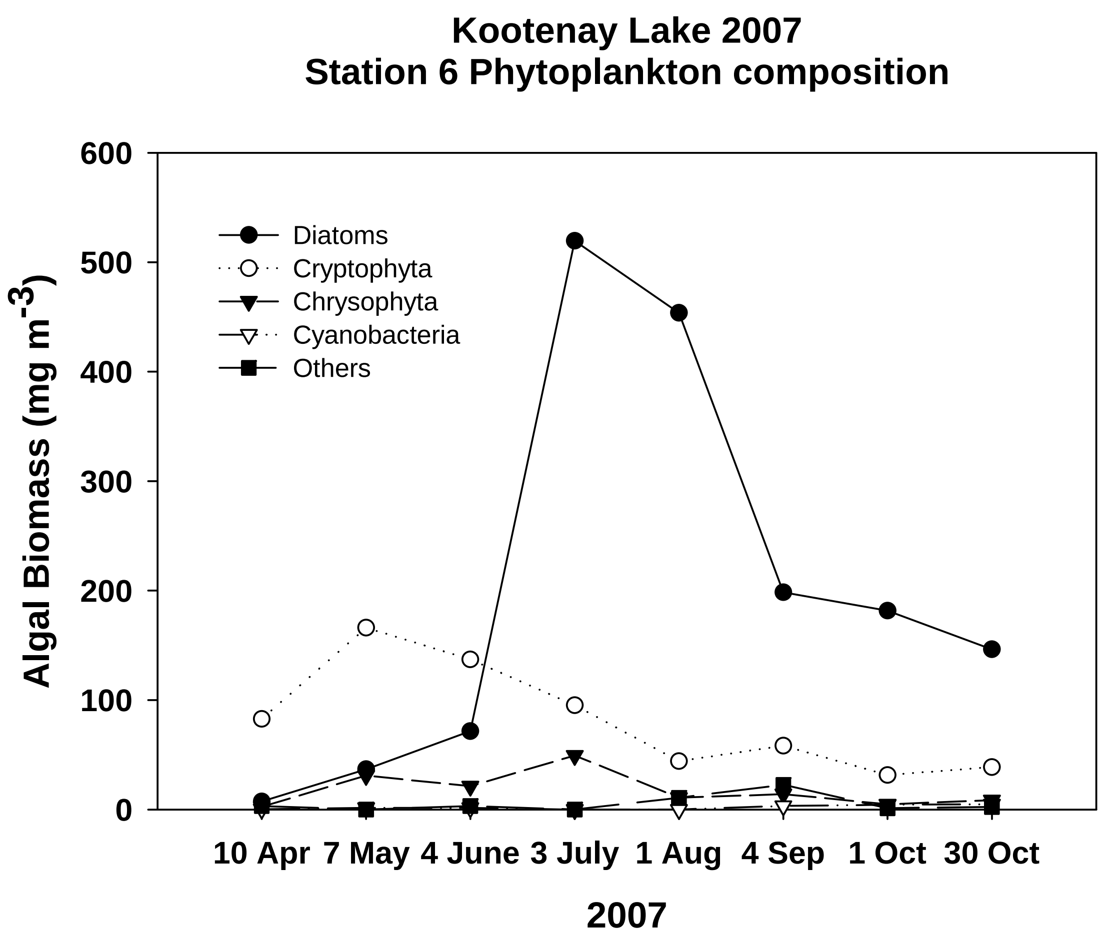

Figure 4.2b. Seasonal algal biomass by algal division, station 6 South Arm in 2007. Lines correspond to divisions as indicated in the legend. "Others" correspond to chlorophytes and occasional pyrrhophytes (dinoflagellates).

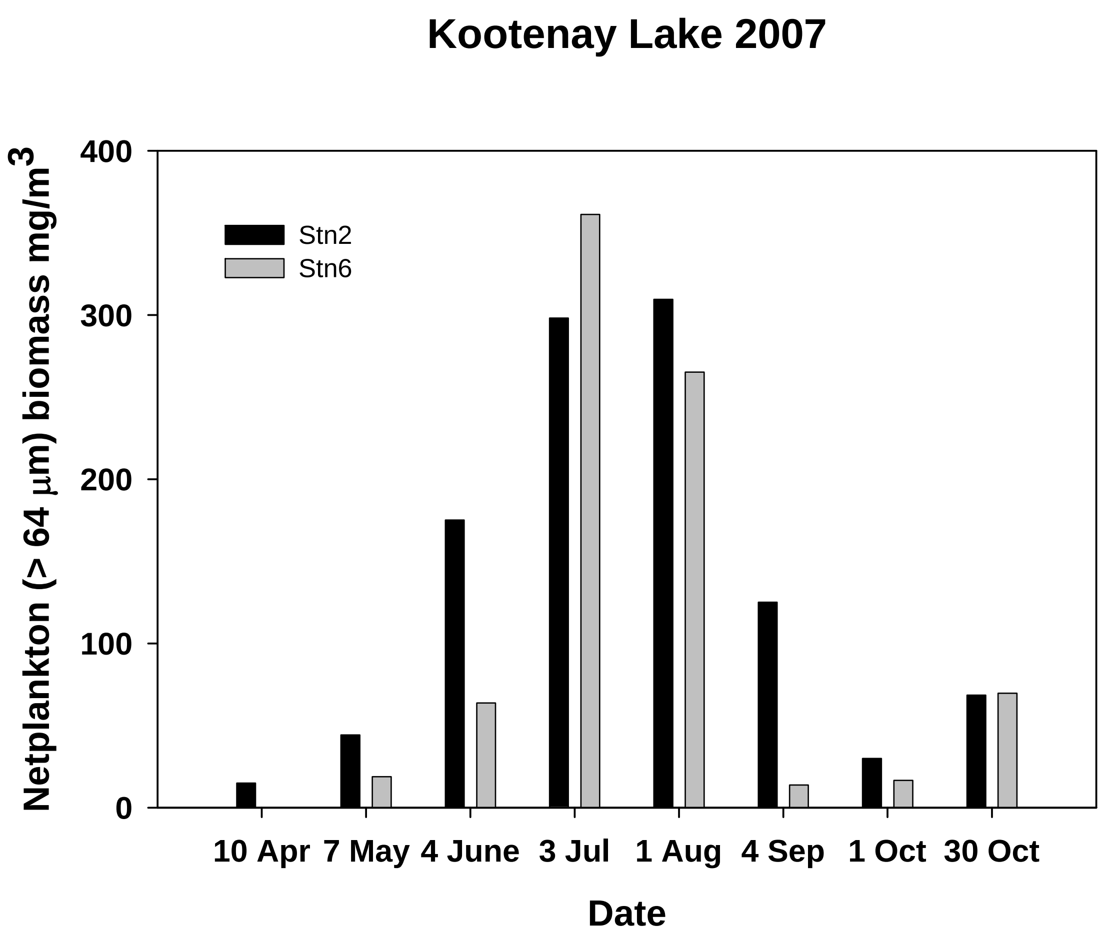

Figure 4.3. Seasonal biomass of netplankton (> 64 µm) at stations 2 (dark histograms) and 6 (light histograms).

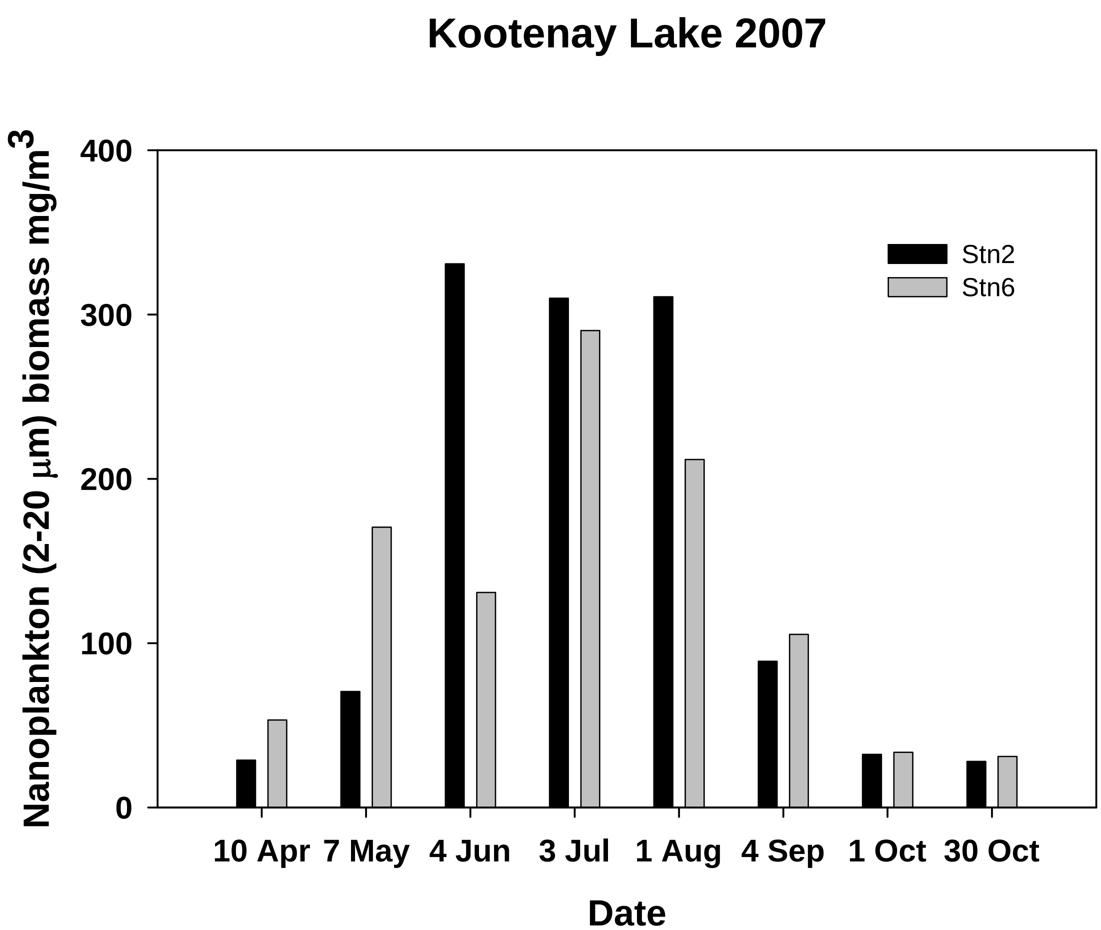

Figure 4.4. Seasonal biomass of nanoplankton (2 - 20 µm) at stations 2 (dark histograms) and 6 (light histograms).

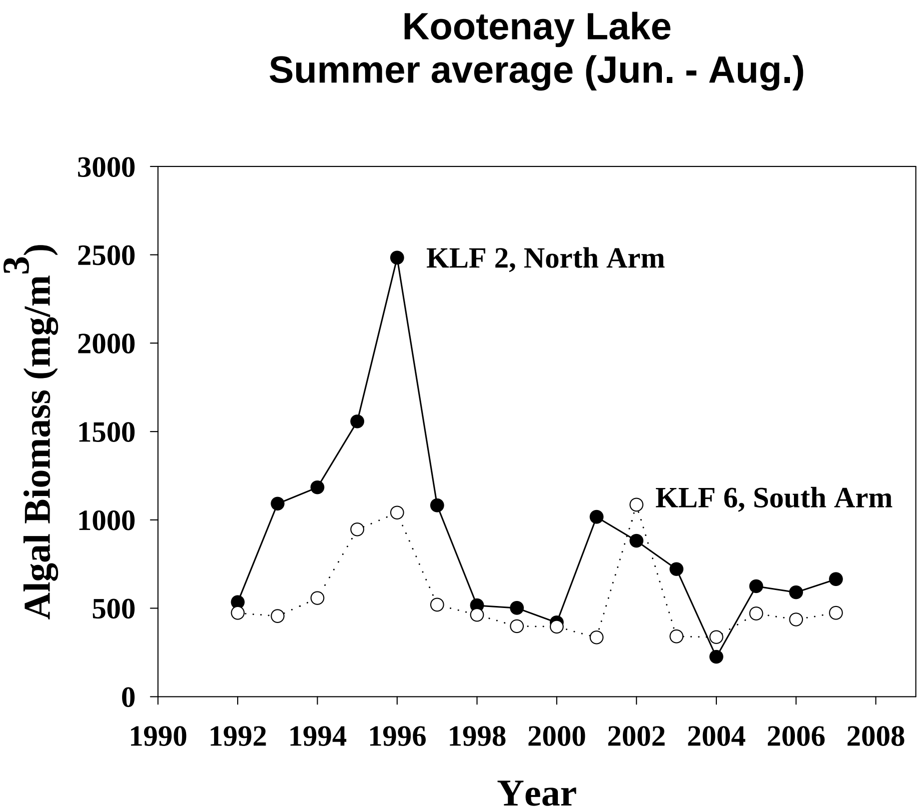

Figure 4.5. Summer average biomass of Kootenay Lake since 1992. Fertilized station KLF 2 in the North Arm compared to old "reference" station KLF 6 in the South Arm. Note that N additions began in the South Arm in 2004.

CHAPTER 5

PHYTOPLANKTON VERTICAL PROFILES AND PRIMARY PRODUCTIVITY IN KOOTENAY LAKE 2004 - 2007

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Introduction

Phytoplankton consists 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 group 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*, 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). Given that the community composition and the size structure of phytoplankton may change with the application of nutrients, the trophic levels need to be closely monitored, as it can affect the recovery of kokanee.

Primary productivity, expressed as the formation rate of new organic material by phytoplankton and autotrophic bacteria is studied to measure the immediate effects of nutrient addition,. Primary productivity measures the direct and immediate effects of nutrient addition on lake productivity and is free of the confounding effects of grazing by higher trophic levels or trophic time lags. The first trophic level to respond to nutrient restoration will be the phytoplankton level. The study of size fractionated primary productivity provides detailed information on the response of each fraction of the phytoplankton community. The three most commonly studied size fractions are the picoplankton (0.2-2.0 µm), nanoplankton (2.0-20 µm) and microplankton (>20.0 µm).

This chapter summarizes analyses of Kootenay Lake phytoplankton data collected during 2007 from discrete depth, and compares these results to those from 2004 through 2006). This chapter also describes primary productivity studies carried out on Kootenay Lake during 2004 through 2007.

Methods

Field Sampling

Phytoplankton sampling at discrete depth has occurred each year since August 2003 as a component of the monitoring program for the South Arm nutrient restoration project. Samples were collected monthly from June to September using a Van Dorn water sampler. Samples were taken from 2, 5, 10, 15, and 20 m depths at stations KLF 2 and KLF 4 in the North Arm and KLF 6 and KLF 7 in the South Arm of Kootenay Lake (Chapter 1, Fig. 1.1). These collection depths were chosen to characterize the vertical profile of the euphotic zone, which was with a Licor LI-

185A quantum sensor and meter. Samples were collected in amber glass bottles and were preserved in acid Lugol's iodine preservative, and were analyzed by Eco-Logic Ltd., in West Vancouver.

Water samples for primary productivity analysis were collected between 0800 and 0930 using a Van Dorn water sampler. Two light and one dark 300 ml acid-cleaned BOD bottles were filed using a silicon filling tube. Each BOD bottle was rinsed three times with lake water before filling. The samples were maintained under low light conditions during all manipulations until the start of the incubation. Disposable latex gloves were used for all sampling to avoid contamination. Care was taken to eliminate contact with latex since latex is toxic to phytoplankton (Price *et al*. 1986). Samples were inoculated with 0.185 MBq (5 µCi) of $NaH^{14}CO_3$ New England Nuclear (NEC-086H). The BOD bottles were attached to acrylic plates and were suspended *in situ* for 2-4 h, generally between 0900 and 1400 hours. Alkalinity samples were collected from 0 and 15 m in 0.5 L polycarbonate bottles. All samples were stored in the dark on ice until processing at the Balfour lab.

Laboratory Analysis

Phytoplankton Enumeration

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 2007 appears in Appendix 1 (from Stockner 2007; in Schindler et al. 2007).

Alkalinity

A Beckman 44 pH meter and electrode were used to determine total alkalinity according to the standard potentiometric method of APHA (1995). Each sample was titrated with 0.02 N H_2SO_4 to pH 4.5. All samples had an initial pH of less than 8.3. Titrations were performed in duplicate or triplicate to check the analytical precision of the results.

Primary Productivity

Primary productivity was determined from the amount of ^{14}C incorporated into particulate organic carbon retained on a filter over a given period of time (Steemann Nielsen, 1952). The ^{14}C

incorporation into the phytoplankton in the dark bottle determined non-photosynthetic ^{14}C incorporation.

Following retrieval of the incubation array, the BOD incubation bottles were transported to the Balfour laboratory in a dark box. The incubations were terminated by parallel filtration of 100 ml of sample through each of a 0.2, 2.0 and 20.0 µm 47-mm polycarbonate filter using <100 mm Hg vacuum differential (Joint and Pomroy, 1983). Each folded wet filter was placed in a 7-ml scintillation vial and stored in the dark until processing at UBC.

In the fumehood, 100 µL of 0.5 N HCl were added to each vial to eliminate the unincorporated inorganic $NaH^{14}CO_3$. The scintillation vials were left uncapped in the fumehood until the filters were dry (approx. 48 h), and 5 ml of Ecolite® scintillation fluor was then added to each vial. The vials were stored in the dark for >24 hours before the samples were counted using a Beckman® Model #LS 6500 liquid scintillation counter. Each vial was counted for up to 10 minutes while the counter operated in an external standard mode to correct for quenching.

The specific activity of the ^{14}C stock was determined by adding 100 µL ^{14}C-bicarbonate solution to scintillation vials containing 100 µL of ethanolamine and 5 ml Ecolite® scintillation cocktail.

Hourly primary productivity rates were calculated using methods reported by Parsons et al. (1984), and were vertically integrated according to procedures of Ichimura et al. (1980). Daily primary productivity was calculated by multiplying hourly primary productivity by the incubation time and by the ratio of the solar radiation during the incubation to the solar radiation of the incubation day.

Results

North Arm – stations KLF 2 and KLF 4 2007

Generally, phytoplankton community composition at stations KLF 2 and KLF 4 was similar throughout the sampling season, with the exception of the first sampling trip in June when a localized bloom was noted only at station KLF 2. The highest abundance and biovolume of chryso/cryptophytes occurred at 2, 5, and 10 metres. On average, the biovolume at KLF 2 was 0.99 mm^3/L, nearly double the biovolume measured at KLF 4 of 0.47 mm^3/L (Fig. 5.1). The bloom was largely composed of chrysophytes and chryptophytes, which accounted for ~67% of the total phytoplankton abundance. *Chryptomonas* spp, an edible genera, was the most common flagellate found but *Chrysochromulina spp*, *Chroomonas acuta*, *Rhodomonas spp. A* mixed assemblage of microflagallates was also commonly observed. In contrast, at station KLF 4, flagellates accounted for only 43% of the biovolume. Temperature differences alone cannot explain the differences between the two stations (Chapter 3, Figs. 3.2 and 3.4), which show slightly warmer temperatures at KLF 2 at the surface but cooler temperatures from 3 metres down. The availability of nutrients may explain the differences between the two stations. In June 2007, the total dissolved phosphorus (TDP) concentrations at KLF 2 were higher than those measured at KLF 4 (Chapter 3, Fig.3.19). At both stations the relative contribution of chryso/chyrptophytes decreased with depth (Fig. 5.1).

Starting in July and persisting until September, species composition at KLF 2 and KLF 4 was dominated by bacillariophytes, primarily composed of large inedible phytoplankton, specifically *Asterionella formosa* and *Fragillaria crotonensis,* with a minor contribution of the edible genus *Cyclotella*. Diatoms accounted for 68-76% of the community biovolume at station KLF 2 and between 57-73% at station KLF 4. The relative contribution of chyso/cryptophytes was low from July to September accounting for between 7-31% of the total biovolume. The low abundances of chryso/chryptophytes coincide with higher *Daphnia* biomass in July through September. Chryso/cryptophytes are the dominant group of phytoplankton that are most nutritious to zooplankton (Brett, 2000). Therefore, the decrease in July, August and September could potentially be due to zooplankton grazing (see Chapter 6 for zooplankton results).

Despite the decreased predominance of flagellates, the absolute biovolume of flagellates at KLF 4 was relatively high in July and September (Fig.5.1). In July, chrysophytes and chryptophytes accounted for 0.46 mm^3/L at 2 m and 0.52 mm^3/L at 10 m and in September ~0.2 mm^3/L at 2 and 5 m. These taxa provide a rich forage base for zooplankton despite the predominance of inedible diatoms.

The North Arm peak abundance and biovolume over the four months during 2007 occurred at station KLF 4 in August at 5 m with 11,759 cells/ml and 1.828 mm^3/L with diatoms accounting for 9,903 cells/ml and 1.34 mm^3/L (Fig. 5.1). *Fragilaria crotonensis* was the dominant species contributing to 39% of the total abundance and 30% of the total biomass.

South Arm – stations KLF 6 and KLF 7 2007

Phytoplankton community composition was similar at both stations during each sampling month during 2007. Generally, the seasonal trend noted in the North Arm was also observed in the South Arm. Early in the season, chyso/chryptophytes were most abundant, accounting for 50% of the total biovolume (Fig 5.2). In July and August the community shifted to a predominance of diatoms, which accounted for 60% of the biovolume in July and 72.5% in August. In September there was an approximate equal contribution of the two groups.

On average, total phytoplankton biovolume was ~57% lower in the South Arm with 0.622 mm^3/L compared to 0.980 mm^3/L in the North Arm, which was partly accounted for by lower diatom abundances. This is similar to results presented for the integrated sample results (see Chapter 4 in this report). Despite on average lower abundances and biovolume in the South Arm, the highest biovolume observed in Kootenay Lake, occurred at station KLF 6 in August at 10 m with 2.303 mm^3/L with bacillariophytes contributing 1.66 mm^3/L (Fig. 5.2). Chyso/chryptophytes were mainly composed of *Chyrptomonas* sp, small microflagellates and a mixed assemblage of *Chrysochomulina*, *Rhodomonas* and *Chroomonas acuta. Fragilaria crotonensis* (a bacillariophyte) was the dominant species found in August with a strong contribution by *Cycotella* sp.

Comparisons of 2004 to 2007

The average phytoplankton abundance in the North Arm averaged over the five discrete depths and over the four month collection period, was generally lower in 2004 relative to 2005-2007. The mean phytoplankton abundance were relatively stable from 2005 to 2007, averaging 5998 ±69 cells/ml at KLF 2 which was nearly 30% higher than abundances measured in 2004 (Table 5.1). A similar trend was noted at KLF 4 where 2005 and 2007 mean abundances were 5918 ±128 cells/ml, nearly 15% higher than found in 2004. This trend was not observed in the South Arm, where mean abundances were more dynamic from 2004-2007 and where differences in the trends between stations were observed. At KLF 6, similar abundances were noted in 2004 and 2005 of ~5030 ±14 cells/ml cells/ml, despite differences in phosphorus loading between the two years (Chapter 2, Table 2.2). In contrast, fertilizer loading rates were similar from 2005 to 2007, but phytoplankton community responses were different over this time period, increasing to 5300 cells/ml in 2006 and decreasing to 4659 cells/ml in 2007. In contrast, phytoplankton abundances at station KLF 7 increased nearly 40% during 2005, decreased by ~20% in 2006, and then dropped by 8% during 2007. It should be noted that station KLF 7 is outside of the fertilizer application zone and is not expected to show a response to the fertilization of the South Arm, but may show a response due to the fertilization of Kootenai River, a fertilization experiment completed by Kootenai Tribe of Idaho. Tonnage of SRP from the Kootenai River was higher in 2005 than in 2006 (Chapter 3, Fig 3.40) which may explain the higher abundances in 2005.
The trends noted above were also reflected in the biomass data presented in Table 5.1.

Table 5.1. Average abundance and biovolumes from vertical profiles for Kootenay Lake in 2004 - 2007. 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**
KLF 1	6205	6375	-	-
KLF 2	4721	6062	6009	5925
KLF 3	4846	5094	-	-
KLF 4	5150	6003	-	5821
KLF 5	4666	5684	-	-
KLF 6	5021	5040	5300	4759
KLF 7	3741	5255	4219	3856
	Biovolume (mm^3/L)			
	2004	**2005**	**2006**	**2007**
KLF 1	0.88	1.17	-	-
KLF 2	0.75	1.15	1.11	1.02
KLF 3	0.69	1.01	-	-
KLF 4	0.65	0.96	-	0.93
KLF 5	0.74	0.95	-	-
KLF 6	0.80	0.85	1.04	0.78
KLF 7	0.60	0.91	0.73	0.62

Bacillariophytes – 2004 to 2007

Stations KLF 2 and KLF 4

The only consistent trend observed during all months and depths was that the lowest diatom biovolume was generally found in 2004 (Fig 5.3 & 5.4). Otherwise the inter-annual pattern was not consistent from June to September. For instance at station KLF 2 in July, the peak occurred during 2007, followed by 2005, 2006, and 2004. In contrast, the peak occurred during August in 2006, followed by 2007, 2005, and 2004; the September peak occurred during 2006, followed by 2005, 2007 and finally 2004.

During the month of June, diatom biovolume was generally low in all years except in 2005 when a small bloom was observed. *Fragilaria angustissima* was commonly observed during this small bloom, but its biovolume was relatively low (Fig. 5.3). In July, interannual variability was high and biovolume was generally low, except during 2007 when *Fragilaria crotonensis* and *Asterionella formosa* were common. In August, high interannual variability was again observed, with an extremely high biovolume in 2006 of nearly 2.0 mm^3/L at KLF 2 and relatively high biovolume in 2007 with *Fragilaria crotonensis* being dominant. In September, the annual variability was moderate with generally high biovolumes during all years at all depths.

The timing of the peak biovolume was not consistent over the 4 year period. In fact, although the time series is limited to only 4 years it appears that the timing of the seasonal peak has shifted from early Fall to mid-summer over the study period. The peak occurred during September in 2004 and 2005 but during August, 2006 and July, 2007.

Stations KLF 6 and KLF 7

As was observed in the North Arm, the interannual pattern was not consistent from June-September. The peak biovolume generally occurred during July in 2004 and 2005 compared to August, 2006 and 2007.

Phytoplankton biovolume and interannual variability were low in June during all study years (Fig 5.4). In July, biovolume and interannual variability increased and as seen in the North Arm, peaked during August when biovolume reached 2.28 mm^3/L in 2006 at KLF 6, when *Fragilaria crotonensis* and *Tabellaria fenstrata* collectively accounted for 76% of the biomass (Fig. 5.4). September biovolume was highest during 2005, with *Cyclotella* sp. and *Fragilaria crotonensis* being dominant.

The timing of the peak biovolume was not consistent over the 4 year period. At station KLF 6, the seasonal peak occurred during July in 2004 and 2005, and during August in 2006 and 2007. This pattern was different at station KLF 7 where the seasonal peak occurred during July in 2004 but in August during 2005, 2006, and 2007.

Chrysophytes/cryptophytes – 2004 to 2007

Stations KLF 2 and KLF 4

Interannual variability and biovolume were generally higher at station KLF 2 during June and July (Fig. 5.5) than in August and September. Among years, phytoplankton biovolume was highest during 2006 and 2007 at 2 and 5 m, where *Chryptomonas sp.* dominated. Biovolume was high during July 2005 at 2 m and at 5 m during 2006. During August and September, biomass and inter-annual variability were low. This decline coincided with increasing *Daphnia* biomass. Because chryso/cryptophytes are nanoplankton, which is a preferred size of phytoplankton, this decline may have been due to zooplankton grazing.

Biomass was lower at KLF 4 during June 2006 and 2007, indicating a spatial difference among stations in the North Arm. The peaks observed during June 2006 and 2007 at KLF 2 were not observed at KLF 4. However, a modest increase was observed during July 2005 and 2007..This temporal trend was similar to that seen at station KLF 2 with biomass being higher during June and July than in August and September. These results were consistent among years (Fig. 5.5).

Stations KLF 6 and KLF 7

Biomass was similar among years except during June 2006 and July 2006 at 2 and 5 m, where *Chryptomonas spp.* dominated. Biomass decreased in September, potentially attributable to grazing by *Daphnia* (Fig 6.13 in Chapter 6).

Biomass was similar among years in June and September. Biomass was highest in July 2006 at all depths and in August 2005 at 2 and 5 m. Results were spatially different from station KLF 6; zooplankton biomass was slightly higher at station KLF 7, indicating a potential zooplankton grazing effect.

Dinophytes – 2004 to 2007

Stations KLF 2 and KLF 4

Dinophyte biovolume was relatively low during all study years, never exceeding 0.30 mm^3/L. Little interannual variability was observed over the 4 year study period. A small bloom was noted in 2004, particularily during June 2004 at 2 and 5 m and September 2004 at all depths, with *Gymnodinium* the dominant genus (Fig. 5.7). This small bloom was not observed at station KLF 4. Biovolume was generally similar among months and years at station KLF 4, with the exception of a small peak during August at 20 m (Fig. 5.7).

Stations KLF 6 and KLF 7

Greater interannual variability was observed in the South Arm compared to the North Arm and there was greater variability at station KLF 6 than at station KLF 7. Relatively high biovolume was observed at both stations during 2004 compared to the other study years (Fig. 5.8). The dominant genus was *Gymnodinium*, which are edible to zooplankton depending on cell size. Another peak was observed at station KLF 7 during August 2005, with the inedible species *Ceratium* being the dominate genus. There was a localized peak at KLF 7 during 2007 in August at 2 and 5 m, which was primarily composed of *Gymnodinium spp.*.

Chlorophytes – 2004 to 2007

Stations KLF 2 and KLF 4

Little variability was observed during the study period with very low biovolume during most study years. June biovolume was highest during 2005 at station KLF 2, with *Oocsystis sp.* being dominant and edible for zooplankton. In July, no peaks were observed and biomass was similar among years. August biomass was highest during 2006 at 2, 5, and 10 m, with an inedible genus, *Planctosphaeria* being dominant. September biomass was similar among years, except during 2005 and 2006 at 2 and 10 m, with *Planctosphaeria* being dominant. Biomass at station KLF 4 was similar between years and among the months, except during August 2007 when peaks occurred at depths of 2, 5 and 10 m, with *Oocsystis* being dominant at 2 m, and *Planctosphaeria* being dominant at 5 and 10 m. Biomass at both stations was higher during August and September than in June and July (Figs. 5.9).

Stations KLF 6 and KLF 7

Biomass showed a similar trend to the North Arm stations with higher peaks occurring during August and September. Biomass was higher during August 2006 at station KLF 6 at 2 m and during August 2007 at station KLF 7 at 2 metres, compared to other years, and was dominated by *Planctosphaeria sp*. (Figs 5.10).

Cyanophytes – 2004 to 2007

Stations KLF 2 and KLF 4

Cyanophyte biomass was lower during June than during July, August, and September at both stations. June biomass was similar and showed little variability among the four study years. Biomass was highest during July and August 2005 at all depths, with *Lyngbya sp.* and *Microcystis spp.* being dominant. In September, biomass was highest during 2004 at depths of 2 m with *Lyngbya sp.*, *Microcystis sp.*and *Coelosphaeria spp.* being dominant. *Anabaena circinalis* and *Microcystis spp.* were dominant at 5 m, and *Coelosphaeria sp.*and *Lyngbya spp.* were dominant at 20 m depths. All are considered inedible for zooplankton (Figs. 5.11).

Stations KLF 6 and KLF 7

At both stations, June biomass was similar among all four years. In July biomass at station KLF 6 was similar among years, except during 2005 when *Microcystis* was dominant and five times higher than during the other three years. August biomass was similar among years except during 2004 when *Microcystis* was dominant at 2, 5, and 10 m and *Lyngbya* was dominant at 15 and 20 m. At station KLF 7, biomass was similar among months and years except during August 2004 when biomass was higher at all depths than during other years, with *Microcystis* being dominant (Figs. 5.12).

Primary Productivity - 2004 to 2007

Primary productivity was generally higher in the North Arm than in the South Arm except during 2007 (Fig. 5.13). Depth integrated primary productivity over the study period for the North and South Arms was 430 and 303 mg C/m^2/d respectively. These average rates fell at the lower end of the classification for mesotrophic lakes (Wetzel, 2001), but there are many months when primary productivity was classified as oligotrophic, with rates between 50-300 mg C/m^2/d (Table 5.2). These rates were higher than the mean values of 150-180 mg C/m^2/d measured in fertilized coastal lakes (Stockner, 1987). There was considerable interannual variability, particularly in the North Arm, where productivity was similar during 2004 and 2006 and similar during 2005 and 2007. This trend was also noted in the South Arm, but the variance between years was lower. Production is generally lower early in the season and peaks in August. This seasonal cycle was observed in both the North and South Arms.

Table 5.2. Primary productivity from vertical profiles for Kootenay Lake in 2004-2007. Shading represents stations in the North Arm.

		Primary Productivity (mg C/m^2/d)			
	Station	**2004**	**2005**	**2006**	**2007**
KLF 2	June	239.6	239.2	606.6	151.8
	July	278.8	109.5	540.6	118.7
	Aug	1113.0	248.3	664.3	390.9
	Sept	1239.1	100.8	543.5	147.8
	Oct	588.0	-	-	-
	Mean	695.1	174.5	588.8	202.3
KLF 6	June	100.0	207.0	135.9	265.8
	July	258.3	109.5	590.8	136.4
	Aug	938.2	321.3	409.1	303.8
	Sept	250.4	54.2	244.3	214.5
	Oct	625.9	-	-	-
	Mean	434.6	173.0	345.0	230.1

Size Fractionated Primary Productivity - 2004 to 2007

Nanoplankton was the dominant primary producer in both basins where they accounted for approximately 40% of the primary production (Fig 5.14). A noteworthy exception occurred during 2006 when a large decrease in nanoplankton production and a large increase in microplankton production were observed, particularly in the North Arm. This shift was also observed in the taxonomy data which clearly showed that the highest diatom biovolume over the 4 year study period occurred during 2006. The contribution of nanoplankton ranged from a low of 25% in 2006 to a high of 47% in 2007. On average, picoplankton accounted for ~30% of the production in Kootenay Lake and microplankton accounted for ~33%. Generally picoplankton production was similar at the two stations with the exception of 2005 when picoplankton production was ~19% higher. Phytoplankton size distribution at stations KLF 2 and KLF 6 was remarkably similar over the study period. Microplankton production was also remarkably similar at both stations during all years, ranging from 26 to 43% of the total production.

Picoplankton production showed no clear trends over the growing season (Fig. 5.15). Generally we would expect picoplankton to dominate production early in the growing season due to their extremely efficient nutrient uptake rates owing to their high surface area. However, this feature was not observed likely due to the absence of production sampling early in the season. Nanoplankton production remained relatively consistent throughout the growing season in 2004, 2005 and 2007. Despite high nanoplankton primary production, the taxonomy data does not always show an accumulation of nanoplankton sized cells. For instance, in August 2004 in the North Arm and in September 2004 in the South Arm, despite high nanoplankton production the taxonomy data does not show an accumulation of chrysophytes/chryptophytes (Fig 5.5 and 5.6) which suggests a very fast grazing rate of nanoplankton. It appears that as fast as nanoplankton are produced they are cropped down by the abundant zooplankton community. Nanoplankton production showed considerable variability during July 2006, when high nanoplankton production was observed largely due to a large bloom of *Chryptomonas*,. This was immediately followed in August by reduced nanoplankton production and high microplankton production when a large bloom of diatoms occurred. Microplankton production is generally lowest early in the season and increases as the growing season progresses. This was clearly apparent during 2006 and 2007 and was reflected in the taxonomy data. Microplankton are large and not easily grazeable because they tend to either sink out of the euphotic zone or accumulate in the community. It appeared that their production exceeded sinking and grazing losses, as indicated by the high biovolume.

Discussion

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). Chryso-cryptophytes, which are largely considered edible by zooplankton (J. Stockner, pers. comm.), were dominant at station KLF 2 in 2006 and 2007 and at station KLF 6 in 2006. Temporal variation was well illustrated during 2007 when the trend of chyrso-cryptophytes being dominant in the spring and decreasing in the summer and fall months coincided with the increase in *Daphnia* biomass in the lake, indicating that grazing on the phytoplankton was potentially occurring. Cyanophyte abundance decreased during 2006 and 2007 compared to 2004 and 2005. Overall phytoplankton abundance and biovolume were higher from 2005 through 2007 compared to 2004.

The high nanoplankton production in both basins was encouraging because nanoplankton are considered the preferred prey size class by *Daphnia spp.,* which in turn are the main food source for kokanee. Therefore, in order to stimulate the food chain and kokanee salmon production the growth of nanoplankton is desirable. In 2000, production in Kootenay Lake was dominated by picoplankton (see Harris, 2002 in Wright et al, 2002), likely in response to reduced fertilizer loading. However, since 2001, fertilizer loading was restored to 1992-1996 levels and nanoplankton production now dominates primary production in Kootenay Lake.

The size structure of the phytoplankton community is fundamentally important to the productive capacity of lakes and reservoirs. Food chains are relatively inefficient, with only 10% of the carbon "passed on" or assimilated in the next level of the food chain. As such, lakes with short food chains are more efficient system because a high proportion the phytoplankton are incorporated into the biomass of kokanee salmon, which are the dominant forage item for the larger piscivorous native fishes. The productivity measurement in Kootenay Lake clearly revealed that nutrient restoration efforts are effectively leading to increased nanoplankton production that will facilitate efficient incorporation of nutrients to higher trophic levels.

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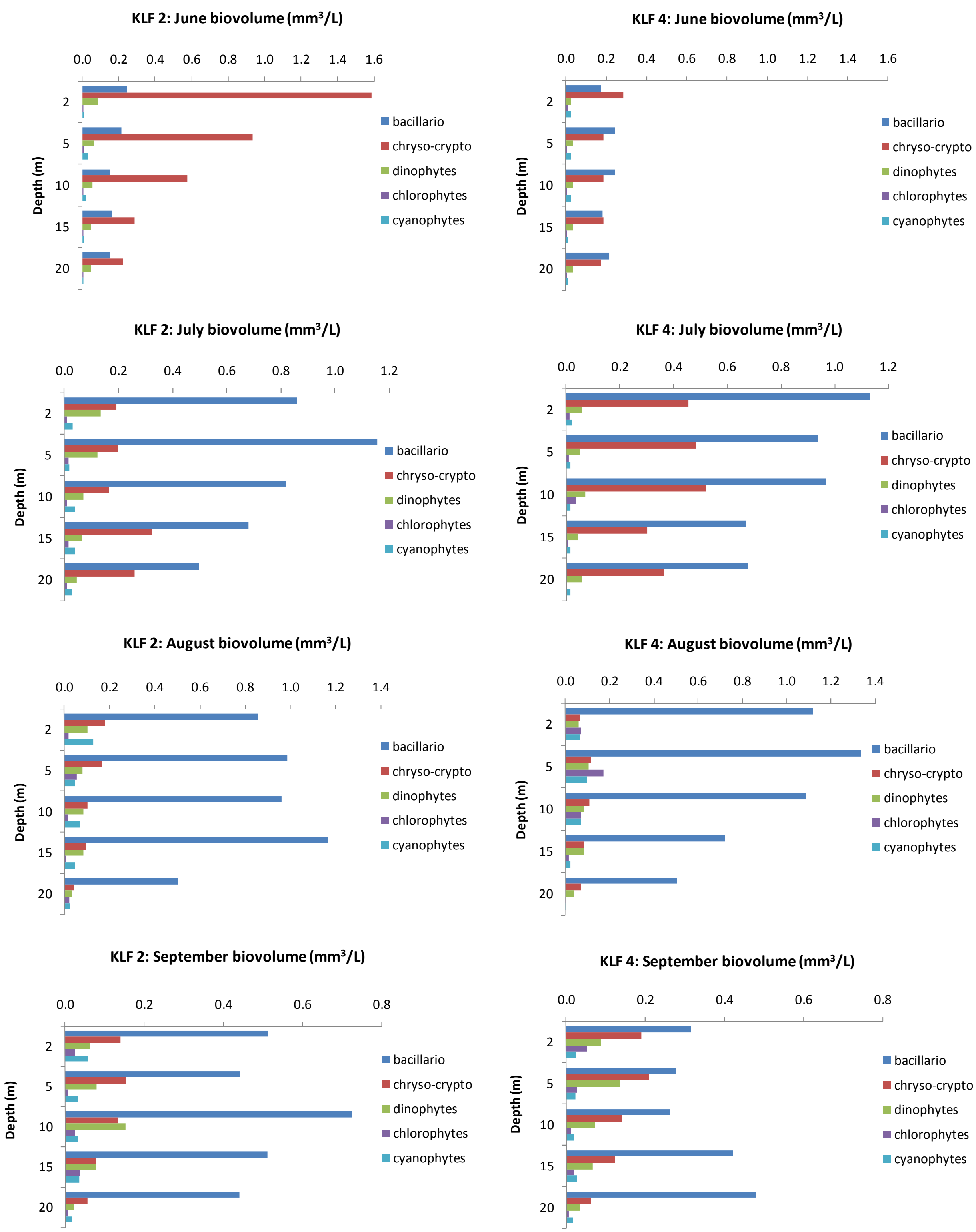

Figure 5.1. Discrete depth phytoplankton profiles for North Arm stations, June to September, 2007.

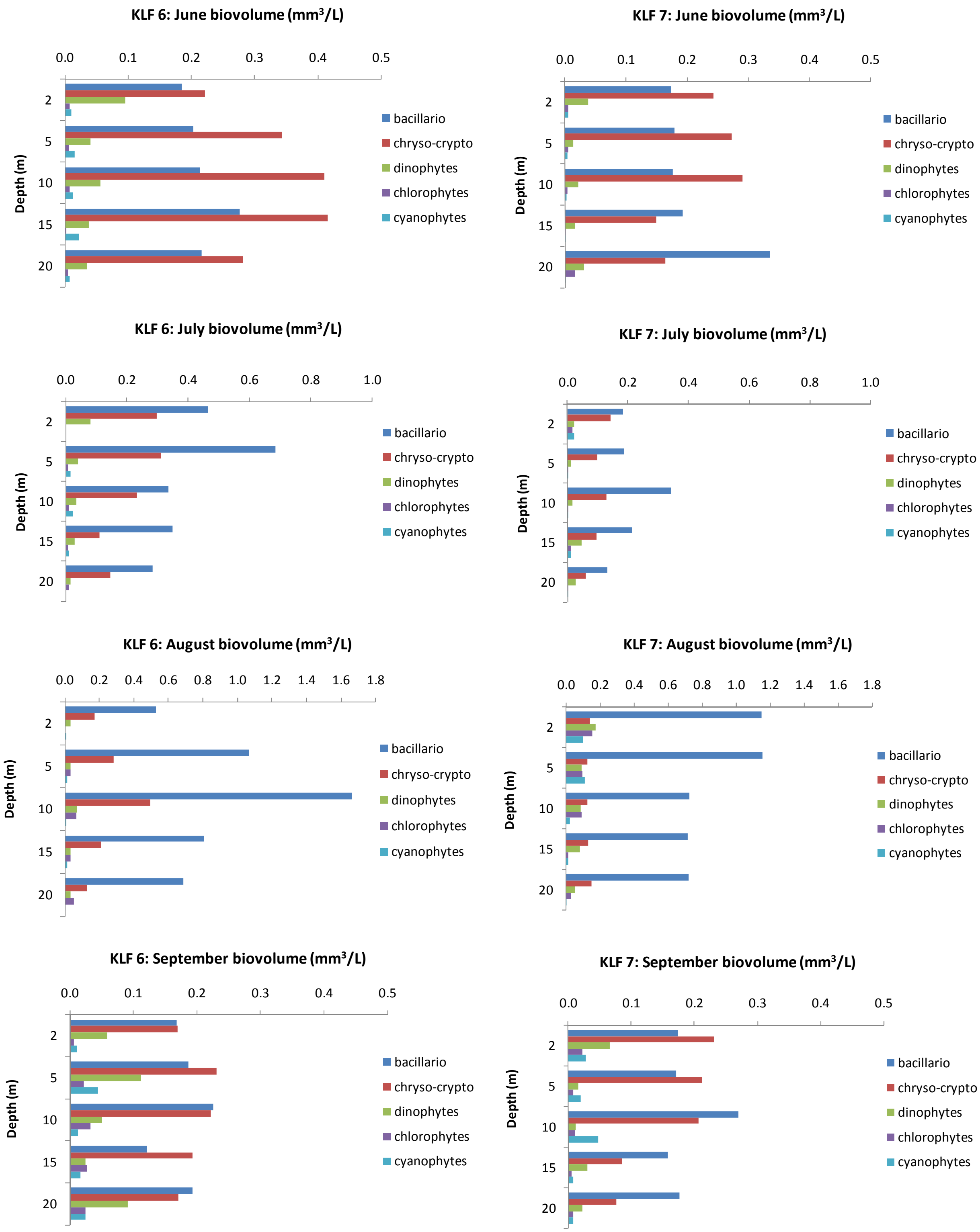

Figure 5.2. Discrete depth phytoplankton profiles for South Arm stations, June to September, 2007.

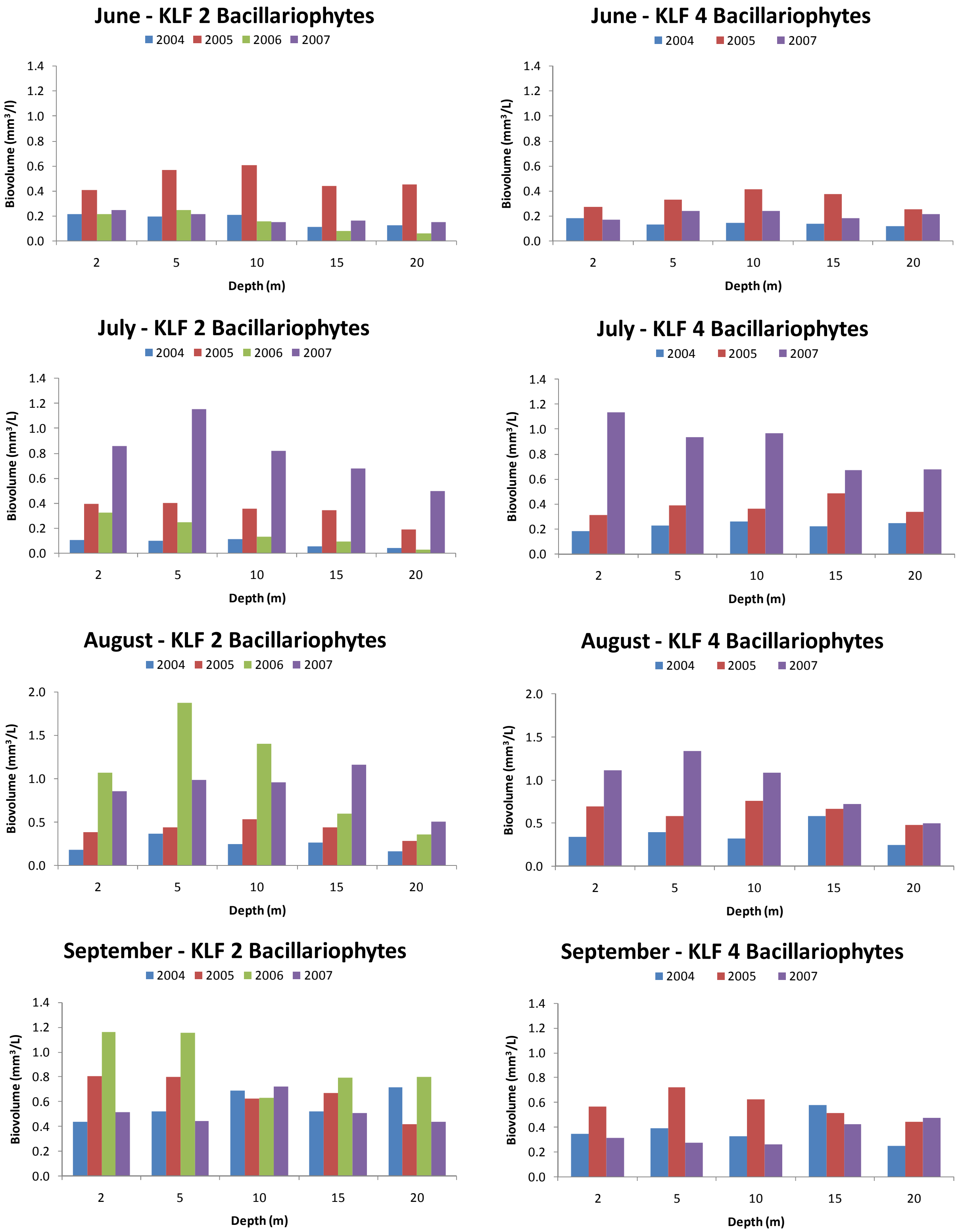

Figure 5.3. Bacillariophyte biovolume from discrete profiles for North Arm stations, June to September, 2004-2007. KLF 4 not sampled in 2006.

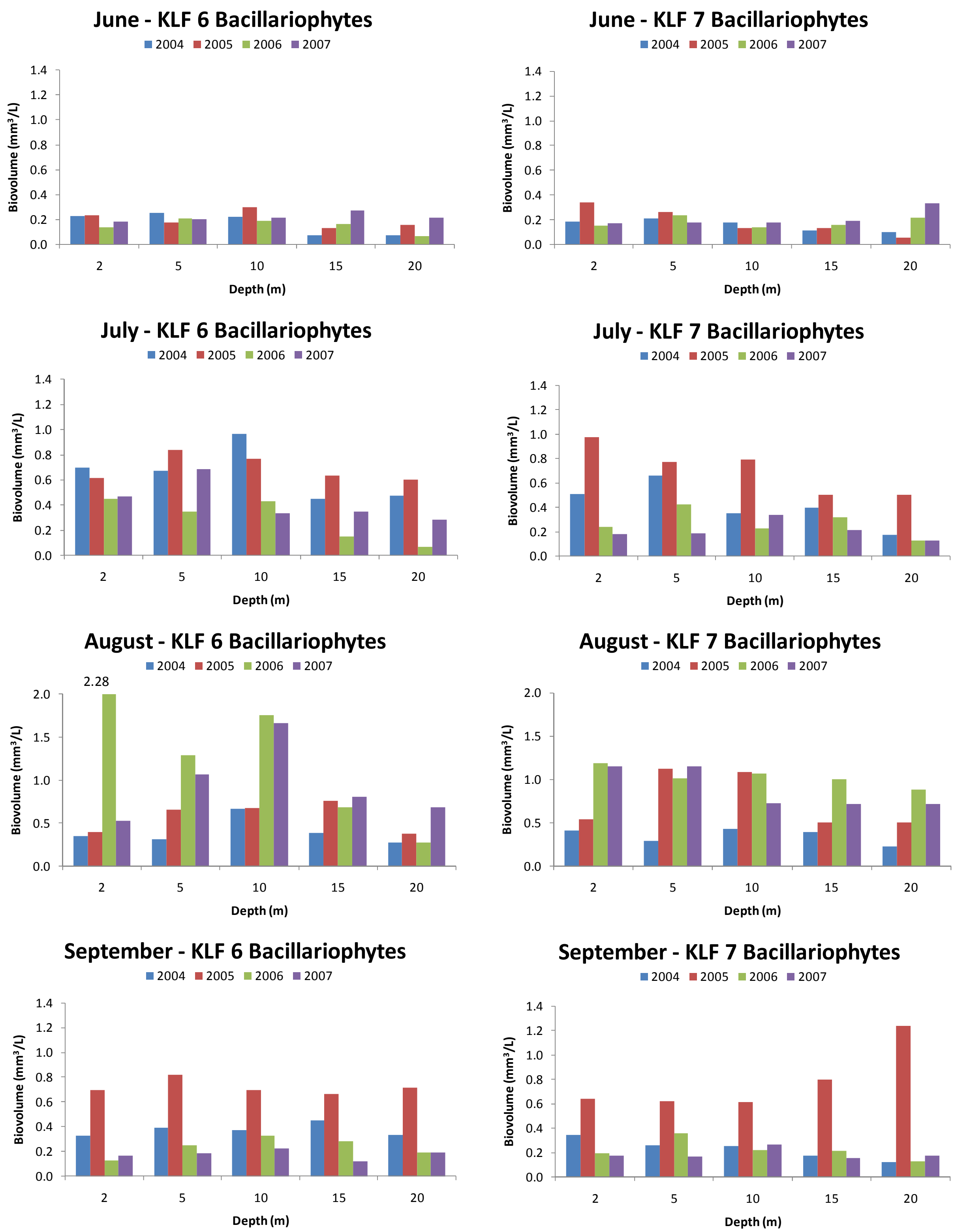

Figure 5.4. Bacillariophyte biovolume from discrete profiles for South Arm stations, June to September, 2004-2007.

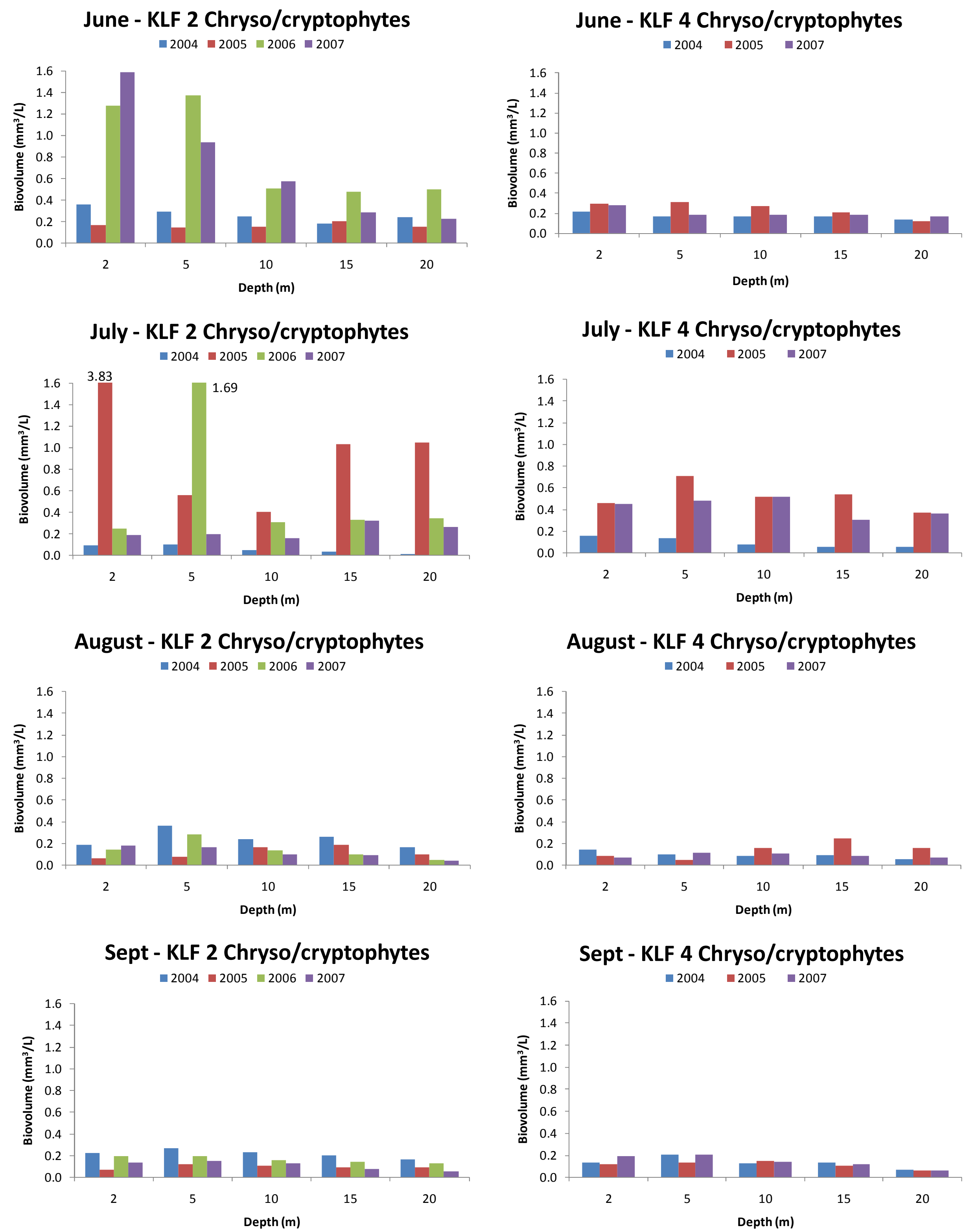

Figure 5.5. Chrysophyte/cryptophyte biovolume from discrete profiles from North Arm stations, June to September, 2004-2007. KLF 4 not sampled in 2006.

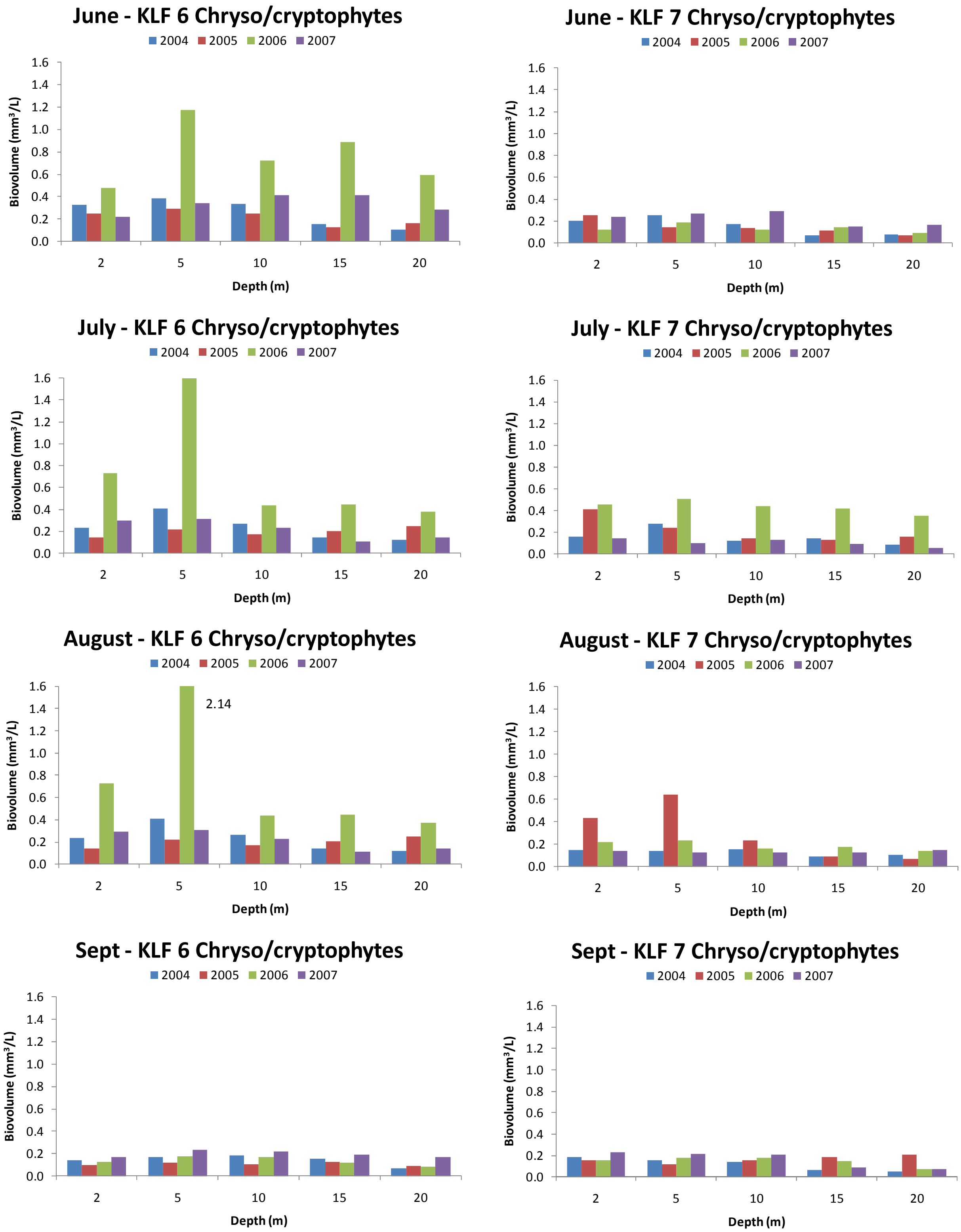

Figure 5.6. Chrysophyte/cryptophyte biovolume from discrete profiles from South Arm stations, June to September 2004 to 2007.

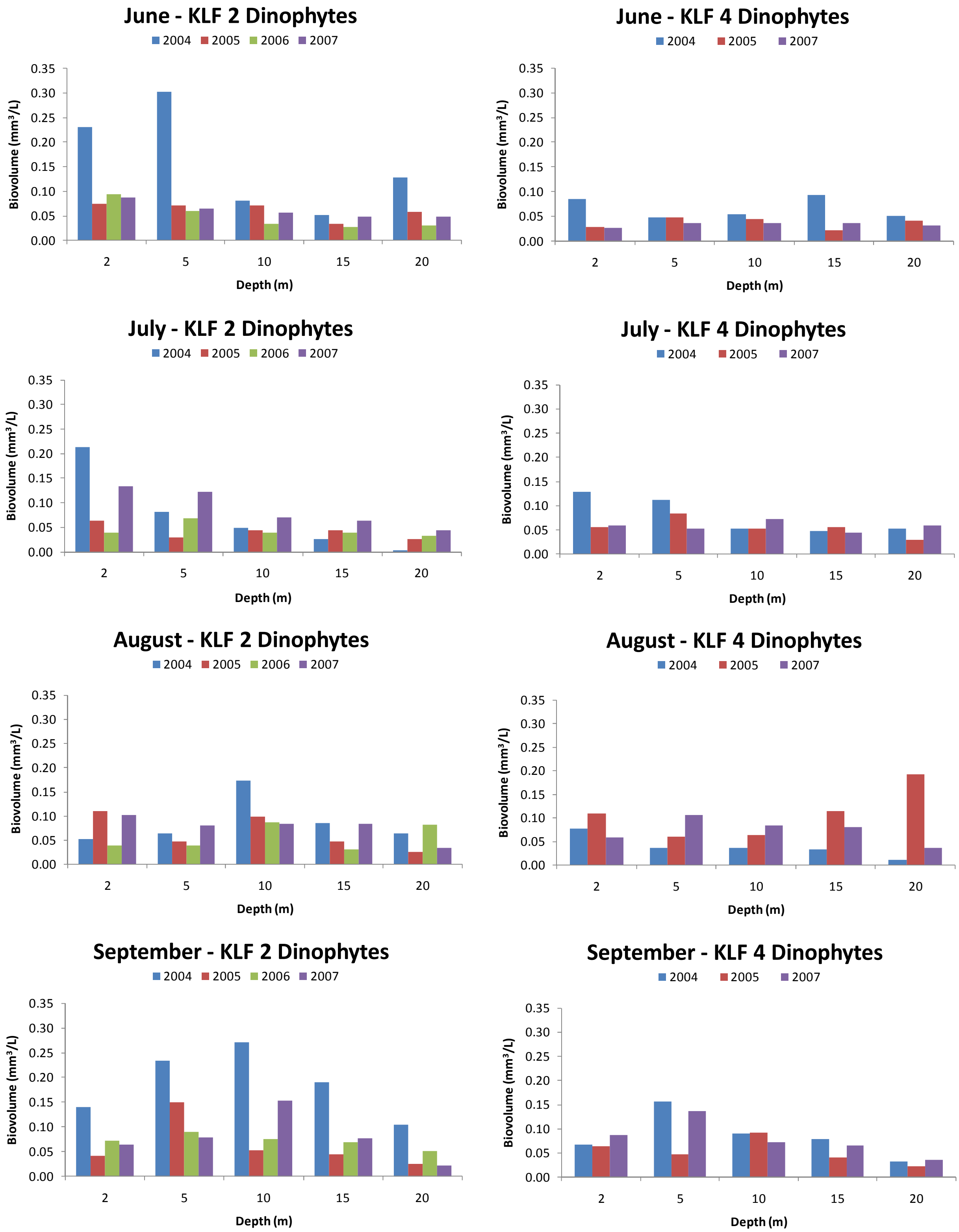

Figure 5.7. Dinophyte biovolume from discrete profiles for North Arm stations, June to September, 2004 - 2007. KLF 4 not sampled in 2006.

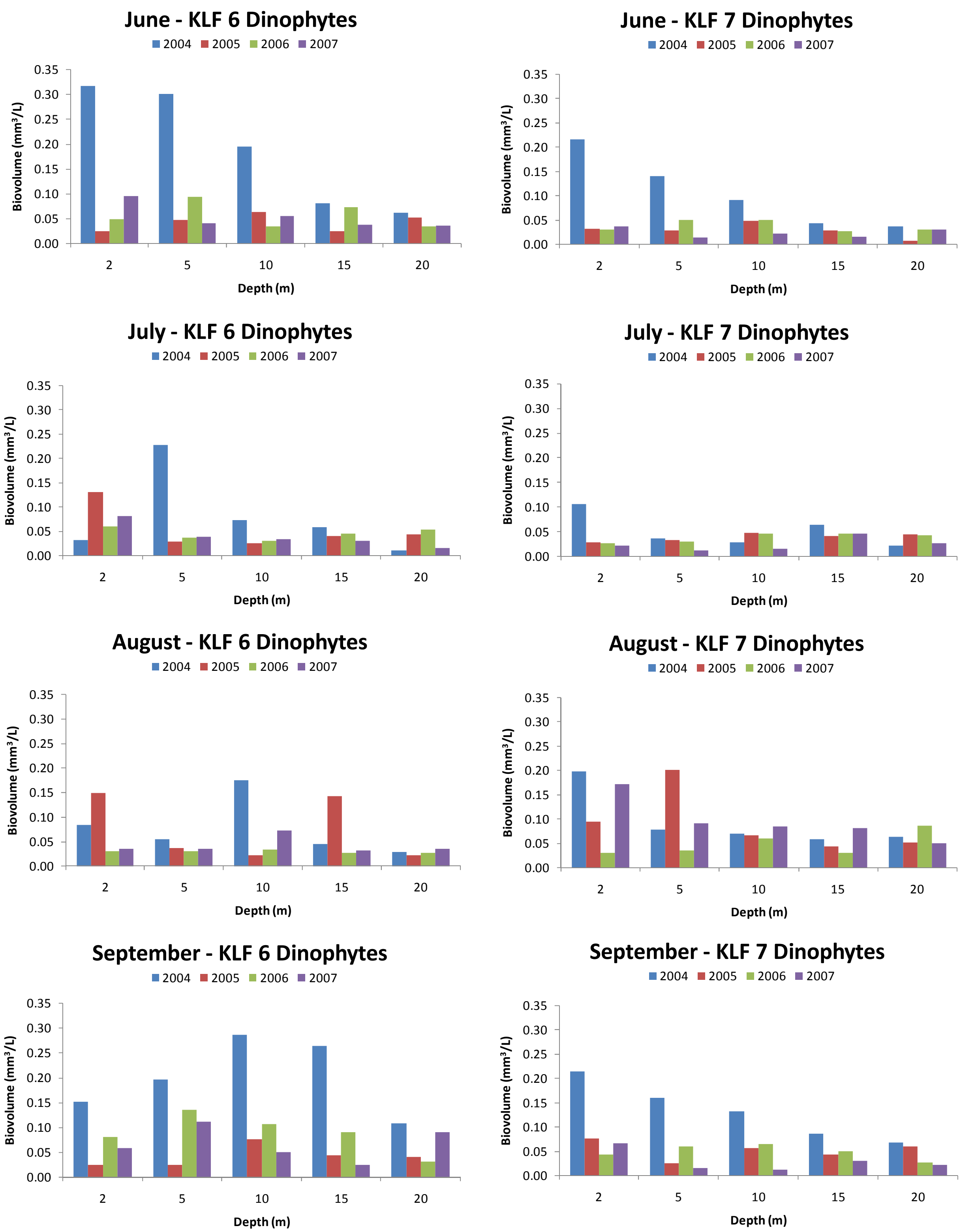

Figure 5.8. Dinophyte biovolume from discrete profiles from South Arm stations, June to September, 2004 to 2007.

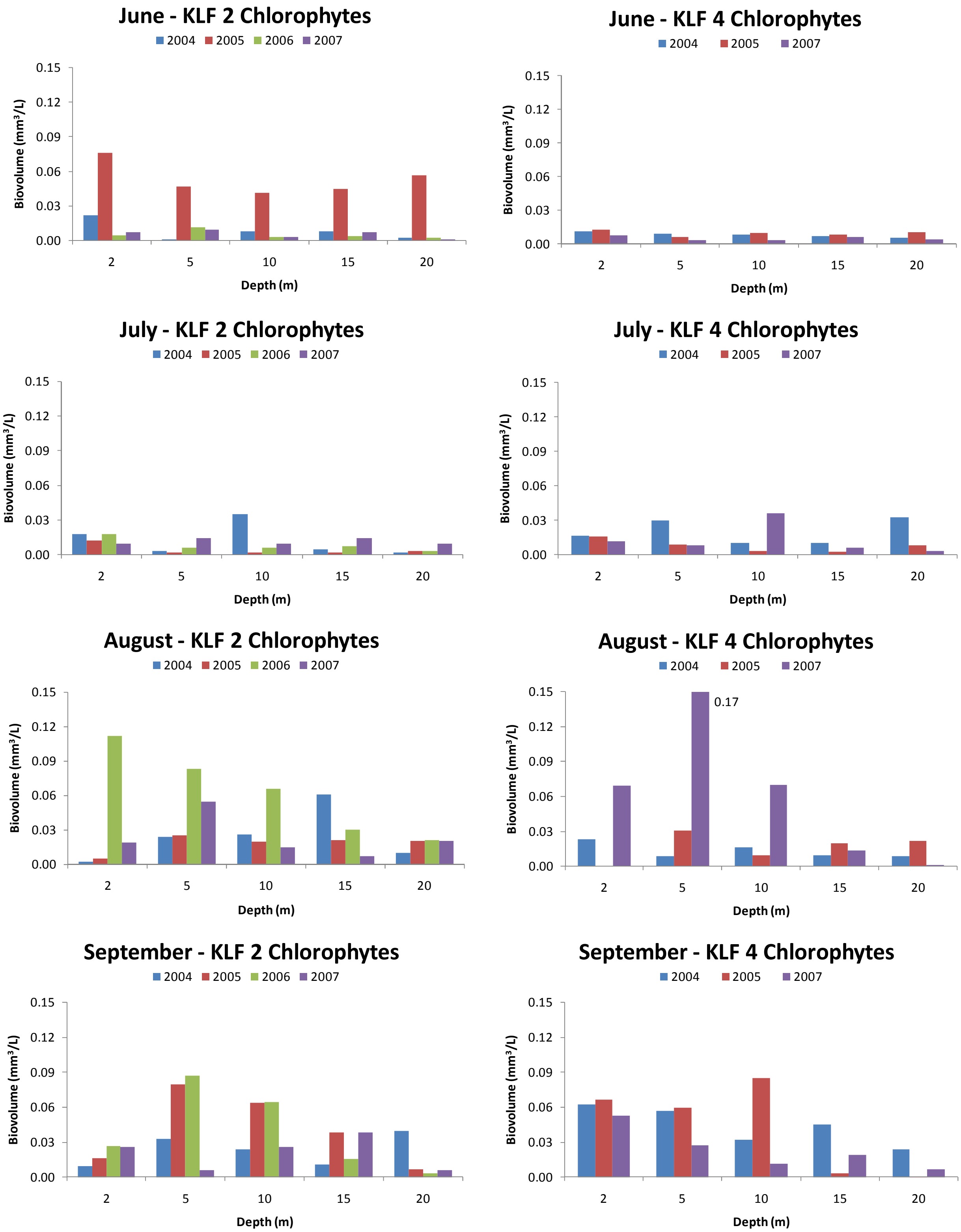

Figure 5.9. Chlorophyte biovolume from discrete profiles from North Arm stations, June to September 2004-2007. KLF 4 not sampled in 2006.

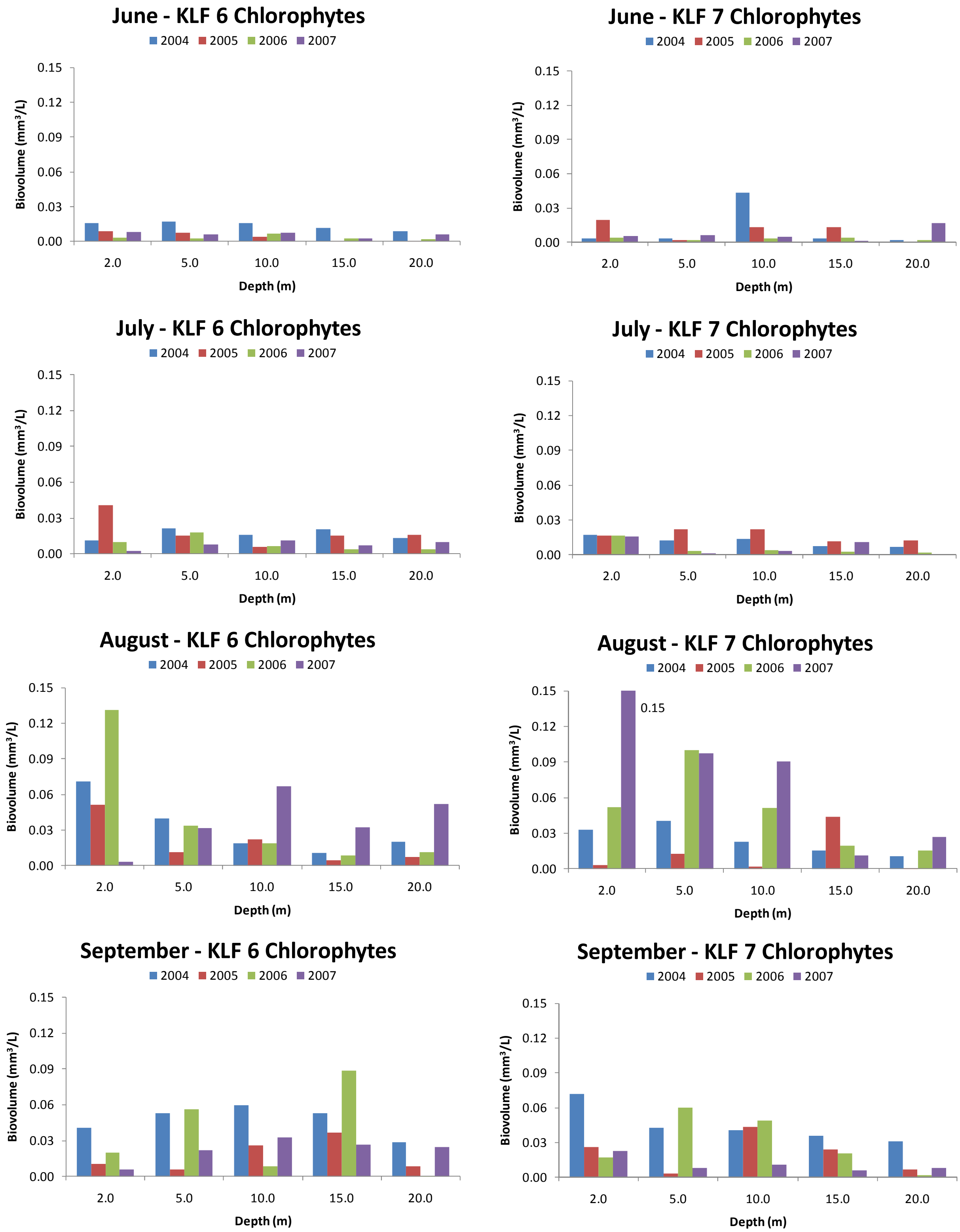

Figure 5.10. Chlorophyte biovolume from discrete profiles from South Arm stations, June to September, 2004 to 2007.

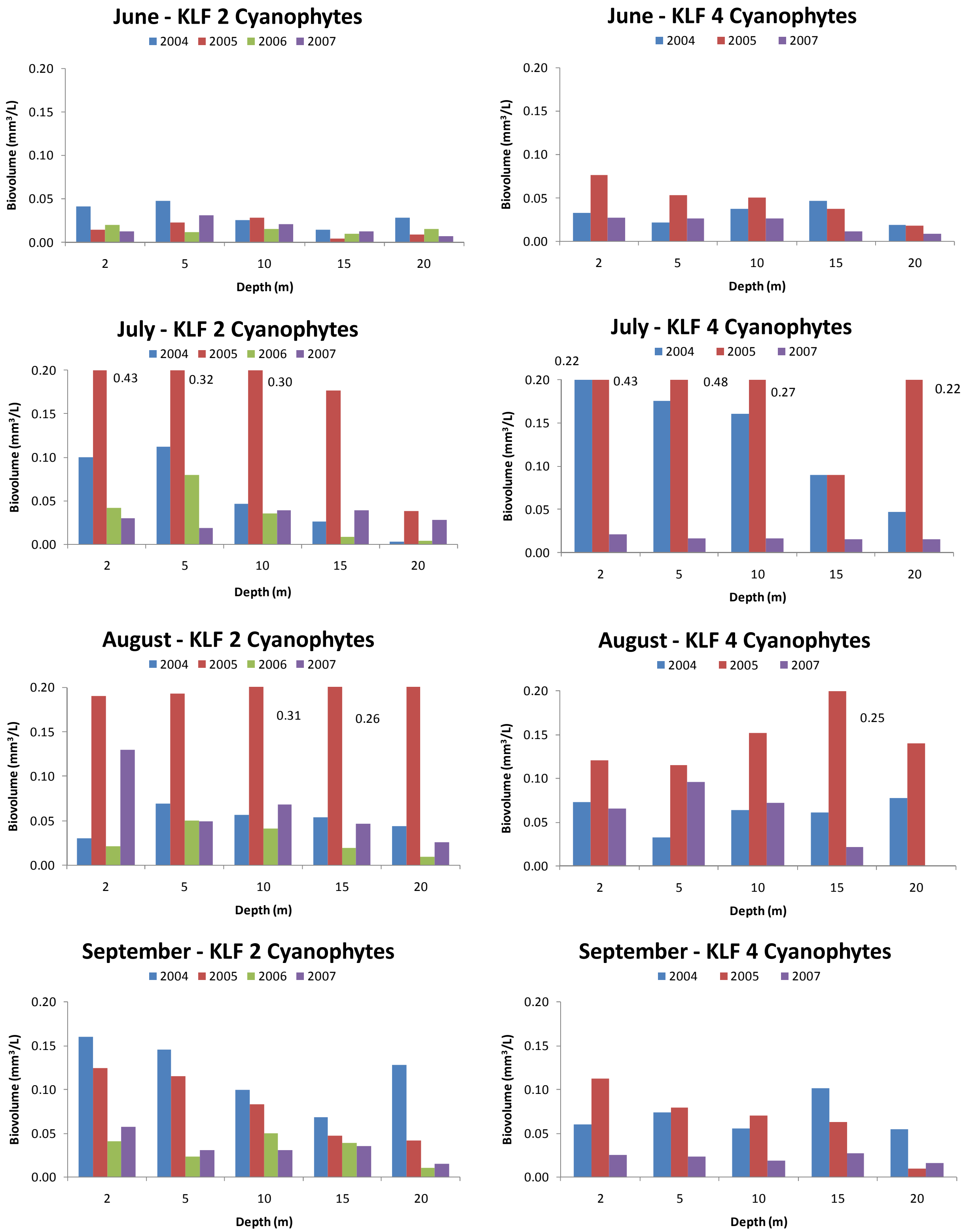

Figure 5.11. Cyanophyte biovolume from discrete profiles from North Arm stations, June to September 2004-2007. KLF 4 not sampled in 2006.

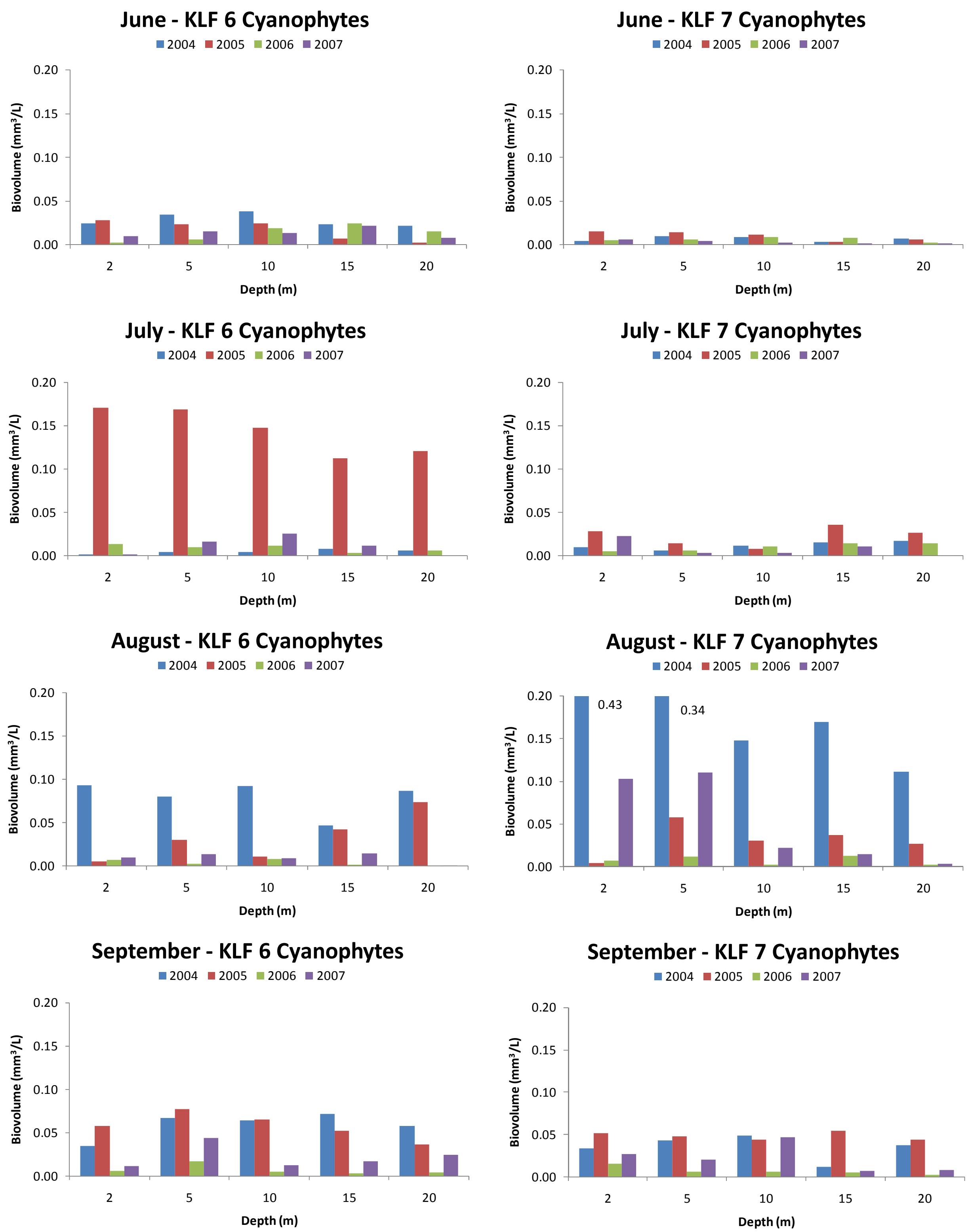

Figure 5.12. Cyanophyte biovolume from discrete profiles from South Arm stations, June to September, 2004 to 2007.

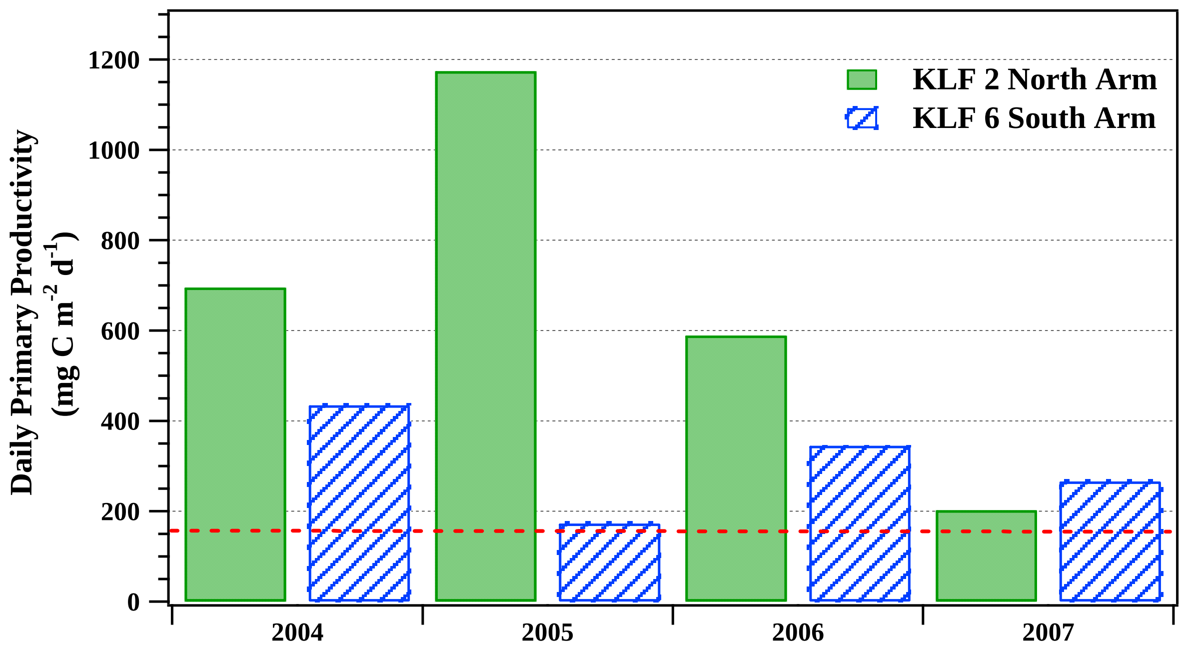

Figure 5.13. Daily primary productivity in Kootenay Lake from 2004 – 2007.

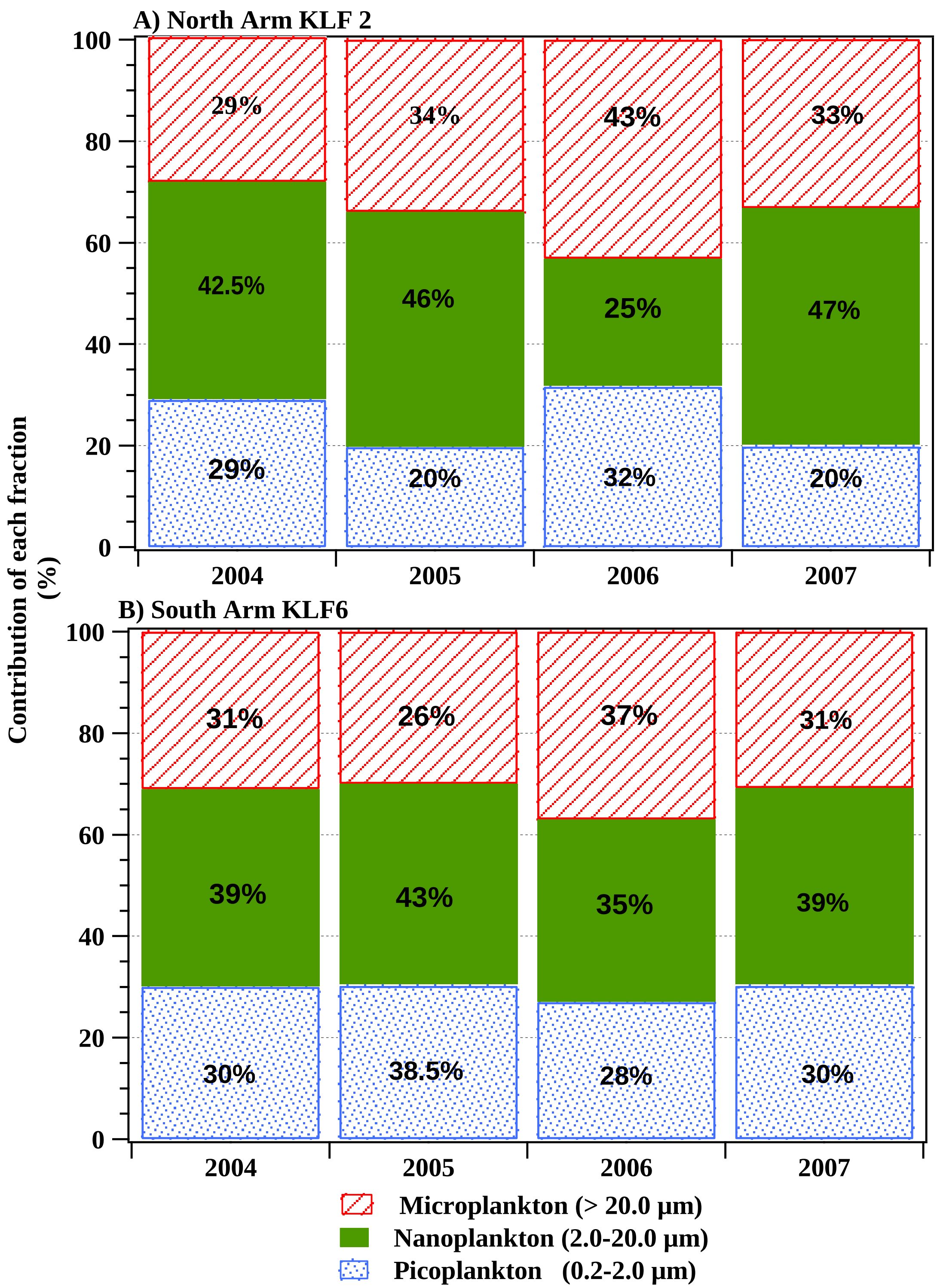

Figure 5.14. Relative contribution of picoplankton, nanoplankton and microplankton to primary productivity from 2004-2007, averaged over four months, June to September.

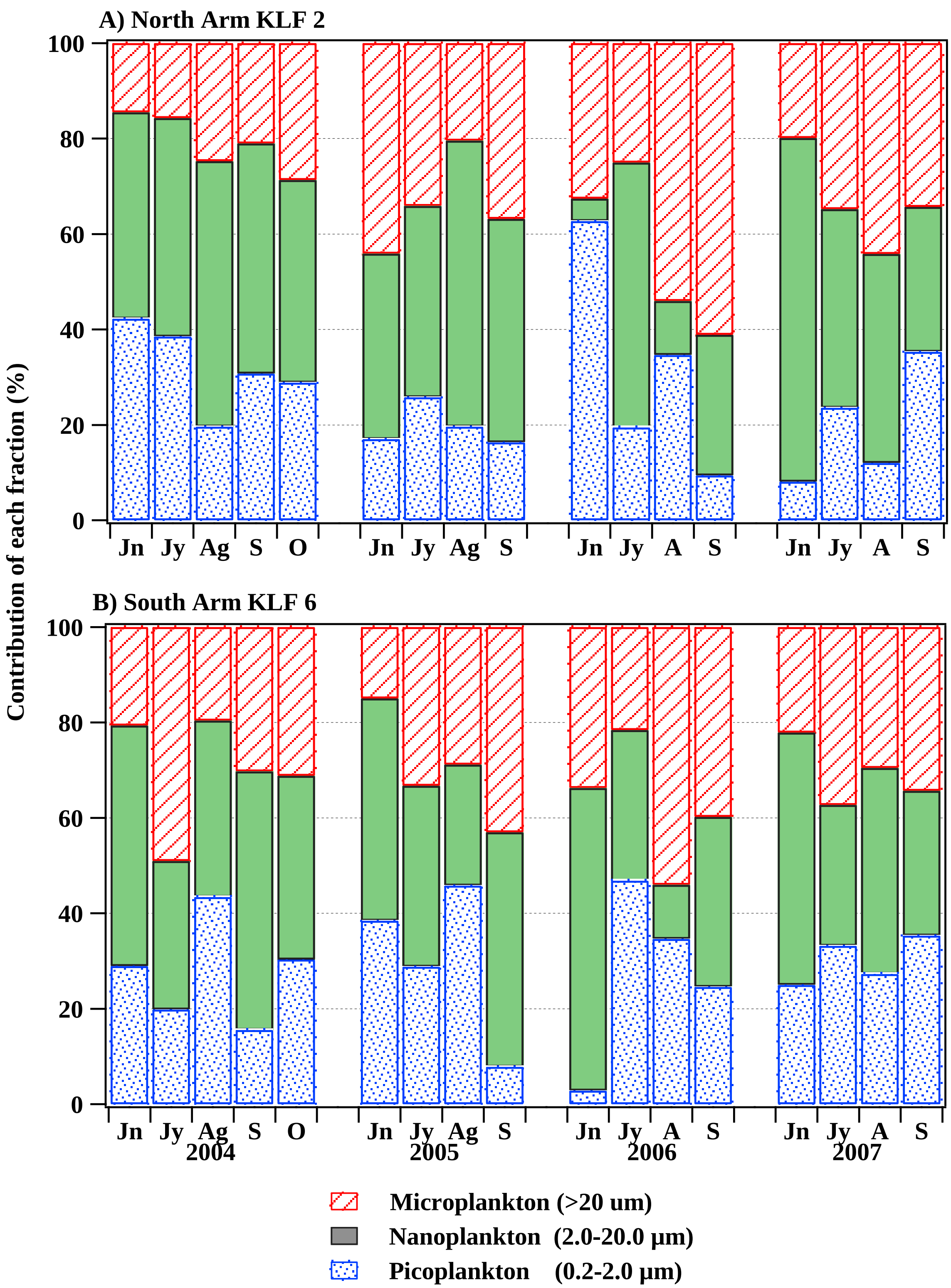

Figure 5.15. Relative contribution of picoplankton, nanoplankton and microplankton to primary productivity from 2004-2007.

Appendix 1. Kootenay Lake phytoplankton species and biovolume (mm^3), 2007.

Bacillariophytes - diatoms	**Bvol**	***Chryso-Cryptophyte flagellates***	**Bvol**	***Chlorophytes***	**Bvol**
Achnanthes sp.	80	Bitrichia sp.	200	Ankistrodesmus sp.	80
Asterionella formosa var1	100	Chilomonas sp.	250	Coccomyxa sp.	150
Asterionella formosa var2	120	Chromulina sp1	20	Coelastrum sp.	500
Cocconeis sp.	200	Chroomonas acuta	150	Cosmarium sp.	500
Cyclotella bodanica	500	Cryptomonas sp.	500	Crucigenia sp.	200
Cyclotella comta	350	Chrysochromulina sp.	75	Crucigeniella apiculata	700
Ceratoneis sp.	350	Dinobryon sp1	150	Dichtyosphaerium	900
Cyclotella stelligera	150	Dinobryon sp2	200	Langerheimia	30
Cyclotella glomerata	50	Kephyrion sp.	50	Elakatothrix sp3	250
Cyclotella sp	150	Isthmochloron	200	Euglena	2500
Cymbella sp. (large)	500	Mallomonas sp1	500	Gonium	500
Cymbella sp.	250	Mallomonas sp2	700	Oocystis sp.	500
Diatoma sp.	150	Stenokalyx	75	Scenedesmus sp.	60
Eunotia sp.	250	Small microflagellates	15	Staurodesmus sp.	1500
Fragilaria construens	80	Pseudokephrion sp.	100	Quadrigula	250
Fragilaria crotonensis	120	Pseudopedinella sp.	150	Ulothrix	700
Fragilaria capucina	100	Chrysoikos sp.	75	Closteriopsis	150
Gomphonema sp.	750	Synura	700	Monoraphidium	200
Aulicoseira distans	350	Rhodomonas sp.	100	Nephrocytium	350
Aulicoseira italica	200	Chrysidiastrum	250	Staurastrum sp.	1000
Aulicoseira granulata	250			Planctonema sp.	350
Aulicoseira sp.	350	***Dinophytes***		Planctosphaeria	1000
Navicula sp.	500	Gymnodinium sp1	500	Paulschultzia sp.	100
Nitzschia sp.	200	Gymnodinium sp2	1500	Chlorella	20
Rhizosolenia sp.	50	Ceratium	5000	Kirchneriella sp.	50
Stephanodiscus hantschii.	500	Peridinium sp1	350	Pediastrum sp.	1000
Stephanodiscus sp.	1500	Peridinium sp2	700	Pandorina sp.	1500
Fragilaria acus	100			Tetraedron	50
Fragilaria angustissima	150			Volvox	4000
Fragilaria ulna	1000			Xanthidium	700
Suriella	500				
Fragilaria sp.	250			***Cyanophytes***	
Pinnularia sp.	2000			Anabaena circinalis	900
Tabellaria fenestrata	500			Aphanothecae sp.	100
Tabellaria flocculosa	500			Merismopedia sp.	20
Diploneis sp.	250			Oscillatoria sp2	20
				Oscillatoria limnetica	350

CHAPTER 6

RESPONSE OF ZOOPLANKTON AND *MYSIS RELICTA* TO NUTRIENT ADDITIONS, YEAR 16 (NORTH ARM) AND YEAR 4 (SOUTH ARM) (2007)

by

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Introduction

Experimental fertilization of 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. The release of mysids interfered with established food webs and affected benthic, phytoplankton, zooplankton, and fish communities.

During the first five years of the experiment (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 2007. 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 were a part of the multidisciplinary project to restore kokanee stocks by experimental fertilization of the lake’s North Arm. This report will focus on results from 1997 through 2007. 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. In 2004 to 2007, samples were collected from April through November at all stations. Three samples were collected at each station and two replicates from each station were analyzed for stations KLF 2, 4, 6 and 7 whereas all three samples were analyzed at stations KLF 1, 3, 5 and 8.

In 2007, samples were collected monthly from April 11th to November 02nd, 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 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 relicta

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 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 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 analyzed for density, biomass, life history stage, and maturity. 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).

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.

Mysids were counted and had their life history stage and maturity identified. 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 7.1). 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 nine 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 eleven 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 6.1. List of zooplankton species identified in Kootenay Lake, 1997–2007.

	97	98	99	00	01	02	03	04	05	06	07
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 (1992–2007) have been generally 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 1986 (Fig. 6.1). The zooplankton populations in Kootenay Lake show a diverse species assemblage, with relatively steady population density in 2007 compared to the previous year. The zooplankton community in the North Arm was composed of 89% copepods, 6% *Daphnia* spp., and 5% cladocerans other than *Daphnia* spp. in 2007 (Fig. 6.2). The proportion of cladocerans (including *Daphnia* spp.) varied from about 4–16% from 1997 to 2007, except in 2001 when cladocerans composed 27% of the zooplankton community. The South Arm population in the 2007 sampling season was similar to the North Arm and was comprised of 92% copepods, 2% *Daphnia* spp., and 3% cladocerans other than *Daphnia* spp. The proportion of cladocerans (including *Daphnia* spp.) over the course of the study fluctuated from 5% to 18% from 1997 to 2007.

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, 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. 6.3 and 6.4). Copepods were the most abundant zooplankton at each station from 1997 to 2007. They dominated during the entire sampling season, with populations peaking in July-August. In 2007, copepod density peaked in July at all stations in the North, South and West Arms. The largest copepod population was in the South Arm at station KLF 5 in July 2007 and averaged 58.06 individuals/L. 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.

Zooplankton density in the North Arm fluctuated from year to year during the study period (Fig. 6.5). The fertilizer load in 2001 was increased to the 1992 to 1996 levels, and zooplankton density increased significantly 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. 6.1). During the next two years, 2004 and 2005, the zooplankton density decreased, followed by an increase in 2006. In 2007 the seasonal average zooplankton abundance in the North Arm was similar to the previous year with 23.92 individuals/L. 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 the annual average density of *Daphnia* increased to 1.66 individuals/L and in 2007 was similar with 1.51 individuals/L (Fig. 6.6). The density of other cladocerans fluctuated during the course of the study with a significant increase in 2001 to 7.96 individuals/L from 0.62 individuals/L in the previous year. In 2007, the seasonal average abundance of cladocerans other than *Daphnia* was 1.15 individuals/L.

Zooplankton density during the eleven years studied was lower in the South Arm than in the North Arm, except in 1997, 2004, and 2007 (Fig. 6.5). In the South Arm, the total zooplankton density increased from 2001 to 2003 compared to the 1997 to 2000 period. In 2004 and 2005 a decrease of total zooplankton occurred in the South Arm followed by a slight increase in 2006 and 2007. A similar pattern of density fluctuation of Copepoda and other Cladocera occurred during the study period (Fig. 6.5c). *Daphnia* spp. density fluctuated in each successive year of the study. In 2007, the seasonal average density of zooplankton in the South Arm was 24.88 individuals/L (Fig 6.5a).

In 2007, the total zooplankton density and densities of copepods and *Daphnia* in the West Arm decreased while Cladocera other than *Daphnia* increased compared to the previous year. The seasonal average density (April to November) of zooplankton in the West Arm was 21.86 individuals/L (Fig. 6.5a). The zooplankton community in 2007 was composed of 83% copepods, 9% *Daphnia* spp., and 8% cladocerans other than *Daphnia* spp (Fig. 6.2).

Zooplankton biomass had similar trends in both the North and South arms of Kootenay Lake. From 1997 to 2007, biomass fluctuated with the highest values recorded in 2003 in all three arms (Fig. 6.7a). 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. 6.7b, 6.7c, Fig. 6.8), while in 2001 to 2003 and in 2006 and 2007, 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 2007, biomass of total zooplankton and *Daphnia* decreased in both the North and South arms, while copepods and cladocerans other than *Daphnia* were similar to the previous year. 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. 6.8). In the North Arm, *Daphnia* spp. comprised of 11% to 49% of the total zooplankton biomass from 1997 to 2007. During the same period, *Daphnia* spp. varied from 12% to 48 % of the total zooplankton biomass in the South Arm (Fig. 6.9). In 2007 *Daphnia* biomass made up 40% and 36% of the total zooplankton biomass in the North and South Arm respectively.

During 2007, biomass of all categories decreased in the West Arm in comparison to the previous year. 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 2007 the seasonal average biomass of zooplankton in West Arm decreased from 90.24 μg/L in 2006 to 57.20 μg/L (Fig. 6.7a). *Daphnia* biomass decreased significantly from 57.56 μg/L in 2006 to 26.29 μg/L in 2007 (Fig. 6.8). From 2003 to 2007 the proportion of copepod biomass varied from 33-66%, cladocerans other than *Daphnia* made up 3-10% and *Daphnia* made up 26-64% of the total zooplankton biomass. In 2007 the zooplankton biomass was made up of 49% copepods, 46% *Daphnia* spp., and 5% cladocerans other than *Daphnia* spp. (Fig. 6.9).

The decrease in *Daphnia* biomass in 2007 compared to 2006 could be the result of grazing from kokanee. Kokanee were more abundant in the lake in 2007 and were also slightly larger, therefore requiring additional food than 2006 (see Chapter 7).

Seasonal and Along-Lake Patterns

In 2007, copepods were the predominant form of zooplankton, cladocerans were present throughout the sampling period and *Daphnia* spp. was observed from May to November. The seasonal development of zooplankton density did not differ between the North and South arms of Kootenay Lake in 2007. Total zooplankton density increased from the spring to the summer and decreased in the fall. Copepods dominated in density during the entire season, however *Daphnia* dominated by biomass in all three basins from August to November in 2007. Cladoceran abundance was low and the peak occurred in August in the North and South arms and in September in the West Arm. *Daphnia* spp. density peaked in September in the North and West Arms, and in August in the South Arm of Kootenay Lake.

During 2007, peak total zooplankton densities occurred in July in the South and West Arms with 53.68 and 47.74 individuals/L respectively, and in August in the North Arm with 50.07 individuals/L (Table 6.2). The peak total zooplankton biomass occurred in August at 144.11 μg/L in the South Arm, and in September at 131.31 μg/L in the North Arm, and at 167.26 μg/L in the West Arm. The peak *Daphnia* spp. biomass also occurred in August in the South Arm with 74.66 μg/L, and in September in the North and West Arm with 93.39 μg/L and 139.70 μg/L respectively (Table 6.2). During the August-September peak, *Daphnia* spp. comprised of a small proportion of zooplankton density; however, the large body size of the adults resulted in peak *Daphnia* biomass of 71%, 52%, and 83% 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 in May, which was earlier than other years. In those years *Daphnia* was the most numerous in August and continued to October. Conversely, 2004 was a late-season year, in which *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 eleven 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-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 6.2. Monthly average density and biomass of zooplankton in the North, South and West arms of Kootenay Lake in 2007. Density is in units of individuals/L, and biomass is in units of µg/L.

Density		April	May	June	July	Aug.	Sept.	Oct.	Nov.
North Arm	Copepoda	4.97	9.23	11.34	43.88	42.91	20.65	20.00	17.09
	Daphnia	0.00	0.00	0.00	0.36	3.63	5.23	2.50	0.37
	Other Cladocera*	0.03	0.03	0.02	1.90	3.53	1.00	2.46	0.20
	Total Zooplankton	5.00	9.27	11.36	46.13	50.07	26.89	24.95	17.67
South Arm	Copepoda	5.77	9.98	17.03	51.81	39.82	20.36	18.30	21.05
	Daphnia	0.00	0.02	0.02	0.53	3.75	3.54	0.72	0.25
	Other Cladocera*	0.01	0.01	0.08	1.35	2.97	0.66	1.02	0.03
	Total Zooplankton	5.78	10.01	17.13	53.69	46.54	24.56	20.03	21.33
West Arm	Copepoda	1.47	6.79	26.45	42.97	26.63	12.36	10.52	17.85
	Daphnia	0.00	0.01	0.00	0.50	5.96	8.09	0.50	0.22
	Other Cladocera*	0.00	0.01	0.00	4.27	4.09	5.33	0.81	0.07
	Total Zooplankton	1.48	6.81	26.45	47.74	36.68	25.77	11.83	18.13
Biomass									
North Arm	Copepoda	11.20	15.84	19.00	84.89	62.85	36.58	31.98	26.00
	Daphnia	0.00	0.00	0.00	4.51	52.39	93.39	48.77	3.60
	Other Cladocera**	0.04	0.05	0.03	2.65	6.72	1.34	4.37	0.59
	Total Zooplankton	11.23	15.89	19.03	92.05	121.97	131.31	85.13	30.19
South Arm	Copepoda	10.92	20.38	24.09	73.54	60.60	32.43	27.80	34.80
	Daphnia	0.00	0.08	0.30	8.42	74.66	69.86	14.46	3.31
	Other Cladocera**	0.01	0.04	0.10	1.75	8.85	1.10	3.05	0.16
	Total Zooplankton	10.93	20.50	24.49	83.71	144.11	103.39	45.31	38.27
West Arm	Copepoda	3.43	13.27	36.33	63.33	39.90	20.24	17.23	29.39
	Daphnia	0.00	0.07	0.00	4.64	53.02	139.70	9.34	3.55
	Other Cladocera**	0.01	0.01	0.00	6.37	8.52	7.32	1.71	0.23
	Total Zooplankton	3.44	13.36	36.33	74.33	101.44	167.27	28.28	33.17

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

The maximum zooplankton density in 2007 occurred in July, in the main body of Kootenay Lake at station KLF 5, averaging 60.19 individuals/L. The West Arm averaged 47.74 individuals/L. Copepod densities peaked in July at most stations, Cladocerans were occasionally captured in April-May (when sampling began), with significant populations developing in August (Figs. 6.10 and 6.11). Peak *Daphnia* densities along the lake were generally 8 - 31% of the total zooplankton density. The highest seasonal density was in September at station KLF 2, averaging 10.38 individuals/L, and at station KLF 8 in the West Arm averaging 8.09 individuals/L. The highest *Daphnia* biomass in the main body of the lake was observed at station KLF 2 with 171.18 µg/L in September, while in the West Arm the highest *Daphnia* biomass was 139.70 µg/L, also recorded in September (Figs. 6.12 and 6.13). From August onward in previous years, biomass trends along the main body of the lake were largely driven by the development of *Daphnia* spp., since *Daphnia* made up the majority of zooplankton biomass during that period. If zooplankton, particularly *Daphnia*, is available late in the growing season, it may allow fish and other predators to continue their growth into the fall. An increase in fish size prior to winter may lead to lower over-winter mortality (Johnson and Evans 1991; Miranda and Hubbard 1994).

Zooplankton Fecundity

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

L. ashlandi females were gravid throughout the sampling period in 2007 (Fig. 6.14). The proportion of females that were gravid was highly variable. This trend occurred in previous years, and was always below 0.4. There was no consistent trend for females to carry more eggs in one of the basins. 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 the pattern changed and females from the North Arm had more eggs than those from the South Arm (App. 6.1).

In 2007 *L. ashlandi* females carried an average of 15.82, 16.23, and 13.31 eggs per gravid female in the North, South and West arms respectively. Number of eggs ranged from 6 to 28 per gravid female (App. 6.1, Fig. 6.15). The number of eggs per water volume averaged 1.83 eggs/L in the North Arm, 1.86 eggs/L in the South Arm, and 0.94 eggs/L in the West Arm. The number of eggs per capita averaged 0.32, 0.23, and 0.23 eggs/individual in the North, South, and West arms respectively.

D. bicuspidatus thomasi females were gravid throughout the sampling period in 2007 (Fig. 6.14). The proportion of gravid females ranged from 0 to 0.53. From April to November, the proportion of gravid females averaged 0.16 in the North and the South Arm, and 0.12 in the West Arm (App. 6.1, Fig. 6.15). The seasonal average number of eggs per gravid female was 18.00, 17.54, and 16.91 in the North, South and West arms respectively, ranged from 8 to 37 eggs per gravid female. During the sampling season, the number of eggs per litre of water averaged 4.62, 3.39, and 2.60 eggs/L, while the number of eggs per capita averaged 0.45, 0.47, and 0.54 eggs/individual in the North, South, and West arms respectively.

Gravid females of *Daphnia* spp. were observed in samples from June to November in 2007. The proportion of gravid *Daphnia* spp. ranged from 0 to 0.75 in 2007 and averaged 0.14 in the North Arm, 0.17 in the South Arm and 0.04 in the West Arm (App. 6.1, Fig. 6.16). The proportion of gravid females was at the similar level as in the previous year. The seasonal average fecundity in 2007 was 2.49, 2.46, and 1.81 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 0.42, 0.50, and 0.11 (Fig. 6.17), while the number of eggs per capita averaged 0.40, 0.48 and 0.08 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 2007 sampling season.

Gravid females of *B. longirostris* were observed from May to November in 2007 (Fig. 6.16). The proportion of gravid females averaged 0.18, 0.25, and 0.14 in the North, South, and West arms respectively in 2007. The seasonal averages were 1.93, 1.72, and 1.73 eggs per gravid female in the North, South, and West arms respectively, ranged from 1 to 6 eggs per gravid female (App. 6.1, Fig. 6.17). During the sampling season, the number of eggs per litre of water averaged 0.33, 0.18, and 0.67, while the number of eggs per capita averaged 0.36, 0.56 and 0.26 in the North, South, and West arms respectively. None of the fecundity measures were consistently higher in either the North Arm or South Arm over the eleven-year period.

Comparison to other lakes

Zooplankton density and biomass in Kootenay Lake did not show a steady increase across years (Fig. 6.5). Total average density and biomass and *Daphnia spp*. average density and biomass fluctuated during the years 1997–2007. 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 increased to results similar to Kootenay Lake (Fig. 6.18) (Schindler et al. 2006, 2007). 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. 6.19). From 2001 to 2007, 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 results 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 twice of that in Lower Arrow and almost six times of that in Upper Arrow, while zooplankton biomass in the West Arm was similar to that in Upper and Lower Arrow (Fig. 6.19). These differences are due to the fluctuation in the proportion of *Daphnia spp*. in total zooplankton density and biomass in these lakes (Fig. 6.20). Since individual *Daphnia* have a higher biomass than individuals of most other zooplankton species in these systems, it causes significant increases of zooplankton biomass in those years with a higher percentage of grazeable phytoplankton available, lower predation pressure and optimal abiotic factors such as temperature, oxygen or other environmental factors.

Seasonal average zooplankton density and biomass in Kootenay Lake was higher than in Alouette Lake during the study period, except in 2006 when biomass in Alouette Lake exceeded biomass values in the North and South Arm of 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 and 2006 the *Daphnia* population in Alouette Lake increased, comprising of 56-65% of the total zooplankton biomass (Fig. 6.20). *Daphnia* density and biomass were higher than in the North Arm of Kootenay Lake in both years and higher than in South Arm in 2006. *Daphnia* density and biomass in South Arm in 2005 and in 2005-2006 in West Arm of Kootenay Lake were at the similar level as in Alouette 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 2001, while in the period from 2002 to 2007 the proportion of *Daphnia* density and biomass fluctuated from lake to lake. In 2007 the proportion of *Daphnia* density and biomass in Kootenay Lake exceeded those values in both Arrow basins and in Alouette Lake.

Mysis Relicta

Abundance and Biomass

Seasonal average mysid densities during the fertilization experiment were well below the historical high values observed in the late 1970s and the mid-1980s (Fig. 6.21). However, the very erratic values observed during this period may have arisen due to sampling frequency and the methods used at that time. Samples were collected less regularly than during the current study, and the plankton net used to collect samples had a finer mesh (Crozier and Duncan 1984). From 1992 onward, during the fertilization experiment, sampling of mysids began in January and continued until December, so all annual average values represent a twelve-month period. In 2005, samples were not collected in February; therefore annual average values represent an eleven-month period. In 2006 samples were collected for ten months, between February and November, and in 2007 for eight months from April to November. During the course of the fertilization experiment, mysid densities were highest in 1992, declined over the four years from 1993 to 1996, but increased again from 1997 to 2001. In 2002 and 2003, densities decreased significantly by 50% compared to the 2001 results. In 2004 and 2005 densities increased followed by a slight decrease in 2006 and a slight increase in 2007 (Fig. 6.21).

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 and 2007. 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 (Fig. 6.22).

Samples collected at pelagic stations tended to have higher densities than near-shore samples. From 1999 to 2007, mysid densities at shallow sites in both the North and South arms were generally below 300 individuals/m^2 throughout the year (Fig. 6.23). At deep sites from July to October, densities were greater than 300 individuals/m^2 in five of the eleven years (1999, 2000, 2001, 2004, and 2005) and less than 300 individuals/m^2 during the other six years. From 1999 to 2006, there was a trend of higher mysid densities at the deep stations in the North Arm, except in 2001 and 2002 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 when the density in the South Arm was greater than in the North Arm (Fig. 6.23). In 2007 mysid densities at both pelagic and near-shore stations in the North and South arms of Kootenay Lake were similar during the entire sampling season.

Peak monthly values at shallow sites were usually recorded in June-July, mainly due to a higher number of juveniles (Figs. 6.24 and 6.25). 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. 6.26 and 6.27)**.** In 2007, the mysid density increased at deep sites in both the North and the South Arm from the previous year. At the near shore stations during the same time period, a slight increase in mysid density in both basins was noted. The highest seasonal mysid abundance at a deep site during 2007 was in July at station KLF 3 in the North Arm, with 733 individuals/m^2 (mainly immature males and females) (Fig. 6.26). The highest seasonal abundance of mysids at a shallow site occurred in July at station KLF 1, with 379 individuals/m^2 (mainly immature male and female) (Fig. 6.24).

During the period 1999–2007, average mysid biomass was generally below 2,500 mg/m^2 at deep sites at all stations (Fig. 6.28). The average biomass was generally below 1000 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 September toward the end of the season. At the shallow sites, high peaks in biomass occasionally occurred. For example, in July 2000 the biomass exceeded 3,000 mg/m^2 at station KLF 5, in June 2002 the biomass exceeded 4,400 mg/m^2 at station KLF 1 and 2,300 mg/m^2 at station KLF 5 (Figs. 6.29 and 6.30). There was a trend of increased biomass from 1999 to 2001 at deep sites at stations KLF 1 and KLF 7 and from 2002 onward, biomass decreased at all deep sites (Figs. 6.31 and 6.32). Overall biomass was higher at deep stations than at shallow stations, because of the greater proportion of older (and therefore larger) individuals in deeper water. In 2007, biomass was generally higher at the deep sites, similar to previous years. From April to June 2007, mysid biomass was below 600 mg/m^2 at deep sites and below 100 mg/m^2 at shallow sites. From June onward, average biomass increased but did not exceed 2,000 mg/m^2 at deep sites and 400 mg/m^2 at shallow sites (Fig. 6.28). The highest biomass at deep sites in 2007 was 2,189 mg/m^2 (mainly immature males and females) at station KLF 1 in November. The highest biomass at shallow sites was 1,124 mg/m^2 (mainly immature males and females) at station KLF 1 in July.

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 dominating the mysid population during the summer and fall. 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 2007 was similar to previous years (Figs. 6.24 and 6.25). 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. 6.26 and 6.27. From April to June in 2007, 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 from 1997 to 2000 was consistently higher than the density observed in Arrow Lakes Reservoir (Fig. 6.33). In the same time period mysid density in the South Arm fluctuated and was similar to results in Arrow Lakes Reservoir (Schindler 2006, 2007). 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. 6.33). In 2003, mysid density and biomass in Upper Arrow had increased to twice of that in Kootenay Lake. From 2004 to 2007 mysid biomass in Arrow Lakes Reservoir was similar or lower than Kootenay Lake. In Okanagan Lake, mysid density and biomass was higher than in Kootenay Lake during the entire study period. Seasonal average biomass in Okanagan Lake exceeded those values in Kootenay Lake two to three times, and in 2004 exceeded the values five times (Andrusak et al. 2006). Generally, annual average biomass in Kootenay Lake fluctuated between 500 and 1,500 mg/m^2, while in Okanagan Lake, annual average biomass ranged between 1,500 and 4,000 mg/m^2 (Fig. 6.33).

Discussion

Seasonal average zooplankton abundance and biomass in both the main body of the lake and in the West Arm slightly decreased in 2007 from 2006. From 1997 to 2000, the fertilizer load was reduced relative to previous years, but in 2001 the fertilizer load was increased to the similar rates as the beginning of the experiment. Climatic conditions, changes in algal composition, or changes in *Mysis relicta* and kokanee abundance may have made conditions more favourable for *Daphnia* spp. and other cladocerans in Kootenay Lake in 1999 and 2000. These same factors, and potentially the increase of fertilizer load to the North Arm, may have made conditions even 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 fluctuated 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 grazeable 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 grazeable 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. Fertilization of the South Arm commenced in 2004 and has continued through 2007. In 2004 and 2005, phytoplankton biomass in Kootenay Lake was the lowest recorded in the North Arm since 1992. The fertilization 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 the grazeable phytoplankton increased, especially in the South Arm of the lake, providing more favourable conditions for *Daphnia,* causing an increase of density and biomass in comparison to previous years.

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 relicta* 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.

Changes in zooplankton density and biomass from 2001 to 2007 suggest that the system has shifted towards more productive conditions compared to previous years with decreased nutrient loads (1997-2000). Total zooplankton density and biomass in Kootenay Lake during the 2007 season were higher than those of Arrow Lakes Reservoir and Alouette Lake. 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. relicta* as Arrow Lakes Reservoir did between 1997 and 1999.

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 2007, an increased trend was recorded. Average mysid density was higher in the South Arm than the North Arm in 2001, 2002 and 2007. 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 fertilization experiment started, 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 fertilization in Arrow Lakes Reservoir in 1999. In 2002 and 2003, mysid densities in Kootenay Lake decreased sharply 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 fertilizer 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 supplies. 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*, consists of what remains after they have been grazed by predators. In addition to predation, other factors such as changes in the availability of grazeable algae may affect zooplankton biomass. Contrary to the previous years, zooplankton densities and biomass in 2001–2007 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 of zooplankton in the lake.

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Appendix 6.1. Fecundity data for *L. ashlandi, D. bicuspidatus thomasi, Daphnia spp.* and *B. longirostris* in the North, South and West arms of Kootenay Lake in 1997–2007. Values are seasonal averages, calculated for samples collected April-October 1997–2002 and April-November 2003 and 2007.

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

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

Daphnia spp.	Basin	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Proportion of Gravid	North Arm	0.17	0.17	0.29	0.02	0.07	0.22	0.2	0.34	0.16	0.12	0.14
Females	South Arm	0.12	0.22	0.16	0.04	0.09	0.18	0.21	0.23	0.16	0.15	0.17
	West Arm							0.23	0.26	0.06	0.19	0.04
# Eggs per Gravid	North Arm	2.19	2.17	2.71	1.75	1.71	2.78	2.61	2.98	2.43	2.28	2.49
Female	South Arm	2.24	2.41	2.42	2.24	1.83	2.14	2.1	2.93	2.58	2.30	2.46
	West Arm							3.18	2.96	2.28	2.62	1.81
# Eggs per Litre	North Arm	0.1	0.37	0.11	0.02	0.17	0.49	0.95	0.24	0.14	0.53	0.42
	South Arm	0.15	0.48	0.07	0.11	0.14	0.28	0.52	0.14	0.15	0.40	0.50
	West Arm							0.69	0.72	0.18	0.74	0.11
# Eggs per Capita	North Arm	0.41	0.36	1.05	0.04	0.13	0.78	0.55	1.19	0.37	0.28	0.40
	South Arm	0.26	0.71	0.6	0.14	0.17	0.48	0.47	0.68	0.50	0.44	0.48
	West Arm							1.34	0.73	0.16	0.67	0.08

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

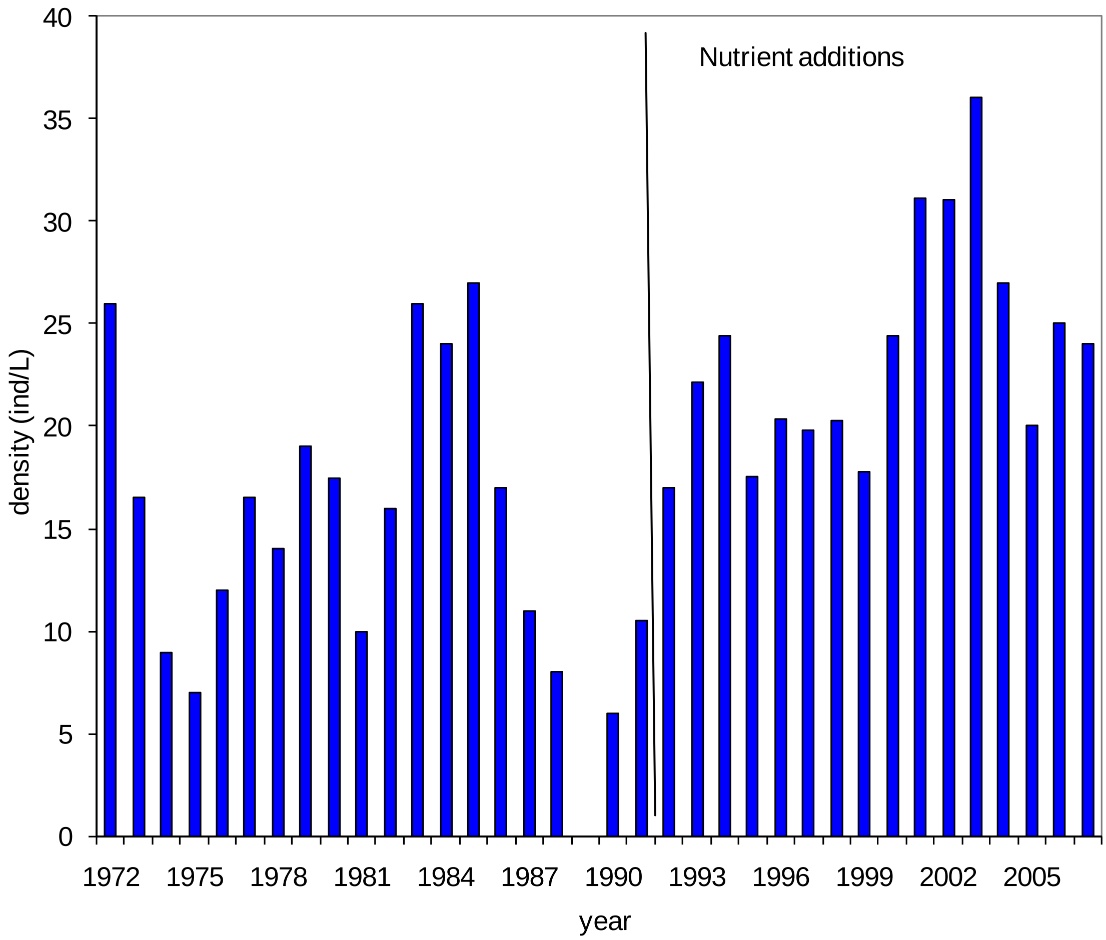


Figure 6.1. Zooplankton density, 1972 to 2007. Note: 1972-1990 for mid-lake station, near current station KLF 5, and 1992 to 2007 for whole-lake average).

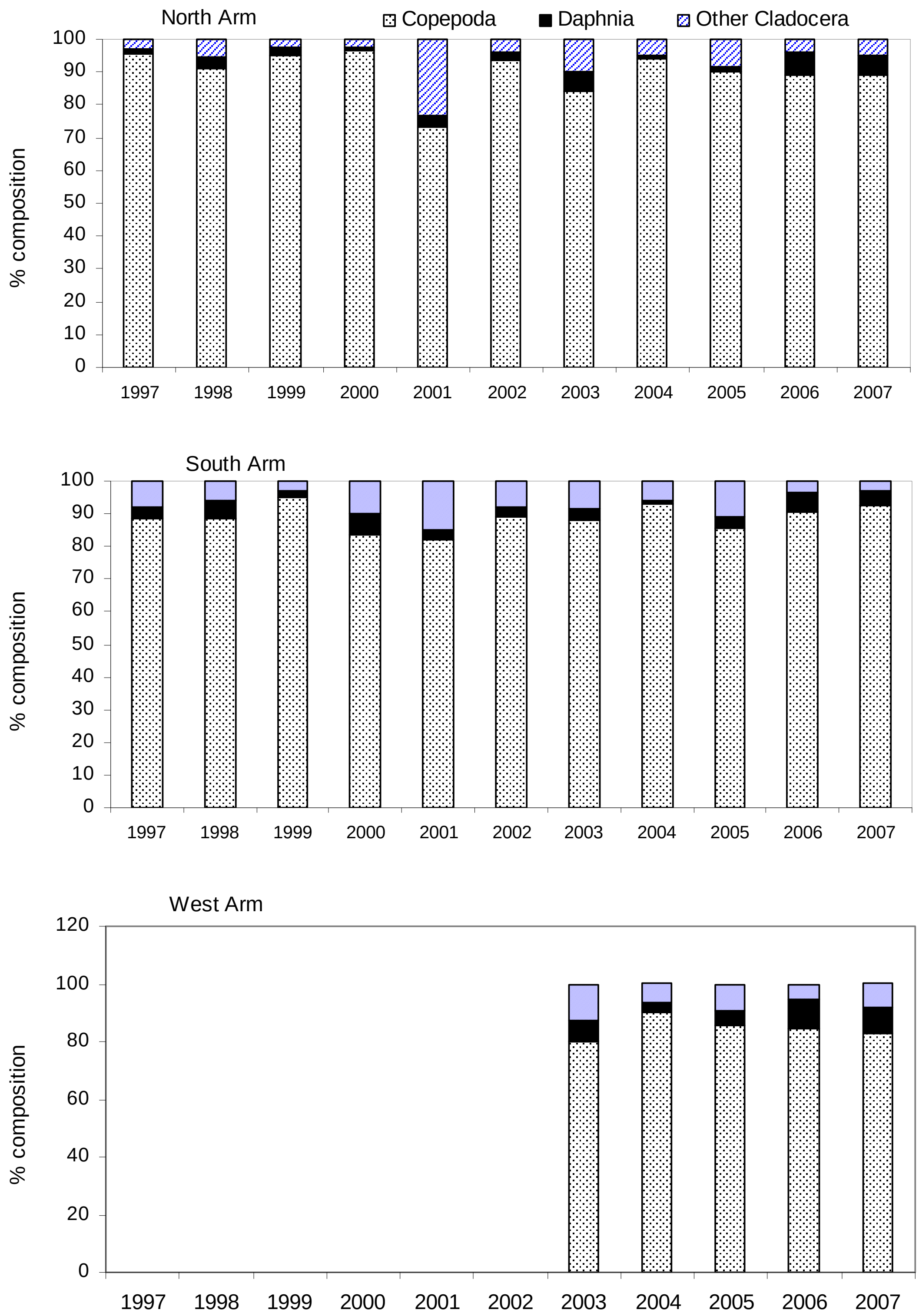


Figure 6.2. Seasonal composition of zooplankton as a percentage of average density in the North, South and West arms of Kootenay Lake, 1997 to 2007 (2003 to 2007 for the West Arm).

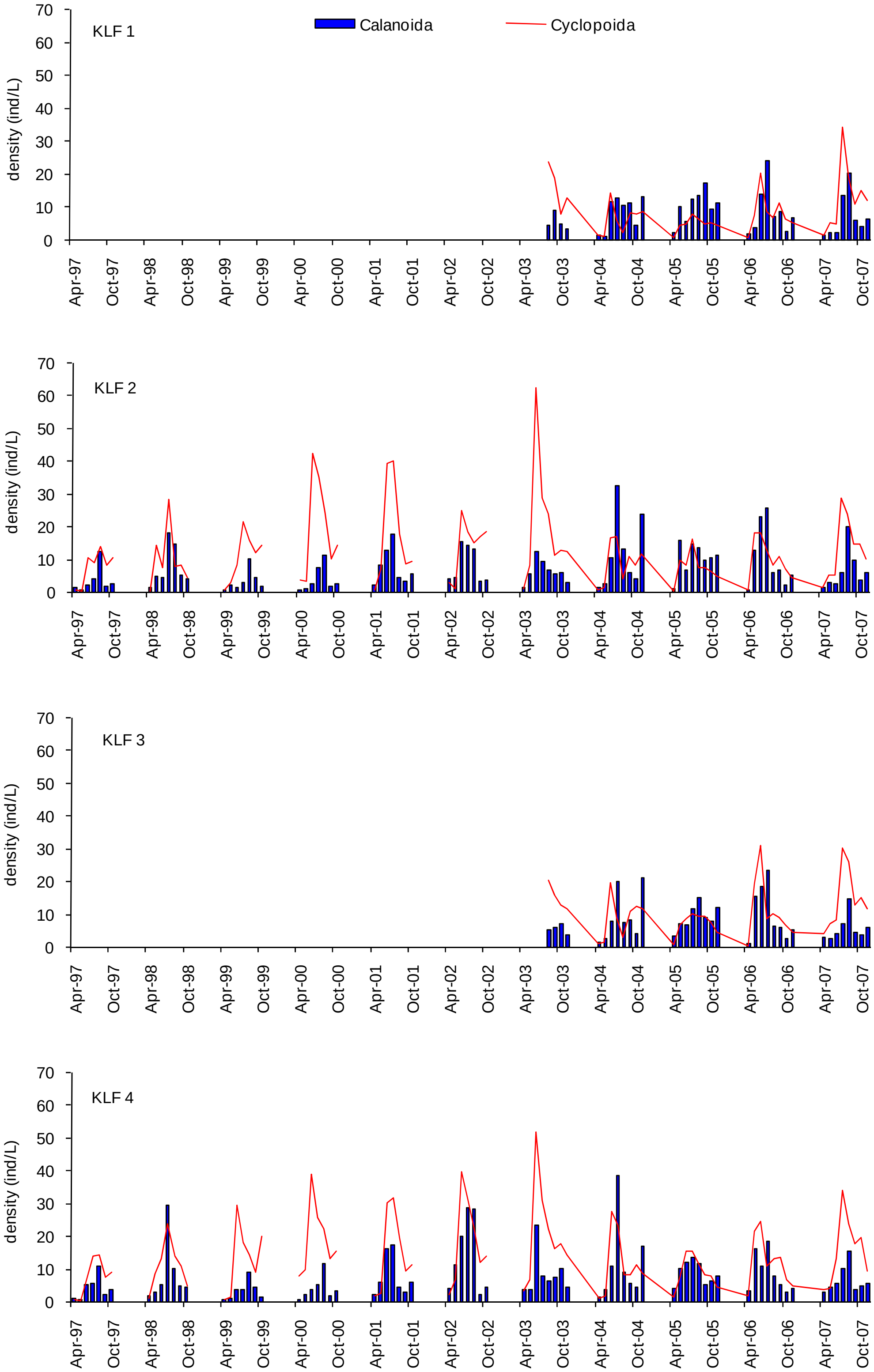


Figure 6.3. Density of calanoid and cyclopoid zooplankton in North Arm stations, 1997 to 2007.

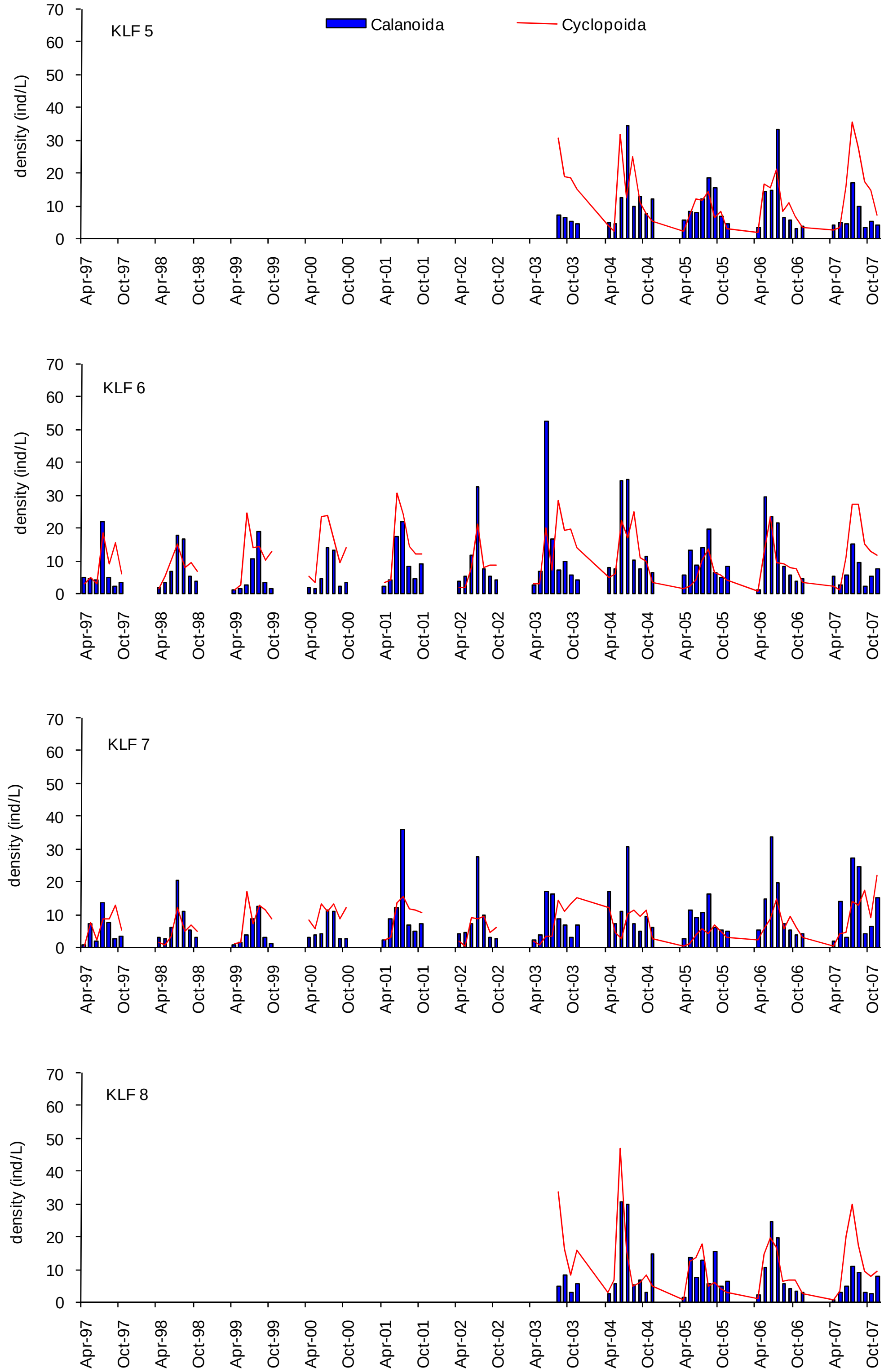


Figure 6.4. Density of calanoid and cyclopoid zooplankton in South Arm stations 1997 to 2007 and the West Arm station, 2003 to 2007.

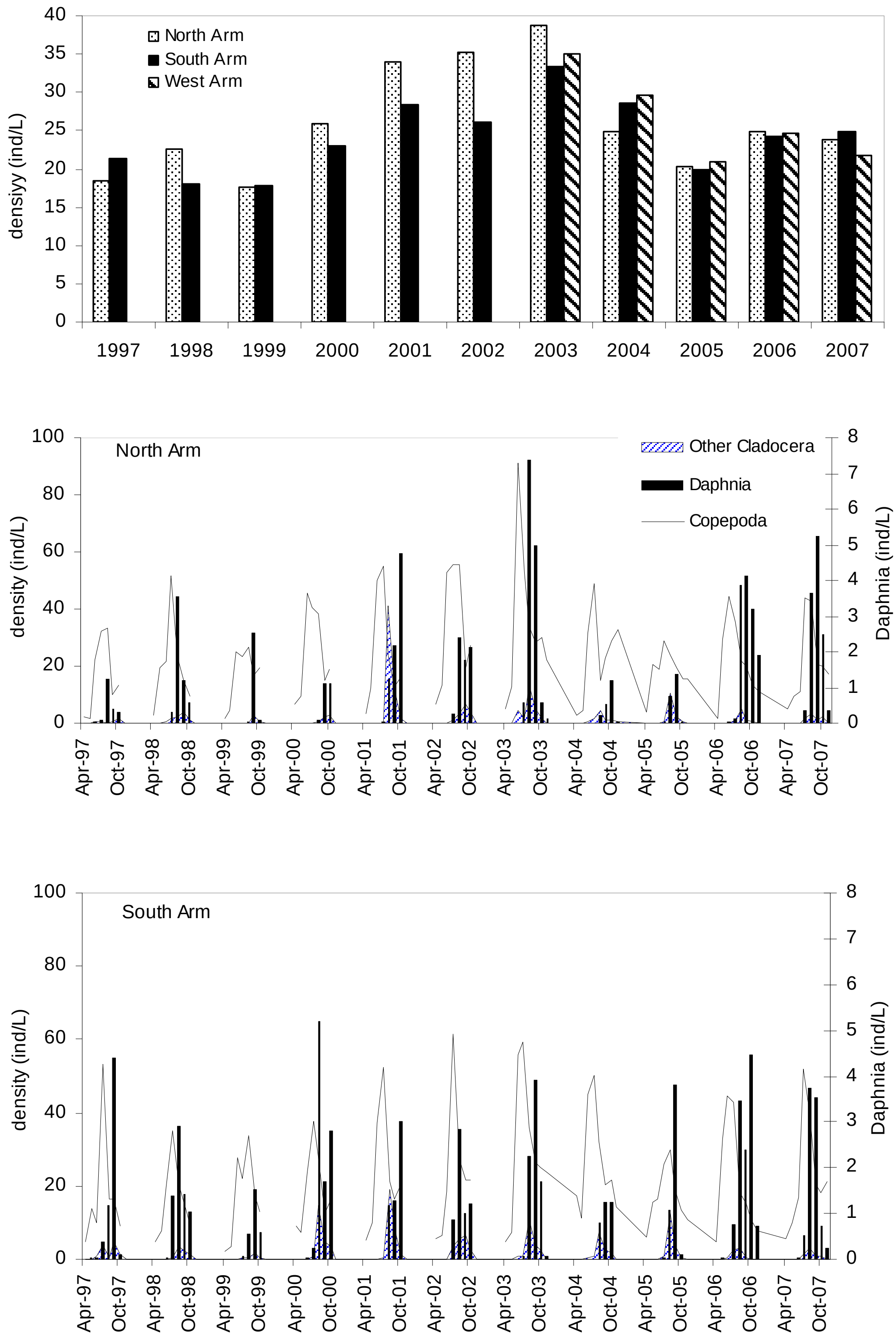


Figure 6.5. Zooplankton density in Kootenay Lake, 1997 - 2007. The top graph is annual average density. The middle and bottom graphs are average seasonal density for the North and South Arm.

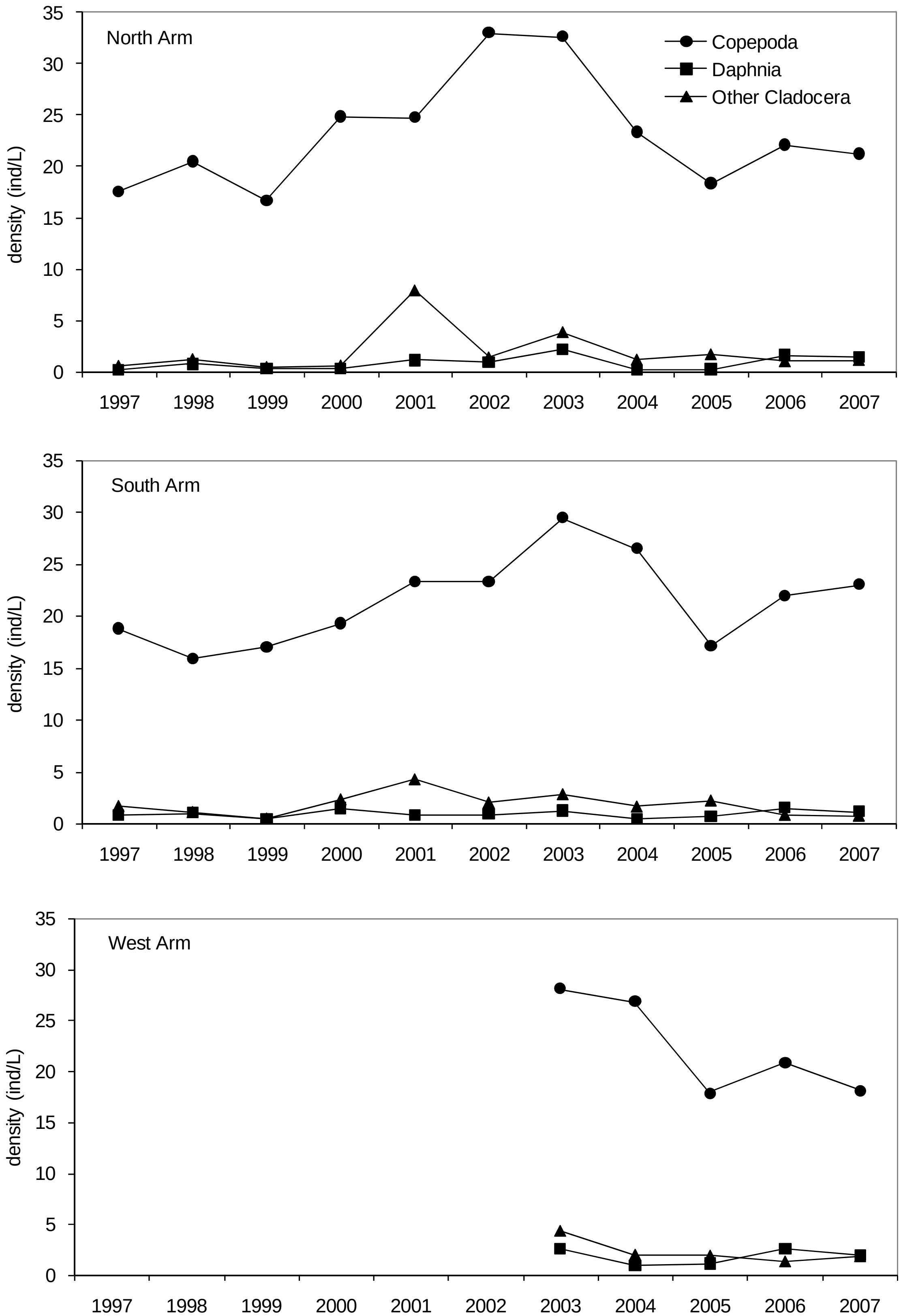


Figure 6.6. Seasonal average zooplankton density in Kootenay Lake, 1997 to 2007.

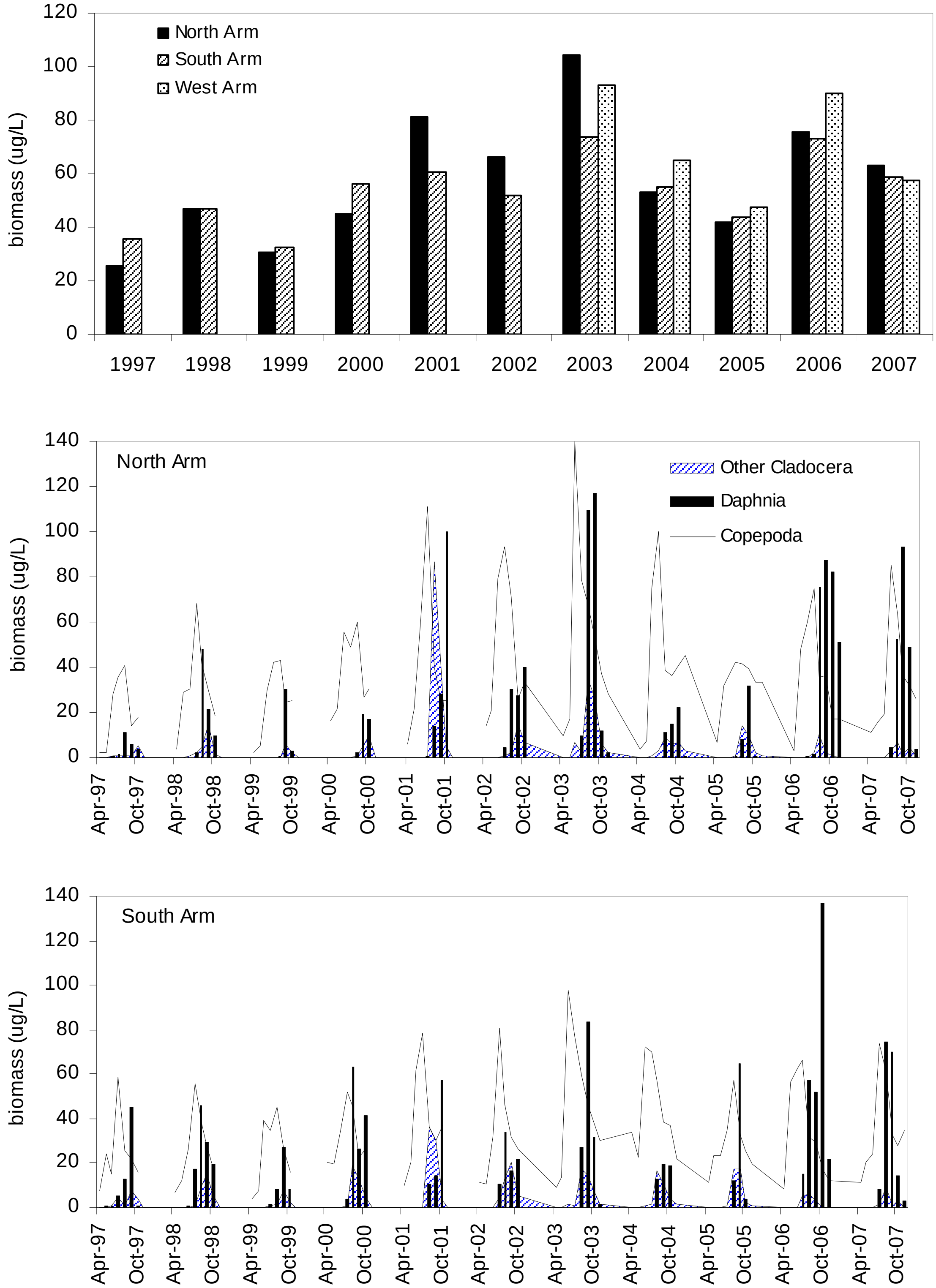


Figure 6.7. Zooplankton biomass in Kootenay Lake, 1997 - 2007. The top graph is annual average biomass and the middle and bottom graphs are seasonal average biomass.

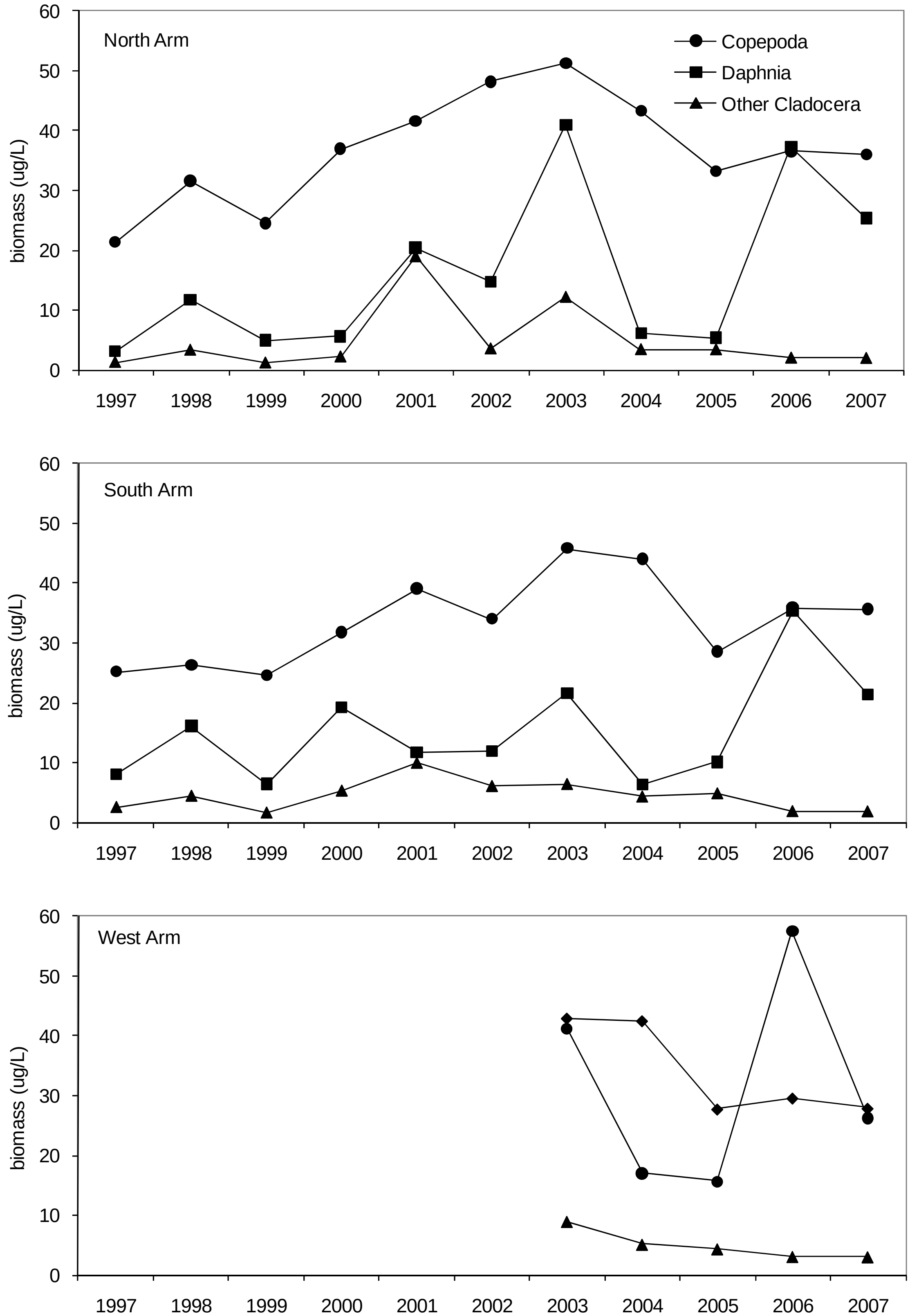


Figure 6.8. Seasonal average zooplankton biomass in Kootenay Lake, 1997 to 2007.

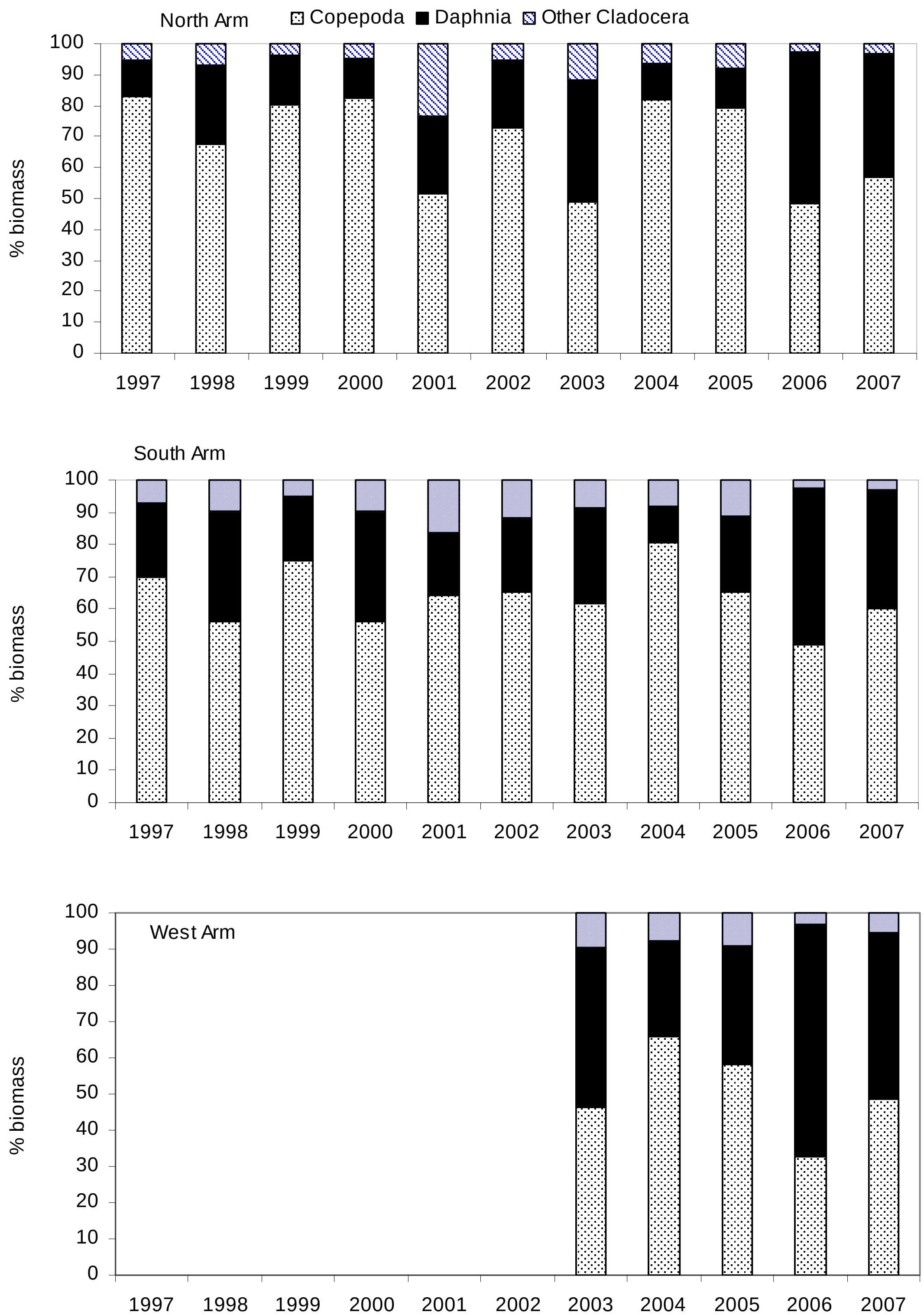


Figure 6.9. Seasonal composition of zooplankton as a percentage of average biomass in the North, South and West arm of Kootenay Lake, 1997 - 2007.

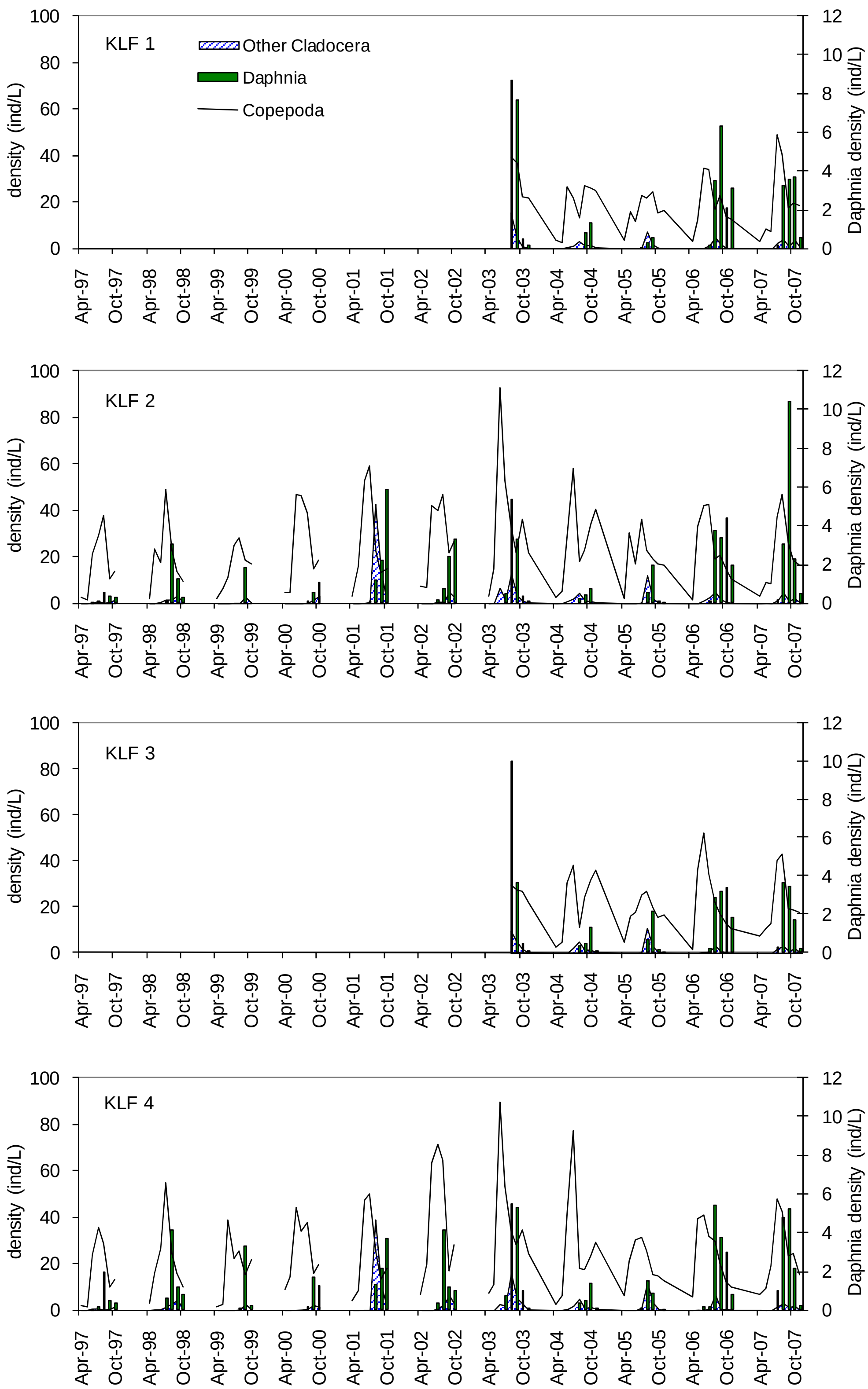


Figure 6.10. Density of cladoceran and copepod zooplankton in the North Arm of Kootenay Lake, 1997 – 2007.

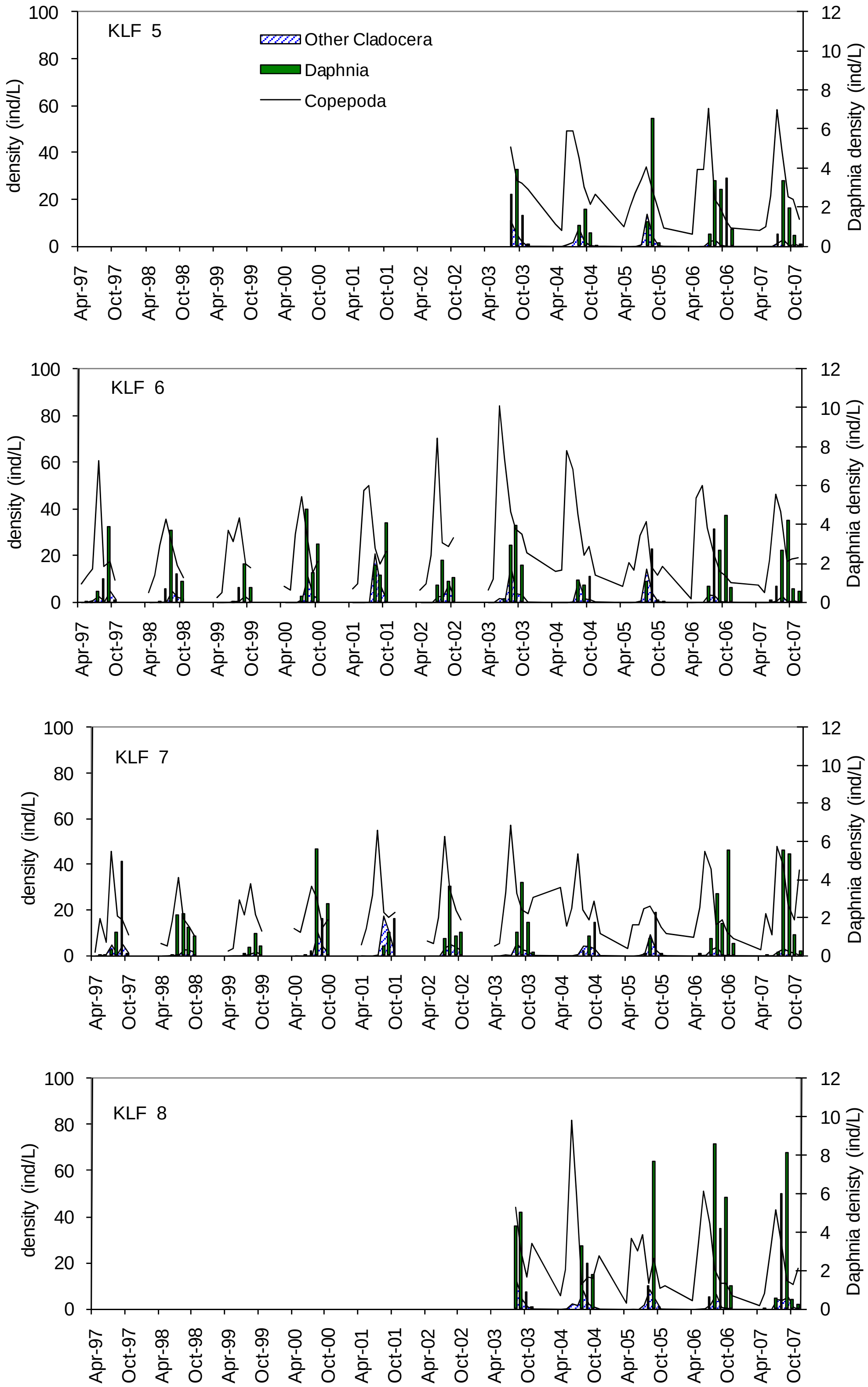


Figure 6.11. Density of cladoceran and copepod zooplankton in the South Arm (1997 – 2007) and West Arm of Kootenay Lake (2003 – 2007).

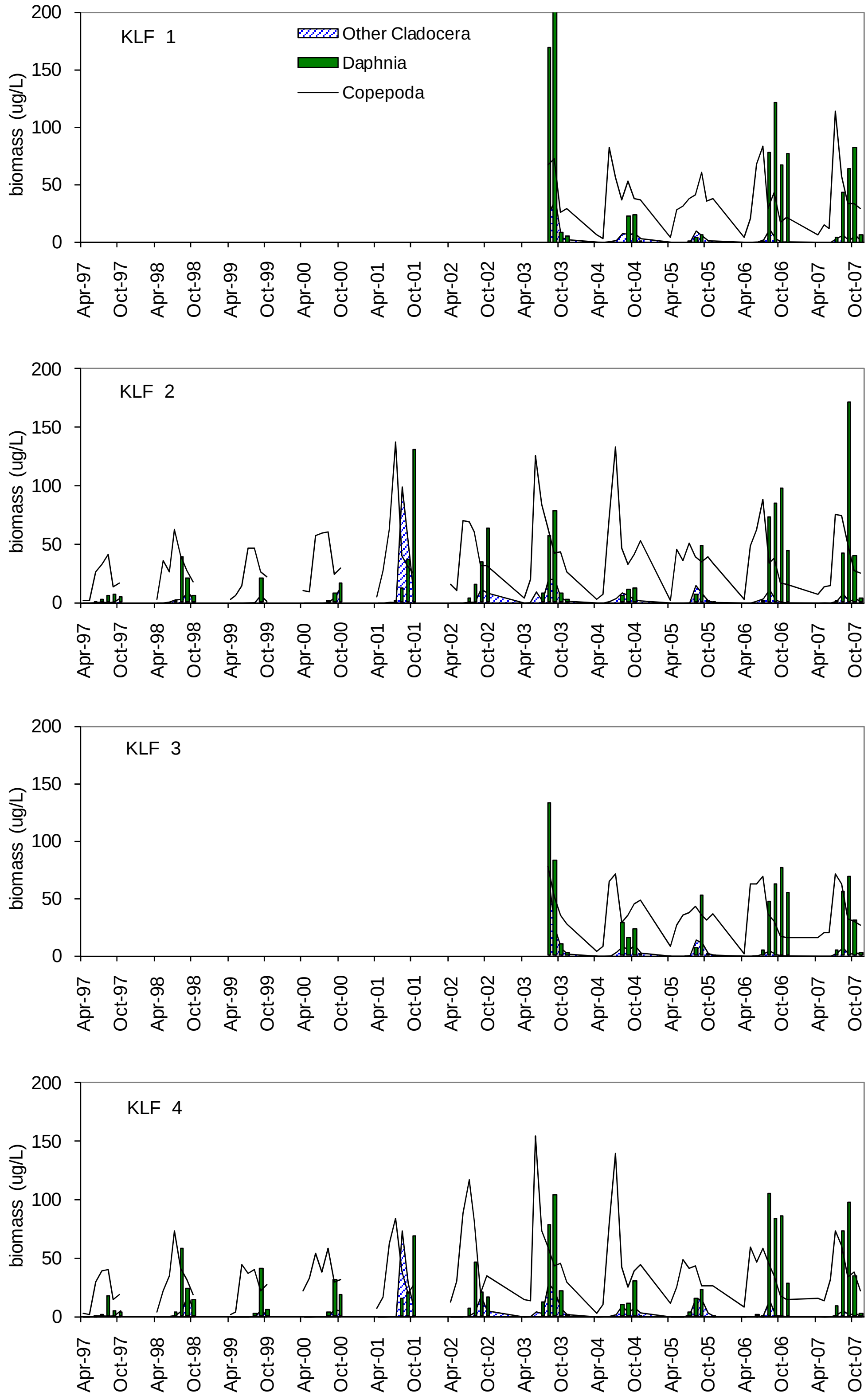


Figure 6.12. Biomass of cladoceran and copepod zooplankton in the North Arm of Kootenay Lake, 1997 – 2007.

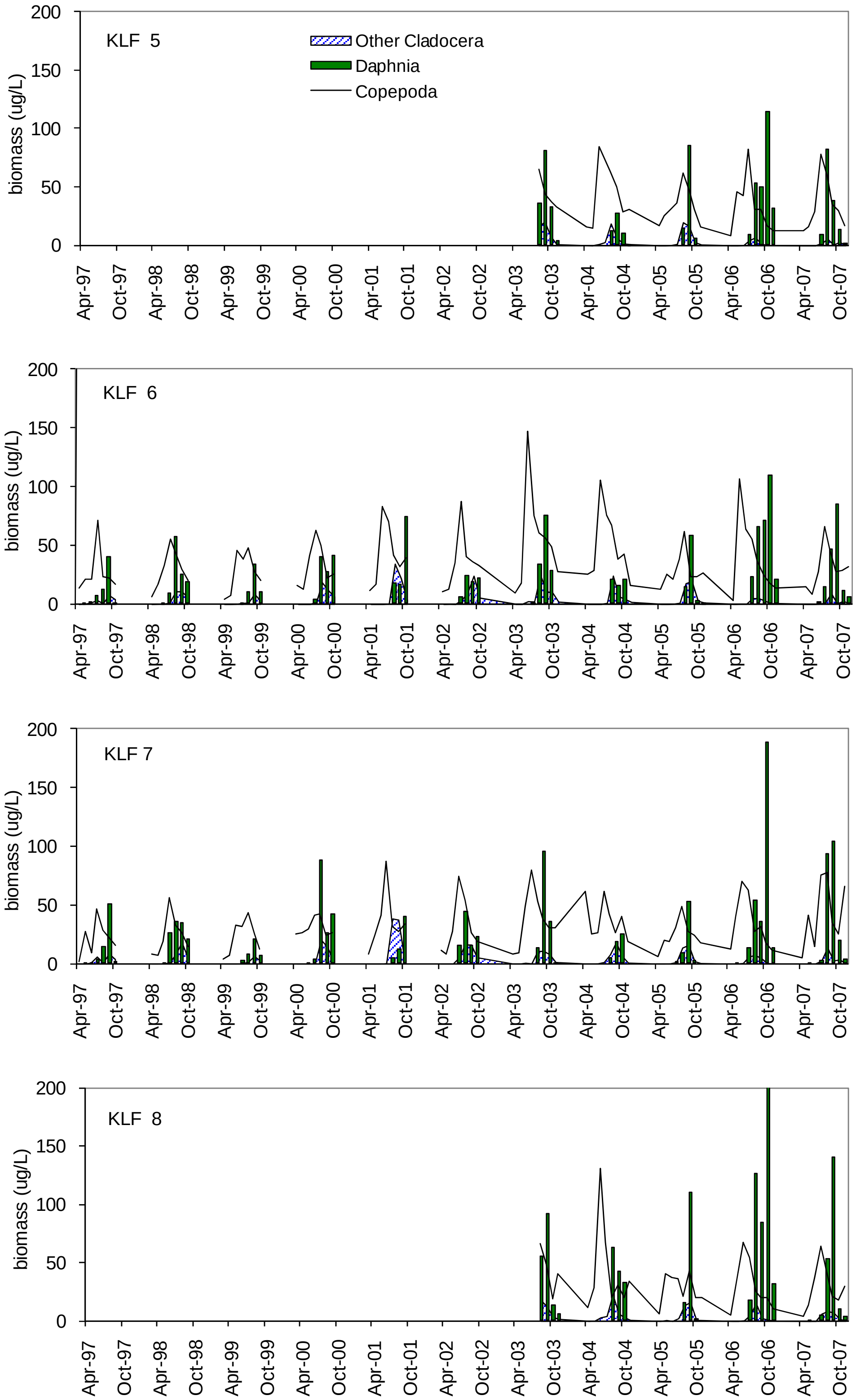


Figure 6.13. Biomass of cladoceran and copepod zooplankton in the South Arm (1997 – 2007) and West Arm of Kootenay Lake (2003 – 2007).

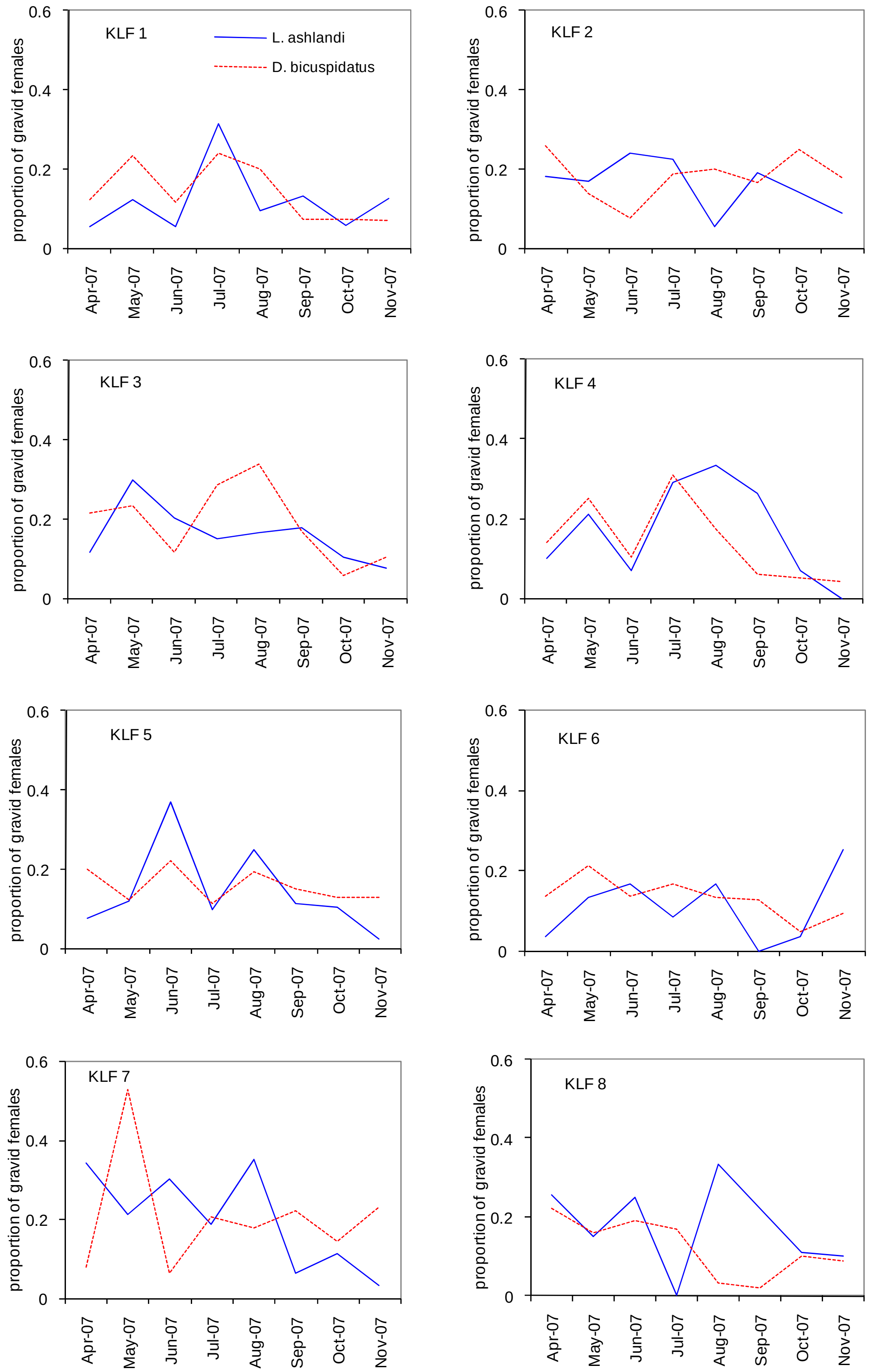


Figure 6.14. Proportion of gravid females of two species of Copepoda in Kootenay Lake, 2007.

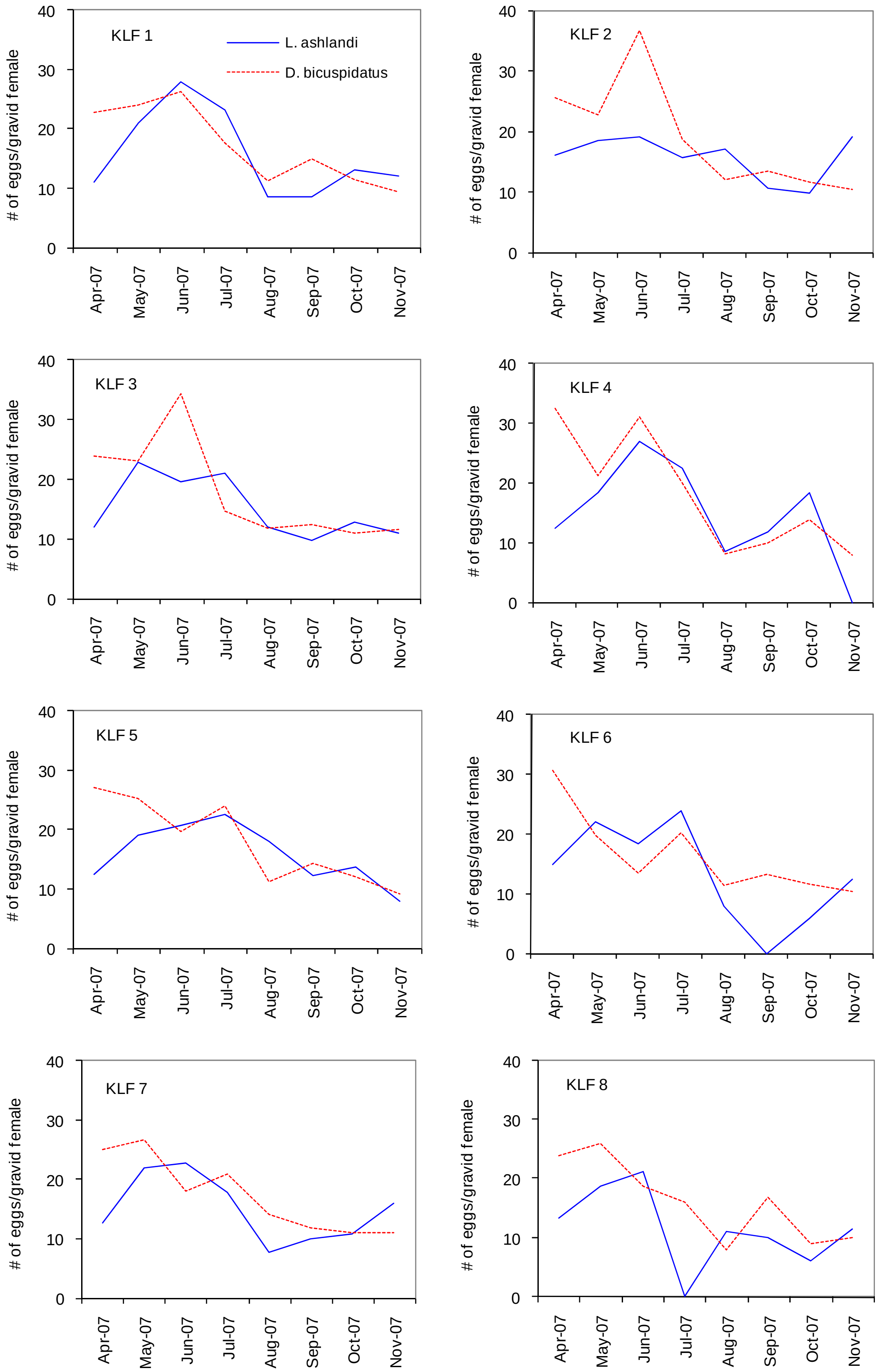


Figure 6.15. Number of eggs per gravid female in two species of Copepoda in Kootenay Lake, 1997.

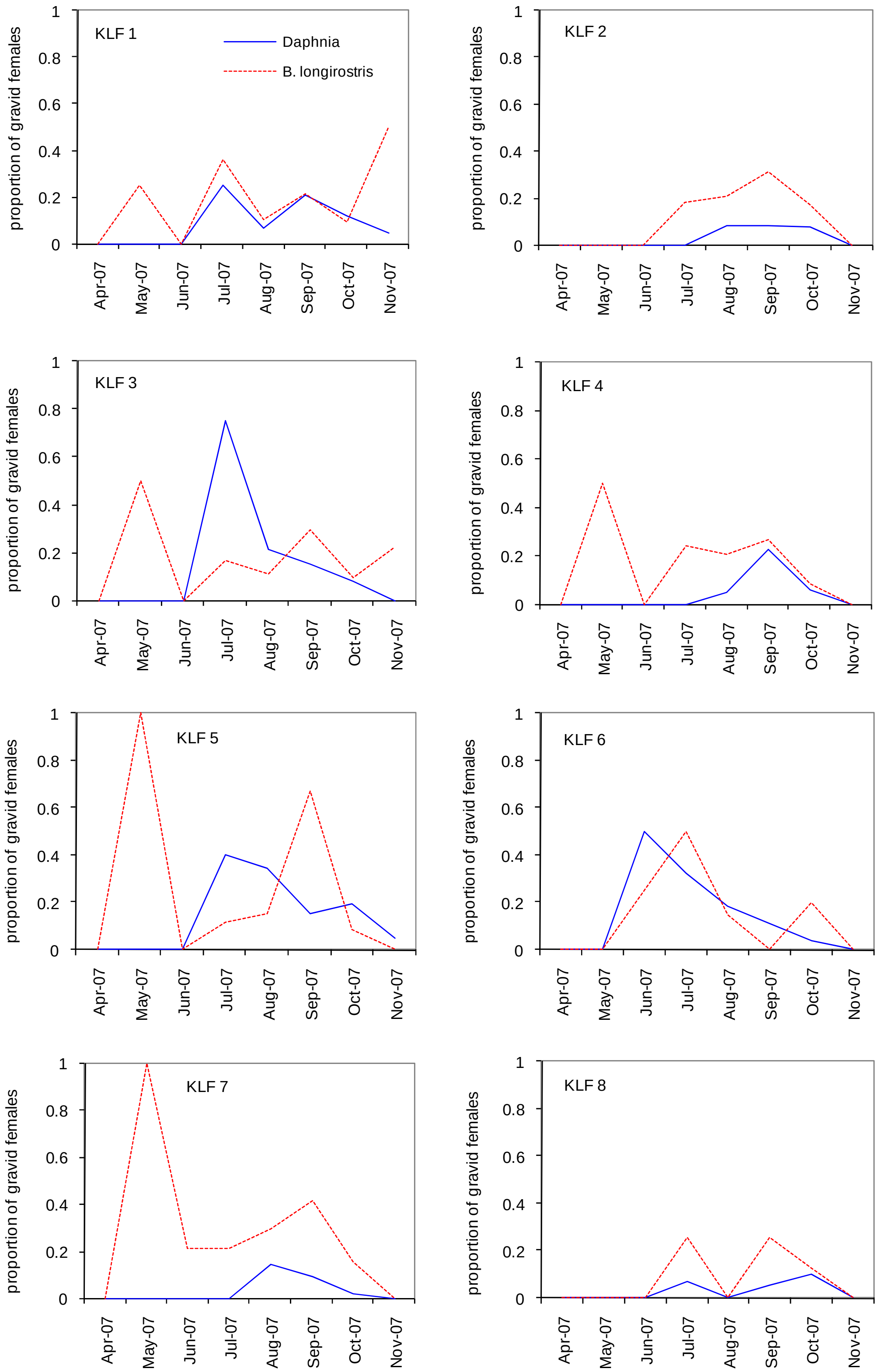


Figure 6.16. Proportion of gravid females in two species of Cladocera in Kootenay Lake, 2007.

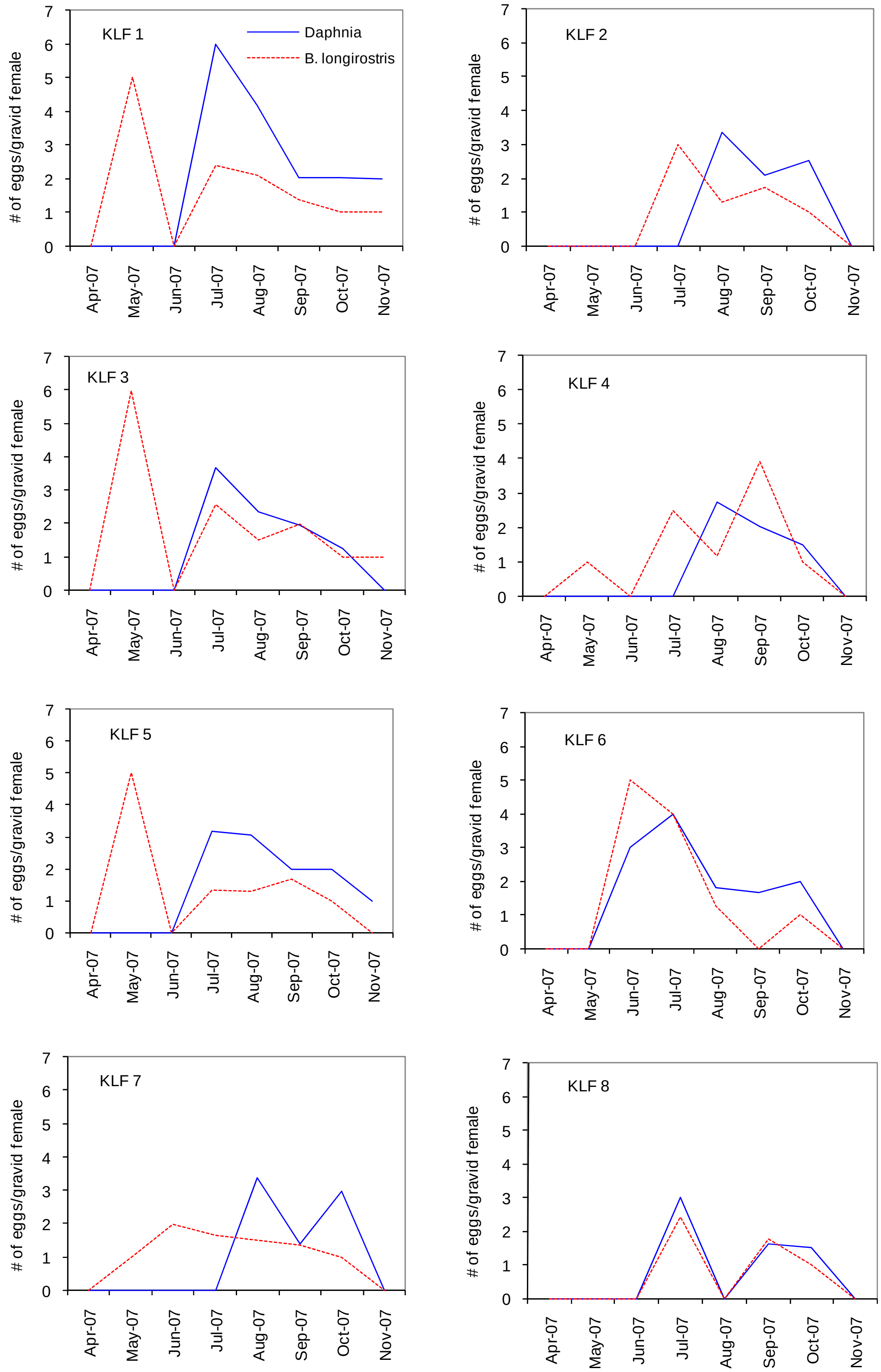
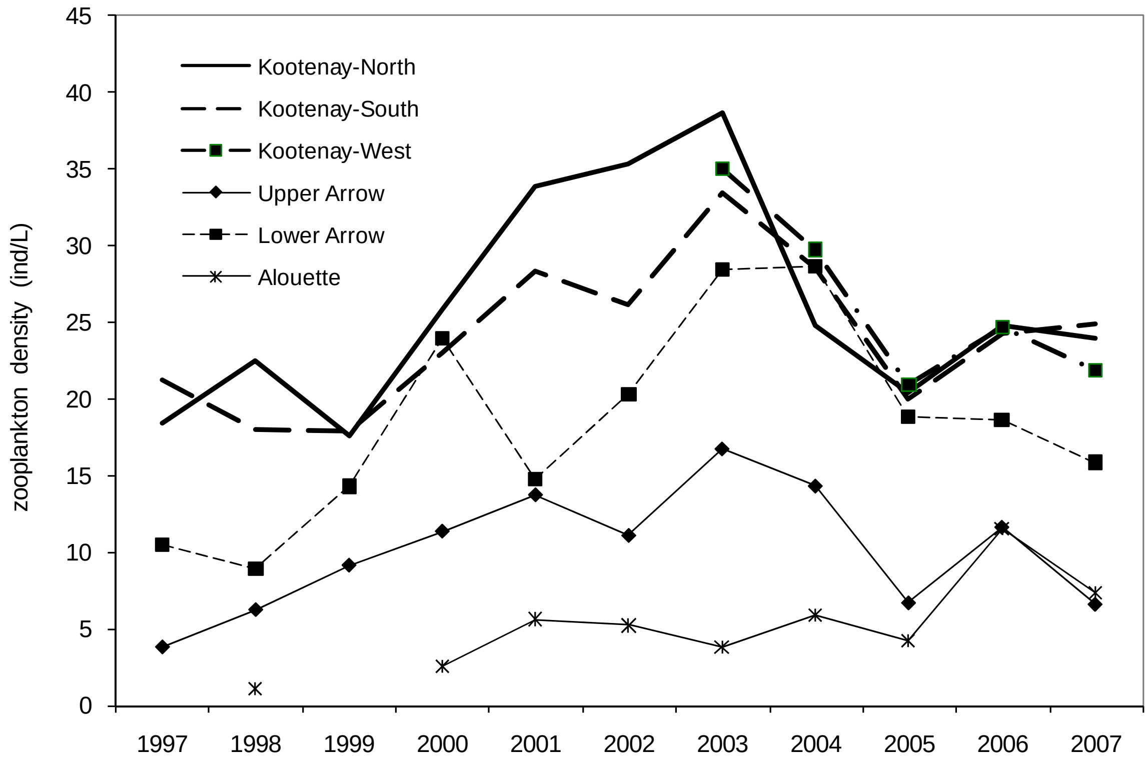


Figure 6.17. Number of eggs per gravid female in two species of Cladocera in Kootenay Lake, 2007.



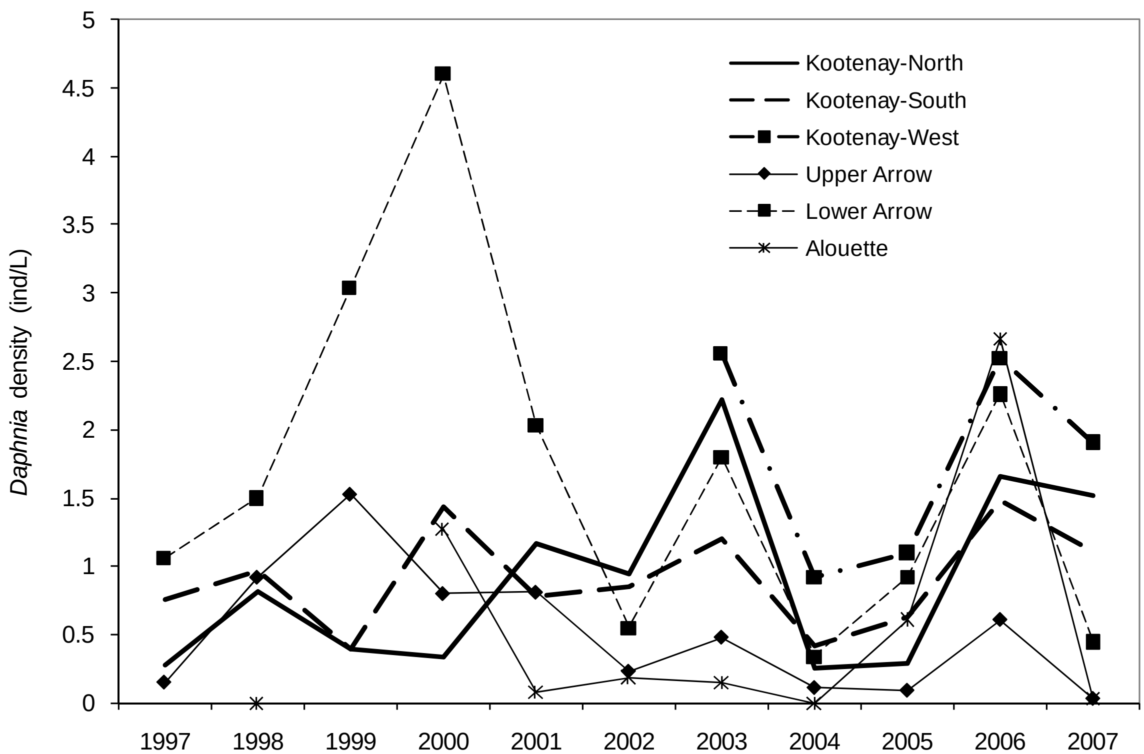


Figure 6.18. Seasonal average density (top) and *Daphnia* density (bottom) in some British Columbia lakes.

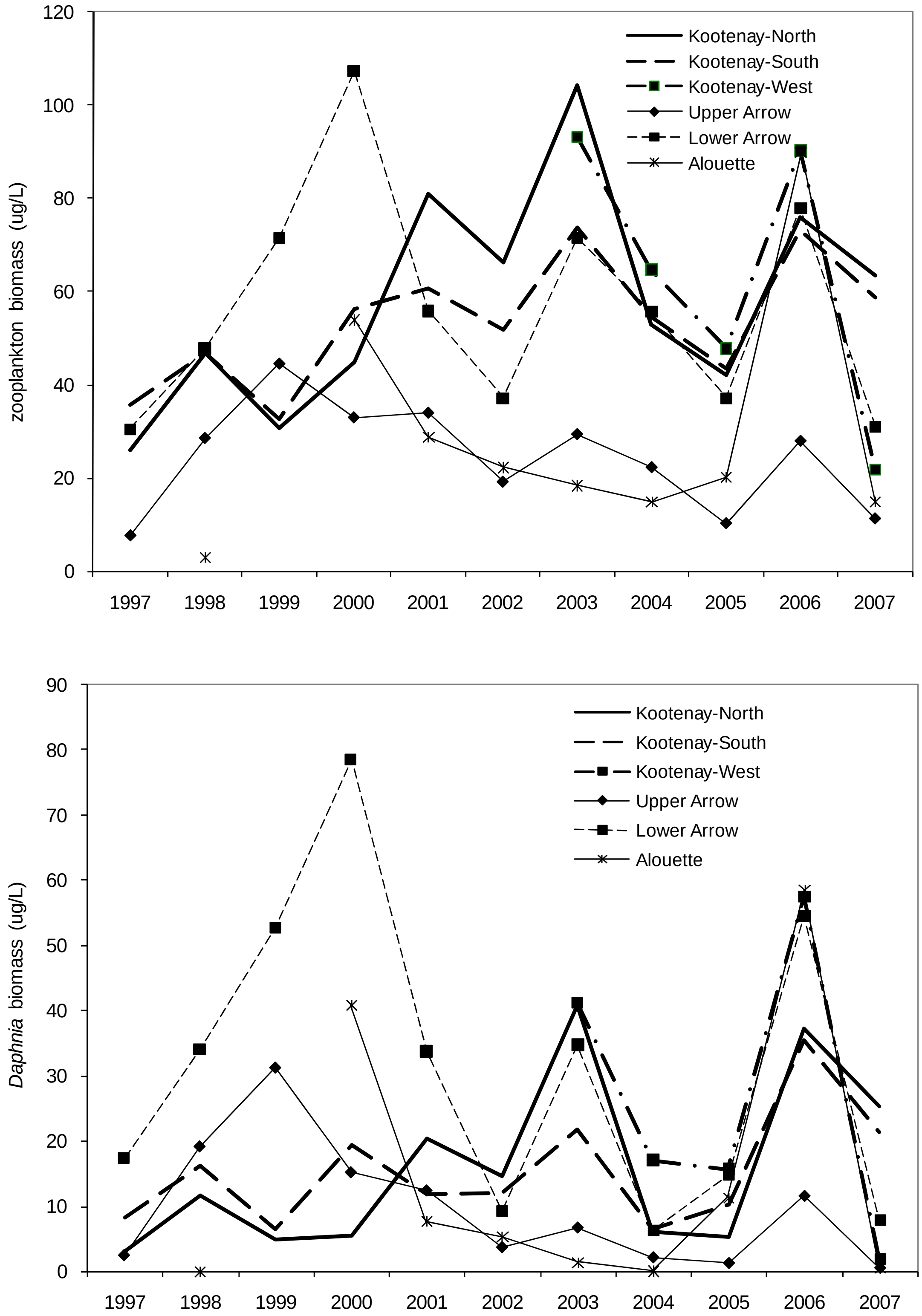


Figure 6.19. Seasonal average biomass (top) and *Daphnia* biomass (bottom) in some British Columbia lakes.

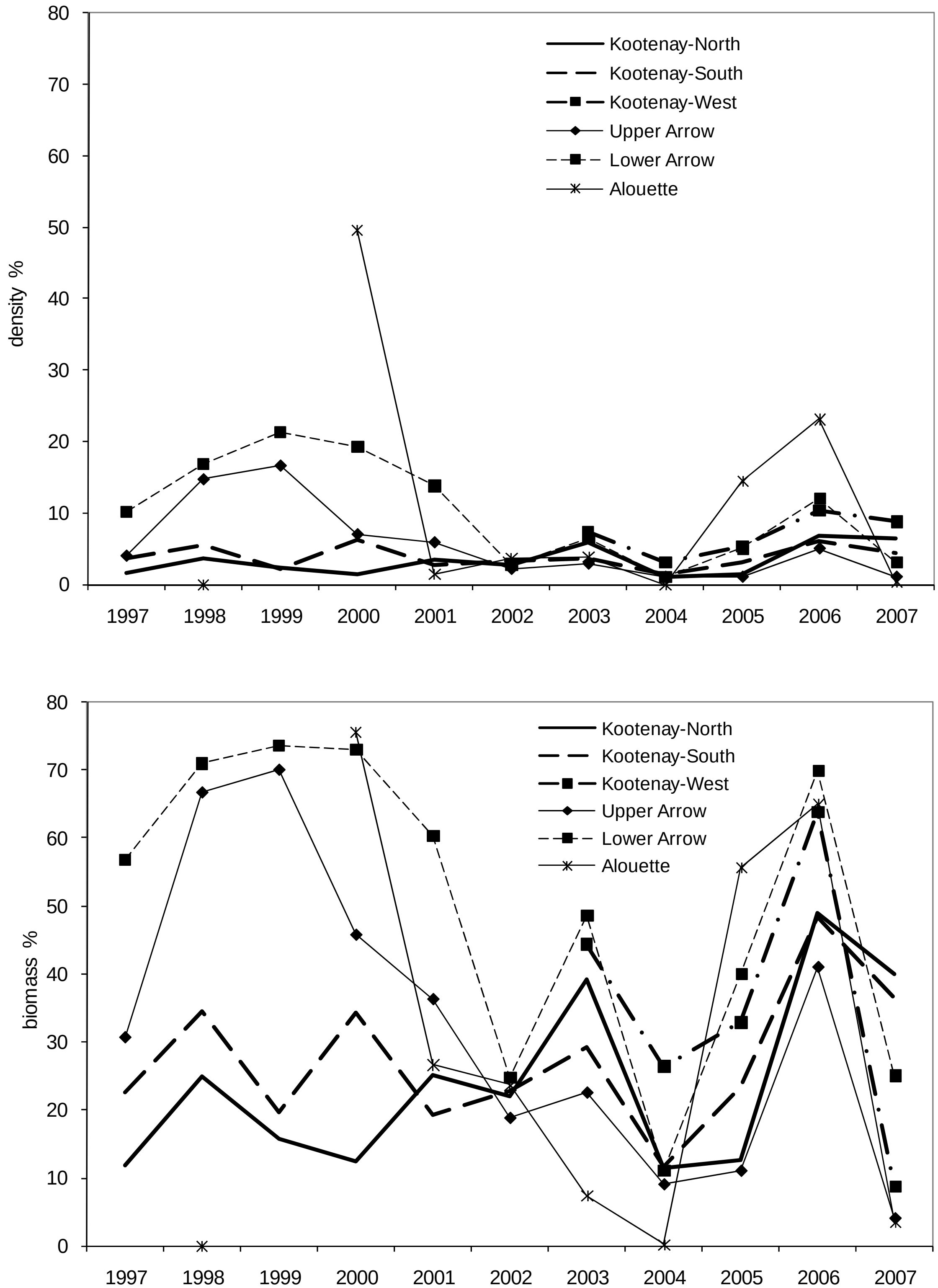


Figure 6.20. *Daphnia* density (top) and biomass (bottom) as a percentage of total zooplankton density and biomass in some British Columbia lakes.

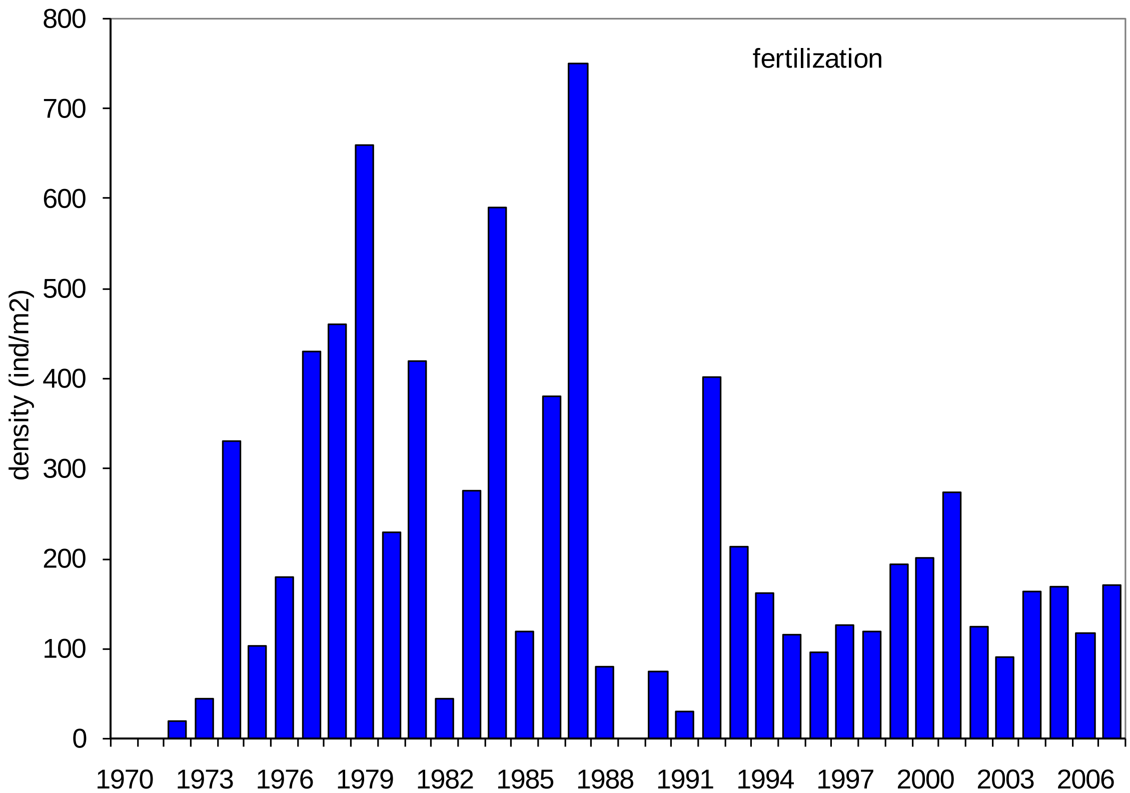
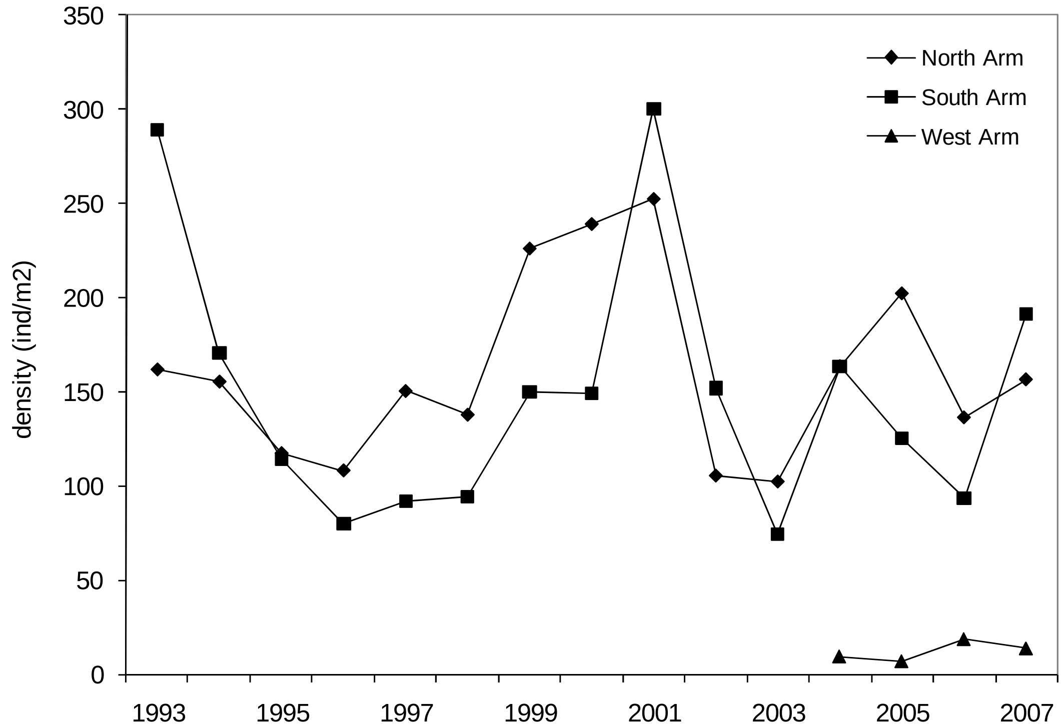


Figure 6.21. Annual average density of *M. Relicta* in Kootenay Lake, 1972 – 2007.



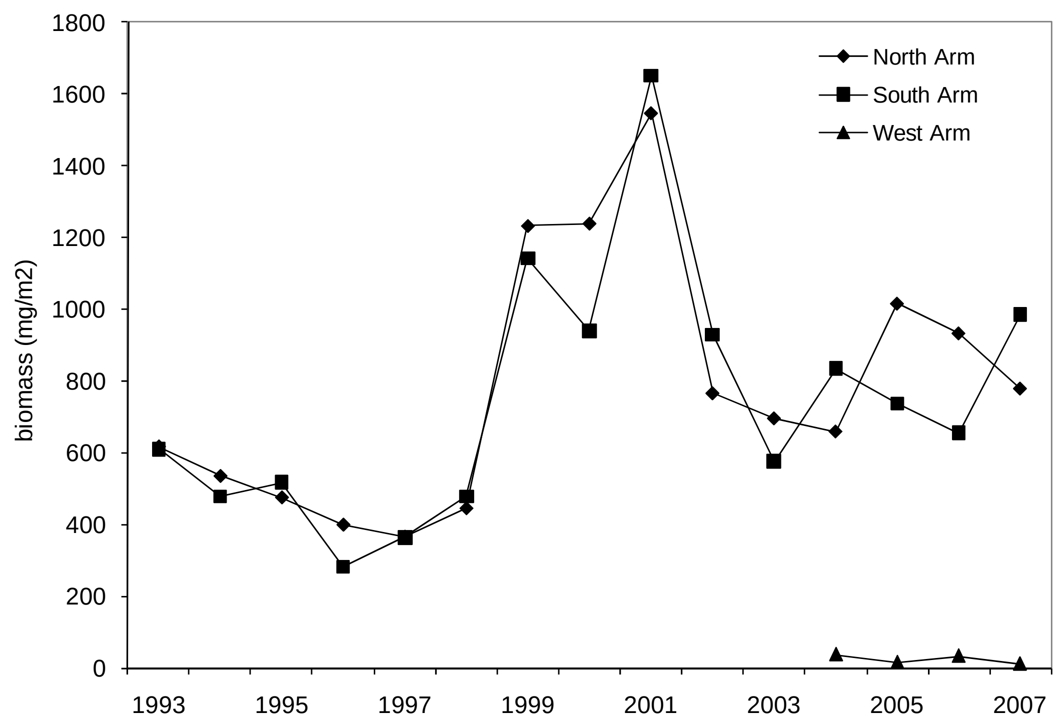
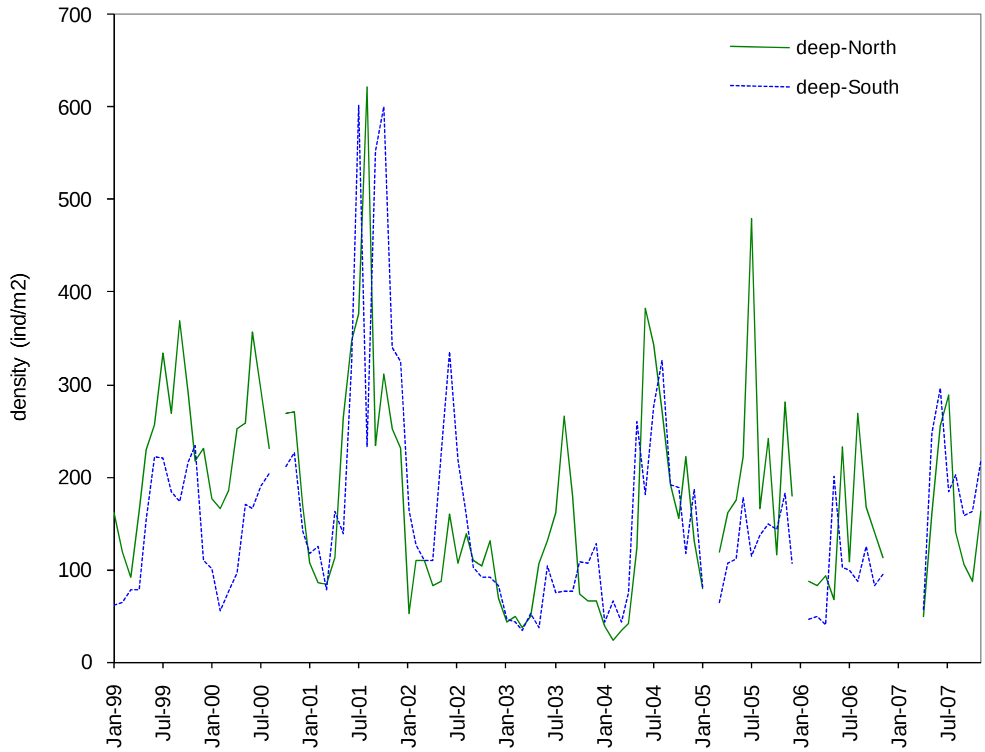


Figure 6.22 Annual average density (top) and biomass (bottom) of *M. Relicta* in the North and South Arm, 1993 – 2007 and the West Arm, 2003 – 2007 of Kootenay Lake.



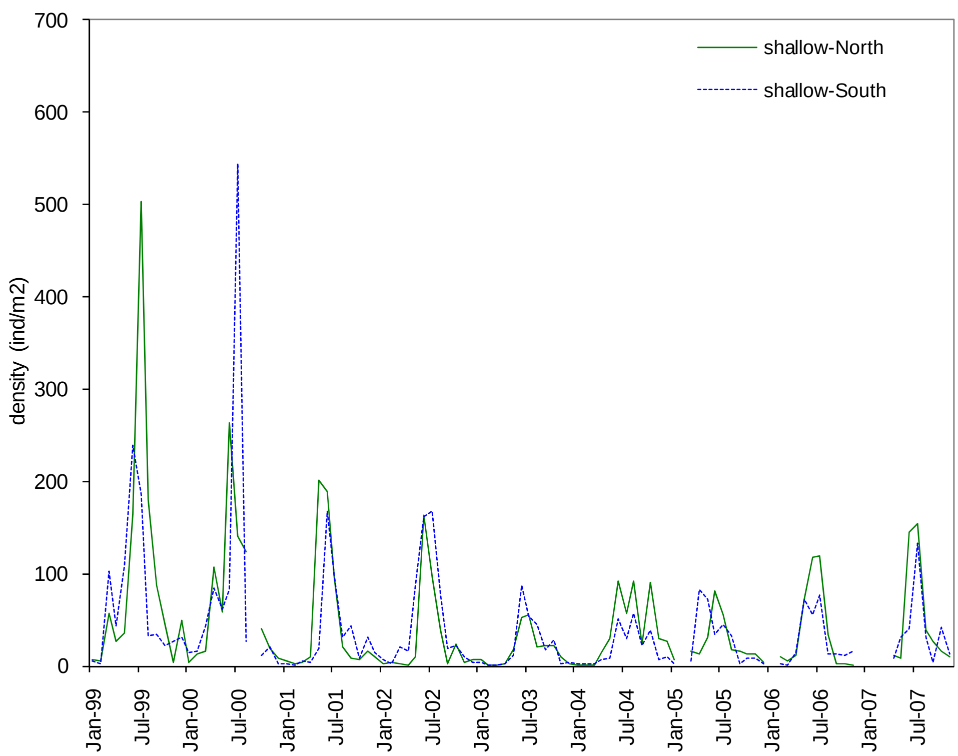


Figure 6.23. Seasonal average density of *M. Relicta* at pelagic and near-shore stations in Kootenay Lake, 1999 - 2007.

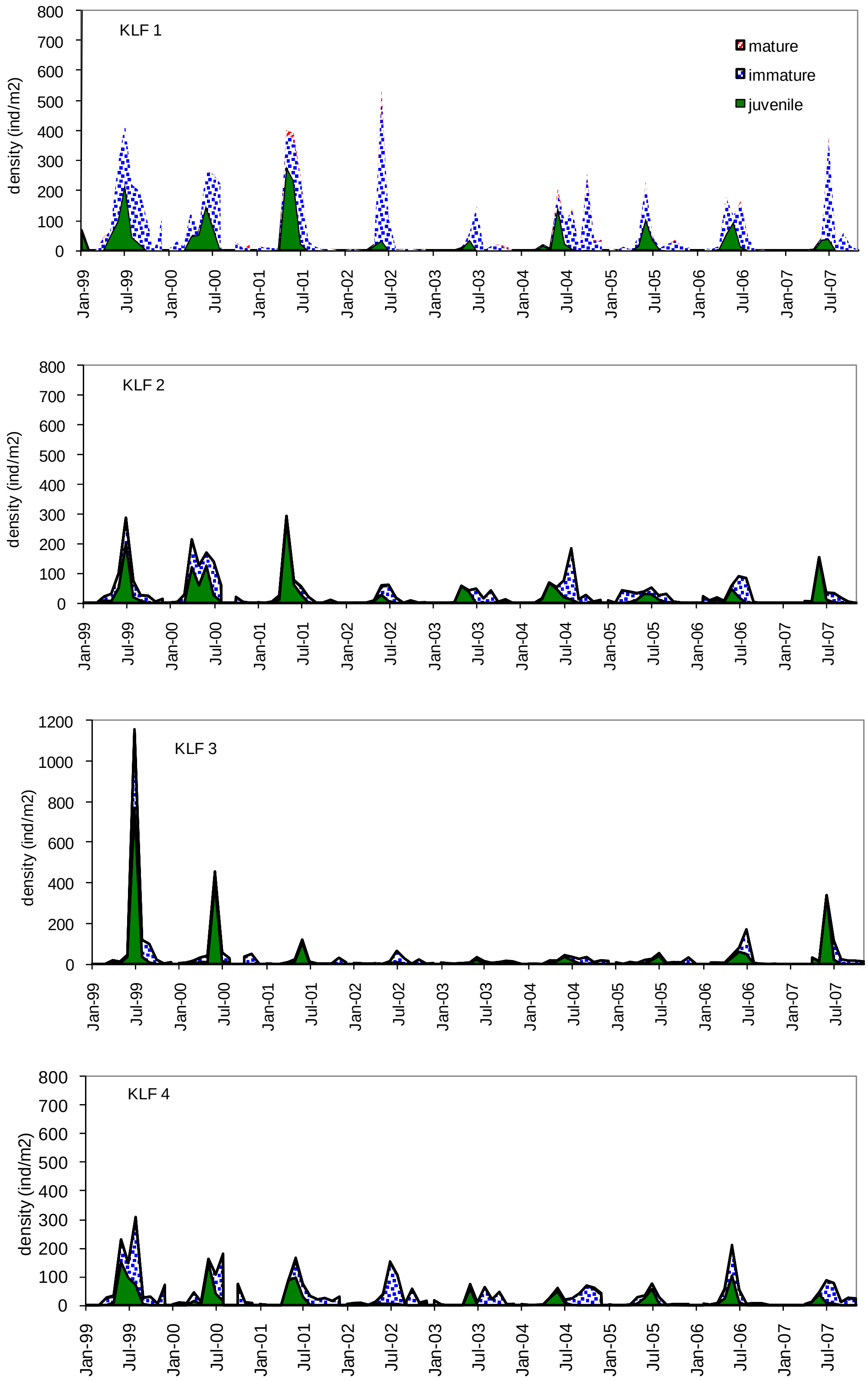


Figure 6.24. Density of developmental stages of *M. Relicta* at shallow sites in the North Arm of Kootenay Lake, 1999 – 2007.

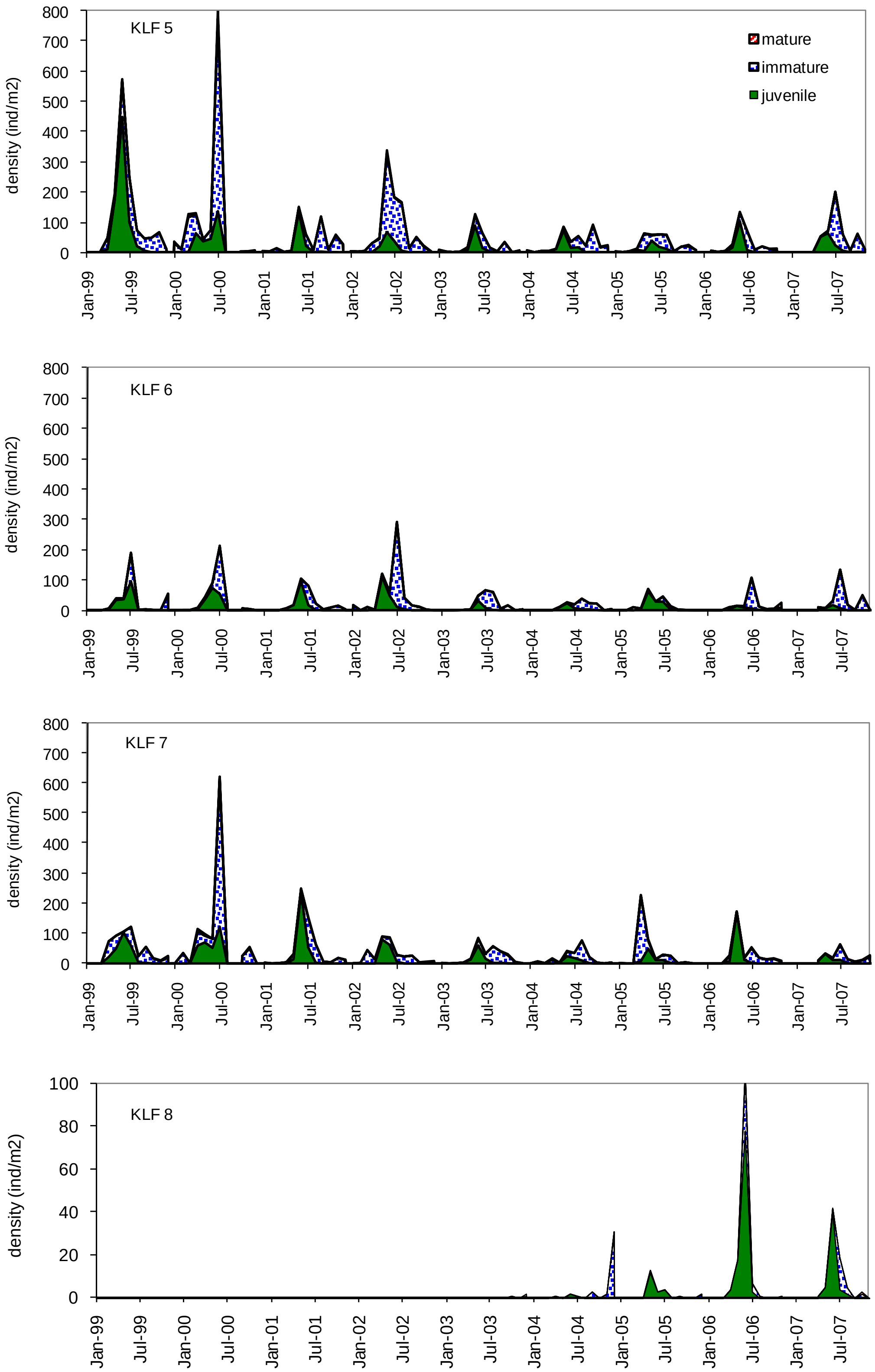


Figure 6.25. Density of developmental stages of *M. Relicta* at shallow sites in the South Arm 1999 – 2007 and the West Arm, 2003 – 2007.

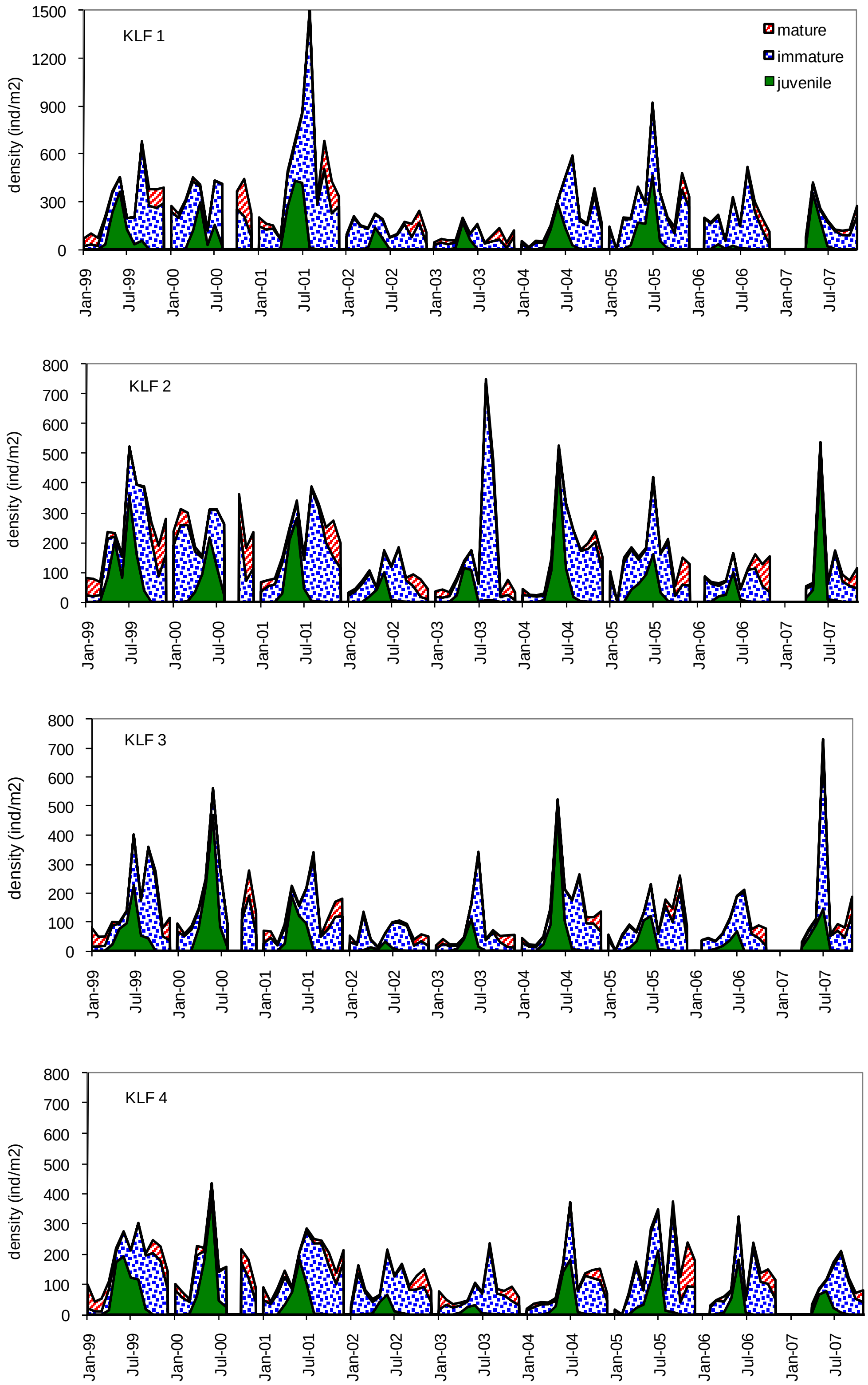


Figure 6.26. Density of developmental stages of *M. Relicta* at deep sites in the North Arm of Kootenay Lake, 1999 – 2007.

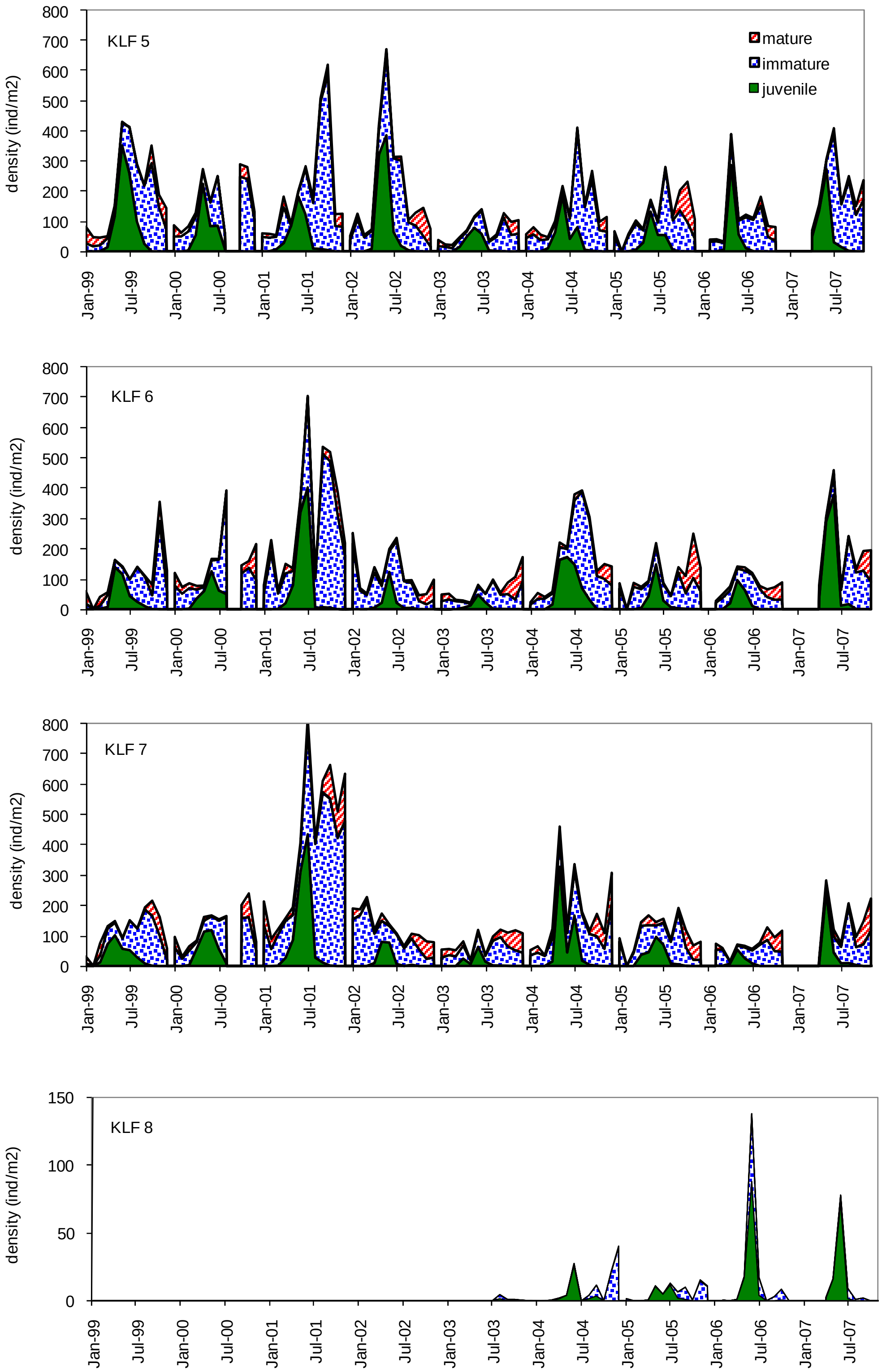


Figure 6.27. Density of developmental stages of *M. Relicta* at deep sites in the South Arm 1999 – 2007 and the West Arm, 2003 – 2007. Note: scale is different for the West Arm station KLF 8.

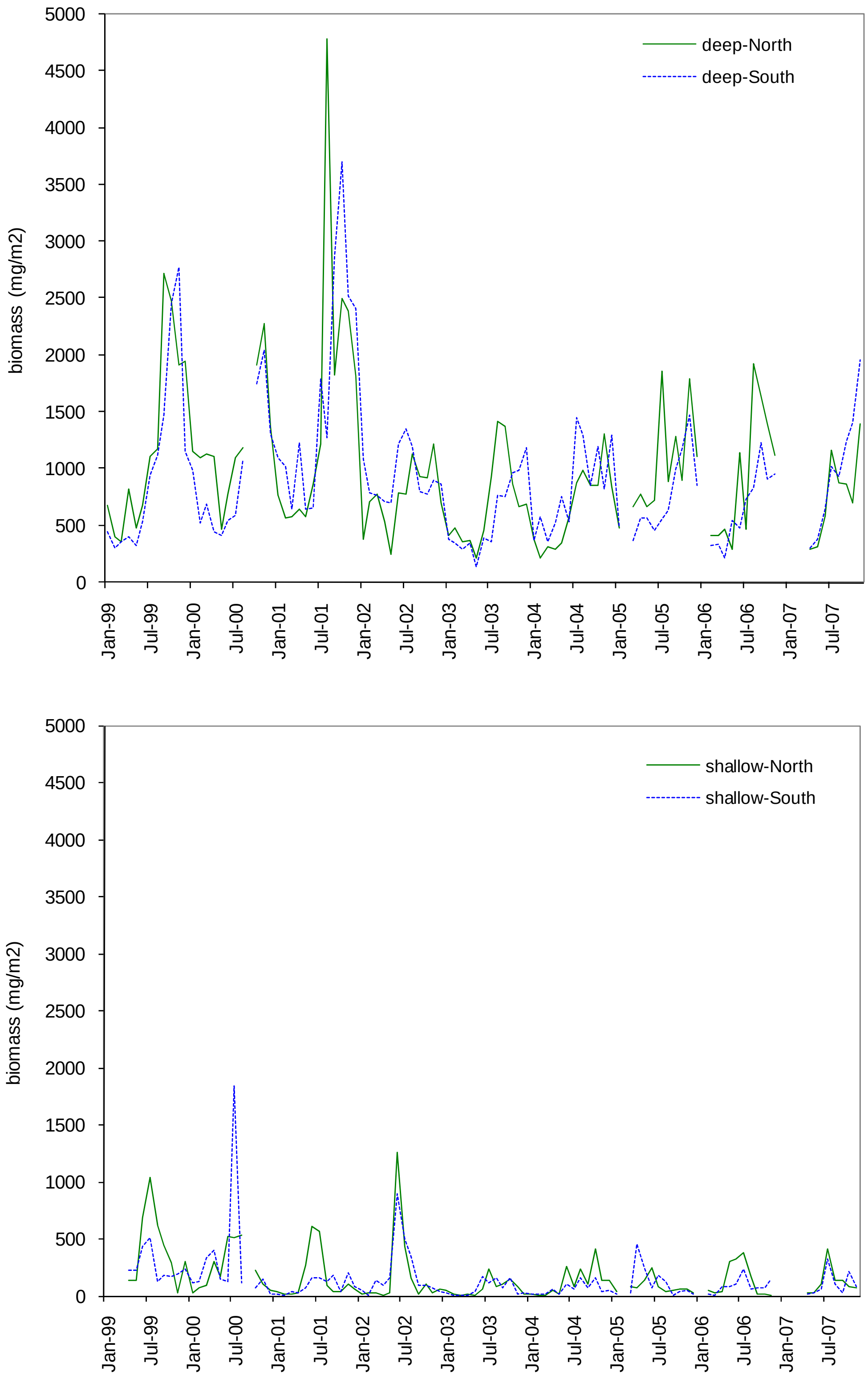


Figure 6.28. Seasonal average biomass of *M. Relicta* at pelagic and near-shore stations in Kootenay Lake, 1999 – 2007.

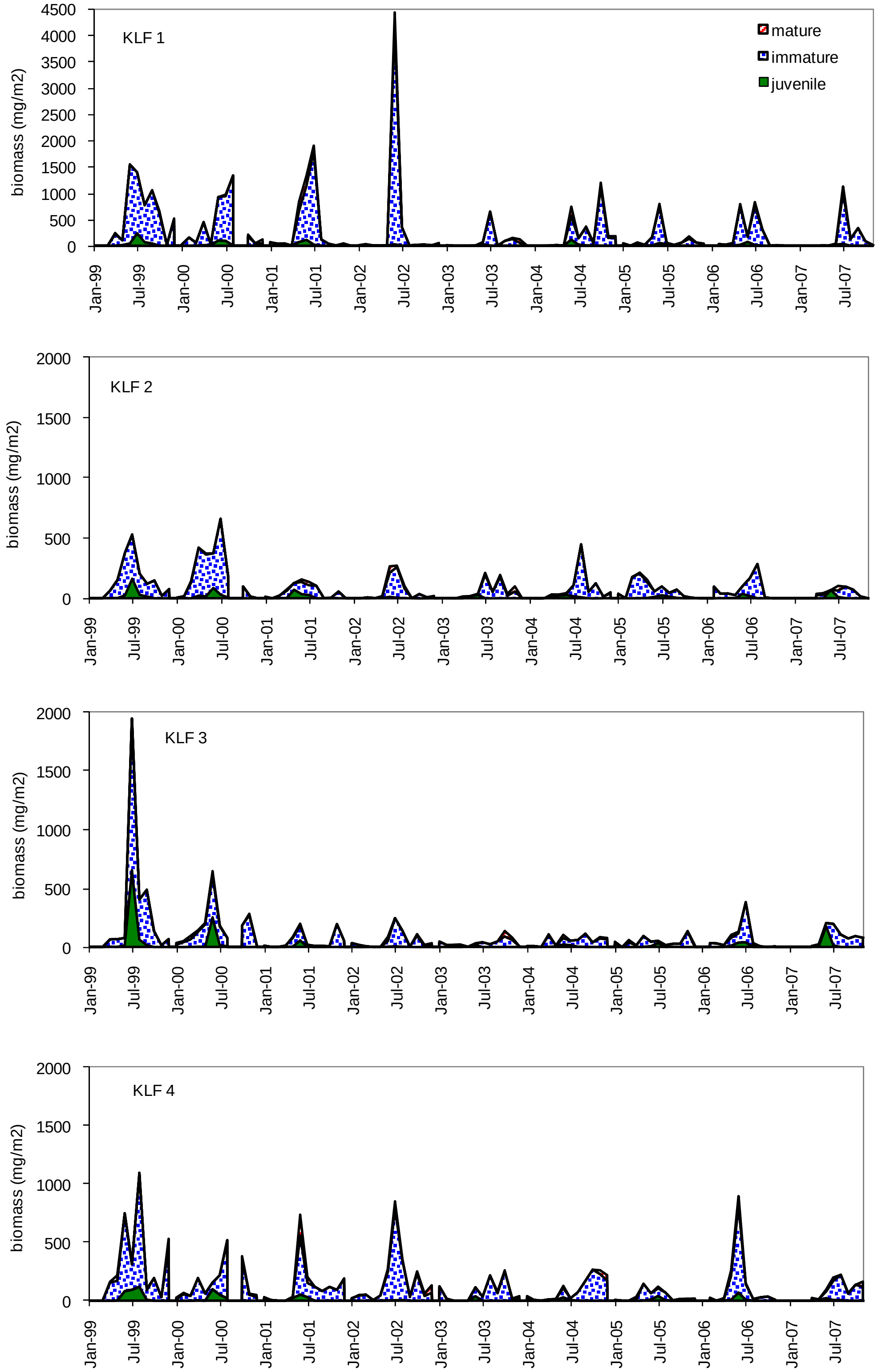


Figure 6.29. Biomass of developmental stages of *M. Relicta* at shallow sites in the North Arm of Kootenay Lake, 1999 -2007.

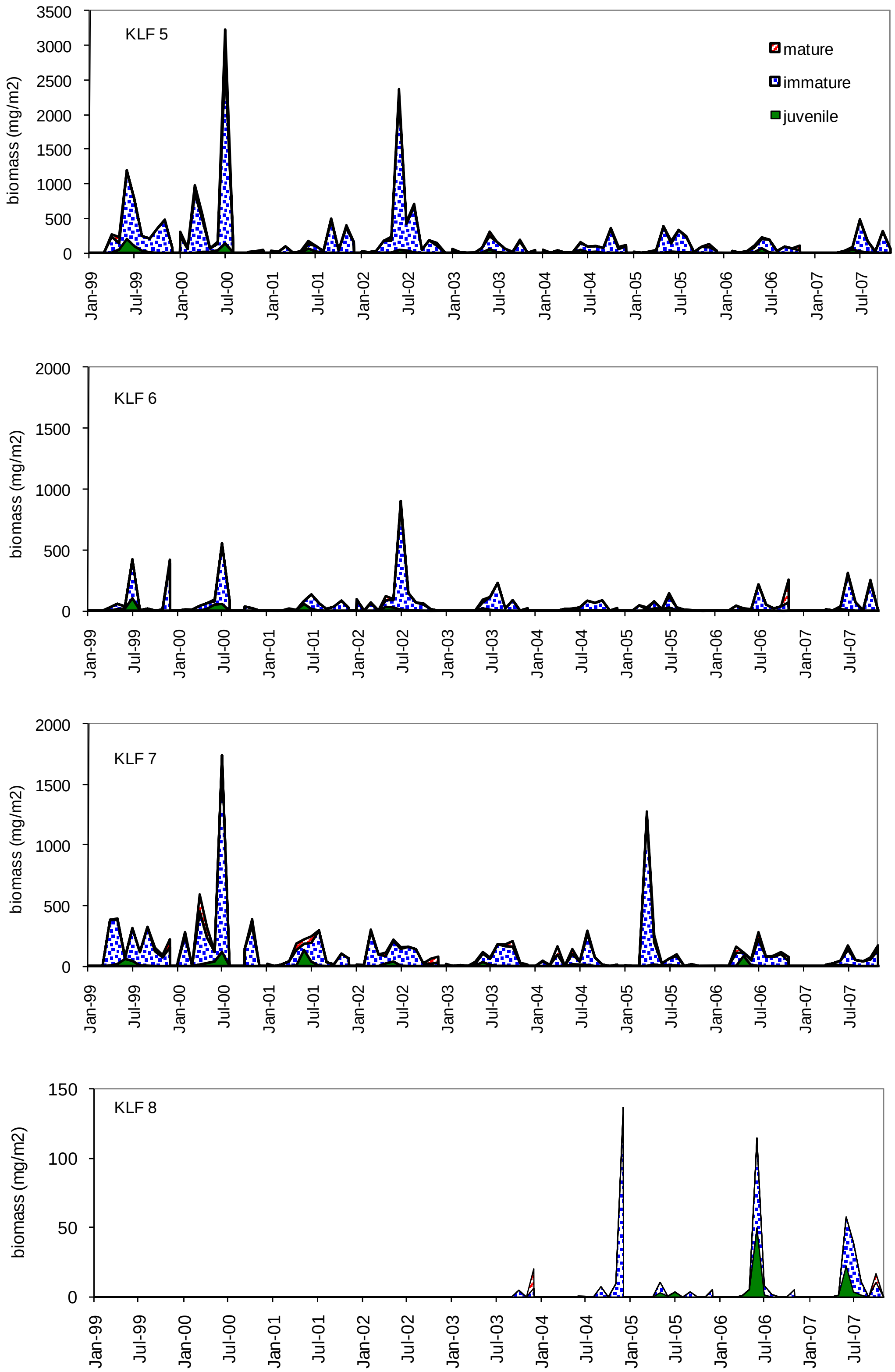


Figure 6.30. Biomass of developmental stages of *M. Relicta* at shallow sites in the South Arm, 1999 -2007 and West Arm of Kootenay Lake, 2003 – 2007.

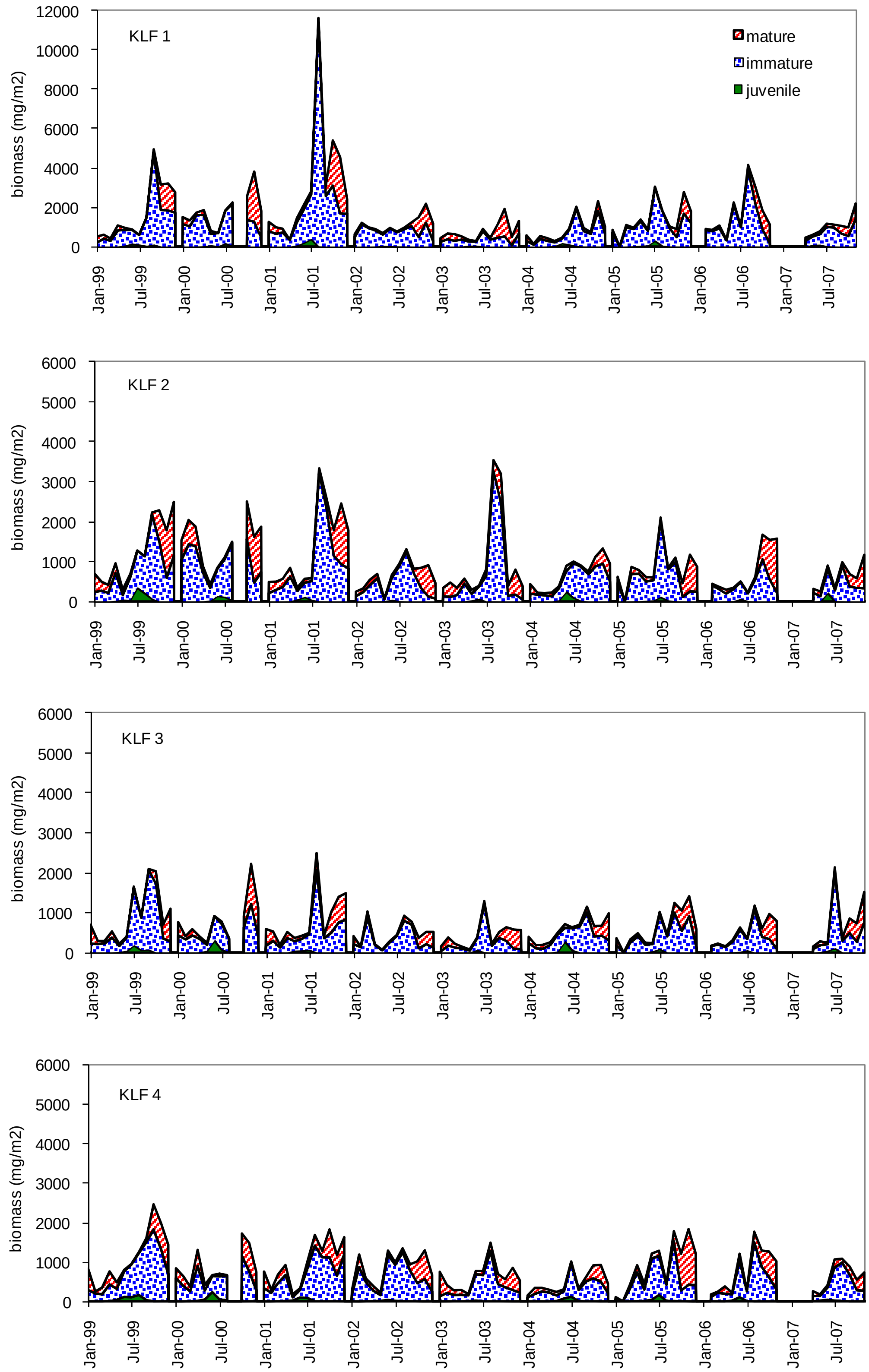


Figure 6.31. Biomass of developmental stages of *M. Relicta* at deep sites in the North Arm of Kootenay Lake, 1999 -2007.

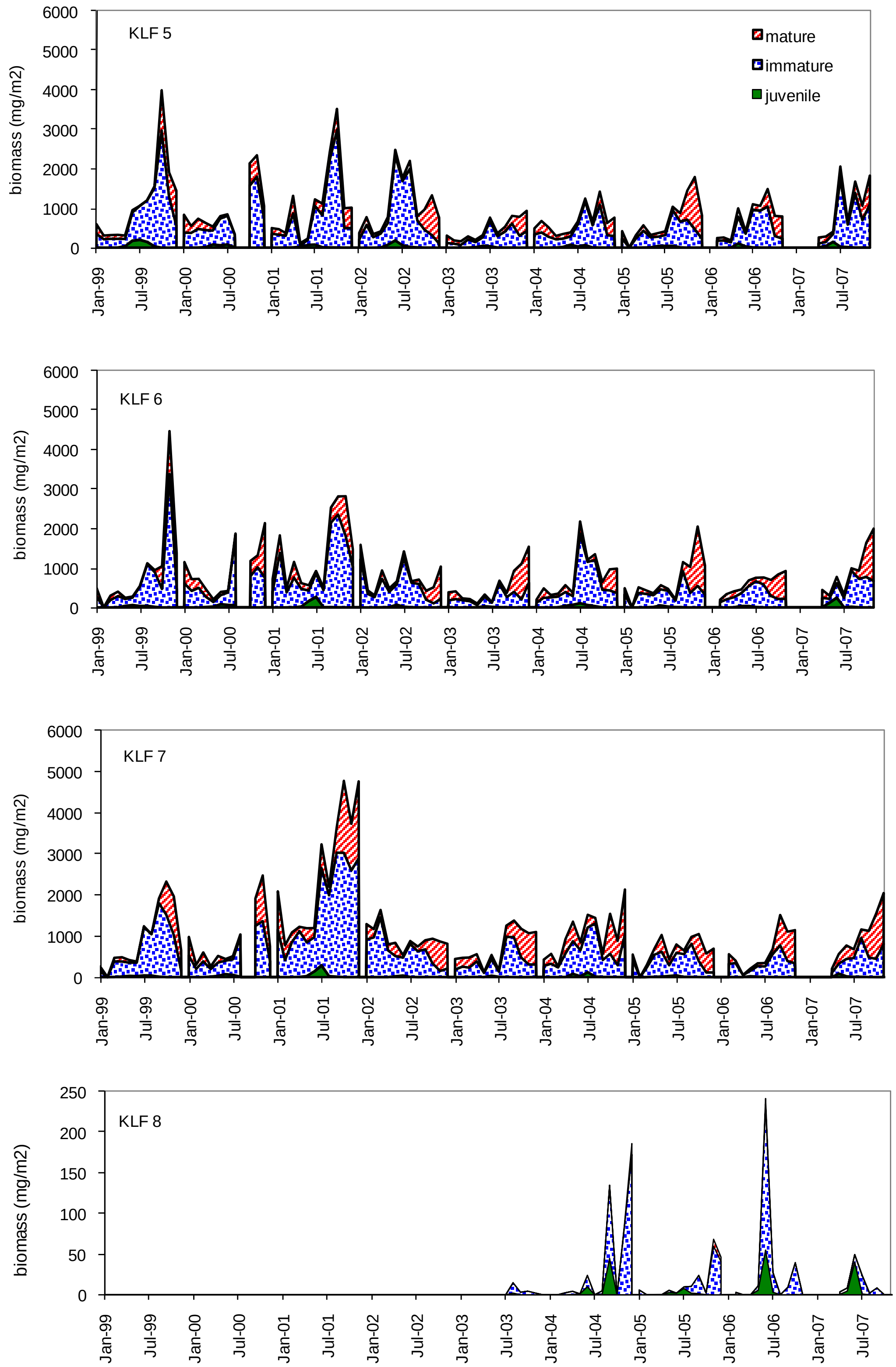


Figure 6.32. Biomass of developmental stages of *M. Relicta* at deep sites in the South Arm, 1999 -2007 and West Arm of Kootenay Lake, 2003 – 2007.

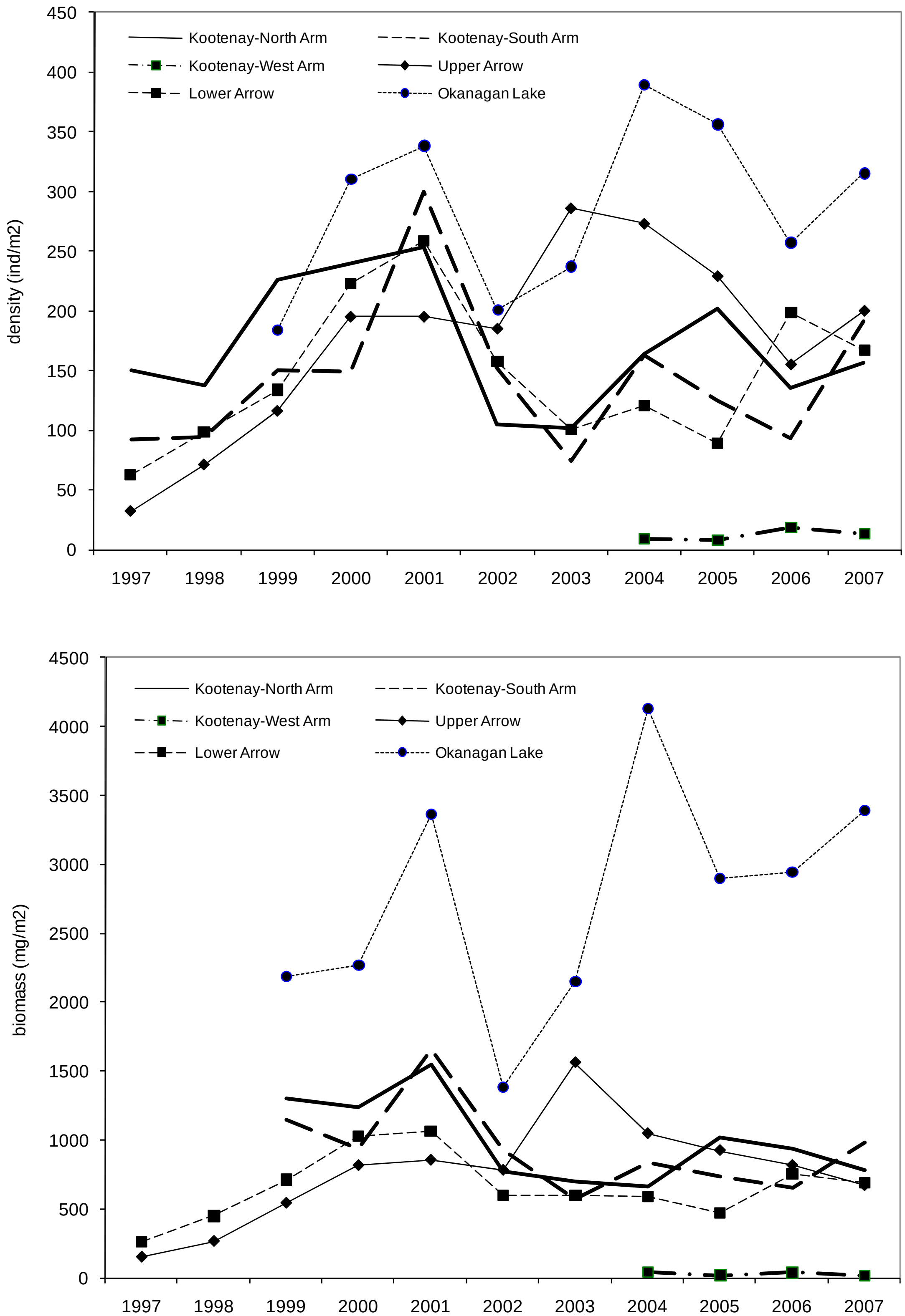


Figure 6.33. Annual average density (top) and biomass (bottom) of *M. Relicta* in some British Columbia lakes.

CHAPTER 7

RESPONSE OF KOKANEE TO NUTRIENT ADDITIONS IN THE NORTH ARM OF KOOTENAY LAKE IN 2007

by

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Introduction and Background

Experimental fertilization of a portion of the North Arm of Kootenay Lake has been undertaken for sixteen years with the most recent results reported by Schindler et al. (2009a). (Note: the project is presently described as nutrient restoration, therefore, the terms fertilization and nutrient restoration be used interchangeably in this report) This work began as a result of a severe decline in Kootenay Lake's productivity during the 1980s due to a combination of nutrient retention in newly formed upstream reservoirs and cessation of a major discharge of phosphorous from a phosphate fertilizer plant (Daley et al. 1981; Ashley et al. 1997). By the early 1990s the main lake kokanee population had decreased to the lowest levels recorded in over four decades and the primary reason(s) have been attributed to nutrient impoverishment combined with possible increased competition for food between mysids and kokanee (Ashley et al. 1997). In response to the dramatic kokanee decline an ambitious experiment to fertilize a small portion of the North Arm was initiated in 1992. The primary objective of the experiment was to restore the nutrient balance that had been changed as a result of the two upstream reservoirs (Binsted and Ashley; Ashley et al. *in:* Murphy and Munawar 1999).

Changes to Kootenay Lakes' ecology have been dramatic during the last century. Aside from the impacts of the upstream reservoirs other human developments have also played some part in change to this system. Turn of the century mining and logging impacted important spawning streams, an exotic species *Mysis relicta* was introduced in 1949, while in more recent times linear developments such as power lines, highways and residential homes have added further pressures. There are also examples of over fishing that has had an effect on some sport fish species (Martin 1984). Collectively these impacts caused major changes to sport fish populations that have been well documented in a series of publications (Northcote 1973; Daley et al. 1981; Ashley et al. 1997; Wright et al. 2002; Andrusak et al. 2006, Schindler et al. 2007, 2009).

Fisheries research on Kootenay Lake dates back to the early 1950s with a great deal of the work 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 the lake has been studied in some detail and the status of North Arm kokanee was well documented long before lake fertilization began. There has been a comprehensive monitoring program measuring trophic level responses to lake fertilization since 1992 (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, 2009). The North Arm kokanee population has responded to lake fertilization and the numbers recovered to near historical levels by 1996 (Ashley et al. 1999).

The top predators in Kootenay Lake that include rainbow trout, bull trout, sturgeon, and burbot are highly dependent on kokanee (*Oncorhynchus nerka*) as their primary source of food. It follows then that these piscivores should thrive if kokanee abundance is sustained at a very highly level. The relative abundance of kokanee in Kootenay Lake has been tracked since the early 1960s, likely making them the most studied kokanee population in British Columbia. Meadow Creek and the Lardeau River are the key spawning systems and their escapement estimates are used as an index of abundance for the main lake population. In the mid-1960s, a kokanee spawning channel (initially designed for a capacity of 0.25 million spawners) was constructed on Meadow Creek as partial compensation for kokanee losses incurred due to construction of the Duncan Dam (Redfish Consulting Ltd. 1999). This channel commenced operation in 1967 and escapements and subsequent fry production estimates have been made annually since thus providing excellent time series data that can be used to track the major ecological changes that have taken place in Kootenay Lake.

Kootenay Lake was considered to be nearly mesotrophic in the 1950s and 1960s due to unregulated input of phosphorus into the Kootenay River (Northcote 1973). At that time, North Arm total escapement levels were high (1–3 million) as documented by Bull (1965) and Acara (1970). Meadow Creek spawner numbers were <350,000 in 1964, the only year kokanee were enumerated before the Duncan Dam became operational. Meadow Creek spawning channel production began in 1967, and escapement levels gradually increased over two cycles until the late 1970s when escapements exceeded 1 million. By the mid 1970s two changes took place that dramatically impacted lake productivity. First, fertilizer loading to the lake declined with closure of Cominco's upstream fertilizer plant and secondly, Libby Dam became operational. While there were concerns about the impact of this dam on Kootenay Lake, the combined impact of reduced P loadings and nutrient retention in Koocanusa Reservoir was largely unforeseen. Daley et al. (1981) documented these changes, which resulted in a significant decline in lake productivity by 1980. Nutrient input to the lake declined <u>below</u> pre-dam conditions, and it underwent a gradual reduction in productivity through to the early 1990s. Lagging slightly behind decreased productivity was a decline in kokanee numbers.

Main lake kokanee numbers began to decline in the mid-1980s (Andrusak 1987; Ashley et al. 1997). By the late 1980s there were virtually no South Arm kokanee while North Arm stock escapements had decreased from a range of 0.5–4.1 million during the 1960s and 1970s to 0.3–0.5 million in the late 1980s and early 1990s (Ashley et al. 1999; Andrusak and Fleck 2007). This decline led researchers to consider a means of reversing this trend especially since the highly valued Gerrard rainbow trout are dependent upon kokanee as their primary food source (Andrusak and Parkinson 1984).

In 1990, a series of meetings was conducted amongst fisheries researchers and managers to consider options for reversing the downward trend. Korman et al. (1990) described various alternatives that were contemplated. Walters et al. (1991) developed a fertilization response model to determine what could possibly happen if a portion of the lake was fertilized to pre-impoundment and pre-cultural enrichment levels. The model predicted that fertilization was unlikely to be successful, because it was believed that the introduced *Mysis relicta* would respond more rapidly to increased food supply and out-compete the kokanee. Despite the models prediction, Provincial fisheries managers, faced with declining kokanee numbers and no other options, decided to proceed with a high risk a five-year experiment to fertilize a portion of the North Arm of the lake commencing in 1992.

The experiments' primary objective was to restore the nutrient level 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, comparable to escapement levels in the 1960s and 1970s (Ashley et al. 1999). As part of the experiment, there was a deliberate reduction in fertilizer loading from 1997–1999 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. 2009) and this prompted fisheries managers to increase the loading rate commencing in 2000.

Results of the Kootenay Lake 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). A parallel program of nutrient addition to the nearby Upper Arrow Reservoir began in 1999 (Pieters et al. 2000, 2003, Schindler et al. 2009b) and provides the opportunity for some comparisons between these two large experimental programs.

This report documents the results of the North Arm kokanee response to 16 years (1992–2007) of consecutive nutrient addition, with emphasis on kokanee responses to different nutrient loadings. The specific objectives of this report are:

1. to summarize and analyze 2007 kokanee trawl and hydroacoustic data;
2. to summarize and interpret 2007 North and South Arm kokanee escapement data;
3. to demonstrate the apparent response of kokanee to various levels of experimental nutrient additions since 1992.

Methods

North Arm 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.

Trawl and Hydroacoustic Sampling

Trawl

There was no trawling conducted in 2007 owing to a major equipment failure that occurred just before the annual fall survey. Since 1985 the survey design and sampling techniques have been carried out each fall during the new moon period on Kootenay Lake using consistent methods (Schindler et al. 2009a). Stepped-oblique trawls were done to ensure a representative sample of fish was attained from each depth strata where fish were observed on the echosounder. The net was fished for 8 minutes at each consecutive 5-m depth layer, covering fish from 20–40-m depth. 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 were adjusted to an October 1 standard using empirical growth data from Rieman and Myers (1992) in Appendix 7.1.

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. In the absence of trawl data in 2007, the species composition in the night time layer was assumed to be almost exclusively kokanee as in previous years. For estimating biomass, the age structure was assumed to be similar to the previous two years, since the acoustic data indicated a similar proportion of fry to larger fish. Mean weight at age was assumed to be similar to 2006.

Hydroacoustics

A complete nighttime survey of the limnetic habitat in Kootenay Lake was conducted during the new moon phase in September 2007. 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). Surveys were conducted using a Simrad model EY200P operating at 70 kHz. 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 1–2 pings/s while cruising at 2 m/s. The data were converted to digital format and both stored on a PC computer and backed up on Sony digital audio tape (DAT). Navigation was by radar, GPS, and a 1:75,000 Canadian Hydrographics bathymetric chart. The Simrad system was calibrated in the field at the beginning of the survey. Field calibrations were conducted by collecting target strength data from a copper sphere suspended in the centre of the echosounder beam, 20 m from the transducer. The received signal level was adjusted to a level of –39.1 decibels (dB), which corresponds to the empirical strength of the sphere at 70 kHz. Echosounder specifications and field settings are presented in Appendix 7.2 and acoustic size classes and fork length equivalents in Appendix 7.3.

The Simrad survey data were digitized and then analyzed using the Hydroacoustic Data Acquisition System (HADAS) program, version 3.98, by Lindem (1991). The HADAS statistical analysis performed a function similar to manual counting to determine the number of targets per unit area by depth stratum. Habitat was stratified by 5-m depth layers and then further stratified into relatively homogeneous zones. Regression through origin of echo counts on areas sampled produced mean density and standard error values for each zone and depth stratum. A Monte Carlo Simulation procedure was used to combine all strata and develop maximum likelihood estimates and statistical bounds for each zone and for the combined zones using 30,000 iterations per run. Average fish densities by transect are shown in Appendix 7.4, and maximum likelihood population estimates and bounds are presented in Appendix 7.5. Fish size distribution was also estimated using a statistical de-convolution based on Craig and Forbes (1969). The resulting acoustic size distribution was used to proportion the fish population into two size classes representing age 0 fish and ages 1–3 fish, respectively.

Kokanee Biomass

Biomass estimates for pelagic habitat were determined from acoustic abundance proportioned into age groups based on both trawl and acoustic surveys (Appendix 7.6). In the absence of trawling in 2007, mean weights at age from the 2006 trawl data were applied to the total estimated numbers of fish at each age to determine total biomass in the reservoir. 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/ha).

Results

2007 Kokanee Escapements

Since fertilization began in 1992, spawner returns can be characterized as having two peaks and two troughs. Record high numbers through the late 1990s were followed by three years (2000-2002) of comparatively low (<400,000) numbers. From 2003-2005 there were three consecutive years when escapements were ~ 1 million. During the last two years spawner numbers declined dramatically to slightly less than 400,000, similar to the level of returns from 2000-2002 (Fig. 7.1). The 2007 spawner numbers in Meadow Creek were only about one half their parental numbers in 2003. A peak count of 147,000 for the Lardeau River in 2007 however was only slightly lower than the 2003 estimate of

~200,000 (Fig. 7.2). Lardeau River escapements remain comparatively low and the amplitude of peak counts has not increased as dramatically as observed at Meadow Creek.

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=39 years), falling within a narrow size range from 20.0–27.0 cm with the mean size of females (22.2 cm) slightly smaller than of males (22.5 cm). Thus it was an unusual spawning run in 2007 with the largest size fish recorded in four decades (Fig. 7.3). The mean size of females in 2007 was 27.7 cm while mean size of males was 28.2 cm; mean spawner size in 2006 was also quite high followed by even larger size fish in 2007. The exceptional growth of 2007 spawners is most likely a growth response resulting from a relatively weak cohort that can be tracked through from fry in 2004 to spawners in 2007 (Fig. 7.9; Appendix 7.6c). Previously the largest spawner size in 2001 was also preceded by two years of relatively low age 1-3 kokanee numbers (eg <5 Million) in the lake. The large mean size of the females in 2007 was reflected in fecundity that was the highest yet recorded at 411 eggs/female, much higher than the long term average of 262 eggs per female (Fig. 7.3).

Meadow Creek Kokanee Fry Production

Fry production from the spawning channel in the spring 2007 was estimated to be 15.94 million slightly lower than the 2006 estimate but similar to most years in the 2000s except for 2005 when ~25 million were produced (Fig. 7.4). Since the inception of lake fertilization fry production has increased substantially with all but three years exceeding 15 million (Fig. 7.4). During the 1980s the total numbers seldom exceeded 7 million (Fig. 7.4). 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. 7.1). 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 levels for fry has not been reached in Meadow Creek Spawning Channel. 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

Although no trawl data was obtained in 2007 it is instructive to take account of 2005 and 2006 data that includes cohorts that would have been represented in a 2007 trawl sample. Firstly, all trawl data over the period of sampling have been dominated (99.6%) by kokanee so it can be assumed that this was also the case in 2007 (Table 7.1). In recent years the majority of kokanee have been captured in the nutrient addition zone at the north end of the lake. In 2006 the majority (96.5%) of the 754 kokanee caught were age 0+, with 2.8% age 1+, 0.7% age 2+ with no age 3+ fish captured (Table 7.2). Most age 3+ fish were already in the spawning streams at the time of the survey. The low numbers of age 2+ fish caught in 2006 trawl sampling would suggest that age 3+ spawner numbers in 2007 would likely be low. Ageing of the 2007 spawners is discussed below.

Table 7.1. Species composition from standard trawl surveys in Kootenay Lake during 1985-2006.

Year	Month	No. of Trawls	Number Caught by Species						Percent Kokanee (%)
			Kokanee	Peamouth Chub	Sucker	Whitefish	Rainbow trout	Bull trout	
1985	10	11	234	0	0	0	0	0	100.0
1986	10	17	541	0	0	0	0	0	100.0
1987	10	20	293	0	0	0	0	0	100.0
1988	10	21	212	0	0	0	0	0	100.0
1989	9	24	258	0	0	0	0	0	100.0
1990	10	24	269	0	0	0	0	0	100.0
1991	10	24	241	0	0	0	0	0	100.0
1992	9	27	939	0	0	0	0	0	100.0
1993	9	25	1064	0	0	1[3]	0	0	99.9
1994	10	25	1366	0	0	0	0	0	100.0
1995	9	30	2198	0	3[1]	0	0	1	99.8
1996	9	29	1947	0	1[1]	0	0	0	99.9
1997	9	18	676	1	0	2[3]	1	0	99.4
1998	9	18	689	0	0	0	0	0	100.0
1999	9	18	377	0	0	0	0	0	100.0
2000	9	18	614	0	0	1[3]	0	0	99.8
2001	9	18	692	0	0	0	1	0	99.9
2002	9	21	667	0	1[2]	0	0	0	99.9
2003	10	21	903	0	0	1[4]	0	0	99.9
2004	9	20	827	0	0	0	1	0	99.9
2005	9	19	250	0	0	1[4]	1	0	99.2
2006	9	17	754	0	0	0	1	2	99.6
2007	N/A								

[1] White sucker (*Catostomus commersoni*) [2] Longnose sucker (*Catostomus catostomus*)
[3] Lake whitefish (*Coregonus clupeaformis*) [4] Pygmy whitefish (*Prosopium coulteri*)

Table 7.2. Summary of kokanee trawl catches by age for Kootenay Lake 1985-2006.

Survey Year	Survey Period	No. of stations	No. of trawls	Number of kokanee caught				
				age 0	Age 1	age 2	age 3	All ages
1985	Oct 8	3	11	117	43	65	9	234
1986	Oct 7	3	17	465	26	41	9	541
1987	Oct 20	4	20	160	83	49	1	293
1988	Oct 4-7	4	21	113	56	43	0	212
1989	Sep 26-29	4	24	179	33	41	5	258
1990	Oct 16-18	4	24	210	32	21	6	269
1991	Oct 1-4	4	24	193	24	20	4	241
1992	Sep 21-26	6	27	794	43	100	2	939
1993	Sep 10-22	7	25	922	82	31	29	1064
1994	Oct 3-6	4	25	1191	115	59	1	1366
1995	Sep 24-27	6	30	1537	572	88	1	2198
1996	Sep 9-13	5	29	964	494	476	13	1947
1997	Aug 31-Sep 3	6	18	313	177	178	8	676
1998	Sep 17-21	6	18	348	71	253	17	689
1999	Sep 9-15	6	18	346	14	17	0	377
2000	Sep 25-29	6	18	599	5	10	0	614
2001	Sep 17-20	6	18	675	33	5	0	713
2002	Sep 11-14	7	21	595	67	4	1	667
2003	Oct 21-26	7	21	824	44	35	0	903
2004	Sep 15-18	7	20	699	69	52	7	827
2005	Sep 1-4	7	19	202	24	21	3	250
2006	Sep 19-26	6	17	728	22	4	0	754
2007	Not done	0	0					
	Total			**12,174**	**2128**	**1614**	**116**	**16,032**

Size and length-at-age

Age determination for the main lake population of Kootenay Lake kokanee has relied on length frequency supported by scale analyses for trawl caught fish and on length frequency supported by otoliths for Meadow Creek spawners. Trawling was not done in 2007, however, the 2005 and 2006 trawl length frequency plots provide useful length-at-age information for tracking growth through to spawning in 2007. Trawl length frequency shows three modes corresponding to age 0+, 1+ and 2+ fish, respectively (Fig. 7.6). Shifts in length-at-age for both 1+ and 2+ age groups are evident between 2005 and 2006 and can be followed through to increasing spawner size in 2006 and 2007. The mean length-at-age in 2006 was 58mm for age 0+, 128mm for age 1+ and 221mm for age 2+ fish, compared with 53, 116 and 199mm for age 0-2+ fish respectively in 2005 (Fig. 7.7). The average spawner size increased from 217mm in 2005 to 249mm in 2006 and 279mm in 2007.

Trawl catches of age 0+ fish in 2006 were higher in the North Arm in the vicinity of the fertilization zone (stations 1-2), age 1+ fish were more evenly distributed and age 2+ fish (although catch was limited) were higher in the South Arm (Table 7.3). It is also of interest to note that mean size of South Arm fish captured in 2006 was larger for all age groups than those captured in the North Arm (Table 7.4). This suggests that nutrient additions in the South Arm may be having a beneficial effect on growth.

Table 7.3. Kokanee catch statistics from the September 2006 trawl surveys.

Survey time	Section	Station	Hauls	Age 0	age 1	age 2	Age 3	total
Sept 2006	North Arm	1 Johnson	2	142	3	0		145
		2 Shutty Bench	2	186	6			192
		4 Woodbury Cr	3	111	4			115
	South Arm	5 Wilson Creek	3	69	4	2		75
		6 Rhinoceros Pt	3	60	2	1		63
		7 Redman Point	3	160	3	1		164
		Both arms		728	22	4		754
		Proportion by age		*97*	*3*	*<1*		

Table 7.4. Size statistics from trawl captured kokanee September 2006.

Survey time	Basin	Station	age 0	age 1	age 2	age 3
Sept 2006	North Arm	Ave. length (mm)	56	126		
		Length range (mm)	40-77	101-158		
		Standard deviation	5.38	21.01		
		Sample size (n)	439	13	0	0
	South Arm	Ave. length (mm)	61	136	233	
		Length range (mm)	47-77	104-154	227-235	
		Standard deviation	7.73	24.60	4.44	
		Sample size (n)	289	9	4	0

Age-at-maturity

Trawl caught kokanee in 2005 and 2006 provide good insight into ages of 2006 and 2007 spawners when the size of spawners the year following trawl samples were plotted on the same graph; i.e. 2006 spawner lengths were plotted with the 2005 trawl data (Fig. 7.6). When spawners are included with trawl data, four size (age) groups typically make up the majority of kokanee in Kootenay Lake. The age 1+ and 2+ fish from the trawl in 2006 would have contributed to the 2007 spawning population as age 2+ and 3+ spawners. Mean size of age 2+ from the 2006 trawl sample were 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%) but ages 2+ (32%) also contributed significantly to the 2007 spawning population. The smaller mode of smaller fish in the 2007 spawner distribution appear to be a significant but smaller contribution of age 2+ spawners in 2007. This analyses would suggest the unimodal distribution of spawners in 2006 were most likely to be age 3+ fish when compared with 2005 trawl data.

For most recent years Meadow Creek spawners have been age 3+ but rapid growth prior to 2007 resulted in some fish maturing a year earlier in 2007. The growth leading up to the 2007 record spawner size was likely due to a combination of low densities of age 1-3+ fish in 2005 and improved growth conditions at the onset of South Arm nutrient additions in 2005-07.

There have been some deviations in the age at maturity of Meadow Creek kokanee spawners mostly related to the impact of lake fertilization. Vernon (1957) initially reported that virtually 100% of North Arm kokanee matured at age 3+. Martin (1984) reaffirmed that most North Arm kokanee spawn at age 3+. However, Thompson (1999) observed a shift in age-at-maturity of Meadow Creek fish from 1993–1996 following initial fertilization. Although Thompson found the dominant age-at-maturity remained age 3+ from 1989–1992, a higher percentage (ranging from 15–42%) of 2+ fish were evident from 1993–1996, as well as a greater contribution of 4+ fish. These results are not surprising given the significant changes to lake productivity that occurred at the time these cohorts were growing in the lake. 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. In 2004 age of Meadow Creek kokanee was re-examined and the majority was determined to be age 3+ (J. Burrows, Senior Fisheries Biologist, Ministry of Environment (MOE), Nelson BC, pers. comm.) At that time a return to a dominant age of 3+ at maturity was likely due to the higher densities (Fig. 7.8) of kokanee and greater competition for food.

In-lake abundance declined during 2004 and 2005 and much higher growth was observed from 2005-2007 (Fig. 7.7a). As a consequence some age 2+ matured early resulting in mixed ages of spawners in 2007. As in-lake abundance is again increasing it is expected that age-at-maturity will once again be predominately age 3+ in 2008.

Hydroacoustic Abundance Estimates

Acoustic surveys provide key data to the nutrient addition monitoring program on Kootenay Lake. There is a wealth of information on kokanee as a result of long term hydroacoustic surveys that provide considerable insight into changes that have taken place before and after lake enrichment. Nighttime surveys of the limnetic zone of the main lake have been conducted in a standardized manner since 1991. As well, comparable manual echo counts date back to 1985. Initial surveys in the late 1980s and early 1990s, indicated total numbers of ~6-13 million (Fig. 7.8). 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. 7.3). 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. 7.4] which led to increased numbers of ages 1–3+ fish after two years (i.e., 1996–1998) (Fig. 7.9). 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.7.3, 7.4, 7.9). Reduced numbers of fry during 1997–2000 was 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. 7.3, 7.9).

Total abundance increased substantially from 2001–2003 ranging from 25–35 million (Fig. 7.8). These increases were most likely due to the combined result of increased fry production (Fig. 7.3) and improved rearing conditions from increased nutrient additions that began in 2001. During 2004 and 2005 estimated numbers decreased to ~ 16 million followed by increases in 2006 and 2007 to ~22 million. The 2006 and 2007 estimates represent sizeable increases in fry compared to 2004-2005 and increases in age 1-3+ kokanee compared to 2005 (Fig. 7.9). 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. 7.10). This relationship (R^2=0.80) suggests that fry survival rates over the summer period have been quite consistent from year to year. Note the obvious outlier represented by the 2005 data in Figure 7.10 that suggests poor survival during summer 2005, a major departure from other years. The 2006 and 2007 data again shows a strong linear relationship.

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. 7.11). 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. 7.8) but resumed in 2001 as fertilizer loading was increased. In 2002 and 2003 the densities were higher in the South Arm and in 2005 and 2006; densities were higher in the North Arm. In 2007 the densities were similar in the two arms.

The density being similar in the two arms of the lake in 2007 may be a sign that fertilizer being added to the South Arm as well as the North Arm may be affecting kokanee distribution. During the last four years early summer (June-July) acoustic surveys have been conducted in addition to the long term fall surveys. Distribution of fry along the length of the lake in early summer has usually been highly skewed to the north end since the majority are produced from Meadow Creek and the Lardeau River (See Fig. 8.5 in Chapter 8). By the end of summer the fry tend to disburse more evenly throughout the lake as illustrated by the September 2007 data (Fig. 7.12, bottom panel). In 2006 and 2007, the age 1-3+ fish densities were higher in the South Arm by late summer. 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. 7.12, 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.

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 7.6 for details). The calculated biomass is then converted to kg/ha based on known pelagic areas of the lake. Prior to fertilization (1985-1991) the average kokanee biomass density was ~3.5 kg/ha in the lake (i.e., not including spawners). Since fertilization (1992-2007) the kokanee biomass densities has increased to an average of ~ 9.8 kg/ha, close to a three-fold increase (Fig. 7.13). Spawner biomass was calculated by applying average weights from Meadow Creek Spawning Channel to the combined escapement from Meadow Creek and Lardeau River. The average spawner biomass averaged 1.8 kg/ha prior to treatment and has averaged 3.5 kg/ha or approximately double since nutrient additions (Appendix 7.3c). Because of survey timing (i.e. acoustic surveys occur once spawners have left the lake) the inlake 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 13.3 kg/ha respectively (Fig. 7.13).

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. The most convincing data is probably the biomass estimates shown in Figure 7.13. Analysis of growth and survival in the lake to determine fry-to-adult survival rates also provides insight of in-lake conditions with high rates usually following a period of low total numbers in the lake whereas low survival rates suggest high in-lake abundance or unproductive growing conditions. Crude estimates of fry-to-adult survival rates have been determined using long-term data available from Meadow Creek. There are some limitations on this methodology due to accuracy of the data (especially fry estimates), and several assumptions. However, it is felt that such estimates are valid because the data have been collected in a consistent fashion, using the same methods over a long period of time. Therefore, the estimates may not be accurate but consistency in data collection allows for trend analysis. The assumptions made in determining survival rates include:

- one dominant age at spawning (i.e., age 3+);
- minimal harvest that does not appreciably influence escapement levels;
- 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 calculated on the basis of age 3+ at time of spawning. It should be noted that even if these fish spawned as a mix of ages or at a dominant age (e.g., at age 2+), the long-term trend of calculated fry-to-adult survival rates would illustrate a similar pattern; i.e., the trend would be similar but offset by a year.

The most recent spawners (2007) were primarily the progeny of parents from the 2003 spawning year, although, as mentioned, some may have been age 2+ from 2004 parents. In 2003, an estimated 0.86 million spawners returned to Meadow Creek, deposited an estimated 57 million eggs in the system that produced an estimated 15 million fry. These fry returned as 0.39 million spawners therefore, the fry-to-adult survival rate for this cohort (2003–2007 cycle) was only 2.5% (Fig. 7.14). This low survival rate does not equate to poor growing conditions (hence survival) in the lake. On the contrary, high spawner numbers that grew in the lake the preceding four years should result in lower fry-to-adult survival rates. The more important issue and objective of lake fertilization is to achieve high spawner returns, so lower fry to adult survivals would be expected. 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 high spawner numbers during 1996-1999. The 2006 and 2007 survival rates represents the lowest rates in three decades following high spawner escapements from 2003-2005.

Survival rates in the four years prior to fertilization was ~6.5% that reflect lower numbers growing in the lake during the late 1980s while the survival rates have been < 4% during the 2000s when kokanee abundance has been high. It should be mentioned that the average survival rate since fertilization began was ~5%, while some historic data from the 1970s indicate the survival rate was much higher at ~ 12%. The possible reasons for these differences are discussed below.

Recruit-Spawner Relationship

The relationship between parents and offspring over a number of generations provides some valuable insights into how kokanee respond to coarse-scale changes in productivity. A generalized stock-recruitment relationship can be generated from the Meadow Creek spawning channel data based on 16 cycles of relatively consistent enumeration. This analysis 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. 7.15). In 2007 the recruits did not equal parental numbers. 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. 7.9, 7.15).

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 7.15. 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.

Discussion

Escapements

Kootenay Lake nutrient additions have now been underway for sixteen years and have evolved into a highly successful restoration program. The long-term data set of Meadow Creek kokanee escapements and fry production estimates provides an excellent opportunity to evaluate the numerical and biological responses of this pelagic species to nutrient addition. Since the mid-1960s, kokanee spawner numbers returning to Meadow Creek have been monitored as part of a long-term assessment of a spawning channel that was constructed on this system in 1967. Spawner numbers have been estimated as high as ~1.4 million and as low as ~ 0.2 million (Fig. 7.1). 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 were >1 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) followed by numbers < 0.5 million in 2006 and 2007. The increases during 2003-2005 were predicted 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 (Figs. 7.4, 7.9). Low in-lake abundance acoustic estimates in 2004 and 2005, especially for the age 1-3+ group in 2005, foreshadowed the lower escapements in 2006 and 2007. The 2006 and 2007 surveys indicate strong 0+ cohorts and some improvement in the age 1-3+ and these data suggest an increase in spawner numbers by 2008. Unlike Meadow Creek, the Lardeau River escapements have not shown large increases during the 2000s. Since lake growing conditions have greatly improved during the last two decades it is most likely that lower Lardeau River egg-to-fry survival rates account for the lack of significant increased escapements.

Biological Response to Lake Fertilization

The long term data set from Meadow Creek illustrated in Figures 7.3 and 7.7 provides excellent insight into kokanee responses to varying levels of nutrient additions as there have been three distinct increases in size-at-age and fecundity. Prior to nutrient additions, numbers of kokanee, mean size, and fecundity had all declined (Fig. 7.3). These changes triggered the fertilization experiment as it was quite evident that the decrease in lake productivity would otherwise be permanent (Daley et al. 1981; Ashley et al. 1997). Shortly after nutrient addition began, the mid-1990s mean size of adults increased, as did fecundity. 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 (Fig. 7.1). The lower mean sizes and fecundities recorded from 1996–1999 suggest a density-growth response due to large numbers of fish produced by the 1992–1996 spawners. In previous reports it was noted that increased fecundity and spawner length observed in 2000 and 2001 coincided with the decrease in total spawner abundance (Fig. 7.1), most likely because of reduced nutrient additions from 1997–2000.

The decrease in mean size and fecundity from 2003-2005 reflected a density-growth response as the whole lake population increased following the increase in nutrient loading that began in 2001. The acoustic data 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 (Fig. 7.9 and 7.4). This suggests that fry survival over the summer was lower than average, particularly in 2005 which was considered an outlier on Figure 7.10. Reasons for the apparent fry survival problems are discussed later in this report. The 2006 and 2007 fry estimates were much improved and the relation between fry production at Meadow Creek and late summer fry returned to a more typical state (Fig. 7.10). In previous reports by the authors, it was predicted that increased fish size and fecundity observed in the 1990s and 2000s would decline and stabilize close to the long-term average as the abundance of kokanee reached the lake's 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 the lake's carrying capacity. Total in-lake abundance illustrated in Figure 7.8 now suggests improvement in 2006 and 2007 compared to 2004 and 2005 i.e., ~22 million vs. ~16 million.

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 has not changed appreciably since the fertilization experiment began (Fig. 7.7a). This remains the case for fry with little size variation evident before and after fertilization (Fig. 7.7a). Age 1+ kokanee size also does not show any real change before and after fertilization but variation in their size is quite evident with density dependency most likely affecting their size more so than with the fry.

Lake nutrient addition and variations in the nutrient loading rates is reflected in size and growth of the 2+ and 3+ fish. Growth rates for the older age fish (3+) increased for the spawner years 1991–1993 (Figs. 7.1, 7.3, 7.7), but then declined during 1994-1997, most likely reflecting intra-specific competition as total whole lake abundance of age 1–3+ fish increased (Fig. 7.9). Growth rates for mature fish for year classes 1999 and 2000 increased probably because of low total lake densities of ages 1–3+ fish during this period. From 2003-05 the size of spawners was relatively small following three years when age 1-3+ kokanee were relatively abundant (Fig. 7.3, 7.9).

A change occurred again in 2006 with the spawners much larger, females far more fecund, but fewer of them. As noted earlier the mean size of 2007 Meadow Creek spawners was a record mean size of 279 mm. The acoustic data for 2004 and 2005 confirmed lower abundance in the lake which translated to lower numbers of age 1-3+ fish in 2005-06 and lower escapements of large spawners in 2006 and 2007. The 2006 and 2007 data indicates larger escapements can be expected in 2008 and 2009, but also predicts size will again decline. The trawl and acoustics data combined with spawner size data demonstrates quite clearly that ages 2+ and 3+ fish in terms of growth appear to benefit the most from fertilization.

In-Lake Abundance and Biomass

It is quite apparent that increased lake productivity due to nutrient additions provided excellent growing conditions especially for ages 2 and 3+ fish. These conditions 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 (Figs. 7.9). 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 2% in 2006 and 2007 (Fig. 7.14). As the number of spawners peaked in the mid-1990s, spawner size, fecundity, and fry-to-adult survival rates all declined, indicating a strong density-dependent response. This response most likely occurred when the fertilizer loadings were reduced from 1997–2000 and led to a rapid decline in population abundance through 2000 (Figs 7.8, 7.9). Since 2001, fertilizer loadings were increased to the 1992 to 1996 rates and in-lake abundance again increased. During this time the fry-to-adult survival rates increased and led to a recovering in-lake population. Unfortunately a decline in fry survival and numbers in 2004 and 2005 translated to a decrease in spawner numbers and decrease in the fry-to-adult survival rates to ~2% by 2006 and 2007. Fry survival (discussed later) appears to have returned to normal and in-lake abundance has increased to ~ 22 million.

Trawl data was not obtained in 2007 but limited ageing data indicates a mix of ages contributed to the 2007 spawning population with age 3+ still the dominant age-at-maturity. Otolith interpretation suggested a mix of age 2+ and 3+ spawners and was consistent with the bimodal length distribution of spawners observed in 2007. The first mode of smaller sized spawners aligned well with the size of age 2+ fish from the 2006 trawl. The second mode of larger sized spawners would therefore represent primarily age 3+ spawners making up the majority of fish (Fig. 7.6). 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, it is likely that kokanee would shift to older age 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).

Some anomalies exist with the kokanee data during the nutrient addition era. Total kokanee abundance in 2004 (Fig. 7.8) based on the acoustics survey was lower than expected at about 16 million, and was only partly attributed to lower fry production from Meadow Creek in spring 2004 (Fig. 7.4). The relationship between acoustic late summer fry abundance and Meadow Creek fry production has been quite strong (Fig. 7.10; R^2=0.80). At the 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 (Fig. 7.10). 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. The longitudinal distribution of fry in 2005 determined by the acoustic survey in September (Fig. 7.12a) was very unusual, with the majority of fry found in the northern part of the lake. 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 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. Assessing the top down affects of predators on kokanee abundance and survival requires some additional monitoring of the predator populations and diet. The 2006 and 2007 acoustic surveys estimated increased fry numbers compared to 2004 and 2005 and there was again a good relationship between fry produced and the fall estimate (Figs. 7.4, 7.10). 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.

The most convincing evidence of the beneficial effects of lake fertilization is based on estimates of kokanee biomass. There has been nearly a threefold increase in kokanee fall biomass or standing crop (measured in the lake) from 3.5 kg/ha to 9.8 kg/ha since fertilization began (Fig. 7.13). 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 spawner biomass increased by approximately twofold from 1.8 kg/ha to 3.5 kg/ha following fertilization. Combined biomass density (i.e. inlake + spawners) before and during nutrient addition averaged 5.3 kg/h and 13.1 kg/ha, respectively. 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; Fig. 7.13). The biomass estimates in 2005 and 2006 decreased to 10-12 kg/ha due to lower numbers of age 1-3+ fish following two lower fry survival years in 2004 and 2005. Biomass increased to 13.9 kg/ha in 2007.

Meadow Creek Fry Production

Monitoring fry production at the Meadow Creek spawning channel provides an outstanding long term data set that indicates fry production from the late 1960s through to the early 1990s was <15 million (Fig. 7.4). No monitoring occurred from 1979-1984 but thereafter fry production was determined to be especially low in the late 1980s ranging from approximately 4–10 million. Fry production then increased from10–30 million in the 1990s and 2000s as a result of a combination of improved spawning channel performance (data on file, MOE, Nelson BC) and improved in-lake kokanee growth and survival. In recent years production has been fairly constant ranging from ~15-25 million.

Estimated Meadow Creek fry-to-adult survival rates were comparatively quite high during the early 1970s (Fig.7.14). These cohorts would have grown in Kootenay Lake when nutrient levels were highly elevated as a result of phosphorus being released into Kootenay Lake from Cominco's fertilizer plant (Daley et al. 1981). The Duncan Dam became operational in 1967 and blocked very large numbers of spawning kokanee (>1 million), 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] (Fig. 7.4). 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 likely in the late 1980s and early 1990s as evidenced by declining escapements (Fig. 7.1) reflecting the period of reduced nutrient levels (Daley et al. 1981; Ashley et al. 1997). Today it is reasonable to conclude that lake fertilization has been primarily responsible for the increases in kokanee production at Meadow Creek.

Based on known escapements it is clear that the Meadow Creek spawning channel is the key production centre for Kootenay Lake kokanee. Fry production has been as high as 28 million but as noted above in recent years fry production ranged between 15-25 million. The relationship between egg deposition and fry production shown in Figure 7.5 is linear (R^2=0.76) suggesting that 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 to define the optimum number of fish that should be permitted to spawn in the channel to achieve maximum fry production.

Piscivore Response

It is well known that Kootenay Lake Gerrard rainbow trout (and bull trout) rely heavily on kokanee (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 an overall decrease in size (KLRT data on file MoE Nelson). On the otherhand anglers also report an upturn in catch and success rates of bull trout, with this opinion supported by the annual Kootenay Lake angler survey results (data on file, MOE, Nelson BC). Given all of these changes, 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 merely reinforces the need to continue to monitor these highly valued piscivores.

Lake Productivity

A series of investigators including Northcote (1973), Daley et al. (1981), and Ashley et al. *in* Murphy and Munawar (1999) and Schindler et al. (2007, 2009a) have all described a number of major changes to Kootenay Lakes' productivity. During the last four decades 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. These events are illustrated quite well by analyzing the North Arm kokanee recruit-spawner relationships (Fig. 7.15). Through most of the 1970s, replacement levels were achieved when the lake was in a highly productive state but the spawning channel was producing comparatively low fry numbers. During this period, all of the kokanee year classes replaced themselves. The end of the 1970s 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 increasing; therefore in-lake competition resulted in below average fish size and fecundity (Fig. 7.4). In other words for a short period of time kokanee production increased even though lake productivity was declining. Thus there were a few cycles in the mid 1980s that actually replaced themselves despite decreasing lake productivity.

The third productivity event occurred during the late 1980s and early 1990s when the lake became extremely unproductive and escapement levels fell to record lows with four successive kokanee cycles failing to replace themselves. This precipitous decline led to the decision to add nutrients to a portion of the North Arm. The fourth event that is on-going due to nutrient additions has seen the swift recovery of kokanee with replacement easily accomplished for two consecutive cycles (1992–1999). Deliberate reduction of nutrient loading resulted in low escapements from 2000-2002 with these cohorts not replacing themselves. 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 (Fig. 7.14). The in-lake abundance estimates (Figs. 7.8, 7.10) indicated that increased numbers of age 0+ fish were present by 2001 and 2002 once the fertilizer loading was again increased. 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 acoustic abundance estimates of age 1-3+ fish in 2006 and 2007 predicts potential improvement in 2008 and 2009.

Summary

The wealth of information gathered on Kootenay Lake over the course of the nutrient additions 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 (see Chapter 6 in this report), and there is growing evidence that Gerrard rainbow trout and bull trout are benefiting. Results of experimental fertilization of the South Arm should become more evident in the near future.

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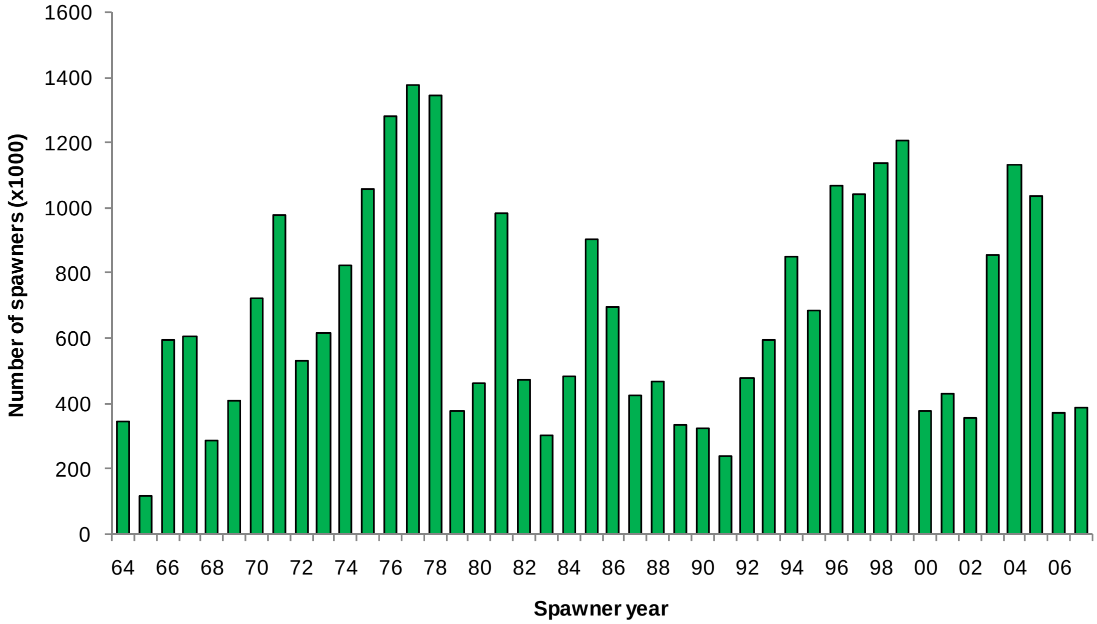


Figure 7.1. North Arm of Kootenay Lake kokanee escapements to Meadow Creek and Spawning Channel, 1967–2007. (Note: 1964–1968 data from Acara 1970).

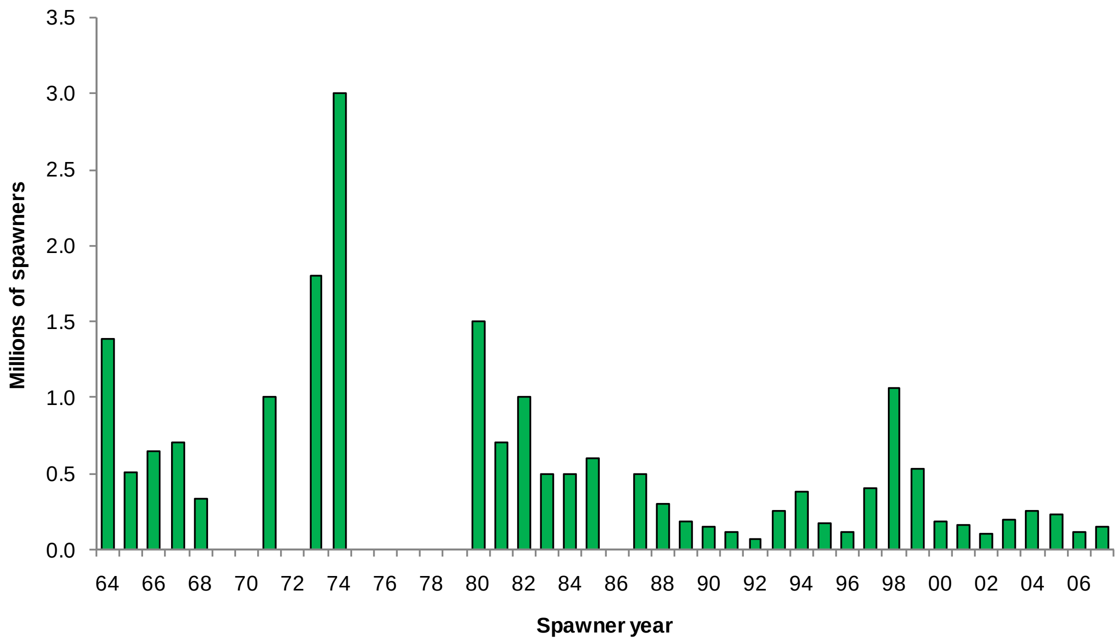


Figure 7.2. Kokanee escapements to Lardeau River 1964–2007 tributary to the North Arm of Kootenay Lake (Note: 1964–1968 data from Acara 1970).

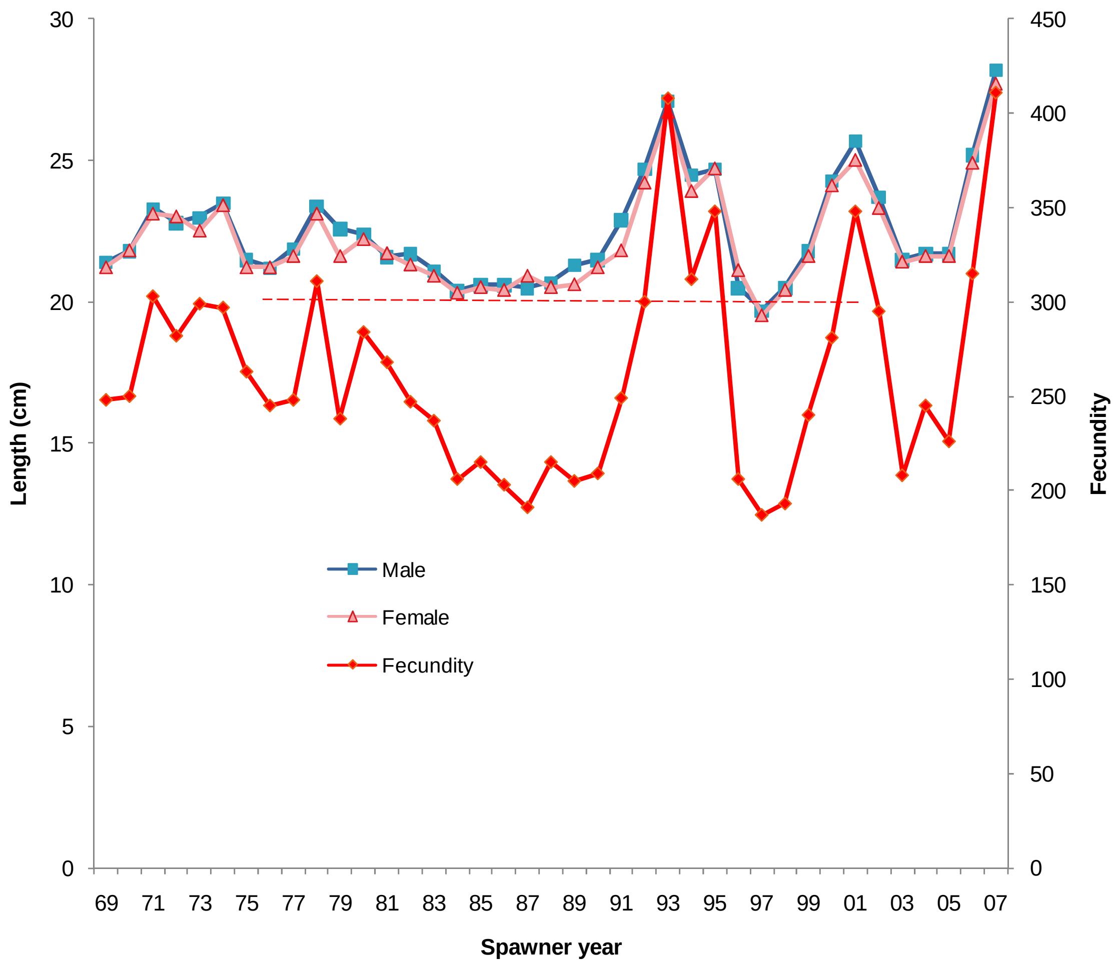


Figure 7.3. Mean length (cm) of Meadow Creek female and male kokanee spawners and fecundity, 1969–2007. Dotted horizontal line illustrates 39-year average fecundity of 259.

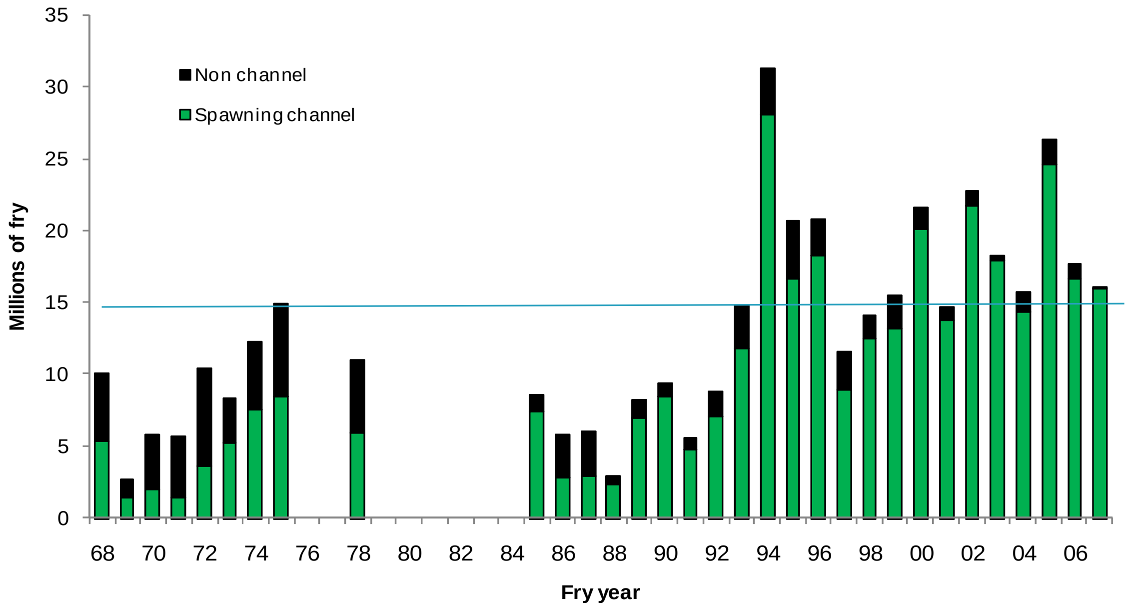


Figure 7.4. Kokanee fry production estimates from the Meadow Creek system and that portion from the spawning channel, 1968–2007.

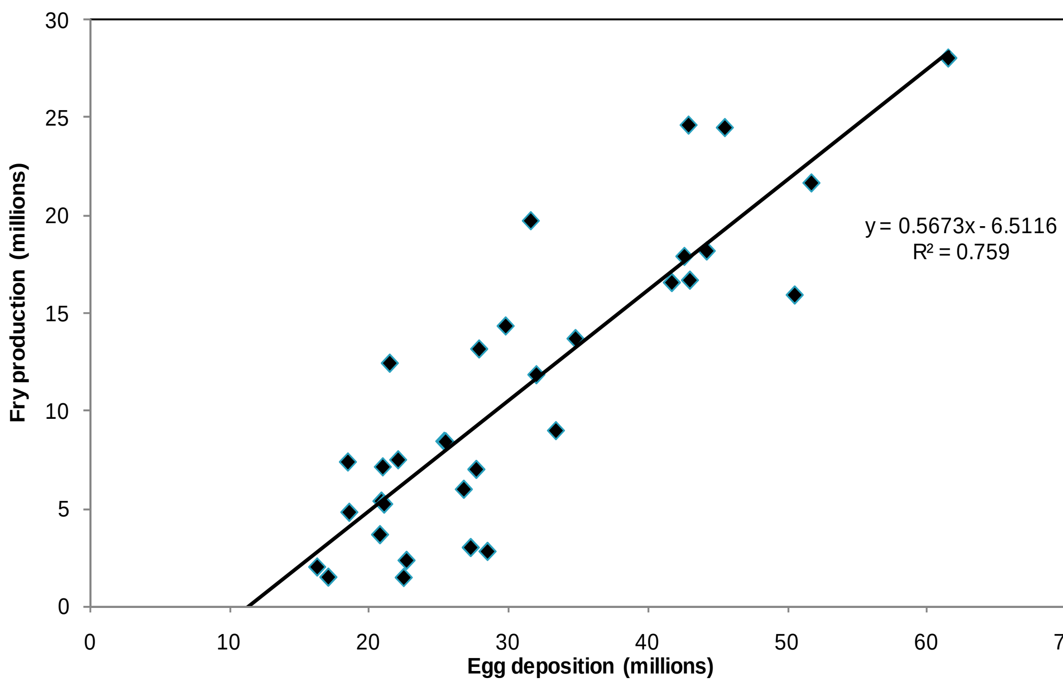


Figure 7.5. Relationship of Meadow Creek spawning channel fry production to the potential egg deposition the previous fall.

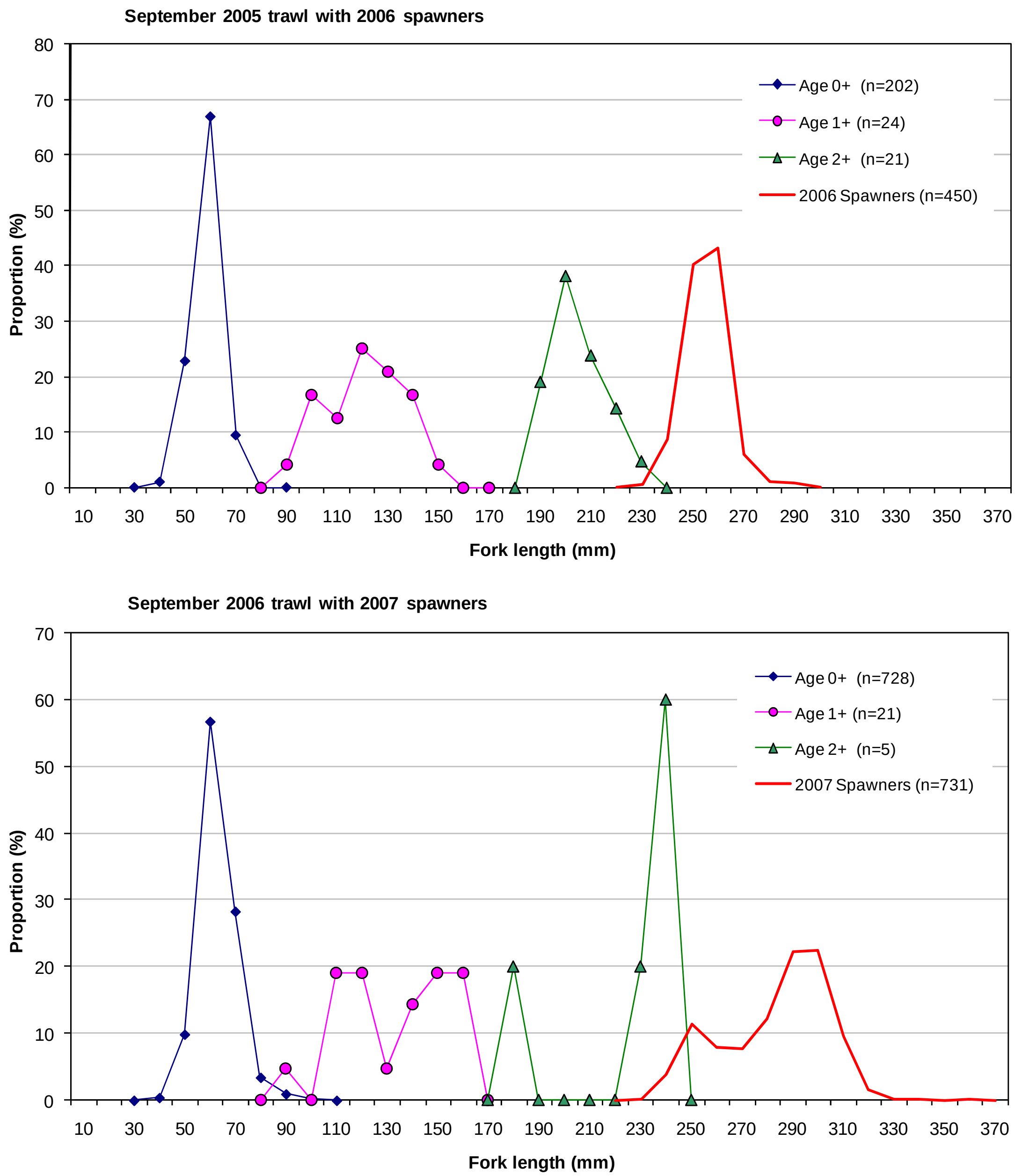


Figure 7.6. Kokanee length-frequency distributions by scale age for trawl-caught fish in Kootenay Lake in 2005 and 2006 and spawners returning to Meadow Creek in September 2006 and 2007.

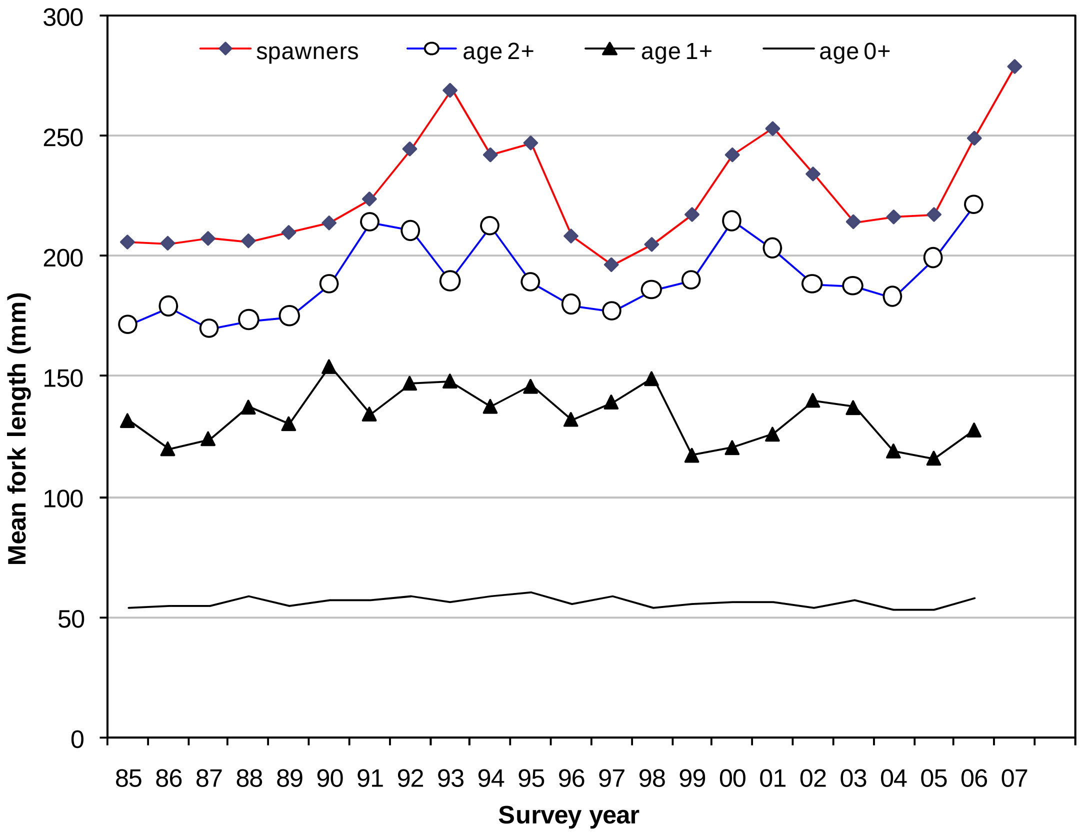


Figure 7.7. Comparisons of trends in kokanee mean length-at-age from trawl captures and Meadow Creek spawner samples.

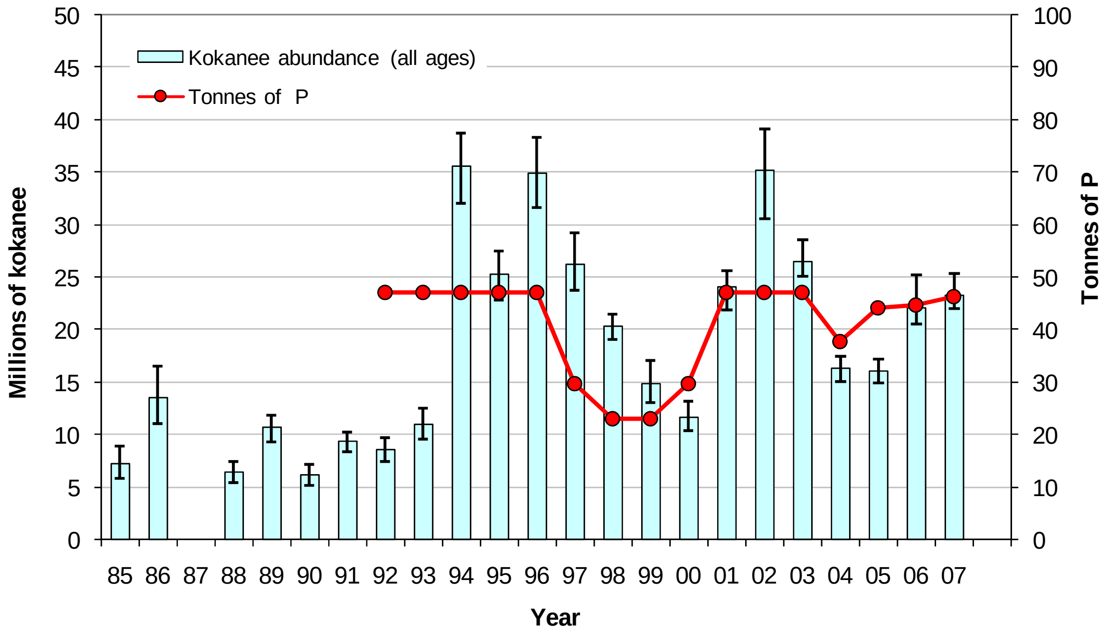


Figure 7.8. Response of in-lake kokanee populations (all ages) to nutrient enrichment, based on acoustic surveys. Error bars represent 95% confidence limits.

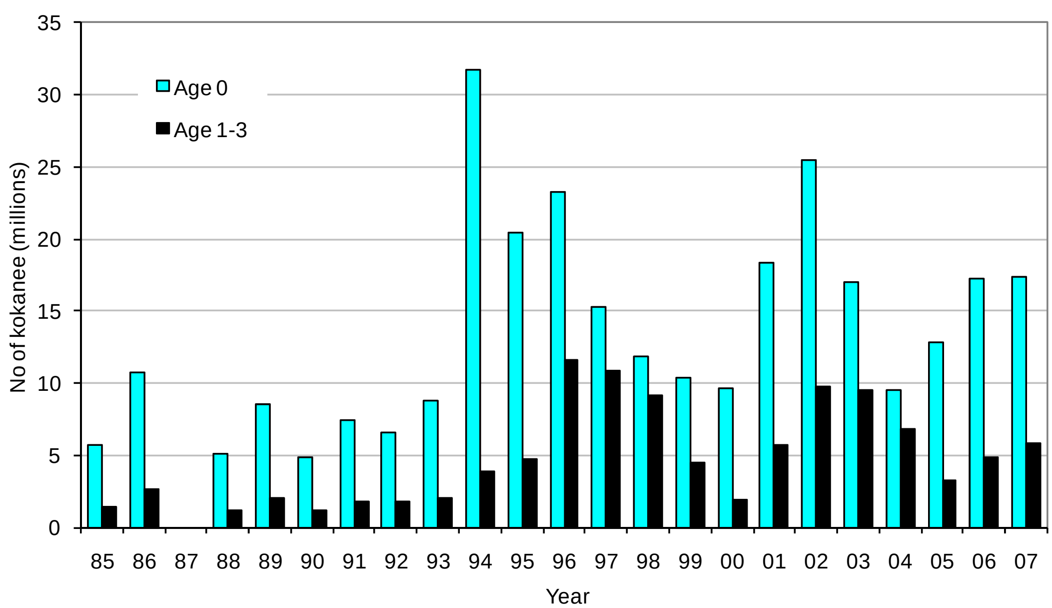


Figure 7.9. Kokanee abundance estimates for age 0 and ages 1–3 kokanee in Kootenay Lake based on fall acoustic sampling 1992–2007.

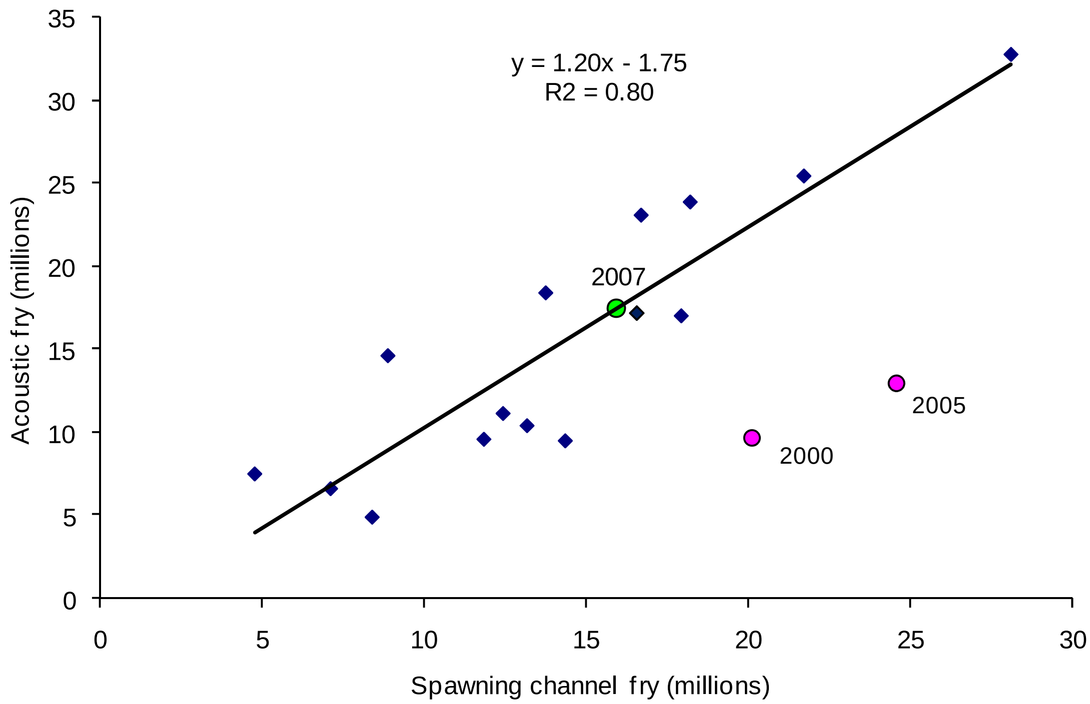


Figure 7.10. Relationship between numbers of kokanee fry produced from the Meadow Creek spawning channel and estimated numbers of fall fry determined by hydroacoustics.

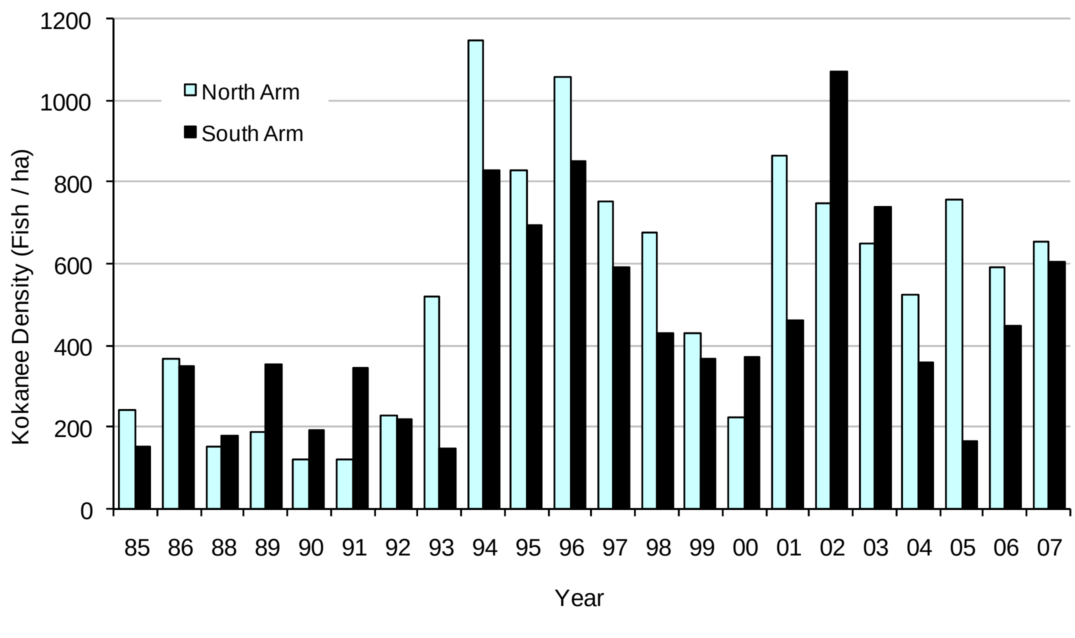


Figure 7.11. Comparison of kokanee density in North and South Arms of Kootenay Lake based on annual acoustic monitoring, 1985–2007.

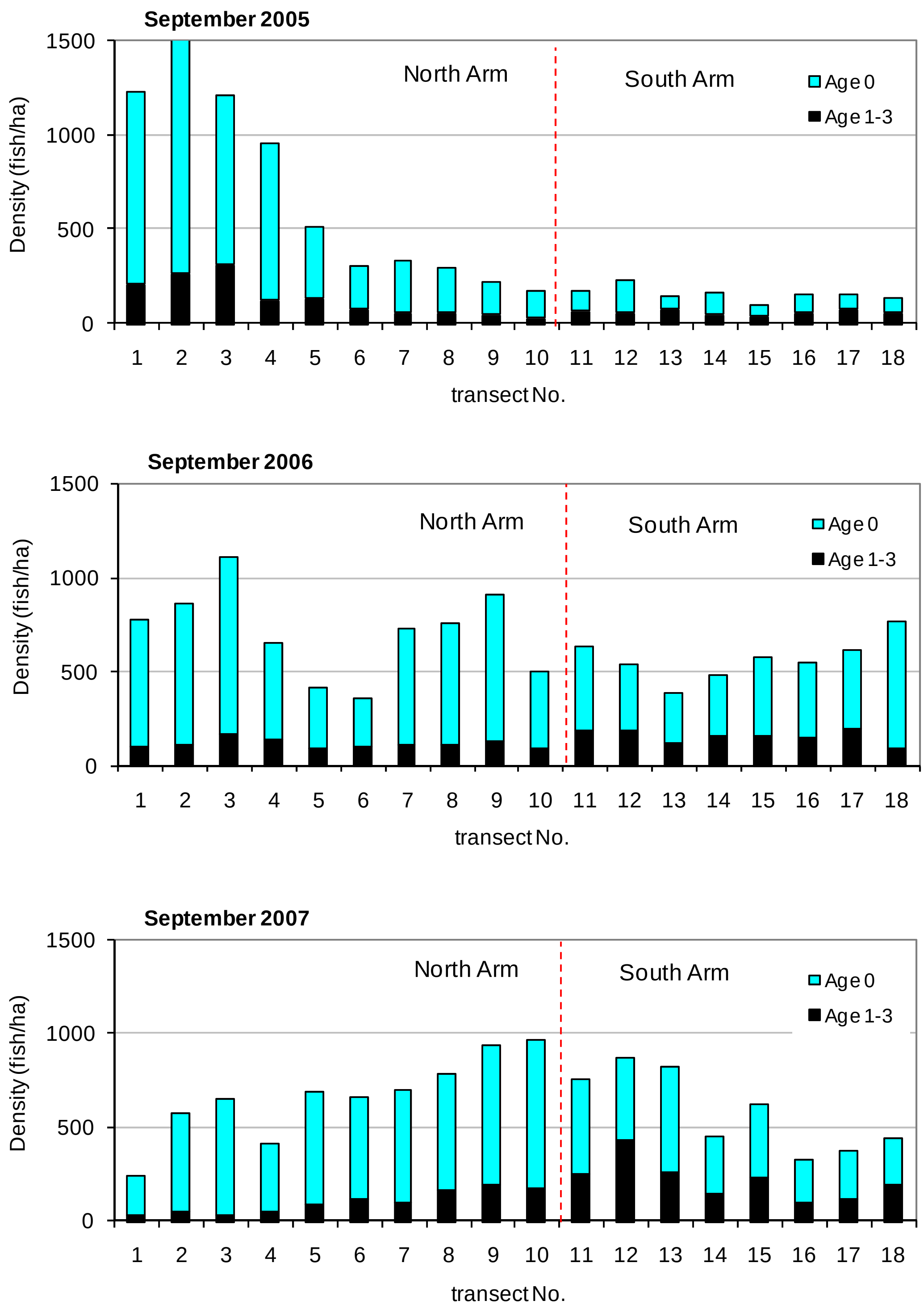


Figure 7.12. Longitudinal density distribution for age 0 and ages 1–3 kokanee in Kootenay Lake during a) September 2005 and b) September 2006.

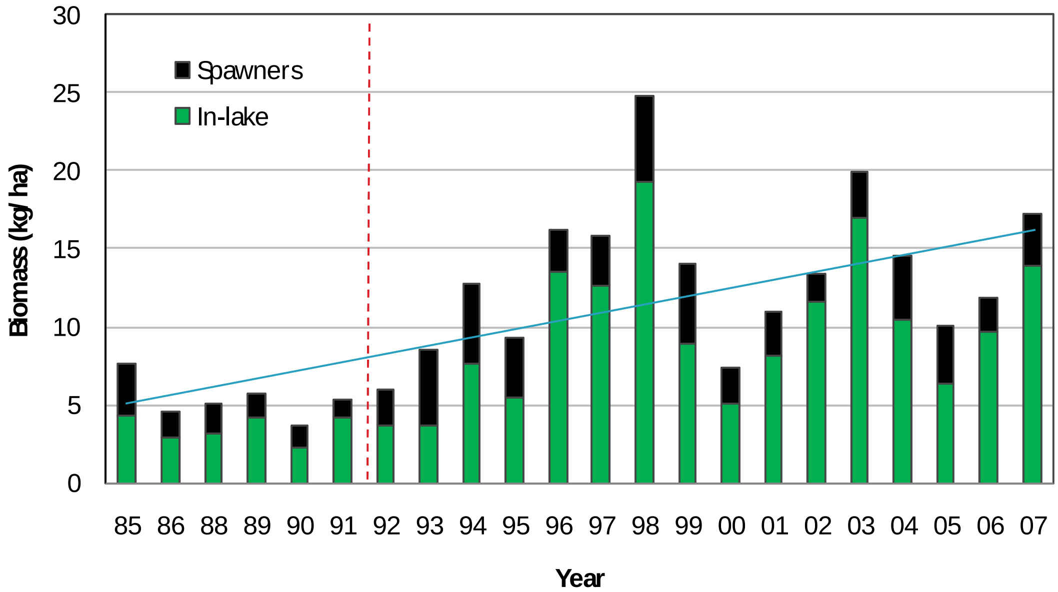


Figure 7.13. Annual biomass estimates (kg/ha) for all ages of kokanee (inlake + spawners) developed from hydroacoustic and trawl surveys and spawner counts and size in Meadow Creek and tributaries of Kootenay Lake. Dotted line indicates commencement of fertilization; solid line indicates general trend.

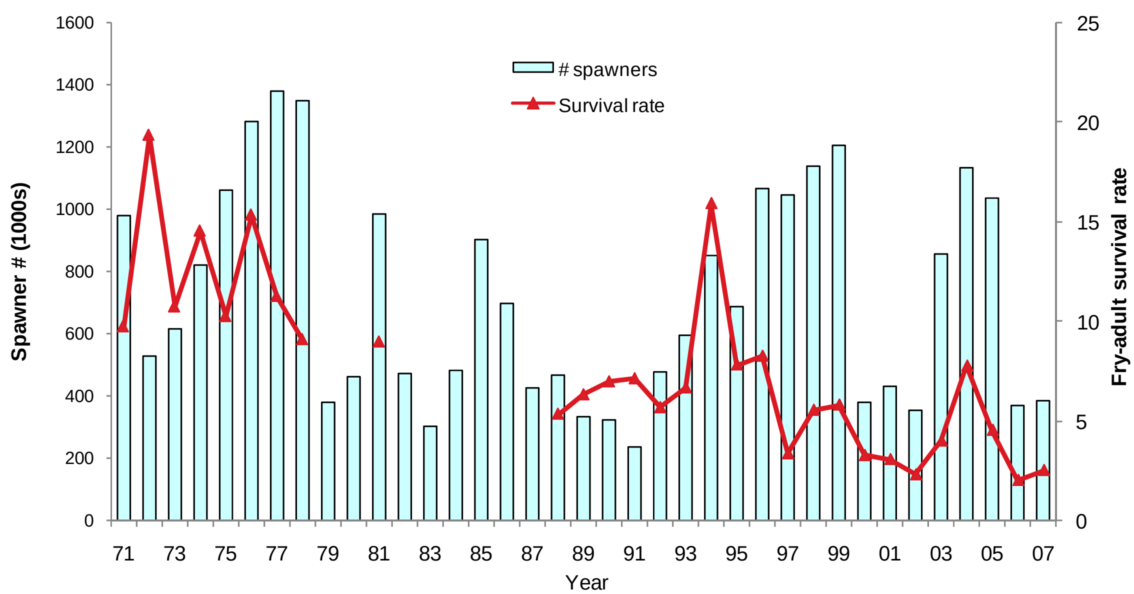


Figure 7.14. Kokanee egg-to-fry survival rate based on Meadow Creek data. Number of spawners illustrated to emphasize that low survival rates are associated with high escapement levels and vice versa.

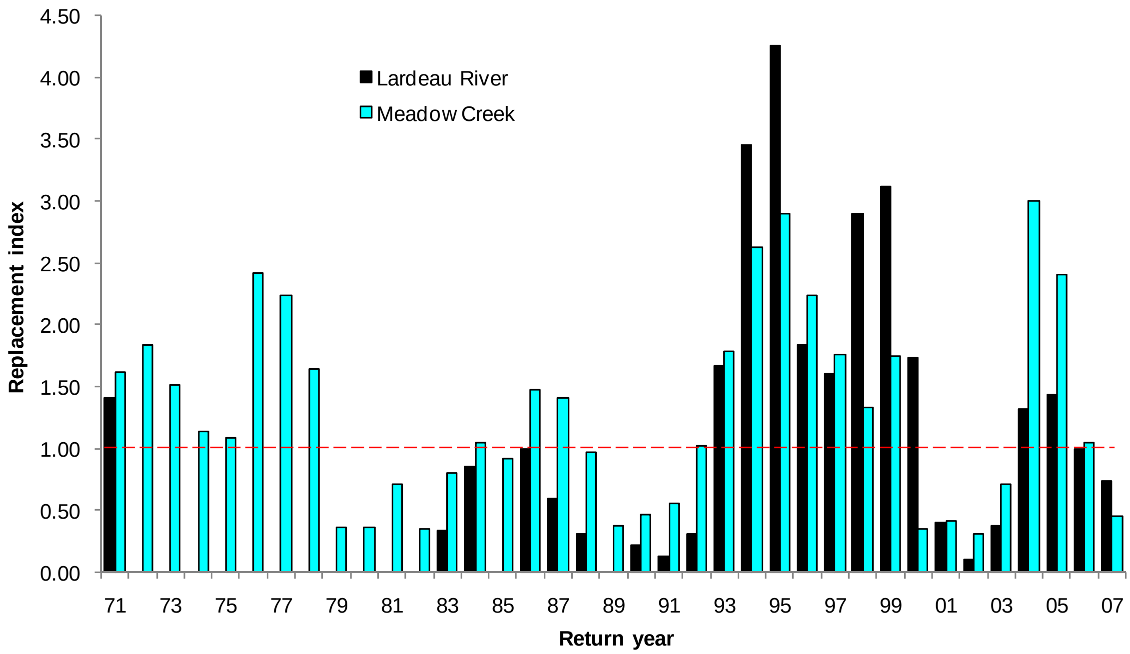


Figure 7.15. Recruit-spawner relationship for Lardeau River and Meadow Creek (1971-2007). Dotted line indicates replacement level of 1.0.

Appendix 7.1. 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	Date	>180 mm	100–180 mm	<100 mm
1-Sep	1.025	1.064	1.090	7-Oct	1.000	1.000	0.982
2-Sep	1.023	1.061	1.087	8-Oct	1.000	1.000	0.979
3-Sep	1.021	1.058	1.084	9-Oct	1.000	1.000	0.976
4-Sep	1.020	1.056	1.081	10-Oct	1.000	1.000	0.973
5-Sep	1.018	1.053	1.078	11-Oct	1.000	1.000	0.970
6-Sep	1.016	1.050	1.075	12-Oct	1.000	1.000	0.967
7-Sep	1.014	1.047	1.072	13-Oct	1.000	1.000	0.964
8-Sep	1.012	1.044	1.069	14-Oct	1.000	1.000	0.961
9-Sep	1.011	1.042	1.066	15-Oct	1.000	1.000	0.958
10-Sep	1.009	1.039	1.063	16-Oct	1.000	1.000	0.955
11-Sep	1.007	1.036	1.060	17-Oct	1.000	1.000	0.952
12-Sep	1.005	1.033	1.057	18-Oct	1.000	1.000	0.949
13-Sep	1.003	1.030	1.054	19-Oct	1.000	1.000	0.946
14-Sep	1.002	1.028	1.051	20-Oct	1.000	1.000	0.943
15-Sep	1.000	1.025	1.048	21-Oct	1.000	1.000	0.940
16-Sep	1.000	1.023	1.045	22-Oct	1.000	1.000	0.936
17-Sep	1.000	1.022	1.042	23-Oct	1.000	1.000	0.933
18-Sep	1.000	1.020	1.039	24-Oct	1.000	1.000	0.930
19-Sep	1.000	1.018	1.036	25-Oct	1.000	1.000	0.927
20-Sep	1.000	1.017	1.033	26-Oct	1.000	1.000	0.924
21-Sep	1.000	1.015	1.030	27-Oct	1.000	1.000	0.921
22-Sep	1.000	1.013	1.027	28-Oct	1.000	1.000	0.918
23-Sep	1.000	1.011	1.024	29-Oct	1.000	1.000	0.915
24-Sep	1.000	1.010	1.021	30-Oct	1.000	1.000	0.912
25-Sep	1.000	1.008	1.018	31-Oct	1.000	1.000	0.909
26-Sep	1.000	1.006	1.015	1-Nov	1.000	1.000	0.906
27-Sep	1.000	1.005	1.012	2-Nov	1.000	1.000	0.903
28-Sep	1.000	1.003	1.009	3-Nov	1.000	1.000	0.900
29-Sep	1.000	1.001	1.006	4-Nov	1.000	1.000	0.897
30-Sep	1.000	1.000	1.003	5-Nov	1.000	1.000	0.894
1-Oct	1.000	1.000	1.000	6-Nov	1.000	1.000	0.891
2-Oct	1.000	1.000	0.997	7-Nov	1.000	1.000	0.888
3-Oct	1.000	1.000	0.994	8-Nov	1.000	1.000	0.885
4-Oct	1.000	1.000	0.991	9-Nov	1.000	1.000	0.882
5-Oct	1.000	1.000	0.988	10-Nov	1.000	1.000	0.879
6-Oct	1.000	1.000	0.985	11-Nov	1.000	1.000	0.876

Appendix 7.2. Equipment and data processing specifications.

Echosounder Specifications and Field Settings

Description	SIMRAD EY200P-P
Transducer type	Single beam 70 kHz
Beam angle	11.6 degree
Receiver gain	3 (0 dB)
Pulse width (msec)	0.3
Ping rate (p/sec)	Medium (1.5)
Time varied gain	40 log r
TVG range (m)	2 to 66
Attenuation	–15 dB
Power	1/1
Calibration	2 min. AC tone
Tape recorder	Sony TCD-D10
Record volume	3.5 fixed

Data Processing Specifications

Description	HADAS version 3.98
Interface gain	Calibration tone to intersect 2 volts at 50 milliseconds
Threshold	Minimum detectable target approximately –65 dB
Field calibration	September 9, 2005, Kootenay Lake; Peak sphere voltage = 4100 mV; Sphere depth = 12m; Threshold used for survey = 240 mV
Lab calibration	July 8, 1998, Applied Physics Laboratory, UWA

Appendix 7.3. Love's (1977) empirical relation of fish length to acoustic targetstrength.

$$TS = 19.1 \log_{10}(L) – 0.9 \log_{10}(F) – 62$$

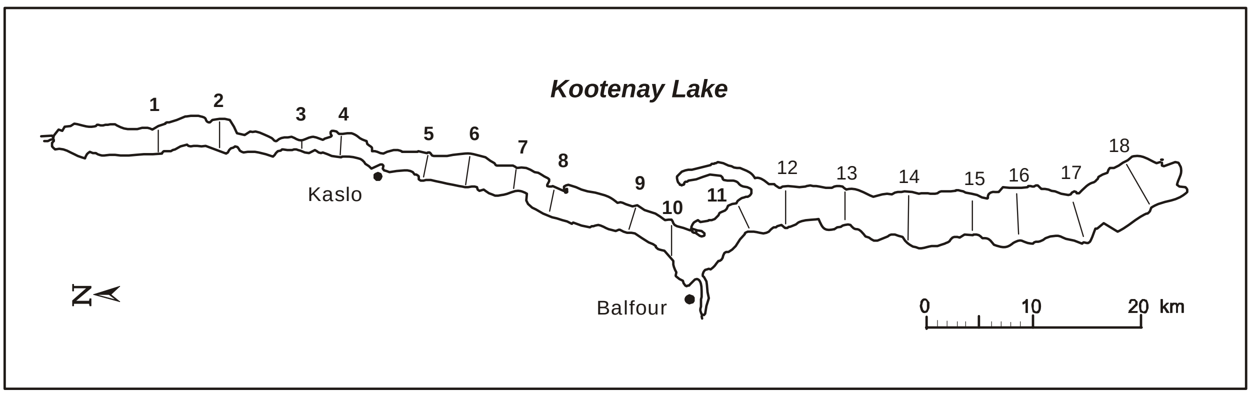
where TS=target strength in decibels (dB), L=length in cm, and F=frequency in kHz.

HADAS size class (db)[1]	Acoustic size range (dB)		Fish length range (mm)[2]	
-35	-35	-33.1	317	500+
-38	-38	-35.1	221	317
-41	-41	-38.1	154	221
-44	-44	-41.1	107	154
-47	-47	-44.1	75	107
-50	-50	-47.1	52	75
-53	-53	-50.1	36	52
-56	-56	-53.1	25	36
-59	-59	-56.1	18	25
-62	-62	-59.1	12	18

[1] HADAS was set up to view a 30dB range in 10 size classes of 3 dB.
[2] From Love's (1977) empirical formula (Dorsal aspect).

Appendix 7.4. Transect fish densities (number/ha) in Kootenay Lake, September 2007.

Transect Number	All Ages	Age 0+	Age 1-3+
1	246	212	34
2	582	532	50
3	657	619	38
4	420	364	56
5	694	603	91
6	669	551	118
7	706	601	105
8	787	621	166
9	939	741	198
10	967	788	179
11	757	502	255
12	873	440	433
13	829	569	260
14	451	298	153
15	623	385	238
16	331	231	100
17	379	258	121
18	441	246	195



Appendix 7.5. Maximum likelihood population estimates and bounds for (a) all ages of kokanee and (b) ages 1-3 kokanee in Kootenay Lake in September 2007.

a) Statistics for kokanee of all ages (>–62 dB) in three zones (transects 1-7, 8-13,14-18)

Zone	Depth	N	R^2	Density	Std Error	Area	Stratum Pop.	Statistic[1]	Abundance
1	5	7	0.16	2.1	1.93	11640	24,269		
1	10	6	0.98	12.8	0.91	11640	149,248		
1	15	6	0.76	12.2	3.05	11640	141,915		
1	20	6	0.97	113.6	9.11	11517	1,308,158		
1	25	7	0.85	215.4	36.44	11409	2,457,306		
1	30	6	0.93	130.9	15.51	11258	1,474,096	LB=	22,097,430
1	35	6	0.96	60.6	5.21	11090	671,900	**MLE=**	23,349,400
1	40	7	0.84	22.0	3.91	10937	240,644	UB=	25,333,545
1	45	6	0.81	3.5	0.77	10780	38,172		
2	5	6	0.28	2.9	2.08	14270	41,069		
2	10	5	0.84	3.4	0.74	14270	48,019		
2	15	6	0.79	6.0	1.36	14270	85,220		
2	20	6	0.98	250.9	17.14	14175	3,555,721		
2	25	5	0.97	391.1	32.05	14077	5,505,232		
2	30	5	0.95	164.4	18.74	13926	2,289,640		
2	35	5	0.90	18.3	3.02	13788	251,781		
2	40	5	0.91	2.6	0.42	13690	35,335		
2	45	6	0.57	0.7	0.28	13596	9,735		
3	5	5	0.18	1.9	2.04	12290	23,855		
3	10	5	0.33	2.7	1.90	12290	32,814		
3	15	4	0.96	1.6	0.20	12290	20,143		
3	20	4	0.90	1.5	0.29	12224	18,324		
3	25	4	0.94	118.0	16.66	12156	1,434,056		
3	30	4	0.97	200.1	18.71	12092	2,419,960		
3	35	4	0.95	105.6	14.67	12033	1,270,363		
3	40	4	0.79	12.4	3.71	11981	148,775		
3	45	5	0.52	1.6	0.77	11927	19,120		

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

b) Statistics for ages 1–3+ kokanee (>–47 dB) in three zones (transects 1-7, 8-13,14-18)

Zone	Depth	N	R^2	Density	Std Error	Area	Stratum Pop.	Statistic[1]	Abundance
1	10	7	0.41	1.42	0.69	11640	16,482		
1	15	7	0.074	0.15	0.21	11640	1,711		
1	20	6	0.976	3.99	0.28	11517	45,989		
1	25	7	0.726	13.19	3.31	11409	150,516		
1	30	6	0.767	20.95	5.16	11258	235,815		
1	35	6	0.894	15.65	2.41	11090	173,498		
1	40	6	0.873	4.61	0.79	10937	50,364		
1	45	6	0.681	1.11	0.34	10780	11,933		
2	10	6	0.451	0.91	0.45	14270	12,971	Total	
2	15	5	0.775	0.76	0.21	14270	10,859	LB=	5,008,592
2	20	6	0.91	33.72	4.75	14175	478,013	MLE=	5,493,700
2	25	5	0.971	105.37	9.09	14077	1,483,257	UB=	6,182,189
2	30	5	0.854	62.33	12.90	13926	867,996		
2	35	5	0.853	8.99	1.87	13788	124,009		
2	40	5	0.782	0.91	0.24	13690	12,513		
3	5	5	0.168	1.01	1.12	12290	12,413		
3	10	5	0.11	0.30	0.97	12290	3,687		
3	15	4	0.937	0.39	0.06	12290	4,756		
3	20	5	0.638	0.79	0.30	12224	9,694		
3	25	4	0.891	17.73	3.58	12156	215,571		
3	30	4	0.972	69.83	6.89	12092	844,381		
3	35	4	0.91	63.48	11.55	12033	763,876		
3	40	4	0.753	4.96	1.64	11981	59,440		

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

Appendix 7.6. 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*

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 tonnes) and biomass density (kg/ha) of kokanee in Kootenay Lake.

	Biomass (metric tonnes)					Biomass Density (kg/ha)				
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*	***13.2***
Pre	12	30	79	13	135	0.3	0.8	2.1	0.4	3.5
Fert	33	113	201	18	365	0.9	3.0	5.3	0.6	9.8

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

c) Calculation of kokanee spawner biomass (metric tonnes) and biomass density (kg/ha) in Kootenay Lake. Note: bottom rows compare average biomass during pre-fertilization (1985-91) and fertilization years (1992-2007).

Year	Total Spawners[2] (no)	Mean Weight (g)	Spawner Biomass (tonnes)	Spawners (kg/ha)	Inlake (kg/ha)	Total (kg/ha)
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*
Pre	718,617	101.7	69.0	1.8	3.5	5.3
Fert	1,023,956	144.4	133.0	3.5	9.8	13.3

1. In-lake biomass assumptions outlined in tables above.
2. Note that early estimates for spawner numbers have been corrected to include Lardeau R and biomass values have been updated from 2006 report.

CHAPTER 8

SOUTH ARM OF KOOTENAY LAKE KOKANEE RESPONSE TO NUTRIENT ADDITIONS; SUMMARY REPORT 2004-2007

by

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Surrey, BC

Introduction

A considerable amount of literature exists on the ecology of Kootenay Lake as a result of a number of anthropogenic impacts that have profoundly affected the lakes' productivity. Upstream hydroelectric plants on the two largest tributaries have created permanent, adverse impacts to most fish species, especially sturgeon, kokanee, bull trout and rainbow trout (Northcote 1973; Daley et al. 1981; Schindler et al. 2009; Ericksen et al. 2009). Over the last half century the lake has also undergone radical changes in its productive capacity. Northcote (1973) described the lake in its natural state as oligotrophic and documented the shift in productivity to near eutrophic condition during the 1950s and 1960s as a result of unregulated input of phosphorus from an upstream fertilizer plant. Eventual provincial control over this discharge led to of the reduction of phosphorus input to minimal levels by the early 1970s. Nearly simultaneously the Libby Dam was completed on the Kootenai River and the reservoir behind this dam became a nutrient sink for essential elements that previously had contributed to Kootenay Lake productivity. Daley et al. (1981) traced the changes as the lake underwent oligotrophication during the 1970s and correctly predicted the lake would become ultra-oligotrophic. This significant change to lake productivity led to a near collapse of the kokanee population during the late 1980s and threatened to reduce the predator populations that relied on kokanee for forage.

To restore the nutrient balance in the lake and rebuild the kokanee population an experimental nutrient addition program (fertilization) was initiated on the North Arm in 1992. During the last two decades this program has been deemed to be highly successful with kokanee rebuilt to numbers believed to be present during oligotrophic conditions (Ashley et al. 1997, 1999; Schindler 2009).

The current status of kokanee is of particular interest since during the mid 1950s the lake supported three distinct populations originating from the North, South and West arms, respectively (Vernon 1957). To date kokanee restoration has focused primarily on the North Arm population benefitting from nutrient addition and a spawning channel at Meadow Creek. West Arm stock has been assisted with small spawning channels at Kokanee and Redfish creeks (Andrusak et al. 2007). Meanwhile South Arm kokanee continue to be virtually extinct and only recently have efforts been made to restore them through nutrient additions to the South Arm. South Arm fertilization partially began in 2004 and since then nutrient additions have occurred annually during the growing season (June through September) (Schindler 2009). This project follows an overall international Kootenai/y River sub-basin plan aimed at restoring the impacted fish species with particular emphasis on kokanee (Anders et al. 2004).

This report summarizes the status of South Arm kokanee during the first four years of south arm nutrient additions and provides some comparisons with the more established North Arm nutrient restoration program.

Project Objectives

Relative to the sub-basin plan's goal and tasks outlined in Anders et al. (2004), the specific objectives of this report are to:

1. Summarize the first four years of South Arm of Kootenay Lake kokanee response to nutrient additions;
2. Compare South Arm results with those from the North Arm kokanee population.

Background

For over half a century, Kootenay Lake has undergone a multitude of ecological changes due to extensive hydroelectric development and other major impacts that have been well documented in a series of publications (Northcote 1973; Daley et al. 1981; Ashley et al. 1997, 1999; Schindler et al. 2009). Lake productivity declined in the early 1980s as a result of nutrient retention by upstream dams (Duncan Dam 1967) and reservoirs (Libby Dam 1972) and cessation of a major discharge of phosphorus from a phosphate fertilizer plant near Kimberly, BC (Daley et al. 1981; Ashley et al. 1997). As a result, Kootenay Lake fish populations have endured a series of significant impacts primarily due to a combination of declining lake productivity, spawning habitat degradation and non-indigenous species introductions.

The main lake populations of kokanee, the keystone species within Kootenay Lake, declined in the early 1990s to the lowest levels recorded in over four decades. Status and health of the kokanee population in Kootenay Lake have a direct influence on other species of fish, primarily piscivorous populations of white sturgeon (*Acipenser transmontanus*), bull trout (*Salvelinus confluentus*), burbot (*Lota lota*) and rainbow trout (*Oncorhynchus mykiss).* The primary reasons for the decline in kokanee numbers have been attributed to the overall nutrient reduction exacerbated by direct competition for selective zooplankton by freshwater opossum shrimp (*Mysis relicta*) (Northcote and Lorz 1966; Northcote 1991; Ashley et al. 1997; Whall and Lasenby 1998).

By 1990 there was considerable public outcry to the decline of the kokanee population that led to a series of public meetings. The conclusion reached by scientists and the public was that nutrient additions should be attempted to reverse the down-turn in productivity. Nutrient additions were initiated in 1992 on a portion of the North Arm of Kootenay Lake to counter declining lake productivity and restore kokanee numbers to historic pre-dam levels (Ashley et al. 1997, Binsted and Ashley 2006; Ashley et al. *in* Murphy and Munawar 1999). Throughout the 1990s, the limnology of Kootenay Lake and particularly the status of North Arm kokanee have been well documented as part of on-going monitoring of trophic level responses to lake fertilization (see Ashley et al. 1997; Ashley et al. *in* Murphy and Munawar 1999; Thompson 1999; Wright et al. 2002, Schindler et al. 2009). The North Arm kokanee population has responded positively to the addition of nutrients which have continued through 2007. The current kokanee escapement levels now approximate those of the 1970s (Schindler et al. 2009).

South Arm kokanee, once considered a morphologically and genetically distinct stock (Vernon 1957) have been virtually extirpated from many of their natal spawning tributaries over the past three decades. Historically, the South Arm tributaries supported modest numbers of spawning kokanee (Vernon 1957) which began a precipitous decline in the late 1970s in concert with declining lake productivity (Andrusak et al. 2009). Recently Anders et al. (2007) 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.

In August 2004, nutrients were added to the South Arm of Kootenay Lake to increase lake productivity and restore depleted kokanee numbers (see Chapter 2 for details). This effort to improve South Arm productivity has been coordinated and integrated through a partnership 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 includes cooperation with various agencies within Canada and the United States including: Kootenai Tribe of Idaho (KTOI); Bonneville Power Association (BPA); British Columbia Ministry of Environment (MOE); and, Idaho State Fish and Game (IDFG).

One of the restoration activities in addition to the nutrient additions to the South Arm is kokanee eyed-egg plants (Meadow Creek stock, Kootenay Lake) in South Arm (BC) streams. These began in the fall of 2005 while the Kootenai Tribe of Idaho began kokanee eyed-egg plants in Idaho tributaries as early as 1997 but far more intensively during the last 5 years (Ericksen et al. 2009). Recently there has also been some stream restoration work undertaken in Northern Idaho Kootenai River tributaries 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).

Annual kokanee escapement estimates to South Arm (BC) and Kootenai/y River (Idaho) tributaries should provide an important metric for assessing the response of kokanee to the addition of nutrients in the South Arm of Kootenay Lake.

Site Description

Kootenay Lake is located in the upper Columbia River drainage of Southeast British Columbia, and lies between the Selkirk and Purcell Mountain ranges (Fig.9.1). 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 (North Arm) and the Kootenai/y River that flows into the south end (South Arm). The outlet of the main lake, at Balfour, British Columbia, forms the upper end of the West Arm before becoming the lower Kootenai/y River which flows into the Columbia River at Castlegar, BC.

The South Arm of the lake receives 61% of the entire inflow to the lake via the Kootenai/y River drainage and represents about two thirds of the entire lake surface and volume (Daley et al. 1981). The Kootenai/y River drainage originates on the western slopes of the Rocky Mountains in eastern BC and flows southwest to Canal Flats, BC where it enters the Rocky Mountain trench and flows south into Montana. Downstream of the Libby Dam in Montana there is a natural waterfall (Kootenai Falls) that represents a barrier to all upstream fish movement. Below the falls the river flows west through Northern Idaho to Bonners Ferry where it shortly thereafter swings north to flow into the South Arm of the lake near Creston, BC.

The primary streams flowing into the east side of the South Arm (BC) include the Goat River, Boulder Creek, Akokli Creek, Sanca Creek, Lockhart Creek, Grey Creek, and Crawford Creek, while Boundary, Corn, Summit, Next, Cultus, and Midge creeks flow into the west side of the lake (Fig. 8.1).

The focus of kokanee work in northern Idaho tributary streams flowing into the Kootenai/y River include: Boundary, Fisher, Smith, Parker, Long Canyon, Trout, and Myrtle creeks (Fig. 8.1).

Methods

2004 - 2007 Kokanee Escapement Estimates

Over the past four years South Arm streams located in BC have been surveyed weekly from mid August to mid-September. Kokanee counts were conducted by an experienced fisheries technician who walked each stream and recorded daily counts for those sections of stream accessible to spawning kokanee. Frequency of stream counts increased during the first two weeks of September when peak spawning was anticipated.

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 were often much less owing to few if any fish being observed.

Kokanee Eyed-egg Plants

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. In addition, 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 to a depth of 0.5m over an area of approximately 0.75m x 1.5 m. 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 anchored in place with large rocks (~ 5-15 cm) and then covered with smaller gravels (< 3cm) to the level of the stream bed. Most redds that were supplemented with small gravels which had been 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. Approximately 40,000 eggs were placed within each "redd" This was done by pouring the eggs and 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 redd, small gravel and fines were placed to hold the eggs within the redd.

Acoustic and trawl surveys

Standardized acoustic and trawl surveys during the fall have been conducted on Kootenay Lake since 1985 and the details of methods have been described by Sebastian et al. (1995) and more recently in Schindler et al. (2009). The mid water trawl samples provide the following information: species verification for the acoustic survey, indices of kokanee abundance, age structure, size-at-age, and the proportion of mature fish in the catch. Trawl gear consisted of a 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 measured with a Notus net depth sensor system and a Global Positioning System (GPS) was used to estimate distances traveled for calculating sampled volumes.

Stepped-oblique trawls ensure a representative sample of fish is obtained from each depth strata where fish are simultaneously observed on an echosounder. For early summer surveys the net is towed for one hour covering up to three 5 m depth layers of approximately 20 minutes each. Note that due to lower fish densities in the South Arm during early season sampling, the fishing time per layer was increased to 20 minutes from the standard 8 minute layers used in fall surveys. Captured fish were kept on ice until processed the following morning. The species, fork length, weight, distinguishing marks (e.g., fin clips), scale code and stage of maturity were recorded and samples then preserved in 10% formalin for long-term storage. Scales have been taken from fish >75 mm for aging.

Trawl surveys were conducted on the North and South Arms during the spring and fall 2004-2007 except for fall 2007 when no survey was undertaken as a result of hydraulic equipment breakdown. The spring surveys have been conducted only since South Arm fertilization commenced in an attempt to differentiate temporal and spatial abundance patterns and any size differences between South Arm and North Arm kokanee fry. During this time, fry from the two stocks are spatially segregated prior to the southward distribution of fry from the north end of the lake. Depending on when the new moon period occurred the spring survey timing ranged from mid-June to mid-July (Table 8.1).

Table 8.1. 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 Pt (3)
2005	July	8-10	Shutty (1), Woodbury (3)	Midge Cr(3)
2006	June	26-28	Shutty (2), Woodbury (2)	Rhino Pt (3), Redmonds (3)
2007	July	4-7	Birchdale (1)	Redmond (3)

A complete night-time hydroacoustic survey of the limnetic habitat in Kootenay Lake has been conducted annually since 1985 during the new moon phase in September or October. Acoustic survey data was collected at 18 transect locations distributed along the length of the main lake including both North and South Arms (Chapter 1, Fig.1.1). Surveys were conducted using a Simrad model EY200P operating at 70 kHz. The transducer was towed on a planer alongside the boat at a depth of 1 m and data was collected continuously along survey lines at 1-2 $pings \cdot s^{-1}$ while cruising at 2 $m \cdot s^{-1}$. The data was converted to digital format and stored both on a PC computer and backed-up on Sony digital audio tape (DAT). Navigation was by radar and 1:75,000 Canadian Hydrographics bathymetric chart. The Simrad system was calibrated in the field at the beginning of the survey. Field calibrations were conducted by collecting target strength (TS) data from a copper sphere suspended in the centre of the echosounder beam 20m from the transducer. The received signal level was adjusted to -39.1 decibels (dB), which corresponds to the empirical strength of the sphere at 70 kHz. Echosounder specifications and field settings are presented in the previous chapter in Appendix 7.2 and acoustic size classes and fork length equivalents in Appendix 7.3.

The Simrad survey data were digitized and then analyzed using the Hydroacoustic Data Acquisition System (HADAS) program version 3.98 by Lindem (1991). The HADAS statistical analysis performed a function similar to manual counting to determine the number of targets per unit area by depth stratum. Habitat was stratified by 5 m depth layers and then further stratified into relatively homogeneous zones. Regression through origin of echo counts on areas sampled produced mean density and standard error values for each zone and depth stratum. A Monte Carlo Simulation procedure was used to combine all strata and develop maximum likelihood estimates and statistical bounds for each zone and again for the combined zones using 30,000 iterations per run. Average fish densities by transect are shown in Appendix 8.1 and maximum likelihood population estimates and bounds are presented in Appendix 8.2. Fish size distribution was also estimated using a statistical de-convolution based on Craig and Forbes (1969). The resulting acoustic size distribution was used to proportion the fish population into two size classes representing age 0+ fish and age 1-3+ fish, respectively.

Results

2004-2007 nutrient additions

South Arm fertilization began in the summer 2004 but during this initial year due to logistical problems additions occurred only in August and early September. Full fertilization during the growing season (June-September) did occur in 2005-2007. Agricultural grade 28-0-0 urea-ammonium nitrate has been added each year but no phosphorus has been required. A description of the dispensing of the fertilizer into the South Arm of Kootenay Lake is described in detail in Chapter 2 of this report. Total annual South Arm nutrient additions are found in Table 8.2 as well as the amounts of phosphorus (P) and nitrogen (N) added to the North Arm for 2004-2007. Small amounts of phosphorus have also been added to the Kootenai River just downstream of the Montana-Idaho border near Bonners Ferry Idaho. This river restoration project was initiated by the KTOI in 2005 with annual phosphorus (only) additions equaling 4.5 tonnes (2005), 7.3 tonnes (2006) and 13.9 tonnes in 2007 (Ericksen et al. (2009).

Table 8.2. South and North Arm of Kootenay Lake fertilizer loadings in tonnes 2004-2007.

Year	South Arm		North Arm	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus
2004	124	0	244	38
2005	234	0	247	44
2006	257	0	248	45
2007	245	0	247	46

All three restoration projects are aimed at increasing fish biomass, especially kokanee. The lower trophic responses to South and North Arm nutrient additions can be found in Chapters 3-6 in this report.

Kokanee escapement estimates

Recent historical records indicate that several thousand South Arm spawners were observed during the lakes' highest productive period (Northcote 1972; Ashley et al. 1997). However during the most recent period of more oligotrophic conditions the South Arm kokanee population became virtually extinct therefore observations of <u>any</u> kokanee spawners in South Arm tributary streams and Kootenai River tributaries in Northern Idaho were expected to be few and far between. For the BC streams this was indeed the case during 2004-2007 with < 200 counted in any year and underscored in 2005 when only one fish was observed in the nine streams surveyed (Table 8.3). Gray and Akokli creeks were the only two streams where a few spawners were observed in more than one of the four survey years. It is speculated that the few fish observed were most likely strays from Meadow Creek or possibly from Koocanusa Reservoir since no system shows any evidence of recruits from known spawners three or four years prior except possibly Gray Creek.

The spawner counts in the Northern Idaho tributaries from 2004-2006 also show little evidence of any sustainable spawning (Table 8.4) with most of the seven index streams having no spawners during these three years. The 2007 escapement estimates were a somewhat different story with appreciable numbers (low hundreds) counted in Smith and Trout creeks and some spawners in the other four streams surveyed. The combined number in 2007 for the six streams surveyed was 787, the highest recorded since the early 1980s. Ericksen et al. (2009) attribute this increase to eyed egg plants during the early 2000s (see below) although they don’t rule out the possibility these spawners were from entrained juvenile kokanee from the Libby Dam.

Table 8.3. Estimates of kokanee spawners in South Arm of Kootenay Lake tributaries Counts represent peak number for the season (data from Andrusak et al. 2009 and E. Schindler MoE, Nelson BC pers. comm).

	British Columbia tributaries											
Year	**CRA**	**GRA**	**LAF**	**LOC**	**AKO**	**SAN**	**BOU**	**MID**	**GOA**	**SUM**	**CUL**	**All**
1951					354							354
1952					172							172
1953-68						No records						
1969										3,100		3,100
1970										4,200		4,200
1971						No records						
1972						650	30		17,500	3,700		21,880
1973										1,400		1,400
1974										900		900
1975										1,750		1,750
1976										2,300		2,300
1977						No records						
1978										1,150		1,150
1979										2,050		2,050
1980										4,100		4,100
1981-85						No records						
1986		204	38	128	13	40	0		3,710	2,500		6,633
1987-88						No records						
1989										1,700		1,700
1990										0		0
1991										0		0
1992						6	3		20	30		59
1993						No records						
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

CRA=Crawford LOC=Lock-hart BOU=Boulder SUM=Summit
GRA=Gray AKO=Akokli MID=Midge CUL=Cultus
LAF=LaFrance SAN=Sanca GOA=Goat River

Table 8.4. Estimates of kokanee spawners in Kootenai River tributaries in Northern Idaho. Counts represent peak number for the season (data from Ericksen et al. 2009).

Year	Boundary	Smith	Long Canyon	Parker	Trout	Myrtle	Ball	All
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

Kokanee egg plants

Given the circumstance where no spawners had been observed for many years, fisheries managers in Idaho and BC determined that the most effective way to reconstruct the South Arm population was to "plant" eyed kokanee eggs. BC commenced egg plants in 2005 (Table 8.5) simultaneously with South Arm nutrient additions while Idaho started planting eggs in 1997 (Table 8.6).

The egg source for the contemporary egg plants in BC and Idaho was Meadow Creek. The number of eggs planted depended on egg supply as dictated by the numbers and size (fecundity) of spawners returning to the Meadow Creek. For example, relatively few eggs were planted in 2006 due to low spawner returns and an average or smaller size of fish. Once full South Arm fertilization began in 2005 egg plants have increased especially in BC. Combined egg plants for all systems exceeded three million in 2007.

Table 8.5. Meadow Creek kokanee eyed eggs planted in BC tributaries 1929-2007 (data from Andrusak et al. 2009 and E. Schindler MoE, Nelson BC pers. comm).

	British Columbia tributaries								
Year	**Akokli**	**Boulder**	**Crawford**	**Cultus**	**Goat R.**	**LaFrance**	**Lockhart**	**Summit**	**All**
1929[a]				40,000					40,000
1930					No records				
1931			120,000						120,000
1932-45					No records				
1946	50,000		50,000			50,000	50,000		200,000
1947	50,000		50,000c			110,000			160,000
1948	50,000		50,000		100,000				200,000
1949	90,000		80,000		160,000	80,000			410,000
1950	100,000		60,000		80,000	30,000			270,000
1951	50,000		30,000		75,000	20,000			175,000
1952	30,000		30,000		30,000	20,000	20,000		130,000
1952-57					No records				
1958[b]		90,000			160,000				250,000
1959-86					No records				
1987					400,000			100,000	500,000
1988[c]					400,000			100,000	500,000
1989-04					No records				
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

Table 8.6. Meadow Creek kokanee eyed eggs planted in Idaho tributaries 1997-2007 (data from Ericksen et al. (2009).

	Idaho tributaries								
Year	**Boundary**	**Long Canyon**	**Parker**	**Trout** (S fork)	**Trout** (N fork)	**Ball**	**Myrtle**	**Fisher**	**All**
1997		100,000							100,000
1998		100,000	100,000[a]	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

Trawl and acoustic surveys

Trawl data

The trawl surveys from 2004-2007 were conducted throughout the lake thus providing some contrast between size of North and South Arm kokanee, age structure, size-at-age and relative abundance. Good estimates of fry size were obtained for the North Arm for all early summer survey years. However fry densities were often too low in the South Arm thus insufficient numbers of fish were caught to make any valid statistical comparison (Table 8.7). Due to low numbers, trawling was conducted where the fry density on the acoustic survey was the highest. Even so, if it was not possible to catch fry in three one hour trawls, no further sampling occurred (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). The numbers of fry captured in early summer sampling in the South Arm ranged from 0-16 fish while age 1+ fish numbers ranged from 2-34 fish indicating the net was fishing properly (Table 8.7a and b). In the North Arm the fry catches ranged from 52-256 and highest numbers were caught in a single trawl during 2007. The early summer trawl data supports other studies of seasonal kokanee distribution in Kootenay Lake indicating fry densities are highest in the North Arm early in the season owing to very high production from Meadow Creek and the Lardeau River and very low production from the entire South part of the lake. Comparisons of fall trawl catch data between the two areas of the lake indicates the fry have dispersed southward by late summer. i.e., mix of all “populations” has occurred.

A cumulative length frequency of north and south arm trawl catches (2004-2007) showed three distinct modes corresponding to the size of age 0+, age 1+ and age 2+ fish (Fig. 8.2). A small number of age 3+ fish were also caught some years, but not reported here. In general it appears fry in the South Arm may have been slightly larger than in the North Arm. The individual plots by year (Fig. 8.3) suggest no difference in 2004 and 2005 between North and South Arms, while fry in the South Arm did appear to be larger in 2006 and 2007, although sample sizes were small. Whether this is partly a response to South Arm nitrogen additions or larger numbers of fish entering the South Arm from Koocanusa Reservoir through entrainment is unknown at this time. There is some evidence from dip netted samples of age 0+ fish in July that entrained fish reared in the Kootenay/ai River and the South Arm of Kootenay Lake may have a growth advantage over fish rearing in the North Arm of Kootenay Lake. Table 8.7a illustrates that mean size of 38 fry captured in the Kootenay River two weeks after the July 2007 trawl survey were fairly similar in size to the South Arm fry (50 mm vs 49 mm) and substantially larger than North Arm fry (mean of 39 mm). This size difference provides further evidence that spring captured fry in the South Arm were of South Arm origin rather than from the North Arm.

Table 8.7. Size statistics for a) age 0+ b) age 1+ and c) age 2+ kokanee based on early summer trawl sampling. (Note: 2007 Kootenay River fry dip netted).

a) Age 0+ kokanee

	Location	Ave. Length (mm)	Length range (mm)	S.D.	Sample size (n)
2004	North Arm	32	25-54	3.4	165
2004	South Arm	34	33-34	0.7	2
2005	North Arm	39	31-50	3.4	103
2005	South Arm				0
2006	North Arm	36	28-41	2.8	52
2006	South Arm	45	36-66	8.4	16
2007	North Arm	39	30-50	3.4	256
2007	South Arm	49	40-63	8.3	9
2007	*Kootenay R*	*50*	*39-67*	*4.8*	*38*

b) Age 1+ kokanee

	Location	Ave. Length (mm)	Length range (mm)	S.D.	Sample size (n)
2004	North Arm	89	74-106	7.2	84
2004	South Arm	89	82-101	8.8	4
2005	North Arm	92	69-127	16.7	14
2005	South Arm	90	75-98	7.3	8
2006	North Arm	83	73-109	9.1	22
2006	South Arm	97	77-124	14.6	34
2007	North Arm	94	83-103	6.1	13
2007	South Arm	94	80-107	7.4	19

c) Age 2+ kokanee

	Location	Ave. Length (mm)	Length range (mm)	S.D.	Sample size (n)
2004	North Arm	180	180		1
2004	South Arm				0
2005	North Arm	191	180-203	16.7	2
2005	South Arm	177	138-197	27.9	4
2006	North Arm	162	162		1
2006	South Arm				0
2007	North Arm				NS
2007	South Arm	176	142-192	17.5	9

Analysis of mean size-at-age of kokanee since South Arm nutrient additions began in 2004 relies almost entirely on response of North Arm fish (mostly Meadow Creek stock) given the paucity of South Arm origin fish. The fall trawl data shown in Figure 8.4 illustrates two points: firstly, mean size of age 0+ and 1+ fish have not changed since 2004; secondly mean size of age 2+ and 3+ have changed. These shifts in mean size were most likely a reflection of density dependent growth due to the entire lake growing conditions rather than due solely to South Arm fertilization.

Acoustics data

There is a wealth of information on Kootenay Lake kokanee as a result of long term hydroacoustic surveys that provide considerable insight into changes that have taken place before and after lake nutrient additions. Nighttime surveys of the limnetic zone of the main lake portion of Kootenay Lake have been conducted in a standardized manner since 1991 (details in Chapter 8 in this report). As well, comparable manual echo counts date back to 1985. Initial surveys in the late 1980s and early 1990s, indicated total numbers were low, not exceeding 15 million. Within two years of North Arm fertilization commencing in 1992 there was a sizeable increase in total numbers, surpassing 35 million by 1994. Sebastian et al. (2009) attribute this increase mainly to rapid growth and increased fecundity leading to higher fry production following the onset of fertilization (i.e., a classic density-growth response to favourable in-lake conditions).

Analysis of the 2004-2007 acoustic data provides some insight into the influence of South Arm nutrient additions on the kokanee population. The majority of kokanee fry were concentrated at the north end of the lake in the vicinity of the fertilization site (transects 2-5, Fig. 8.5) in early summer after emigrating from Meadow Creek. As the summers progressed during most years the fry move southward and by the fall survey period were more evenly distributed throughout the lake. An exception to this general trend was observed in 2005 when the fry remained concentrated in the North Arm throughout the summer and into the fall. Similar distributions of fry were observed in the fall of 1993 and again in 2001, both concurrent with relatively low densities of age 1-3+ fish, large sized spawners and a building fry population. The 2004 data should be considered a pre-(South Arm) treatment condition since nutrient additions didn’t get underway until late in the summer. The only inference that can be drawn from this data is that at least for 2006 and 2007 there was evidently sufficient food in the South Arm for the fry (see Chapter 6).

The age 1-3+ kokanee were more evenly distributed than the fry in the lake during early summer surveys, but did show some tendency to concentrate in the North Arm fertilization zone (Fig. 8.6). By the fall, age 1-3+ fish were fairly evenly distributed over the lake. As with fry, the 2006 year was different for age 1-3+ fish with concentrations remaining in the North Arm fertilization zone into the fall. The 2006 and 2007 data is of some interest as the age 1-3+ fish were slightly more concentrated in the South Arm during the fall, which may be a sign that habitat conditions for kokanee may be improving as a result of South Arm nutrient additions. Combining the acoustic transect data separately for the North and South arms illustrates that fry densities appear to be increasing in the South Arm during the fall. It also shows that age 1-3+ fish densities in the fall have been higher in the South Arm compared to the North Arm which represents a change from the two previous years. (Figs. 8.7a, b). Note that wider bounds on the spring fry estimates indicate how variable the transect densites were in the North Arm early in the season as a result of high concentrations of fish at the North end of the North Arm (vicinity of recruitment and fertilization). In most cases the the mean densities of fry and age 1-3+ kokanee declined between summer and fall census presumably as a result of natural mortality and predation, although the declines were often not statistically significant. The 2006 survey suggests an increase in the overall numbers of both fry and age 1+ fish between June and September sampling and provides evidence to support the notion that spring sampling may under-estimate fish numbers due to their proximity to the surface, particularly in the North Arm fertilization zone (i.e. it is not possible for total numbers of kokanee to increase once the spring fry emigration is complete).

Prior to North Arm fertilization, kokanee densities in the South Arm tended to be higher during late summer than in the North Arm (Fig. 8.8). During the first seven 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 1999 this trend reversed under reduced fertilizer loadings (Fig. 8.9) but resumed in 2001 as fertilizer loading was increased. There was an immediate increase in North Arm numbers with the return to increased nutrient loadings by 2001, and then South Arm numbers increased and remained very high until 2004 when North Arm numbers again were appreciably higher through 2005 and 2006. Although North Arm nutrient loading rates increased from 2004-2007, kokanee numbers in the lake inexplicably declined during 2004 and 2005 and increased again in 2006 and 2007.

Kokanee Biomass Estimates

In-lake total kokanee biomass was estimated by applying the mean weights and proportions of each age group from trawl sampling to the total numbers determined from hydroacoustic fall surveys (see Appendix 7.6 Chapter 7 for details). The calculated biomass is then converted to kg/ha based on known pelagic area of the lake. Because there was no trawl data collected in 2007 the average weights of the previous four years were used to estimate 2007 biomass. Prior to nutrient additions (1985-1991) the average kokanee biomass density was ~3.5 kg/ha. Since nutrient addition (1992-2007) the kokanee biomass densities has increased to an average of ~ 10.9 kg/ha, close to a three-fold difference. These estimates track the fertilizer loading rates that include decreases from 1997-2000 then increased loadings from 2001-2007.

Attempts to apply the current method of estimating biomass to North and South arms separately resulted in some highly variable and questionable results from year to year. It was concluded that there was an insufficient number of trawl stations and fish samples to reliably estimate the age structure separately for each arm each year. At the time of this writing, an alternative method for estimating biomass density directly from acoustic data was under development. The hope is to eliminate the need to rely on age structure from trawling, but rather use size structure from acoustic signals to estimate fish biomass more consistently. If successful, the acoustic approach could enable some back-casting to compare North and South Arm biomass throughout the experimental period and may assist in interpreting relative affects of North and South Arm treatments on kokanee production.

Discussion

Restoration of South Arm Kootenay Lake kokanee was undertaken in 2004 by multi-agencies that included the BC Ministry of Environment, the Kootenai Tribe of Idaho (KTOI), Bonneville Power Administration (BPA) and Idaho State Fish and Game. This work has 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. 2009b) there has been little evidence that four years of South Arm fertilization has resulted in similar increases in South Arm kokanee. This is not surprising since few if any South Arm fish exist and those that do persist are completely “swamped” by the millions of fry and juvenile fish of Meadow Creek origin. While there is no evidence that South Arm kokanee have increased in numbers due to South Arm fertilization, monitoring results of the lower trophic levels indicate South Arm productivity has improved since fertilization began as evidenced by increases in zooplankton biomass (see earlier Chapters in this report).

A five year review of the upper Arrow Lakes Reservoir fertilization program by Schindler et al. (2006) focused on four measures that supported the original hypothesis that nutrient additions would increase the reservoirs’ productivity that in turn would increase kokanee numbers. These metrics included: kokanee escapements, in-lake kokanee abundance, density dependent growth responses, and kokanee biomass.

Realistically it was not 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 2009). Appreciable numbers of eyed eggs were planted in these streams only beginning in 2005 therefore returns from this initial introduction will not likely occur until 2009. It has only been over the last five years (2003-2007) for all South Arm streams combined (BC and Idaho) that large numbers of eyed eggs have been planted with three of these years exceeding 3 million eggs per year. Even these egg numbers at an assumed survival of 50% would produce few fry compared to ~15-25 million fry produced from Meadow Creek (Schindler et al. 2009a). One encouraging note is that Idaho actually planted sizeable numbers of eyed eggs (i.e. > 1 million) in some Idaho tributaries as early as 2003 and their progeny account for a 25 year high return of spawners in 2007.

Any influence of South Arm nutrient addition on South Arm kokanee has most likely been masked by other more dominant factors such as the response to lake growing conditions by variable numbers of North Arm kokanee. For example, escapements to Meadow Creek in 2004 and 2005 exceeded 1.0 million but numbers declined to less than 0.5 million in 2006 and 2007 (Fig. 8.10). Clearly these changes in North Arm escapements during the last four years were not correlated with South Arm nutrient additions but more likely related to other factors such as changes in rates of predation. The influence of Libby Reservoir kokanee on the South Arm population is also an unknown factor. Escapements from entrained kokanee from Libby Dam have not been quantified but evidently spawner numbers below the impassable Kootenai Falls were several hundred thousand in the 1990s. However, changes to the dam discharge regime have greatly reduced entrainment in recent years and few spawners are observed today (P. Anders Cramer Fish Sciences Moscow, Idaho pers. comm.).

Early summer vs. fall trawl and acoustic data shows clear evidence that North Arm kokanee move southward and mix with South Arm fish. It is uncertain as to the origin of the early summer South Arm fish but their mean size (Table 8.7a) suggests they were probably not Meadow Creek fish. It is most likely that these are comprised of a few progeny from South Arm tributaries and entrained kokanee from Koocanusa Reservoir. The increases in mean length at age since 2004 illustrated in Figure 8.3 cannot be attributed to South Arm nutrient additions but rather this increase was almost certainly attributable to a whole lake density dependent growth response by North Arm kokanee. In-lake abundance, particularly during 2004 and 2005, was comparatively low (Fig. 8.9) when growing conditions were sufficient thus ideal growing conditions were present that resulted in size increases for age 1-3+ 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 nutrient addition. It might be expected that growth and or survival rates of Meadow Creek kokanee would improve with South Arm fertilization in addition to North Arm fertilization and this should be reviewed in the near future.

Fall acoustics data for 2006 and 2007 indicated that greater numbers of kokanee were present in the South Arm compared to the North Arm. Presumably this indicated favourable 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 nutrient additions, it should be noted that such southern movements have been observed a number of times prior to 2004 (data on file MoE Victoria BC) i.e., southward movement cannot solely be attributed to South Arm nutrient additions.

Total in-lake abundance based on the acoustic data suggests a decline from 25-35 million in 2002 and 2003 to about 15 million in 2004 and 2005; the 2006 and 2007 estimates increased to ~ 22 million. These changes in total abundance are related to variations in total fry production from Meadow Creek and density dependent growth (Schindler et al. 2009a) i.e., unlikely solely due to South Arm nutrient additions.

Kokanee biomass since fertilization began in the North Arm in 1992 has increased threefold. The influence of South Arm fertilization (alone) cannot be determined from the available data since the trawl data was insufficient to reliably determine age structure and biomass for the individual basins and fall trawl data was not available in 2007. At time of writing a new approach was being developed to estimate fish size distribution and biomass directly from acoustic data. If successful, it will be possible to compare north and south basin biomass over the experimental period, which may assist in evaluating the relative contributions from North and South Arm treatment.

This review suggests there is little direct evidence yet that South Arm nutrient addition has had an immediate impact on South Arm kokanee. There is ample evidence from the monitoring program that primary and secondary productivity has increased. There were more kokanee utilizing the south basin in 2006 and 2007 but it is too early to determine if South Arm nutrient addition alone has improved their growth and survival. Arrow Lakes Reservoir and North Arm Kootenay Lake nutrient restoration projects have greatly improved kokanee numbers through this bottom up approach to ecosystem restoration and the same success is expected for the South Arm. The overwhelming influence of the dominant North Arm kokanee population currently confounds any analysis of specific fertilization impacts on South Arm kokanee. In-lake abundance is dominated by the Meadow Creek stock hence annual variations in total numbers and size are density dependent largely on Meadow Creek operations which overshadows any direct measure of South Arm fertilization on South Arm kokanee. The ultimate measure of the South Arm experiment will be observed increases of kokanee spawners in the South Arm tributaries. Continuation of eyed egg plants, nutrient additions and stream restoration efforts should ultimately result once again in some naturally produced kokanee spawners returning to the South Arm tributaries.

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George Scholten of the Ministry of Environment in Victoria is acknowledged for his tireless hours of collection and analysis of acoustic and trawl data. Thanks to Don Miller and staff of Kootenay Wildlife Services Ltd for conducting the trawl surveys. Les Fleck is thanked for collecting data on kokanee stream escapements on South Arm (BC) streams. Jeff Burrows is acknowledged for direction on the kokanee egg plants. Thanks to the following individuals for their assistance to the 2007 eyed egg plants – Marley Bassett, Jeff Burrows, Gary Munro and Eva Schindler of Ministry of Environment, Nelson; Les Fleck and Jordan Knox of Crystal Springs Contracting, Greg Andrusak of Redfish Consulting Ltd., Mickey McDonald, Traci Jensen and Laird Siemens of the Freshwater Fisheries Society of BC. The Fish and Wildlife Compensation Program – Columbia Basin provided the funds for the North Arm Kootenay Lake Nutrient Restoration program and the fall kokanee hydroacoustic surveys from 1992 through

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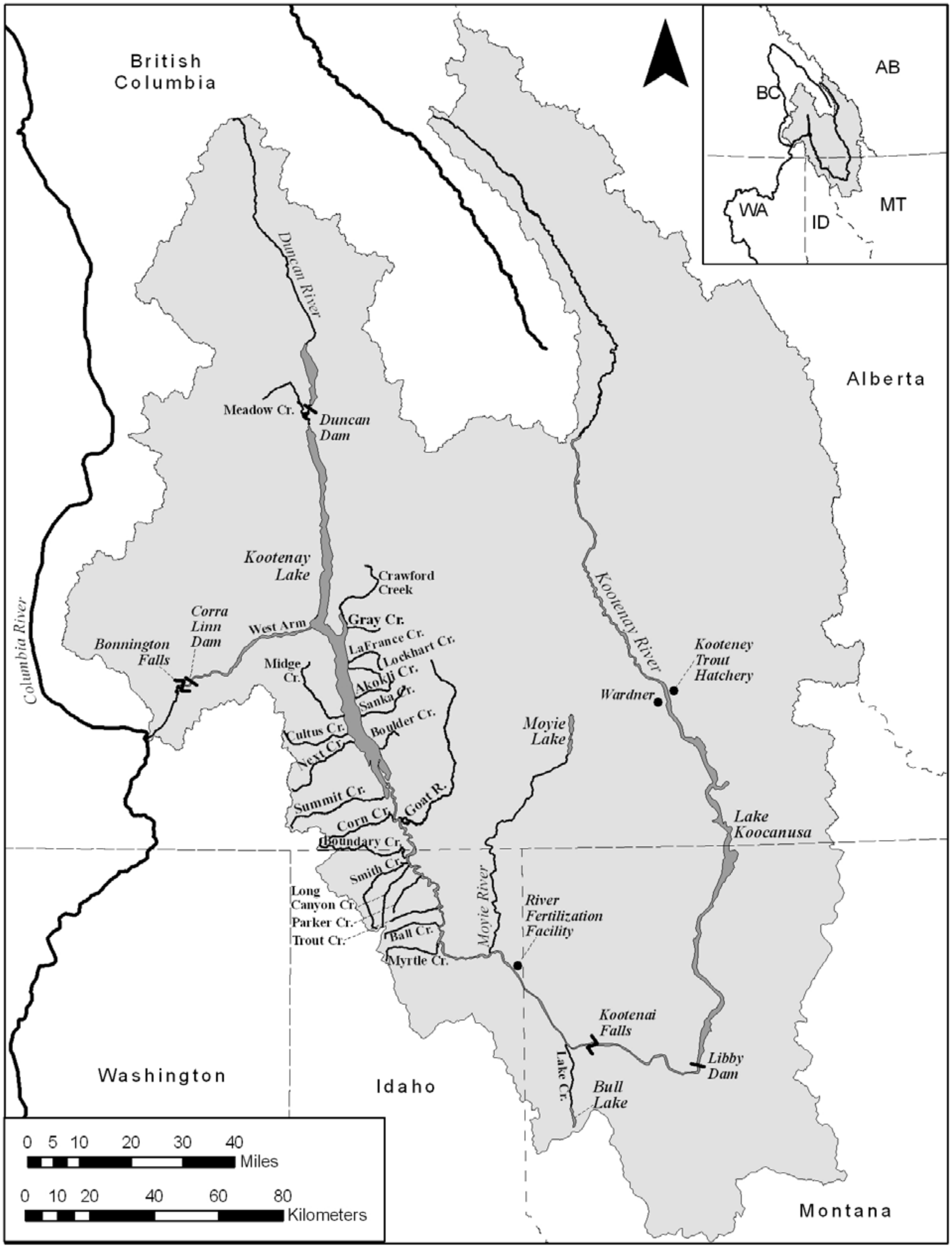

Figure 8.1. Map of the Kootenay River Basin in British Columbia, Montana, and Idaho (adopted from Ericksen et al. 2009).

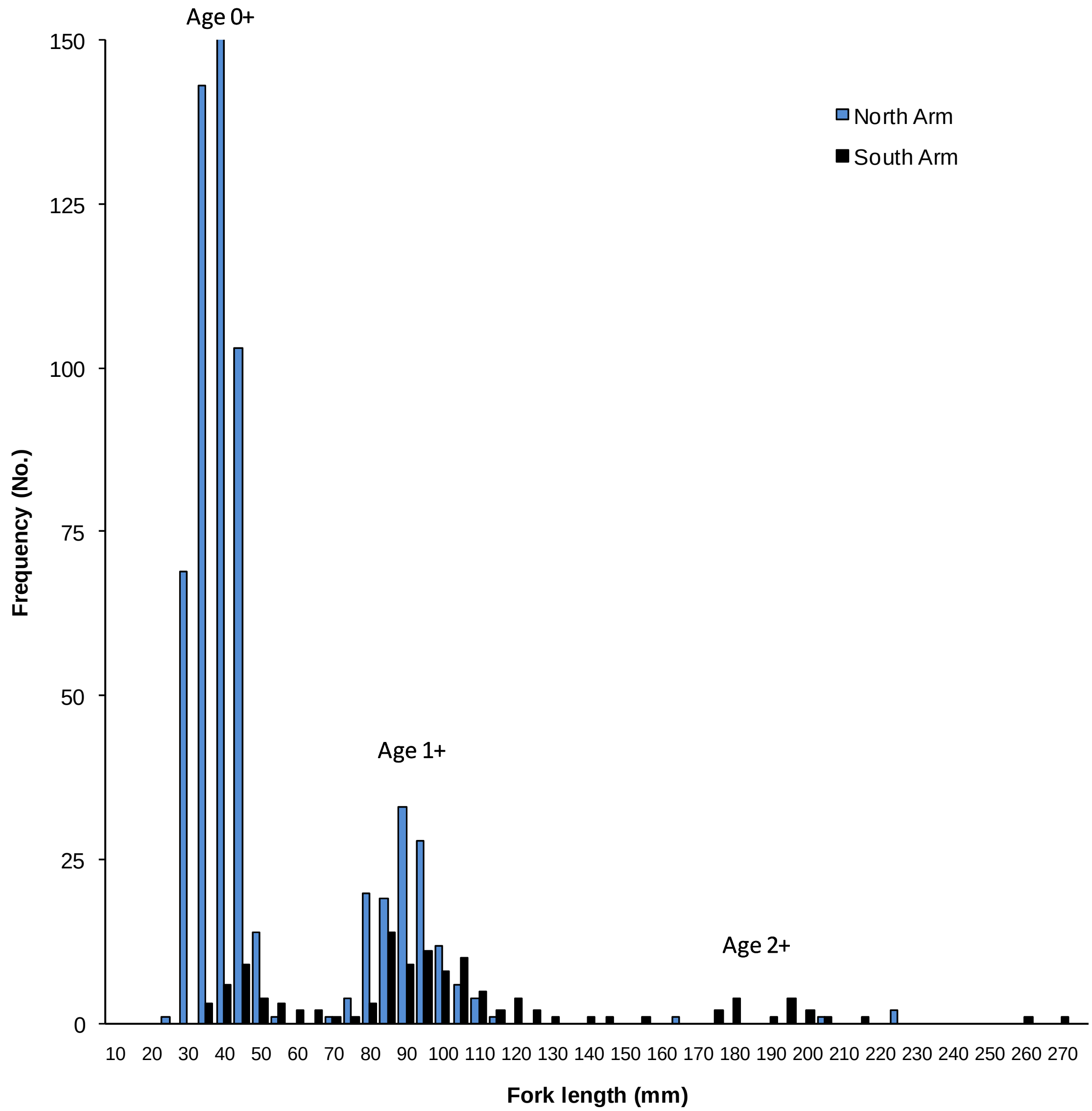

Figure 8.2. Cumulative length frequency for trawl caught kokanee for North and south Arms of Kootenay Lake based on early summer trawl sampling in 2004-2007.

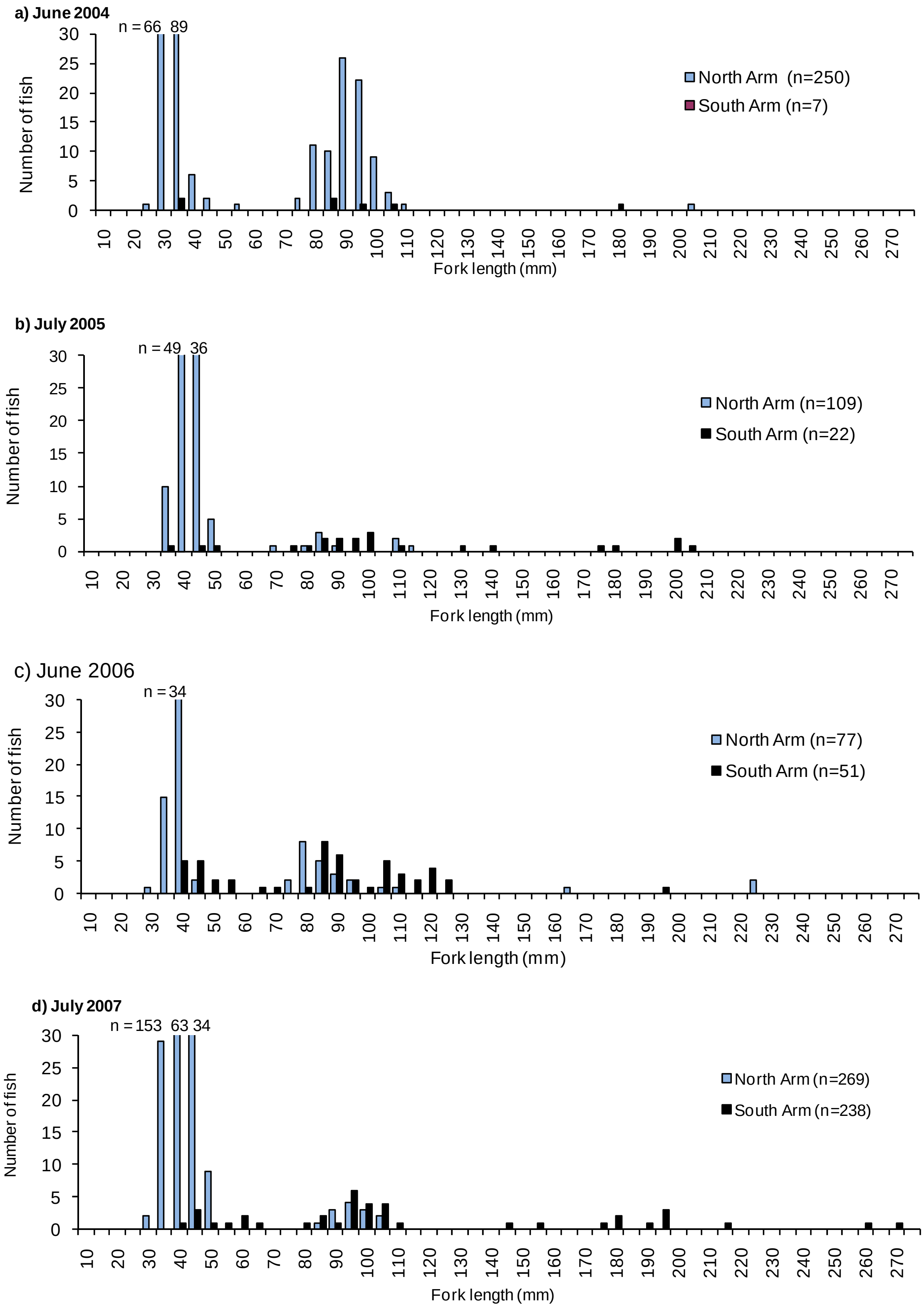

Figure 8.3. Kokanee length frequency for North and South Arm based on a) 2004 b) 2005 c) 2006 and d) 2007. Note: sample sizes of modes of fry shown as they exceed Y-axis range e.g. 2004 n=66, 89.

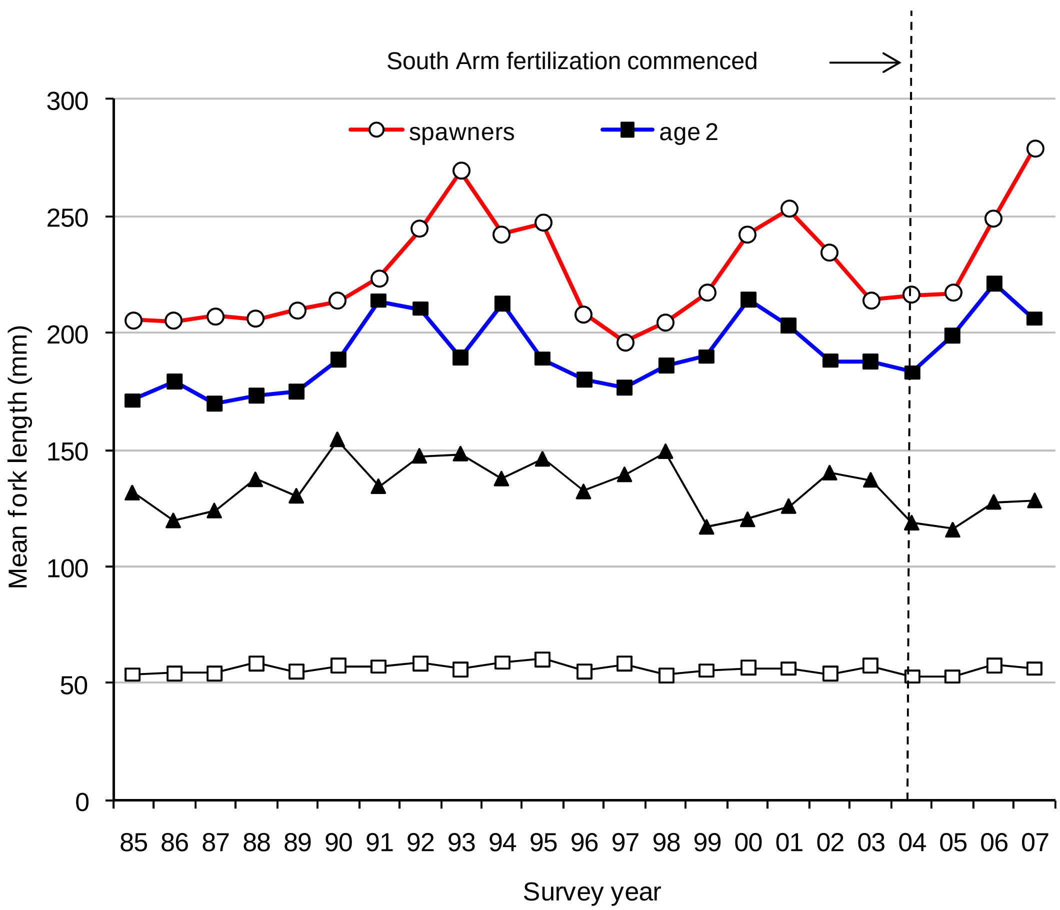

Figure 8.4. Trends in means length-at-age for kokanee in Kootenay Lake based on fall trawl surveys, 1985-2007.

Figure 8.5. Seasonal distribution of kokanee fry in Kootenay Lake during early summer and fall 2004-2007. Transect #1 at north end and #18 at south end of lake. Note scales on early season distributions in 2005 and 2007 were increased.

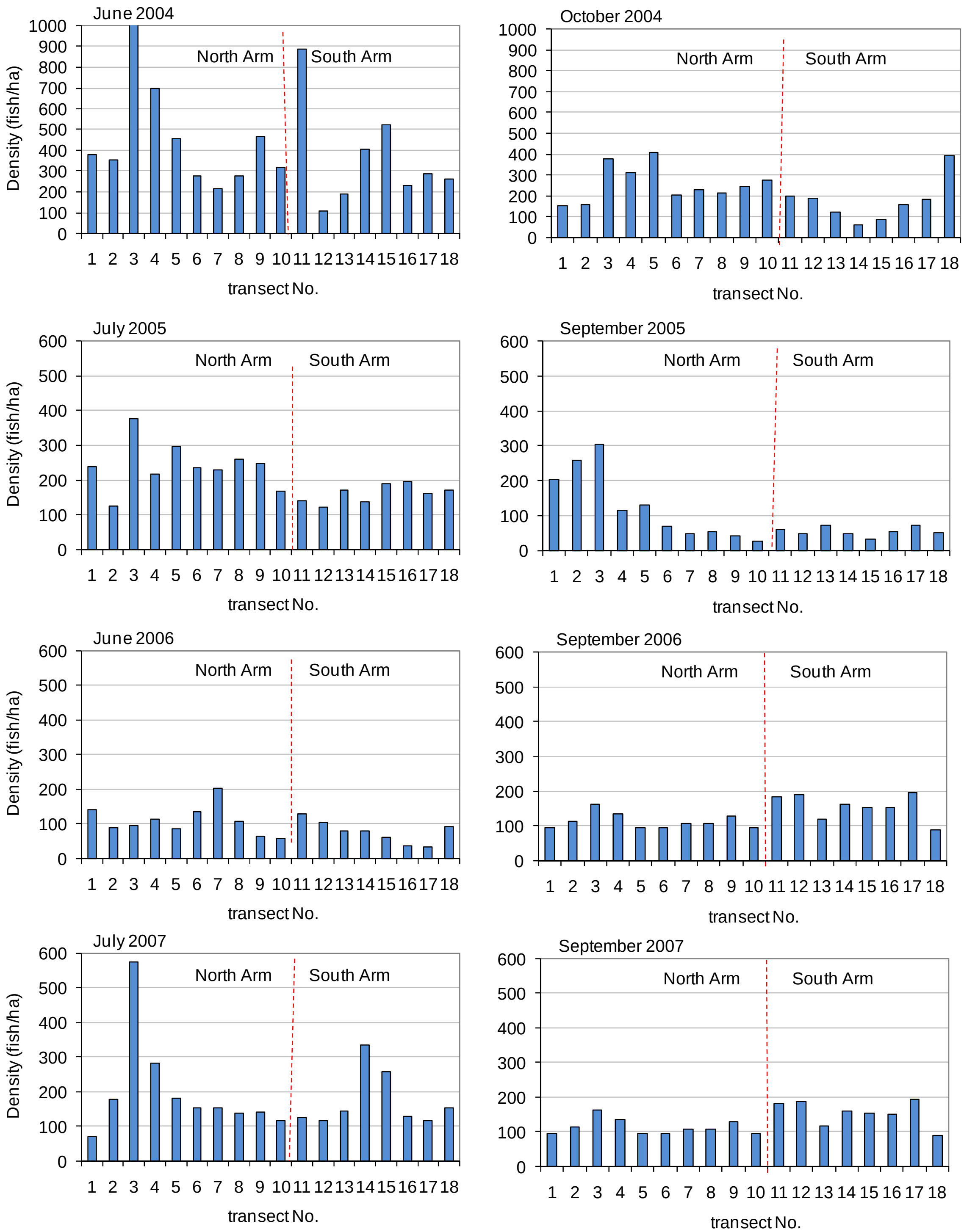

Figure 8.6. Seasonal distribution of ages 1-3+ kokanee in Kootenay Lake during early summer and fall 2004-2007. Transect #1 at north end and #18 at south end of lake.

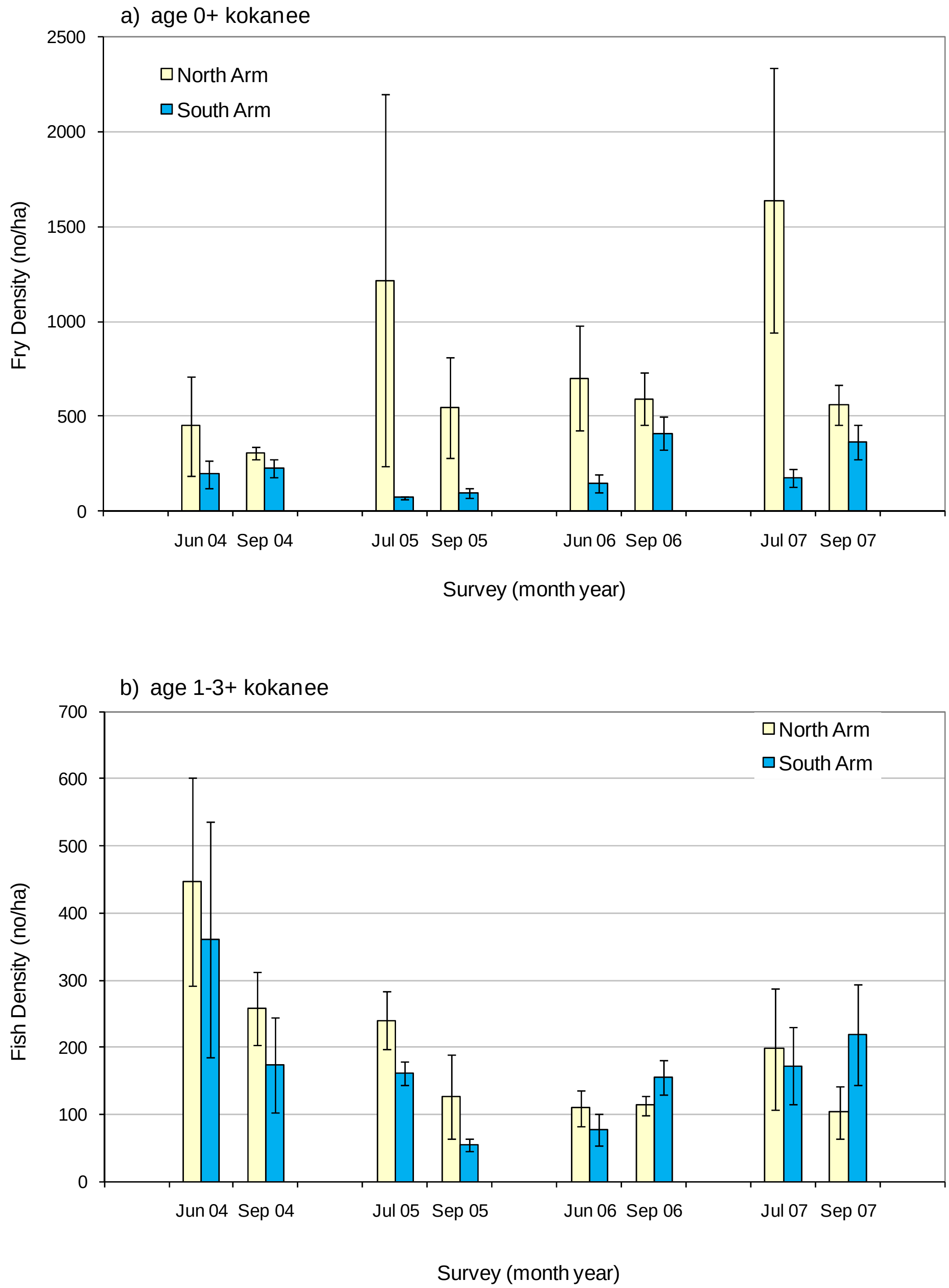

Figure 8.7. Comparison of Kootenay Lake age 0+ kokanee density from summer and fall hydroacoustic surveys during 2004-2007 (top) and comparison of Kootenay Lake age 1-3+ kokanee density from summer and fall hydroacoustic surveys during 2004-2007 (bottom). Error bars indicate 95% C.L. (2*S.E.)

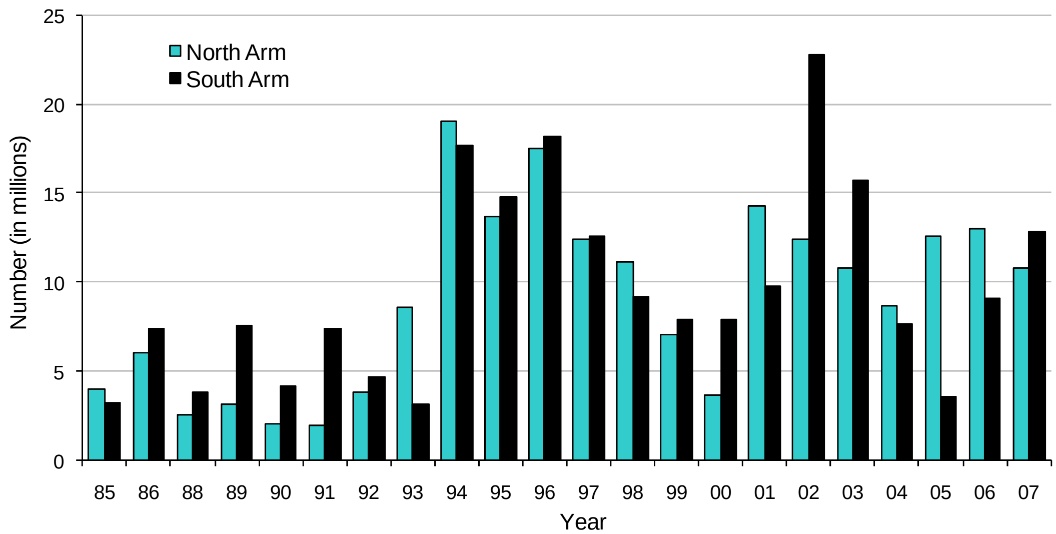

Figure 8.8. Comparison of North and South Arm kokanee populations (all ages) based on acoustic surveys.

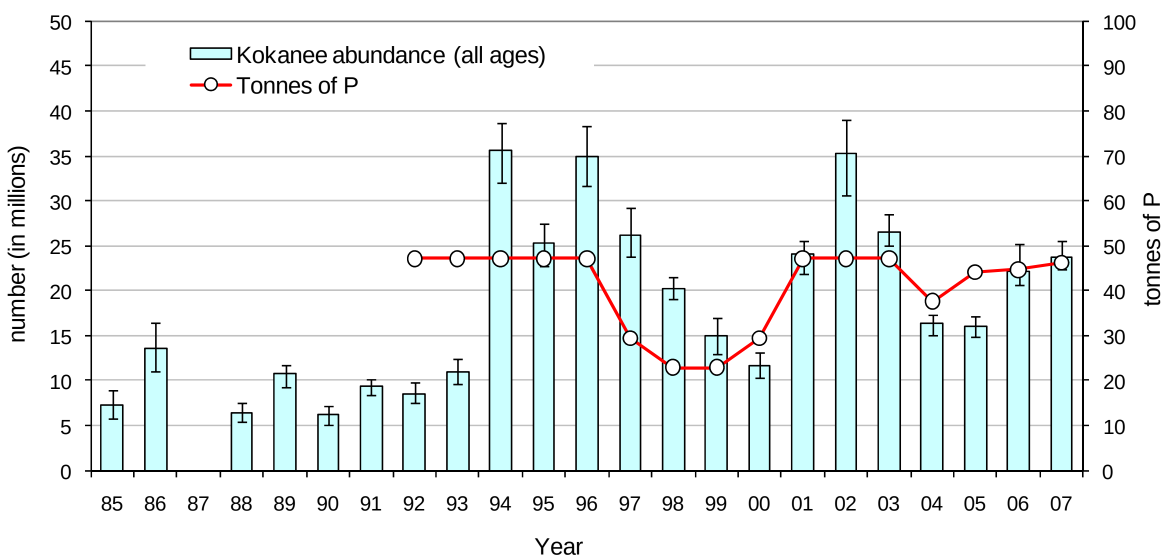

Figure 8.9. Total abundance of kokanee all ages in fall and phosphorous loadings to North Arm.

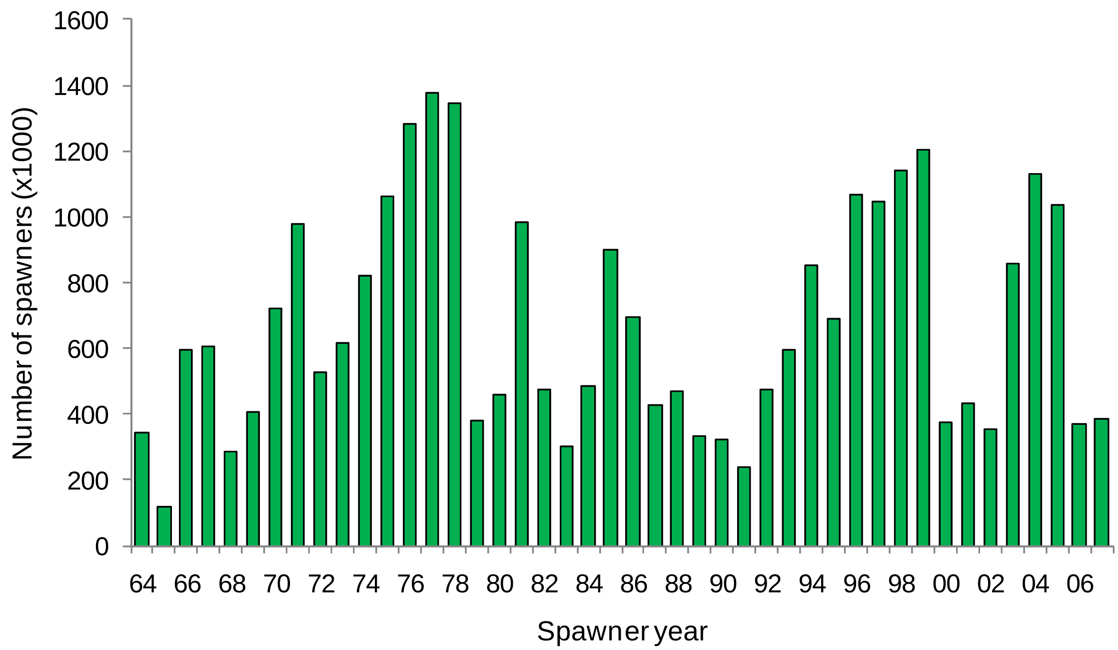

Figure 8.10. North Arm of Kootenay Lake kokanee escapements to Meadow Creek, 1964-2007. (Note: 1964-1968 data from Acara 1970, unpubl. MS)

APPENDICES

Appendix 8.1 Kokanee age 0+ and age 1-3+ densities by transect for early season hydroacoustic surveys in 2004-2007.

Age 0+ kokanee density (no./ha) by transect

Transect No.	2004	2005	2006	2007
1	393	1287	589	665
2	1346	2198	754	2527
3	1063	4929	649	1869
4	433	2293	1415	1563
5	233	351	1335	3480
6	107	393	976	3148
7	190	272	612	1362
8	227	232	235	688
9	266	121	193	577
10	233	89	245	508
11	335	81	137	306
12	76	78	113	211
13	107	61	211	161
14	189	83	135	188
15	200	62	155	221
16	139	76	92	127
17	161	55	52	94
18	366	75	280	116

Age 1-3+ kokanee density (no./ha) by transect

Transect No.	2004	2005	2006	2007
1	380	238	143	70
2	356	125	90	177
3	1024	376	95	574
4	698	218	112	282
5	455	298	86	180
6	275	237	136	153
7	217	231	203	152
8	277	262	106	138
9	467	248	64	142
10	318	168	57	116
11	886	142	129	125
12	107	122	105	118
13	187	172	79	144
14	406	139	81	335
15	522	189	60	260
16	228	196	36	129
17	285	163	33	116
18	263	172	93	155

Appendix 8.2. Maximum likelihood population estimates and bounds from early summer hydroacoustic sampling on Kootenay Lake during 2004-07.

June 2004 Survey for kokanee of all ages (>–62 dB) in three zones (transects 1-5, 6-11, 12-18)

Zone	Depth	N	R^2	Density	Std Error	Area	Stratum Pop.	Stat[1]	Abundance
1	5	4	0.80	175.76	50.66	8030	1411361		
1	10	4	0.88	193.45	41.62	8030	1553371		
1	15	5	0.79	241.80	62.89	8030	1941614		
1	20	5	0.62	166.10	62.01	7944	1319415		
1	25	4	0.86	69.64	16.54	7863	547616		
1	30	4	0.86	18.66	4.31	7759	144767		
1	35	5	0.85	3.76	0.79	7645	28706		
1	40	4	0.93	1.77	0.28	7528	13310		
2	5	6	0.92	48.08	6.50	12060	579809		
2	10	5	0.91	63.36	9.94	12060	764134		
2	15	5	0.97	110.22	9.46	12060	1329253		
2	20	5	0.90	115.43	19.64	11961	1380615	LB=	19,245,000
2	25	5	0.75	100.29	28.62	11868	1190195	MLE=	21,731,000
2	30	5	0.84	86.04	18.55	11709	1007478	UB=	24,003,000
2	35	5	0.71	20.81	6.60	11546	240274		
2	40	5	0.76	4.04	1.13	11454	46242		
2	45	5	0.92	1.53	0.22	11359	17424		
2	50	5	0.96	1.42	0.14	11286	16026		
3	5	6	0.97	36.53	2.67	18110	661540		
3	10	6	0.88	71.23	11.74	18110	1290030		
3	15	6	0.94	108.87	11.85	18110	1971618		
3	20	6	0.81	133.86	28.70	18012	2411102		
3	25	7	0.72	55.55	14.05	17911	994915		
3	30	7	0.77	23.11	5.17	17808	411455		
3	35	6	0.97	10.29	0.77	17720	182339		
3	40	6	0.97	3.75	0.31	17626	66168		
3	45	6	0.91	3.68	0.53	17533	64485		
3	50	7	0.62	1.40	0.45	17424	24412		

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

June 2004 Survey for ages 1-3 kokanee (>–50 dB) in three zones (transects 1-5, 6-11, 12-18)

Zone	Depth	N	R^2	Density	Std Error	Area	Stratum Pop.	Stat[1]	Abundance
1	5	4	0.92	93.55	15.57	8030	751174		
1	10	4	1.00	90.15	3.37	8030	723929		
1	15	5	0.82	141.04	33.35	8030	1132511		
1	20	5	0.55	121.74	54.61	7944	967050		
1	25	4	0.87	48.66	10.89	7863	382584		
1	30	4	0.89	10.78	2.21	7759	83661		
1	35	4	0.98	3.19	0.26	7645	24364		
1	40	5	0.61	0.69	0.28	7528	5180		
2	5	5	0.79	18.58	4.75	12060	224075		
2	10	5	0.87	30.40	5.94	12060	366660		
2	15	5	0.83	62.87	14.33	12060	758152		
2	20	5	0.85	74.24	15.62	11961	887952	LB=	11,457,000
2	25	5	0.74	66.31	19.71	11868	786987	MLE=	12,852,000
2	30	5	0.84	55.97	12.40	11709	655353	UB=	14,834,000
2	35	6	0.70	16.57	4.86	11546	191307		
2	40	5	0.75	2.06	0.60	11454	23631		
2	45	5	0.82	0.93	0.22	11359	10598		
3	5	6	0.81	16.50	3.61	18110	298761		
3	10	6	0.88	24.20	4.02	18110	438226		
3	15	6	0.90	64.34	9.43	18110	1165197		
3	20	6	0.79	107.34	24.79	18012	1933435		
3	25	6	0.82	57.53	12.01	17911	1030360		
3	30	6	0.78	12.44	2.95	17808	221550		
3	35	6	0.89	4.23	0.66	17720	74902		
3	40	6	0.82	1.32	0.27	17626	23231		
3	45	6	0.97	1.10	0.09	17533	19216		

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

June 2005 Survey for kokanee of all ages (>–62 dB) in three zones (transects 1-4, 5-10, 11-18)

Zone	Depth	N	R^2	Density	Std Error	Area	Stratum Pop.	Stat[1]	Abundance
1	5	3	0.95	643.4	100.82	6480	4,169,342		
1	10	3	0.95	961.8	164.41	6480	6,232,762		
1	15	3	0.90	276.0	63.47	6480	1,788,299		
1	20	3	0.92	114.5	24.58	6415	734,694		
1	25	3	0.95	127.9	21.21	6355	812,600		
1	30	3	0.91	44.7	10.23	6271	280,313		
1	35	3	1.00	15.8	0.59	6172	97,298		
1	40	3	0.97	2.3	0.30	6071	14,201		
1	45	3	0.99	1.9	0.16	5971	11,541		
1	50	3	0.98	1.6	0.15	5867	9,398	LB=	20,793,000
2	5	5	0.74	20.7	6.17	10260	212,177	MLE=	22,933,000
2	10	5	0.63	52.5	20.32	10260	538,578	UB=	26,165,000
2	15	5	0.96	57.7	5.92	10260	592,361		
2	20	5	0.96	116.4	12.24	10159	1,182,914		
2	25	5	1.00	134.4	3.10	10066	1,353,269		
2	30	5	0.99	49.9	2.87	9954	496,994		
2	35	6	0.93	7.8	0.93	9843	76,872		
2	40	6	0.94	2.3	0.26	9752	22,450		
3	5	8	0.27	2.6	1.61	21460	56,118		
3	10	8	0.89	16.8	2.28	21460	359,670		
3	15	7	0.97	41.3	2.90	21460	885,418		
3	20	7	0.98	75.9	4.34	21341	1,620,779		
3	25	7	0.98	63.9	4.14	21221	1,356,321		
3	30	7	0.93	20.7	2.25	21051	436,532		
3	35	7	0.91	4.6	0.58	20896	95,389		
3	40	7	0.90	1.5	0.21	20785	31,697		

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

June 2005 Survey for age 1-3 kokanee (>–50 dB) in three zones (transects 1-4, 5-10, 11-18)

Zone	Depth	N	R^2	Density	Std Error	Area	Stratum Pop.	Stat[1]	Abundance
1	5	3	0.92	5.4	1.16	6480	34,707		
1	10	3	0.96	6.4	0.90	6480	41,453		
1	15	3	0.96	43.7	6.46	6480	283,481		
1	20	3	0.90	69.5	16.02	6415	446,139		
1	25	3	0.97	69.9	9.13	6355	444,071		
1	30	3	0.93	27.5	5.45	6271	172,447		
1	35	3	0.99	8.0	0.55	6172	49,667		
1	40	3	0.86	1.0	0.28	6071	5,950		
2	5	6	0.24	2.4	1.89	10260	24,480		
2	10	6	0.84	3.4	0.67	10260	34,740	LB=	6,767,000
2	15	5	0.89	14.1	2.45	10260	144,953	MLE=	7,143,000
2	20	5	0.98	75.0	6.02	10159	762,273	UB=	7,528,000
2	25	5	1.00	99.4	2.54	10066	1,000,592		
2	30	5	0.96	35.1	3.37	9954	348,905		
2	35	5	0.97	4.7	0.39	9843	45,789		
2	40	5	0.91	1.0	0.16	9752	9,674		
3	5	8	0.23	1.7	1.16	21460	35,988		
3	10	7	0.93	5.6	0.63	21460	119,918		
3	15	7	0.97	22.0	1.71	21460	471,283		
3	20	7	0.98	55.4	3.33	21341	1,181,358		
3	25	7	0.98	50.6	3.09	21221	1,072,728		
3	30	7	0.88	17.3	2.60	21051	365,127		
3	35	8	0.89	2.4	0.32	20896	49,878		

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

June 2006 Survey for kokanee of all ages (>–62 dB) in two zones (transects 1-10 ,11-18)

Zone	Depth	N	R^2	Density	Std Error	Area	Stratum Pop.	Stat[1]	Abundance
1	5	6	0.91	469.9	67.25	11640	5,469,927		
1	10	7	0.88	327.1	49.20	11640	3,807,851		
1	15	6	0.66	72.3	23.33	11640	841,258		
1	20	7	0.58	21.7	7.49	11517	249,421		
1	25	6	0.85	8.1	1.53	11409	92,890		
1	30	6	0.74	1.3	0.36	11258	15,187	LB=	14,658,000
2	5	10	0.83	73.8	11.02	26560	1,960,367	MLE=	15,770,000
2	10	10	0.85	60.7	8.37	26560	1,613,440	UB=	18,989,000
2	15	10	0.89	51.5	6.17	26560	1,368,052		
2	20	11	0.77	36.5	6.36	26399	962,445		
2	25	11	0.75	12.8	2.32	26233	334,499		
2	30	10	0.56	3.2	0.94	26018	82,321		
2	35	10	0.88	1.3	0.15	25821	32,431		

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

June 2006 Survey for age 1-3 kokanee (>–50 dB) in two zones (transects 1-10 ,11-18)

Zone	Depth	N	R^2	Density	Std Error	Area	Stratum Pop.	Stat[1]	Abundance
1	5	7	0.85	40.4	6.92	11640	470,279		
1	10	7	0.87	52.7	8.52	11640	613,975		
1	15	6	0.72	22.5	6.35	11640	262,144		
1	20	6	0.64	6.6	2.21	11517	75,497		
1	25	6	0.85	3.1	0.58	11409	35,036		
1	30	6	0.81	0.5	0.10	11258	5,235	LB=	3,162,000
2	5	10	0.71	5.9	1.24	26560	155,721	MLE=	3,432,500
2	10	10	0.87	16.3	2.06	26560	432,981	UB=	4,017,000
2	15	10	0.85	25.2	3.48	26560	669,498		
2	20	11	0.76	22.2	3.93	26399	585,233		
2	25	11	0.70	8.5	1.76	26233	223,060		
2	30	10	0.57	1.7	0.50	26018	44,777		
2	35	11	0.65	0.6	0.14	25821	15,673		

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

July 2007 Survey for kokanee of all ages (>–62 dB) in two zones (transects 1-10 ,11-18)

Zone	Depth	N	R^2	Density	Std Error	Area	Stratum Pop.	Stat[1]	Abundance
1	5	10	0.62	521.8	137.14	16740	8,734,949		
1	10	10	0.68	872.5	200.84	16740	14,606,169		
1	15	10	0.68	293.7	67.70	16740	4,916,839		
1	20	9	0.89	105.7	13.15	16575	1,751,293		
1	25	10	0.84	27.7	3.96	16421	454,735		
1	30	9	0.73	3.6	0.79	16225	58,880	LB=	29,111,377
1	35	10	0.81	1.3	0.21	16015	21,204	MLE=	35,668,500
1	40	10	0.84	0.8	0.12	15824	12,469	UB=	45,679,655
2	5	7	0.87	32.7	5.18	21460	700,798		
2	10	7	0.92	52.9	6.50	21460	1,135,685		
2	15	7	0.99	74.5	2.97	21460	1,597,997		
2	20	8	0.90	101.6	13.19	21341	2,169,255		
2	25	7	0.78	44.4	9.61	21221	941,520		
2	30	7	0.79	9.8	2.07	21051	205,835		
2	35	7	0.83	1.5	0.28	20896	31,803		

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

July 2007 Survey for age 1-3 kokanee (>–50 dB) in two zones (transects 1-10 ,11-18)

Zone	Depth	N	R^2	Density	Std Error	Area	Stratum Pop.	Stat[1]	Abundance
1	5	9	0.71	7.3	1.68	16740	122,955		
1	10	10	0.87	26.4	3.42	16740	442,154		
1	15	9	0.69	51.1	12.08	16740	855,866		
1	20	9	0.84	46.2	7.21	16575	766,561		
1	25	10	0.82	14.4	2.25	16421	236,300		
1	30	9	0.84	1.8	0.28	16225	29,594	LB=	5,039,123
1	35	10	0.62	0.9	0.23	16015	13,885	MLE=	5,608,600
2	5	7	0.91	11.4	1.46	21460	244,279	UB=	6,426,106
2	10	7	0.83	14.4	2.67	21460	308,380		
2	15	7	0.91	37.7	4.71	21460	808,870		
2	20	8	0.87	57.1	8.28	21341	1,218,449		
2	25	7	0.78	26.6	5.76	21221	564,237		
2	30	7	0.72	5.0	1.28	21051	105,381		
2	35	7	0.80	0.8	0.15	20896	15,985		

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