DRAFT: March 5, 2009

Feasibility of Fertilizing Takla Lake for Early Stuart Sockeye Recovery

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Executive Summary

This feasibility analysis evaluated the practicality of restoring Early Stuart sockeye by lake fertilization. The project would involve fertilization of Takla Lake in 2010, targeting the Driftwood River sockeye population. The feasibility of this proposal was examined by evaluating results from other fertilized sockeye lakes, analyzing Takla Lake limnology data and developing an implementation plan.

The report addresses a number of key uncertainties which were rated on a 5-point scale: 1=very likely 2=likely 3=uncertain 4=unlikely 5=very unlikely. The following Table reflects the opinion of the report authors:

Uncertainty	Likelihood
Will Takla Lake respond to fertilization?	very likely
Will Early Stuart sockeye juveniles respond to fertilization?	likely
Will fertilization alter sockeye-kokanee interactions?	uncertain
Will Early Stuart sockeye recover?	likely
Is lake fertilization reversible?	very likely

There are 3 fertilizer application options involving tug and barge, herring skiffs or helicopter. Program costs are estimated as $159,000 in 2009, and ranging between $455,000 to $582,000 in 2010, depending on the fertilizer application method. An agreement to implement the project is required by June of 2009, so that a fertilizer tank farm can be constructed at Takla Landing before September of 2009. Next steps for moving the project forward include review of the concept by DFO, establishing partnerships and securing the necessary funding.

Acknowledgements

The Takla Lake fertilization proposal has been discussed with Tl'azt'en, Nak'azdli and Takla Lake First Nations, the Carrier Sekani Tribal Council, and other First Nations involved in the Inter-Tribal Fishing Treaty. Funding was provided by the Fraser River Salmon Table Society, Fraser Salmon and Watersheds Program, and the Upper Fraser Fisheries Conservation Alliance. Section 4 of the report was prepared by Northwest Hydraulic Consultants Ltd. (Dr. Ken Ashley).

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1. Introduction

Early Stuart (ES) sockeye salmon spawn in more than 40 tributaries of the Stuart-Trembleur-Takla system, mostly concentrating in streams adjacent to Takla Lake and the Middle River. The Driftwood River (Figure 1.1) supports a population that was formerly the most productive component of the ES population, reaching an escapement of 430,000 fish in 1993. The run declined to 30,000 spawners in 1997 due largely to migration difficulties (Levy et al. 2008) and has remained depressed since that time (Figure 1.2).

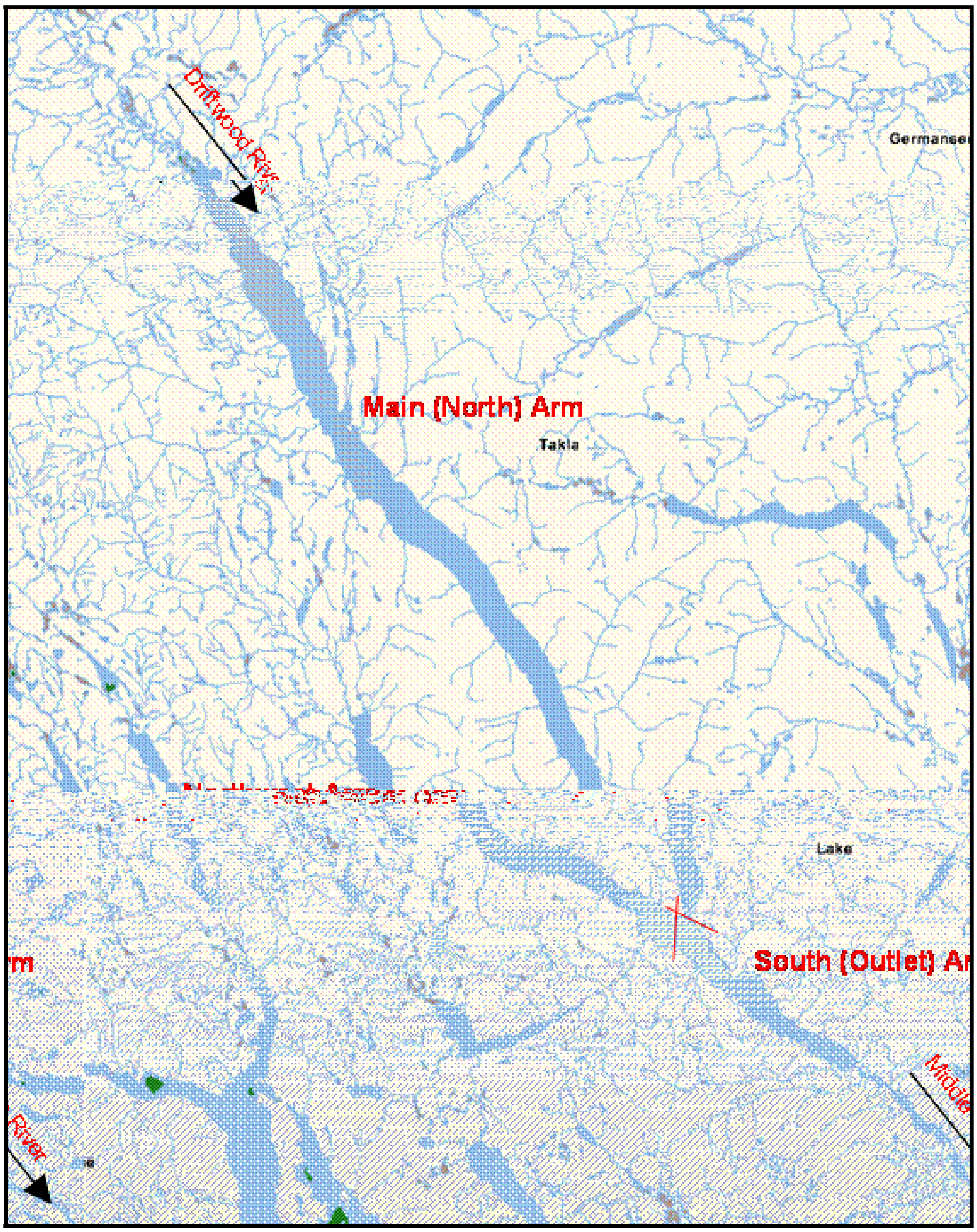


Figure 1.1. Takla Lake.

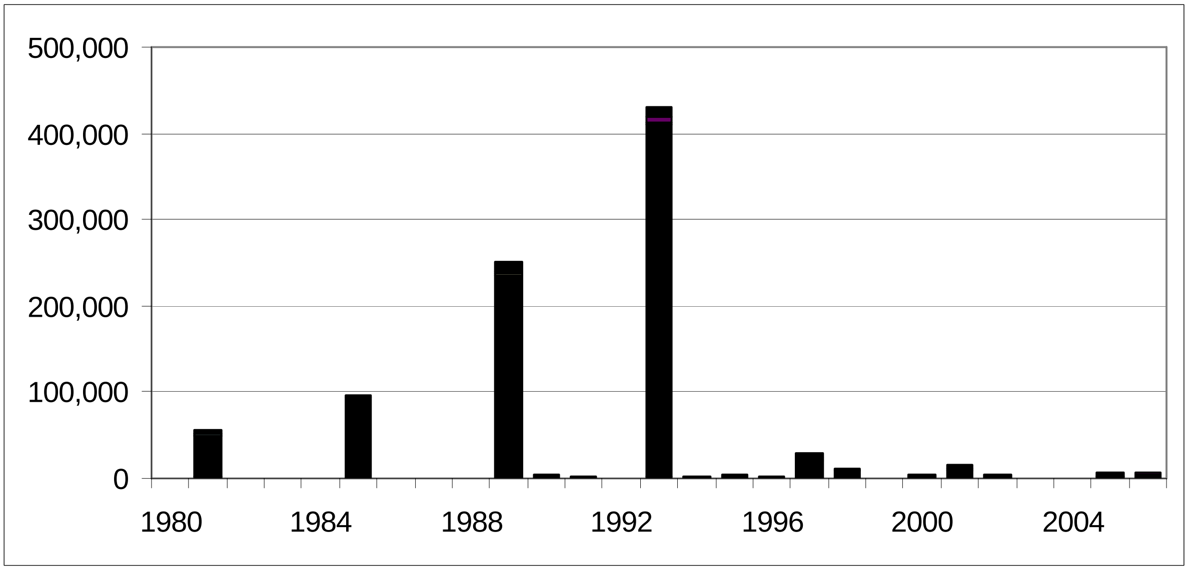


Figure 1.2. Time series of sockeye escapements to the Driftwood River. Source: DFO Kamloops.

Under the right conditions, it may be possible to stimulate the recovery of the Driftwood sockeye population by fertilizing Takla Lake. The present evaluation was undertaken by the Upper Fraser Fisheries Conservation Alliance (UFFCA) to determine the feasibility of such a program for May-September of 2010, the year that dominant brood fry will be present in the Driftwood (Main) Arm of the lake.

2. Theory and Practice of Sockeye Lake Fertilization

Over the past 60 years, a large number of sockeye lakes have been fertilized with nutrients in order to increase salmon production. There have been many successes and a few failures, and there is an extensive body of experience upon which to base lake fertilization decisions. This section of the report presents the theory underlying sockeye and kokanee lake fertilization and provides the results of previous programs that have been carried out in Canada and the U.S.

Theory

Many BC sockeye lakes are oligotrophic and are characterized by low nutrient concentrations and low annual rates of biological production (Stockner and Ashley 2003). Within these lakes, phosphorus (P) is usually a limiting nutrient. A returning adult salmon weighing 4 kg contains about 18 g P that, if available in soluble form, would be capable of producing 7.5 kg of living phytoplankton. In many lakes, returning adult salmon can provide a significant portion of a lakes' phosphorus budget, estimated as 15 – 40% of the annual total P load (Stockner 1987).

When sockeye runs are reduced or depleted, there can be a corresponding reduction in nutrient loading and aquatic productivity. The nutrient input from salmon carcasses returning to the Driftwood River in 1993 (escapement = 430,000) and 1997 (escapement = 30,000) is calculated as:

	1993	1997
Phosphorus (kg)	7,740	540
Nitrogen (kg)	32,000	2,250

There is an opportunity, under the right conditions, to restore the productivity of the ES sockeye population by fertilizing the lake nursery habitat in the Main Arm of Takla Lake (Figure 1.1). The theory has been summarized by Stockner and Ashley (2003):

> *Salmon are a vector by which nutrients are captured and conveyed against the force of gravity into freshwater ecosystems. Especially in the upper reaches of watersheds where salmon are able to spawn and their offspring spend their early lives, these nutrients, in both organic and inorganic forms, play an important, perhaps essential, role in maintaining viable salmon runs along with numerous other ecosystem components….Clearly, it has been the gradual loss of adult salmon through the past century, the anadromous nutrient pump, that has resulted in the oligotrophication of a vast majority of Pacific Northwest salmonid ecosystems.*

To counteract declining productivity it is possible to stimulate production in sockeye lakes by fertilization. There is a large body of experience in applying this approach in BC over the past 40 years. In many cases this has proven to be a cost-effective way to produce sockeye (Guthrie and Peterman 1988; Maxwell et al. 2006). However in some instances the approach has been unsuccessful due to blooms of undesirable (ungrazable by zooplankton) blue-green algae or diatoms which result in a carbon sink, or trophic “dead-end” in the pelagic food chain (Hyatt et al. 2004). In some coastal lakes sockeye competitors e.g. sticklebacks and mysids have also responded to fertilization, negating the benefits for sockeye.

Stockner (1987) provided a review of lake ecology and production in BC lakes that were fertilized during the 1970’s and 1980’s. Lakes were classified into 3 different types: coastal, interior and glacial. Coastal lakes tend to be fast flushing and experience maximum nutrient loads during the winter when water column stability, water temperatures and light intensities are low, rendering the lakes “oligotrophic”. In response to fertilization, oligotrophic coastal lakes show large increases in primary production which are positively correlated with the P load in fertilizer. Interior lakes, including Fraser system lakes, are characterized by higher nutrient and productivity levels and are classified as “oligo-mesotrophic”. The higher biological productivity is reflected by the size of sockeye smolts: interior Age-1 smolts are generally larger than coastal smolts. Some of the smallest Age-1 smolts come from glacial systems.

On average, a 69% increase in smolt size can be achieved when coastal lakes are fertilized (Hyatt and Stockner 1985). Since marine survival correlates positively with smolt size, this implies that overall sockeye production will increase in fertilized systems.

DFO Lake Enrichment Program

Between 1969 and 1975, DFO investigators conducted an experimental fertilization program at Great Central Lake on Vancouver Island. The results were striking: a 5-fold increase in mean summer primary production, a 9-fold increase in zooplankton standing stock, a 2.6 fold increase in egg-to-smolt survival and a 7-fold increase in the mean stock size of adult sockeye, from <50,000 to >360,000 (Hyatt and Stockner 1985). These results prompted DFO to establish the Lake Enrichment Program (LEP) starting in 1975. Over the past 3 decades, LEP aerially fertilized about 25 lakes weekly during the growing season with liquid N and P fertilizer. Most of the lakes were coastal (Figure 2.1) with the exception of Chilko Lake which was fertilized in the late 1980’s and early 1990’s. The LEP has since been concluded due to a shift in DFO priorities, although there has been ongoing fertilization of Great Central Lake by means of a herring skiff.

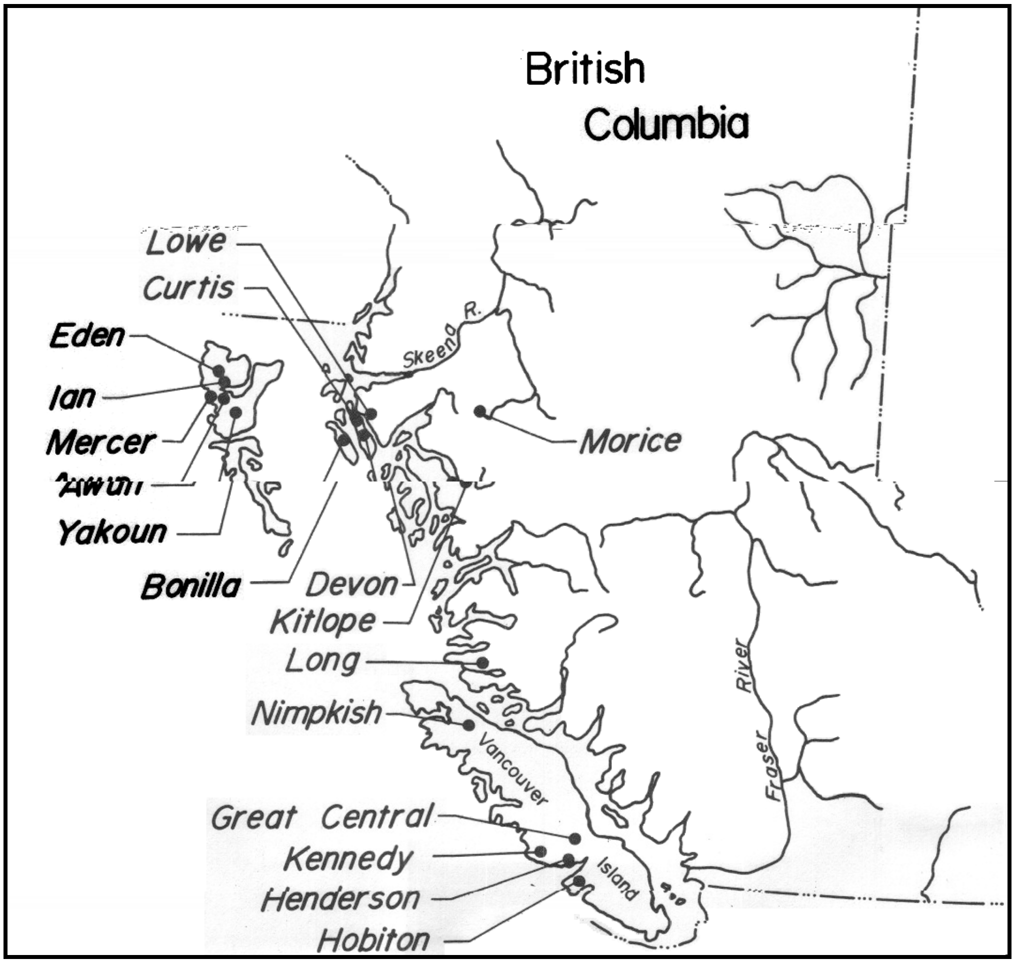


Figure 2.1. Locations for some of the sockeye lakes fertilized under the DFO Lake Enrichment Program. Source: Stockner and Hyatt (1984).

Lakes treated under the LEP showed a positive production response at all trophic levels with an increase in activity and doubling of bacterial abundance, a 50-60% increase in phytoplankton biomass, and a greater than 2-fold increase in primary production and zooplankton biomass (Stockner and MacIsaac 1996). Fertilization increased juvenile sockeye in-lake growth and survival and caused a 60% increase in the weight of seaward migrating smolts. It was estimated that the larger adult sockeye returns due to LEP were worth 10-20 million dollars per annum to the Canadian economy (Stockner and MacIsaac 1996).

Lake Fertilization in Alaska

Bare Lake on Kodiak Island, treated with nutrients between 1950-1953, was the first sockeye fertilization project in Alaska. Thereafter in 1970, Little Togiak Lake was fertilized. Results indicated positive changes in primary production however the effect of fertilization on salmon production was unknown. Since that time, more systematic research and monitoring has been carried out to assess the results of the Alaskan program (Kyle et al. 1997). The Alaskans frequently couple fertilization with fry outplanting. Sixteen lakes have undergone nutrient enrichment for either restoration or enhancement of sockeye or coho salmon stocks (Figure 2.2).

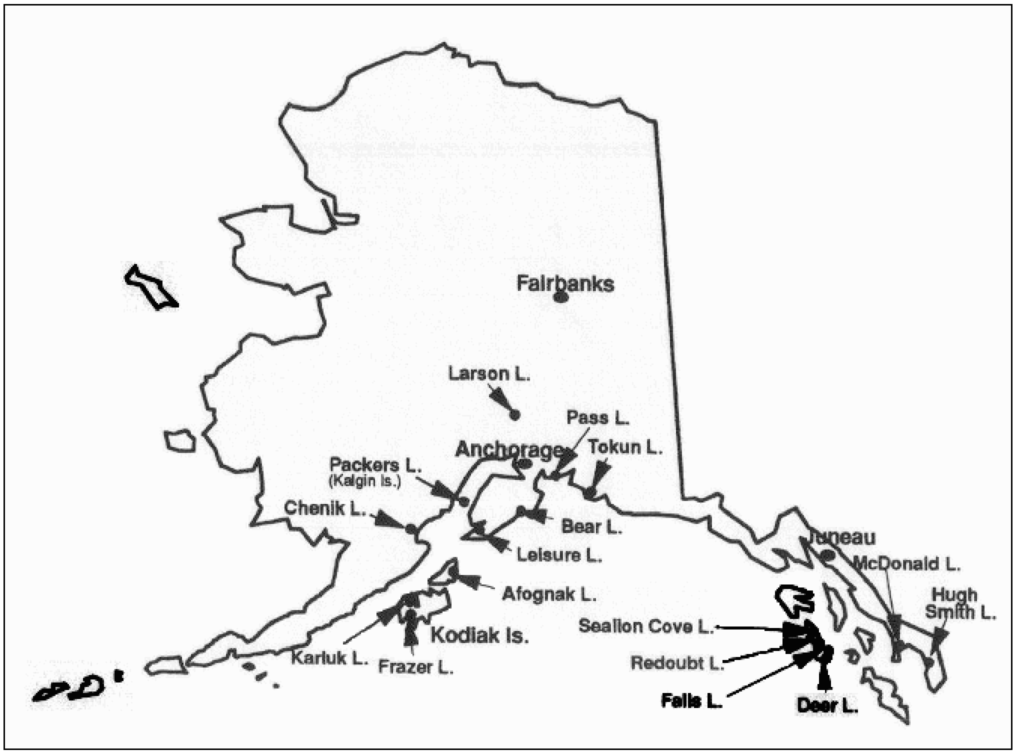


Figure 2.2. Location of 16 Alaskan lakes that were treated with nutrients to enhance salmon production. Source: Kyle et al. (1997).

Lake Fertilization in Idaho

Redfish Lake, tributary to the Snake River in Idaho, was listed under the Endangered Species Act in 1991 due to a precipitous decline in the sockeye run. The run collapsed from perhaps 20,000 adults at the beginning of the 1900’s, to 5,000 fish in the 1970’s, to only a handful of adults in the 1990’s (Luecke et al. 1996). Recovery of the run has been a major focus and hatchery augmentation has played a significant role in preventing the extinction of this population.

Investigators addressed this conservation issue with simulation modeling and experimental limnocorral enclosures. It was concluded that to restore Redfish Lake sockeye, it would be necessary to increase adult survival (Gross et al. 1998). However as a short-term strategy, fertilization of the juvenile nursery lake could serve to stabilize the population decline. Fertilization of limnocorrals (Budy et al. 1997) increased chlorophyll *a* (150%), phytoplankton biovolume (75%), primary productivity (250%), zooplankton biomass (200%) and juvenile kokanee growth (12%). It was concluded that fertilization could aid in the recovery of Snake River sockeye.

There was concern that the growth and survival of hatchery broodstock could be compromised by the presence of kokanee in Redfish Lake. Redfish Lake juvenile kokanee may have subsumed much of the lakes' capacity for rearing juvenile salmon. In their simulation model, Lueke et al. (1996) evaluated the potential of using lake fertilization and/or kokanee reduction strategies to enhance the growth of juvenile sockeye salmon released from the broodstock program. Simulations indicated that the sockeye population could benefit from lake fertilization only if the survival of age-0 kokanee was reduced by 50%-70%.

Redfish Lake was fertilized during 1995-1998 and the lake responded in a similar fashion as other fertilized lakes: Secchi depth declined, chlorophyll *a* doubled, and zooplankton and *Daphnia* biomass increased (Hyatt et al. 2004). Post-fertilization juvenile salmon survival increased from 6.7% to 19.7%, however this increase may have been confounded by the introduction of higher quality hatchery fish during the fertilization period. Compared to juvenile sockeye, kokanee in Redfish Lake may have disproportionately benefited from fertilization. There were also aesthetic (clear water) concerns and the P loading was less than recommended, thus weakening the anticipated bottom-up response by sockeye (Hyatt et al. 2004). The program was discontinued in 1999.

Fraser System Lakes

Adams Lake

Adams Lake (Figure 2.3) was fertilized in 1997 as part of a sockeye recovery program (Hume et al. 2003). This sockeye population was formerly abundant and at the beginning of the 20th century, every spawning tributary was reportedly teeming with adult sockeye on dominant return years. Subsequently, a splash dam below the lake outlet and the Hell's Gate slide decimated the run.

Restoration activities were initiated by the International Pacific Salmon Fisheries Commission and have been pursued more recently by DFO. Over the years recovery strategies have included egg and fry transplants, hatchery production, reduced fisheries exploitation in 1996, and Adams Lake fertilization. The shaded area in Figure 2.3 indicates the zone of the lake that was fertilized by DFO in 1997.

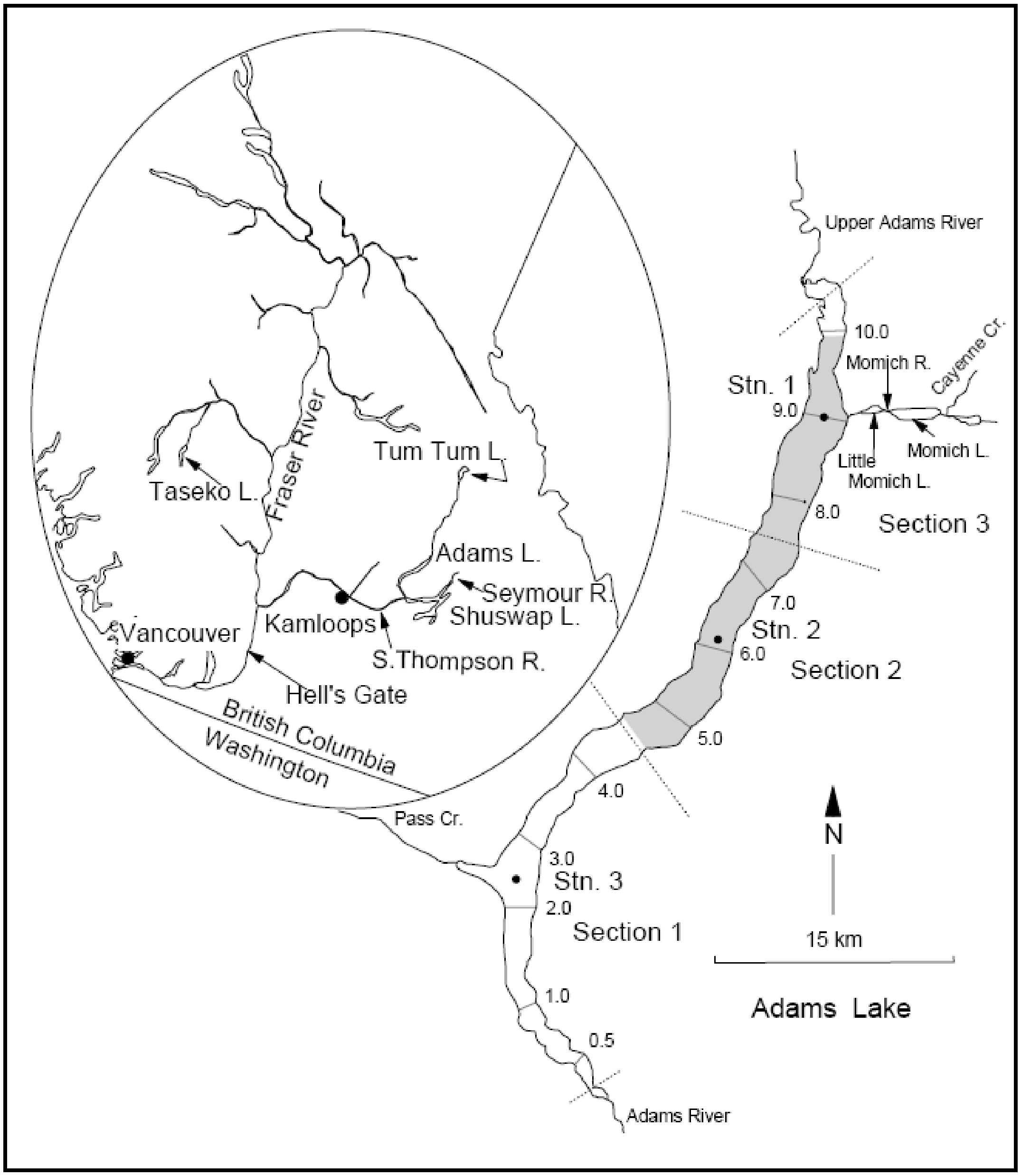


Figure 2.3. Location of Adams Lake and fish sampling transects/limnology stations adopted by Hume et al. (2003).

Adams Lake is a large (129 km^2), deep (mean depth of 169m), oligotrophic lake with a water residence time of 10 years. Based on a primary production rearing model, the lake has the potential to produce 26 million 4.5 g sockeye smolts, equivalent to the offspring of 500,000 spawning adults (Shortreed et al. 2001). While there are numerous fish species in the lake, kokanee comprise the vast majority of the fish population. During the 1997 fish surveys conducted by DFO, the following were the relative numbers of juvenile kokanee and sockeye enumerated in the pelagic zone (Hume et al. 2003):

	Age-0 kokanee population	Age-0 sockeye population
July 19, 1997	1,741,000	317,000
October 20, 1997	2,298,000	396,000

Older age classes of kokanee (1+, 2+) were also present in the lake, but estimation of their relative abundance was confounded by acoustic target strength overlap and size-dependent trawl avoidance.

During 1997, fertilization procedures included the installation of a 36,800 L capacity storage tank adjacent to the shoreline to temporarily hold the premixed nutrient solution. The fertilizer was transported and distributed by a 12 m aluminum herring skiff (4 m wide) fitted with bulkheads to reduce excessive fertilizer movement in the vessel. The skiff carried 7 tonnes of nutrient solution, enough for a single application at the lowest loading rate. Nutrients were dispersed by pumping into the prop wash with a 42 L/min bilge pump connected to a flexible 1” diameter plastic hose. Application strategies included front-end loading the nutrients at the beginning of the growing season (June) and altering the N:P ratio over the summer to optimize the phytoplankton response.

It was concluded that fertilization increased lake productivity at all trophic levels (Hume et al. 2003). The average spring overturn concentration of total P in the year following fertilization was more than 3 times greater than occurred in the reference year, indicating a carry-over of phosphorus from the previous year. The higher average chlorophyll concentration during 1997 suggested that fertilization increased primary productivity. There was a 30% increase in macrozooplankton biomass and a 45% increase in *Daphnia* compared to the reference year. The outmigrating smolts from the fertilized year were 1 g larger than in the reference year. This size increment was responsible for a smolt-to-adult survival increase of 14% in Chilko Lake sockeye (Bradford et al. 2000).

Results obtained from Adams Lake suggest positive carry-over effects of fertilization from one year to the next. They also indicate the possibility for sockeye enhancement in the presence of kokanee populations.

Chilko Lake

Chilko Lake (Figure 2.4) was fertilized by DFO in 1988 and 1990-1993. Chilko is ultraoligotrophic with cool water temperatures and a deep (21 m) euphotic zone, making it the clearest sockeye lake in the Fraser system (Shortreed et al. 2001). Limnology studies indicated that *Daphnia* biomass was low, and that sockeye fry fed primarily on *Diaptomus* and *Bosmina*. In response to helicopter additions of fertilizer, phytoplankton production in Chilko Lake increased, as did zooplankton abundance, especially *Daphnia*. Smolt sizes also increased (Bradford et al. 2000) by 34% (age-1 smolts) and 58% (age-2 smolts). There was a weak positive relation between the size of outmigrating smolts and their marine survival. It was concluded that fertilization increased adult production by improving marine survival of smolts.

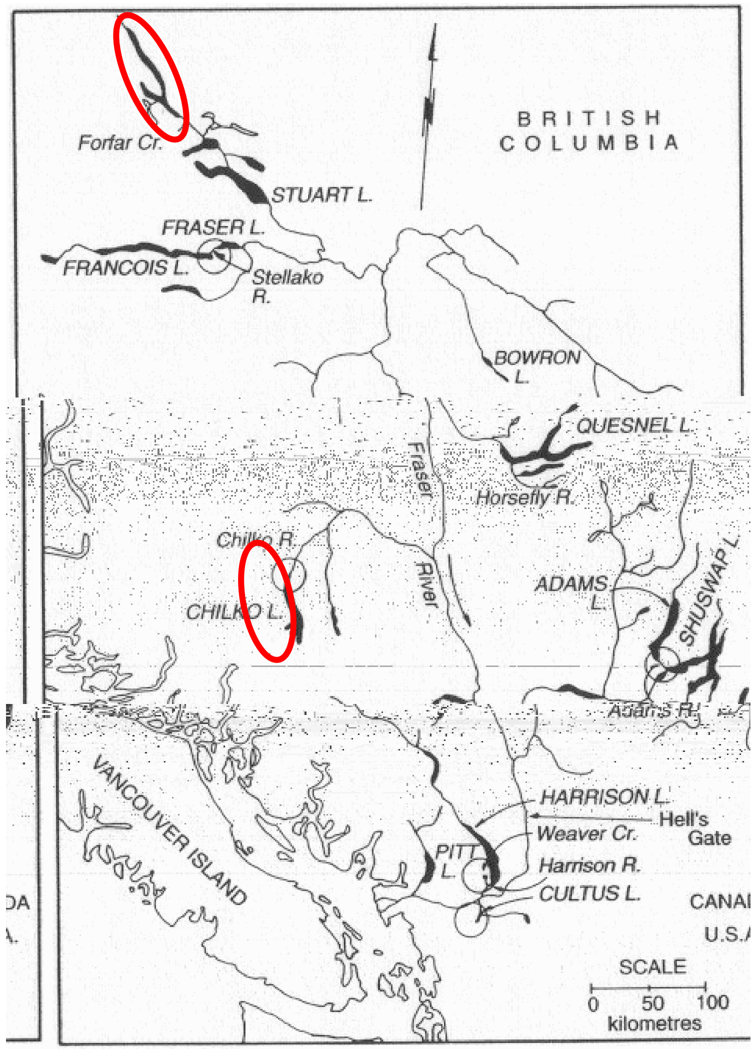


Figure 2.4. Locations of Chilko Lake and Takla Lake in the Fraser River watershed.

Since the early 1990's when fertilization took place, cyclic dominance patterns have broken down and Chilko sockeye now return in abundance in most years. (Shortreed et al 2001). Fertilization may provide a tool to manipulate cyclic patterns of abundance by improving marine survival in off-cycle years (Bradford et al. 2000). Fertilization may have also prevented the declines in productivity that have occurred in other Fraser sockeye populations and may help offset high exploitation rates. Shortreed et al. (2001) recommended the resumption of fertilizer applications at Chilko to compensate for higher than optimum escapements that occurred in the population after the late 1990's.

Quesnel Lake

Quesnel Lake has never been fertilized but was evaluated by DFO as a candidate lake for treatment during the 1990's (Stockner et al. 1994). Quesnel Lake is oligotrophic with a euphotic zone depth of 13 – 16 m. It was anticipated that fertilization of Quesnel Lake could potentially produce around 4 million additional sockeye on dominant cycles and perhaps also on sub-dominant cycles. Since the early 1990's there have been some very high escapements to Quesnel Lake (e.g. > 3 million spawners in both 2001 and 2002) and evidence for strong density dependent interactions that can reduce subsequent run productivity.

The suitability of Quesnel Lake as a fertilization candidate (Stockner et al. 1994) reflects:

- Close to optimal thermal and optical properties;
- Evidence for phosphorus limitation; and,
- The presence of *Daphnia* as a keystone species in the lake to ensure efficient energy transfer from phytoplankton to juvenile sockeye.

The need for selective harvesting of enhanced adult populations in the terminal area was identified. There was a major concern about the adverse impacts of fertilization on kokanee due to their out-competition by sockeye. Large kokanee in Quesnel Lake sustain a unique strain of trophy rainbow trout. A model of kokanee population dynamics in large lakes (Korman et al. 1993) indicated that the kokanee population would be vulnerable to sockeye increases. However, some of the negative effects on kokanee would be offset by the increased lake productivity from fertilization.

Kokanee Fertilization

Restoration of of kokanee by lake fertilization has been undertaken by the BC Ministry of Environment in a number of BC lakes and reservoirs including Kootenay Lake (Ashley et al. 1999), Arrow Lakes Reservoir (Pieters et al. 2003), Wahleach (Perrin et al. 2006) and Alouette Reservoirs. Kootenay Lake was treated because of concerns about the effect of declining kokanee on the famous Gerrard rainbow trout strain. The other 3 reservoirs were fertilized because they had experienced catastrophic kokanee declines in response to nutrient deprivation (associated with reservoir aging) and species introductions – mysid shrimp and threespine stickleback. All of the reservoirs showed strong, positive responses in zooplankton biomass and kokanee populations due to fertilization. For example, kokanee in the North Arm of Kootenay Lake increased from an escapement of 237,000 in 1991 to 1,200,000 in 1999 after 8 years of fertilization. In Alouette Reservoir, kokanee size increased from a prefertilization weight of

122 g in 1998 to 587 g in 2001 (Stockner and Ashley 2003). This size increase took place over the same time period that kokanee numbers increased 5-fold.

An important feature of kokanee ecology is the presence of older 1+ and 2+ conspecifics with relatively high plankton consumption rates. In spite of lower densities of older age classes of kokanee, they likely exert considerable grazing pressure on the planktonic food resource.

Summary

Results from previous sockeye lake fertilization programs indicate that sockeye will respond positively to nutrient additions under most conditions. The necessary conditions for successful fertilization of interior sockeye lakes include:

- Relatively low biological productivity in the nursery lake;
- Suitable optical, thermal and chemical properties;
- Low nutrient concentrations that limit autotrophic plant and bacterial production;
- Presence of *Daphnia* to take advantage of increased primary production;
- Low intensity of kokanee competition: and,
- Ability to selectively harvest the enhanced sockeye population.

3. Takla Lake Limnology and Sockeye Biology

Limnology information is needed to evaluate sockeye lake fertilization. DFO investigated Takla, Trembleur, and Stuart Lakes between 1996-1998 (Figure 3.1). Malange et al. (2005) contains limnological data for Takla Lake. Appendix A1 contains a series of graphics derived from Malange et al. (2005). Interpretation of the Appendix graphics is provided in the text below.

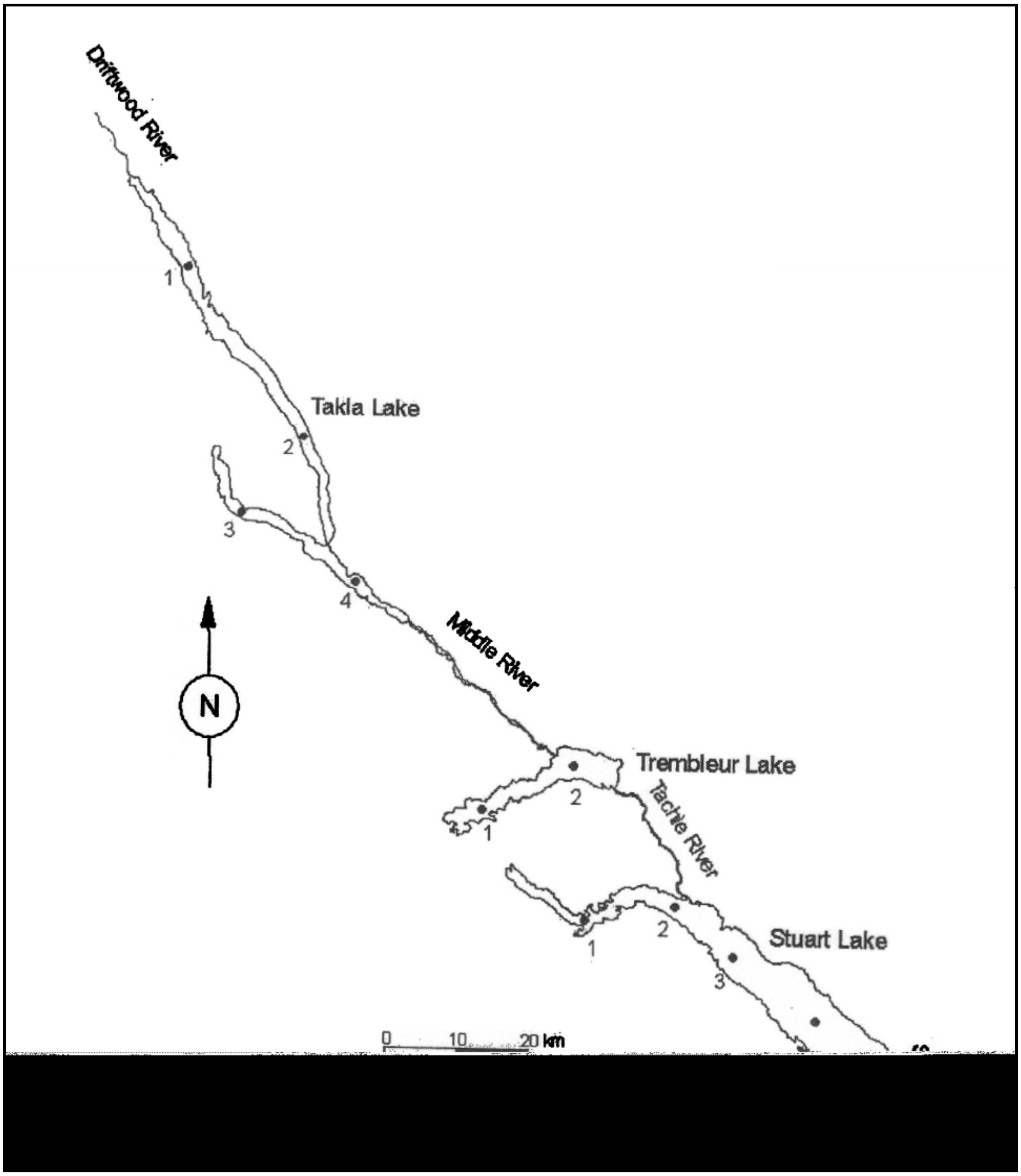


Figure 3.1. DFO limnology stations in Stuart, Trembleur and Takla Lakes.

Stations 2 and 4 were selected for detailed analysis. The limnology stations in Takla have the following depths:

Station 1	207 m
Station 2	229 m
Station 3	159 m
Station 4	36 m

Stations 2 and 4 represent conditions in relatively deep and shallow regions of the lake.

The data collection extended over a 3-yr period (1996-1998). For present purposes, information from 1998 was analyzed extensively, while smaller subsets of 1996 and 1997 data were also examined to evaluate interannual variability.

Thermal Properties

Temperature profiles from Stations 2 and 4 (Figures A1 and A2) indicated a typical dimictic lake which stratifies early in the summer and develops a strong thermocline during July and August. August thermocline depths were around 20 m at Station 2 and 15 m at Station 4. The lake was stratified in September but began to show cooling of surface waters that continued into October, prior to freeze-up.

Isopleth diagrams provide a seasonal comparison of temperature conditions at Stations 2 and 4 (Figure A3), interannual variations at Station 4 between 1996-1998 (Figure A4), differences between stations (Figure A5) and comparison of thermal structure in Takla, Trembleur and Stuart Lakes during 1998 (Figure A6). The results indicate:

Figure	Interpretation
A3	Stations 2 and 4 showed similar patterns of seasonal stratification, with only minor differences due to depth differences and mixing processes.
A4	1997 showed the most pronounced stratification, followed by 1998 and 1996. This pattern reflected that 1996 was the coolest year and 1997 was the warmest.
A5	Stations 1 and 4 were the warmest. All stations showed modest stratification. Similarities were greater than differences.
A6	Takla stratified earlier in the season than Trembleur. Thermocline was shallower in Takla than in the other 2 lakes. Differences in thermal properties between lakes likely reflected differences in wind mixing – Takla is relatively sheltered compared to the other 2 lakes.

Light Transparency

The euphotic zone depth of a lake is the depth where there is sufficient light for photosynthesis to occur. The euphotic zone depth of Takla Lake (Figure A7) varied between 6-9 m. There were only minor variations between Stations 2-4 and seasonal measurements between May to October were consistent between dates.

The transparency of the water, which determines depth of the euphotic zone, wais measured with a Secchi disk. Secchi depths ranged between 4-6.5 m. Station 2 and Station 4 Secchi depths were similar on most dates, except during August when the Station 4 Secchi depth was 2 m deeper than the Station 2 value.

Conductivity

Conductivity (Figure A9) ranged between 60-70 µS/cm. Values were lowest in May and thereafter increased through the summer and fall. On most dates, conductivity values were slightly higher at Station 4 compared with Station 2.

pH

pH (Figure A10) was slightly alkaline and varied between 7.5-7.8. There were only small pH differences between Stations.

Total Dissolved Solids

TDS (Figure A11) ranged between 28 – 60. There were only small differences in TDS between Stations.

Alkalinity

Total alkalinity varied between 29-31. Alkalinities were slightly higher at Station 4 than at Station 2 on most dates.

Nutrient Chemistry

There was a small amount of seasonal and between station variability for the measured nutrient chemistry parameters. These are unlikely to be statistically significant. The range of values is shown below:

Figure	Range
A13 – Total dissolved inorganic C	7300-7800 µg/L
A14 – Silica	2.1-2.3 mg/L
A15 – Total phosphorous	4-7 µg/L
A16 – Total dissolved phosphorus	3-9 µg/L
A17 – Nitrate	38-70 µg/L
A18 – Particulate mass of nitrogen	14-26 µg/L
A19 – Particulate mass of carbon	1.5-2.1 µg/L
A20 – Particulate mass of phosphorus	125-275 µg/L

Bacteria and Phytoplankton

Most of the data were collected at Station 4 only. Based on the previous water chemistry results, it is unlikely that Station 2 values were different. The range of values for bacteria and primary production was:

Figure	Range
A21 – Bacteria	1-2.5 10^6 cells/ml
A22 – Total chlorophyll	0.7-1.7 µg/L
A23 – Daily photosynthetic rate	50-170 mg C/m^2
A24 – Picoplankton (0.2-2µm)	12-26 x10^3/ml
A25 – Nanoplankton (2.0-20 µm)	0.4-0.8 x10^3/ml
A26 – Microplankton (>20 µm)	0.2-0.7 x10^3/ml

Zooplankton

There was considerable variation in the seasonal amount and species composition of crustacean zooplankton at Stations 2 and 4 (Figures A27-28). The zooplankton was dominated by copepods (*Cyclops* and *Diaptomus*) during May – July. Thereafter cladocerans (*Daphnia* and *Bosmina*) comprised a significant component of the crustacean zooplankton community. Zooplanton densities and biomass peaked in August samples. During August and September, there were higher densities and biomass of zooplankton at Station 4 compared to Station 2, due mainly to higher densities of *Bosmina*.

In comparison with Trembleur and Stuart Lakes, whole lake seasonal averages of zooplankton densities and biomass were considerably lower in Takla Lake (Figures A29 and A30). Takla Lake evidently has considerably lower secondary production than the other 2 lakes. This was also reflected in whole lake seasonal biomass of zooplankton during 1996 – 1998 (Figure A31). Highest seasonal biomass of *Daphnia*, the preferred prey of sockeye juveniles, occurred in Trembleur Lake on most dates (Figure A32).

Juvenile Sockeye and Kokanee

During 1996 – 1998, DFO (J.Hume, unpublished data) undertook acoustic and trawl surveys of Takla, Trembleur and Stuart Lakes at the transect locations shown on Figures A33 – A35. Sockeye and kokanee were separated using strontium analysis of otoliths. Tables A1 and A2 (p.x-y) present the results of biomass and density calculations from these surveys.

Age 0 and Age 1 *Oncorhynchus nerka* (both Age 0+ and Age 1+ sockeye and kokanee) were indistinguishable acoustically. Numbers were derived from acoustic estimates and % capture rate in trawls. Biomass values were measured from trawl samples. “Large” fish (>150mm) included mostly Age 2+ nerka, and smaller numbers of whitefish and piscivores e.g. trout, char and burbot. Numbers were estimated from hydroacoustic data and biomass was derived from a length/weight regression equation. The category “Other” represented mainly whitefish and sculpin. Numbers were derived from acoustic estimates and % frequency in trawl catches.

Comparison of juvenile sockeye and kokanee numbers in the entire lake (Figure A36) and the Main (Driftwood) Arm (Figure A37) indicated that between half to two-thirds of the nerkid population was distributed in the Driftwood Arm. In all cases the population estimates declined between summer and fall, which is to be expected due to the juvenile mortality schedule in sockeye populations. In spite of well established sockeye cyclic dominance, the number of juvenile sockeye did not vary greatly between years. This likely reflects the crash in the dominant Driftwood adult population during 1997 (Figure 1.2) which evidently resulted in low recruitment of juveniles to Takla Lake in 1998.

Comparison with Chilko and Adams Lakes

A summary of limnological data for Takla, Chilko and Adams Lakes is shown in Table 3.1. The comparison indicates lower daily photosynthetic rate and zooplankton biomass in Takla compared to the other 2 lakes. Additionally, mean fall fry weights are relatively low in Takla. Given that sockeye fry in both Chilko and Adams Lakes responded positively to fertilization, it seems likely that Takla sockeye would also be enhanced. Shortreed et al. (2001) identified fertilization as an appropriate enhancement technique in Takla, but also pointed out that fry recruitment would need to be increased, perhaps by means of fry outplanting from a hatchery.

Table 3.1. Summary of limnological date for Takla, Adams and Chilko Lakes. (UF = unfertilized; F = fertilized; PR = photosynthetic rate). Source: Shortreed et al. (2001).

	Takla	Adams UF	Adams F	Chilko UF	Chilko F
Surface Area (km^2)	246	129		185	
Water Residence Time (yr)	15	10		16	
Thermocline Depth (m)	13.7	7.5	8.0	24.2	19.9
Euphotic Zone Depth (m)	6.9	13.3	11.6	20.9	20.2
pH	7.51	6.97	7.35	7.10	7.20
Total Alkalinity (mg $CaCO_3$/L)	27.9	21.0	20.2	20.2	20.5
Mean Nitrate (µg/L)	48	67	57	12	12
Mean Phosphorus (µg/L)	4.9	1.6		2.5	3.8
Chlorophyll (µg/L)	1.02	0.81	1.07	0.7	0.96
Daily PR (mg C/m^2)	55	111	113	82	98
Zooplankton biomass (mg dry wt/m^2)	562	1004	921	711	1065
Daphnia biomass (mg dry wt/m^2)	91	374	292	10	123
Mean fall fry weight (g)	3.1	2.6	3.5	4.3	5.5
Mean fall density (N/ha)	252	<1	30	951	1355

While Takla Lake has a higher concentration of total phosphorus than the other 2 lakes, it has a considerably lower photosynthetic rate and much lower zooplankton biomass. Mean fall fry weights are well below those from Chilko, and below the fertilized fry weight at Adams.

Summary

Limnological characteristics of Stuart, Takla and Trembleur Lakes are summarized in Table 3.2. The 3 lakes have different morphometric and limnological characteristics in particular with respect to depth and thermal characteristics (Figure A38). Takla Lake is much deeper than Trembleur and Stuart, and is more sheltered from prevailing winds and as a result has a shallower thermocline depth.

The relative productivity of the three lakes can be evaluated by comparing and ranking the different measurements (Table 3.3). The comparison shows that Stuart Lake is the most productive, followed by Trembleur Lake and lastly Takla Lake. The same productivity gradient is also evident in interannual comparisons (Figures A39 – A40). This suggests that out of the 3 lakes, Takla makes the strongest fertilization candidate.

Table 3.2. Limnological and biological characteristics of Stuart, Takla, and Trembleur Lakes. Source: Shortreed et al. (2001).

	Takla Lake	**Trembleur Lake**	**Stuart Lake**
Surface Area (km^2)	246	116	359
Mean Depth (m)	107	40	20
Water Residence Time (yr)	15	1.9	1.7
Thermocline Depth (m)	13.7	20.0	20.3
Euphotic Zone Depth (m)	6.9	6.0	6.6
pH	7.51	7.62	7.80
Total Alkalinity (mg $CaCO_3$/L)	27.9	34.6	41.6
Nitrate (µg N/L)			
Spring Overturn	74	57	37
Mean Epilimnetic	48	34	14
Seasonal Minimum	29	21	3.3
Total Phosphorous (µg/L)			
Spring Overturn	4.7	8.8	9.8
Mean Epilimnetic	4.9	8.1	7.4
Chlorophyll (µg/L)	1.02	1.40	1.92
Daily Photosynthetic Rate (mg C/m^2)	55	84	138
Zooplankton Biomass (mg dry wt/m^2)			
Total	562	1134	1410
Daphnia	91	231	139
Sockeye Fall Fry			
Mean Weight (g)	3.1	5.1	3.4
Mean Density (N/ha)	252	390	418

Table 3.3. Rank index of relative productivity across different trophic levels.

	Takla Lake	**Trembleur Lake**	**Stuart Lake**
Total Alkalinity	3	2	1
Mean Epilimnetic Phosphorus	3	1	2
Mean Epilimnetic Nitrate	1	2	3
Chlorophyll	3	2	1
Daily Photosynthetic Rate	3	2	1
Zooplankton Biomass	3	2	1
Daphnia Biomass	3	1	2
Mean Weight Fall Fry	3	2	1

Out of the 3 lakes, Takla is the strongest candidate for fertilization by virtue of its relatively low productivity across all trophic levels.

4. Proposed Takla Lake Fertilization Plan

Takla Lake Fertilization Objectives

When the LEP was established by DFO the original objective was sockeye production for the benefit of the commercial industry. Fertilization of the Driftwood Arm of Takla Lake would address an important societal objective: to increase productivity and re-establish a highly valued food, social and ceremonial fishery for ES sockeye. If the program is successful it could create harvesting opportunities, not only in the Stuart Lake system, but also in downstream First Nation fisheries. Fertilization of Takla Lake in order to enhance ES sockeye is consistent with a shift in focus from production to ecosystem restoration. The primary objective can be stated:

> *Restore the Early Stuart sockeye run to permit viable First Nation food, social and ceremonial fisheries in the Fraser River Watershed and its approach areas.*

It is proposed that allocation issues associated with any future increased production be co-managed by Fraser First Nations and DFO.

Background

Takla Lake is the uppermost of three large lakes in North Central British Columbia that comprise the Stuart-Takla lakes system (Figure 1.1). The Driftwood River flows into it from the north-west, and the Middle River drains it from the south-east into Trembleur Lake. Takla Lake is located at an elevation of 689 m, and is the 5th largest natural lake in the province.

Takla Lake is a deep fjord-like lake, with a mean depth of 107 m and a maximum depth of 286.8 m. It contains over 28 km^3 of water with a noticeable humic colouration, and has an unusually long residence time of 15 years (Table 4.1). The surface area of the entire lake is 246 km^2, however, the surface area of the Main Arm of the lake being considered for enrichment is 153 km^2. The summer average thermocline depth is only 13.7 m as the prevailing winds do not blow down the longitudinal axis of the lake (Appendix Figures A1-A2). Most large lakes in BC have thermocline depths in the range of 20-30 m, including nearby Stuart and Trembleur lakes which have summer average thermocline depths of 20.3 m and 20.0 m respectively (Shortreed et al. 2001).

Table 4.1. Morphometric features of Takla Lake.

Surface area (entire lake)	246 km^2
Surface area (North Arm)	153 km^2
Maximum depth	286.8 m
Mean depth	107 m
Elevation	689 m
Volume	28.37 km^3
Thermocline depth	13.7 m
Residence time	15 years
Location	55^o 15' N; 125^o 44' W

Takla Lake is classified as a dimictic lake, as it freezes during winter, develops a stable thermocline during summer and undergoes spring and fall circulation. Takla Lake is very low in nutrients, as shown by the low concentration of spring overturn total P, seasonal average chlorophyll a and related productivity measures (Table 4.2). As a result, Takla Lake is classified as an oligotrophic lake and it is near the lower boundary of the trophic classification scale (Table 4.3; Wetzel 2001).

Table 4.2. Limnological features of Takla Lake.

Lake circulation classification	Dimictic
Mean epilimnetic temperature	11.6 ^oC
Average summer thermocline depth	13.7 m
Average euphotic zone depth	6.9 m
Spring overturn total phosphorus	4.7 µg L^{-1}
Mean epilimnetic total phosphorus	4.9 µg L^{-1}
Spring overturn nitrate-nitrogen	74 µg L^{-1}
Mean epilimnetic nitrate-nitrogen	48 µg L^{-1}
Mid-summer minimum nitrate-nitrogen	29 µg L^{-1}
Seasonal average chlorophyll a	1.02 µg L^{-1}
Seasonal average primary production	55 mg C m^{-2} d^{-1}
pH	7.5
Total alkalinity	27.9 mg L^{-1} (as $CaCO_3$ L^{-1})
Seasonal zooplankton total biomass	562 mg m^{-2} (dry weight)

Table 4.3. General trophic classification of lakes and reservoirs in relation to phosphorus and nitrogen. Source: Wetzel (2001).

Parameter (annual mean value)	**Oligotrophic**	**Mesotrophic**	**Eutrophic**
Mean Total P (μg L^{-1})	8.0	26.7	88.4
Range	3.0 - 17.7	10.9 - 95.6	16 – 386
Mean Chlorophyll a (μg L^{-1})	1.7	4.7	14.3
Range	0.3 – 4.5	3 - 11	3 – 78

A rank index comparison of Takla, Trembleur and Stuart lakes confirms that Takla is the least productive ecosystem in the Stuart-Takla lakes system (Table 4.4; Appendix A1).

Table 4.4. Rank index of relative productivity across different trophic levels, based on data from Shortreed et al. (2001). 1=most productive, 3=least productive.

	Takla Lake	**Trembleur Lake**	**Stuart Lake**
Total Alkalinity	3	2	1
Mean Epilimnetic Phosphorus	3	1	2
Mean Epilimnetic Nitrate	1	2	3
Chlorophyll	3	2	1
Daily Photosynthetic Rate	3	2	1
Zooplankton Biomass	3	2	1
Daphnia Biomass	3	1	2
Mean Weight Fall Fry	3	2	1

Pre-fertilization Data Collection

Pre-fertilization data will be collected during a single limnological sampling campaign in late-August, 2009. The Takla Lake fertilization plan will rely on existing published and non-published data from DFO (Malange et al. 2005; Shortreed et al. 2001) and other sources. Takla Lake was intensively sampled in 1996, 1997 and 1998, and the data clearly indicates Takla is very oligotrophic, and is the least productive of the Stuart lakes system (Tables 4.2 and 4.4). The sample collection program in August 2009 will be used to determine if the limnology of Takla has changed from 1996-1998, and whether there has been a shift in trophic status. Four pelagic lake stations will be sampled (Figure 3.1): Station 1 and 2 in the Main Arm, Station 3 in the Northwest Arm and Station 4 in the South Arm. The limnological parameters to be collected are as follows (Table 4.5):

Table 4.5. Sample collection parameters for Takla Lake (Stations 1-4) in 2009.

Parameter sampled	**Sampling technique**
Temperature, dissolved oxygen, pH, ORP, specific conductance and turbidity	In-situ digital recording at 1m intervals from 0–50 m, and at 5-m intervals from 50–100 m as depth permits.
Transparency	Secchi disk (22 cm white disk without viewing chamber)
Photosynthetically active radiation @ 400-700 nm	Li-Cor light meter with underwater quantum sensor; 1 m intervals to 20 m
Total alkalinity, dissolved inorganic carbon, total metals, pH, total dissolved solids, silica, and nutrients (TP, TDP, SRP, NO_3+NO_2, NH_3,TN)	Sterilized Van Dorn bottle at 3 - 7 epilimnetic depths, and 1 – 3 hypolimnetic depths
Chlorophyll *a (not corrected for phaeophytin)*	Sterilized Van Dorn bottle at 3 equidistant depths in the euphotic zone
Phytoplankton including Pico/Cyano	Sterilized Van Dorn bottle 3 - 7 epilimnetic depths
Limnetic macrozooplankton	Three vertical net hauls with either a 0.05 m^2, 160 µm Wisconsin net or 0.25 m^2 100 µm SCOR net

Desired Nutrient Concentration

The desired concentration of nutrients to be added to the Main Arm of Takla Lake in 2010 is shown in Table 4.6, Figures 4.1 and 4.2, and Appendix A2. The loading rates range from 2.0 to 8.0 mg m^{-2} wk^{-1} for P and 12.6 to 80.8 mg m^{-2} wk^{-1} for N (Table 4.6). Appendix A2 is a detailed lake enrichment spreadsheet that shows the weekly loading rate of nitrogen and phosphorus on a per square meter basis.

Table 4.6. Fertilizer application summary for main Arm of Takla Lake in 2010.

Nutrient	**Loading rates**	**Metric tonnes**	**Metric tonnes of fertilizer**	**Cumulative conc. of N and P**
N	12.6 to 80.8 mg m^{-2} wk^{-1}	105.4	345.5 (28-0-0)	50.3 µg L^{-1}
P	2.0 to 8.0 mg m^{-2} wk^{-1}	12.9	86.6 (10-34-0)	6.1 µg L^{-1}

The total load of applied nutrients is 84.0 mg P m^{-2} and 688.9 mg N m^{-2}. Assuming an average summer thermocline depth of 13.7 m (Table 4.1), this would result in a cumulative instantaneous N and P concentration of 50.3 µg L^{-1} and 6.1 µg L^{-1} respectively (Table 4.6), which is still in the oligotrophic range (Table 4.3).

Figure 4.1 P and N loading (mg m^{-2} wk^{-1}) to the Main Arm of Takla Lake in 2010.

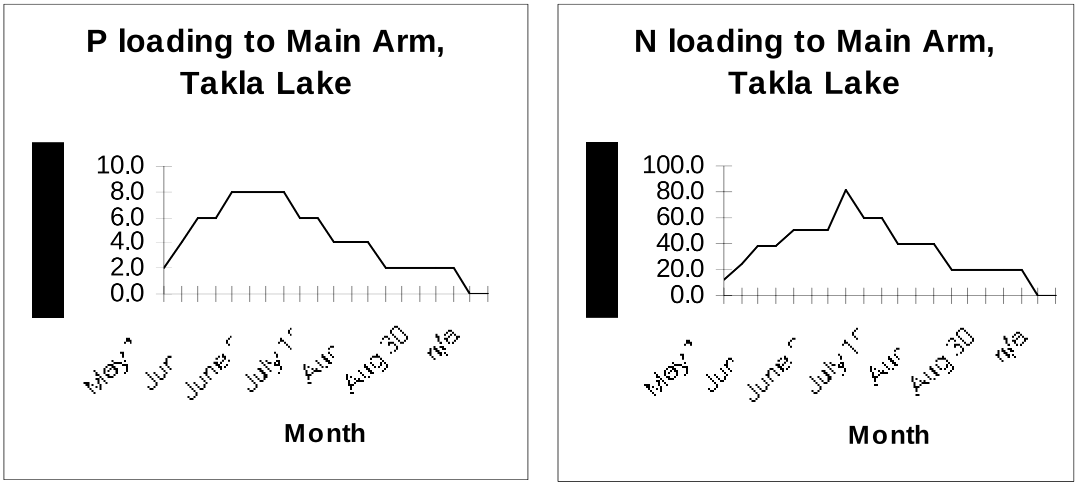
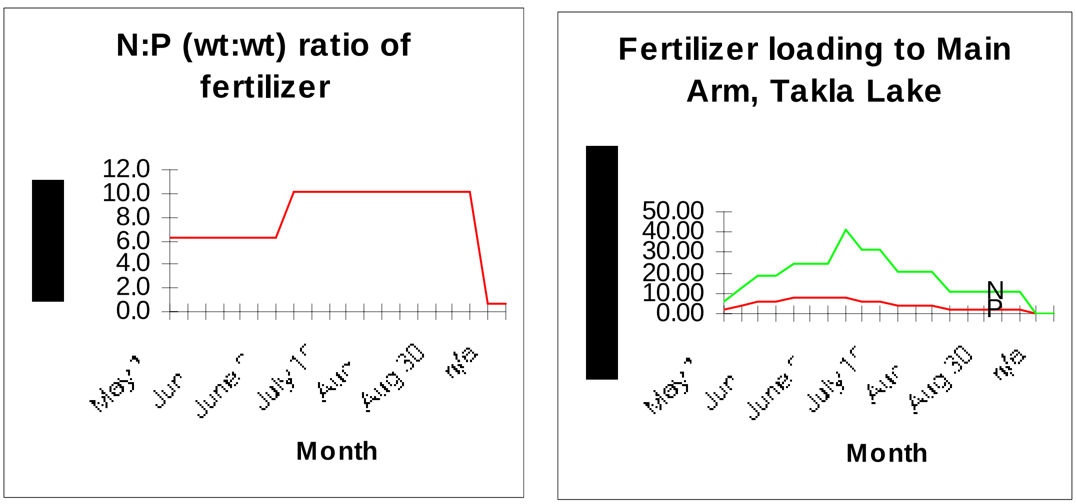


Figure 4.2. N:P ratio and tonnes of fertilizer loading to the Main Arm of Takla Lake.



Nutrient Formulation of Fertilizer

The nutrient formulation of fertilizer to be applied to the North Arm of Takla Lake is a blend of two types of standard liquid agricultural fertilizer, obtained in BC:

a. Ammonium polyphosphate: 10-34-0 (N-P_2O_5-K_2O), is an odourless green liquid with a specific density of 1.4. It is comprised of a mixture of 10% ammoniacal nitrogen and 34% phosphoric acid. The Material Safety Data Sheet is shown in Appendix A3. It is slightly corrosive to some metals.

b. Urea Ammonium Nitrate: 28-0-0 (N-P_2O_5-K_2O) is an odourless clear liquid with a specific density of 1.29. It is comprised of a mixture of 7% ammoniacal nitrogen, 7% nitrate nitrogen and 14% urea nitrogen. The Material Safety Data Sheet is shown in Appendix A4. It is slightly corrosive to zinc, copper, aluminum and ferrous metals, but is compatible with stainless steel.

Fertilizer Application Schedule

The weekly fertilizer N:P ratio and application schedule is shown in Figure 4.2. The detailed fertilizer application schedule is shown in Appendix A5, listing the weekly volumes of fertilizer to be applied to the Main Arm of Takla Lake in 2010. The schedule shows the individual volumes of 10-34-0 and 28-0-0 that are required, the N:P ratio of the blend, total volume of fertilizer mixture and the required application rate per minute. The lowest weekly loading rate is in mid May, when 6,276 liters of blended 10-34-0 and 28-0-0 is applied. The highest weekly loading rate is in early July when 38,081 liters of blended 10-34-0 and 28-0-0 is applied to the lake. A summary table of the weekly fertilization application schedule and weights of liquid fertilizer is shown in Table 4.7.

Application Technique

Nutrient application to most lakes targets pelagic phytoplankton and ultimately the zooplankton forage-base for sockeye salmon or land-locked kokanee. Therefore, on large water bodies like Takla Lake, fertilizer is applied on a transect line near the center of the lake and well away from littoral margins (>500 m from shorelines) and outflow river mouths. It is important to disperse the nutrients over as wide an area as possible so that dilution by epilimnetic water prevents ‘pooling’ and sinking of concentrated fertilizer into the hypolimnion.

It is important to appreciate the density differential between the nutrients being added and the water body being treated. Slight differences in density will cause liquid fertilizer to sink rapidly, hence it is important to dilute the fertilizer to prevent it from sinking through the epilimnion. Dilution ratios in the order of 10,000:1 are required to avoid this problem (Ashley et al. 1999). Dye studies have confirmed that horizontal dispersion in small lakes is consistent with previous observations in oceans and large lakes (Lawrence et al. 1995), hence wind-driven circulation will distribute nutrients over a large area, albeit at a rate considerably slower than the biological uptake of nutrients in the water column (Stockner and Ashley 2003).

Table 4.7. Fertilizer application schedule for Main Arm of Takla Lake in 2010.

	Phosphorus			Nitrogen				
	Load mg/m^2/wk	**Weight kgs**	**10-34-0 M. Tons**	**Load mg/m^2/wk**	**Weight kgs**	**28-0-0 M. Tons**	**N:P Ratio**	**No.**
May 17	2.0	306	2.06	12.6	1,929	6.15	6.3	1
May 24	4.0	612	4.12	25.2	3,857	12.30	6.3	2
May 31	6.0	918	6.18	37.8	5,783	18.45	6.3	3
June 7	6.0	918	6.18	37.8	5,783	18.45	6.3	4
June 14	8.0	1,224	8.24	50.4	7,714	24.61	6.3	5
June 21	8.0	1,224	8.24	50.4	7,714	24.61	6.3	6
June 28	8.0	1,224	8.24	50.4	7,714	24.61	6.3	7
July 5	8.0	1,224	8.24	80.8	12,364	41.21	10.1	8
July 12	6.0	918	6.18	60.6	9,268	30.89	10.1	9
July 19	6.0	918	6.18	60.6	9,268	30.89	10.1	10
July 26	4.0	612	4.12	40.4	6,182	20.61	10.1	11
Aug 2	4.0	612	4.12	40.4	6,182	20.61	10.1	12
Aug 9	4.0	612	4.12	40.4	6,182	20.61	10.1	13
Aug 16	2.0	306	2.06	20.2	3,091	10.30	10.1	14
Aug 23	2.0	306	2.06	20.2	3,091	10.30	10.1	15
Aug 30	2.0	306	2.06	20.2	3,091	10.30	10.1	16
Sept 6	2.0	306	2.06	20.2	3,091	10.30	10.1	17
Sept 13	2.0	306	2.06	20.2	3,091	10.30	10.1	18
n/a	0.0	0	0.00	0.0	0	0.00	0.7	19
n/a	0.0	0	0.00	0.0	0	0.00	0.7	20
	84.0 mg/m^2 in 18 weeks	12.9 P metric ton	86.6 10-34-0 metric ton	688.9 mg/m^2 in 18 weeks	105.4 N metric ton	345.5 28-0-0 metric ton		

One possible application technique for Takla Lake is a pusher tug and barge arrangement (Figure 4.3), where a tug pushes the barge containing the fertilizer storage tanks, and the fertilizer mixture is pumped into the propeller wash from the tug (Figure 4.4). This will achieve the required 10,000:1 dilution ratio, and prevent the fertilizer from sinking out of the epilimnion. The application schedule in Figure 4.2, Table 4.7 and Appendix A5 is based on a weekly application period of 4 hours, traveling near the centerline of the lake, at a speed of 5 knots. On the downward zigzag leg of the application trip, 50% of the fertilizer is applied over a distance of 10 nautical miles (18.5 km). On the return zigzag leg of the trip, the remaining 50% of the prescribed fertilizer load is applied. In total, at least 20 nautical miles (37 km) of the lake surface is covered by the tug/barge unit, and wind driven circulation will distribute the fertilizer over the rest of the lake. The well researched rule of thumb is that surface water currents will move at approximately 3% of wind speed, after an initial equilibration period of a few hours (Lawrence et al. 1995). Two large herring skiffs could also be used to distribute the fertilizer, in the same manner as the tug/barge system.

An alternate delivery mechanism is to use helicopters to dispense the fertilizer to the lake using an aerial spray system. This is a more expensive procedure due to the cost of fuel, pilots, helicopters and ground support crew, and should be considered if a tug/barge unit or herring skiffs are not available on Takla Lake. Fixed wing application of fertilizer using large dedicated aircraft such as a DC-6 are quite expensive, and are not considered any further in this report.

Figure 4.3. Example of barge-pusher tug configuration on Kootenay Lake.

Figure 4.4. Example of spreader bar to achieve 10,000:1 dilution (Kootenay Lake).

Application Strategy

Nutrients can be added at a constant application rate throughout the growing season, or "front-end" loaded to apply more phosphorus and less nitrogen during the early part of the season when concentrations of dissolved inorganic nitrogen (DIN) in most systems are at seasonal maximum concentrations (Ashley and Stockner 2003). The "front end loading" concept is preferred to simulate spring freshet conditions for phosphorus loading and substantially increase spring production on the tail of the 'freshet' P-input. Ever increasing loads of N as the season progresses compensates for the rapid spring biological uptake and gradual depletion of epilimnetic DIN, this regimen also matches phytoplankton production to the seasonal patterns of the early copepod and later cladoceran population increases (Stockner and MacIsaac 1996). This loading pattern results in a late spring peak in P input, which then declines to a constant summer loading and eventually to a reduced late summer loading (Figure 4.1). When sufficient ambient epilimnetic DIN concentrations are initially present to sustain production through the spring growing season without periods of depletion, then nitrogen applications can be safely applied at low application rates in the spring, with higher rates being applied throughout the summer. This strategy is designed to prevent DIN limitation and decrease the likelihood of colonial cyanobacteria (blue-green algae) blooms that are often associated with N depletion or low N:P ratios (Smith 1983; Pick and Lean 1987).

The Takla Lake fertilizer P loading schedule starts off at a low rate in mid May 2010, after a stable thermocline has formed in the lake. The loading rate increases over the spring and summer, reaching a peak P loading rate in June and early July of 8 mg m^{-2} wk^{-1}, then gradually tapering off during the summer and early fall. The nitrogen loading also starts off at a low rate in mid May, and increases throughout the summer, but makes a significant increase in the N:P ratio from 6.3 to 10.1 (weight:weight basis) in July. This is designed to prevent nitrogen depletion in the epilimnion due to algal and microbial uptake of nitrogen, which is the recommended strategy to prevent the development of inedible forms of algae (Ashley and Stockner, 2003). Fertilizer treatments are completed in early September, as the reduced day length and thermal cooling of the epilimnion signal the end of the main phytoplankton growing season.

Logistics

The logistics of Takla Lake fertilization program break down into three main components: transport and delivery of the liquid fertilizer, storage and spill containment of the liquid fertilizer, and application with adequate coverage and dilution of the blended fertilizer mixture (Table 4.8).

Table 4.8. Summary of logistical steps for Takla Lake fertilization.

Product	Application method	Key logistical steps
Liquid fertilizer	Aerial (rotary wing) or tug-barge or herring skiff lake centre dispersion	Logistics of transport and delivery, storage and spill containment, application with adequate coverage and dilution

Transport and Delivery

The fertilizer mixture will be purchased from Agrium Inc., a leading Canadian supplier of fertilizer products. The liquid fertilizer will be blended as per the required Takla Lake specifications at Agrium's Kamloops Storage Facility, and then delivered to Takla Landing using privately contracted "B train" semi-trailer tanker trucks. The key logistical aspect of this step involves placing the fertilizer order, with applicable method of payment (i.e., Purchase Order or Credit Card) several months in advance of the application date to allow Agrium and their contract truck haulers adequate time to develop a transportation and delivery plan. The fertilizer cannot be ordered on short notice and it will not be possible to arrange delivery of large volumes of fertilizer to a remote location like Takla Landing without adequate planning and pre-ordering months in advance. Arrangements must also be made in advance for a project attendant to be on site at an agreed upon day and time to meet and direct the tanker truck to the tank farm and/or tug/barge or herring skiff unit. This must always occur, even on statutory holidays, as the truck drivers are hired to haul the product to the delivery site, and offload it *only* when a project attendant is on site. The project attendant must visually check the colour and viscosity of the product to ensure it is acceptable, and has no apparent contamination. The volume of the product delivered is then verified with the Takla Lake order requirements, and signed off by the project attendant.

Storage and Spill Containment

A secure storage facility must be built in a location where the large "B train" tanker units can park nearby to offload their product, and easily turn their trucks around. The storage facility must also be located near the lake shore, so the product can be delivered via gravity feed to a tug/barge or herring skiffs, or an aerial fertilizer tank/spreader system. It is advisable to use a gravity flow system, rather than pumped systems as the fertilizer is corrosive to most metals, and a specialized corrosion resistant fertilizer pump is required to transfer the product.

The storage facility will consist of high density polyethylene storage tanks, specifically designed for fertilizer storage. The ground must be prepared and leveled in advance of placing the tanks, and any sharp objects or rocks removed, and a 10 cm base of crushed and compacted gravel and 5 cm of compacted sand placed on the ground to form a level, and smooth base for the storage facility. Alternatively, the base for the tanks can be constructed of 6” x 6” beams and 2” x 8” decking, and supported by concrete footings.

The maximum weekly loading for the fertilization project occurs in early July, when 38,081 liters of blended fertilizer is applied to Takla Lake (Appendix A5). The tank farm must have sufficient storage capacity to store the entire volume of fertilizer, plus considerable surplus capacity to accommodate delays in application caused by weather and delivery interruptions. Vertical fertilizer storage tanks are available in a range of sizes, up to 22,681 liters. Since it is advisable to have additional storage capacity, the tank farm should consist of two x 22,681 L tanks and two x 15,122 L tanks (75,606 L total capacity). The largest tank is 2.6 m in diameter, so the dimensions of the land area required for the tank farm is approximately 10 m x 10 m. Adequate land with proper zoning must be secured prior to building the tank farm.

The entire storage facility must be ringed with an earthen berm or concrete lock blocks, and a puncture resistant impervious liner laid over top of the sand and sides of the berm to capture 100% of the storage capacity of the tank farm in case of catastrophic leakage. The liner is laid up and over the berm and secured with sand bags on the exterior walls so it cannot be displaced by the wind. A 2.5 meter chain link fence with a 2 m wide double opening entrance gate is then installed around the storage facility, and kept locked at all times. Material Safety Data Sheets are required to be posted on the entrance gate. An emergency eye wash station should be located inside the gate to protect project staff. The gate must be kept locked at all times, and patrolled on a regular basis to ensure that vandals are not tampering with the storage facility and/or thieves are not stealing the product.

The nutrients in the liquid fertilizers (e.g., 10-34-0) can precipitate or “salt out” in cold weather when mixed with higher concentrations of urea ammonium nitrate fertilizer (e.g., 32-0-0). The resultant jelly-like precipitate will clog pumps and small orifices, and it is a troublesome problem to rectify. In practice, 28-0-0 has proven to be less prone to precipitate when blended with 10-34-0. Ideally, project supplies of fertilizer should not exceed seasonal requirements, so all liquid fertilizer is used during the treatment season and winter storage is not required. Liquid fertilizer is corrosive, and standard safety precautions should be taken when handling the various products, i.e., chemical resistant gloves, eye protection, hardhat, protective coveralls and steel toe rubber or high leather boots. Most metallic and ferrous compounds corrode very quickly when exposed to ammonium polyphosphate and urea ammonium nitrate and care must be taken to thoroughly clean all equipment and tools soon after use.

Application with Adequate Coverage and Dilution

Fertilizer must be diluted to approximately 10,000:1 if it is being dispensed from a tug/barge unit or herring skiffs, or sprayed in fine droplets if it is being applied by helicopter. A pre-arranged application plan is filed with the vessel operator(s) and helicopter pilot(s), and with modern radar and/or GPS, is it a straightforward task to apply the fertilizer exactly as required. The coverage zone should be approximately 37 km in length, with either a zigzag path for a tug/barge or herring skiff units with 18.5 km on each leg of the application trip, or an oval shaped flight path for the helicopter, with 18.5 km on leg of the oval shaped flight path. Wind driven surface circulation will distribute the fertilizer, albeit inside phytoplankton and bacteria cells, throughout the lake at a rate of approximately 3% of the average wind speed (Lawrence et al. 1995).

Legal Application and Notification Requirements

The addition of limiting nutrients, either in the form of salmon carcasses, organic nutrient analogues, or inorganic nutrients, to lakes, rivers and streams initially appears at odds with over four decades of efforts to reduce nutrient discharges to water bodies, and can be interpreted by the regulatory authorities as being in violation of water pollution control laws (Anders and Ashley, 2007). Hence, water users and regulatory agencies must be notified in advance, and provincial permitting processes and guidelines must be followed. The local Department of Fisheries and Oceans, and Ministry of Environment offices must be notified several months in advance of the proposed fertilization treatment.

In addition to the Ministry of Environment, it is important to determine which additional agencies and individuals should be notified. In British Columbia, under the Water Act, all downstream water users must be notified of any activities that may impact the water quality of their licensed withdrawals. Accordingly, Water Licensees on Takla Lake must be notified in advance in order to avoid potential complaints of water quality degradation and health issues. It is also highly advisable to meet in advance with the regional Public Medical Health Officer to discuss the planned treatment and discuss the nutrient loading rates and formulations to alleviate concerns about potential nitrate and heavy metal additions to potable water sources.

The Regional District must also be notified of the intention to build a tank farm for storing fertilizer, and the necessary building permits must be obtained. The tank farm must be designed and built with 100% spill containment capability, and will likely require inspection by DFO, the Ministry of Environment and/or the Regional District. A summary of the legal application and consultation requirements is shown in Table 4.9.

Table 4.9. Legal application and consultation requirements for Takla Lake fertilization in 2010.

Agency/Organization	Legal Authority and Rationale	Timing
DFO	Fisheries Act	mid-2009
Ministry of Environment	Wildlife Act, Water Act	mid-2009
Regional District	Building code, land zoning, foreshore activity	mid-2009
Medical Health Officer	Water Act, Public Health concerns	mid-2009
Public	General information	late-2009
First Nations	Constitutional requirement for adequate consultation and accommodation	mid-2009

Monitoring Program for 2010

The monitoring program for 2010 is more detailed than the single August 2009 monitoring plan outlined in Table 4.5. For 2010, an enhanced monitoring program should be conducted monthly from May through September at each of the four sampling stations in Takla Lake: Station 1 and 2 in the Main Arm, Station 3 in the Northwest Arm and Station 4 in the South Arm (Figure 3.1) and a series of existing DFO hydro acoustic and mid-water trawl transects (Appendix Figure A33). In addition, more detailed information on size-fractionated primary production and bacteria density and biomass is required to assess the effectiveness of the fertilization treatments (Table 4.10).

A series of limnetic fish population estimates are required using hydro acoustics and mid-water trawling to monitor the response of the sockeye and kokanee populations to the fertilization treatment. Hydro acoustic sampling using a scientific echosounder at 29 transect sites, 1-3 times per year is required in 2010 and 2011. In addition, mid-water pelagic trawling in late summer/early fall is required to assess the size-at-age and weight-at-age composition of sockeye and kokanee in Takla Lake (Appendix Figure A33).

Communication Plan

Since nutrient addition to waters is a novel concept in some areas, it is advisable to post notices and conduct public meetings to explain the rationale and risks/benefits of the proposed treatments. Within the Provincial and Federal fisheries agencies, it is important to notify stock assessment personnel, area management staff, stewardship groups and First Nations fisheries officers. A legal application and consultation schedule for the fertilization of Takla Lake is shown in Table 4.9. A communications plan outlining (1) the rationale for the nutrient treatment, (2) the details of the proposed treatment program and (3) examples of where similar treatments have been used in other lakes in BC, and elsewhere, to rebuild sockeye and/or kokanee populations should be prepared

Table 4.10. Sample collection parameters for Takla Lake (Stations 1-4) in 2010.

Parameter sampled	**Sampling technique**
Temperature, dissolved oxygen, pH, ORP, specific conductance and turbidity	In-situ digital recording at 1m intervals from 0–50 m, and at 5-m intervals from 50–100 m as depth permits.
Transparency	Secchi disk (22 cm white disk without viewing chamber)
Photosynthetically active radiation @ 400-700 nm	Li-Cor light meter with underwater quantum sensor; 1 m intervals to 20 m
Total alkalinity, dissolved inorganic carbon, total metals, pH, dissolved solids, silica, and nutrients (TP, TDP, SRP, NO_3+NO_2, NH_3,TN)	Sterilized Van Dorn bottle at 3 - 7 epilimnetic depths, and 1 – 3 hypolimnetic depths
Chlorophyll *a (not corrected for phaeophytin)*	Sterilized Van Dorn bottle at 3 equidistant depths in the euphotic zone
Phytoplankton	Sterilized Van Dorn bottle 3 - 7 epilimnetic depths
Primary production	Size fractionated ^{14}C primary production at 3-7 epilimnetic depths
Bacteria and Pico-cyano	Sterilized Van Dorn bottle 3 - 7 epilimnetic depths
Limnetic macrozooplankton	Three vertical net hauls with either a 0.05 m^2, 160 µm Wisconsin net or 0.25 m^2 100 µm SCOR net
Sockeye and kokanee pelagic enumeration	Hydro acoustic sampling using Biosonics 105 dual beam system at 29 transect sites, 1-3 times per year
Sockeye and kokanee pelagic species, age and size composition	Pelagic mid-water trawl, 3 x 7 m, at prescribed mid-water trawl transects, once per year in late summer/early fall

for distribution the public. The communication plan should be conducted using (1) information pamphlets, (2) PowerPoint presentations at public meetings in late 2009, and (3) posted on an appropriate web-site.

Cost Estimates

2009 Costs

Project Management

Project management by a qualified fisheries scientist/limnologist is required to coordinate this project in 2009. The total project management and scientific monitoring/oversight costs in 2009 are estimated at $25,000.

August Limnological Monitoring

The August 2009 limnological data will be collected during a one week sampling trip with a two person crew. The total estimated cost of the 2009 August sampling program is $52,000 (Limnotek Research and Development Inc.).

August Fish Survey

The hydroacoustic trawl survey, coupled with strontium analysis to separate kokanee and sockeye, with acoustic data processing is $40,000 (Okanagan Nation Alliance).

Tank Farm Construction

The 22,681 L tanks and 15,122 L tanks cost $6,675 and $4,225 respectively. Freight charges to delivery the four fertilizer tanks and fittings to Takla Landing are $3,200, for a total delivered cost of $25,694. The tank farm site preparation, berm, liner, deck and roof will cost approximately $15,000. The total cost for the completed tank farm is $40,694.

Total 2009 Costs
The total costs for the 4 items above is $158,000.

2010 Costs

Project Management

Project management during the fertilizer treatment year is more demanding due to the multiplicity of tasks. This is estimated at $50,000.

Fertilizer Purchase and Delivery

The freight costs for transporting liquid fertilizer to Takla Landing are $125 per metric tonne. The 10-34-0 costs $668 per metric tonne, so the delivered cost is $793 per metric tonne. A total of 86.6 metric tones are required (Table 4.7), for a cost of $68,700.00.

The 28-0-0 costs $370 per metric tonne, so the delivered cost is $495 per metric tonne. A total of 105.4 metric tones are required (Table 4.7), for a cost of $52,200.

The total cost of the fertilizer blends, delivered to Takla Landing, is $121,000.

Fertilization Application – Option 1: Tug/Barge

It is not possible to estimate this cost without a site visit to the area to determine the availability of suitable tugs and barges. For comparative purposes, a similar size tug/barge unit is used to fertilize Kootenay Lake (see Figures 4.3-4.4) at an annual cost of approx. $100,000.

Fertilizer Application – Option 2: Herring Skiffs

The herring skiff option is based on two 7 ton herring skiffs, each with two outboard motors and trailers. The cost of the two skiffs, fertilizer metering systems, tanks and pumps is $61,600. Labour to fit the tanks and assemble the fertilizer delivery system is $4,200. Delivery of the skiffs, tanks, setup and training at Takla Landing is $17,300. Total cost for the skiffs, setup, training and delivery is $83,100.

Skiff crew labour is estimated for a 4 person crew (2 per skiff). The total for labour, application, loading and fuel is $60,000.

The total cost for the herring skiff option is $143,100.

Fertilizer Application – Option 3: Helicopter

A compete package price for the helicopter application option is $240,650. The company did not provide a detailed breakdown of their costs.

Limnological Monitoring

The 2010 limnological data is collected during a one week sampling trip with a two person crew at monthly intervals from May to August. The cost estimates are based on 1.5 travel days to and from Takla Lake, and two days sampling on the lake at the four sampling stations (10 hours/day at $100/hr plus $100/day each for accommodation). The total estimated cost of the 2010 May to August sampling program is $110,264 (Table 4.11).

Table 4.11. 2010 limnology cost estimates

Parameter sampled	Stations	Frequency x Depth x replicates	Labour cost	Lab unit cost	Total
Temperature, dissolved oxygen, pH, ORP, specific conductance and turbidity	4	4 Vertical profile	$66,000	$0	$66,000
Transparency	4	4 Vertical profile	incl.	$0	$0
PAR radiation	4	4 Vertical profile	incl.	$0	$0
Total alkalinity	4	4 x 6 x 1	incl.	$12	$1,152
DIC	4	4 x 6 x 1	incl.	$15	$1,440
pH	4	4 x 6 x 1	incl.	$15	$1,440
TDS	4	4 x 6 x 1	incl.	$5	$480
Si	4	4 x 6 x 1	incl.	$20	$1,920
TP	4	4 x 6 x 1	incl.	$17	$1,584
TDP	4	4 x 6 x 1	incl.	$17	$1,584
SRP	4	4 x 6 x 1	incl.	$15	$1,440
DIN	4	4 x 6 x 1	incl.	$15	$1,440
NH3	4	4 x 6 x 1	incl.	$15	$1,440
TN	4	4 x 6 x 1	incl.	$24	$2,304
Total metals	4	4 x 6 x 1	incl.	$23	$2,160
Chlor a	4	4 x 3 integrated	incl.	$23	$1,080
Phytoplankton	4	4 x 3 integrated	incl.	$115	$5,520
Bacteria and Pico-cyanobacteria	4	4 x 6 x 1	incl.	$90	$8,640
Size fractionated primary production	4	5 depths, 2 sizes	incl.	n/a	$8,000
Zooplankton	4	4 Vertical haul x 3	incl.	$55	$2,640
				Total	**$110,264**

Fish Monitoring

Hydro acoustic monitoring and pelagic mid-water trawling will be undertaken by a contractor (Okanagan Nation Alliance) at a cost of $60,000.

The total costs for 2010 are the May to August limnological monitoring ($110,264), fertilizer purchase and delivery ($120,847), fertilizer application ($143,000 to $240,650), fish survey ($60,000) and project management ($50,000) for a total of $455,000 to $582,000.

The total 2009 and 2010 costs to fertilize the Main (North) Arm of Takla Lake ranges from $614,000 to $741,000 depending on which fertilization application method is selected (Table 4.12). The herring skiff option is the less expensive application method.

Table 4.12. 2009 and 2010 cost estimates to fertilize Main Arm of Takla Lake.

Item	**2009**	**2010**
Project management	$25,000	$50,000
Tank farm	$41,000	n/a
Fertilizer purchase and delivery	n/a	$121,000
Fertilizer application – helicopter	n/a	$240,650
Fertilizer application – herring skiffs	n/a	$114,200
Limnological monitoring	$52,000	$110,264
Fish surveys	$40,000	$60,000
Year total	$158,760	$455,000 to $582,000
Grand total	**$614,000 (herring skiff) to $741,000 (helicopter)**	

5. Uncertainties

Will Takla Lake respond to fertilization?

There is a high probability that Takla Lake will respond positively to lake fertilization. Key limnological indicators demonstrate that the lake has relatively low, inherent productivity compared to other Fraser sockeye lakes. Takla Lake has suitable morphological, optical, thermal and chemical properties; however it has low nutrient concentrations that limit autotrophic plant and bacterial production. Additional nutrients will stimulate this part of the food chain.

Will Early Stuart sockeye juveniles respond to fertilization?

In view of the anticipated phytoplankton and zooplankton responses (especially *Daphnia*) and the experience gained from fertilizing other sockeye lakes, positive juvenile sockeye responses are predicted. Fertilization will most likely increase juvenile in-lake growth and survival.

Will fertilization alter sockeye-kokanee interactions?

Kokanee and sockeye are the same species, *Oncorhynchus nerka*. They are reproductively isolated and genetically distinct (Wood et al. 1999). They overlap the spawning distribution of ES sockeye, concentrating in Takla Lake tributaries. During their juvenile stages, kokanee are similar ecologically to sockeye. If kokanee had a competitive advantage over sockeye, this could potentially negate fertilization benefits.

Takla Lake juvenile sockeye and kokanee were studied in August of 1988 and 1991 (Wood et al. 1999). Ecological interactions were investigated by using genetic markers to identify and distinguish kokanee and sockeye. The two forms were intermingled with no detectable difference in relative abundance by depth or among trawl catches. Sockeye salmon were significantly larger than kokanee due to differences in relative egg size (Figure 5.1) and their food habits strongly overlapped (both forms feed on large-bodied zooplankton), leaving open the possibility of food competition. In view of the larger body size of juvenile sockeye, it seems likely that age 0+ sockeye would have a competitive advantage over age 0+ kokanee. However, it is possibile that age 0+ sockeye compete with age 1+ and 2+ kokanee.

Future alteration of sockeye-kokanee interactions cannot be ruled out. Monitoring would be required in parallel with fertilization to reduce this uncertainty and to track fish responses to fertilization over time.

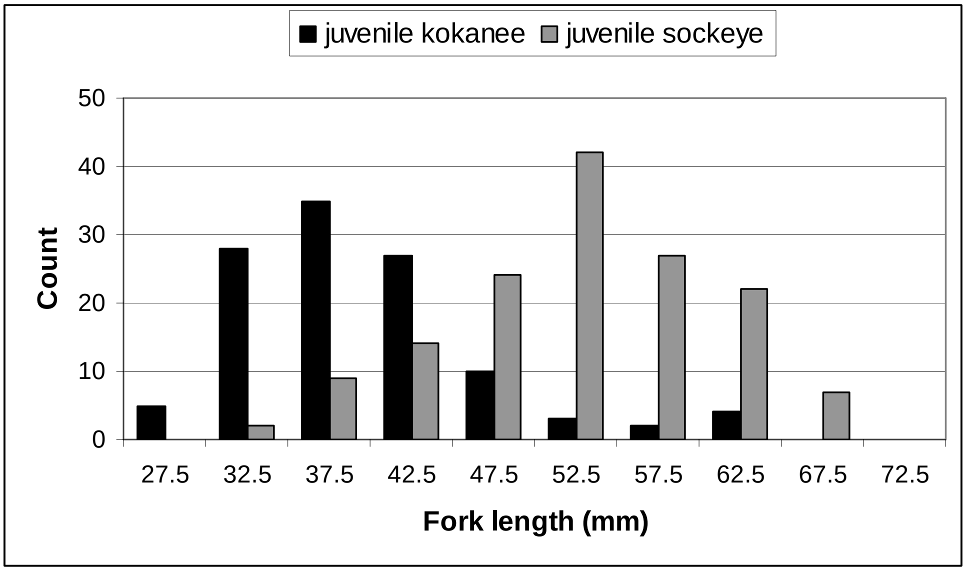


Figure 5.1. Size distribution of Age 0+ juvenile sockeye and kokanee from Takla Lake in 1988 and 1991. Source: Wood et al. (1999).

Will Early Stuart sockeye recover?

It is necessary to define the ES sockeye production target. The time series between 1981 to 2005 (Figure 5.2) indicates that production on dominant cycle years averaged 800,000 fish. Total ES and Driftwood River escapements averaged 282,000 and 126,000 fish, respectively over the same period. It is reasonable to consider these mean values as preliminary targets for ES production and Driftwood River sockeye escapement. Driftwood River spawning escapement in 2005 was 6,800 fish. This implies the need for a 20-fold increase in Driftwood spawner escapement level to reach a target of 126,000 spawners.

The level of Driftwood spawning escapement in 2009[2] will likely be conducive for carrying out fertilization in Takla Lake in 2010. If there were too few spawners, there would be an insufficient number of sockeye fry in 2010 to take advantage of the increased production. If there were high densities of spawners, such as occurred in 1985, 1989, and1993 (Figure 1.2), fertilization would be unnecessary from a restoration perspective.

[2] DFO ES forecast for 2009 (50% probability) is 254,000 sockeye. DFO escapement goal is 108,000

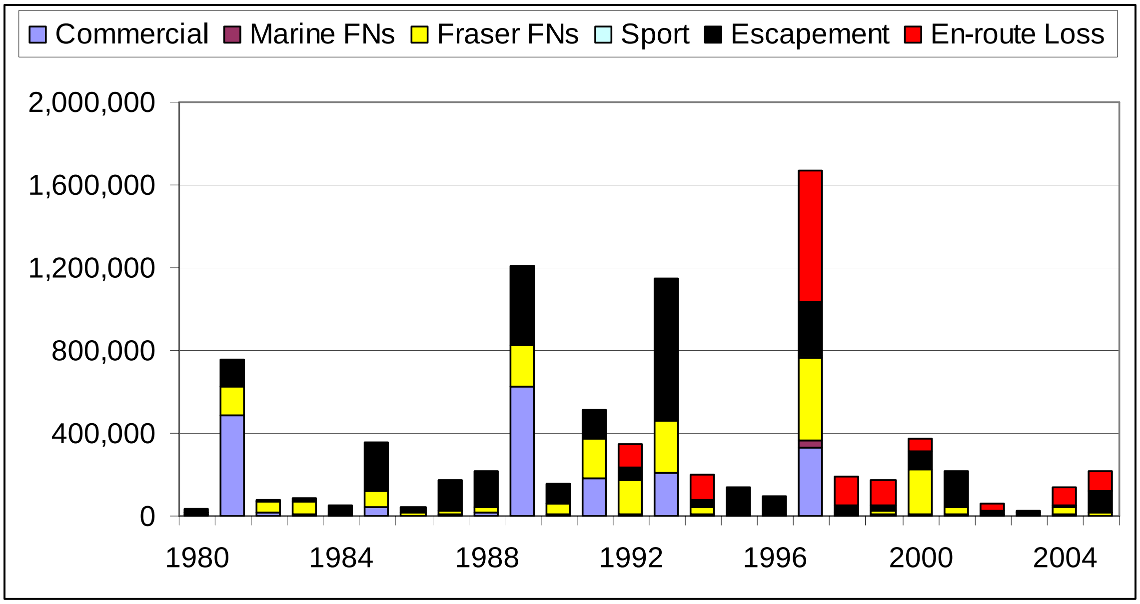


Figure 5.2. Early Stuart sockeye production data.

It is expected that ES sockeye will increase in response to fertilization, but the magnitude of increase may preclude full achievement of production and spawning escapement targets by 2013. It may be necessary to repeat the fertilization in 2014 to maintain an upward population trajectory. Following recovery of the population, fertilization would be terminated. The sub-dominant return years could also be targeted, but as indicated on Figure 5.2, the timing of the sub-dominant year class is not well-defined for ES sockeye.

Is lake fertilization reversible?

Lake fertilization is reversible. It can be terminated in-season at any time if an unexpected biological response (plankton bloom) is detected. If fertilization is terminated at the end of the proposed 2010 treatment year, Takla Lake would gradually revert back to its pre-fertilization trophic state. The rate of change depends on flushing rate and biological uptake of added nutrients. Takla Lake, with a water residence time of 15 years, would gradually revert back to pre-fertilization conditions.

Summary

The uncertainties described above were rated on a 5-point scale: 1=very likely 2=likely 3=uncertain 4=unlikely 5=very unlikely. The following Table reflects the opinion of the report authors:

Uncertainty	Likelihood
Will Takla Lake respond to fertilization?	very likely
Will Early Stuart sockeye juveniles respond to fertilization?	likely
Will fertilization alter sockeye-kokanee interactions?	uncertain
Will Early Stuart sockeye recover?	likely
Is lake fertilization reversible?	very likely

6. Recommendations

1. UFFCA should co-ordinate Takla Lake fertilization on behalf of Tl'azt'en, Nak'azdli and Takla Lake First Nations, the Carrier Sekani Tribal Council and those involved in the Inter-Tribal Fishing Treaty.

2. Engage DFO to become a partner in the project both technically and as a potential funder.

3. Explore funding opportunities with Fraser Salmon and Watersheds Program, Pacific Salmon Commission, Pacific Salmon Foundation, BC Ministry of Environment, BC Ministry of Forests and other interested parties.

4. Secure preliminary funding by June '09 ($41,000) to permit the construction of a fertilizer tank farm at Takla Landing before September '09.

5. Undertake monitoring in 2009 to measure limnological conditions as well as juvenile sockeye and kokanee densities.

6. Develop a pelagic ecosystem simulation model in 2009 to examine the effect of fertilization on competitive interactions between juvenile sockeye and kokanee.

7. Allocation issues associated with future increased production to be co-managed by Fraser First Nations and DFO.

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Appendix A1: Limnology Data

Appendix Figures

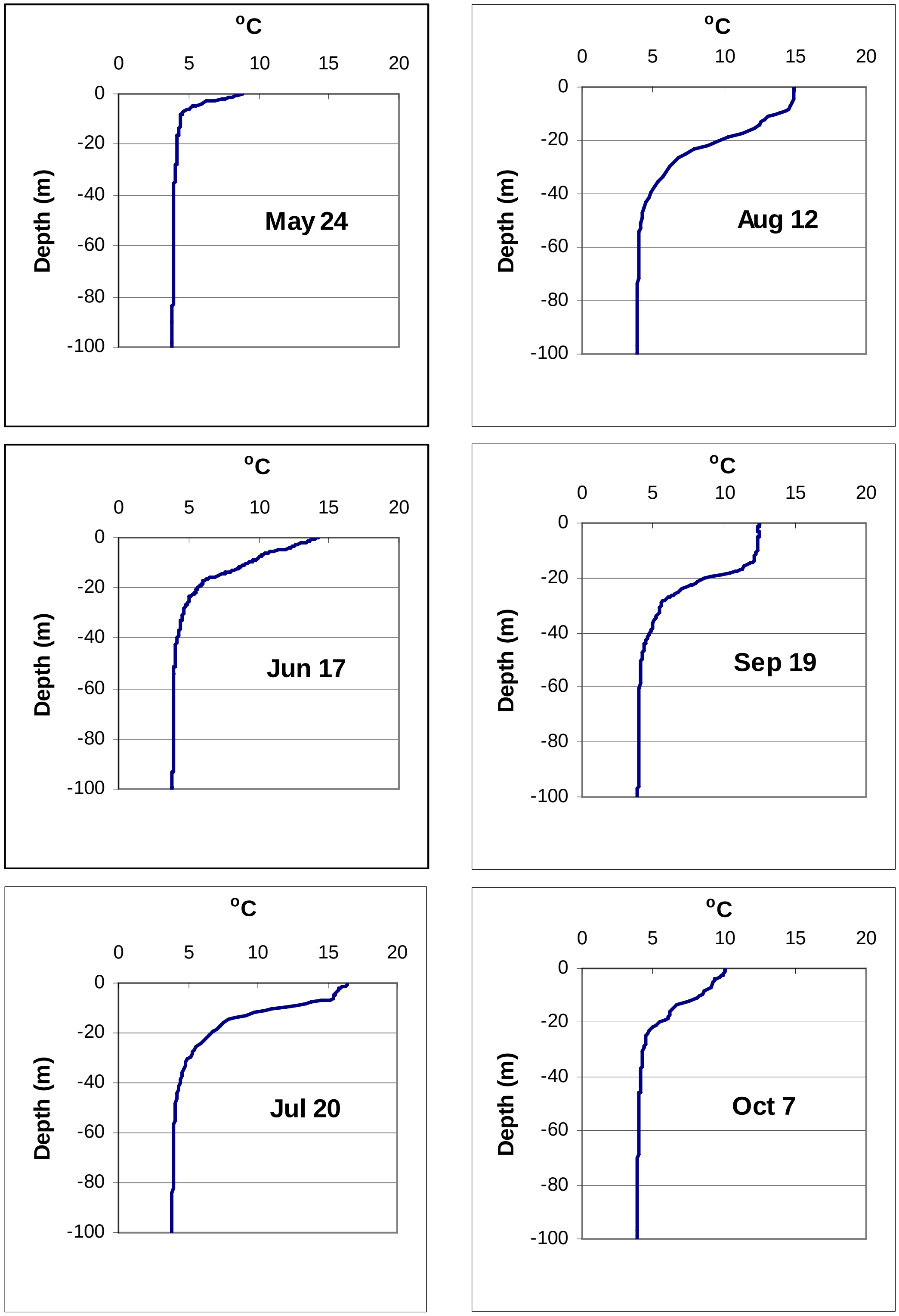


Figure A1. Takla Lake temperature profiles from Station 2 during 1998.

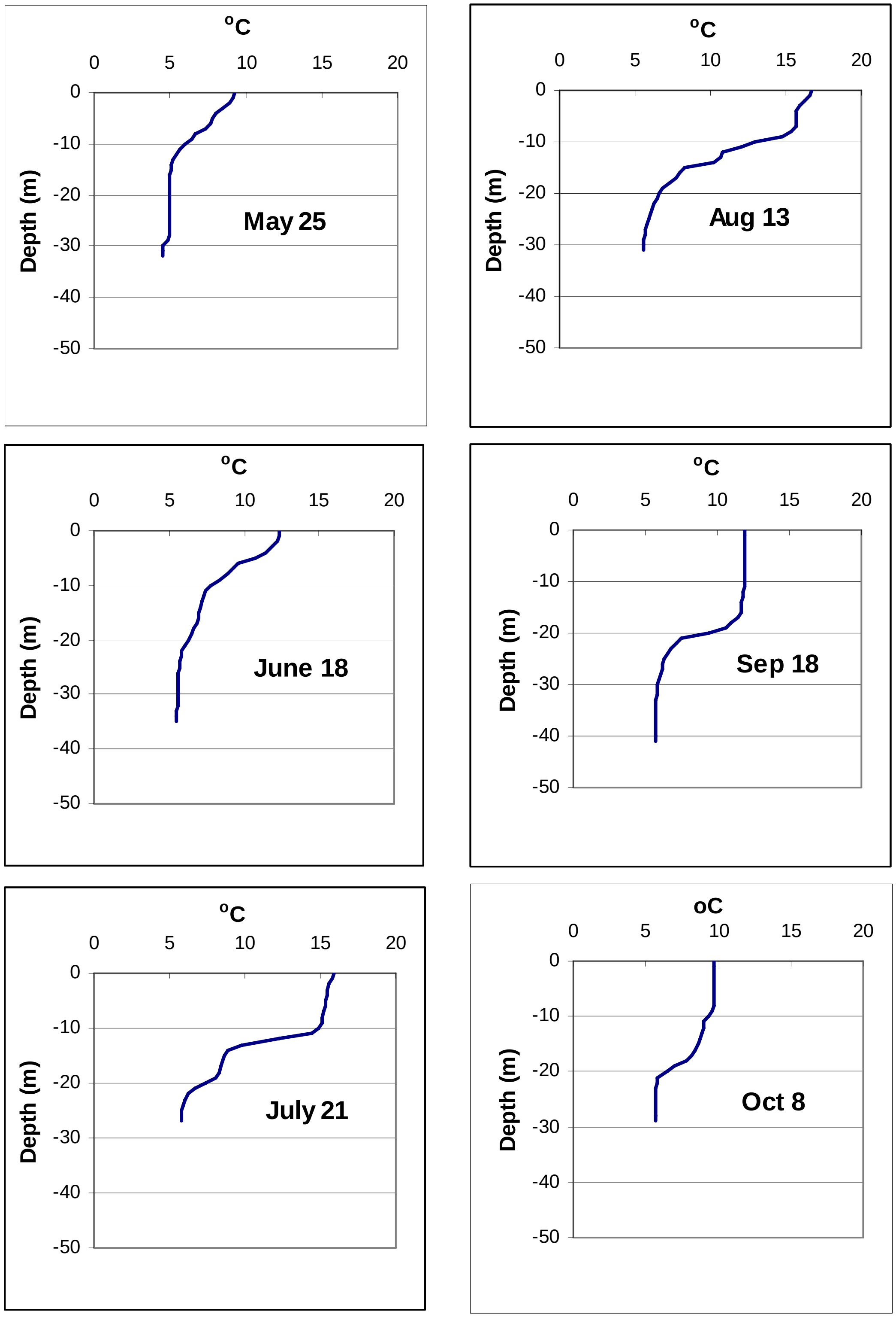


Figure A2. Takla Lake temperature profiles from Station 4 during 1998.

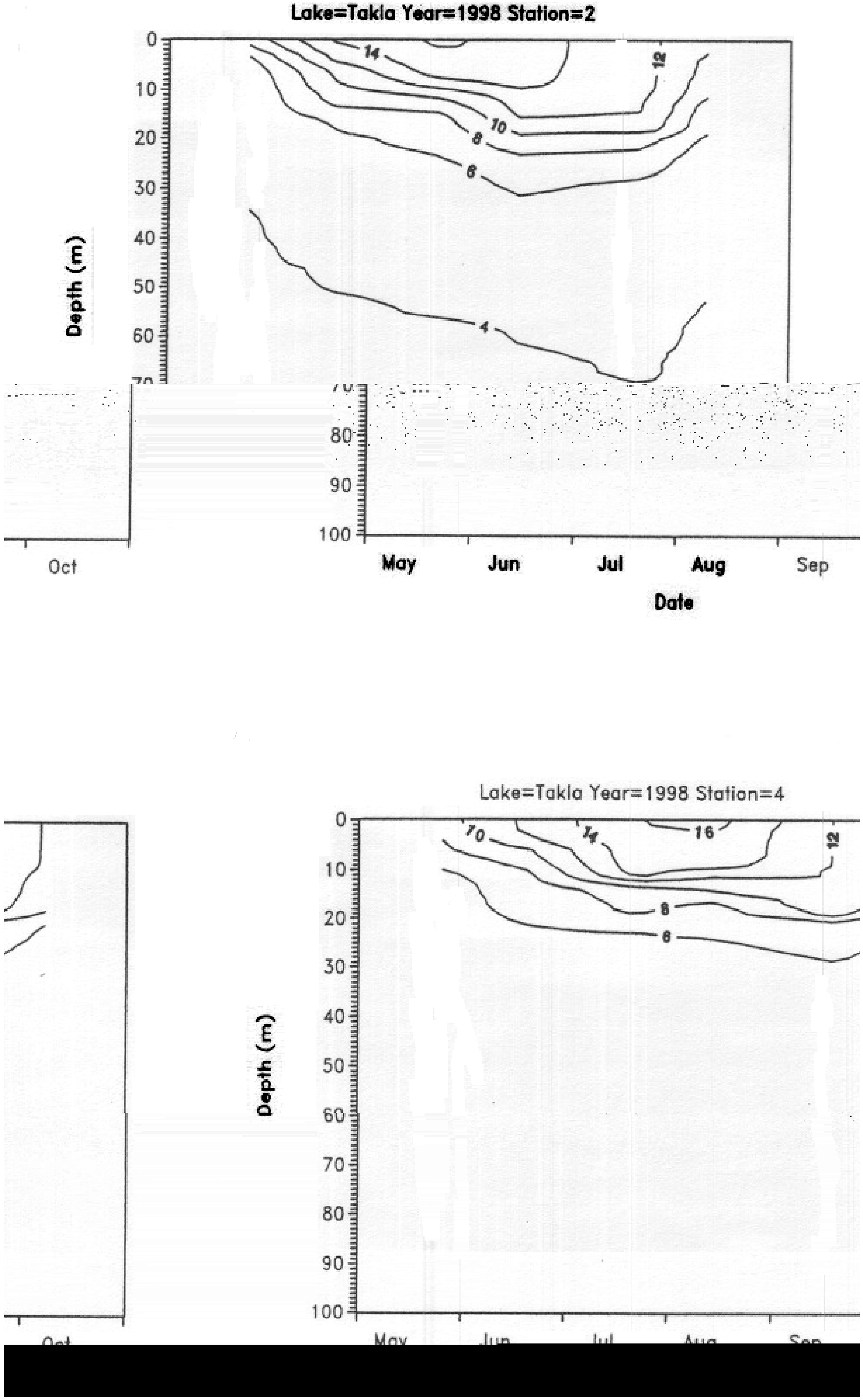


Figure A3. Isopleths showing seasonal variation in thermal structure of Takla Lake at Stations 2 and 4 during 1998.

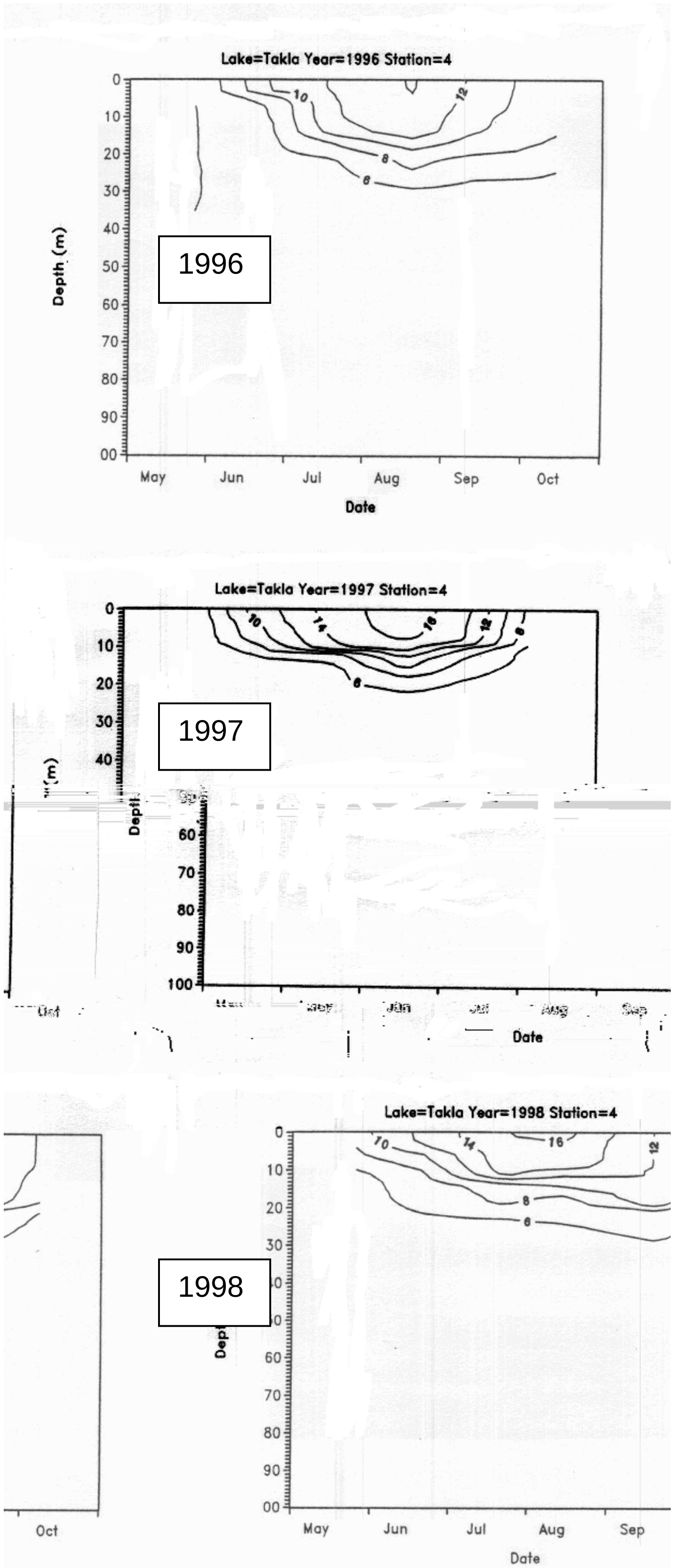


Figure A4. Variation in Takla Lake thermal structure at Station 4 during 1996 -1998.

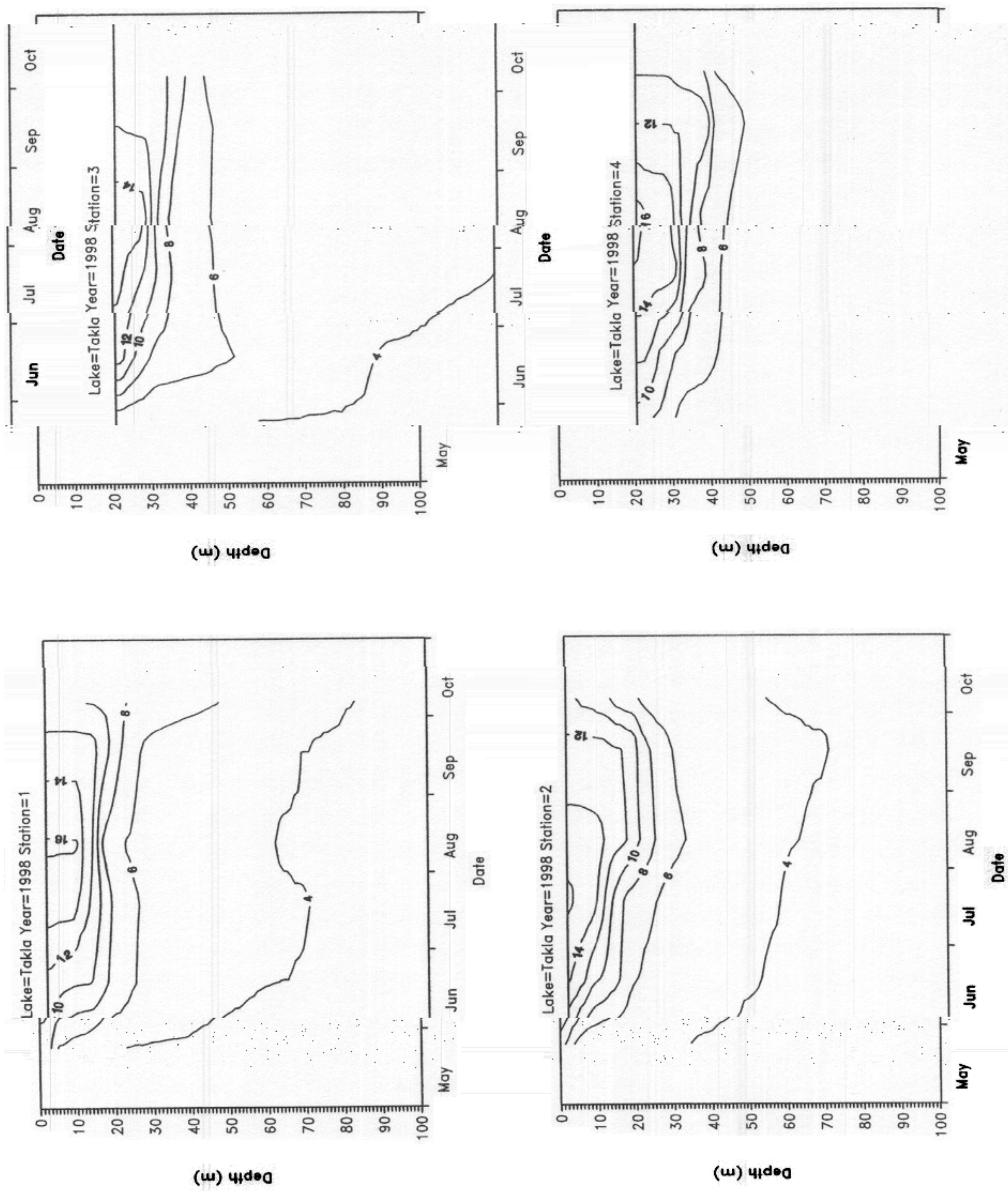


Figure A5. Takla Lake thermal conditions at Stations 1-4 during 1998.

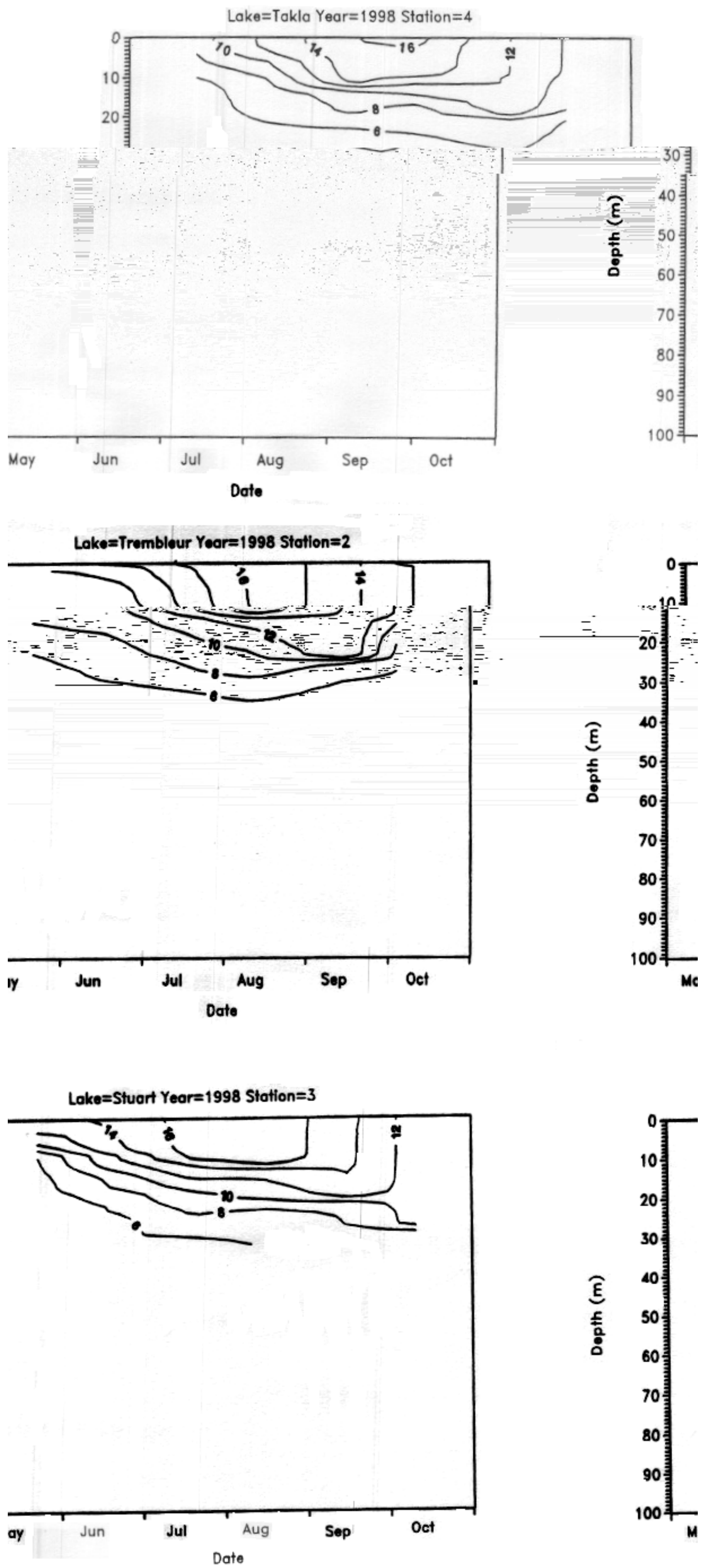


Figure A6. Comparison of thermal structure in Takla, Trembleur and Stuart Lakes during 1998.

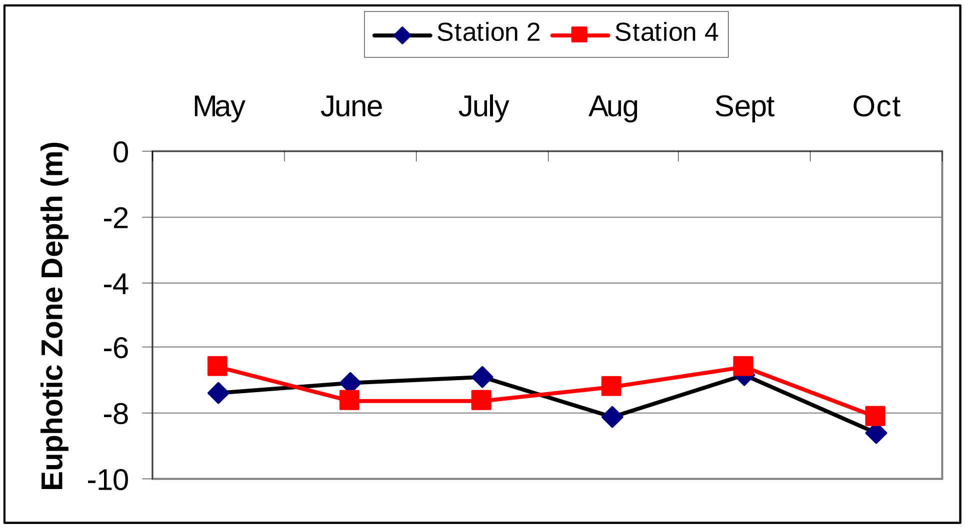


Figure A7. Seasonal variation in euphotic zone depth in Takla Lake during 1998.

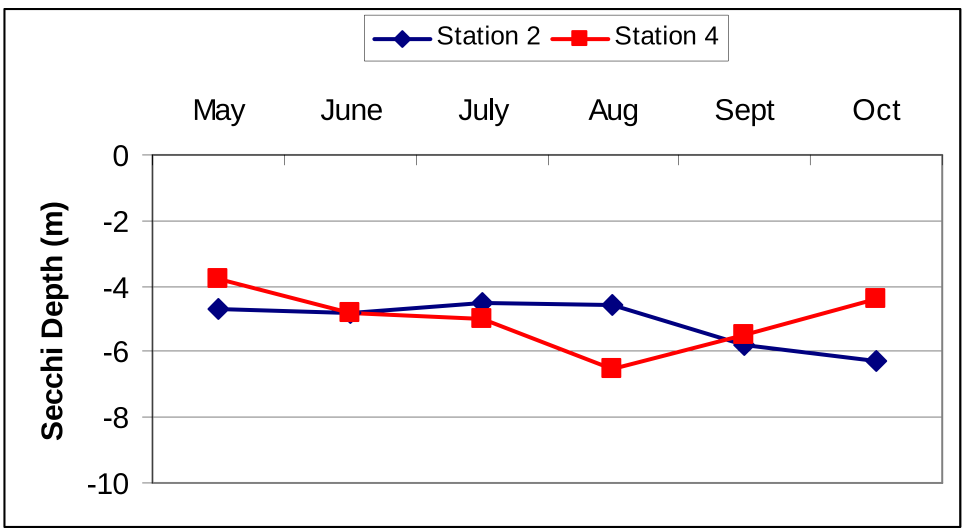


Figure A8. Seasonal variation in Secchi Depth in Takla Lake during 1998.

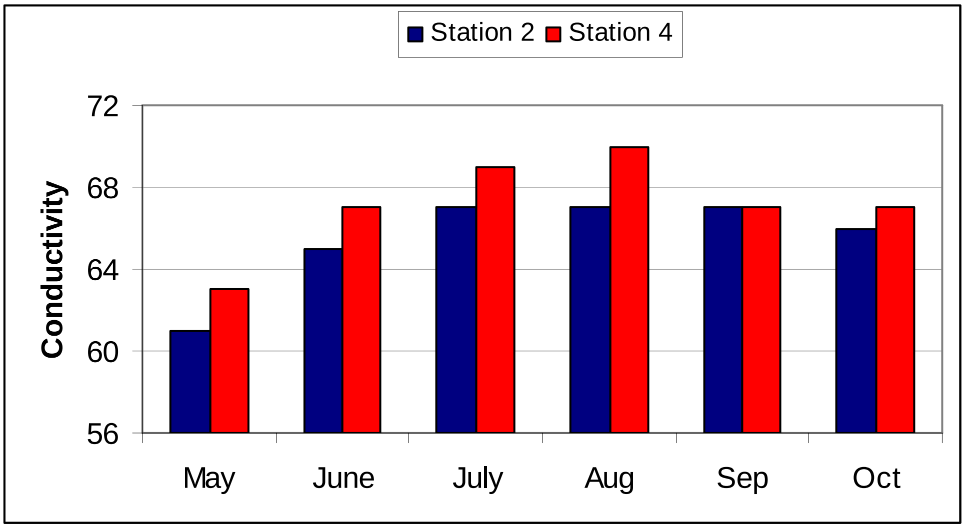


Figure A9. Conductivity (µS/cm @ 25^{o}C) from Takla Lake during 1998.

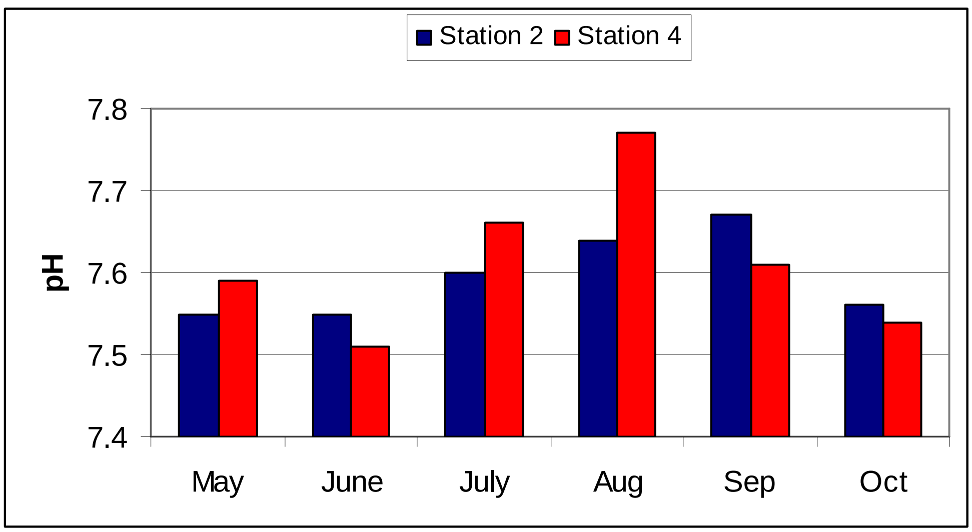


Figure A10. pH of Takla Lake during 1998.

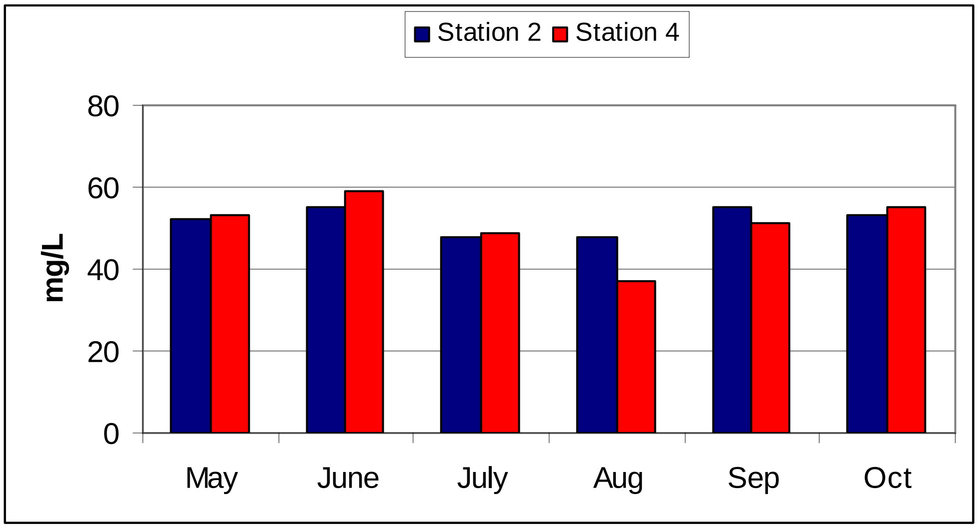


Figure A11. Total dissolved solids from Takla Lake during 1998.

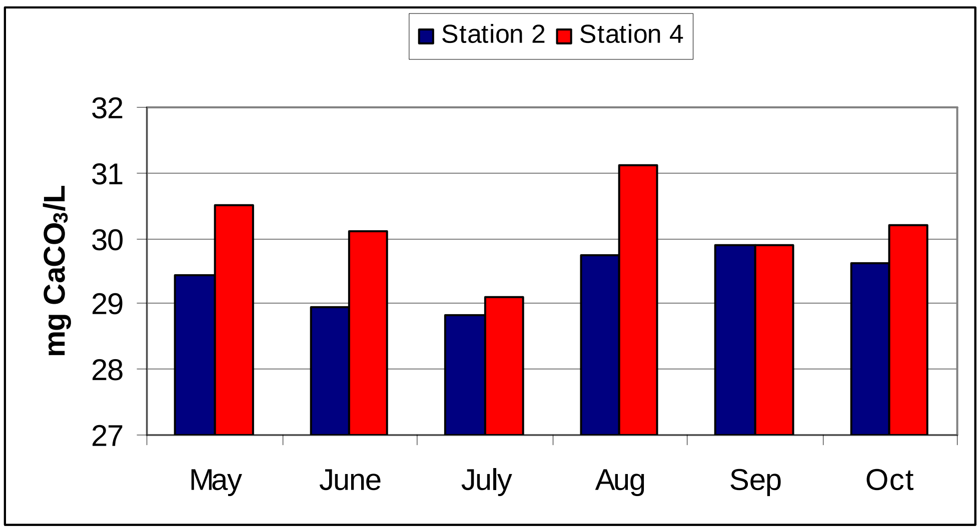


Figure A12. Total alkalinity in Takla Lake during 1998.

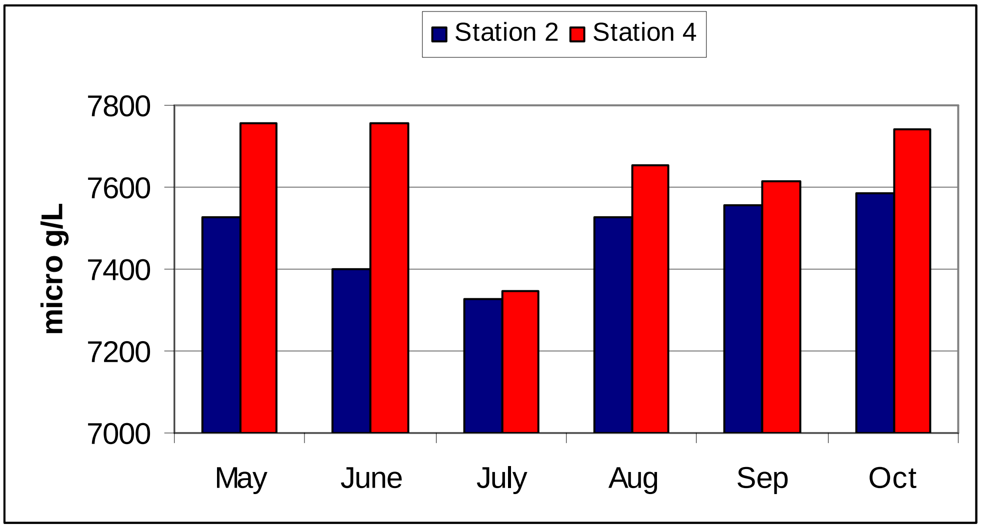


Figure A13. Total dissolved inorganic carbon in Takla Lake during 1998.

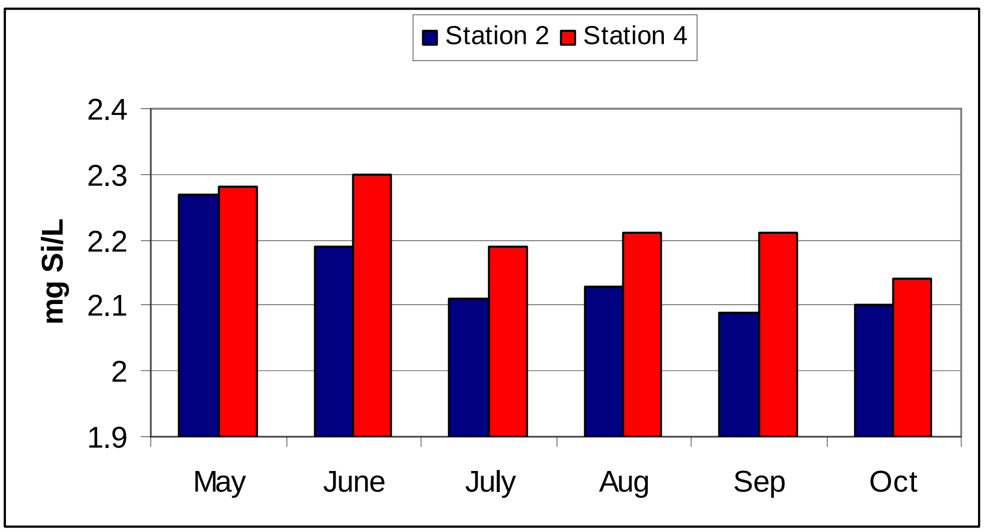


Figure A14. Silica concentration in Takla Lake during 1998.

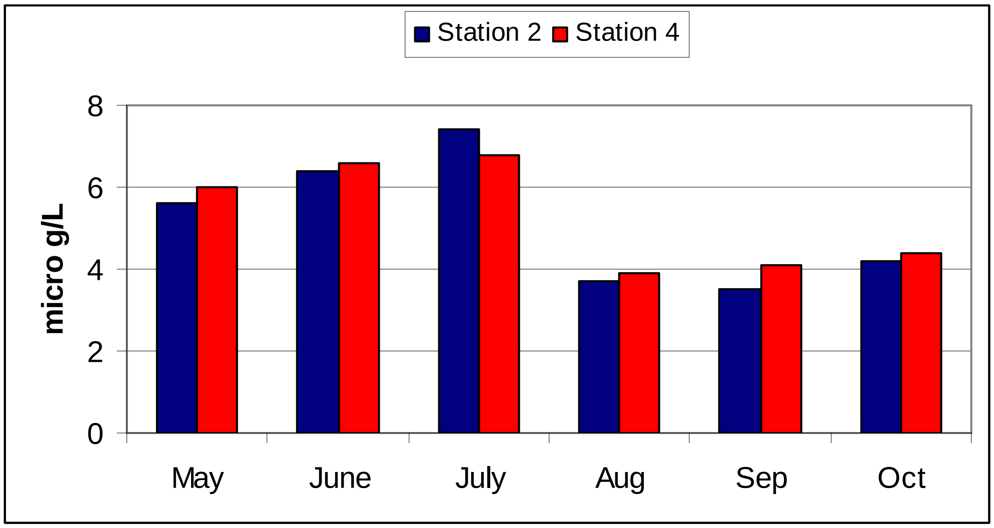


Figure A15. Total phosphorus concentrations in Takla Lake during 1998.

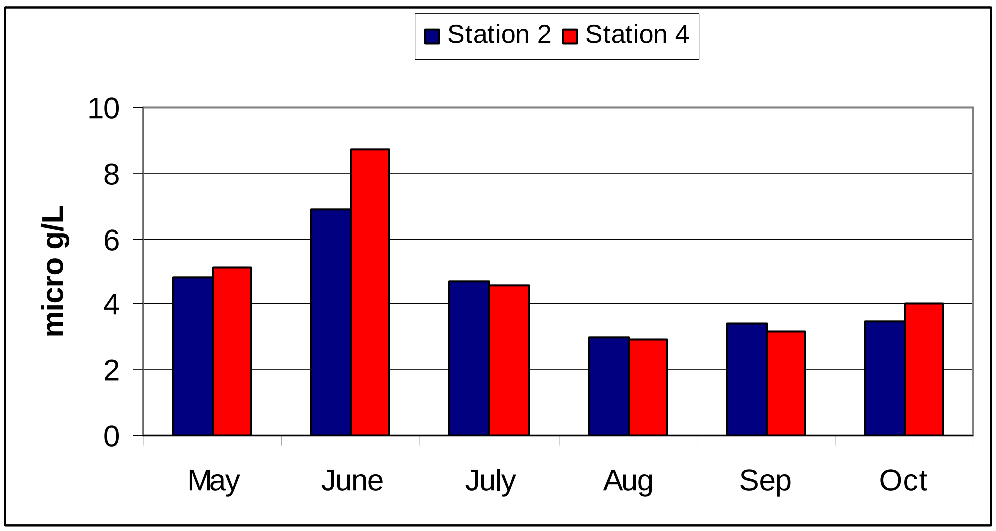


Figure A16. Dissolved phosphorus concentrations in Takla Lake during 1998.

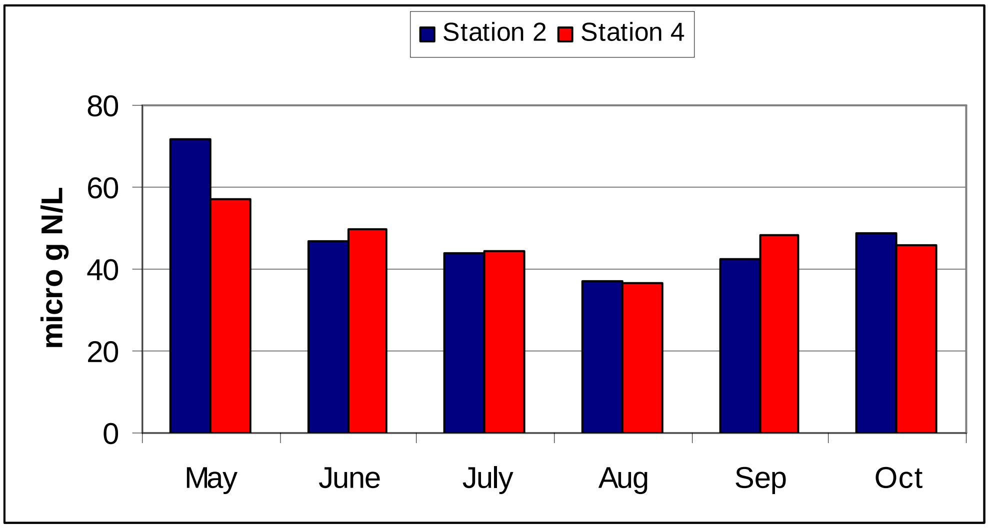


Figure A17. Nitrate concentration in Takla Lake during 1998.

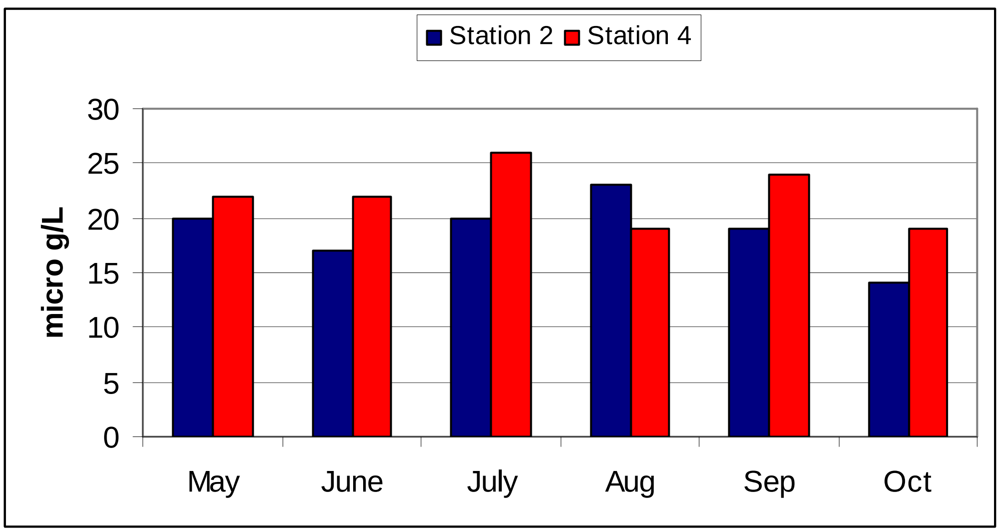


Figure A18. Particulate mass of nitrogen in Takla Lake during 1998.

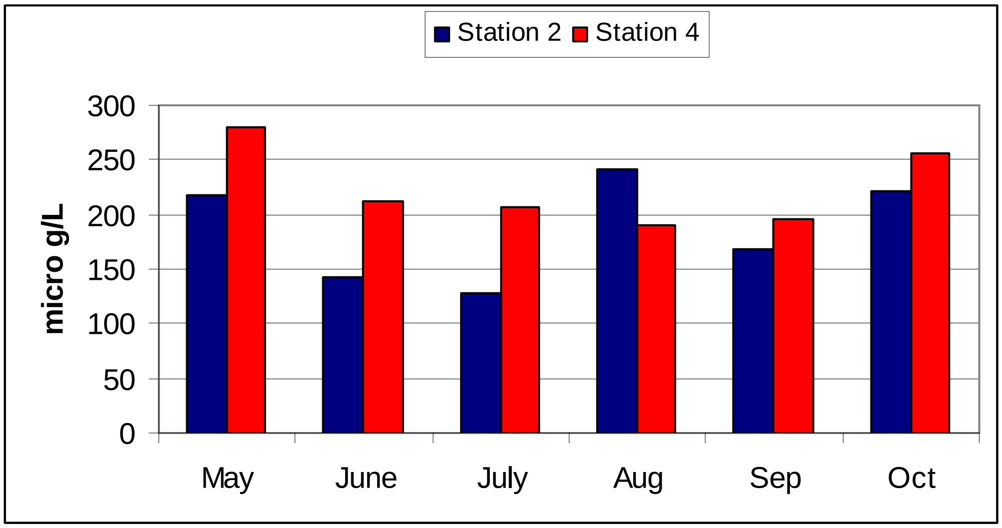


Figure A19. Particulate mass of carbon in Takla Lake during 1998.

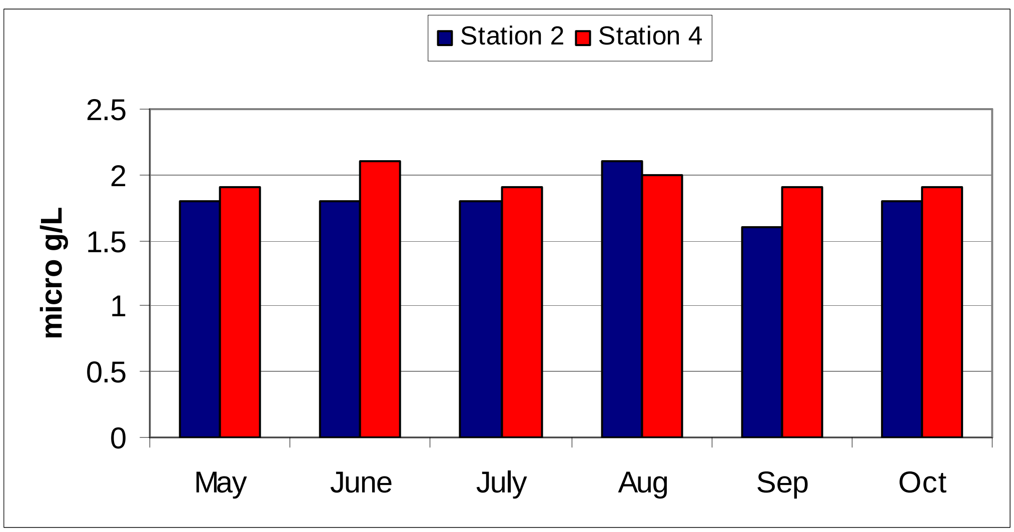


Figure A20. Particulate mass of phosphorous in Takla Lake during 1998.

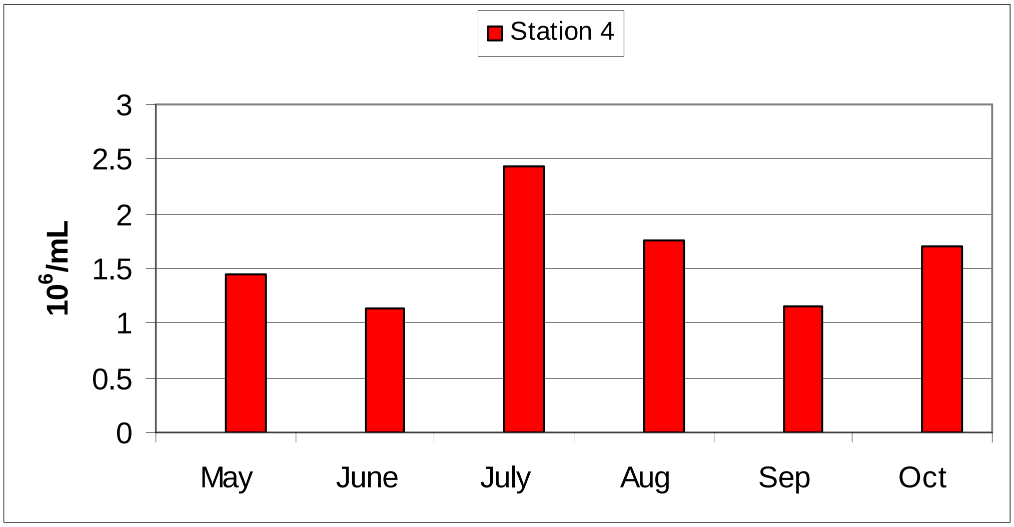


Figure A21. Bacteria concentration in Takla Lake during 1998.

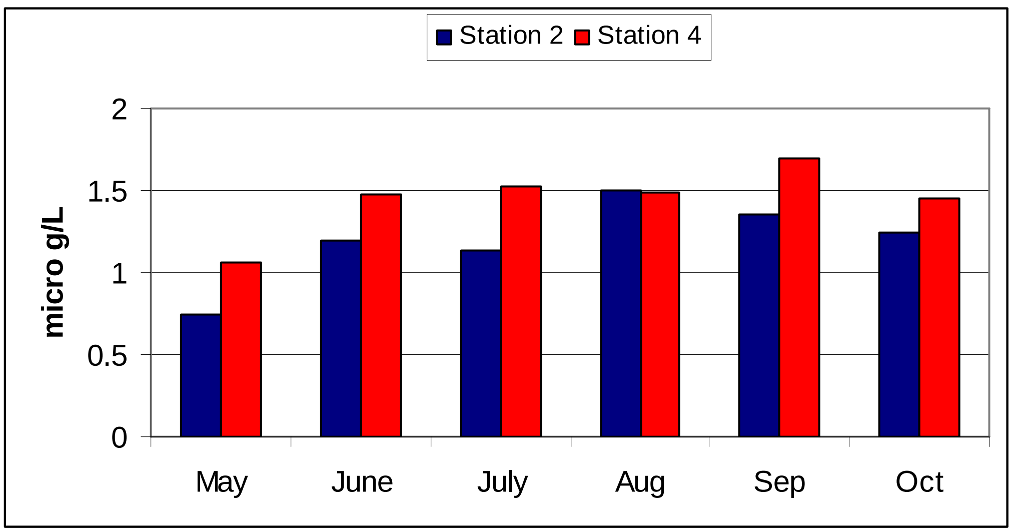


Figure A22. Total chlorophyll concentration in Takla Lake during 2008.

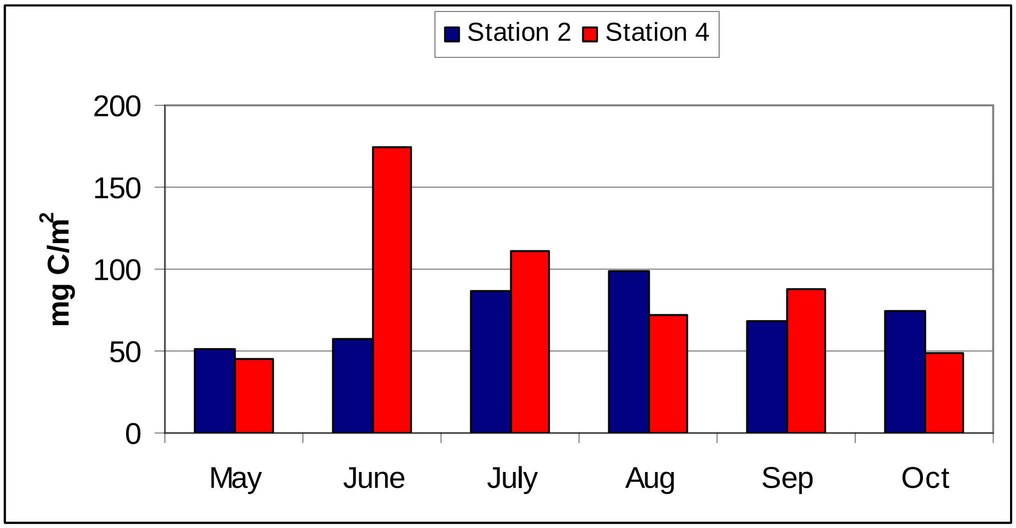


Figure A23. Daily photosynthetic rate in Takla Lake during 1998.

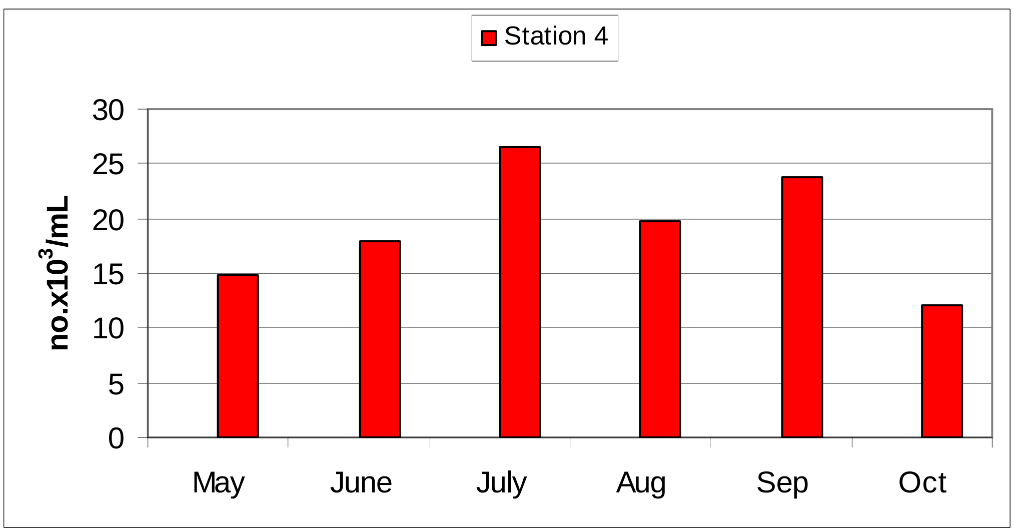


Figure A24. Concentration of picoplankton (0.2-2μm) in Takla Lake during 1998.

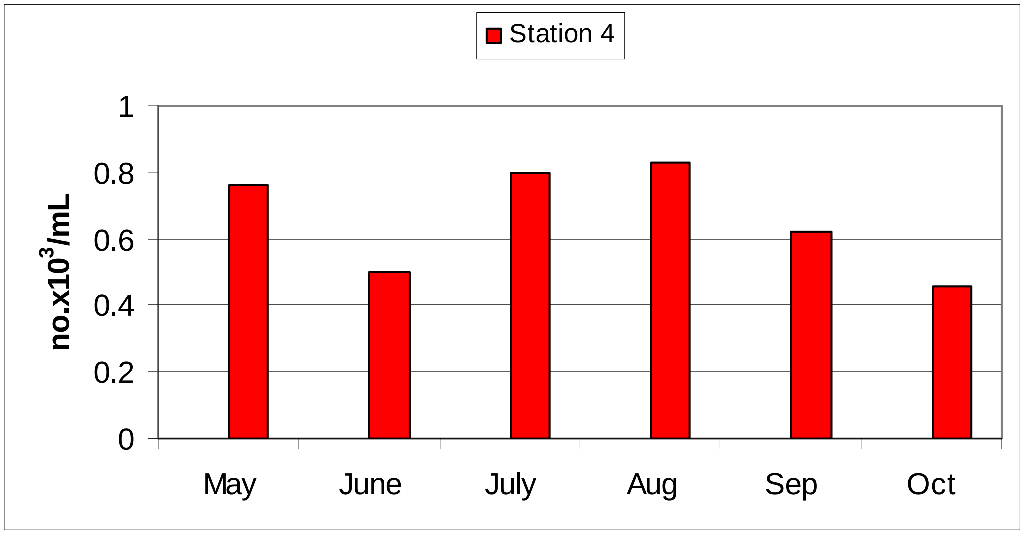


Figure A25. Concentration of nanoplankton (2.0-20 μm) in Takla Lake during 1998.

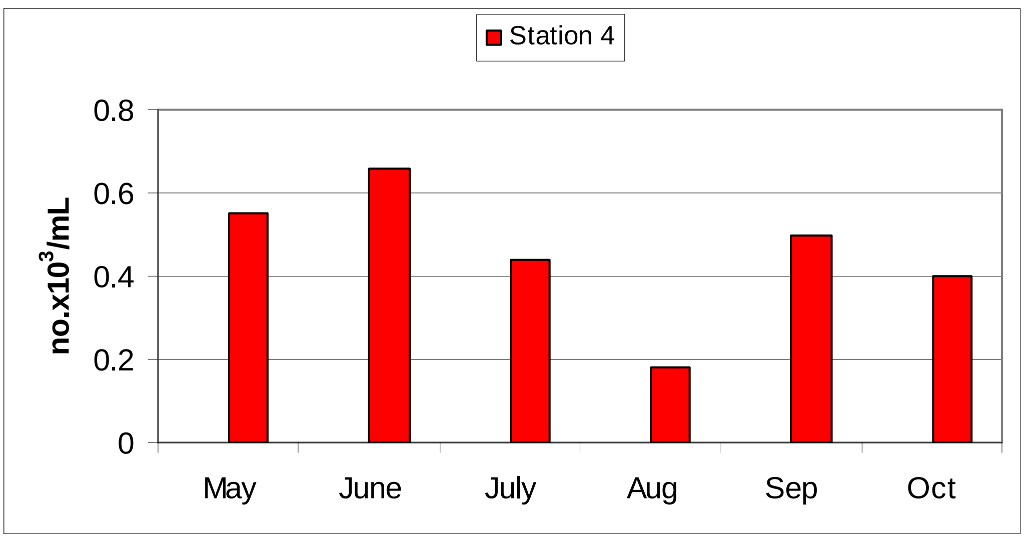


Figure A26. Concentration of microplankton (>20 μm) in Takla Lake during 1998.

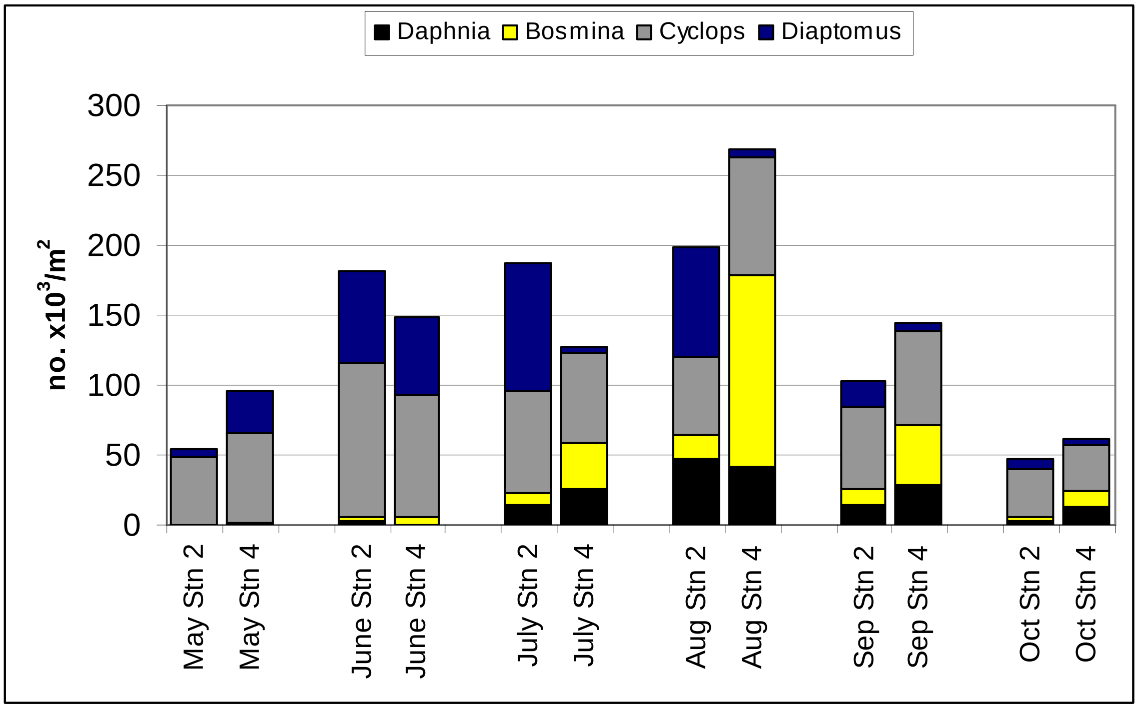


Figure A27. Zooplankton density in Takla Lake during 1998.

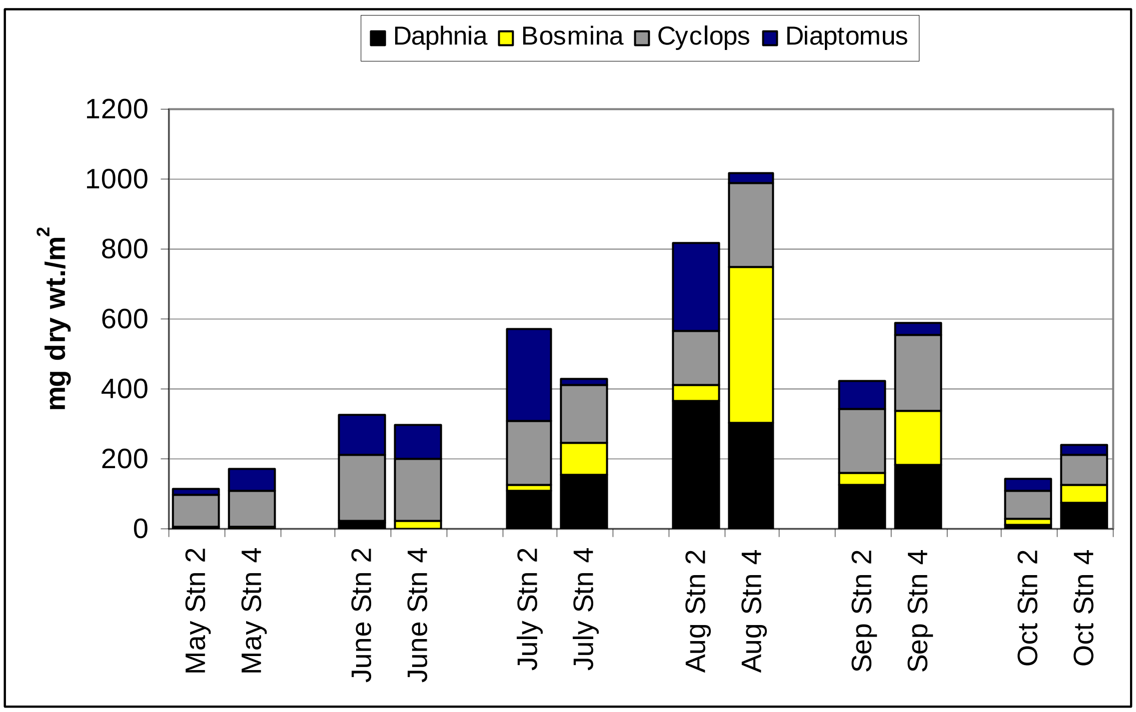


Figure A28. Zooplankton biomass in Takla Lake during 1998.

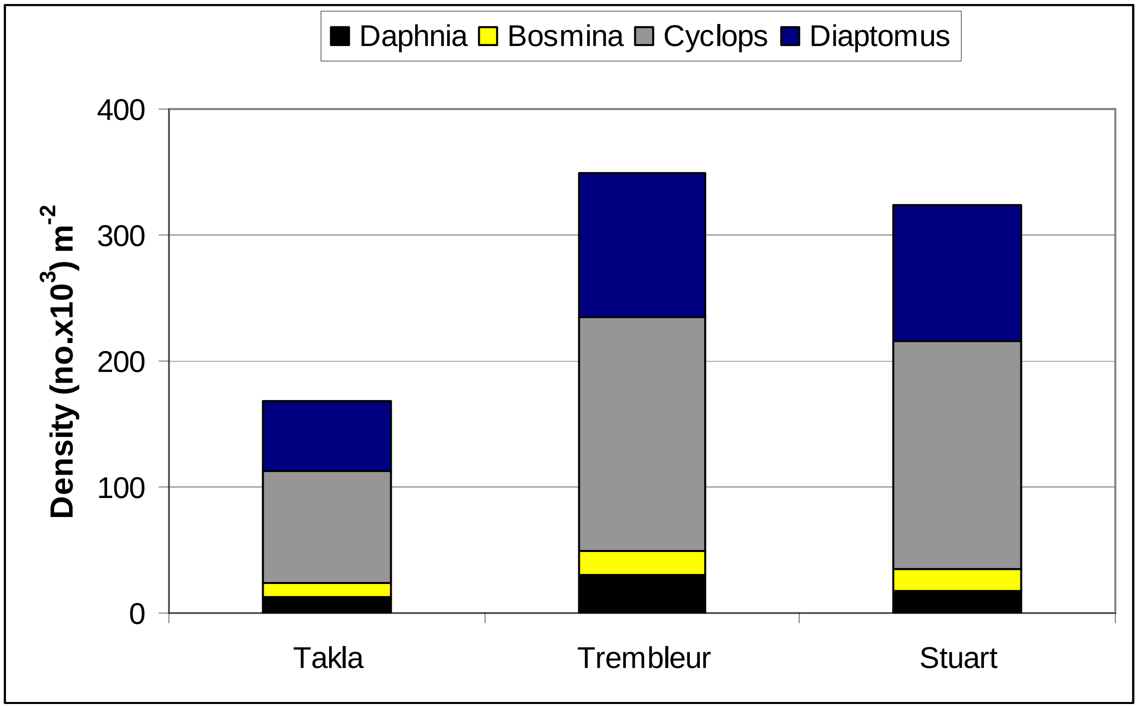


Figure A29. Whole-lake seasonal average density of zooplankton in the 3 lakes.

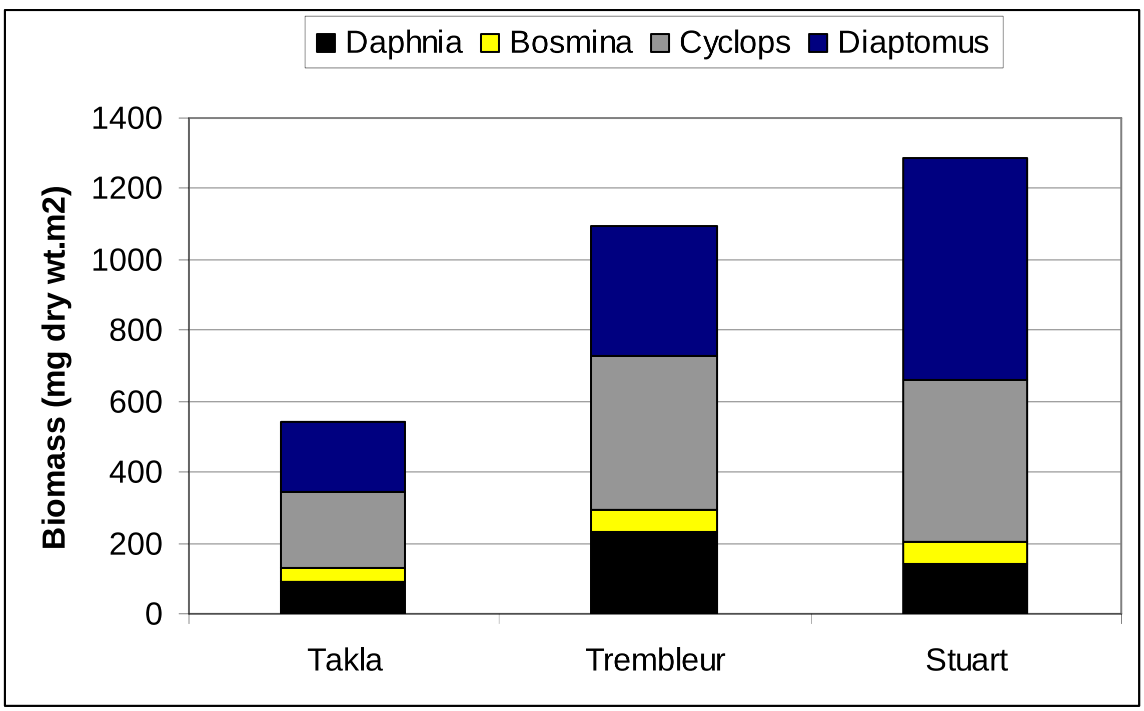
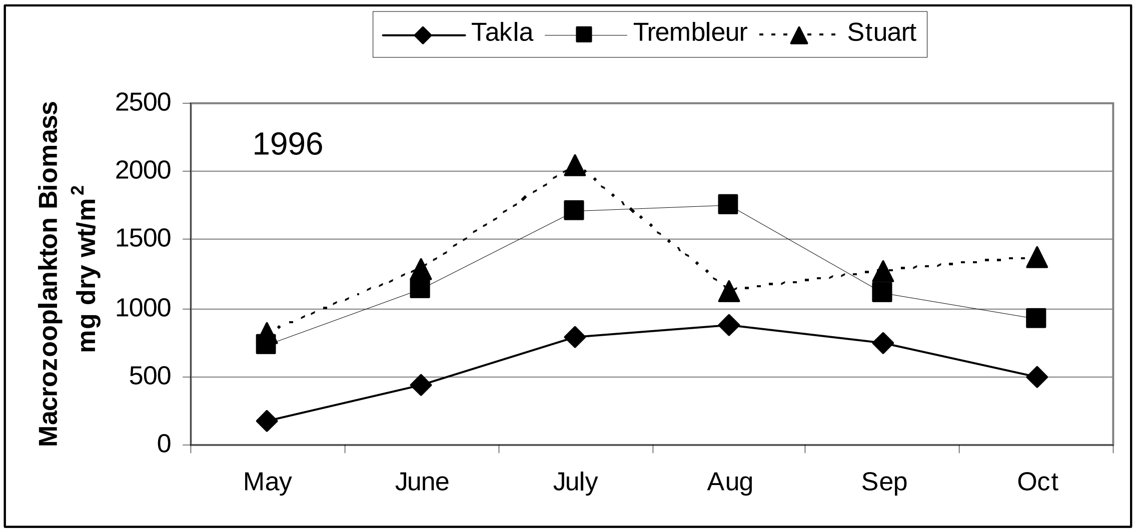
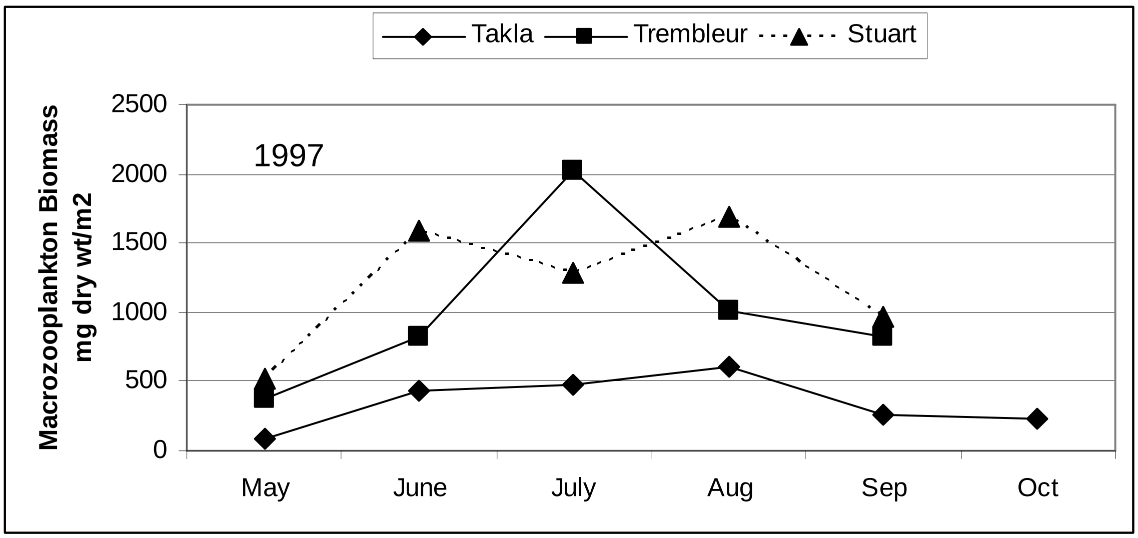


Figure A30. Whole-lake seasonal average biomass of zooplankton in the 3 lakes.





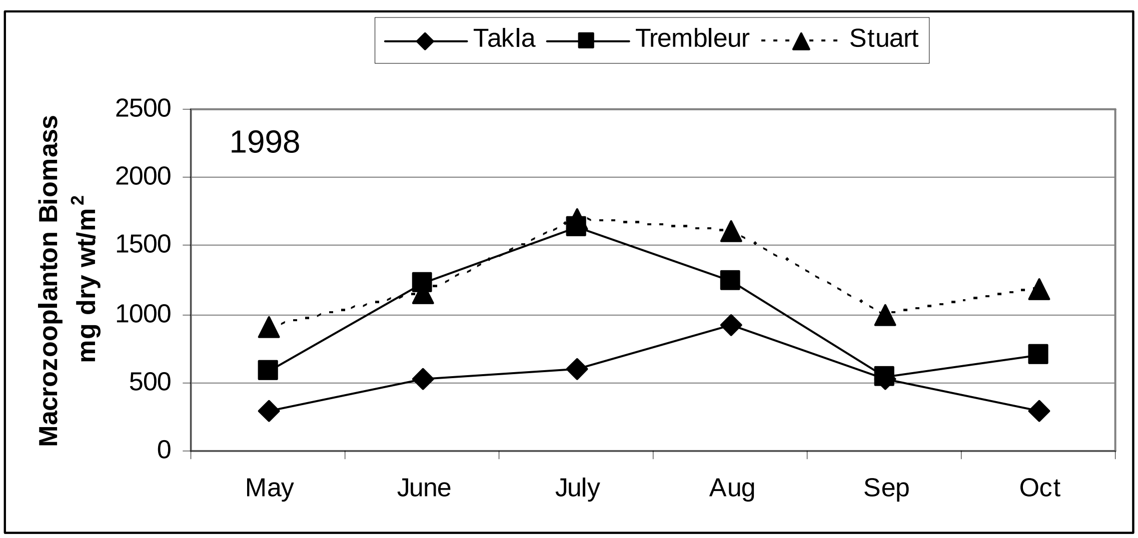


Figure A31. Macrozooplankton biomass in the 3 lakes during 1996 (upper chart), 1997 (middle chart) and 1998 (lower chart).

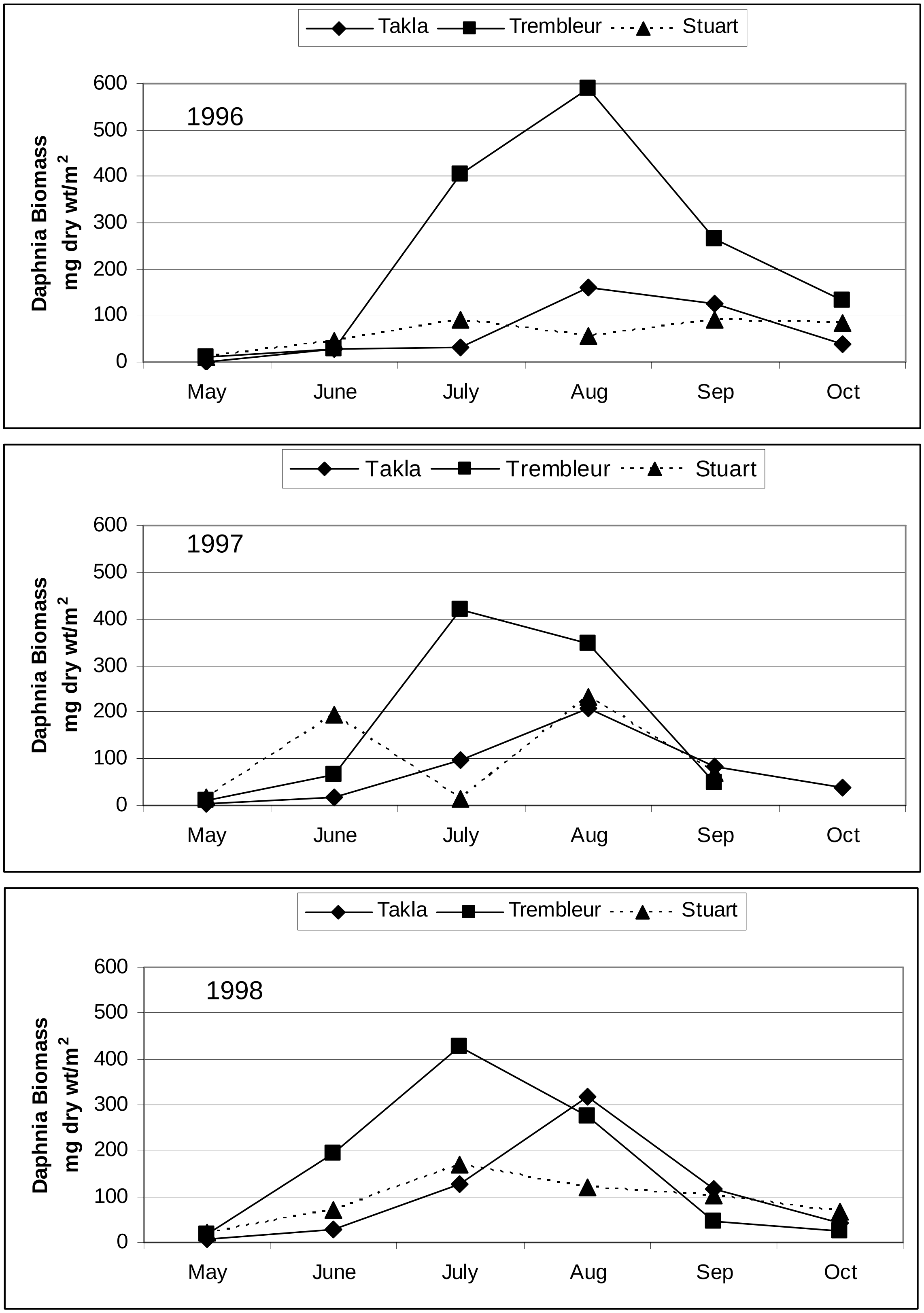
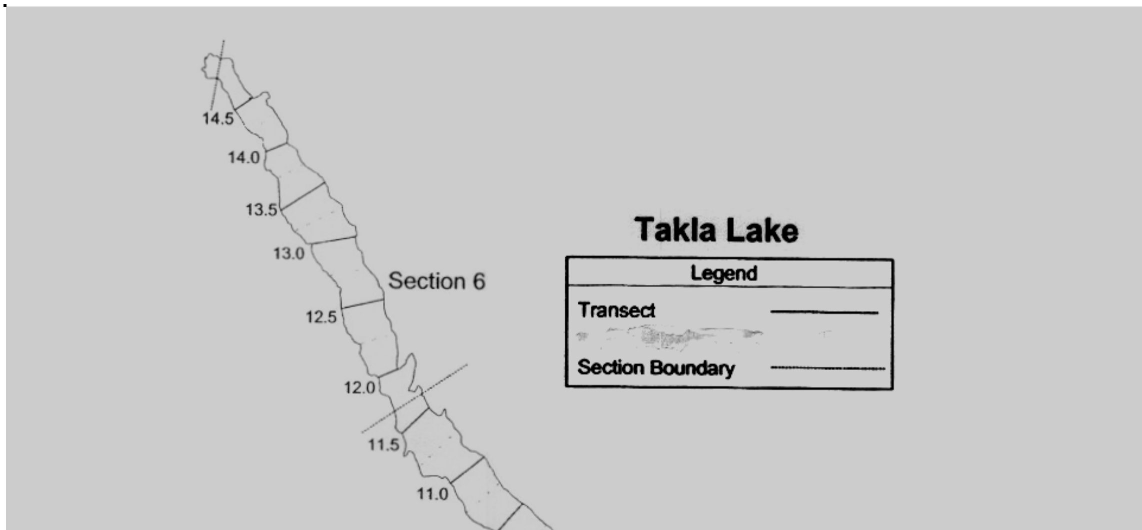


Figure A32. *Daphnia* biomass in the 3 lakes during 1996 (upper chart), 1997 (middle chart) and 1998 (lower chart).


Takla Lake
Legend
Transect
Section Boundary
Section 6
14.5
14.0
13.5
13.0
12.5
12.0
11.5
11.0

[redacted]

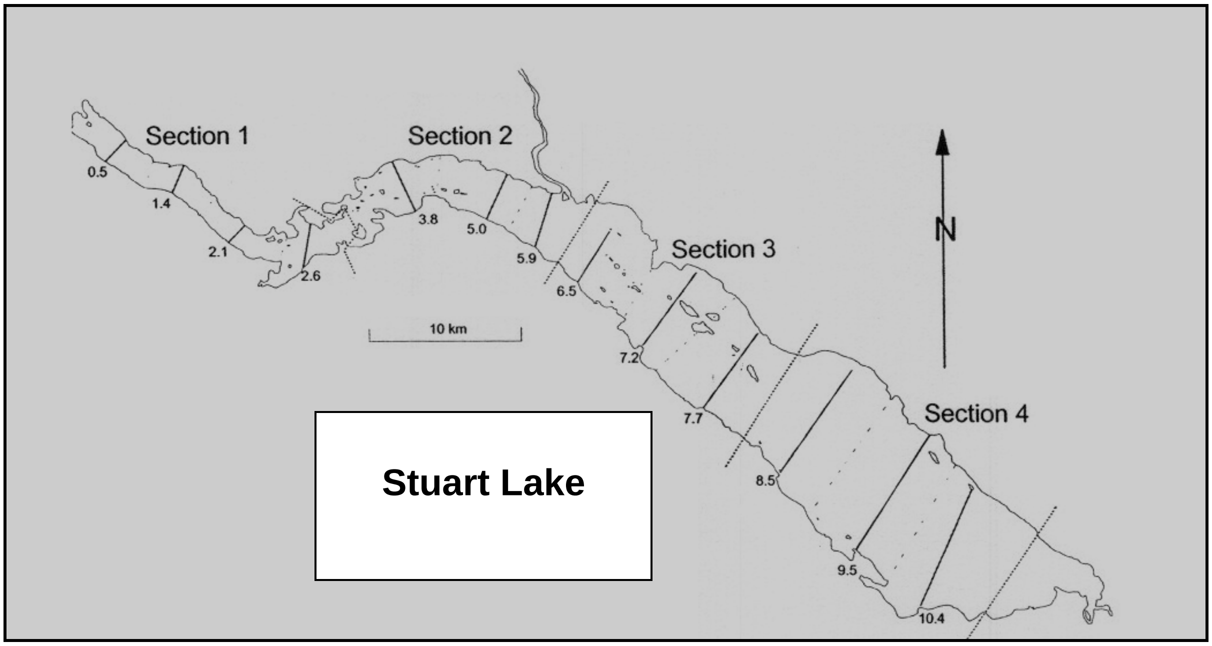


Figure A34. DFO acoustic transect locations and trawl section boundaries in Stuart Lake.

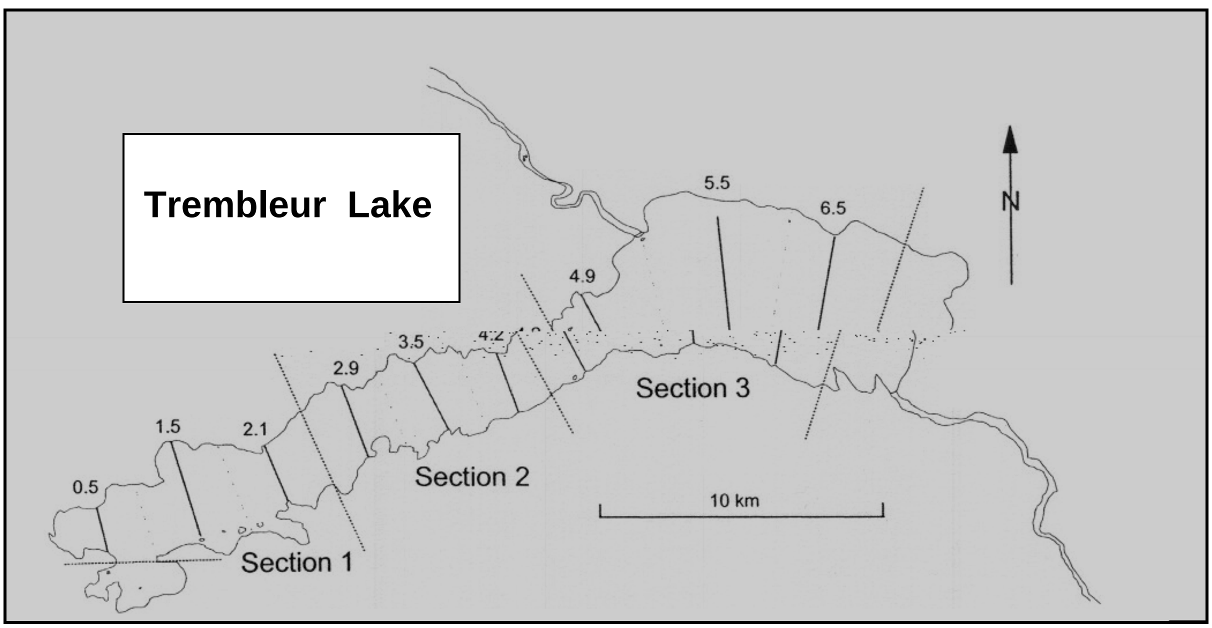


Figure A35. DFO acoustic transect locations and trawl section boundaries in Trembleur Lake.

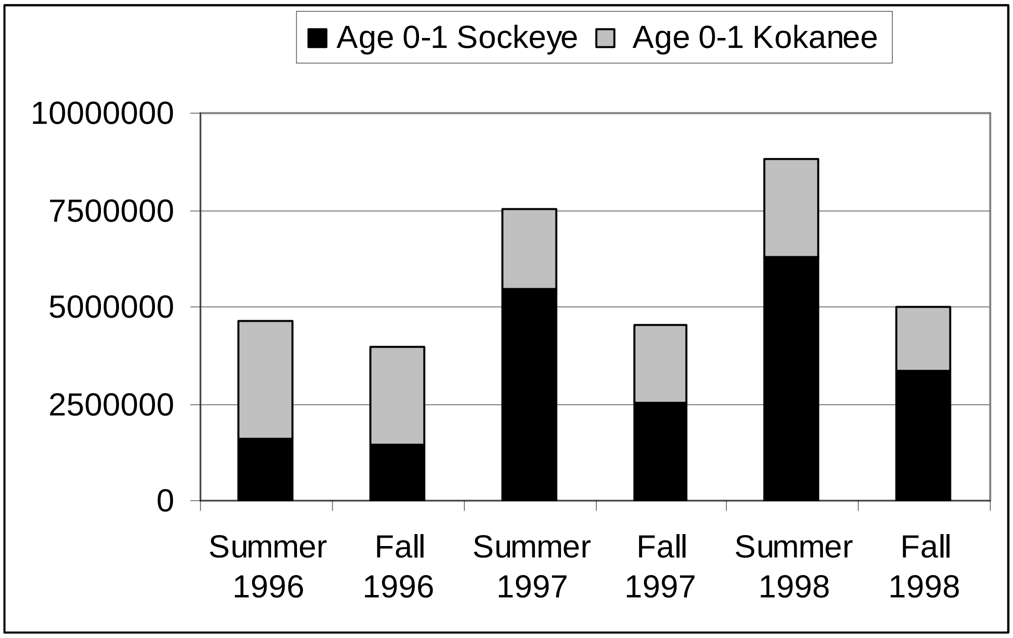


Figure A36. Comparison of juvenile sockeye and kokanee numbers in Takla Lake during DFO surveys in 1996-1998 (sum of all Sections of the lake).

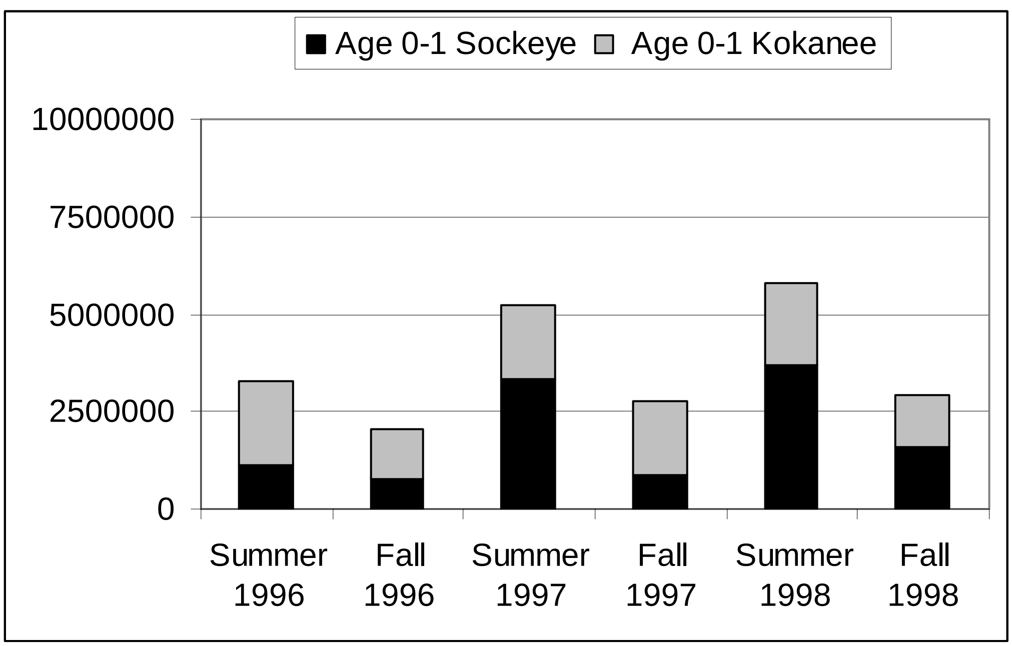


Figure A37. Comparison of juvenile sockeye and kokanee numbers in Driftwood (Main) Arm of Takla Lake during DFO surveys in 1996-1998 (sum of Sections 4-6).

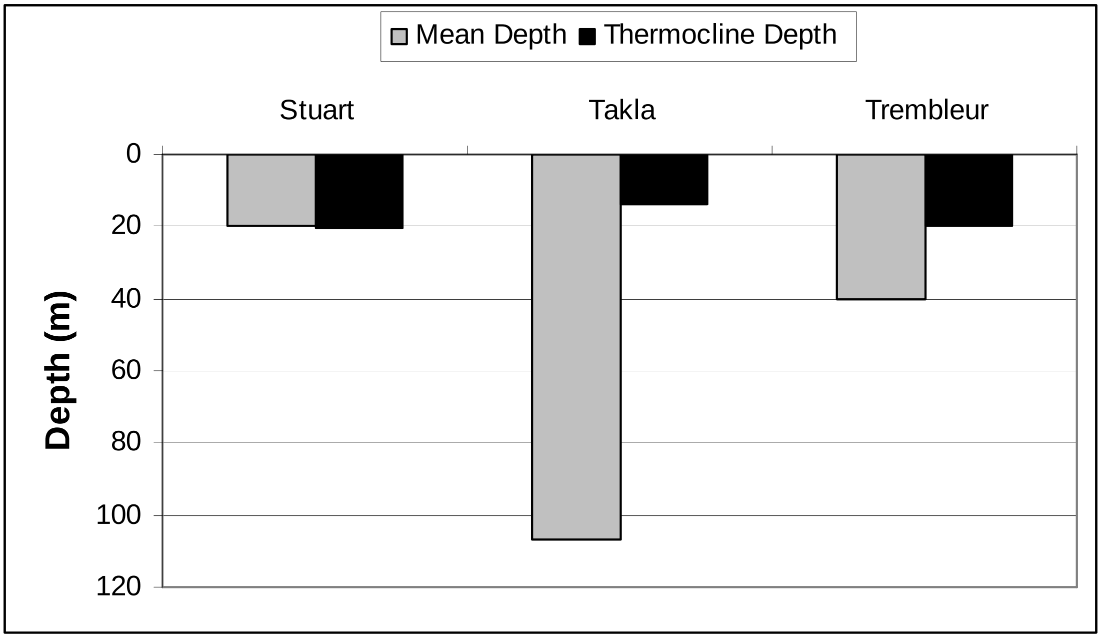


Figure A38. Mean depths and thermocline depths in Stuart, Takla and Trembleur Lakes.

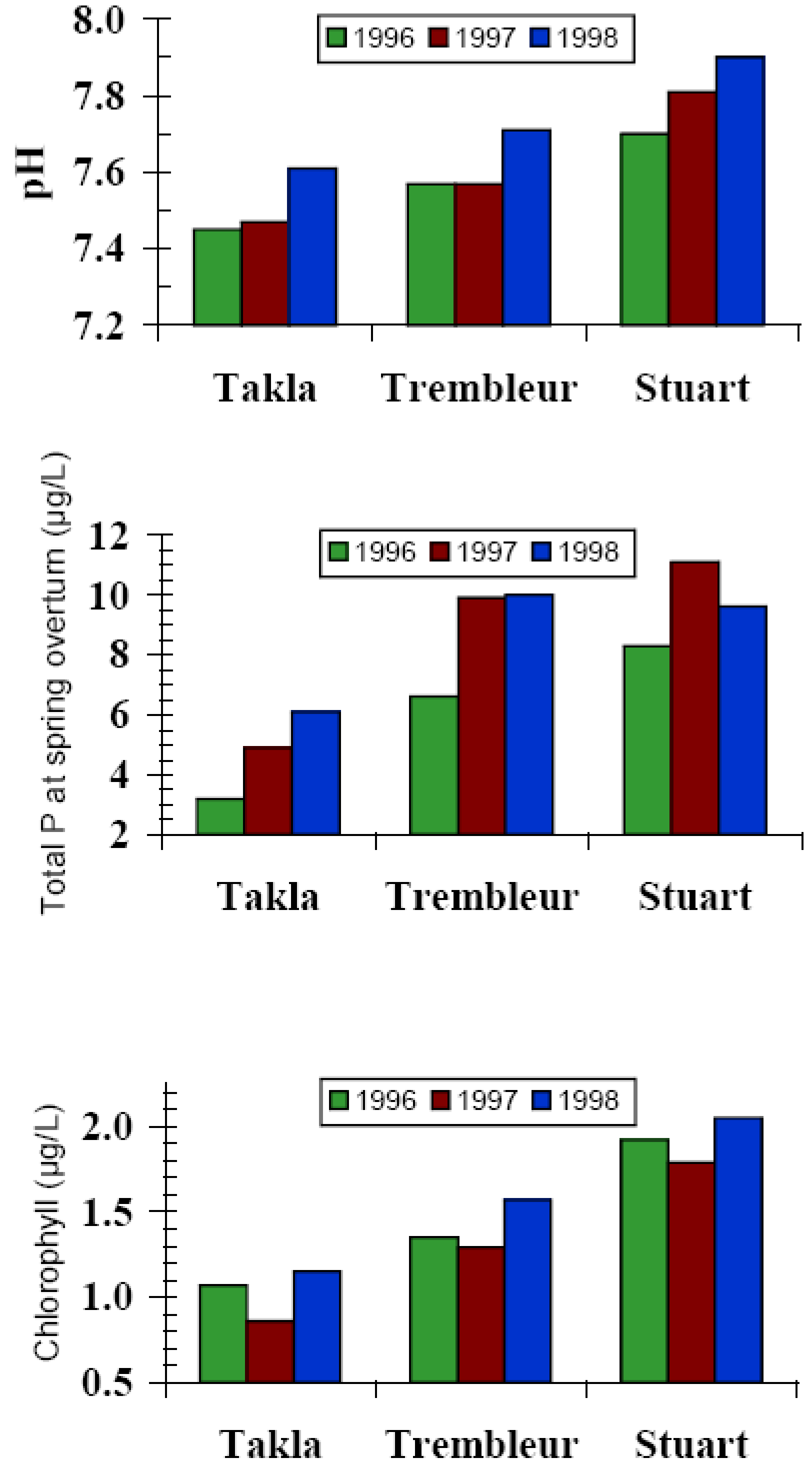


Figure A39. Comparison of limnological conditions in Takla, Trembleur and Stuart Lakes. Source: Morton et al. (2005)

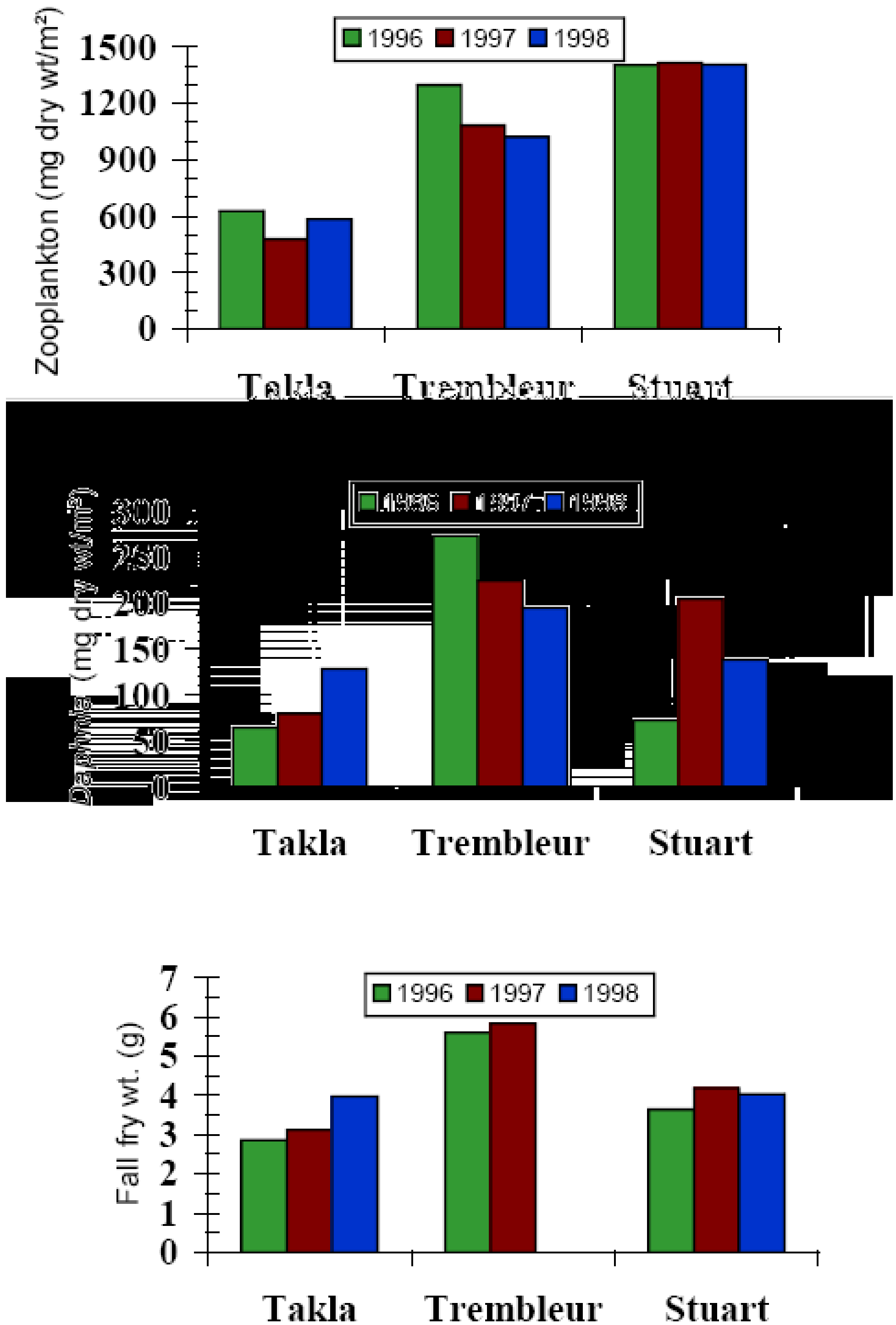


Figure A40. Comparison of biological parameters in Takla, Trembleur and Stuart Lakes. Morton et al. 2005

Table A1. Comparison of juvenile sockeye and kokanee population sizes in Stuart, Takla and Trembleur Lakes during acoustic and trawl surveys conducted in 1996-1998. Source: J.Hume, DFO, unpublished data.

			Population					
Lake	Year	Season	All Fish	Age 0-1 Soc	Age 0-1 Kok	Age 0-1 % Sockeye	Age 0-1 Other	Large Fish
Stuart	1996	Summer	18,425,153	6,511,602	10,085,192	39%	194,116	1,634,243
Stuart	1996	Fall	13,278,415	4,411,624	7,152,985	38%	21,837	1,691,969
Stuart	1997	Summer	20,508,665	10,198,401	5,684,153	64%	15,000	4,611,111
Stuart	1997	Fall	28,114,009	12,012,035	10,881,077	52%	377,621	4,843,276
Stuart	1998	Summer	18,916,675	12,988,200	3,362,675	79%	177,784	2,388,016
Stuart	1998	Fall	14,137,698	7,060,987	5,108,448	58%	480,936	1,561,722
Takla	1996	Summer	5,798,239	1,622,864	2,991,783	35%	0	1,183,592
Takla	1996	Fall	5,184,704	1,429,713	2,548,952	36%	0	1,206,040
Takla	1997	Summer	9,226,794	5,461,748	2,084,119	72%	0	1,680,927
Takla	1997	Fall	6,144,474	2,519,185	2,002,745	56%	182,427	1,622,544
Takla	1998	Summer	9,782,206	6,281,315	2,510,000	71%	0	990,890
Takla	1998	Fall	7,070,484	3,330,231	1,678,989	66%	27,701	2,033,564
Trembleur	1996	Summer	6,266,575	368,321	5,524,818	6%	0	373,436
Trembleur	1996	Fall	2,971,352	330,864	2,295,038	13%	38,442	307,008
Trembleur	1997	Summer	5,476,609	3,654,813	1,544,067	70%	8,082	269,647
Trembleur	1997	Fall	4,758,618	3,433,362	723,251	83%	26,560	575,445
Trembleur	1998	Summer	4,912,688	4,484,495	100,878	98%	0	327,315

			Density (n/ha)					
Lake	Year	Season	All Fish	Age 0-1 Soc	Age 0-1 Kok	Age 0-1 % Sockeye	Age 0-1 Other	Large Fish
Stuart	1996	Summer	544	192	298	39%	6	48
Stuart	1996	Fall	392	130	211	38%	1	50
Stuart	1997	Summer	606	301	168	64%	0	136
Stuart	1997	Fall	831	355	321	53%	11	143
Stuart	1998	Summer	559	384	99	80%	5	71
Stuart	1998	Fall	418	209	151	58%	14	46
Takla	1996	Summer	238	67	123	35%	0	49
Takla	1996	Fall	213	59	105	36%	0	50
Takla	1997	Summer	379	224	86	72%	0	69
Takla	1997	Fall	252	103	82	56%	7	67
Takla	1998	Summer	402	258	103	71%	0	41
Takla	1998	Fall	290	137	69	67%	1	83
Trembleur	1996	Summer	632	37	557	6%	0	38
Trembleur	1996	Fall	299	33	231	13%	4	31
Trembleur	1997	Summer	552	368	156	70%	1	27
Trembleur	1997	Fall	480	346	73	83%	3	58
Trembleur	1998	Summer	495	452	10	98%	0	33

Table A2. Comparison of juvenile sockeye and kokanee biomass density in Stuart, Takla and Trembleur Lakes during acoustic and trawl surveys conducted in 1996-1998. Source: J.Hume, DFO, unpublished data.

			Biomass Density (kg/ha)							
Lake	Year	Season	Nerka (<=150mm)	Other (<=150mm)	Large (>150mm)	All Fish	Age 0-1 Soc	Age 0-1 Kok	Age 0-1 Other	Large Fish
Stuart	1996	Summer	1.68	0.94	83.84	4.88	0.34	0.49	0.01	4.05
Stuart	1996	Fall	5.12	2.69	49.99	4.11	0.62	0.99	0.00	2.50
Stuart	1997	Summer	2.00	0.94	83.84	12.41	0.65	0.34	0.00	11.42
Stuart	1997	Fall	4.80	2.69	49.99	10.22	1.72	1.31	0.03	7.15
Stuart	1998	Summer	2.28	0.94	83.84	7.02	0.90	0.20	0.00	5.91
Stuart	1998	Fall	4.20	2.69	49.99	3.83	0.87	0.62	0.04	2.31
Takla	1996	Summer	1.19		50.12	2.63	0.07	0.12	0.00	2.44
Takla	1996	Fall	7.66		62.68	4.25	0.40	0.74	0.00	3.10
Takla	1997	Summer	2.05		50.12	3.99	0.42	0.11	0.00	3.46
Takla	1997	Fall	7.08	1.06	62.68	5.27	0.76	0.32	0.01	4.17
Takla	1998	Summer	2.01		50.12	2.78	0.52	0.22	0.00	2.04
Takla	1998	Fall	4.62	1.06	62.68	6.23	0.64	0.35	0.00	5.23
Trembleur	1996	Summer	2.94	2.35	82.38	4.74	0.10	1.54	0.00	3.10
Trembleur	1996	Fall	5.66	0.71	50.76	3.07	0.19	1.30	0.00	1.57
Trembleur	1997	Summer	2.51	2.35	82.38	3.56	0.93	0.39	0.00	2.24
Trembleur	1997	Fall	5.80	0.71	50.76	5.39	2.02	0.42	0.00	2.94
Trembleur	1998	Summer	2.24	2.35	82.38	3.72	0.98	0.02	0.00	2.72

Appendix A2. Lake enrichment spreadsheet for Takla Lake

Appendix A3. Material Safety Data Sheet for 10-34-0

Appendix A4. Material Safety Data Sheet for 28-0-0

Appendix A5. Fertilizer application schedule for Takla Lake