Limnological and limnetic fish surveys of North Coast Area lakes in 2007

Ken Shortreed and Jeremy Hume

Fisheries and Oceans Canada,
Cultus Lake Salmon Research Laboratory
4222 Columbia Valley Highway
Cultus Lake, B.C. V2R 5B6

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INTRODUCTION

This report summarizes findings from our 2007 surveys of seven North Coast Area lakes (Elbow, Kimsquit, Kitlope, Lonesome, Port John, Rainbow, Yeo) (Table 1, Fig. 1-9). We carried out limnological surveys on all seven lakes in order to obtain estimates of the lakes' trophic status, juvenile sockeye rearing capacity, and factors limiting their productivity. Fish ecology surveys were carried out on four of the lakes (Elbow, Kimsquit, Kitlope, Lonesome) in order to obtain population estimates of limnetic fish, to determine the species composition of the lakes' fish communities, and to obtain estimates of juvenile *O. nerka* size and diet.

Four of the lakes (Kimsquit, Kitlope, Port John, and Yeo) surveyed in 2007 are in the coastal western hemlock biogeoclimatic (BGC) zone (Meidinger and Pojar 1991). BGC subzones for these lakes ranged from very wet hypermaritime (Port John and Yeo) to very wet maritime (Kitlope) to wet submaritime (Kimsquit) (http://www.for.gov.bc.ca/hre/becweb). Based on the Koppen climate classification system (Peel et al. 2007), these lakes have a maritime temperate climate, with high annual precipitation, cool summers and mild, wet winters. The three Atnarko River system lakes (Elbow, Lonesome, Rainbow) were in the interior Douglas fir BGC zone and the wet warm subzone. They have a warm summer continental climate, with warm summers and cold winters. Downstream distances to salt water ranged from only 2.6 km at Port John Lake to a maximum of 130 km at Elbow Lake (Table 1). Elevations ranged from 13-580 m (Table 1). The lakes were relatively small, with surface areas ranging from 0.8 km² (Yeo Lake) to 11.7 km² (Kitlope Lake). Using data collected on the acoustic surveys, we constructed new bathymetric maps of Elbow, Kimsquit, and Kitlope lakes (Appendix Fig. 1-3). With the exception of Yeo Lake, bathymetric maps were already available for the other lakes. Mean depths ranged from only 3.8 m in Rainbow Lake to 51 m in Kitlope Lake (Table 1).

Data from the nearest climate stations (Environment Canada, Canadian Climate Normals 1971-2000, http://www.climate.weatheroffice.ec.gc.ca/index.html) indicate that total annual precipitation was highest (2.5 m) at the lakes on the outer coast (Port John and Yeo) and lowest (1.0 m) at the Atnarko lakes. Estimated total annual precipitation at Kimsquit and Kitlope lakes was 1.9 m. Discharge data for the Atnarko River is available from a site 26 km downstream of Stillwater Lake (Water Survey of Canada, Hydat data base, http://www.wsc.ec.gc.ca). Seasonal patterns were similar to that seen in many other interior lakes, with maximum seasonal discharge occurring in May or June as a result of spring snowmelt (Fig. 10). Minimum seasonal flows usually occurred in March.

We computed preliminary estimates of water residence times for the three Atnarko lakes. These lakes flushed rapidly, with residence times ranging from only 32 d in Rainbow Lake to 0.4 yr in Elbow Lake. Although Lonesome Lake was the largest of the Atnarko lakes by a substantial margin, its drainage basin area was proportionately even greater, so its residence time was much lower than that of Elbow Lake (Table 2). Robertson (1954) estimated the residence time of Port John Lake as 1.4 yr. Given their morphology, geographic location and climate, it is probable that all seven lakes sampled in 2007 flush rapidly. The Atnarko lakes are dimictic but Rainbow Lake could also be classified as a discontinuously cold polymictic. The two lakes on the outer coast are warm monomictic and it is likely that winter ice cover occurs on Kimsquit and Kitlope lakes in some years.

No logging activity was observed around any of the Atnarko lakes. Human presence at Lonesome Lake was restricted to one homestead near the upper end of the lake, but this was destroyed in the large wildfire which occurred in the summer of 2004. In this fire, approximately 206 km^2, or 18% of Lonesome Lake's drainage basin was burned (R.L. Mackay, British Columbia Ministry of Forests, Alexis Creek, B.C., personal communication). Of Lonesome Lake's 25 km perimeter, only 7 km was not affected by the fire. The fire burned approximately 4% of Rainbow Lake's drainage basin and did not directly affect Elbow Lake or its drainage basin. No human development was visible at either Elbow or Rainbow lakes. All three lakes had extensive shallow areas. Based on average euphotic zone depth, 30% of Elbow Lake's surface area was within the littoral zone. Bathymetric data for Rainbow Lake is poor, but an estimated 80% of the lake is within the littoral zone. Even in Lonesome Lake, 53% of the surface area was within the littoral zone. In all three lakes, aquatic macrophytes were abundant in littoral areas. They were identified as coontail (*Ceratophyllum demersum*), yellow pond lily (*Nuphar lutea*), Richardson's pondweed (*Potamogeton richardsonii*), and white-stemmed pondweed (*P. praelongus*).

No permanent human settlements were observed on any of the remaining four lakes (Kimsquit, Kitlope, Port John, and Yeo). Signs of logging activity were seen only at Yeo Lake. These lakes were all steep-sided with limited littoral areas. In Kimsquit Lake, limited amounts of aquatic macrophytes were observed in littoral areas near the lake outlet and at the upper end of the lake. These were water horsetail (*Equisetum fluviatile*), Bolander's quillwort (*Isoetes bolanderi*), spatter-dock (*Nuphar polysepalum*), and slender-leaved pondweed (*P. filiformis*).

Methods used in the limnological surveys were the same as those used in studies of many other B.C. sockeye lakes (Shortreed et al. 2007). We sampled the Atnarko lakes four times (June, July, August, and October) and the other four lakes on one occasion in late August. We sampled one central location in each lake, except in Lonesome Lake, where we sampled two locations (Fig. 3-9). The fish ecology surveys took place in September and methods used were also the same as those used in many other B.C. lake surveys (Shortreed et al. 2007). During these surveys, we employed acoustics (200-kHz Biosonics DTX split beam sounder), mid-water trawling (2x2-m trawl), and gillnets (small mesh Swedish nets) to sample the lakes' fish communities.

LIMNOLOGY

Physical Data

Of the coastal lakes sampled in 2007, Kimsquit, Port John, and Yeo lakes were strongly thermally stratified at the time of sampling (Fig. 11). Thermal stratification in Kitlope Lake was weak (Fig. 11). In late August, surface temperatures ranged from 11.8ºC in Kitlope Lake to 19.1ºC in Port John Lake (Table 2). Also in late August, epilimnion depths ranged from 2.4 m in Yeo Lake to 20 m in Kitlope Lake (Table 2, Fig. 11). Epilimnion depths in August were strongly correlated with the lakes' surface areas (EPD=1.52xSA+2.5, r^2=0.98). This correlation has been reported for other lakes (Shortreed et al. 2007, Shortreed and Hume 2007) and has been attributed to a general increase in fetch with increasing surface area. The Atnarko lakes had already warmed substantially by the first sampling date in early June (surface temperatures were 9.6-13.8ºC), suggesting a relatively long growing season (Table 2).

Port John and Yeo lakes were strongly dystrophic (organically stained) and had shallow (<4 m) euphotic zones (EZD) (Table 2). The other lakes had varying degrees of glacial turbidity, with average EZD ranging from 3.6 m in Elbow Lake to 21.6 m in Kimsquit Lake. Secchi depths (SD) were lowest (1.4 m) in July in Elbow Lake and deepest (11.6 m) in Kimsquit Lake (Table 2). As has been found elsewhere (Shortreed et al. 2007), EZD and SD were strongly correlated (EZD=1.68xSD, r^2=0.84). EZD in the Atnarko lakes were shallowest in June or July and became progressively deeper from August to October. Turbidity was highest (2.5-4.9 NTU) in July in Elbow and Rainbow lakes. In Lonesome Lake, turbidity never exceeded 0.9 NTU, most likely because a substantial proportion of its drainage basin comes from Charlotte Lake and the Atnarko River, which has much clearer water than the South Atnarko River.

Chemical Data

Conductivities in the Atnarko lakes exhibited little variation, averaging from 44-48 µS/cm (Table 3). Conductivities of the other lakes were lower and ranged from 21-35 µS/cm. Vertical conductivity profiles also exhibited relatively little variation, indicating that none of the lakes sampled in 2007 were meromictic (Fig. 12). Average epilimnetic dissolved oxygen (DO) concentrations were relatively high (9.0-9.7 mg/L) in all lakes (Table 2). As with conductivity, none of lakes exhibited much variability in DO concentration down the water column (Fig. 13).

The Atnarko lakes were slightly acidic, with average pH values of 6.8. The other lakes were more acidic, with pH values ranging from only 5.6 in Port John Lake to 6.5 in Kimsquit Lake (Table 3). Also in the Atnarko lakes, total alkalinities averaged relatively low values of only 12.9-15.9 mg/L $CaCO_3$. Kimsquit Lake had a similar total alkalinity of 12.0 mg/L $CaCO_3$, but the other three coastal lakes had far lower alkalinities (range: 0.8-2.2 mg/L $CaCO_3$ (Table 3). With the exception of Kitlope Lake, where TDS was only 4 mg/L, TDS varied relatively little between lakes, ranging from 26-37 mg/L. As has been noted elsewhere (Shortreed et al. 2007), the coastal lakes have very little buffering capacity and would be extremely sensitive to any increase in acid precipitation. Both increasing human activity in B.C. and the current rapidly expanding use of coal as an energy source in China, with accompanying transport of pollutants to North America (Wilkening et al. 2000), could result in increased acid precipitation.

Average dissolved silica concentrations ranged from 1.1-1.4 mg Si/L in the Atnarko lakes. They were much lower (0.72 mg Si/L) in Kimsquit Lake and in the remaining coastal lakes were lower still (<0.1 mg Si/L) (Table 4).

Given that the Atnarko lakes, particularly Elbow and Rainbow, were glacially turbid for most of the year, total phosphorus (TP) data are not likely indicative of the amount of biologically available P or of trophic status, even after turbidity corrections (Table 4). This is because glacial flour can contain substantial amounts of biologically unavailable P in the form of apatite. In our study the least amount of interference from apatite-P likely occurred on the October sampling date, when glacial runoff was minimal. At this time, TP ranged from 3.7-4.7µg/L, placing the lakes in the low to middle range of oligotrophy. TP in the coastal lakes tended to be lower, and ranged from 1.5 µg/L in Kitlope Lake to 3.6 in Yeo Lake (Table 4). Soluble reactive phosphorus (SRP) concentrations were low (≤1 µg/L) in all lakes, but tended to be slightly higher in the Atnarko lakes (Table 4).

Epilimnetic nitrate became depleted (<1 µg/L) for a portion of the growing season in Elbow and Lonesome lakes and the seasonal averages for the Atnarko lakes ranged from 2.1-7.6 µg N/L (Table 4, Fig. 14). Values for three of the four coastal lakes were in the same range (2.7-7.2 µg N/L), but in Kimsquit Lake nitrate concentrations were far higher (94 µg N/L). Seasonal average hypolimnetic nitrate concentrations were 27 µg N/L Elbow Lake and much higher (80 µg N/L) in Lonesome Lake. Concentrations of hypolimnetic nitrate in the coastal lakes ranged from a low of 11 µg N/L in Kitlope Lake to a high of 207 µg N/L in Kimsquit Lake (Table 4). As in most lakes, phosphorus appeared to be the primary limiting nutrient in these lakes, but the low nitrate concentrations in several of the lakes suggest that co-limitation of N and P may occur for a portion of each growing season. These nutrient concentrations indicate the lakes are oligotrophic and nutrient-limited, although the shallow euphotic zones in several of the lakes also contribute to the low productivity.

Bacteria and Phytoplankton

Average bacterioplankton numbers were much higher in the Atnarko lakes (range: 1.35-2.14 million/mL) than in the coastal lakes, where the range was 0.51-0.86 million/mL (Table 5). Bacterioplankton numbers in the Atnarko lakes were higher than expected, given the oligotrophic status other variables indicate. However, a limnological survey of these lakes carried out in early September of 1999 also found relatively high numbers (1.64-2.07 million/mL) (K. Shortreed, unpublished data). Bacteria numbers in Kitlope Lake were in the same range observed in the lake in a previous study, which took place in 1979 and 1980 (Stockner et al. 1993).

Average chlorophyll (CHL) concentrations were relatively low (0.23-0.85 µg/L) in all lakes sampled in 2007 (Table 5). The CHL-based trophic classification of Forsberg and Ryding (1980) indicates that all lakes were highly oligotrophic (CHL<3 µg/L). In most lakes, vertical profiles of chlorophyll concentration were typical of those seen in relatively turbid lakes, with highest values occurring near the surface (Fig. 15). The exceptions to this were Kitlope Lake, where a subsurface peak occurred at 8 m, and Kimsquit Lake, which had a subsurface peak at 23 m. CHL concentrations in the Atnarko lakes were similar to those observed in 1999 (K. Shortreed, unpublished data). Stockner et al. (1993) reported that CHL concentrations in Kitlope Lake were unusually variable, both spatially and temporally. On one day in July of 1980, 10 locations around the lake were sampled and CHL ranged from 0.22-1.06 µg/L. Although Kitlope Lake CHL was very low (0.23 µg/L) in 2007, it was within the range observed in the earlier study. Further, the subsurface CHL maximum seen in Kitlope in 2007 was also observed in the earlier study.

Areal photosynthetic rates (PR) varied from 25 mg $C\cdot m^{-2}\cdot d^{-1}$ in Port John Lake to 185 mg $C\cdot m^{-2}\cdot d^{-1}$ in Kimsquit Lake (Table 5, Fig. 16). These values are within the range observed for other coastal lakes (Shortreed et al. 2007). Expressed volumetrically, average PR was 15 mg $C\cdot m^{-3}\cdot d^{-1}$ in each of the Atnarko lakes and was lower (3.2-10.4 mg $C\cdot m^{-3}\cdot d^{-1}$) in the coastal lakes. With the exception of Kimsquit and Kitlope lakes, vertical PR profiles were generally typical of those seen in relatively turbid lakes, with rapid attenuation of PR with depth (Fig. 17-24). In Kimsquit and Kitlope lakes, the deeper euphotic zones resulted in much less rapid attenuation.

In most of the lakes sampled in 2007, phytoplankton community structure was similar to that seen in many other oligotrophic B.C. lakes (Shortreed et al. 2007). As in most other lakes, picoplankton were numerically the most abundant phytoplankton, with averages ranging from 10.0-38.6 thousand/mL (Table 5). In all lakes surveyed, the unicellular form of the cyanobacteria *Synechococcus* was the dominant picoplankton genus (Table 6, Fig. 25). An unidentified eukaryotic picoplankton was common in all lakes but tended to be more abundant in coastal lakes, where the pH was lower (Stockner and Shortreed 1991).

In all lakes, the flagellate *Chromulina* spp. was the most common nanoplankton (Table 7, Fig. 25). This ubiquitous genus is the dominant nanoplankton in most B.C. sockeye nursery lakes. Next to *Chromulina*, the flagellates *Chroomonas* and *Chrysochromulina* were the most important nanoplankton.

In the microplankton size fraction, the large diatom *Urosolenia* (previously called *Rhizosolenia*) was dominant in all lakes except Kimsquit (Table 8, Fig. 25). In Kimsquit Lake, *Urosolenia* was abundant, but biomass of the desmid *Arthrodesmus* was slightly greater. A large *Cyclotella* was the next most important member of the microplankton. The diatoms *Asterionella* and *Tabellaria* were common in the Atnarko lakes but were rare or absent in the coastal lakes.

In all lakes, microplankton comprised the major portion of phytoplankton volume, ranging from 60-96% (mean: 78%) of the total. However, microplankton made up an average of only 14% (range: 8-25%) of total chlorophyll and an even smaller proportion (11%, range: 5-22%) of total PR (Table 9). The ultraplankton (picoplankton and nanoplankton combined) are generally considered to be the edible portion of the phytoplankton community (Wetzel 2001). In the lakes sampled in 2007, ultraplankton volume ranged from 4-40% (mean: 22%) of total volume Table 9). However, ultraplankton averaged 83% of total chlorophyll and 90% of total PR. Obviously, the ultraplankton were turning over far more rapidly than the microplankton.

All lakes sampled in 2007 were oligotrophic, with Kitlope Lake the least productive (ultraoligotrophic) and Kimsquit Lake the most productive. Trophic status of the Atnarko lakes increased in an upstream to downstream direction (Elbow to Rainbow to Lonesome), which is consistent with observed differences in other lake chains (Soranno et al. 1999; Malange et al. 2005).

Zooplankton

Both zooplankton biomass and community structure exhibited considerable variability in lakes sampled in 2007. Total biomass was extremely low (20 mg dry wt/m²) in Kitlope Lake and unusually high (1,718 mg dry wt/m²) in Lonesome Lake (Table 10, Fig. 26). Zooplankton biomass in Lonesome Lake was approximately twice that observed in the other two Atnarko lakes. *Daphnia* was the dominant component of the zooplankton community in the Atnarko lakes, comprising 63% of total biomass in Elbow Lake, 88% in Rainbow Lake, and 85% in Lonesome Lake. The copepod *Diacyclops* was the next most important genus, although its biomass was much lower (range: 9-35% of the total).

Daphnia was either absent or rare in all four coastal lakes sampled in 2007. The total zooplankton biomass of 491 mg dry wt/m² in Kimsquit Lake was much higher than the other coastal lakes, but substantially lower than any of the Atnarko lakes. The gelatinous cladoceran *Holopedium gibberum* was the dominant plankton in Kimsquit Lake, followed closely by *Diacyclops*, with a substantially lower biomass of the cladoceran *Eubosmina coregoni* (Table 10, Fig. 26). Total zooplankton biomass in Port John and Yeo lakes was lower than that observed in many other coastal lakes (Shortreed et al. 2007) and diaptomid copepods were dominant. Kitlope Lake's biomass of 20 mg dry wt/m² was among the lowest ever observed for a B.C. sockeye nursery lake. *Diacyclops* was the dominant genus.

The phantom midge *Chaoborus* spp. is a common macroinvertebrate in coastal B.C. lakes. These animals are effective planktivores and larger instars can compete directly with juvenile sockeye, but *Chaoborus* can also be a food resource for juvenile sockeye in what is often referred to as a "trophic triangle" (Shortreed et al. 2007). Currently, the effect of these animals on the lakes' sockeye rearing capacity is unknown. In 2007, *Chaoborus* was found only in Port John and Yeo lakes. While daytime vertical hauls with a Wisconsin net do not always yield quantitative samples, they do provide an index of abundance. *Chaoborus* densities from Wisconsin net hauls were 165/m² in Port John Lake and 159/m² in Yeo Lake. These were within the range often observed in coastal lakes (Shortreed et al. 2007) and relative to other lakes, would be classified as low-to-medium densities.

LIMNETIC FISH

O. nerka diet

Zooplankton community structure and consequently *O. nerka* diet may exhibit substantial seasonal variability. Sockeye stomach samples collected in 2007 are representative of those lakes for the date sampled but may not be representative of the whole growing season. Composition of the diet from the four lakes sampled in 2007 was relatively simple (Table 11). In Elbow and Lonesome lakes, *Daphnia* averaged 98-99% of the total stomach contents and stomachs averaged 52-58% full (Table 11). Insects made up a very small proportion of the stomach contents (0% in Lonesome and 1.5% in Elbow). In Kimsquit Lake, *Holopedium* made up 46% of total stomach biomass. Insects made up a further 44% and *Diacyclops* made up 10% of the total. Stomachs averaged only 28% full. *Eubosmina* was numerically the most important diet item in Kitlope Lake, making up 86% of the total plankters/stomach. However, insects made up 80% of the biomass of the stomach contents. *Eubosmina* averaged 11% of total stomach biomass and chironomids a further 6.6%. Stomach fullness averaged 25% in Kitlope Lake. Zooplankton made up only 12% of stomach contents in Kitlope Lake, which is likely a result of the depauperate plankton community and the lake's ultraoligotrophic status.

Fish species composition and size

O. nerka was the dominant species captured in all four of the lakes sampled in 2007 (Table 12). Age-0 and age-1 *O. nerka* made up 65% of the trawl catch in Elbow Lake, 88% in Lonesome Lake, 97% in Kimsquit Lake, and 98% in Kitlope Lake (Table 12). Age-0 *O. nerka* formed a smaller proportion of the gillnet catch, but *O. nerka* (all age classes) were the largest component of the gillnet catch. Age-1 *O. nerka* were captured in all four lakes sampled in 2007, indicating the presence of kokanee and/or age-2 smolts (Fig. 27, 28). Age-2 *O. nerka* were captured in Elbow, Lonesome and Kitlope lakes, confirming the presence of kokanee. We caught a total of six other fish species in the lakes (prickly sculpin, juvenile coho salmon, rainbow and cutthroat trout, threespine stickleback, and northern pikeminnow) (Table 12). Numbers of other species in each lake ranged from one in Kimsquit Lake to five in Lonesome Lake.

The 2x2-m trawl used in this survey is reported as being increasingly biased against fry >40 mm in length (McQueen et al. 2007). Thus, the mean size of *O. nerka* in the trawl catch may be lower than the true population mean size (Table 12).

After correction for trawl bias using the McQueen et al. (2007) correction factor, age-0 sockeye weights ranged from 1.0-1.8 g in Kimsquit and Kitlope lakes to 1.9-6.8 g in Lonesome and Elbow lakes (Table 12). Age-0 sockeye in Kimsquit and Kitlope lakes were smaller than often found in coastal lakes (Hume and Shortreed 2006; Shortreed et al. 2007), but they should exceed the minimum size of 2.0 g needed for smolting (Koenings et al 1993). Reason(s) for the large size difference between fish in Elbow and Lonesome lakes are not known at this time. Some of the difference may be attributable to differences in fish densities (Elbow densities were 4x higher than those in Lonesome), but given the high biomass of *Daphnia* in Lonesome Lake, this is not the probable cause. Another possible explanation would be that Lonesome Lake had a much higher proportion of kokanee, since age-0 kokanee tend to be smaller than age-0 sockeye.

Abundance and biomass

The hydroacoustic estimate was made using the tracked target method as recommended in Hume and MacLellan (2008). Tracked targets use a set of criteria to determine if a group of single targets represents the track of a single fish and is appropriate when fish densities are low to moderate. *Chaoborus* often interfere with hydroacoustic estimates of age-0 *O. nerka* in coastal lakes but none were present in any of the four lakes acoustically surveyed in 2007.

We found low to moderate densities of age-0 *O. nerka* in all lakes sampled in 2007 (Table 13). Lonesome Lake had one of the highest age-0 *O. nerka* densities in 2007 at 650 fish /ha while nearby Elbow Lake was much lower at 150 age-0 *O. nerka*/ha. Kimsquit Lake also had high densities of age-0 *O. nerka* at 770 fish/ha while Kitlope had 275 *O. nerka*/ha. Densities of other small fish species were very low in all of the lakes, ranging from 0-23/ha. There were also low pelagic densities of larger predator-sized fish in all lakes, with densities ranging from 9/ha in Kitlope Lake to 149/ha in Kimsquit Lake (Table 13).

Numerous kokanee were observed feeding in the shallows of Elbow and Lonesome lakes. Older kokanee (age-2+)were sampled in gill nets in both these and Kitlope lakes. We did not sample the kokanee population quantitatively but we did attempt to approximate a likely population and biomass estimate for use in the PR model (see next section). We used a portion of the hydroacoustic large fish estimate as an approximation of the older kokanee (age-1-3). As a first cut, we set the kokanee at 50% of the large fish acoustic estimate, the rest being predator fish such as trout. Work done on kokanee rearing lakes in north western North America found that on average, age-1 and older kokanee represented about 35% of the total kokanee population, or that age-0 kokanee are about 65% of the population (McGurt 1999; Sebastian et al. 2003). We applied that between-year-class relationship to our acoustic density data and calculated an age-0 kokanee population; and by subtraction from the age-0 *O. nerka* estimate we also calculated an age-0 sockeye estimate (Table 14). We did not detect older kokanee in Kimsquit lake and assumed the age-1 *O. nerka* in this lake were sockeye which would smolt at age-2.

We then applied estimates of fish size from these surveys and others on coastal lakes to the derived density estimates to determine current biomass of sockeye and possible competitors in the study lakes (Table 14). Kokanee of all age classes comprise the highest proportion of the current biomass in both Elbow (60%) and Lonesome (78%) lakes. Age-0 *O. nerka* biomass comprised only 26% in Elbow and 22% in Lonesome lake. In Kitlope Lake, kokanee were a much smaller component of the *O. nerka* population comprising only 23% of the current population. Age-0 sockeye comprised 75% of total limnetic fish biomass and threespine stickleback comprised the remaining 2%. In Kimsquit Lake age-0 sockeye comprised 85% of the current biomass while age-1 sockeye comprised 15%.

PRODUCTIVE CAPACITY

We estimated the sockeye production capacity of the lakes using the photosynthetic rate (PR) model (Cox-Rogers et al. 2004). The model uses lake area and seasonal average (May-Oct) PR (PR_{mean}, mg $C \cdot m^{-2} \cdot d^{-1}$) to compute total tonnes of carbon (PR_{total}) produced in a growing season. When data are collected on only one occasion in late summer (coastal lakes in 2007), PR_{mean} was calculated from the relationship between PR collected in late summer and PR_{mean} (PR_{mean}=0.748xPR_{summer}, r^2=0.60, Cox-Rogers et al. 2004). The Atnarko lakes were sampled four times (June-October), so PR_{mean} in those lakes was not adjusted. However, the Atnarko lakes had extensive shallow areas, so PR_{total} in those lakes was adjusted for bathymetry (Cox-Rogers et al. 2004) (Table 15).

PR_{total} available to sockeye was calculated by subtracting the biomass of sockeye competitors (planktivorous fish) from the total predicted smolt biomass (Table 14,15). Biomass of these other planktivorous fish species was estimated using their density and weights corrected for sample bias using the McQueen et al. (2007) correction factor discussed previously. In the three lakes where direct estimates of limnetic fish biomass were not obtained, we assumed that biomass was the same as observed in other lakes of similar type (Shortreed et al. 2007). Observed PR in these other lakes was then used to adjust biomass estimates (i.e. estimated fish biomass = observed fish biomass in similar lakes X (PR in study lakes/PR in similar lakes)).

Assuming there were negligible numbers of age-2 smolts in any of the lakes, the PR model predicts that optimum escapements (S_{max}) to the lakes range from 500 in Port John Lake to 14 thousand in Lonesome Lake (Table 15). Expressed as spawner density, this was a range of 5-47 adult spawners/ha of lake surface area. Optimum escapement to all three Atnarko lakes sampled in 2007 is 21,000. If the other two Atnarko lakes (Stillwater and Tenas) are included and it is assumed their PR is equivalent to the average of the other lakes, optimum escapement to all Atnarko lakes increases to 25,000.

Although historic escapement data to these lakes are generally of poor quality, data are available for most years since 1950 in DFO's NUSEDS data base (http://oraasprod.pac.dfo-mpo.ca:7778/NUSEDS/NUSEDS) (Table 16, Fig. 27-29). With the exception of Kimsquit Lake, the lakes show a trend of decreasing escapements (Fig. 27-29). Kimsquit Lake escapements appear relatively stable, but no estimates are available since 2000. In the other lakes, average escapements from 1981-2006 were only 24-58% of those from 1950-1980 (Kimsquit escapements were 20% higher from 1981-2000).

Since 1981, average escapements to Kimsquit and Kitlope lakes have exceeded PR predictions of S_{max} by 70% and 25%, respectively. However, the most recent available escapements to both lakes were substantially less than PR predictions. Given the extremely oligotrophic nature of Kitlope Lake and its depauperate plankton community, it is unlikely that it could have supported progeny from the numbers of spawners often reported in the Tezwa River. It is likely that a portion of these spawners are river or ocean-type sockeye (Wood et al. 1987; Murphy et al. 1997). It is interesting to note that the Haisla First Nation reports that there are three different sockeye stocks entering Kitlope Lake, each with different run-timing (http://www.wildernesscommittee.org/campaigns/historic/otherpub/reports/Vol10No05b/facts). Given that Kimsquit escapements substantially exceed predicted S_{max} in most years, it is again likely that a portion of Kimsquit sockeye are river or ocean-type sockeye.

In 1999, 64% of the total sockeye escapement to the Bella Coola River were ocean-type (C. Wood, DFO, Pacific Biological Station, Nanaimo, B.C., personal communication). Of 20 adult sockeye sampled near the Atnarko lakes in 2007, one-half were ocean-type (Matt Mortimer, DFO, Campbell River, B.C., personal communication). Several ocean-type sockeye were collected upstream of Lonesome Lake, suggesting that not all offspring of upper Atnarko sockeye rear in the lakes. Regardless of juvenile rearing location, the entire 2005 and 2006 Bella Coola sockeye escapements were substantially below the PR estimate for the Atnarko lakes (Fig. 29).

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Table 1. Salient morphometric and bathymetric data from North coast lakes sampled in 2007.

Variable	Elbow	Rainbow	Lonesome	Kimsquit	Kitlope	Port John	Yeo
Limnological surveys	√	√	√	√	√	√	√
Fish ecology surveys	√		√	√	√		
1:50,000 map numbers	93C4	93C4	93C4,5	93E3	93E4	93D4	103A8
Latitude (°N)	52°04.7'	52°07.8'	52°15.9'	53º06.50'	53º06.4'	52°09.3'	52°20.1'
Longitude (°W)	125°41.7'	125°42.7'	125°43.7'	127º24.0'	127º47.0'	127º48.6'	128º08.2'
Location	Atnarko R.	Atnarko R.	Atnarko R.	Dean Channel	Gardner Canal	Fisher Channel	Return Channel
Elevation (m)[a]	580	566	483	358	13	44	35
Total annual precipitation (m)[b]	1.1	1.1	1.1	1.9	1.9	2.5	2.5
Surface area (ha)[c]	138	164	410	166	1,170	91	83
Shoreline length (km)	8.3	12.0	24.8	10.7	28.7	6.4	6.3
Shoreline development	2.0	2.6	3.5	2.3	2.4	1.9	2.0
Drainage basin area (km²)	144	209	1,136	22	857	7.2	10.5
Drainage basin/lake area ratio	105	128	277	13	73	8	13
Distance to salt water (km)	130	124	106	57	12	2.6	3.3
Mean depth (m)	13.3	3.8	12.0	35	51	25	
Maximum depth (m)	34	9	41	75	123	49	35
Water residence time (yr)	0.39	0.09	0.15			1.4	

[a] - Elevation data from Geobase.ca and NTS 1:50,000 topographic maps in Oziexplorer.

[b] - Environment Canada, 1971-2000 Canadian climate normals for the closest climate station.

[c] - Surface areas from NTS 1:50,000 topographic maps in Oziexplorer.

Table 2. Variation in thermal structure and water clarity in the study lakes (EPZ=epilimnion depth, SD=Secchi depth, EZD=euphotic zone depth).

Lake	Station	Sampling date	Surface temperature (ºC)	EPZ (m)	SD (m)	EZD (m)	Turbidity (NTU)
Elbow	1	7-Jun-07	9.6	.	2.9	4.6	1.15
	1	19-Jul-07	15.0	12.0	1.4	3.7	4.80
	1	29-Aug-07	14.2	5.5	1.8	5.2	4.66
	1	3-Oct-07	10.8	17.0	2.7	5.6	3.20
Mean			13.2	9.9	2.0	4.6	3.87
Rainbow	1	7-Jun-07	10.4	.	3.7	5.3	0.71
	1	19-Jul-07	15.2	2.4	2.2	5.3	2.48
	1	29-Aug-07	14.5	5.2	3.4	7.5	1.57
	1	3-Oct-07	10.2	.	4.2	8.7	1.43
Mean			13.4	3.8	3.2	6.5	1.72
Lonesome	1	6-Jun-07	10.7	.	2.3	6.2	0.90
	1	18-Jul-07	15.4	.	2.9	5.5	0.72
	1	26-Aug-07	15.0	.	>2.7	10.4	0.19
	1	4-Oct-07	8.7	.	>2.3	12.7	0.00
Mean			13.4	.		8.4	0.46
Lonesome	2	6-Jun-07	13.8	6.4	4.8	6.7	0.18
	2	18-Jul-07	18.5	9.0	5.3	7.3	0.29
	2	26-Aug-07	17.0	9.2	8.6	11.8	0.00
	2	4-Oct-07	12.0	17.0	9.1	13.1	0.00
Mean			16.1	9.9	6.9	9.6	0.13
Kimsquit	1	27-Aug-07	14.5	5.8	11.6	21.6	0.1
Kitlope	1	27-Aug-07	11.8	20.0	5.2	11.2	1.3
Port John	1	28-Aug-07	19.1	3.2	3.3	3.9	0.0
Yeo	1	28-Aug-07	19.0	2.4	2.4	3.3	0.0

Table 3. Variation in mean epilimnetic values of selected chemical variables.

Lake	Station	Sampling date	Conductivity (µS/cm)	DO (mg/L)	pH	T. Alk. (mg $CaCO_3$/L)	DIC (mg/L)	TDS (mg/L)	Diss. silica (mg Si/L)
Elbow	1	7-Jun-07	47	10.2	6.63	12.35	4.52	37	1.12
	1	19-Jul-07	.	8.8	6.68	10.94	3.97	33	1.02
	1	29-Aug-07	48	9.5	6.75	15.66	5.32	37	1.51
	1	3-Oct-07	54	9.8	7.16	18.47	5.34	46	1.60
Mean			48	9.4	6.77	13.83	4.71	37	1.28
Rainbow	1	7-Jun-07	50	10.4	6.79	15.21	5.14	39	2.06
	1	19-Jul-07	38	9.8	6.58	10.25	4.06	37	0.81
	1	29-Aug-07	45	9.1	6.74	13.23	4.55	27	1.02
	1	3-Oct-07	50	9.9	7.15	15.79	4.58	35	1.09
Mean			44	9.7	6.75	12.91	4.49	34	1.14
Lonesome	1	6-Jun-07	55	10.0	6.66	16.67	6.45	39	1.63
	1	18-Jul-07	42	8.4	6.87	13.48	4.23	36	1.40
	1	26-Aug-07	46	8.8	6.58	15.72	6.25	29	0.78
	1	4-Oct-07	50	10.0	6.92	16.39	5.41	27	1.36
Mean			47	9.1	6.75	15.24	5.47	33	1.23
Lonesome	2	6-Jun-07	56	10.0	6.76	19.22	6.80	40	2.49
	2	18-Jul-07	42	9.5	6.92	13.96	4.30	33	1.39
	2	26-Aug-07	45	9.7	6.62	15.60	5.94	32	1.03
	2	4-Oct-07	48	9.5	7.01	16.89	5.24	33	0.88
Mean			46	9.6	6.81	15.89	5.42	34	1.38
Kimsquit	1	27-Aug-07	35	11.1	6.48	12.0	3.11	28	0.72
Kitlope	1	27-Aug-07	25	11.8	5.97	1.77	0.87	4	<0.1
Port John	1	28-Aug-07	21	9.0	5.62	0.82	0.92	26	<0.1
Yeo	1	28-Aug-07	24	9.0	6.08	2.27	1.19	30	<0.1

Table 4. Variation in epilimnetic and hypolimnetic values for nutrient data

			Phosphorus (µg/L) (epil.)			Nitrate (µg N/L)		Ammonia (µg N/L)	
Lake	Station	Sampling date	Total	Dissolved	Soluble reactive	Epil.	Hypol.	Epil.	Hypol.
Elbow	1	7-Jun-07	6.0	5.5	0.9	3.2	21.1	4.1	6.7
	1	19-Jul-07	12.0	4.5	0.7	1.0	31.8	3.0	9.2
	1	29-Aug-07	3.7	4.2	1.6	4.3	55.7	6.6	3.9
	1	3-Oct-07	4.7	4.4	1.3	12.5	60.9	4.5	4.9
Mean			9.0	5.0	0.8	2.1	26.5	3.6	7.9
Rainbow	1	7-Jun-07	6.4	4.7	1.1	6.8	.	3.8	4.5
	1	19-Jul-07	5.2	4.2	0.9	2.7	.	4.1	5.4
	1	29-Aug-07	3.9	3.1	0.9	5.3	.	5.4	4.7
	1	3-Oct-07	4.1	3.5	0.8	7.1	.	17.2	4.8
Mean			5.8	4.4	1.0	4.8	.	4.0	4.9
Lonesome	1	6-Jun-07	11.5	7.1	2.0	18.0	.	4.9	.
	1	18-Jul-07	7.8	7.1	0.8	3.6	.	4.8	.
	1	26-Aug-07	3.9	2.7	0.5	1.1	.	4.2	.
	1	3-Oct-07	3.7	3.6	0.7	14.0	.	6.2	.
Mean			6.6	5.1	0.9	7.0	.	4.8	
Lonesome	2	6-Jun-07	6.3	5.4	1.2	13.0	43.9	8.8	12.4
	2	18-Jul-07	4.6	3.7	0.6	1.0	79.7	5.0	4.1
	2	26-Aug-07	4.0	2.9	0.4	1.1	91.0	6.5	2.7
	2	4-Oct-07	3.9	4.1	0.9	28.7	99.1	13.7	3.1
Mean			4.6	3.8	0.7	7.6	80.2	7.5	5.0
Kimsquit	1	27-Aug-07	1.6	1.5	0.7	94.3	206.6	4.0	2.9
Kitlope	1	27-Aug-07	1.5	1.1	0.1	4.0	11.2	3.6	5.9
Port John	1	28-Aug-07	1.7	1.6	0.1	2.7	13.5	5.6	8.1
Yeo	1	28-Aug-07	3.6	2.7	0.1	7.2	16.2	4.9	15.5

Table 5. Variation in biological variables. With the exception of daily PR, data are trophogenic zone means.

				Chlorophyll (µg/L)				Daily PR (mg C·m^{-2}·d^{-1})				Phytoplankton							
		Sampling	Bacteria									No. (thousands/mL)				Volume (mm³/m³)			
Lake	Stn	date	(#x10^6/mL)	Total	Pico.	Nano.	Micro.	Total	Pico.	Nano.	Micro.	Total	Pico.	Nano.	Micro.	Total	Pico.	Nano.	Micro.
Elbow	1	7-Jun-07	1.65	0.56	0.35	0.16	0.05	64	24	29	11	8.3	5.6	2.1	0.5	775	11	126	638
	1	19-Jul-07	1.73	0.64	0.20	0.26	0.18	89	.	.	24	45.0	41.5	3.2	0.4	794	76	174	543
	1	29-Aug-07	1.36	0.81	0.67	0.08	0.05	116	57	52	8	35.5	34.4	0.9	0.2	445	63	51	331
	1	3-Oct-07	1.39	0.46	0.21	0.22	0.03	59	25	29	4	12.5	11.7	0.5	0.2	309	26	32	251
Mean			1.55	0.65	0.38	0.18	0.10	68	31	31	10	30.6	28.4	1.9	0.3	606	53	105	448
Rainbow	1	7-Jun-07	1.41	0.96	0.51	0.36	0.08	142	63	60	19	17.0	13.9	1.7	1.3	1899	27	111	1761
	1	19-Jul-07	1.34	0.68	0.19	0.31	0.18	130	.	.	32	36.8	33.5	2.6	0.7	1170	63	147	960
	1	29-Aug-07	1.21	0.54	0.33	0.16	0.05	129	60	61	7	31.7	29.3	1.8	0.6	1081	60	104	917
	1	3-Oct-07	1.61	0.48	0.17	_	0.10	80	43	24	14	22.1	20.1	1.3	0.7	932	41	80	811
Mean			1.35	0.66	0.29	0.25	0.11	101	47	44	15	29.4	26.7	2.0	0.8	1236	52	117	1067
Lonesome	2	6-Jun-07	1.33	0.68	0.34	0.19	0.16	60	20	27	13	13.0	11.2	1.3	0.6	819	23	74	722
	2	18-Jul-07	2.07	0.75	0.18	0.31	0.25	180	.	.	75	8.9	7.0	1.3	0.6	686	15	70	600
	2	26-Aug-07	2.71	0.65	0.37	0.18	0.10	176	91	67	19	11.5	10.3	0.9	0.4	435	21	51	362
	2	4-Oct-07	1.99	0.91	0.35	0.33	0.23	313	153	112	48	19.1	17.4	1.2	0.6	666	35	78	553
Mean			2.14	0.73	0.30	0.25	0.18	147	64	51	32	12.2	10.5	1.1	0.5	624	22	66	537
Kimsquit	1	27-Aug-07	0.51	0.66	0.20	0.42	0.04	185	64	110	11	15.8	13.0	1.1	1.7	2348	37	65	2246
Kitlope	1	27-Aug-07	0.64	0.23	0.11	0.10	0.02	35	26	7	3	38.6	37.0	1.4	0.3	368	73	75	220
Port John	1	28-Aug-07	0.54	0.64	0.17	0.36	0.11	25	12	11	2	10.0	8.6	0.9	0.6	432	27	58	348
Yeo	1	28-Aug-07	0.86	0.85	0.34	0.40	0.11	35	16	16	2	11.9	9.8	1.4	0.7	282	33	72	177

Table 6. Variation in volume of the major picoplankton groups.

Lake	Station		Unic. *Synechococcus*	Colon. *Synechococcus*	Eukaryotes
Elbow	1	7-Jun-07	10.42	0.05	0.73
	1	19-Jul-07	73.78	0.04	2.53
	1	29-Aug-07	61.27	0.00	1.63
	1	3-Oct-07	23.42	0.00	2.95
Mean			51.01	0.02	1.98
Rainbow	1	7-Jun-07	25.98	0.09	0.85
	1	19-Jul-07	59.77	0.07	2.96
	1	29-Aug-07	52.23	0.13	7.66
	1	3-Oct-07	34.42	0.33	4.88
Mean			47.57	0.13	4.38
Lonesome	2	6-Jun-07	19.99	0.00	2.31
	2	18-Jul-07	13.01	0.13	2.10
	2	26-Aug-07	15.56	1.44	4.03
	2	4-Oct-07	30.33	2.60	1.93
Mean			17.88	0.93	2.73
Kimsquit	1	27-Aug-07	19.63	1.94	13.93
Kitlope	1	27-Aug-07	68.58	0.20	3.69
Port John	1	28-Aug-07	10.06	0.11	6.51
Yeo	1	28-Aug-07	5.73	0.25	18.66

Table 7. Variation in volume of major nanoplankton genera.

Lake	Station		*Chromulina*	*Chroomonas*	*Chrysochromulina*	*Ochromonas*	*Cyclotella glomerata*	*Gymnodinium*	Others
Elbow	1	7-Jun-07	65.0	8.7	12.9	6.2	4.0	17.0	11.9
	1	19-Jul-07	122.3	17.5	6.1	7.8	1.7	3.3	15.9
	1	29-Aug-07	31.0	8.5	2.3	2.0	0.7	1.7	5.2
	1	3-Oct-07	15.2	7.8	1.1	0.9	0.6	3.1	2.9
Mean			66.8	11.6	5.3	4.6	1.62	5.2	9.8
Rainbow	1	7-Jun-07	45.4	22.8	12.9	3.2	5.6	9.5	11.5
	1	19-Jul-07	87.7	26.6	5.8	3.4	2.7	6.3	14.6
	1	29-Aug-07	50.5	22.2	7.6	3.0	2.9	8.5	9.5
	1	3-Oct-07	37.3	19.9	4.5	5.1	2.4	3.3	7.3
Mean			60.7	23.5	7.4	3.5	3.2	7.1	11.4
Lonesome	2	6-Jun-07	34.2	20.5	3.0	2.8	1.7	4.3	7.4
	2	18-Jul-07	37.3	13.1	2.3	1.5	2.3	5.2	8.2
	2	26-Aug-07	19.2	12.6	2.3	4.0	1.9	4.7	6.3
	2	4-Oct-07	22.5	27.7	5.3	3.4	2.2	7.6	9.0
Mean			28.48	16.61	2.89	2.85	2.05	5.26	7.56
Kimsquit	1	27-Aug-07	27.2	4.1	10.2	2.4	8.2	5.8	7.5
Kitlope	1	27-Aug-07	44.8	1.3	7.0	3.2	1.4	7.4	10.0
Port John	1	28-Aug-07	23.8	2.2	8.3	2.1	3.8	13.2	4.5
Yeo	1	28-Aug-07	29.1	13.9	1.5	2.9	7.3	0.9	16.2

Table 8. Variation in volume of major microplankton genera.

Lake	Station	Date	*Arthrodesmus*	*Urosolenia*	*Tabellaria*	*Asterionella*	*Cyclotella*	Others
Elbow	1	7-Jun-07	0.0	450	2.4	6.8	70	109
	1	19-Jul-07	0.0	499	0.0	0.0	15	29
	1	29-Aug-07	0.0	306	0.0	2.3	8	15
	1	3-Oct-07	0.0	222	0.0	0.0	10	19
Mean			0.0	387	0.4	1.9	22	37
Rainbow	1	7-Jun-07	0.0	1299	3.3	8.5	294	157
	1	19-Jul-07	0.0	890	0.0	4.6	21	45
	1	29-Aug-07	0.0	767	19	11	62	58
	1	3-Oct-07	0.0	670	4.7	6.8	65	64
Mean			0.0	890	7.4	7.8	89	72
Lonesome	2	6-Jun-07	0.0	582	21	18	32	69
	2	18-Jul-07	0.0	372	35	76	48	69
	2	26-Aug-07	0.0	290	0.0	0.0	32	40
	2	4-Oct-07	0.0	252	111	41	83	66
Mean			0.0	363	34	35	46	59
Kimsquit	1	27-Aug-07	962	911	1.6	0.0	221	150
Kitlope	1	27-Aug-07	0.0	138	0.9	0.0	59	23
Port John	1	28-Aug-07	2.4	58	0.0	0.0	218	70
Yeo	1	28-Aug-07	0.0	78	0.0	0.0	36	64

Table 9. Variation in the average contribution of pico-, nano-, and microplankton to chlorophyll, PR, and phytoplankton volume. Ultraplankton are pico- and nanoplankton combined.

		% ultrapl.			% picopl.			% nanopl.			% micropl.		
Lake	Station	Chl	PR	Vol.	Chl	PR	Vol.	Chl	PR	Vol.	Chl	PR	Vol.
Elbow	1	85%	91%	26%	58%	45%	9%	28%	46%	17%	15%	15%	74%
Rainbow	1	82%	91%	14%	44%	47%	4%	38%	43%	9%	17%	15%	86%
Lonesome	2	55%	78%	14%	41%	44%	4%	34%	34%	11%	25%	22%	86%
Kimsquit	1	94%	94%	4%	30%	35%	2%	63%	60%	3%	6%	6%	96%
Kitlope	1	92%	92%	40%	48%	73%	20%	44%	19%	20%	8%	8%	60%
Port John	1	83%	93%	20%	26%	47%	6%	57%	45%	13%	17%	8%	80%
Yeo	1	87%	95%	37%	40%	47%	12%	47%	48%	25%	13%	5%	63%

Table 10. Variation in dry biomass of the major zooplankton groups. To convert to volumetric biomass (mg dry wt/m^3), data should be divided by haul depth.

				Zooplankton biomass (mg dry wt/m^2)					
Lake	Station	Station	Haul depth (m)	Total	*Daphnia*	*Eubosmina coregoni*	*Diacyclops*	Diaptomid copepods	*Holopedium*
Elbow	1	7-Jun-07	30.0	433	142	6.0	285	0.0	0.0
	1	19-Jul-07	30.0	457	284	30	143	0.3	0.0
	1	29-Aug-07	30.0	1,887	1,408	23	455	0.0	0.0
	1	3-Oct-07	30.0	916	234	47	635	0.0	0.0
Mean				981	613	26	342	0	0
Rainbow	1	7-Jun-07	8.5	282	44	2.4	235	0.0	0.0
	1	19-Jul-07	8.5	565	521	0.5	43	0.0	0.0
	1	29-Aug-07	7.0	1,313	1,235	4.4	73	0.2	0.0
	1	3-Oct-07	7.0	248	226	0.9	21	0.0	0.0
Mean				709	622	2	83	0	0
Lonesome	2	6-Jun-07	30.0	3,013	2,458	13	301	0.0	198
	2	18-Jul-07	30.0	1,597	1,432	27	134	3.4	0.0
	2	26-Aug-07	30.0	1,564	1,341	24	140	57	0.0
	2	4-Oct-07	30.0	886	708	74	92	12	0.0
Mean				1,718	1,465	31	159	22	34.7
Kimsquit	1	27-Aug-07	30.0	491	0.0	63	200	0.0	228
Kitlope	1	27-Aug-07	30.0	20	3.7	3.2	13	0.0	0.0
Port John	1	28-Aug-07	30.0	101	0.4	31	9	55	0.4
Yeo	1	28-Aug-07	30.0	155	0.0	17	46	66	17.1

Table 11. Stomach contents and estimated fullness of *O. nerka* collected from the study lakes in 2007.

	Stomach contents (% of total weight of stomach contents)				Stomach contents (# of bugs/stomach)			
Prey item	Elbow	Lonesome	Kimsquit	Kitlope	Elbow	Lonesome	Kimsquit	Kitlope
Alona	0	0	0	<0.1	0	0.0	0	0.2
Chaoborus	0	0	0	1.1	0	0.0	0	0.1
Daphnia	98	99	0	1.2	1,648	428	0	2.0
Diacylops	<0.1	0.2	10	0.6	3	4	24	1.0
Eubosmina	0.3	0.5	1.0	10.6	11	5	2.1	59
Holopedium	0	0	46	0	0	0	124	0
Diaptomous	0	0.6	0	0	0	0.9	0	0
Chironomid	0	0	0	6.6	0	0	0	0.3
Insects	1.6	0	44	80.2	3	0	3	6
% stomach fullness	58	52	28	25				

Table 12. Size of fish caught in the study lakes by the various gear types. Measured lengths from trawl caught O. nerka were corrected for size selective bias using: corrected mean length = 0.629 X (length in trawl)$^{1.125}$ for mean lengths >40 mm and then weight was calculated with a generalized length-weight coefficient of 3.047 (McQueen et al 2007).

			Measured Weight (g)					Measured Length (mm)[1]					2x2 trawl bias correction	
Gear	Taxa	Preservative	N	Mean	95% CI	Min	Max	N	Mean	95% CI	Min	Max	Weight (g)	Length (mm)
Elbow Lake														
Midwater Trawl	Age-0 O. nerka	Ethanol	11	5.7	1.65	2.5	12.0	11	80	6.3	64	102	6.9	87
	Coho Salmon		1	9.9		9.9	9.9	1	99		99	99		
	Sculpin sp.	Formalin	5	0.1	0.12	0.0	0.3	5	21	7.7	15	31		
Swedish Gillnet	Age-0 O. nerka	Formalin	3	9.2	3.95	7.6	10.7	3	88	13.1	82	92		
		Ethanol	4	7.3	5.94	3.8	12.6	4	86	22.1	72	105		
	Age-1 O. Nerka	Ethanol	1	26.2		26.2	26.2	1	134		134	134		
	Age-2+ O. nerka	Formalin	3	95.9	37.83	78.7	107.5	3	192	26.6	180	199		
		Ethanol	2	82.8	146.82	71.3	94.4	2	198	38.1	195	201		
	Northern pikeminnow	Formalin	3	139.3	45.81	123.8	159.7	3	223	32.3	210	236		
Lonesome Lake														
Midwater Trawl	Age-0 O. nerka	Formalin	34	1.9	0.24	1.1	4.0	34	54	2.1	45	70	1.9	56
		Ethanol	29	1.8	0.42	0.9	6.1	29	58	3.2	48	87	2.3	61
	Age-1 O. Nerka	Ethanol	3	10.0	5.92	7.7	12.4	3	101	19.9	93	109	15.4	113
	Prickly Sculpin	Formalin	3	4.3	5.96	1.9	6.7	3	66	28.6	54	77		
	Sculpin sp.	Formalin	2	0.3	1.52	0.2	0.4	2	30	57.2	26	35		
		Ethanol	1	0.2		0.2	0.2	1	27		27	27		
Swedish Gillnet	Age-0 O. nerka	Formalin	3	2.9	1.76	2.2	4.0	4	62	11.1	56	68		
		Ethanol	6	3.2	0.22	2.9	3.4	7	70	2.1	67	73		
	Age-1 O. Nerka	Formalin	1	25.6		25.6	25.6	1	127		127	127		
	Age-2+ O. nerka	Live	0					1	212		212	212		
		Formalin	2	203.6	1001.3	124.8	282.4	2	238	565	193	282		
	Cutthroat trout	Live	0					1	265		265	265		
	Rainbow trout	Live	0					1	331		331	331		
Dip Net	Northern pikeminnow	Formalin	1	96.3		96.3	96.3	1	193		193	193		
	Prickly Sculpin	Formalin	1	41.4		41.4	41.4	1	135		135	135		
Kimsquit Lake														
Midwater Trawl	Age-0 O. nerka	Formalin	13	1.3	0.55	0.3	3.0	13	45	6.4	29	61	1.0	46
	Age-0 O. nerka	Ethanol	20	1.2	0.42	0.2	2.5	20	48	6.1	31	64	1.2	49
	Sculpin sp.	Ethanol	1	0.3		0.3	0.3	1	34		34	34	0.4	34
Swedish Gillnet	Age-0 O. nerka	Formalin	8	4.1	0.77	2.1	5.0	9	68	4.8	56	74		
	Age-1 O. Nerka	Formalin	8	7.0	2.05	4.4	11.8	8	82	7.6	70	97		
Kitlope Lake														
Midwater Trawl	Age-0 O. nerka	Formalin	75	1.4	0.11	0.7	2.9	75	49	1.3	37	65	1.3	50
	Age-0 O. nerka	Ethanol	25	1.1	0.13	0.6	1.9	25	51	1.9	42	61	1.5	52

Table 12. Size of fish caught in the study lakes by the various gear types. Measured lengths from trawl caught O. nerka were corrected for size selective bias using: corrected mean length = 0.629 X (length in trawl)$^{1.125}$ for mean lengths >40 mm and then weight was calculated with a generalized length-weight coefficient of 3.047 (McQueen et al 2007).

			Measured Weight (g)					Measured Length (mm)[1]					2x2 trawl bias correction	
Gear	Taxa	Preservative	N	Mean	95% CI	Min	Max	N	Mean	95% CI	Min	Max	Weight (g)	Length (mm)
	Age-1 O. Nerka	Live	0					1	90		90	90	10.4	99
		Formalin	5	4.6	1.13	3.9	6.2	5	73	7.9	68	83	5.1	79
		Ethanol	5	3.4	0.88	2.7	4.2	5	70	5.8	66	77	4.4	75
	Threespine stickleback	Formalin	2	1.0	4.38	0.6	1.3	2	44	69.9	39	50		
Swedish Gillnet	Age-0 O. nerka	Formalin	6	2.4	0.55	1.9	3.4	6	59	3.7	55	65		
	Age-1 O. Nerka	Live	0					2	92	31.8	90	95		
		Formalin	15	5.0	0.57	4.1	7.3	17	76	2.9	71	89		
	Age-2+ O. nerka	Formalin	1	14.7		14.7	14.7	1	107		107	107		
	Coho Salmon	Formalin	2	4.9	16.01	3.7	6.2	2	71	76.2	65	77		
	Threespine stickleback	Formalin	1	1.1		1.1	1.1	1	46		46	46		

Table 13. Preliminary hydroacoustic estimates of whole lake fish abundance and density in four North Coast area sockeye rearing lakes in 2007. Estimates are based on tracked target hydroacoustic techniques, TS analysis and net catch.

					Density		Abundance		± 95% as prop. of estimate	
Lake	Date	Surface area (ha)	Taxa	Transects (N)	N/ha	+/-95%	N	+/-95%		Comments / Net catch
Elbow	Sep. 20	105	Age_0 *O. nerka*	7	153	133	15,993	13,922	87%	
			Other small fish	7	14	12	1,448	1,260	87%	1 coho caught in trawl
			Large fish	7	31	17	8,229	4,385	53%	
Lonesome	Sep. 08	261	Age_0 *O. nerka*	7	654	257	170,949	67,085	39%	
			Other small fish	7	0		0			only small sculpins caught with a probable TS too small for sounder
			Large fish	7	100	71	10,453	7,431	71%	
Kimsquit	Sep. 13	158	Age_0 *O. nerka*	7	772	207	122,407	32,824	27%	
			Other small fish	7	23	6	3,656	980	27%	only small sculpins caught with a probable TS too small for sounder
			Large fish	7	149	69	23,681	10,956	46%	
Kitlope	Sep. 15	978	Age_0 *O. nerka*	7	275	77	269,217	74,854	28%	Partly estimated using trawl catch for 0-2 m layer as catch indicated many fish near surface and not in ensonified layer.
			Other small fish	7	5	1	4,935	1,372	28%	threespine stickleback and sculpin
			Large fish	7	9	16	9,125	15,779	173%	
Lonesome	September 28 1999		Age_0 *O. nerka*	7	293	190	119,617	77,902	65%	Rutherford, Wood, Bacen 1999
			Other small fish	7	0		0			2 sculpins and1 sucker sp were captured

Table 14. Estimated current biomass (wet weight) of significant planktivores for each lake sampled in 2007.

					Biomass		
Lake	Taxa	Mean weight (g)	Density (n/ha)	Prop. of observed density	kg/ha	kg/lake	Prop. of observed biomass
Elbow	Age-0 *O. nerka*	5.7	153		0.9	91	
	Calculated Age-0 sockeye [a]	5.7	123	68%	0.7	73	33%
	Calculated Age-0 kokanee [a]	5.7	29	16%	0.2	17	8%
	Older kokanee [b c]	70	16	9%	1.1	116	52%
	Other small fish (coho?)	10	14	8%	0.1	15	7%
Lonesome	Age-0 *O. nerka*	1.9	654		1.2	323	
	Calculated Age-0 sockeye [a]	1.9	562	80%	1.1	277	22%
	Calculated Age-0 kokanee [a]	1.9	93	13%	0.2	46	4%
	Older kokanee [b c]	70	50	7%	3.5	912	74%
	Other small fish	-	-	0%	-	0	0%
Kimsquit	Age-0 *sockeye* [d]	1.4	772	97%	1.1	168	85%
	Age-1 *sockeye* [b d]	8.4	23	3%	0.19	31	15%
Kitlope	Age-0 *O. nerka*	4.4	275		1.2	1182	
	Calculated Age-0 sockeye [a]	4.4	267	94%	1.2	1145	75%
	Calculated Age-0 kokanee [a]	4.4	9	3%	0.0	37	2%
	Older kokanee [b c]	70	5	2%	0.3	319	21%
	Other small fish	5.0	5	2%	0.0	25	2%

a Used total estimated density of older kokanee to determine likely density of age-0 kokanee based on the mean relationship between kokanee age classes (age-0 kokanee = 65% total kokanee abundance; McGurt 1999; Sebastian et al 2003).

b Used mean size of age-1 & -2+ kokanee captured in other coastal lakes, as sample size in study lakes was insufficient (Hume and MacLellan 2008).

c Due to the shallow nature of these lakes, we assumed that many large fish targets would belong to fish normally considered residents of the littoral zone. Therefore we used a value of 50%.

d No older kokanee captured during survey therefore assumed they are not resident in these lakes and all O. nerka caught are

Table 15. PR model predictions for North Coast Area lakes surveyed in 2007.

		Average daily PR (mg/m²)						Non-sockeye competitors adjustment		
Lake	Surface area (ha)	PR_{mean}	Adjusted for bathymetry	# sampling dates	Converted to mean seasonal PR	PR_{total} (t C/lake)	Total predicted limnetic biomass (kg)	Obs. non-sockeye biomass (kg/lake)[3]	Prop. of non sockeye limnetic biomass	PR_{total} available to sockeye (t C/lake)
Elbow	138	68	59	4	59	14.6	665	133	20%	11.7
Rainbow	164	101	88	4	88	26.0	1185	54	5%	25
Lonesome	410	147	134	4	134	98.7	4489	958	21%	78
Kimsquit	166	185	185	1	138	41.4	1885	0	0.0%	41
Kitlope	1170	35	35	1	26	55.5	2525	357	14.1%	48
Port John	91	25	25	1	19	3.0	139	18	13%	2.6
Yeo	83	35	35	1	26	3.9	176	23	13%	3.4

	Age-2 smolt adjustment				PR model predictions					
Lake	Age-1 smolt wt at capacity	Age-2 smolt wt at capacity	% of age-1's at capacity	Mean smolt wt.	Kg smolt biomass (R_{max})	Smolt #'s (thousands)	Escapement (S_{max}) (thousands)	Escapement (#/ha)	Observed juvenile sockeye biomass (kg)	% of rearing capacity used
Elbow	4.5	.	100%	4.5	531	118	2.2	16	73	14%
Rainbow	4.5	.	100%	4.5	1,131	251	4.6	28	.	.
Lonesome	4.5	.	100%	4.5	3,532	785	14.5	35	277	8%
Kimsquit	4.5	10	97%	4.7	1,885	404	7.5	45	168	9%
Kitlope	4.5	.	100%	4.5	2,168	482	8.9	8	1145	53%
Port John	4.5	.	100%	4.5	120	27	0.5	5	.	.
Yeo	4.5	.	100%	4.5	153	34	0.6	8	.	.

Means from Shortreed et al. 2007		
	Non sox biomass (kg/ha)	PR_{mean}
clear	0.68	158
galcial	0.40	124
stained	1.28	157

Table 16. Sockeye escapements to lakes sampled in 2007. Data are for the years 1950-2007, but were not collected in every year. Escapement data to the various Atnarko lakes are not available, so the total sockeye escapement to the Bella Coola River is presented.

	Total escapement					Escapement/ha				
	Kimsquit	Kitlope	Port John	Yeo	Bella Coola River	Kimsquit	Kitlope	Port John	Yeo	Bella Coola River
Mean (1950-1980)	11152	26200	818	627	50210	65	22	9	8	71
Minimum	3500	3500	25	20	8000	0.0	3.0	0.3	0.2	11.2
Maximum	55000	175000	2566	2500	150000	331	150	28	30	211
No. years data	25	30	23	29	31	26	30	23	29	31
Mean (1980-2006)	13153	12892	193	290	29010	79	11	2	4	41
Minimum	1000	3000	10	20	6000	6.0	2.6	0.1	0.2	8.4
Maximum	30000	25000	750	800	55000	181	21	8	10	77
No. years data	17	24	18	14	26	17	24	18	13	26

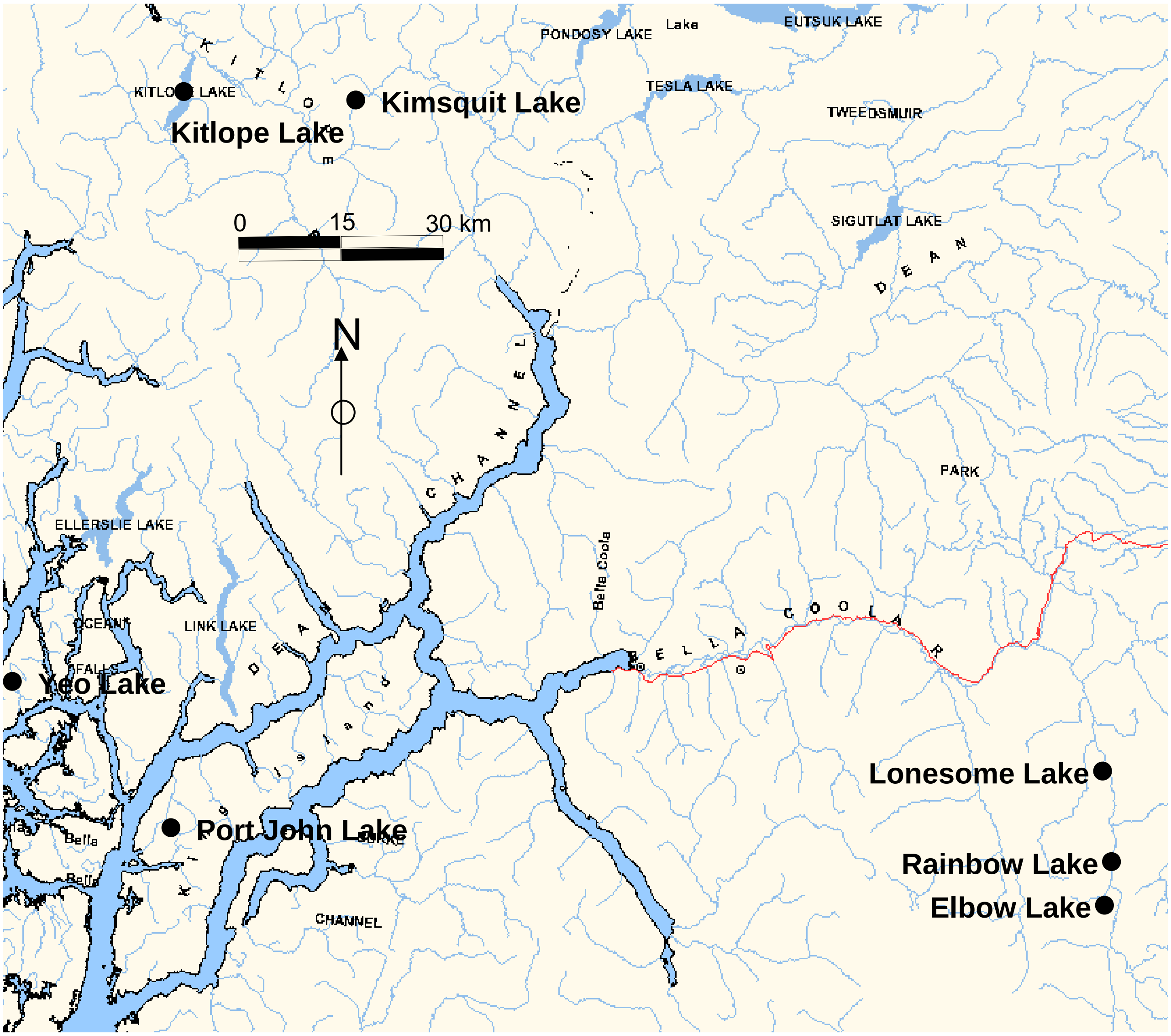


Fig. 1. Map showing the location of the seven lakes sampled in 2007.

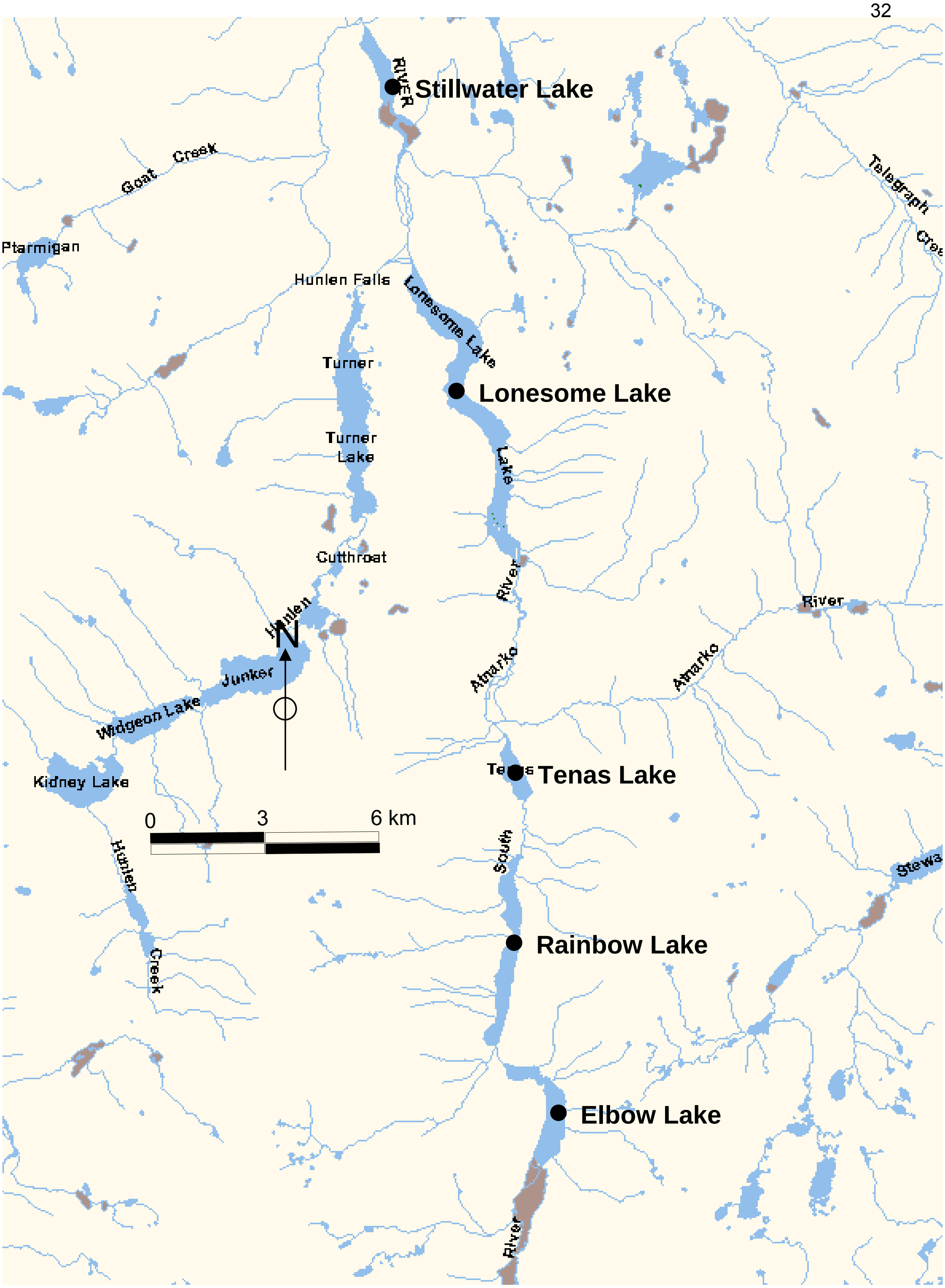


Fig. 2. Map showing all five Atnarko system lakes.

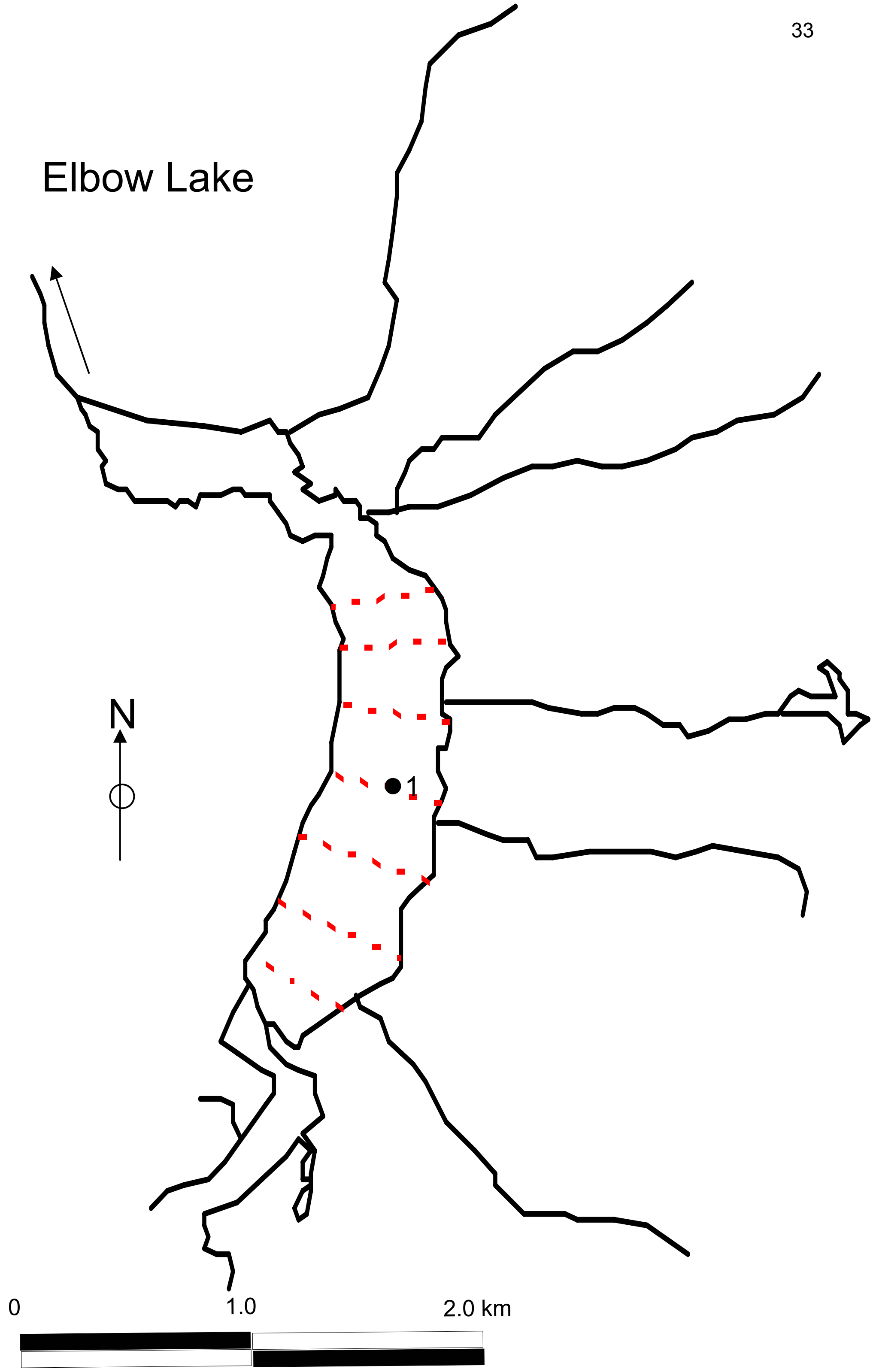


Fig. 3. Outline map of Elbow Lake and the location of the limnological sampling station. Dotted lines are the locations of the acoustic transects.

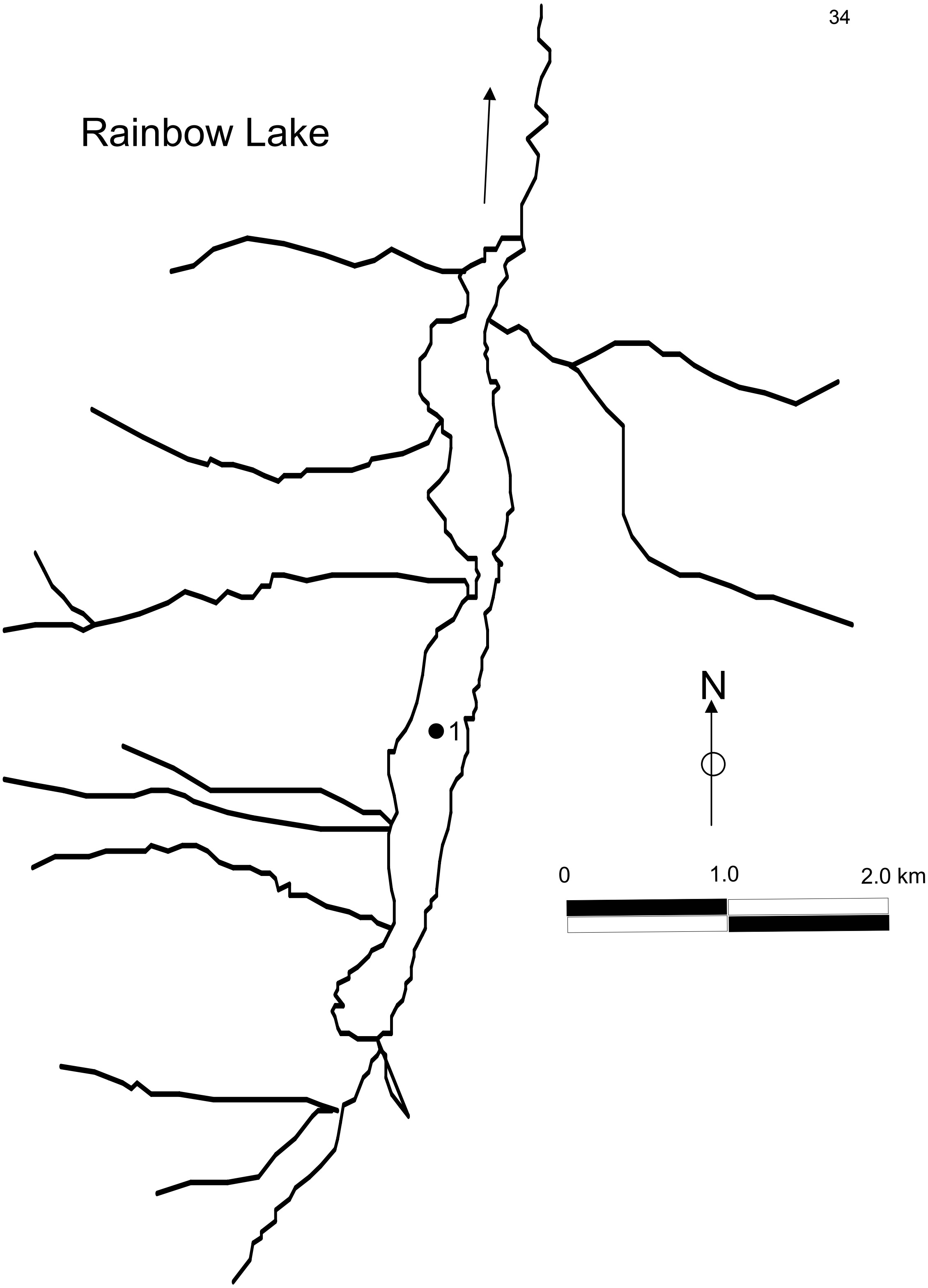


Fig. 4. Outline map of Rainbow Lake and the location of the limnological sampling station.

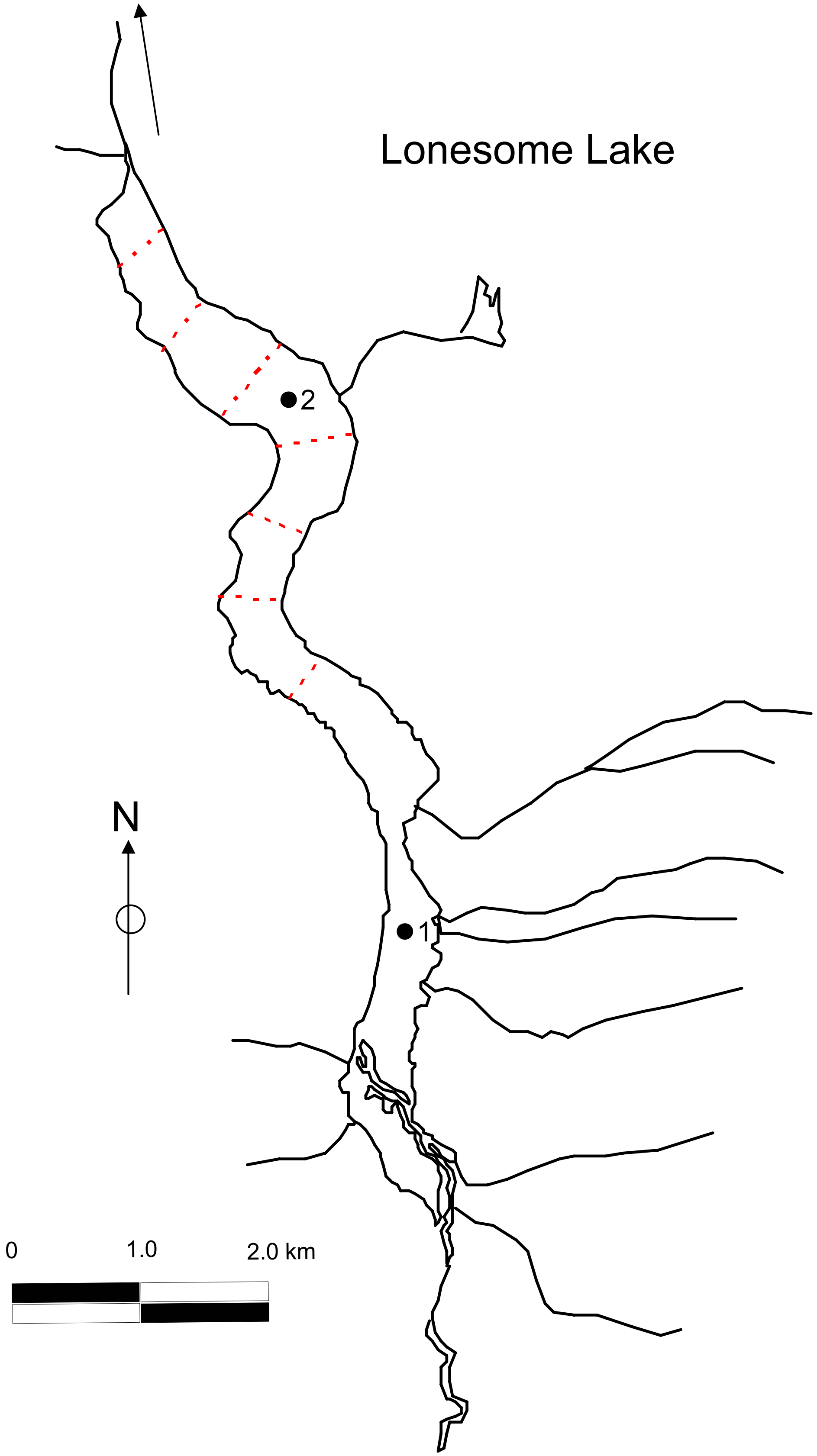


Fig. 5. Outline map of Lonesome Lake and the location of the limnological sampling stations. Dotted lines are the locations of the acoustic transects.

Kimsquit Lake

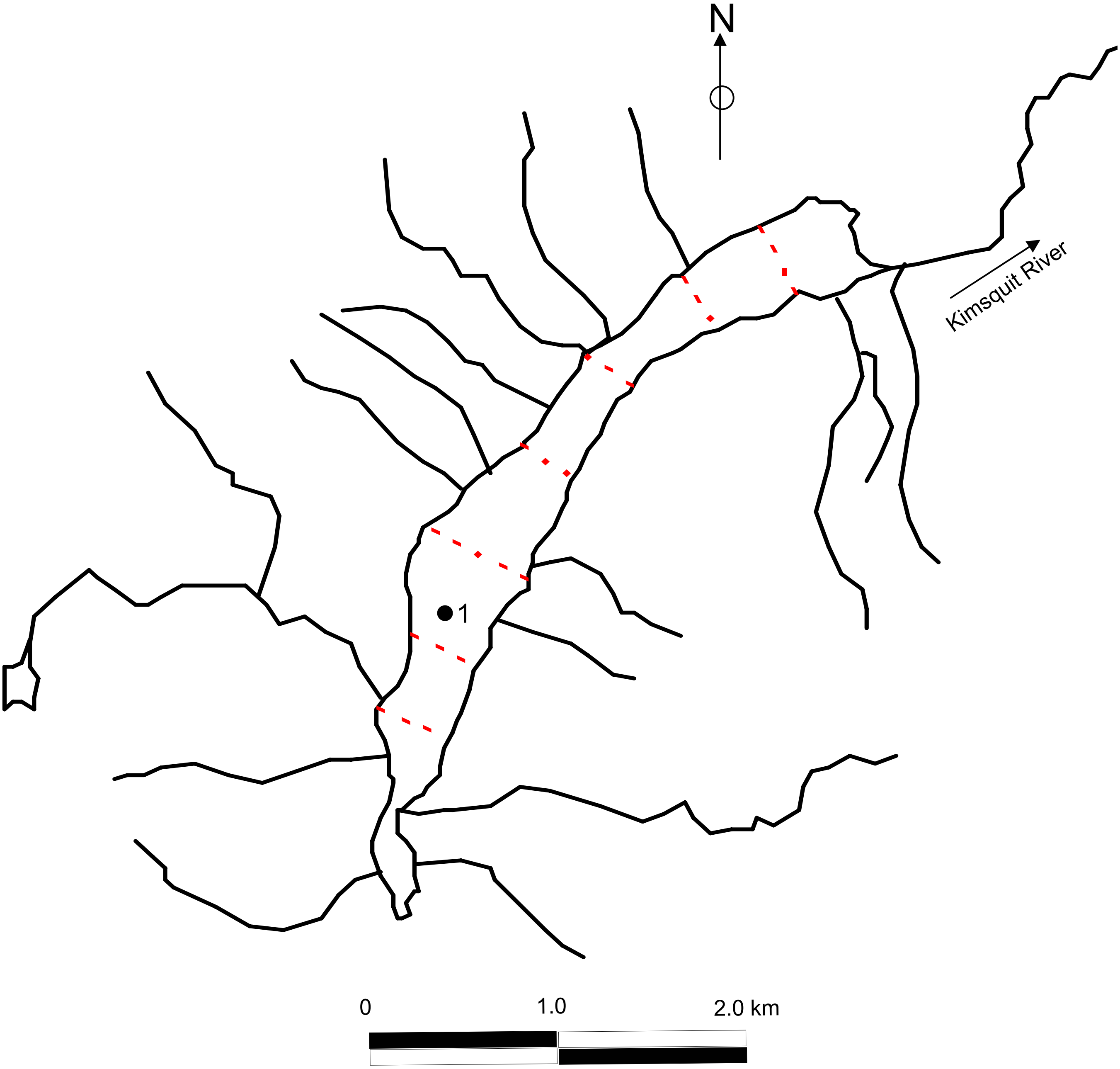


Fig. 6. Outline map of Kimsquit Lake and the location of the limnological sampling station. Dotted lines are the locations of the acoustic transects.

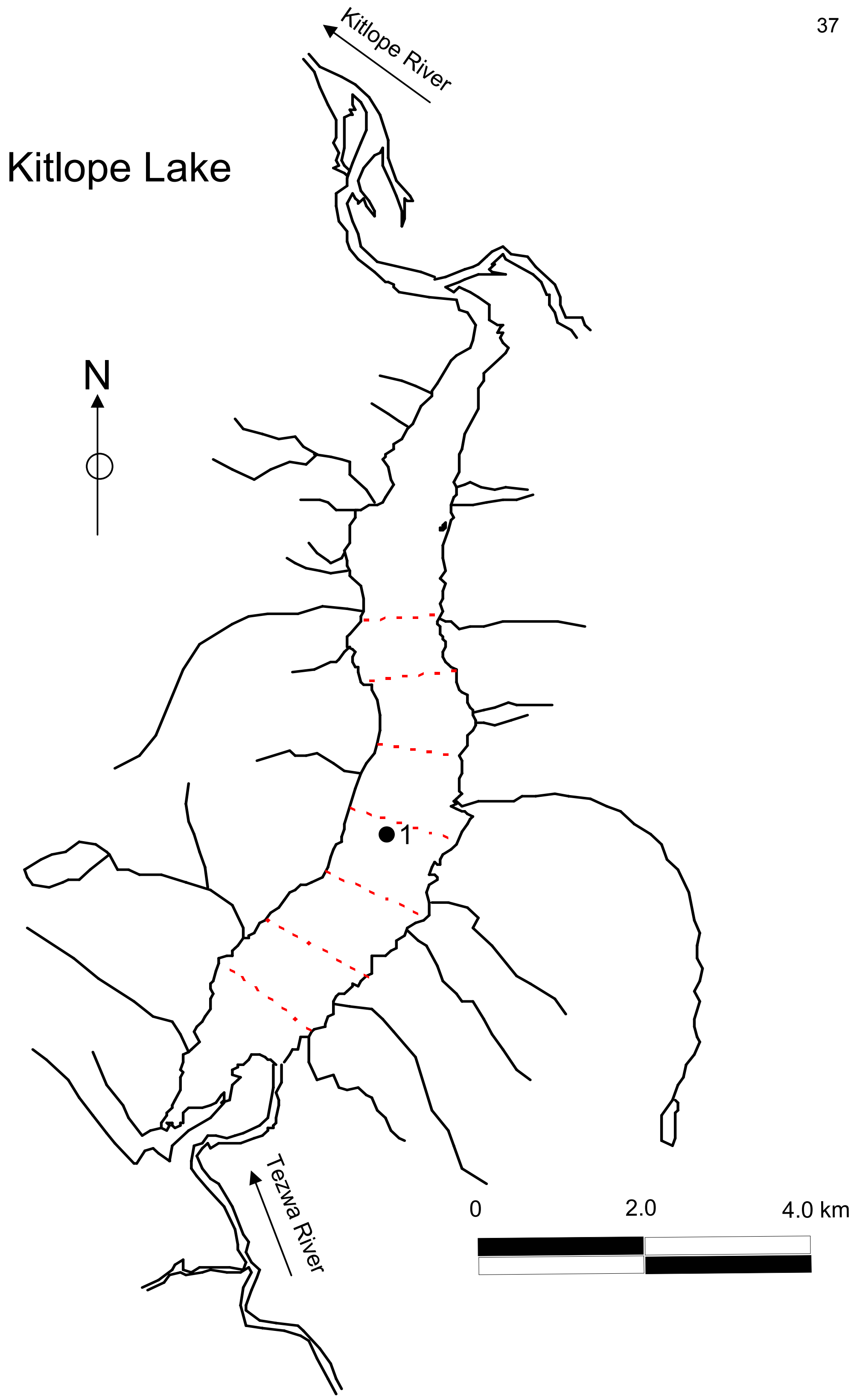


Fig. 7. Outline map of Kitlope Lake and the location of the limnological sampling station. Dotted lines are the locations of the acoustic transects

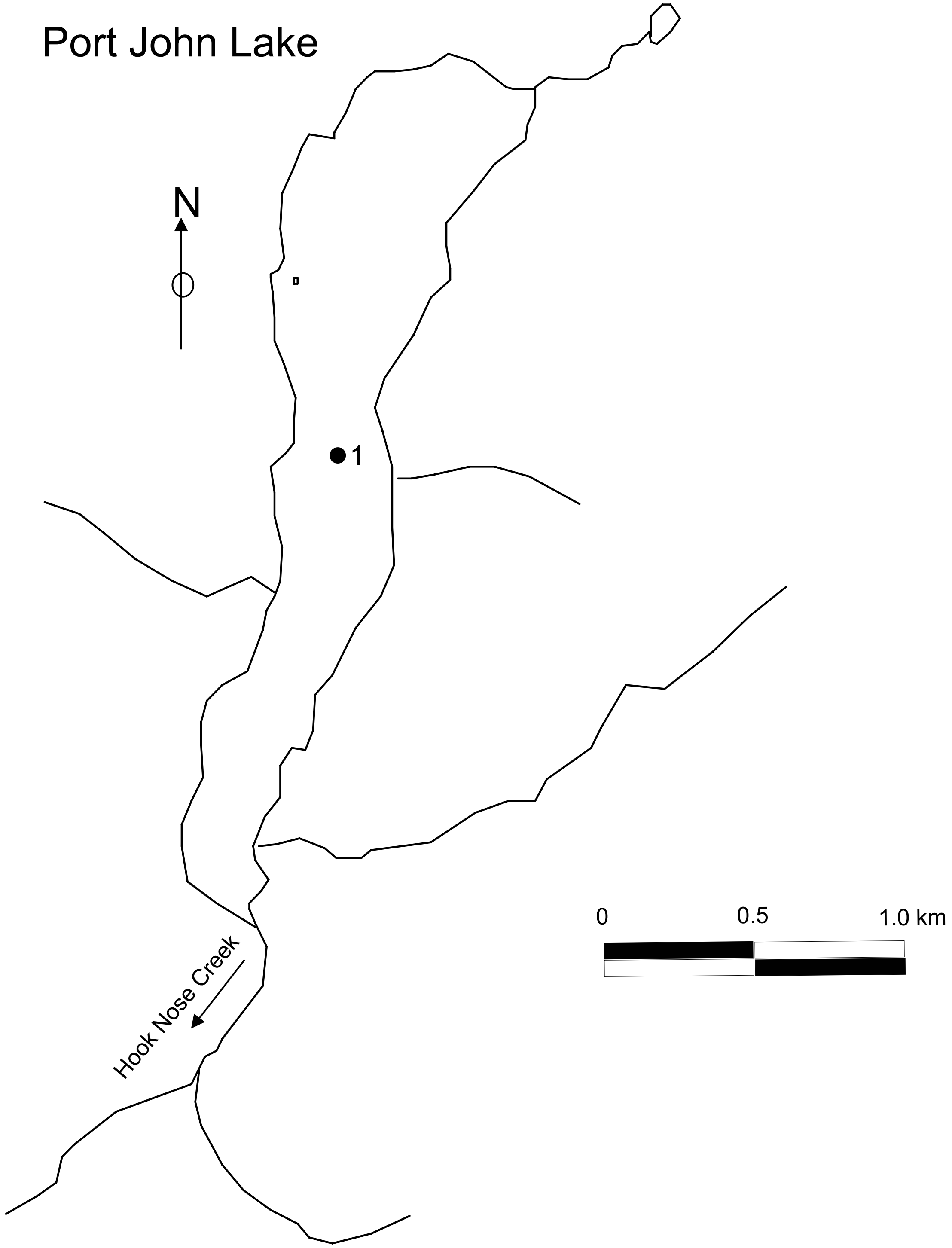


Fig. 8. Outline map of Port John Lake and the location of the limnological sampling station.

Fig. 9. Outline map of Yeo Lake and the location of the limnological sampling station.

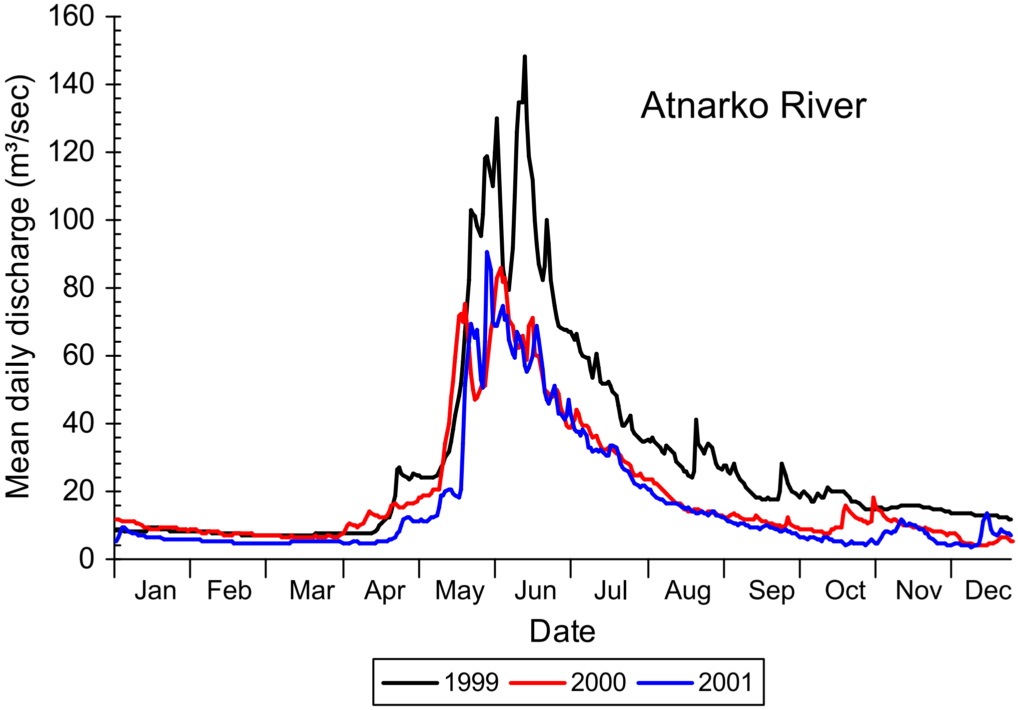


Fig. 10. Atnarko River discharge at a site 26 km downstream of Stillwater Lake.

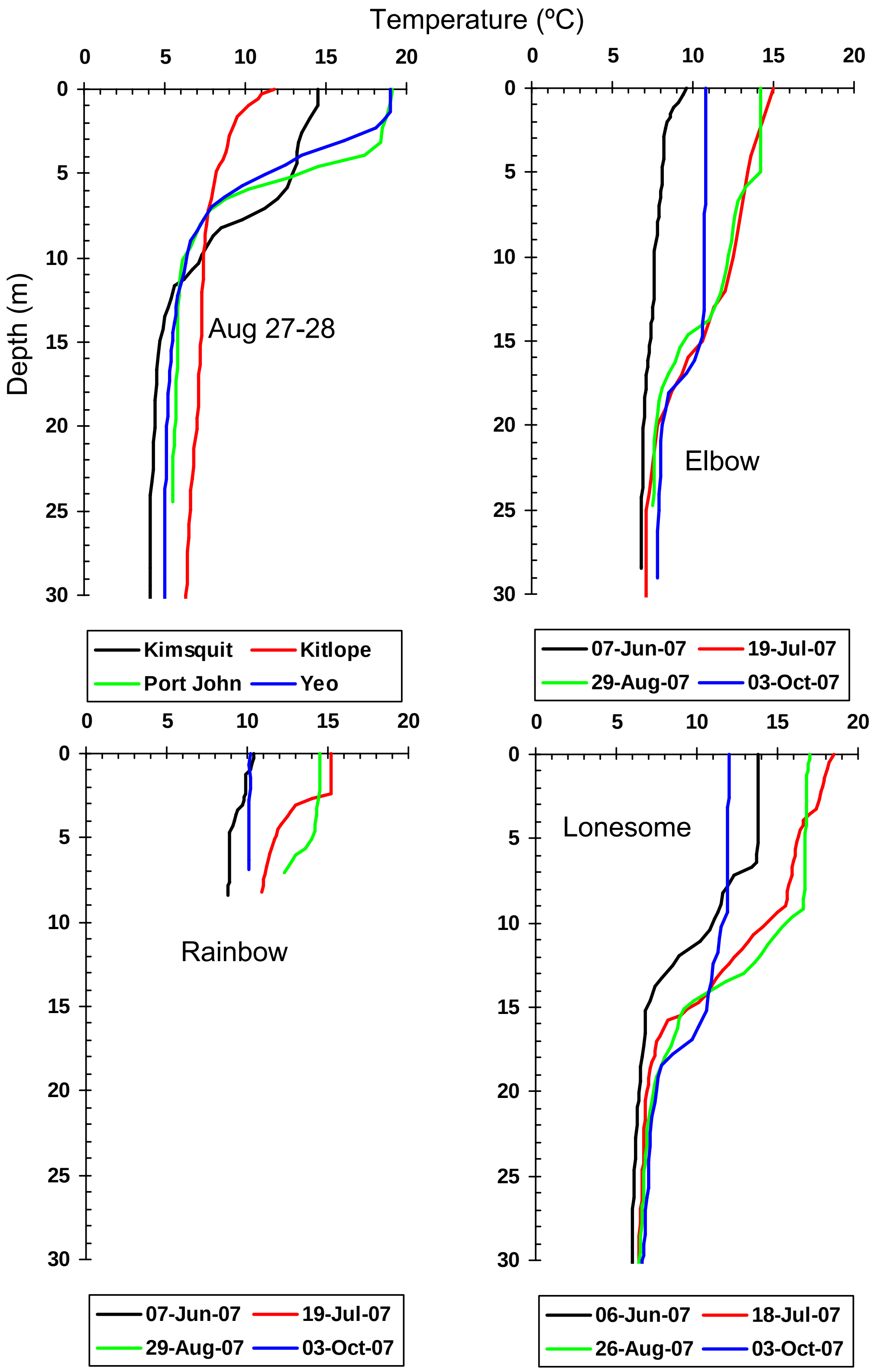


Fig. 11. Vertical temperature profiles from the lakes sampled in 2007.

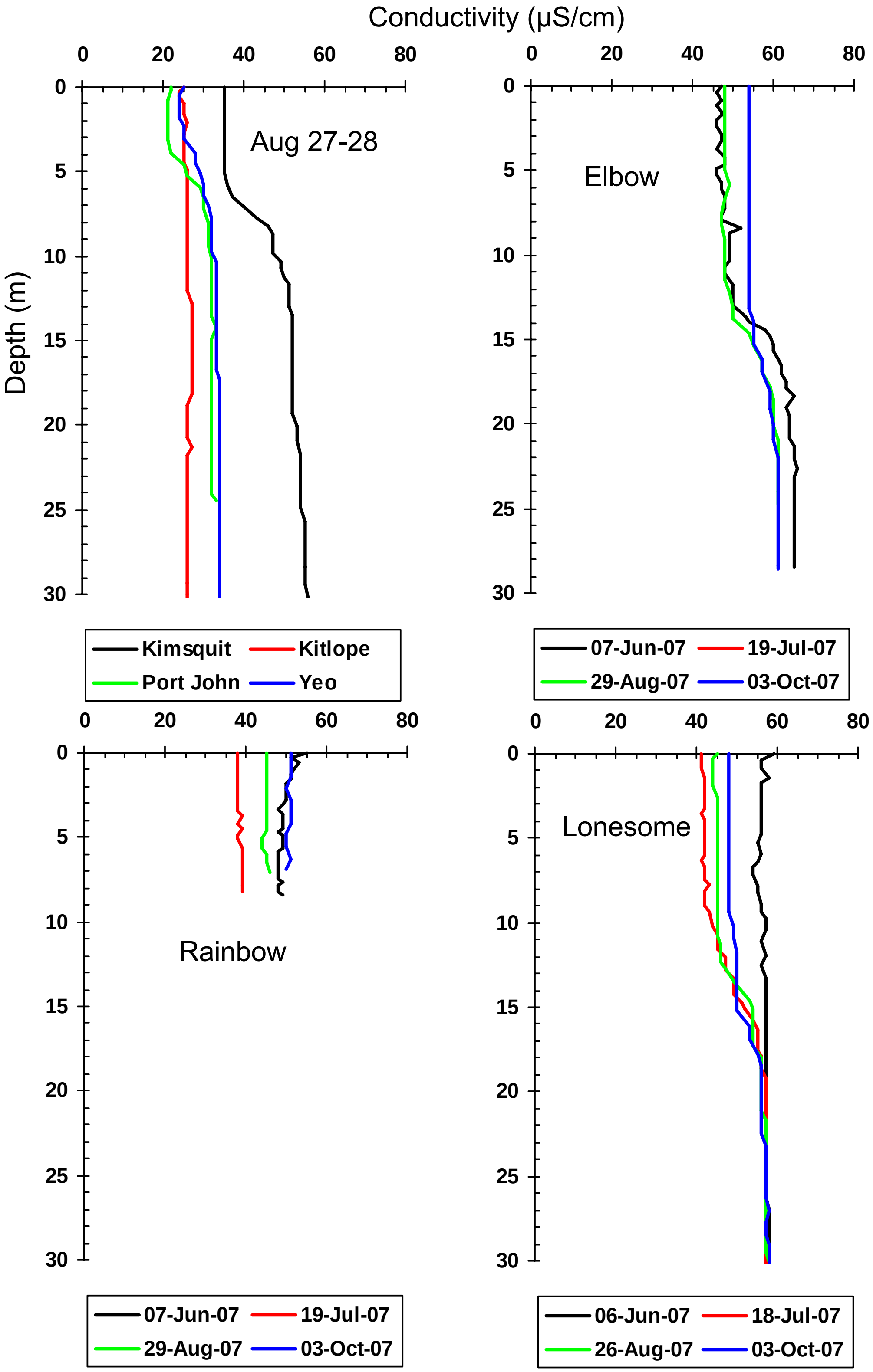


Fig. 12. Vertical conductivity profiles from the lakes sampled in 2007.

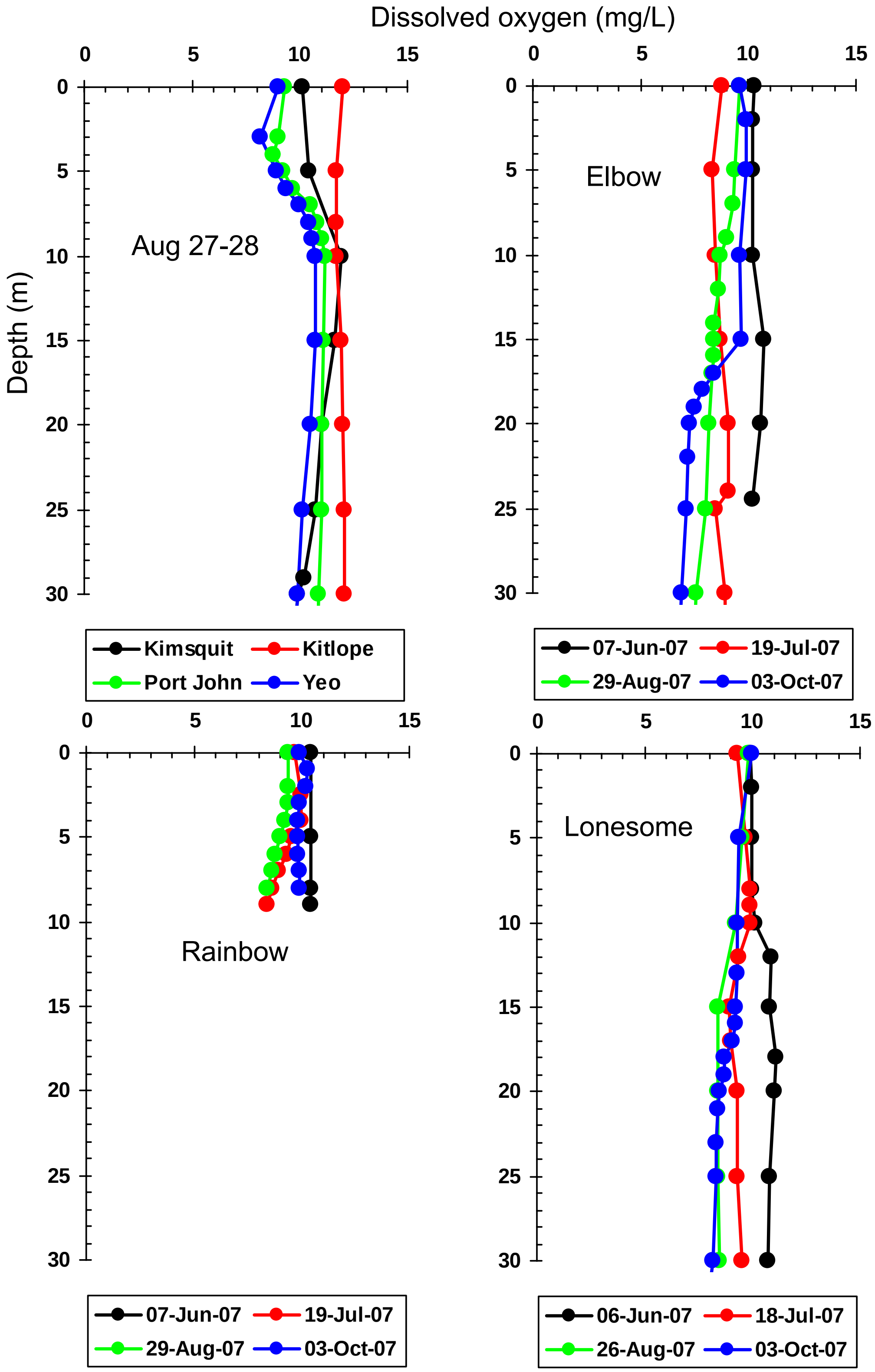


Fig. 13. Vertical dissolved oxygen profiles from the lakes sampled in 2007.

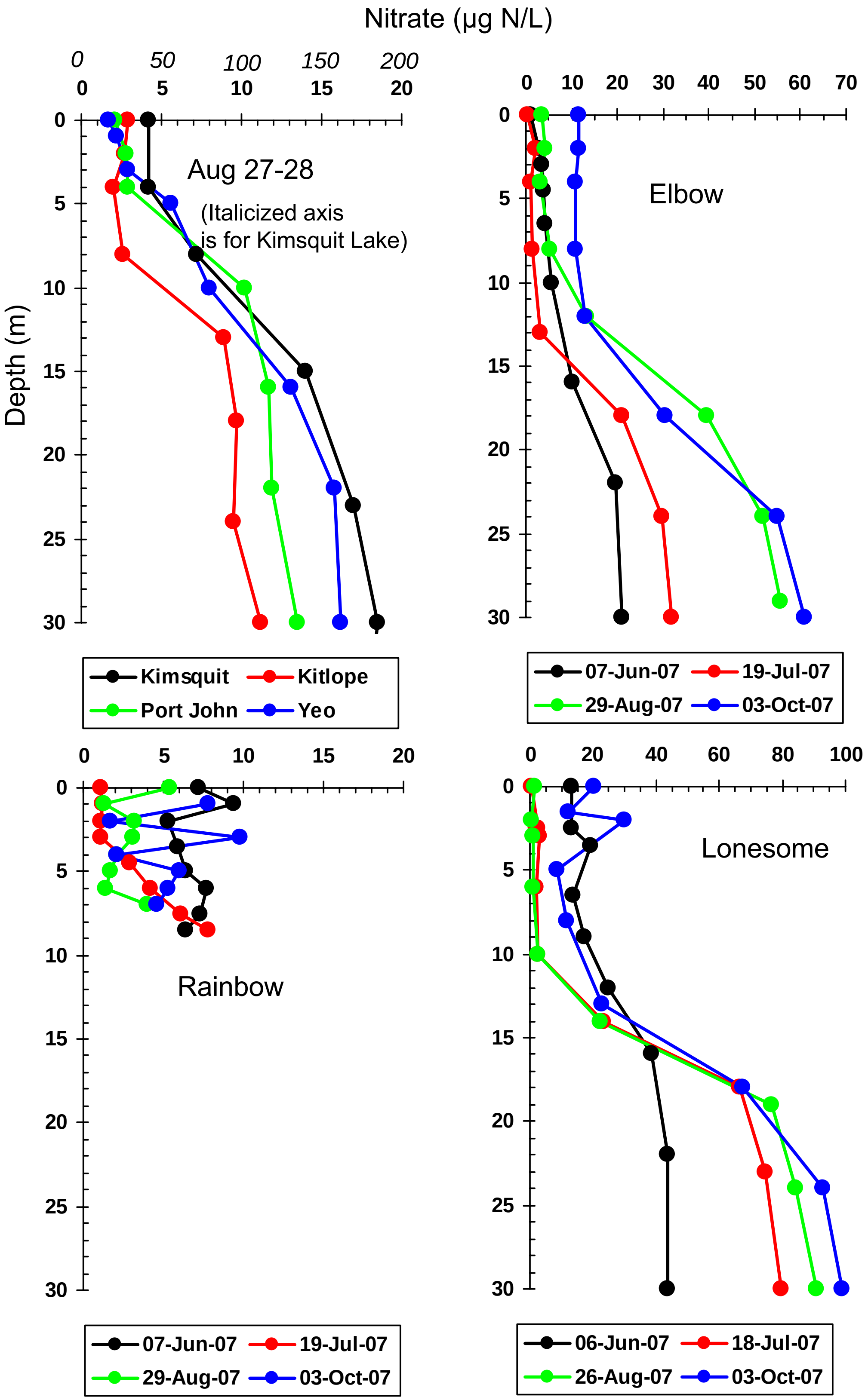


Fig. 14. Vertical profiles of nitrate concentration in the lakes sampled in 2007. Note the different axes units.

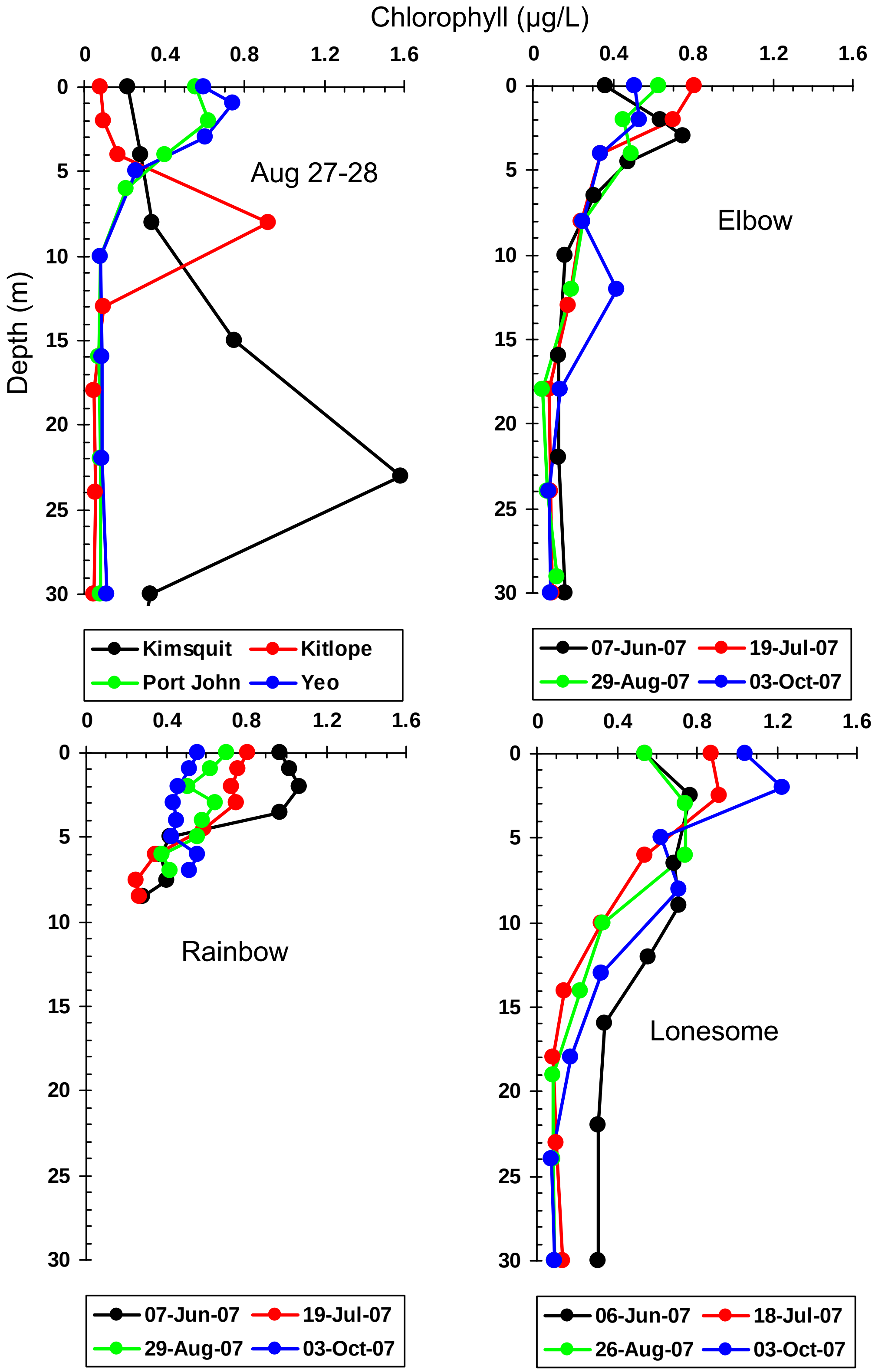


Fig. 15. Vertical profiles of chlorophyll concentration from the lakes sampled in 2007.

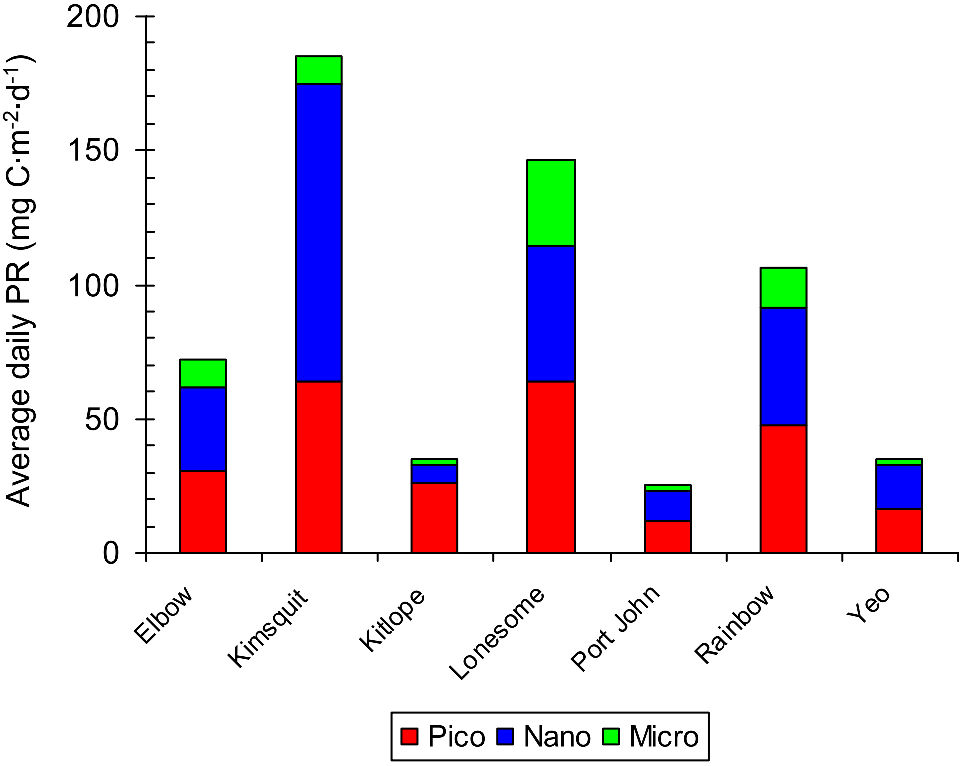


Fig. 16. Average daily photosynthetic rates (mg C·m^{-2}·d^{-1}) of the pico- (<2 µm), nano- (2-20 µm), and microplankton (>20 µm) size fractions in the lakes sampled in 2007.

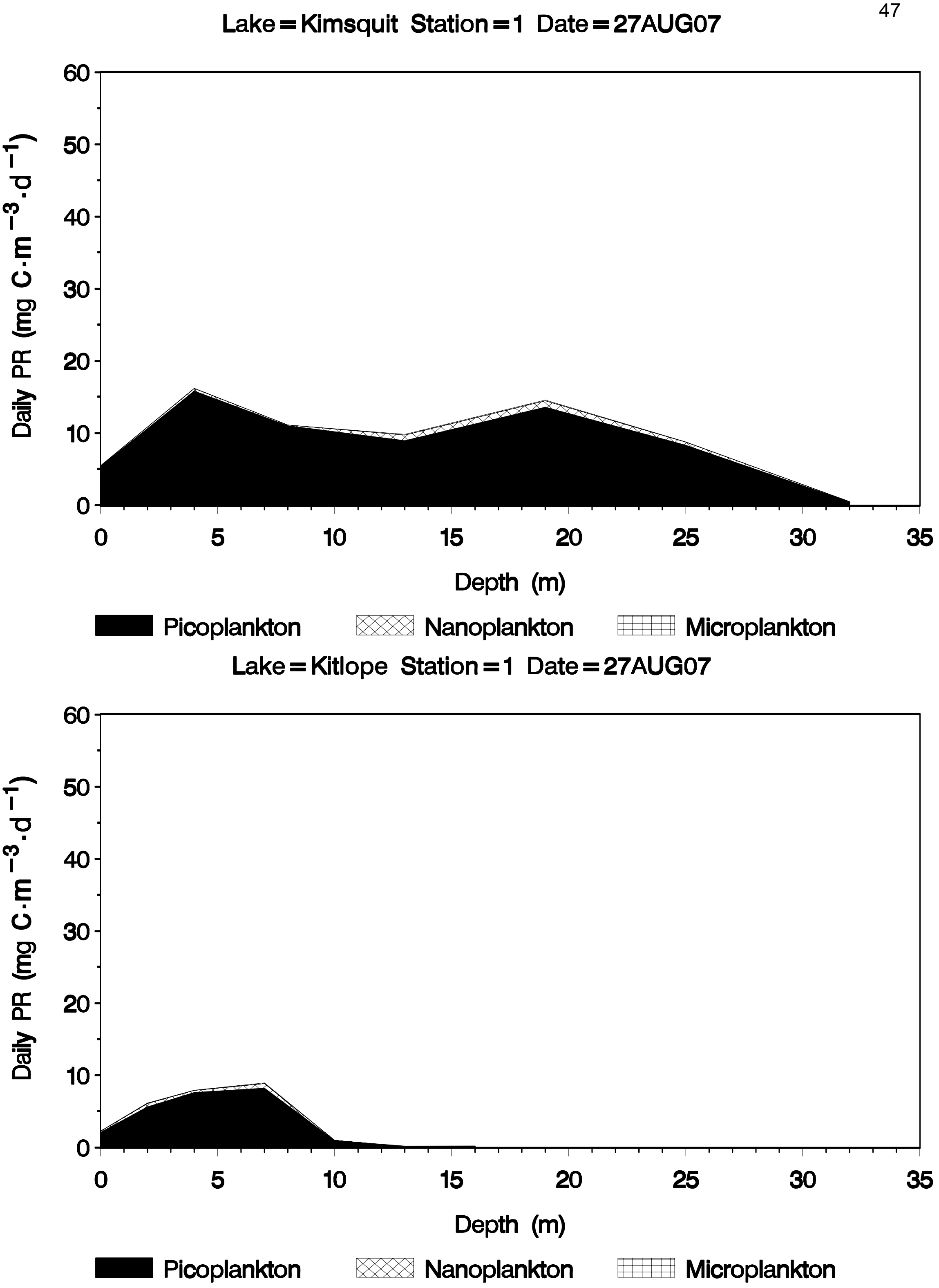


Fig. 17. Vertical profiles of daily photosynthetic rates (mg C·m^{-3}·d^{-1}) of the pico- (<=2 µm), nano- (2-20 µm), and microplankton (>20 µm) size fractions in Kimsquit and Kitlope lakes.

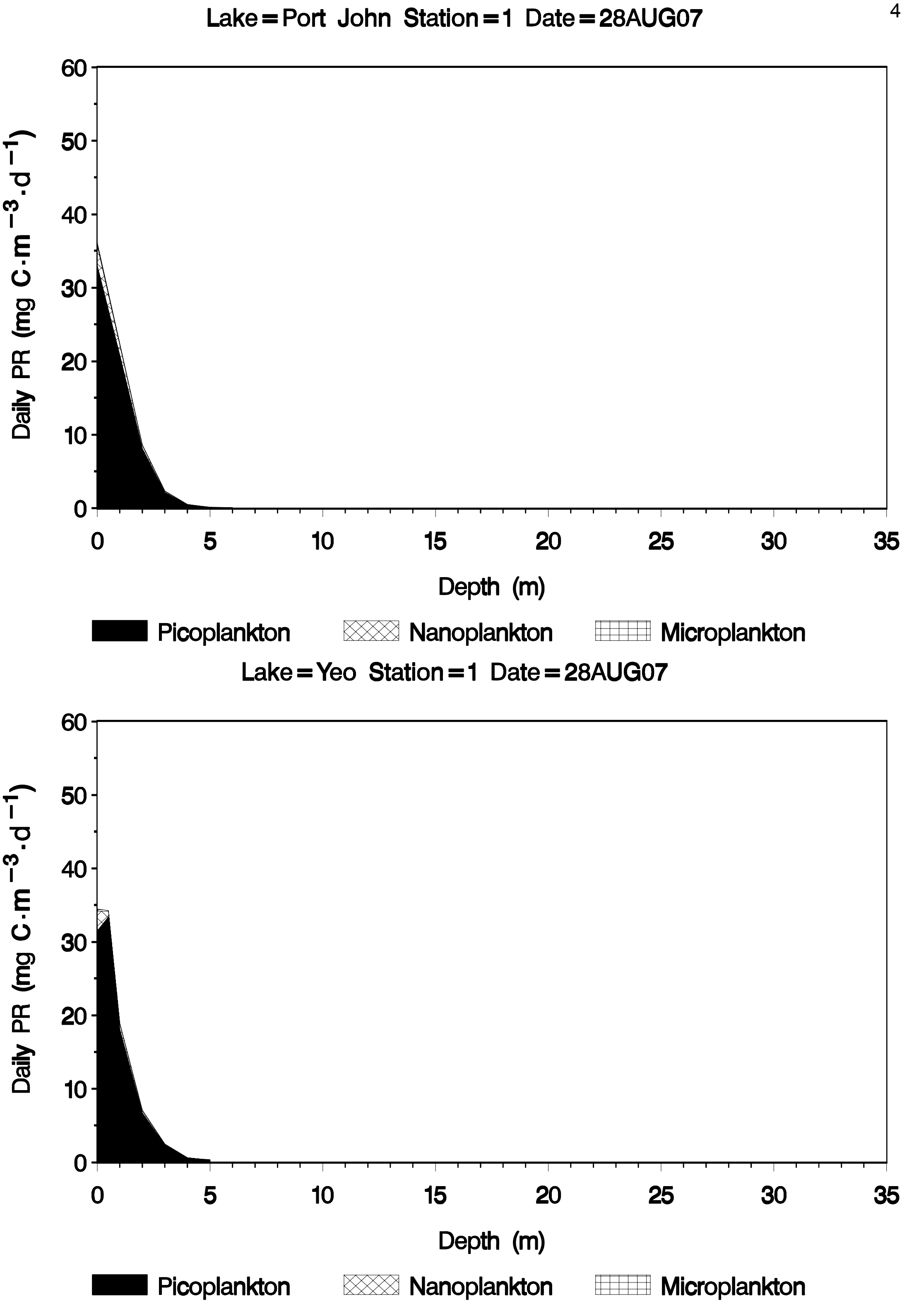


Fig. 18. Vertical profiles of daily photosynthetic rates (mg C·m^{-3}·d^{-1}) of the pico- (≤ 2 µm), nano- (2-20 µm), and microplankton (>20 µm) size fractions in Port John and Yeo lakes.

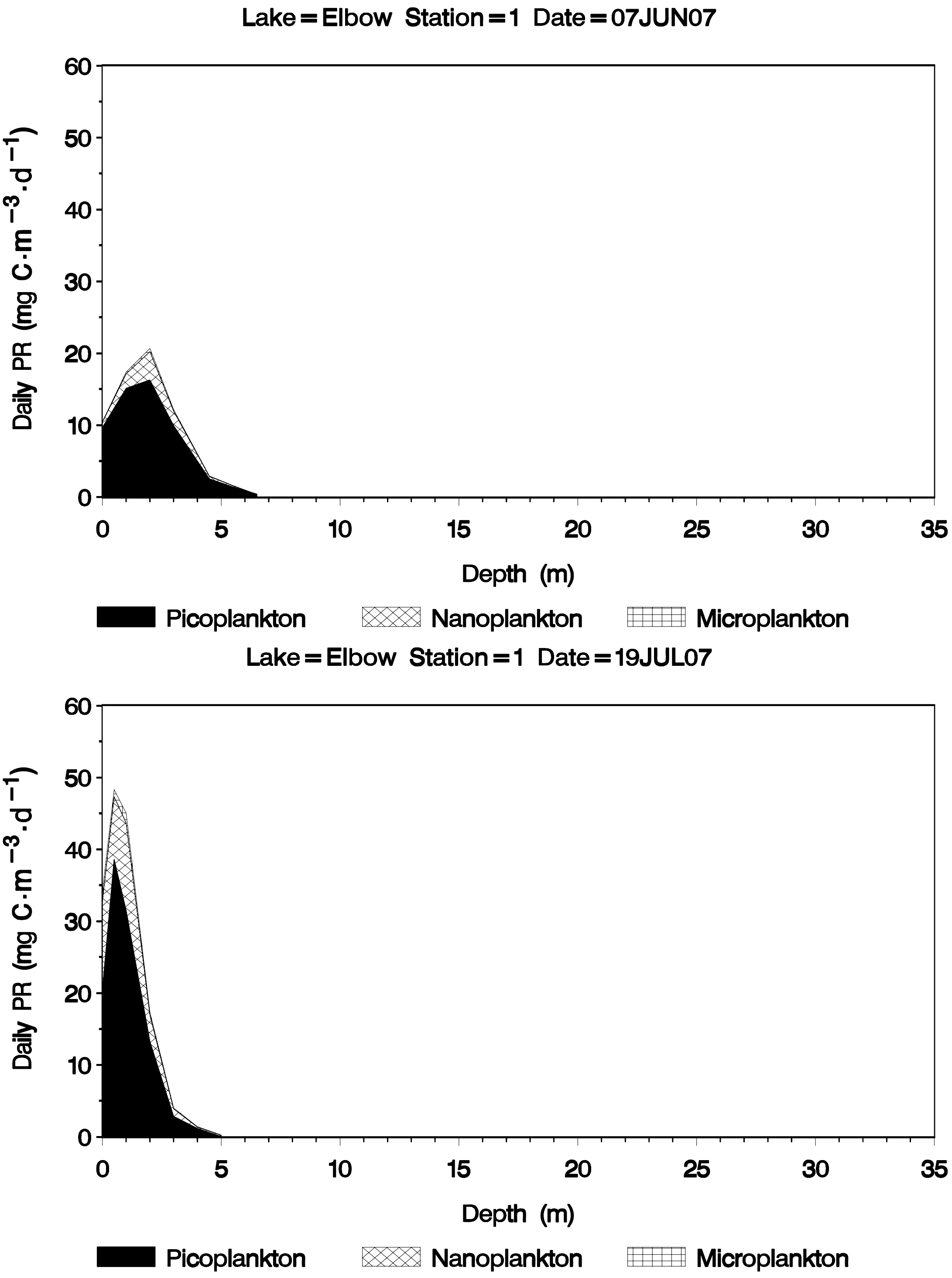


Fig. 19. Vertical profiles of daily photosynthetic rates (mg C·m^{-3}·d^{-1}) of the pico- (<=2 µm), nano- (2-20 µm), and microplankton (>20 µm) size fractions in Elbow Lake.

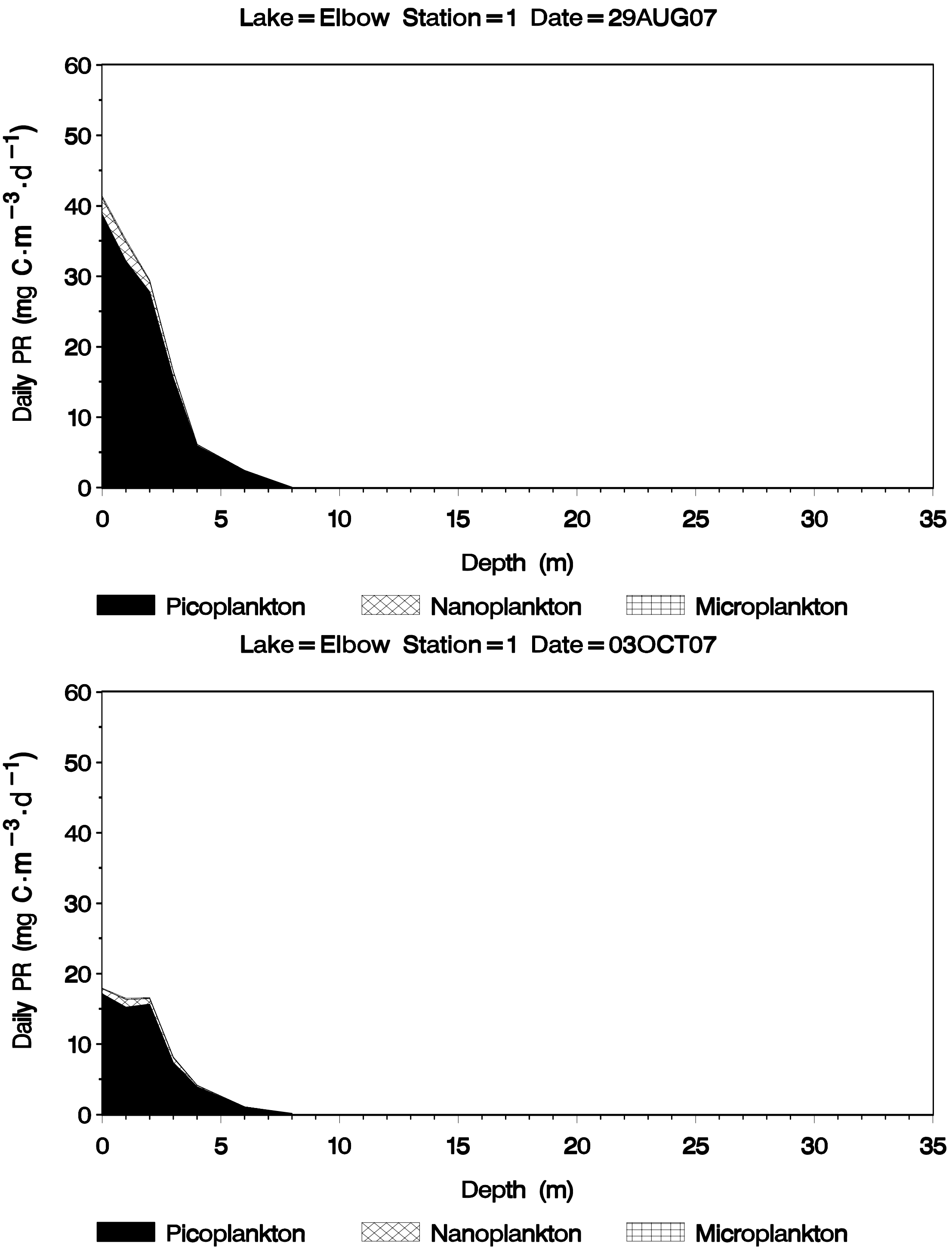


Fig. 20. Vertical profiles of daily photosynthetic rates (mg C·m^{-3}·d^{-1}) of the pico- (<=2 μm), nano- (2-20 μm), and microplankton (>20 μm) size fractions in Elbow Lake.

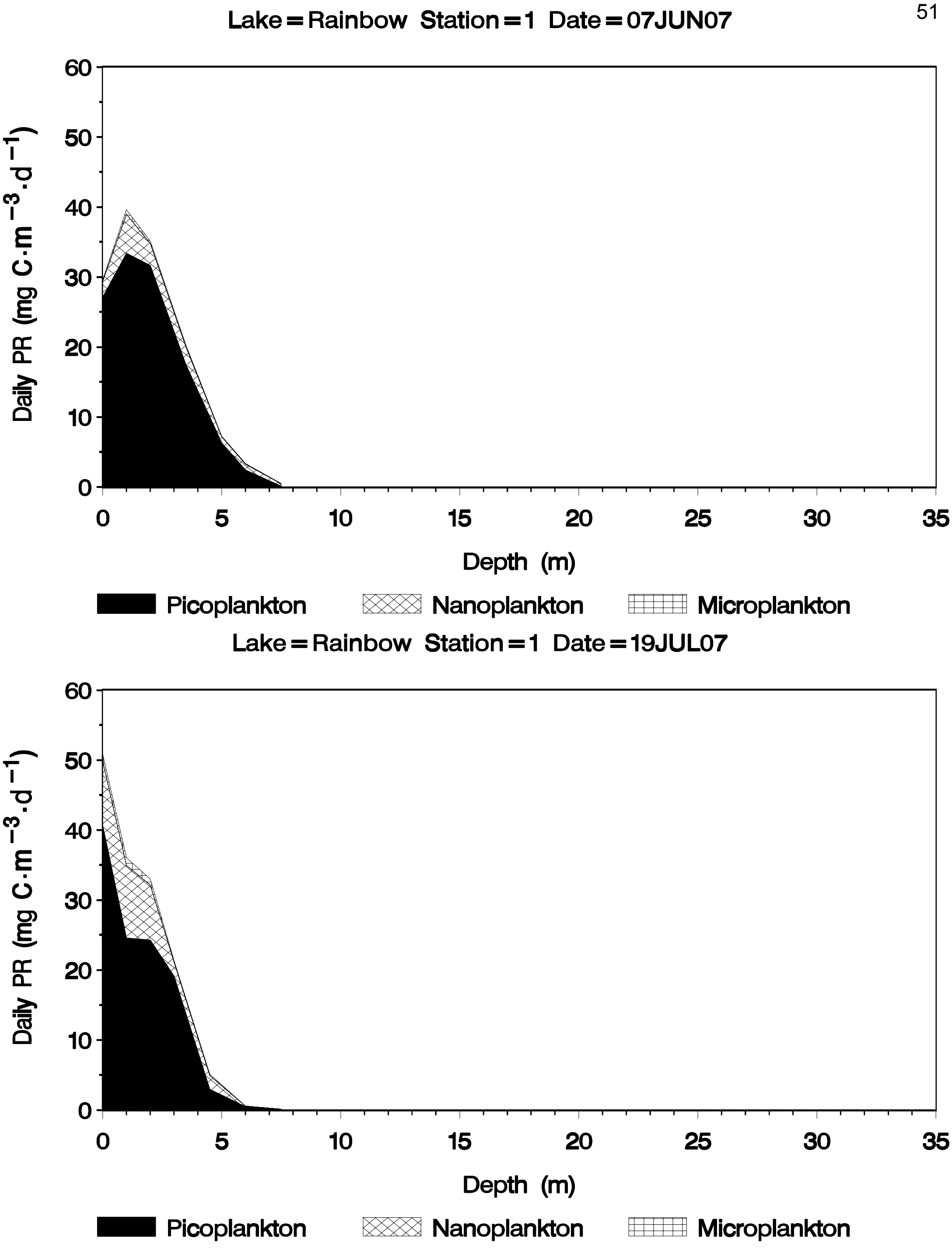


Fig. 21. Vertical profiles of daily photosynthetic rates (mg C·m^{-3}·d^{-1}) of the pico- (<=2 µm), nano- (2-20 µm), and microplankton (>20 µm) size fractions in Rainbow Lake.

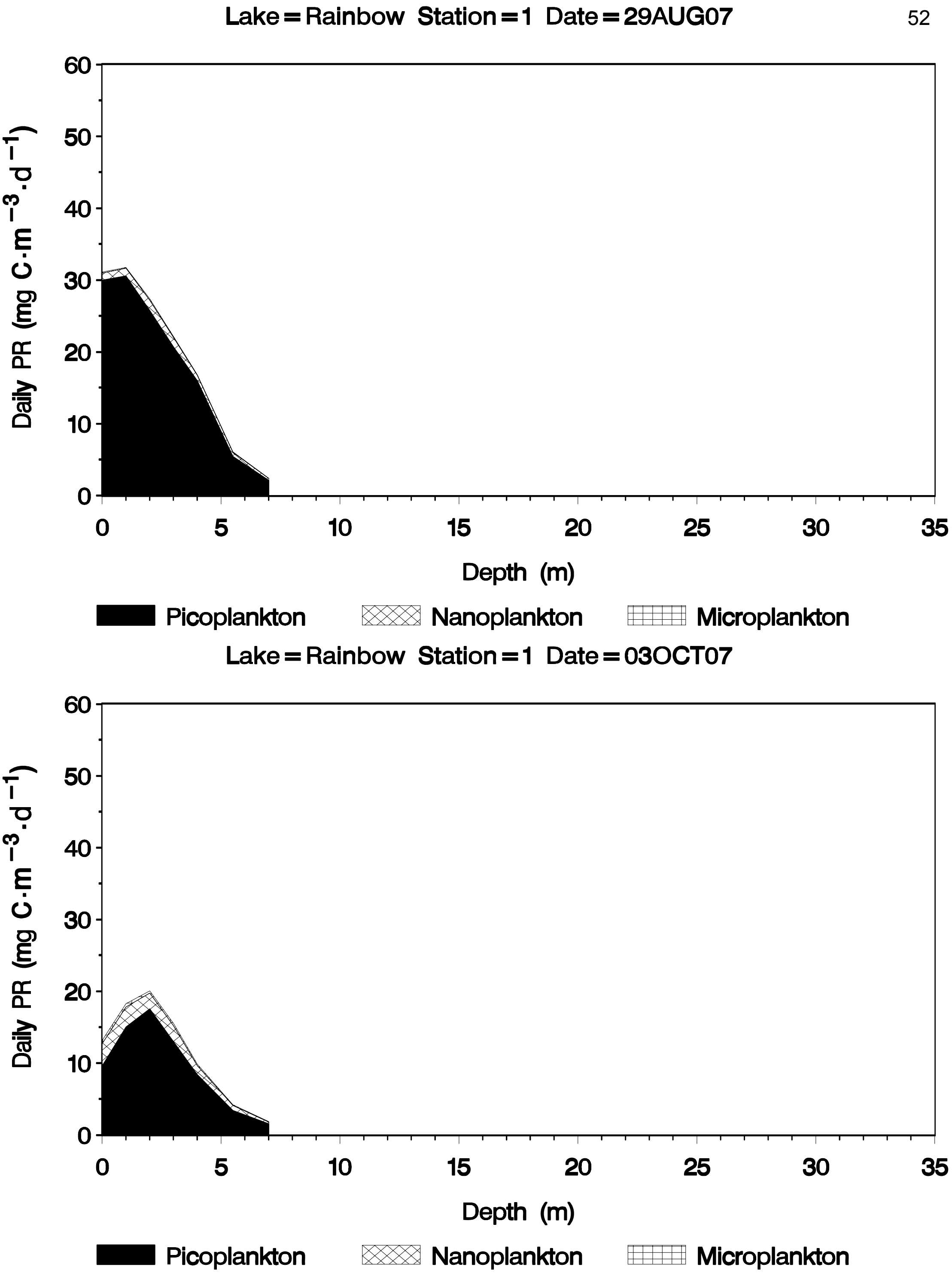
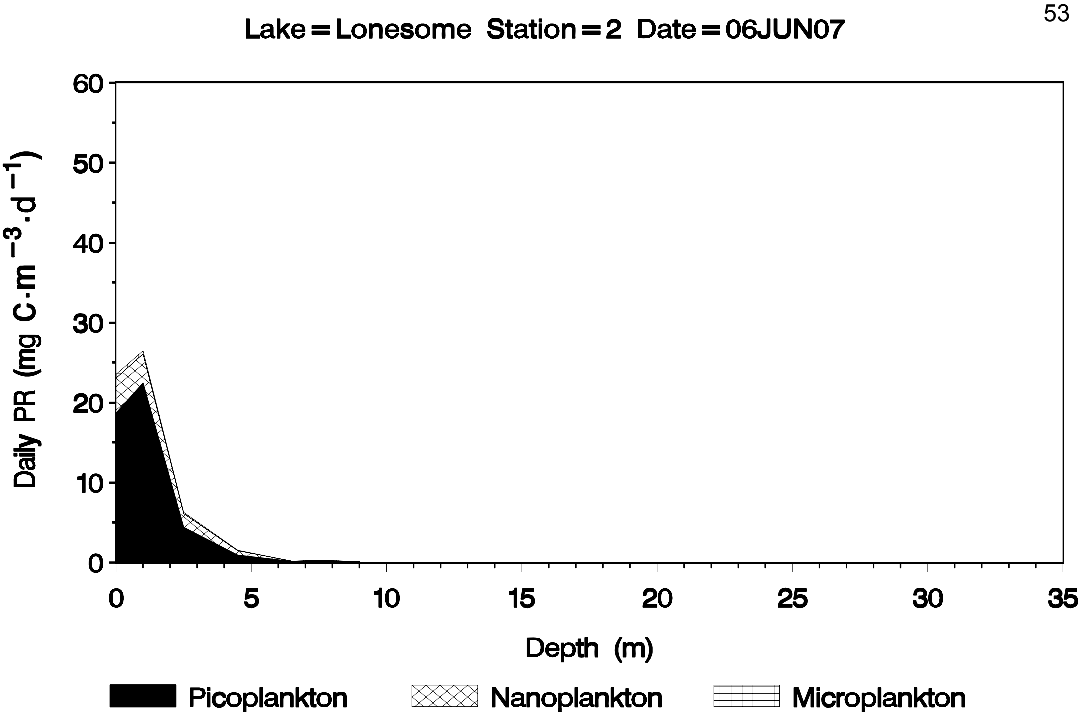


Fig. 22. Vertical profiles of daily photosynthetic rates (mg C·m^{-3}·d^{-1}) of the pico- (<=2 µm), nano- (2-20 µm), and microplankton (>20 µm) size fractions in Rainbow Lake.



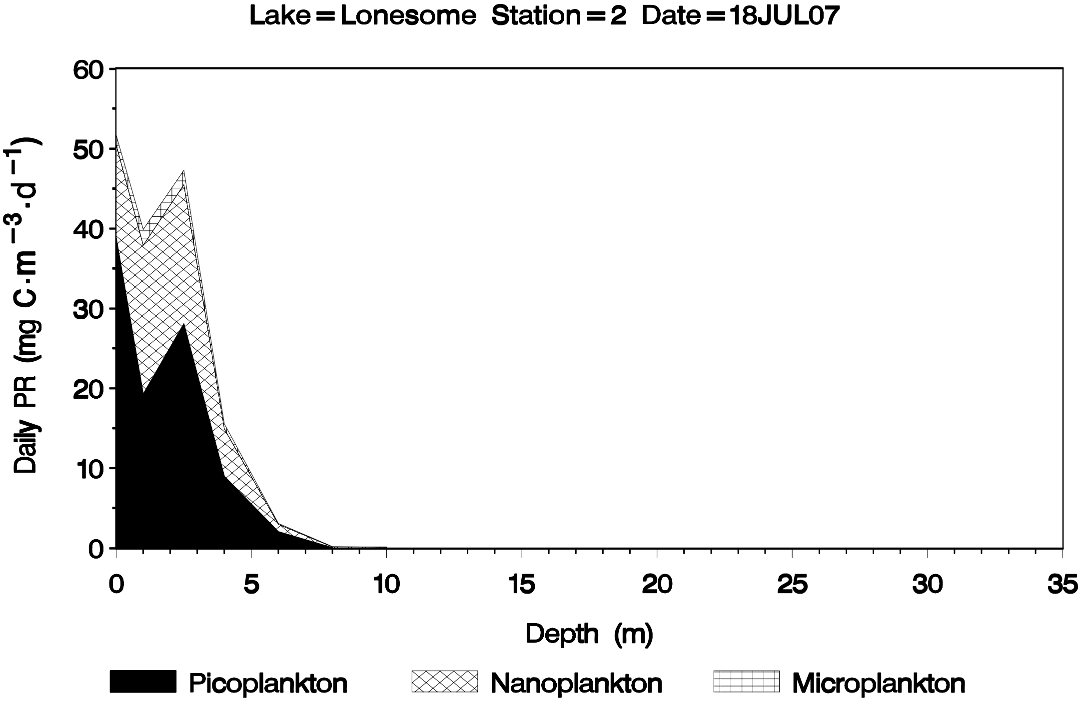
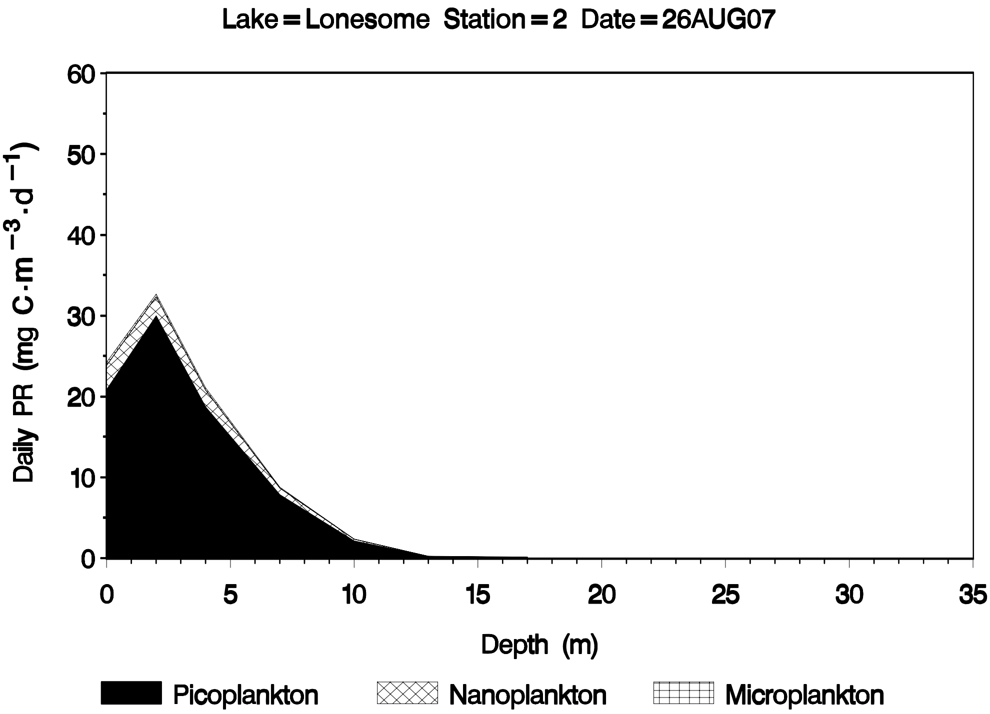
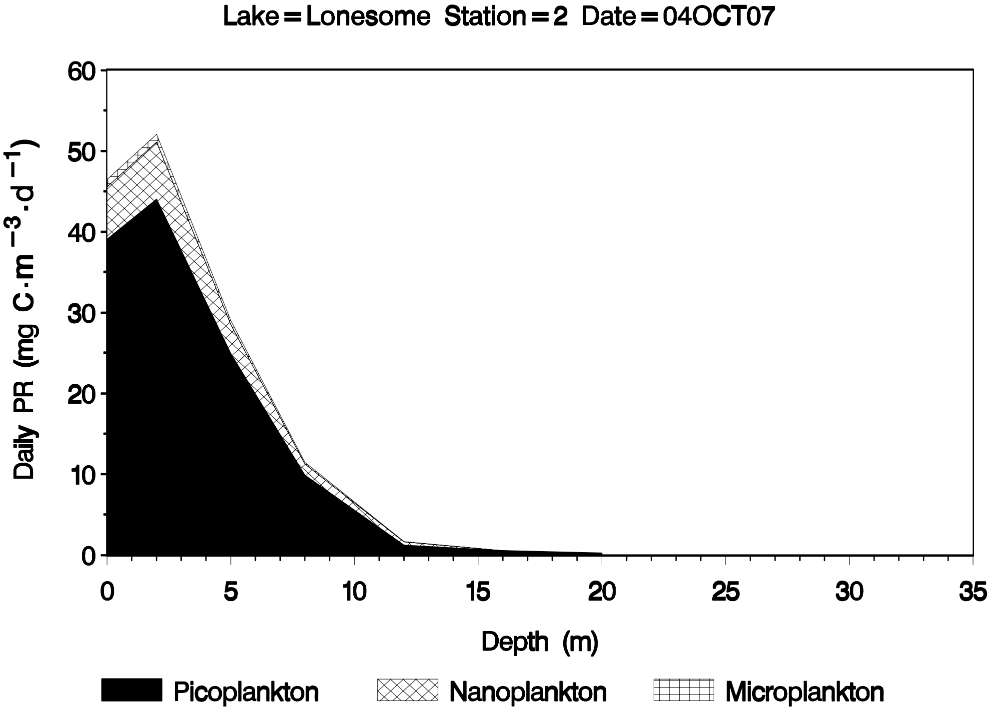


Fig. 23. Vertical profiles of daily photosynthetic rates (mg C·m^{-3}·d^{-1}) of the pico- (<=2 µm), nano- (2-20 µm), and microplankton (>20 µm) size fractions in Lonesome Lake.



Lake=Lonesome Station=2 Date=26AUG07



Lake=Lonesome Station=2 Date=04OCT07

Fig. 24. Vertical profiles of daily photosynthetic rates (mg C·m^{-3}·d^{-1}) of the pico- (<=2 µm), nano- (2-20 µm), and microplankton (>20 µm) size fractions in Lonesome Lake.

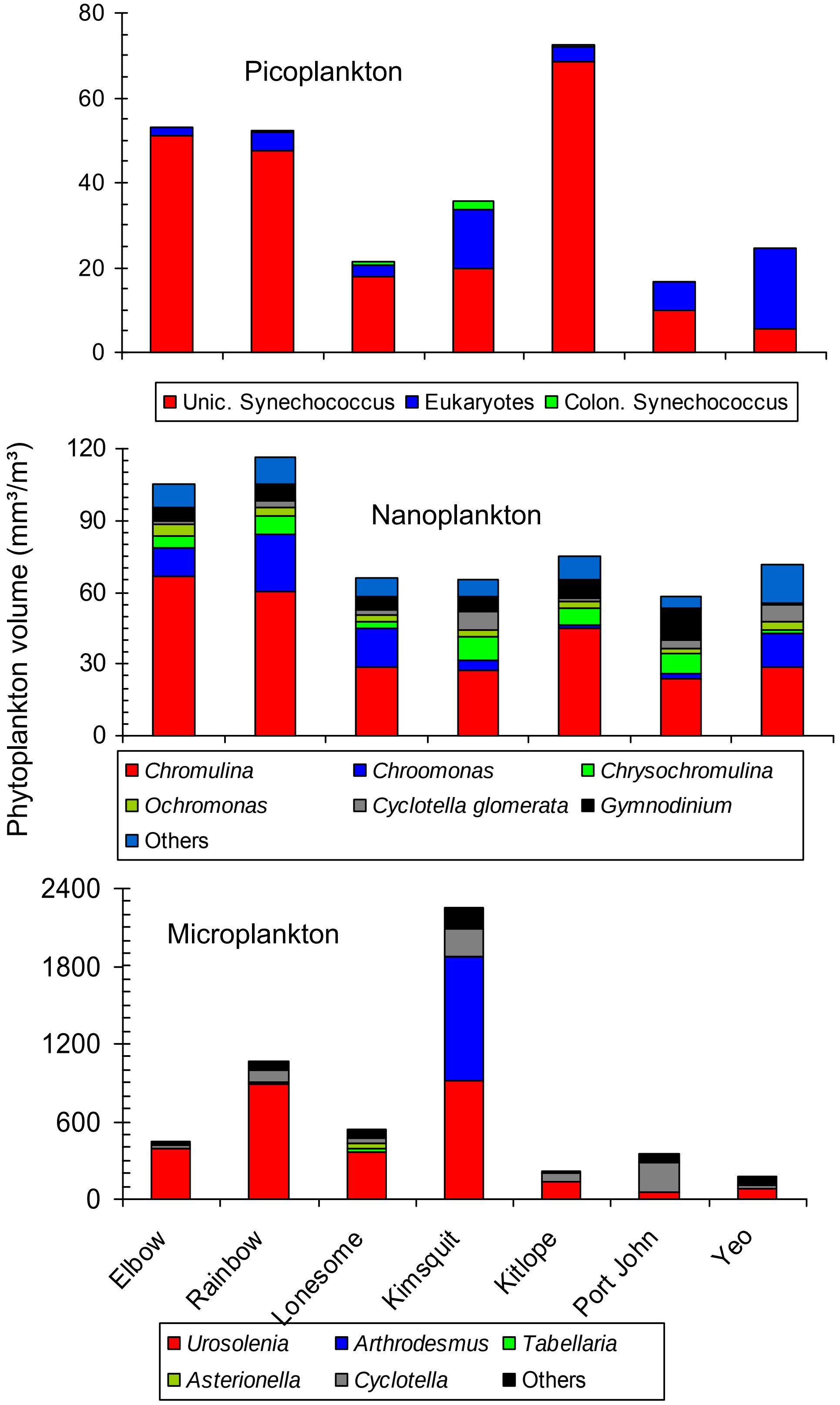


Fig. 25. Average volume (mm³/m³) of the pico- (<2 µm), nano(2-20 µm), and microplankton (>20 µm) size fractions in the lakes sampled in 2007.

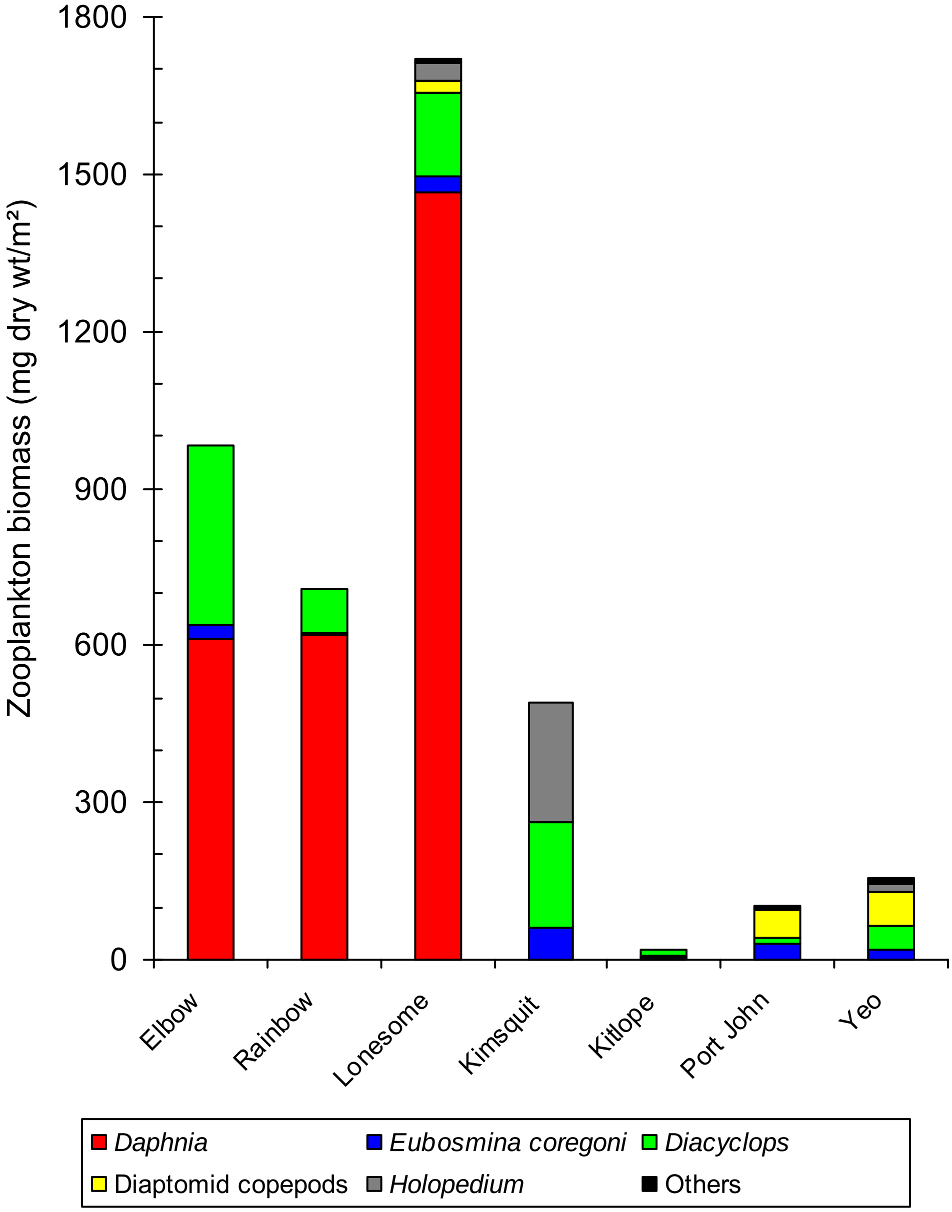
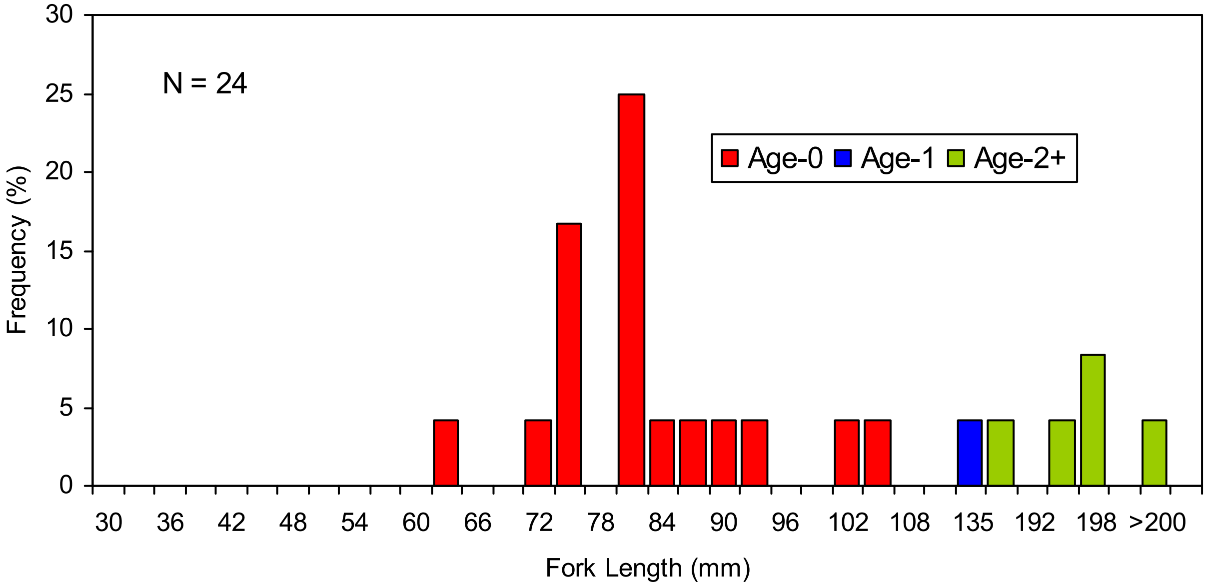


Fig. 26. Average biomass (mg dry wt/m²) of the major zooplankton genera in the lakes sampled in 2007.

A. Elbow Lake



B. Lonesome Lake

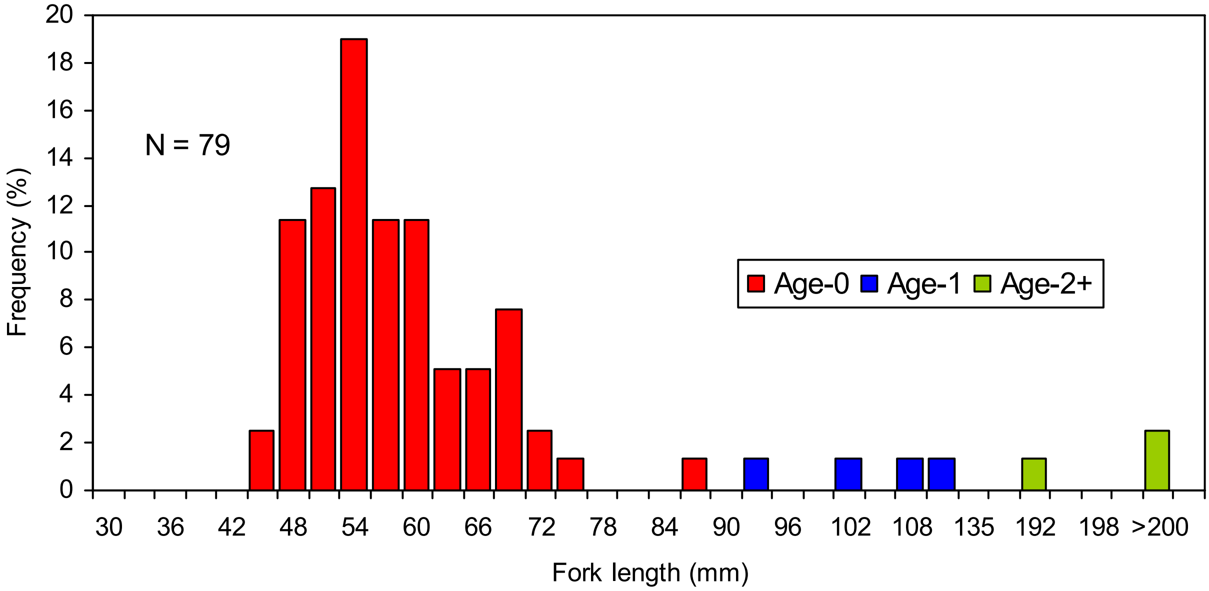
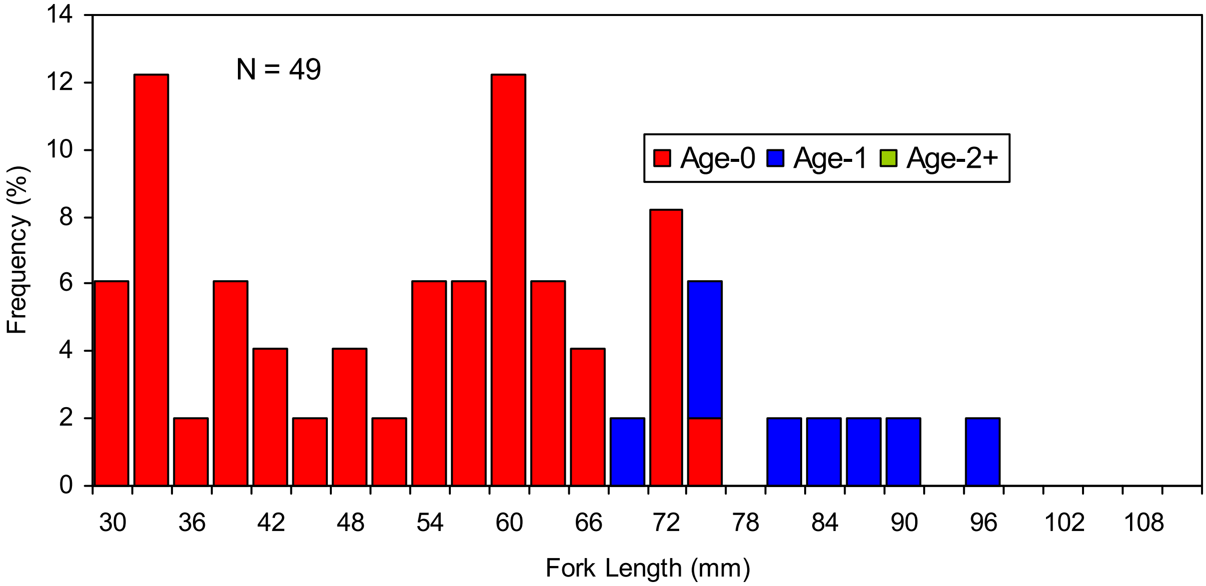


Fig. 27. Length frequency in 3 mm bins of all *O. nerka* caught in Elbow and Lonesome lakes. Ages are based on the determination of scale annuli by the PBS Scale Lab.

A. Kimsquit Lake



B. Kitlope Lake

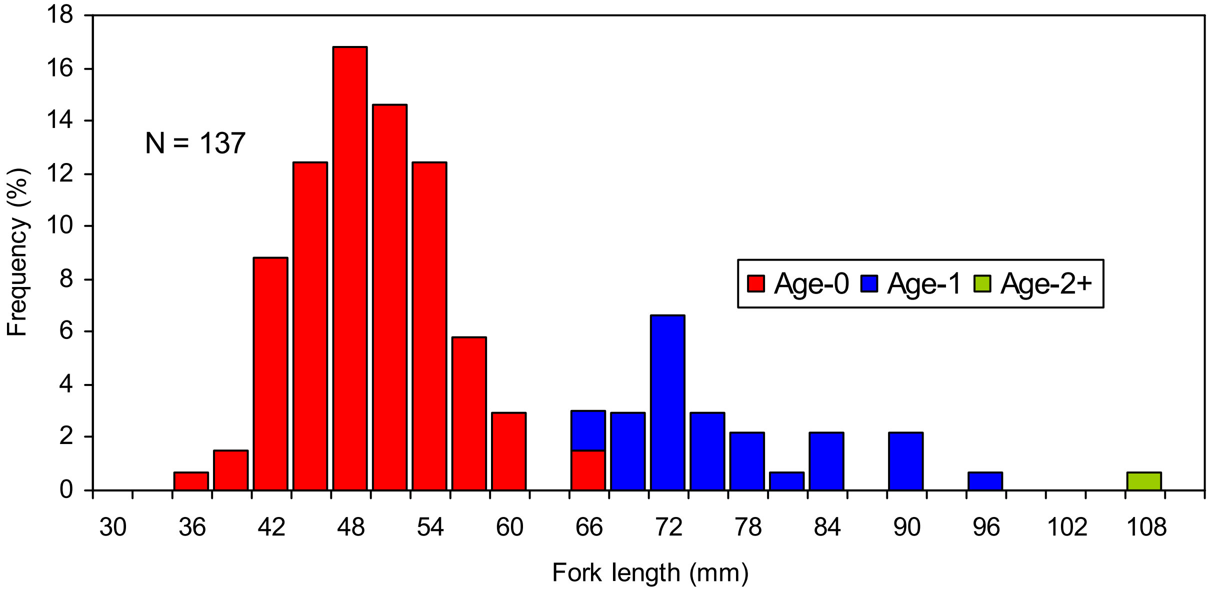
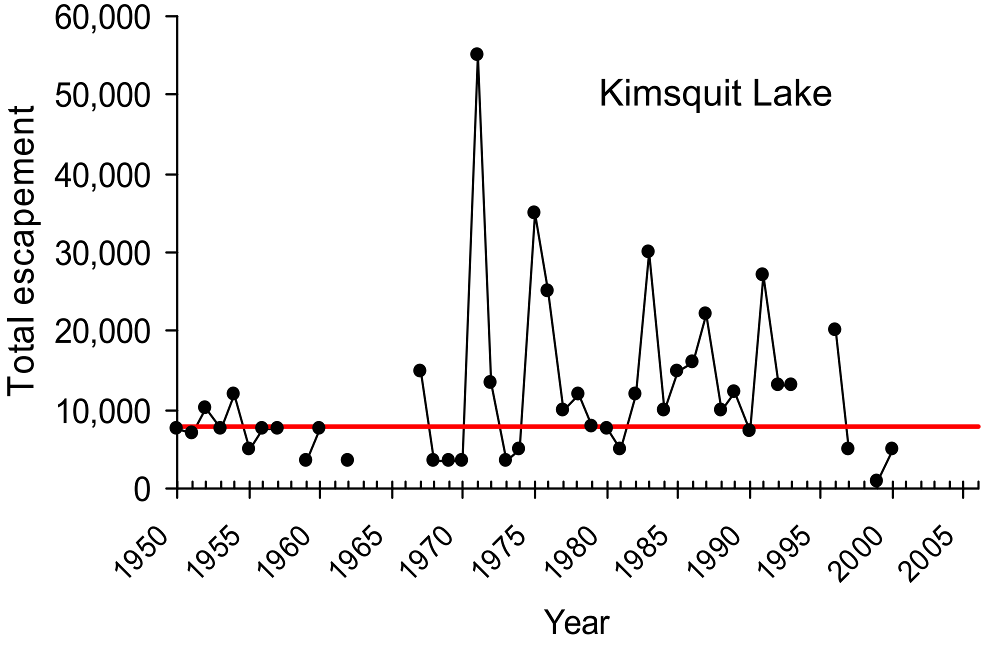


Fig. 28. Length frequency in 3 mm bins of all fish caught Kimsquit and Kitlope lakes. Ages are based on the determination of scale annuli by the PBS Scale Lab.



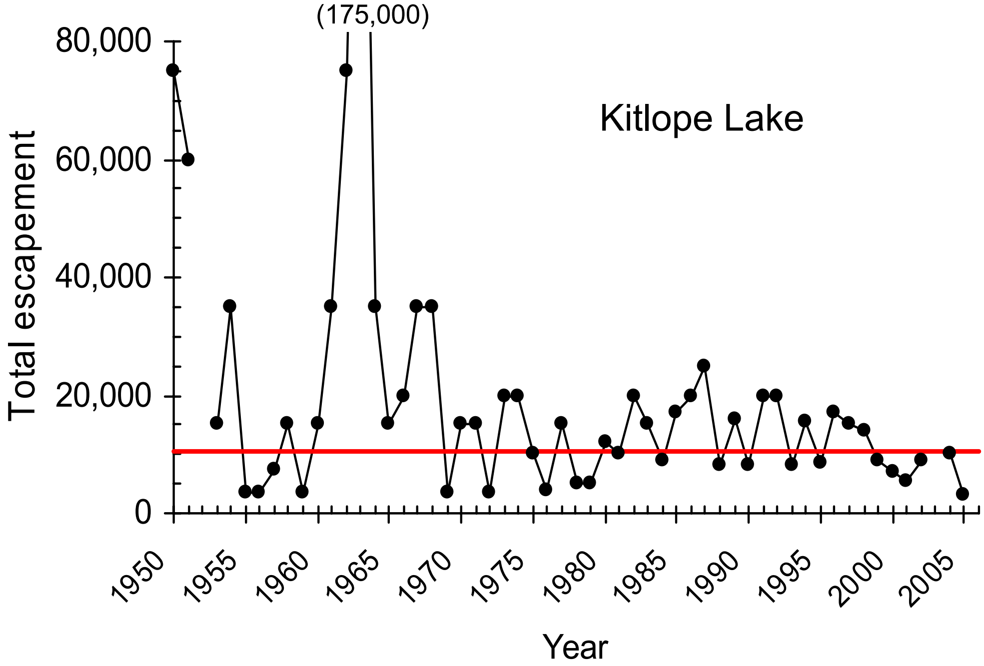
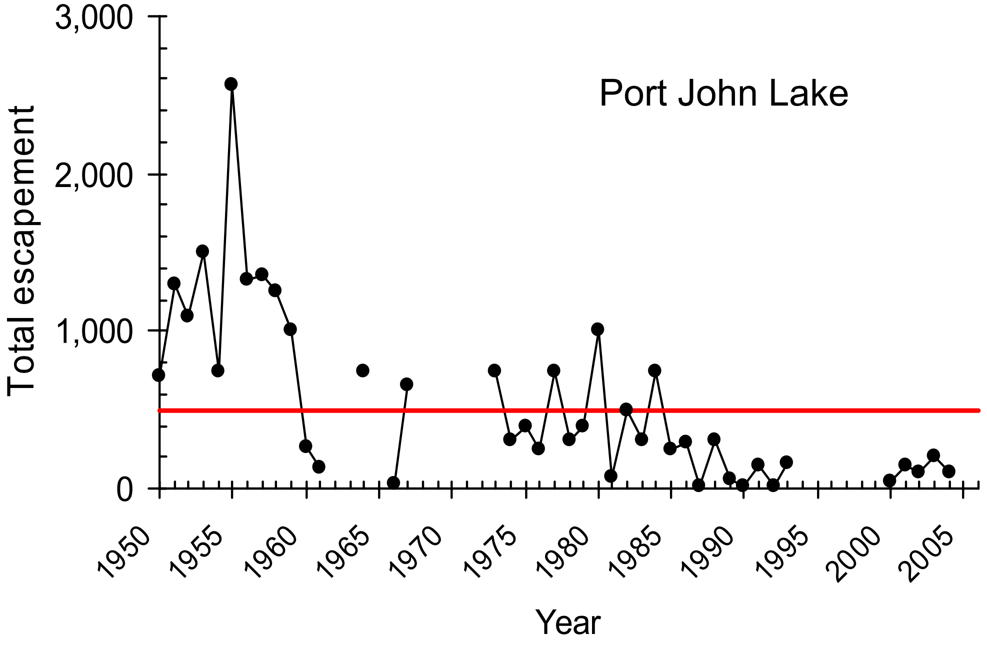


Fig. 29. Total sockeye escapements to Kimsquit and Kitlope lakes from 1950 to 2006. Horizontal red lines are the PR model predictions of optimum escapement (S_{max}).



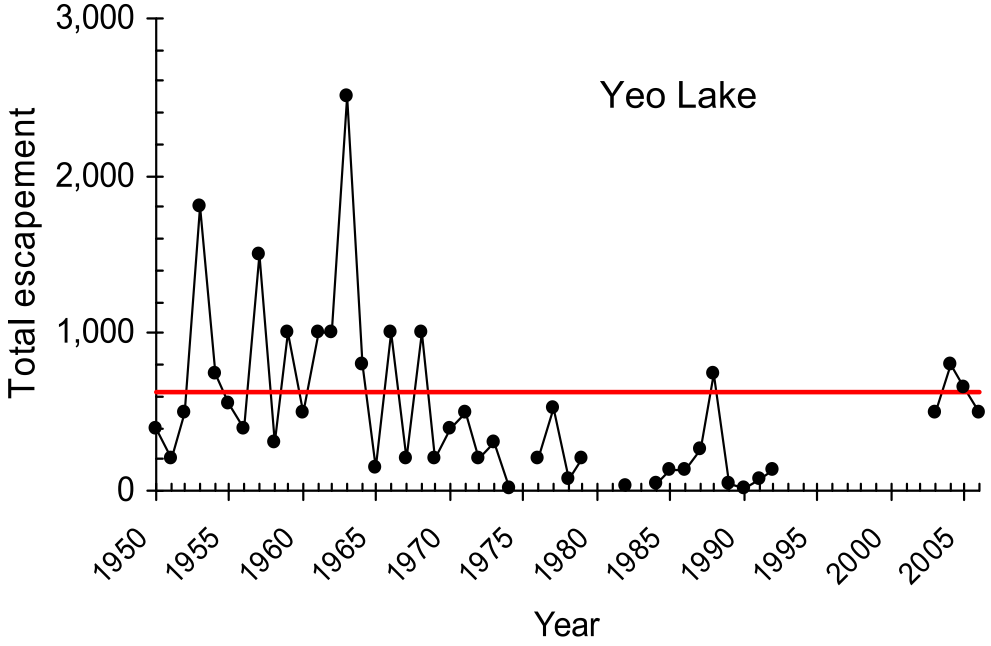


Fig. 30. Total sockeye escapements to Port John and Yeo lakes from 1950 to 2006. Horizontal red lines are the PR model predictions of optimum escapement (S_{max}).

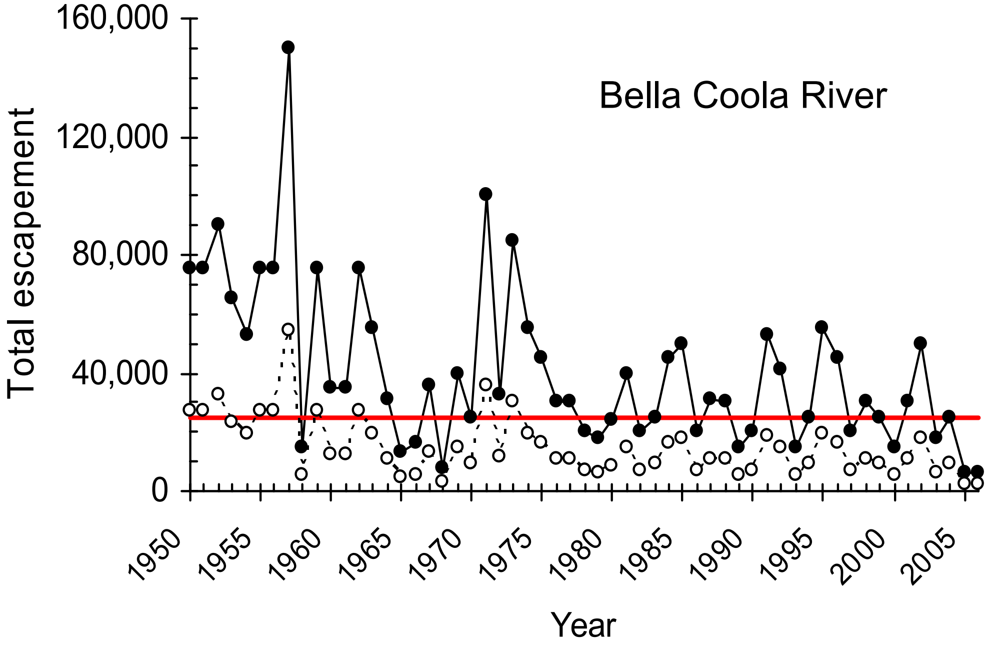
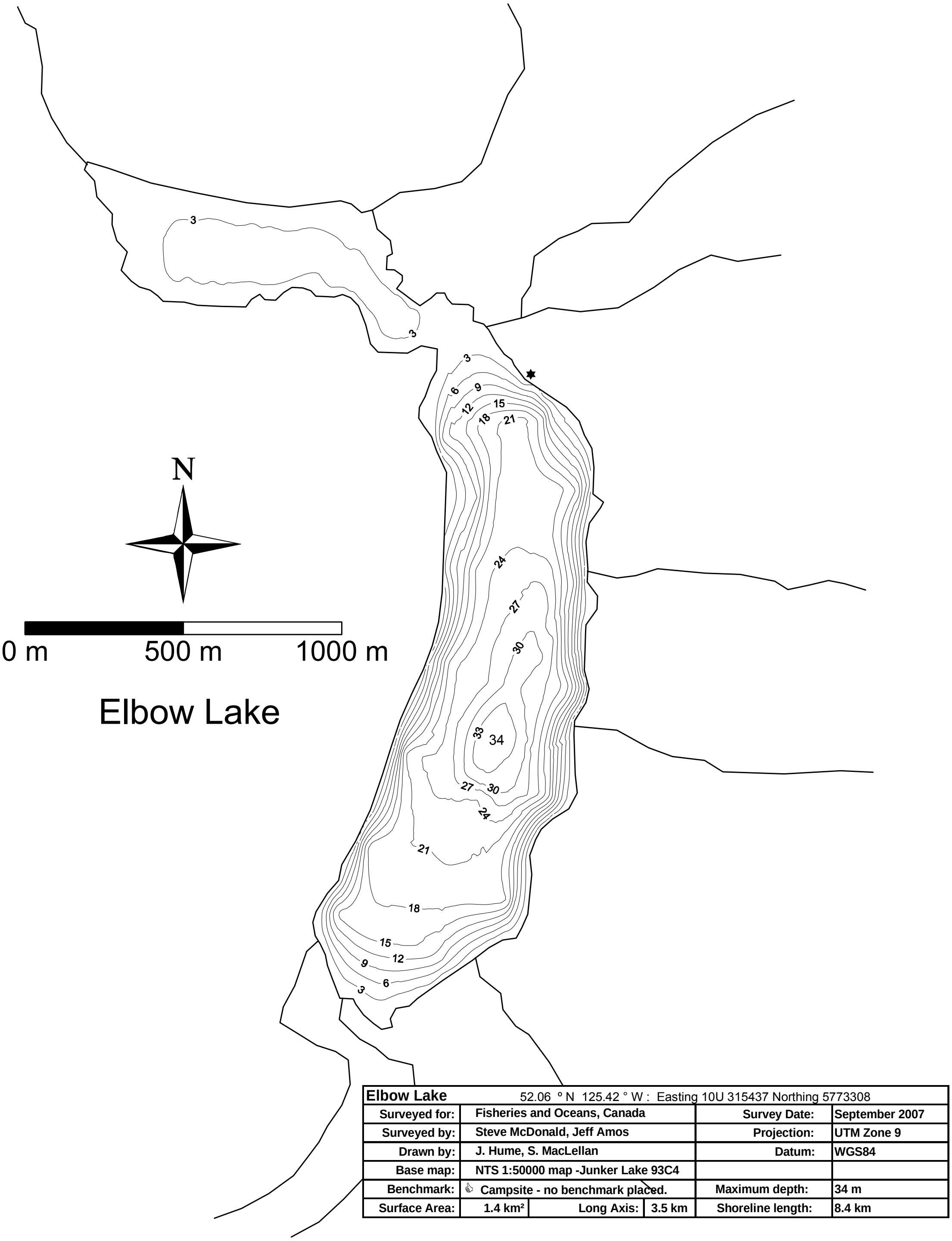


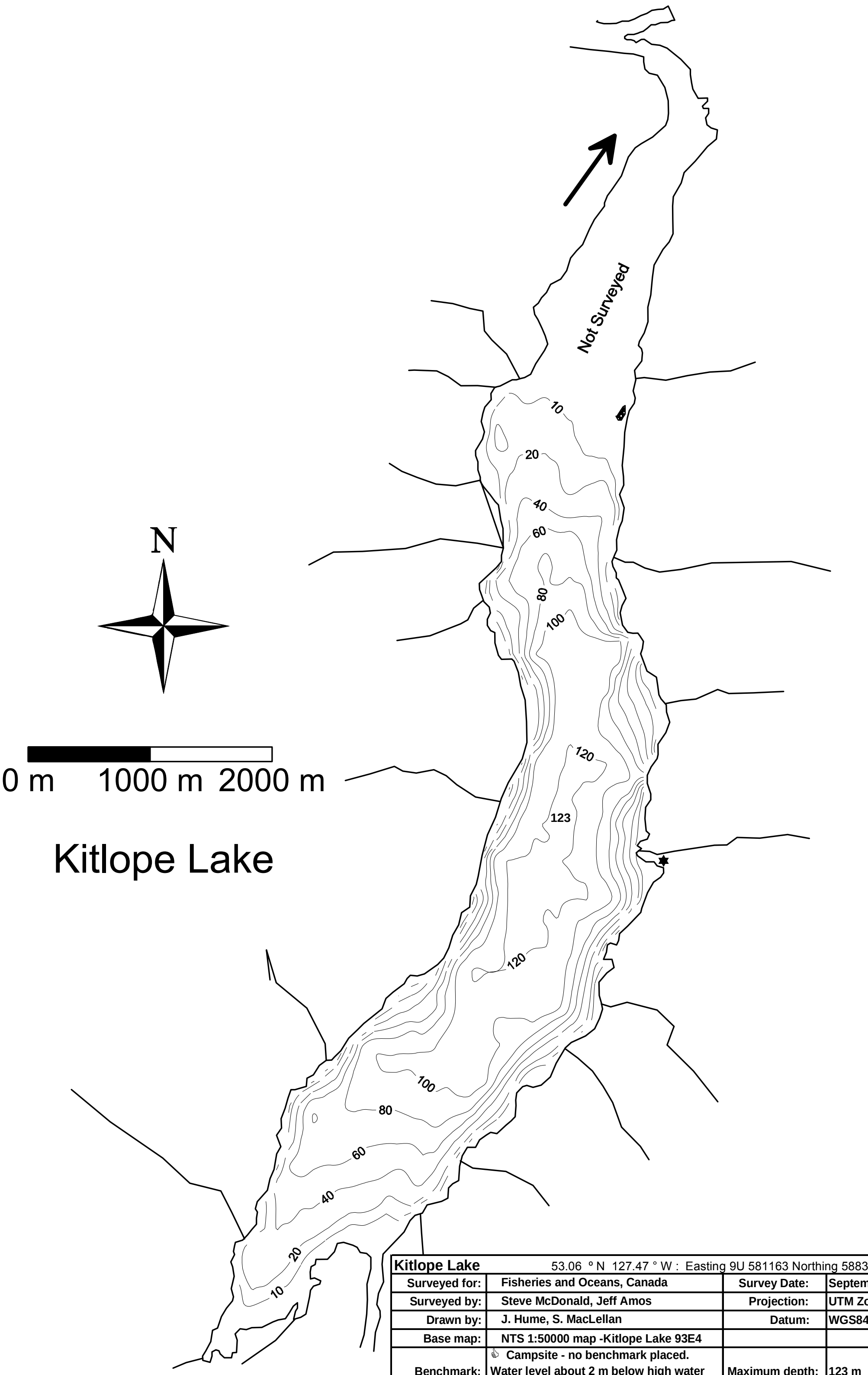
Fig. 31. Total sockeye escapements (solid line) to the Bella Coola River from 1950 to 2006. The dotted line is 36% of the total, which is the estimated proportion of lake-type sockeye (C. Wood, DFO, Pacific Biological Station, Nanaimo, B.C., personal communication). Horizontal red line is the PR model prediction of optimum escapement to all Atnarko lakes (S_{max}).

Appendix figures



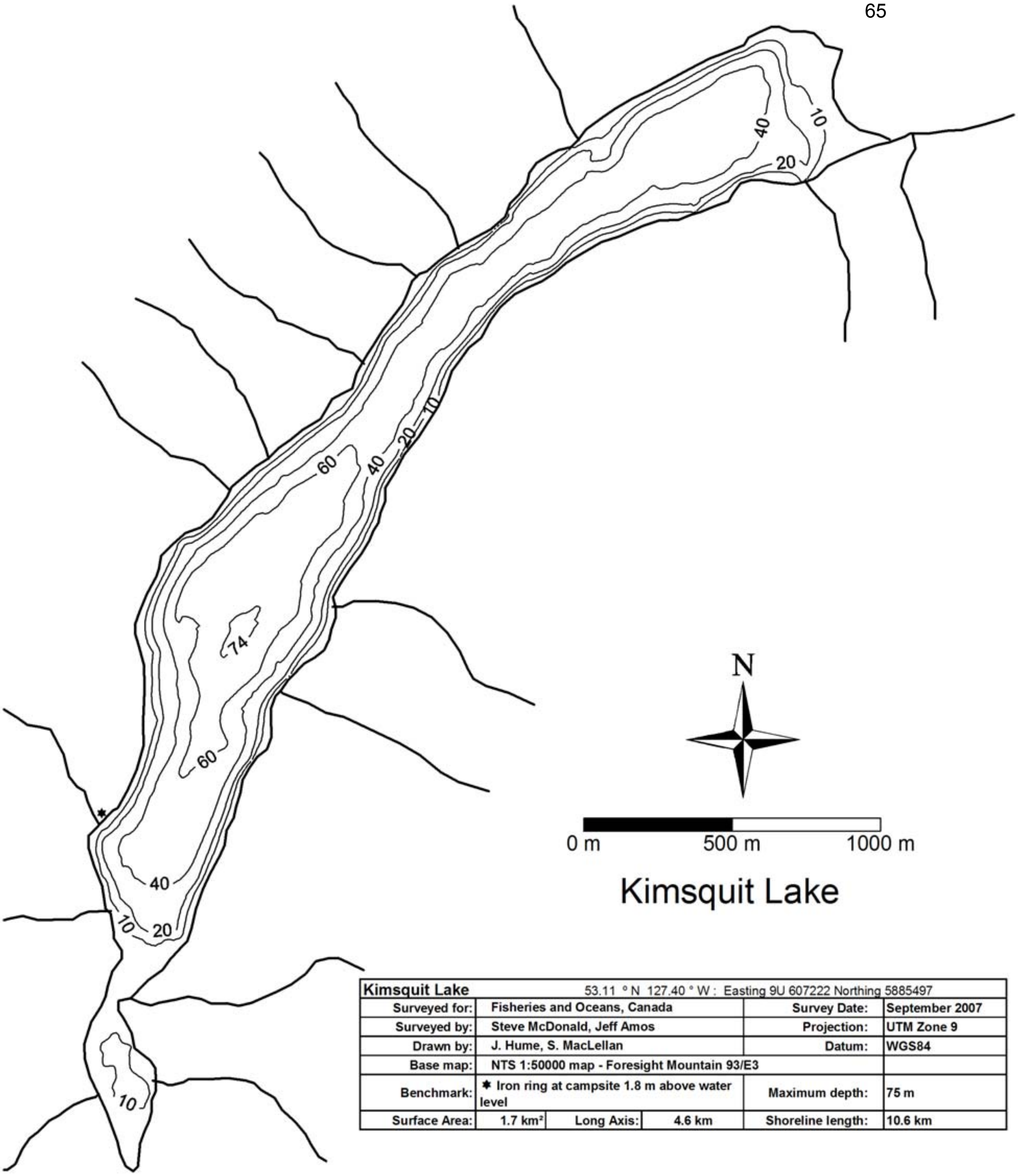
Elbow Lake	52.06 ° N 125.42 ° W : Easting 10U 315437 Northing 5773308				
Surveyed for:	**Fisheries and Oceans, Canada**			**Survey Date:**	**September 2007**
Surveyed by:	**Steve McDonald, Jeff Amos**			**Projection:**	**UTM Zone 9**
Drawn by:	**J. Hume, S. MacLellan**			**Datum:**	**WGS84**
Base map:	**NTS 1:50000 map -Junker Lake 93C4**				
Benchmark:	**Campsite - no benchmark placed.**			**Maximum depth:**	**34 m**
Surface Area:	**1.4 km²**	**Long Axis:**	**3.5 km**	**Shoreline length:**	**8.4 km**

Appendix Fig. 1. New bathymetric chart of Elbow Lake from the 2007 hydroacoustic data.



Kitlope Lake	53.06 ° N 127.47 ° W : Easting 9U 581163 Northing 5883812				
Surveyed for:	**Fisheries and Oceans, Canada**			**Survey Date:**	**September 2007**
Surveyed by:	**Steve McDonald, Jeff Amos**			**Projection:**	**UTM Zone 9**
Drawn by:	**J. Hume, S. MacLellan**			**Datum:**	**WGS84**
Base map:	**NTS 1:50000 map -Kitlope Lake 93E4**				
Benchmark:	**👍 Campsite - no benchmark placed. Water level about 2 m below high water mark on rocks**			**Maximum depth:**	**123 m**
Surface Area:	**11.7 km^2**	**Long Axis:**	**11.7 km**	**Shoreline length:**	**28.4 km**

Appendix Fig. 2. New bathymetric chart of Kitlope Lake from the 2007 hydroacoustic data.



Kimsquit Lake	53.11 ° N 127.40 ° W : Easting 9U 607222 Northing 5885497				
Surveyed for:	Fisheries and Oceans, Canada			Survey Date:	September 2007
Surveyed by:	Steve McDonald, Jeff Amos			Projection:	UTM Zone 9
Drawn by:	J. Hume, S. MacLellan			Datum:	WGS84
Base map:	NTS 1:50000 map - Foresight Mountain 93/E3				
Benchmark:	✱ Iron ring at campsite 1.8 m above water level			Maximum depth:	75 m
Surface Area:	1.7 km²	Long Axis:	4.6 km	Shoreline length:	10.6 km

Appendix Fig. 3. New bathymetric chart of Kimsquit Lake from the 2007 hydroacoustic data.