Limnological and limnetic fish surveys of North Coast Area lakes in 2005

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This report summarizes findings from our 2005 surveys of 7 North Coast Area lakes (Ecstall, Johnston, Kitkiata, Hartley Bay Lower, Ian, Lakelse, and Kitsumkalum Lakes) (Table 1, Fig. 1-8). Limnological surveys were carried out on 5 of the lakes (Lakelse and Kitsumkalum lakes had been previously surveyed) in order to obtain a first estimate of the lakes' trophic status, juvenile sockeye rearing capacity, and factors limiting their productivity. Objectives of the fish ecology surveys (carried out on all but Ian Lake) were to obtain population estimates, determine the species composition of the lakes' limnetic fish communities, and obtain estimates of juvenile sockeye size and diet.

The 7 lakes surveyed in 2005 were located in DFO management areas 1, 5, and 6. All four Skeena system lakes (area 5) were in the lower portion of the river (Table 1, Fig. 1). Only Ian Lake was in area 1 and two lakes (Hartley Bay and Kitkiata) were in area 5. All lakes are located in the coastal western hemlock biogeoclimatic zone, which is noted for high annual precipitation, cool summers, and relatively mild winters. The 5 lakes surveyed for the first time in 2005 were near the coast, with relatively low elevations ranging from 19-39 m (Table 1). Kitsumkalum and Lakelse lakes are somewhat higher, with elevations of 148 and 73 m, respectively. Four of the lakes were relatively small (surface areas ranged from 0.9-2.7 km^2). The remaining 3 lakes (Ian, Kitsumkalum, and Lakelse) were substantially larger, with surface areas ranging from 13.0-18.8 km^2. The acoustic surveys provided data for construction of the first bathymetric maps of Hartley Bay and Kitkiata lakes (Fig. 3, 6). Mean depths ranged from only 3.5 m (Hartley Bay) to 81 m in Kitsumkalum Lake. Maximum depths ranged from 9.5 to 165 m (Table 1). Flushing rate from most of the lakes has not been determined, but given their mean depths, geographic location, and climate, it is expected that all flush rapidly. Several of the lakes are most likely monomictic, while on others partial or complete ice cover probably occurs in most winters.

Methods used in the limnological surveys were similar to those used in studies of numerous other B.C. sockeye lakes (Shortreed et al. 2001). The lakes were sampled once in late August of 2005 at one or two (Ian Lake only) locations (Fig. 2-6). Standard methods (Hume et al. 2003) were also used for the fish ecology surveys, which took place in late August and September. Hydroacoustic estimates of fish population were obtained using a 200-kHz Biosonics DT6000 split beam sounder. Fish were sampled using a 2x2-m trawl. We also deployed small mesh “Swedish’ gillnets (12.5-,16-, 20-, and 25-mm stretched mesh) in all lakes.

LIMNOLOGY

Limnological data reported here are from the August, 2005 surveys of Ecstall, Hartley Bay, Ian, Johnston, and Kitkiata lakes. Except for Ian Lake, these were the first detailed limnological surveys of these lakes. Limnological sampling took place on Ian Lake from 1979-1984, although on only one date in 1984 are data available when the lake was not being fertilized with inorganic nutrients. In addition, photosynthetic rates (PR) were not determined in the earlier studies of Ian Lake.

Physical Data

Johnston Lake was glacially stained and the remaining 4 lakes exhibited varying degrees of dystrophy (organically stained). As a result, euphotic zone depths (EZD) were relatively shallow, ranging from an average of 3.6 m in Ian Lake to 10.7 m in Johnston Lake (Table 2; Fig. 9). Secchi depths (SD) ranged from 3.3 m to 10.1 m (Table 2; Fig. 9). Turbidity was <0.4 NTU in all lakes except Johnston Lake, where it was slightly higher (1.0 NTU).

Surface temperature during the August, 2005 survey was lowest (16.1ºC) in Johnston Lake (Table 2). In the remaining lakes, surface temperatures were quite similar (range:18.5-20.6ºC). The lakes were all thermally stratified at the time of the survey, with Johnston Lake exhibiting the least stable stratification and the deepest (10.7 m) epilimnion (Table 2; Fig. 10-11).

Chemical Data

As with many coastal lakes, conductivities in all five lakes were very low (range: 13-30 µS/cm) (Table 2; Fig. 12-13). Average epilimnetic dissolved oxygen (DO) concentrations were relatively high (8.8-11.9 mg/L) in all lakes (Table 2; Fig. 14-15). Only in two lakes (Ecstall and Hartley Bay) did DO decline with depth, but not to levels deleterious to fish (Brett and Blackburn 1981). All lakes sampled in 2005 were acidic, with a range in pH from 5.7-6.4 (Table 2). This is the norm in dystrophic coastal lakes, as is a low alkalinity (range: 1.27-9.54 mg/L $CaCO_3$) and low TDS (range:11-34 mg/L). The lakes have very little buffering capacity and would be extremely sensitive to any increase in acid precipitation. Increasing human activity in B.C. and the current rapidly expanding use of coal as an energy source in China could both result in increased acid precipitation, which would have deleterious effects on many coastal B.C. lakes.

Concentrations of dissolved silica were low (range: 0.01-0.28 mg Si/L) in all lakes, but similar to those found in many other coastal B.C. lakes. Total phosphorus (TP) concentrations ranged from 2.1-5.5 µg/L, placing them in the low to middle range of oligotrophy (Table 2). Soluble reactive phosphorus (SRP) concentrations were <1 µg/L in all lakes but Ian, where they were slightly higher (1.9 µg/L). Epilimnetic nitrate concentrations were also low (<3 µg N/L) in all lakes except Ian, where they averaged 18 µg N/L (Table 2; Fig. 16-17). Hypolimnetic nitrate concentrations were much higher and more variable, ranging from 16.5 µg N/L in Ecstall Lake to 132 µg N/L in Johnston Lake. The low near-surface nitrate concentrations are commonly seen in the stratified epilimnia of nutrient-limited lakes in summer. The least epilimnetic nitrate depletion occurred in Ian Lake, as did the highest SRP concentrations. This suggests that in Ian Lake, nutrients may not be the primary factor limiting productivity. Ian Lake was strongly dystrophic, resulting in a euphotic zone substantially shallower than the thermocline. The rapid light attenuation may be an important limiting factor in Ian Lake.

Bacteria, Phytoplankton, and Trophic Status

Average bacterioplankton numbers ranged from 1.18-2.33 million/mL (Table 2). Based on the bacteria-based trophic classification of Bird and Kalff (1984), 3 of the lakes (Ecstall, Ian, and Johnston) were oligotrophic, while Hartley Bay and Kitkiata lakes were mesotrophic. However, the relatively high bacteria numbers in Hartley Bay were likely due more to the lake being so shallow rather than to high limnetic productivity. Average chlorophyll (CHL) concentrations were lowest (0.61 µg/L) in Hartley Bay and highest (3.43 µg/L) in Kitkiata Lake. CHL concentrations indicated the lakes were oligotrophic, except for Kitkiata Lake, which was mesotrophic (CHL>3 µg/L) (Forsberg and Ryding 1980). In Ecstall and Ian lakes vertical profiles of chlorophyll concentration were typical of those seen in oligotrophic lakes, with no distinct peaks, and highest values occurring in the upper part of the euphotic zone (Fig. 18-19). Hartley Bay had a distinct CHL peak near the lake bottom (>6 m). Johnston Lake had a distinct CHL peak at the bottom of the euphotic zone (Fig. 18).

Photosynthetic rates (PR) varied substantially among the five lakes, from 66 mg $C \cdot m^{-2} \cdot d^{-1}$ in Ian Lake to 387 mg $C \cdot m^{-2} \cdot d^{-1}$ in Kitkiata Lake (Table 2). All lakes except Johnston Lake had vertical PR profiles typical of lakes with rapid light attenuation (maximum PR at the surface followed by a rapid decline) (Fig. 20-21). In Johnston Lake the water was clearer, resulting in a subsurface (2 m) PR maximum. Daily PR was strongly correlated with both chlorophyll and total phosphorus concentrations in the lakes sampled in 2005 (Fig. 22). Correlations between these variables are commonly found in many groups of lakes, but the relationships are usually less robust.

For the most part, phytoplankton community structure was similar to that seen in many other coastal B.C. lakes. As in most other lakes, picoplankton were numerically the most abundant phytoplankton, ranging from 8.4-62.5 thousands/mL. These numbers are similar to those observed in many other coastal sockeye lakes (Shortreed and Hume 2005). In all lakes surveyed, the cyanobacteria *Synechococcus* was the dominant genus in the picoplankton community. The most common nanoplankton was the ubiquitous flagellate *Chromulina*, which is within the preferred size range for herbivorous zooplankton. Most abundant diatom genera in all lakes were *Cyclotella* spp. and *Rhizosolenia* sp., both of which are common in almost all B.C. sockeye lakes. In Johnston Lake, *Rhizosolenia* numbers were unusually high (14 thousand/mL), which is among the highest number of that genus ever recorded in a B.C. sockeye lake. It comprised approximately 95% of total phytoplankton biomass in Johnston Lake (Fig. 23). This large diatom is not generally eaten by zooplankton, so in Johnston Lake an unusually high proportion of the primary trophic level was not grazeable. Consequently, the lake’s sockeye rearing capacity is no doubt lower than the unadjusted PR model indicates.

The limnological data indicate that Hartley Bay and Ian lakes were highly oligotrophic, due to nutrient limitation and rapid light attenuation. Ecstall and Johnston lakes were also oligotrophic, but were much more productive than Hartley Bay or Ian lakes. Most limnological data indicated that Kitkiata Lake was mesotrophic.

Zooplankton

Both zooplankton biomass and community structure exhibited considerable variability in lakes sampled in 2005. Macrozooplankton biomass was very low (range: 49-71 mg dry wt/m^2) in four of the lakes and much higher (494 mg dry wt/m^2) in Ian Lake (Table 2; Fig. 24). *Daphnia* comprised a substantial proportion (64%) of total zooplankton biomass in Ian Lake only. In the remaining lakes, *Daphnia* biomass ranged from 1.5-8.3% of total biomass. The small cladoceran *Eubosmina coregoni* was common, making up a substantial (range:38-75%) proportion of total biomass in all lakes except Ian, where it made up only 5% of the total (Table 2; Fig. 24). Invertebrates such as mysids (freshwater shrimp), *Leptodora* (a predatory cladoceran), and *Chaoborus* larvae (a midge) are effective planktivores and can compete directly with juvenile sockeye. The presence of any of these in a sockeye nursery lake may reduce its rearing capacity for juvenile sockeye. Neither mysids nor *Leptodora* were found in any of the lakes surveyed in 2005. Mysids are present in Lakelse Lake but they were not sampled in 2005. Relatively high numbers (506/m^2 or 72/m^3) of *Chaoborus* were found in Hartley Bay Lake, but not in any of the other lakes. A length-frequency plot of these *Chaoborus* had a bimodal distribution, indicating there were two generations present in the lake at the time of the survey (Fig. 25).

Limnetic fish diet

It should be noted that zooplankton community structure and consequently sockeye diet may exhibit substantial seasonal variability. Sockeye stomach samples collected in 2005 are representative of that lake for a specific date but are not likely to be representative of the whole growing season. Further, considerable variation in stomach contents may occur even between individual fish collected at the same time.

Contents of age-0 sockeye stomachs were collected from 5 lakes in 2005. Stomach fullness ranged from 8% (Kitkiata Lake) to 40% (Lakelse Lake) (Table 3). Only in Lakelse Lake was *Daphnia*, the preferred prey item of juvenile sockeye, a major prey item. *Neomysis* was found in the stomachs of some Lakelse sockeye in 2005, confirming what was suggested by stable isotope data collected in 2003 (Shortreed and Hume 2004), which was that *Neomysis* in Lakelse Lake is both a competitor and a food resource. In the four other lakes, dominant zooplankton prey items were less favourable genera such as the small cladoceran *Eubosmina* (Kitkiata Lake) and diaptomid or cyclopoid copepods (Ecstall, Johnston, and Kitsumkalum lakes). Insects were important prey items in Ecstall, Kitkiata, and Kitsumkalum lakes. Stomach data were not collected in Ian Lake, but given the high *Daphnia* biomass, there is little doubt it would be the dominant prey item.

Three-spine sticklebacks were abundant in Ecstall, Hartley Bay, and Kitkiata lakes. In all three lakes, insects were the dominant items in their stomachs (chironomids in Ecstall Lake, *Chaoborus* in Hartley Bay Lake, and adult insects in Kitkiata Lake).

Fish species composition and size

Only 2 fish species (age-0 *O. nerka* and three-spine stickleback) were commonly captured in the limnetic zone of the four coastal lakes sampled in 2005. Age-0 *O. nerka* dominated in Johnston and Kitkiata lakes, were a minor component (8%) in Ecstall Lake, and were not captured in Hartley Bay Lake (Table 4). Trawl catches from both Ecstall and Hartley Bay lakes were predominantly three-spine stickleback. In Hartley Bay Lake smaller numbers of prickly sculpins were also caught. Trawl catches from Kitsumkalum and Lakelse lakes were predominantly age-0 sockeye, with only one prickly sculpin caught in Kitsumkalum Lake and one river lamprey in Lakelse Lake.

The 2x2-m trawl used in this survey is reported as being increasingly biased against fry >40 mm in length (Paul Rankin, DFO, and Don McQueen, limnologist, personal communications). Thus, the mean size of a trawl catch may be lower than the true population mean size. McQueen's revision of Rankin's' original correction factor was used here to estimate the population mean size (Table 4). We also assumed the same bias would apply to three-spine stickleback although it has not been tested for this species.

After correction for trawl bias, age-0 sockeye weights ranged from 0.5 g in Johnston Lake to 4.4 g in Lakelse Lake. No yearling sockeye fry were captured in any of the lakes, so it must be concluded that in these lakes virtually all sockeye emigrate as age-1 smolts. If, as Koenings et al (1993) suggest, a threshold size of 2.0 g is needed for smolting, sockeye fry in the coastal lakes must grow substantially between late summer and the following spring. Smolt sampling is needed to test this hypothesis.

Fish abundance

Fish distribution, density, and abundance were estimated using echo integration techniques on Ecstall, Johnston, Kitkiata, Kitsumkalum, and Lakelse lakes. There were high densities of the midge larvae, *Chaoborus,* in Hartley Bay Lake. The acoustic target strength (TS) of *Chaoborus* can be very similar to that of age-0 sockeye, making population estimates using standard techniques difficult and often impossible. However, no sockeye fry were captured with either the trawl or the gillnets in this lake, indicating that densities were very low. Mysids were abundant in Lakelse Lake but, unlike *Chaoborus*, they did not present a acoustic estimation problem as their target strength was well below that of age-0 sockeye.

There was a wide variety of age-0 abundances and densities found in the study lakes this year (Table 5). At 6,000/ha, Johnston Lake had an exceptionally high density of age-0 sockeye. We have observed similar densities only in high escapement years in major producers such as Shuswap and Quesnel lakes. Kitkiata Lake had a moderately high age-0 sockeye density (2,300/ha), while Ecstall Lake had a very low density of 71/ha. No estimate was made for Hartley Bay Lake but the lack of obvious fish targets and our failure to capture any age-0 sockeye indicates their density was very low.

Three-spine stickleback were the most common species other than *O. nerka* in the study lakes. They were abundant (>1,500/ha) in Ecstall and Kitkiata lakes and moderately abundant (240/ha) in Johnston Lake. Their population was not acoustically determined in Hartley Bay Lake but they were the predominant species caught in the trawl (Table 4). Based on trawl catch/unit effort and the stickleback density determined for Ecstall Lake, stickleback density in Hartley Bay Lake was approximately 950/ha.

Productive capacity

The sockeye production capacity of the lakes was estimated using the photosynthetic rate (PR) model (Hume et al. 1996; Shortreed et al. 2000), which is now being used to estimate stock status of North Coast Area lakes (Cox-Rogers et al. 2003). The PR 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 C (PR_{total}) produced in a growing season. In shallow lakes, PR_{mean} must be adjusted for bathymetry. Of lakes sampled in 2005, Hartley Bay Lake required the bathymetric adjustment, resulting in a reduction in PR_{mean} from 68.7 to 50.0 mg $C \cdot m^{-2} \cdot d^{-1}$ (Table 3). When data are collected on only one occasion in late summer (all lakes in 2005), 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. 2003).

PR_{total} available to sockeye was calculated by subtracting the biomass of sockeye competitors (planktivorous fish and invertebrates) from the total predicted smolt biomass (Table 6). Biomass of other planktivorous fish species was estimated using their density and weights corrected for sample bias using the Rankin/McQueen correction factor discussed above. Substantial numbers of invertebrate competitors were found in Hartley Bay (*Chaoborus*) and Lakelse lakes (*Neomysis*). We sampled *Chaoborus* quantitatively during the survey of Hartley Bay Lake and estimated a density of 506/m^2, which was quite high considering this was based on a 7-m vertical haul. Based on length-weight relationships we have developed for north coast lakes, biomass of *Chaoborus* in Hartley Bay Lake was 82.4 mg dry wt/m^2. Using a dry-to-wet weight conversion factor of 10, total *Chaoborus* wet biomass in Hartley Bay Lake was 38 kg (Table 6). *Neomysis* in Lakelse Lake were not quantitatively sampled in 2005, so we used densities and biomass obtained during a quantitative sampling program in 2003. Because *Neomysis* is both a competitor and a prey item for juvenile sockeye, we arbitrarily assigned only 50% of mysid biomass to the category of non-sockeye competitors.

In lakes sampled in 2005, no yearling fry were captured. Consequently, no adjustments for the proportion and size of age-2 smolts were made (Table 8).

After the various adjustments, predicted optimum escapements (S_{max}) to the lakes sampled in 2005 ranged from 500 to Hartley Bay Lake and 31 thousand to Ian Lake. Expressed as spawner density, this was a range of 5-87 adult spawners/ha of lake surface area. It should be noted that the estimate to Hartley Bay Lake is highly uncertain because of the large but poorly understood biomass of sockeye competitors (stickleback and *Chaoborus*) in the lake. The proportion of available sockeye rearing capacity used in 2005 was low in all lakes surveyed, ranging from 0% in Hartley Bay Lake (no sockeye captured) to 19% in Kitsumkalum Lake.

There are obvious problems with PR model predictions in some of these lakes. For example, the model predicts that only 17% of Johnston Lake's rearing capacity was utilized, despite the fact that it had a very high age-0 sockeye density of 6,000/ha and a very small fry size of 0.5 g. This was a sockeye biomass of 536 kg, while the model predicted a much larger maximum biomass of 3,150 kg (Table 7). There are several possible reasons for this discrepancy. First, the model predicts smolt biomass. The assumption that fry biomass in late summer is equal to subsequent smolt biomass may be invalid, particularly when so much growth must occur between summer and the following spring. Second, in Johnston Lake there was an exceptionally high density of the large diatom *Rhizosolenia* sp. (Fig. 23). This diatom is not readily grazeable by zooplankton and so represents an energy sink. The unusually high number (15,000/mL) of this diatom meant that >95% of phytoplankton biomass was not readily grazeable by zooplankton. While the proportion of total PR produced by this ungrazeable fraction was no doubt lower than this, it would still have been much higher than usually seen in B.C. sockeye lakes. Consequently, the lake's sockeye rearing capacity would be much smaller than total PR would indicate. Techniques are available to estimate PR of this ungrazeable fraction, but this was not done in 2005. Consequently, we arbitrarily assumed that only one-third of Johnston Lake PR could be applied to rearing capacity.

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Table 1. Morphometric data for the 2005 study lakes.

	Lakes surveyed							Depth (m)		
Lake	Limnology	Fish ecology	Latitude	Longitude	Location	Elevation (m)	Surface area (ha)	Mean	Maximum recorded	Water type
Ecstall	√	√	53º44.50'	129º24.05'	Lower Skeena	35	102	7.0	20	Dystrophic
Johnston	√	√	53º52.56'	129º27.24'	Lower Skeena	25	187	47	80	Glacial
Hartley Bay	√	√	53º25.61'	129º17.21'	Douglas Channel	18	93	3.5	9.5	Dystrophic
Kitkiata	√	√	53º43.26'	129º17.09'	Douglas Channel	31	270	26	59	Dystrophic
Ian	√		53º46.00'	132º33.32'	Graham Island	39	1,878	47	165	Dystrophic
Kitsumkalum		√	54º45.79'	129º46.82'	Lower Skeena	148	1,850	81	140	Glacial
Lakelse		√	54º23.23'	128º32.79'	Lower Skeena	73	1,300	8.0	32	Clear

Table 2. Physical, chemical, and biological data collected from the 2005 limnological investigation of North Coast lakes. Chemical and biological data are trophogenic zone means except where otherwise noted.

Variable	Ecstall	Johnston	Hartley Bay	Kitkiata	Ian 1	Ian 2	Ian - whole lake
Sampling date	20-Aug	20-Aug	21-Aug	21-Aug	23-Aug	23-Aug	23-Aug
Secchi depth (m)	10.1	4.2	4.1	4.4	2.9	4.2	3.3
Euphotic zone depth (EZD, m)	9.0	10.7	4.7	6.8	3.4	4.1	3.6
Turbidity (NTU)	0.24	0.96	0.26	0.39	0.23	0.24	0.23
Surface temperature (ºC)	19.2	16.1	19.1	19.3	20.6	18.5	20.0
Epilimnion depth (m)	9.0	10.7	4.8	6.8	8.3	6.7	7.8
Conductivity (µS/cm at 25ºC)	26	20	13	21	30	31	30
Dissolved oxygen (mg/L)	9.3	11.9	8.8	11.3	9.4	9.3	9.4
pH	6.41	6.29	5.67	6.16	6.30	5.76	6.1
Total alkalinity (mg $CaCO_3$/L)	9.54	4.78	1.27	4.44	4.31	4.19	4.27
Total dissolved solids (mg/L)	21	11	13	16	35	32	34
Dissolved inorganic carbon (mg/L)	2.78	2.58	1.99	2.78	2.25	5.30	3.15
Soluble reactive silica (mg Si/L)	0.28	0.11	0.01	0.16	0.07	0.11	0.1
Total phosphorus (µg/L)	3.7	5.1	2.1	5.5	2.5	2.7	2.6
Total dissolved phosphorus (µg/L)	2.0	0.5	0.1	1.2	1.9	1.5	1.8
Soluble reactive phosphorus (µg/L)	1.0	0.5	0.6	0.3	2.1	1.2	1.9
Epilimnetic nitrate (µg N/L)	1.7	1.2	0.4	1.5	17.4	20.5	18.3
Hypolimnetic nitrate (µg N/L)	16.5	131.7	0.9	76.1	41.9	51.0	44.6
Epilimnetic ammonia (µg N/L)		5.5	5.9	5.4	6.2	7.1	6.5
Hypolimnetic ammonia (µg N/L)	18.1	4.8	2.7	7.5	30.6	19.9	27.4
Bacteria (No.x10^6/mL)	1.38	1.18	1.91	2.33	1.61		1.61
Chlorophyll (µg/L)	1.54	2.79	0.61	3.43	1.02	0.69	0.92
Daily PR (mg C·m^{-2}·d^{-1})	190	283	69	387	63	74	66
Picoplankton (thousands/mL)	33.8	15.4	12.9	62.5	8.4		8.4
Nanoplankton (thousands/mL)	1.0	1.3	0.8	1.5	1.4		1.4
Microplankton (thousands/mL)	2.2	14.9	0.4	0.8	0.3		0.3
Total zooplankton biomass (mg dry wt/m^2)	67.4	53.9	85.9	80.7	422.7	664.6	494.1
Macrozooplankton biomass (mg dry wt/m^2)	56.3	49.0	71.0	67.1	422.7	664.5	494.0
Daphnia biomass (mg dry wt/m^2)	1.0	8.3	1.5	4.4	272.2	420.0	315.8
Daphnia (% of total biomass)	1.5%	15.3%	1.7%	5.5%	64.4%	63.2%	64.0%
Eubosmina coregoni biomass (mg dry wt/m^2)	50.6	36.2	32.9	50.9	32.4	11.7	26.3
Cyclopoid copepod biomass (mg dry wt/m^2)	13.9	4.6	1.3	19.7	56.1	196.0	97.4
Diaptomid copepod biomass (mg dry wt/m^2)	0.0	0.0	47.3	0.1	2.4	5.8	3.4
Epischura biomass (mg dry wt/m^2)	0.0	0.0	0.0	0.0	29.5	10.5	23.9
Holopedium biomass (mg dry wt/m^2)	1.3	0.0	0.5	0.0	29.5	20.7	26.9

Table 3. Stomach contents and estimated fullness of fish collected from the study lakes in 2005.

	Stomach contents (% by number)					
Prey item	Ecstall	Hartley Bay	Johnston	Kitkiata	Kitsumkalum	Lakelse
Age-0 O. Nerka						
Alona	5					
Chaoborus larvae					<1	
Chironomid				<1		
Cyclopoid copepod	65		76		2	
Daphnia					1	92
Diacyclops				1		2
Diaptomous					77	
Epischura						<1
Eubosmina coregoni	15		23	90		1
Insect	15		<1	8	18	
Neomysis						4
% stomach fullness	25		16	8	22	40
Threespine stickleback						
Acari		45				
Alona	<1					
Chaoborus larvae		33				
Chironomid	26	2		<1		
Chydorus				<1		
Cyclopoid copepod	<1					
Diacyclops	4					
Diaptomous		<1				
Eubosmina coregoni	66	12		60		
Insect	3	7		39		

Table 4. Size of fish caught in the study lakes by the various gear types. Measured lengths from trawl caught fish are corrected for size selective bias using: $5.996 \cdot 10^{-6} \cdot L^{2.3}$ for mean lengths >40 mm and then weight is calculated with a lake specific length-weight relationship. (D. McQueen, personal communications)

			Measured Weight (g)[1]					Measured Length (mm)[2]					2x2 trawl bias correction	
Gear	Taxa	Preservative	N	Mean	95% CI	Min	Max	N	Mean	95% CI	Min	Max	Weight (g)	Length (mm)
Ecstall Lake, August 25, 2005														
Trawl (2 x 2m)	Age-0 sockeye	Formalin	4	1.0	0.9	0.55	1.8	4	43	9.8	36	51	1.0	43
	3-spine stickleback	Formalin	49	1.3	0.2	0.12	3.1	49	49	3.1	24	70	1.5	50
Swedish Gillnet	3-spine stickleback	Live						3	52	2.5	51	53		
	Cutthroat trout	Live						1	300		300	300		
	Pink salmon	Live						1	600		600	600		
Johnston Lake, September 01, 2005														
Trawl (2 x 2m)	Age-0 sockeye	Formalin	69	0.5	0.1	0.20	2.1	69	35	1.2	28	55	0.5	35
	Age-0 sockeye	Ethanol	59	0.4	0.1	0.21	1.8	59	39	1.5	29	58	0.4	39
	3-spine stickleback	Formalin	5	1.6	1.2	0.87	2.9	5	53	11.4	44	65	2.0	55
Swedish Gillnet	3-spine stickleback	Ethanol	2	1.8	1.8	1.61	1.9	2	58	6.4	58	59		
	Adult/Jack sockeye	Live						1	380		380	380		
Hartley Bay Lake, August 30, 2005														
Trawl (2 x 2m)	3-spine stickleback	Formalin	29	1.3	0.4	0.03	3.1	29	44	5.8	15	65	1.0	44
	Prickly sculpin	Formalin	3	0.1	0.1	0.11	0.2	3	24	3.8	22	25		
Swedish Gillnet	3-spine stickleback	Live						2	54	50.8	50	58		
Kitkiata Lake, August 27, 2005														
Trawl (2 x 2m)	Age-0 sockeye	Formalin	71	0.8	0.1	0.15	1.9	71	40	1.5	26	54	0.8	40
	3-spine stickleback	Formalin	47	1.1	0.1	0.48	3.4	47	48	1.4	37	68	1.4	49
Swedish Gillnet	3-spine stickleback	Live						1	11		11	11		
Kitsumkalum Lake, September 04, 2005														
Trawl (2 x 2m)	Age-0 sockeye	Ethanol	42	1.3	0.2	0.38	4.0	42	53	2.8	35	79	2.0	55
Swedish Gillnet	Age-0 sockeye	Ethanol	1	4.4		4.37	4.4	1	72		72	72		
	Prickly sculpin	Ethanol	1	7.7		7.74	7.7	1	86		86	86		
Lakelse Lake, September 05, 2005														
Trawl (2 x 2m)	Age-0 sockeye	Formalin	153	4.0	0.3	0.90	8.0	153	66	1.7	41	84	4.4	70
	Age-0 sockeye	Ethanol	19	2.5	0.9	0.70	6.8	19	60	7.3	42	88	3.2	63
	River lamprey	Formalin	1	0.5		0.47	0.5	1	59		59	59		

[1] No weight were taken for live fish. Weights for fish preserved in ethanol tend to be lower than those for live or formalin preserved fish.

[2] Total length for sculpins and sticklebacks, fork length for all other taxa.

Table 5. Preliminary hydroacoustic estimates of whole lake fish abundance and density in six North Coast area sockeye rearing lakes in 2005. Estimates are based on echo integration or single target hydroacoustic techniques, TS analysis and net catches.

Lake	Date	Surface area (ha)	Transects (N)	Density		Abundance		± 95% as prop. of estimate	Comments / Net catch
				N/ha	+/-95%	N	+/-95%		
Age-0 sockeye									
Ecstall	Aug. 25	82	7	71	42	5,798	3,429	59.1%	
Johnston	Sep. 01	187	7	6,084	3,238	1,137,068	605,105	53.2%	
Hartley Bay	Aug. 30			No estimate made					lake very shallow, numerous *Chaoborus* , no sockeye caught in trawl
Kitkiata	Aug. 27	270	8	2,356	324	635,336	87,478	13.8%	
Kitsumkalum	Sep. 04	1,850	7	254	118	470,322	217,726	46.3%	
Lakelse	Sep. 05	1,360	7	288	241	391,401	328,484	83.9%	
Small non-*O. nerka*									
Ecstall	Aug. 25	82	7	1,587	848	129,634	69,267	53.4%	92% three spine stickleback in trawl catch
Johnston	Sep. 01	187	7	240	128	44,915	23,902	53.2%	4% threespine stickleback in trawl catch
Hartley Bay	Aug. 30			No estimate made					91% threespine stickleback & 9% prickly sculpin in trawl catch
Kitkiata	Aug. 27	270	8	1,749	216	471,702	58,154	12.3%	40% three spine stickleback in trawl catch
Kitsumkalum	Sep. 04	1,850	7	0					only sockeye caught
Lakelse	Sep. 05	1,360	7	32	26	43,647	35,346	81.0%	<1% river lamprey in trawl catch
Large fish									
Ecstall	Aug. 25	82	7	0		0			no large targets on echosounder
Johnston	Sep. 01	187	7	23	32	4,309	5,907	137.1%	1 adult sockeye caught (<30 cm)
Hartley Bay	Aug. 30			No estimate made					
Kitkiata	Aug. 27	270	8	15	16	3,946	4,325	109.6%	
Kitsumkalum	Sep. 04	1,850	7	11	5	19,510	9,078	46.5%	
Lakelse	Sep. 05	1,360	7	26	21	34,693	28,447	82.0%	

Table 6. Estimated biomass (wet weight) of significant planktivores for each lake sampled in 2005. Small trawl correction factor for for fish >40 mm (~0.7 g): W_c=1.3922*W_m^1.2512

Lake	Taxa	Mean Weight (g)	Small trawl correction (g)	Biomass Denstiy (kg / ha)	Biomass Total (kg / lake)	Biomass Prop. of total biomass
Ecstall	Age-0 sockeye	1.0	1.0	0.1	6	3%
	Three-spine stickleback	1.3	1.5	2.4	199	97%
Johnston	Age-0 sockeye	0.5	0.5	2.9	536	85%
	Three-spine stickleback	1.6	2.0	0.5	91	15%
Hartley Bay	Age-0 sockeye[1]	-	-	0	0	0%
	Prickly sculpin	0.1	0.1	0.10	9.021	6%
	Three-spine stickleback[2]	1.3	1.0	1.22	113.46	71%
	Chaoborus			0.4	38.26	24%
Kitkiata	Age-0 sockeye	0.8	0.8	1.9	515	43%
	Three-spine stickleback	1.1	1.4	2.5	672	57%
Kitsumkalum	Age-0 sockeye	1.3	2.0	0.5	955	100%
Lakelse	Age-0 sockeye	4.0	4.4	1.3	194	4%
	Sculpin, stickleback	-	-	-	-	0%
	Neomysis[3]			3.6	4,838	96%
Total non-sockeye planktivore biomass						
Ecstall	Three-spine stickleback			2.4	199	97%
Johnston	Three-spine stickleback			0.5	91	15%
Hartley Bay	Pricky sculpin, three-spine stickleback, Chaoborus			1.7	161	100%
Kitkiata	Three-spine stickleback			2.5	672	57%
Kitsumkalum	None			-	-	0%
Lakelse	Sculpin, stickleback, Neomysis3			3.6	4,838	96%

[1] - no sockeye in trawl catch, no acoustic estimate made due to high *Chaoborous* density, prop. of biomass estimated from trawl catch.

[2] - Stickleback density in Hartley Bay Lake estimated from trawl catch-per-unit-effort and acoustically determined density in Ecstall Lake.

[3] - *Neomysis* biomass was estimated in 2003. Because sockeye fry also feed on mysids, we estimated that 50% of mysid biomass affected productive capacity

Table 7. PR model predictions for North Coast Area lakes surveyed in 2005.

Lake	Surface area (km²)	PR_{mean}	Average daily PR (mg/m²): Adjusted for bathymetry	# sampling dates	Converted to mean seasonal PR	PR_{total} (t C/lake)	Total predicted limnetic biomass (kg)	Non-sockeye competitors adjustment: Non-sockeye biomass (kg/lake)³	Prop. of non sockeye limnetic biomass	PR_{total} available to sockeye (t C/lake)
Ecstall	1.02	190.1	190.1	1	142.2	26.0	1,183	199	17%	22
Johnston[1]	1.87	283.1	283.1	1	211.7	23.7	1,078	91	8%	22
Hartley Bay	0.93	68.7	50.0	1	37.4	6.2	284	161	57%	3
Kitkiata	2.70	386.6	386.6	1	289.1	140.3	6,385	672	11%	126
Kitsumkalum	18.50	33.0	33.0	6	33.0	109.9	5,000	0	0%	110
Lakelse	13.50	102.0	83.0	6	83.0	201.7	9,177	4838	53%	95
Ian - whole lake[2]	18.78	66.0	66.0	1	49.4	166.8	7,591	119	2%	164

Lake	Age-2 smolt adjustment: Age-1 smolt wt at capacity	Age-2 smolt wt at capacity	% of age-1's at capacity	Mean smolt wt.	PR model predictions: Kg smolt biomass (R_{max})	Smolt #'s (thousands)	Escapement (S_{max}) (thousands)	Escapement (#/ha)	Observed juvenile sockeye biomass (kg)	% of rearing capacity used
Ecstall	4.5		100%	4.5	984	219	4.0	40	6	1%
Johnston	4.5		100%	4.5	987	219	4.1	22	536	54%
Hartley Bay (Lower)	4.5		100%	4.5	123	27	0.5	5	0	0%
Kitkiata	4.5		100%	4.5	5,714	1,270	23.5	87	515	9%
Kitsumkalum	4.5		100%	4.5	5,000	1,111	20.5	11	955	19%
Lakelse	4.5		100%	4.5	4,339	964	17.8	13	194	4%
Ian - whole lake[1]	4.5		100%	4.5	7,472	1,660	30.7	16	750	10%

1 - PR_{total} used was one-third of actual PR_{total} to account for the large proportion of ungrazeable phytoplankton

² Average of age-O sockeye and stickleback data (1993-2003, yrs= 5) from P. Rankin, personal communications

Fig. 1. Map of the north coast area showing the location of the study lakes.

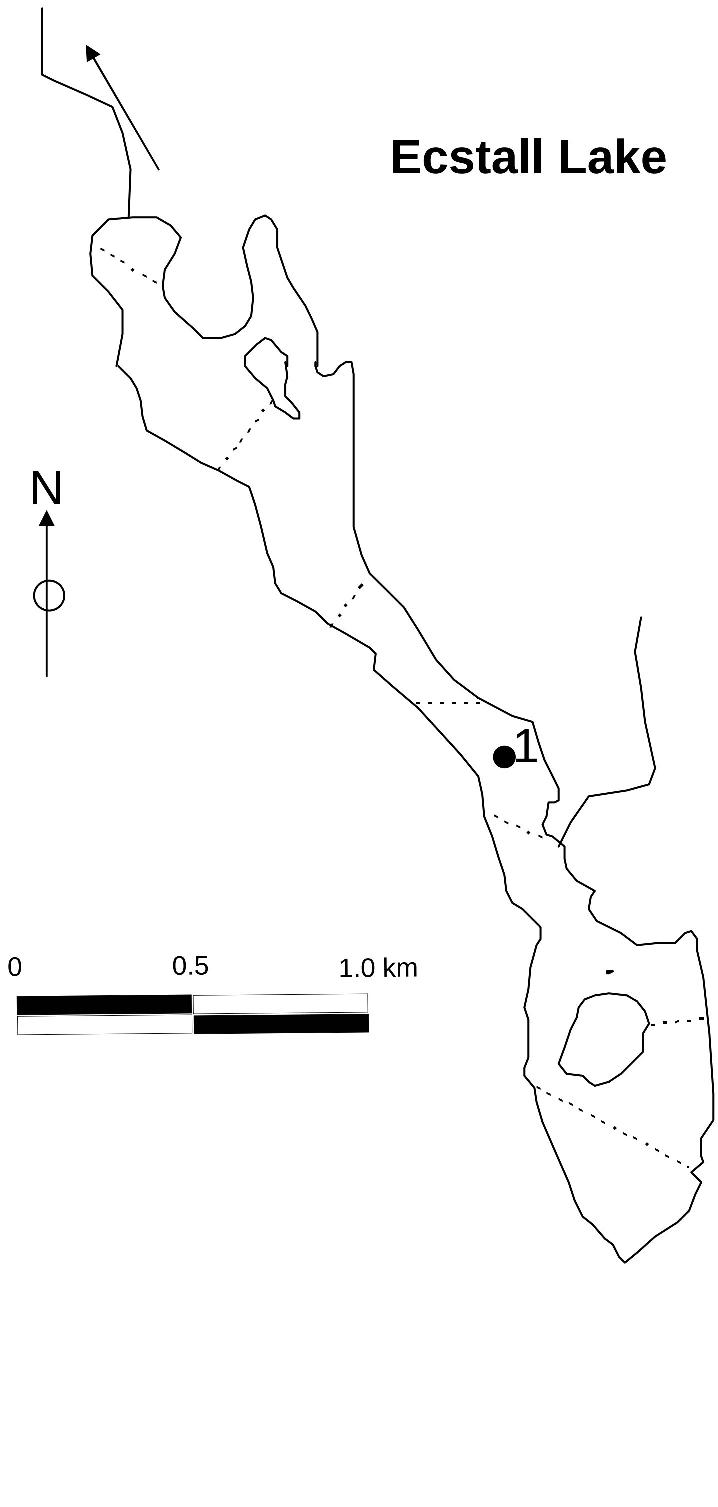

Fig. 2. Outline map of Ecstall Lake showing hydroacoustic transects (dotted lines) and the limnological sampling station.

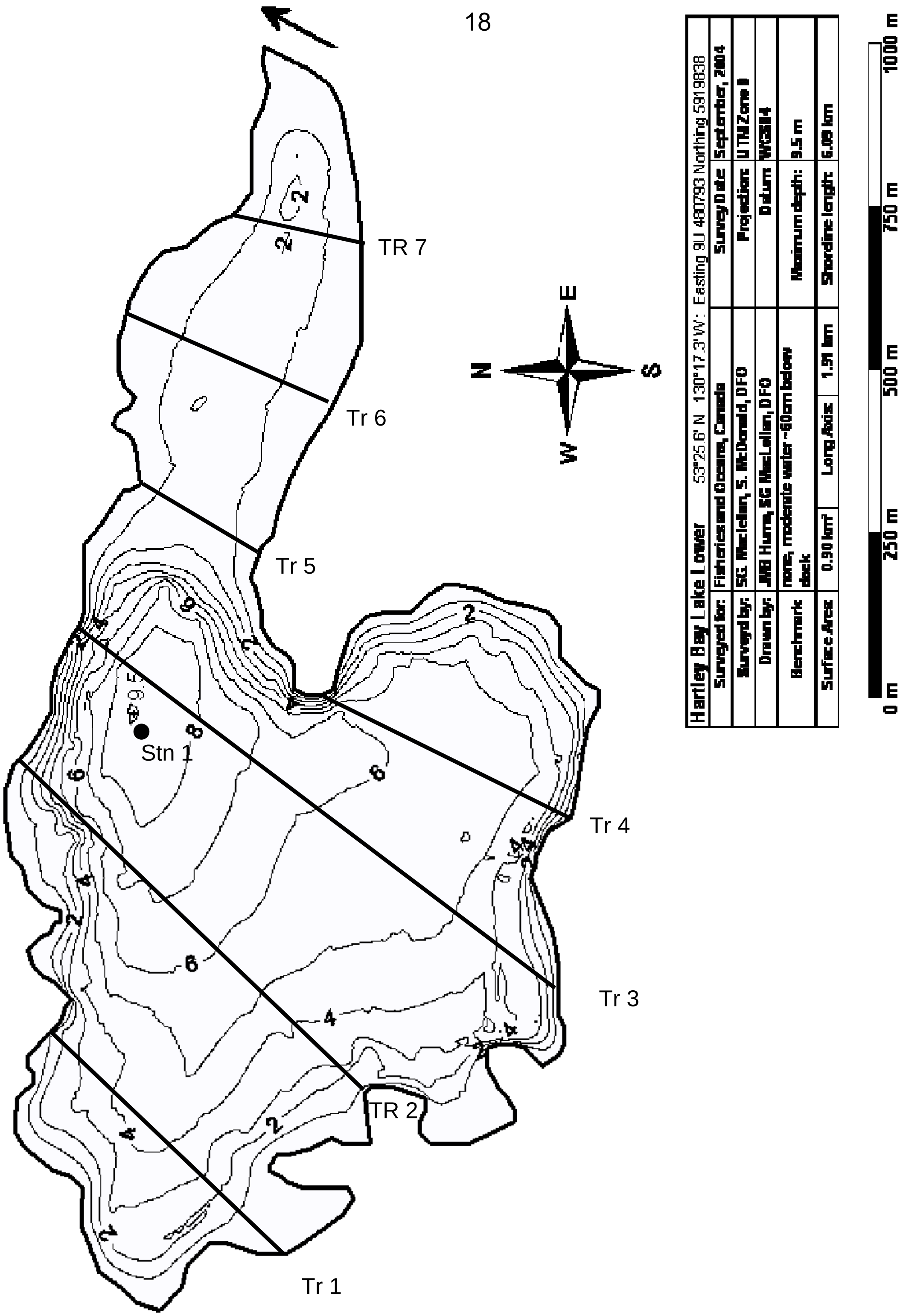

Fig. 3. New bathymetric chart of Hartley Bay Lower Lake showing hydroacoustic transects and the limnological sampling station.

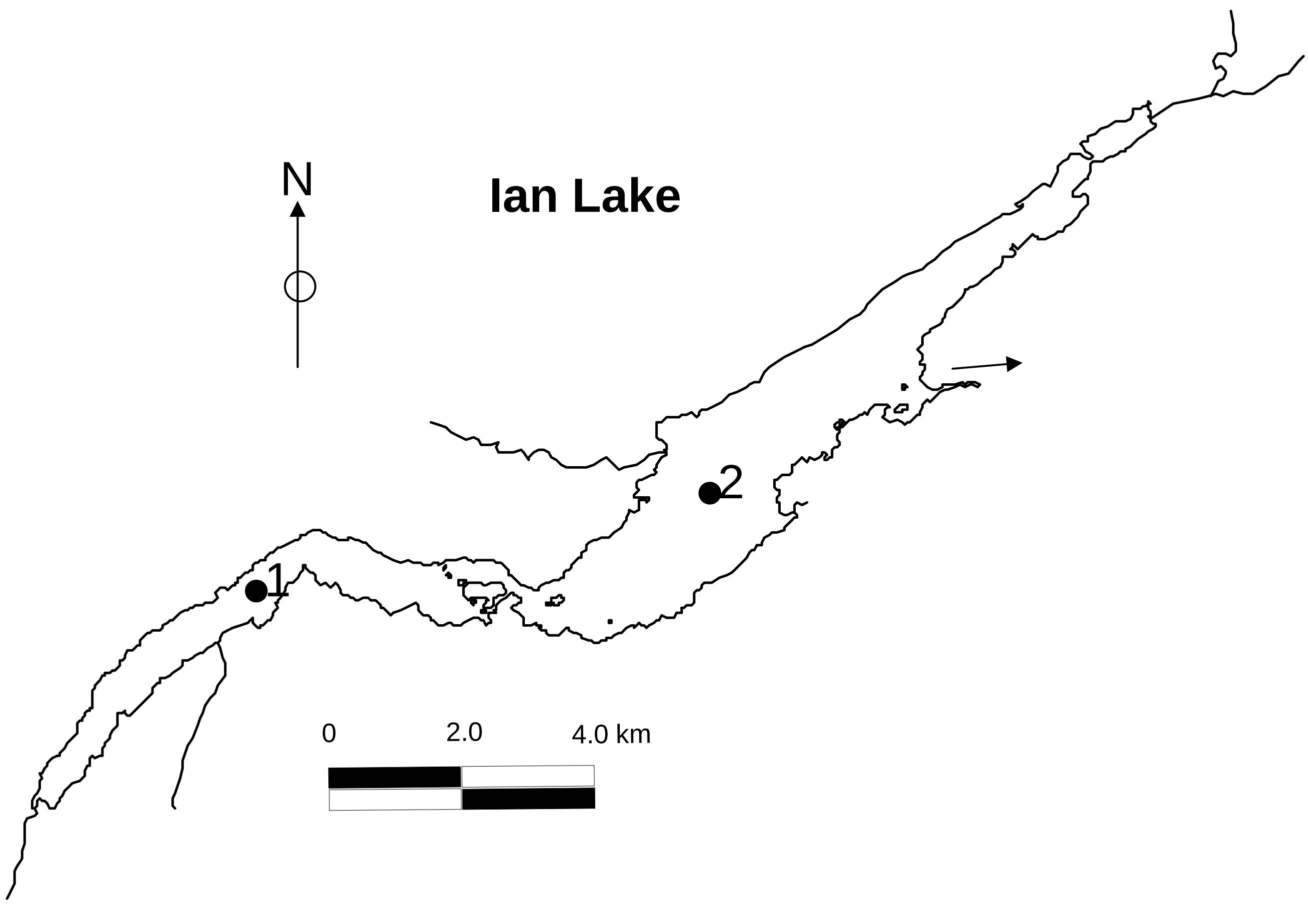

Fig. 4. Outline map of Ian Lake showing the limnological sampling stations.

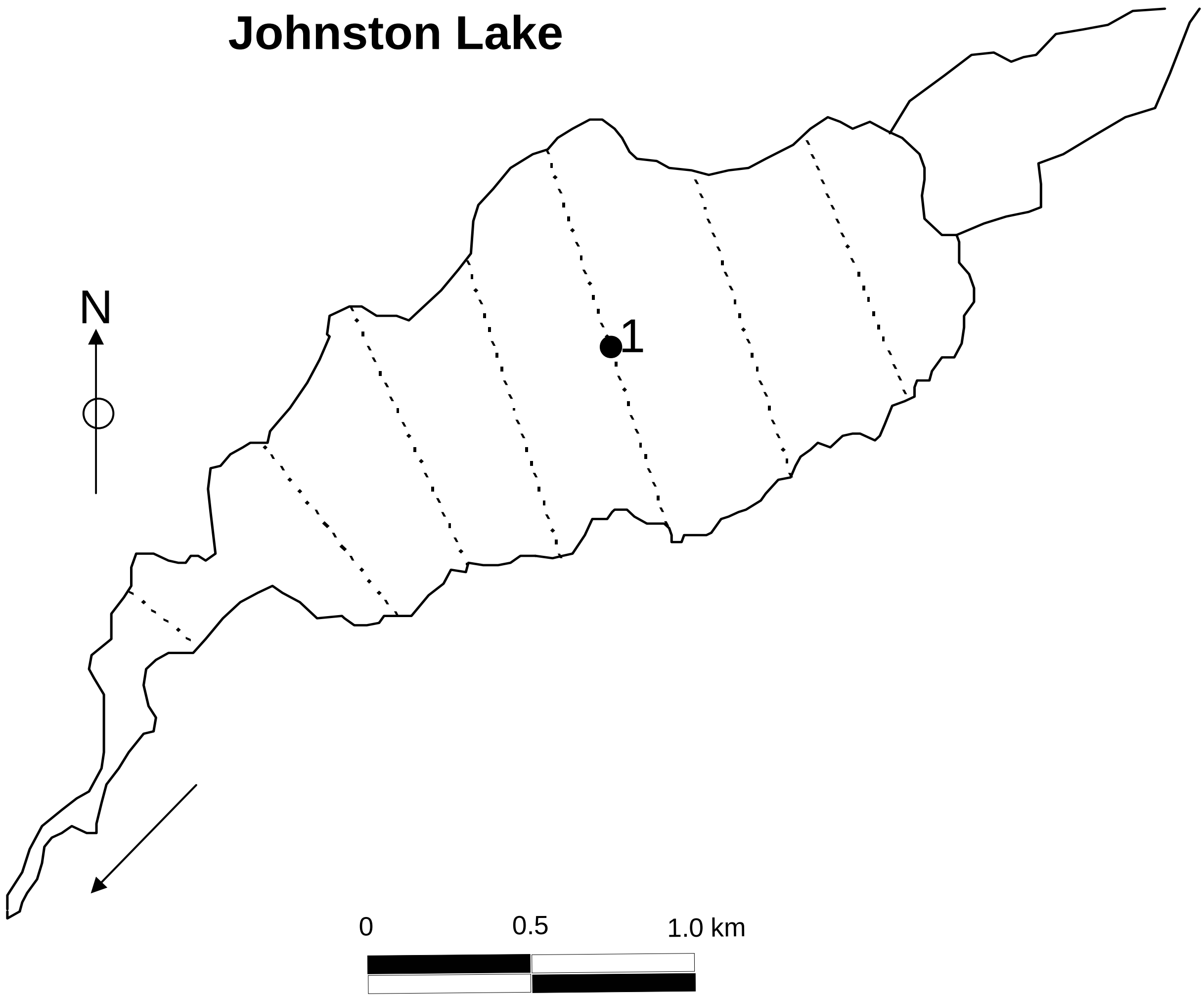

Fig. 5. Outline map of Johnston Lake showing hydroacoustic transects (dotted lines) and the limnological sampling station.

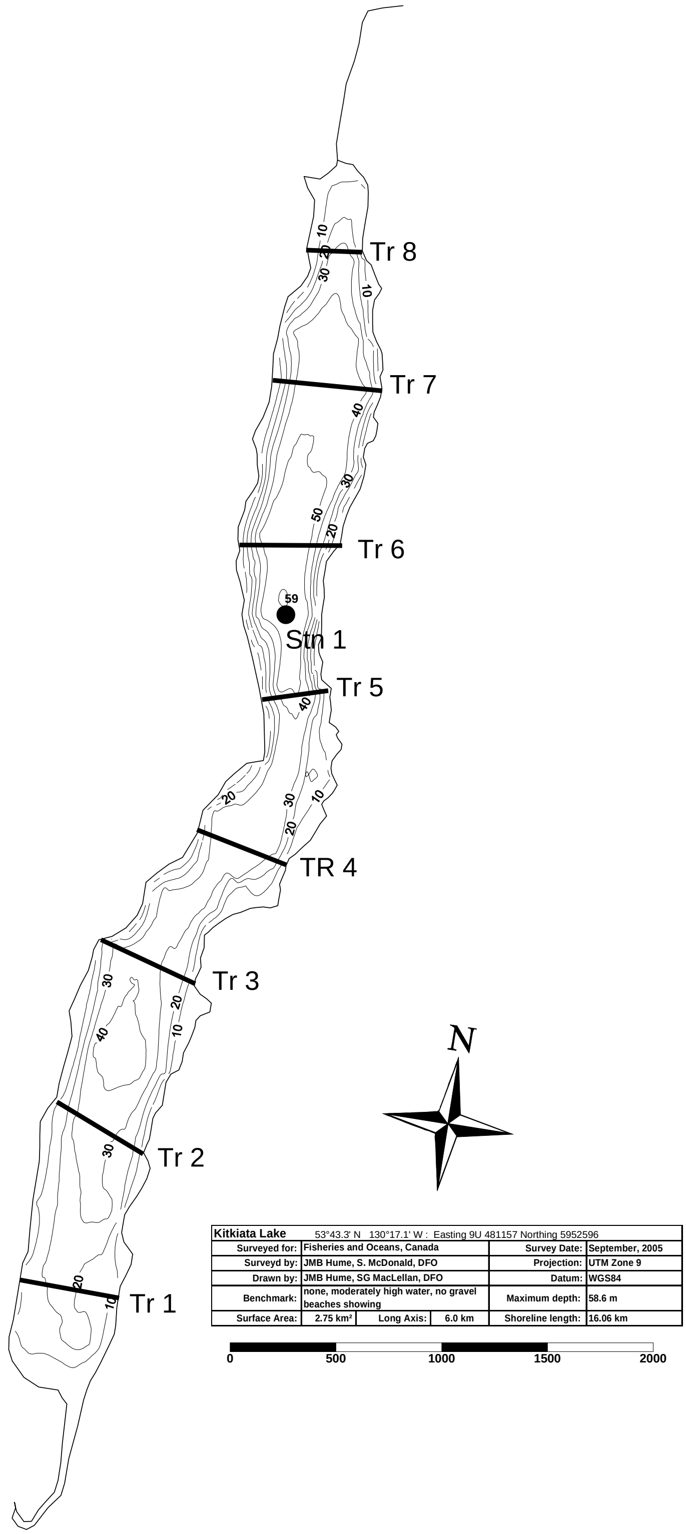

Fig. 6. New bathymetric chart of Kitkiata Lake showing hydroacoustic transects and the limnological sampling station.

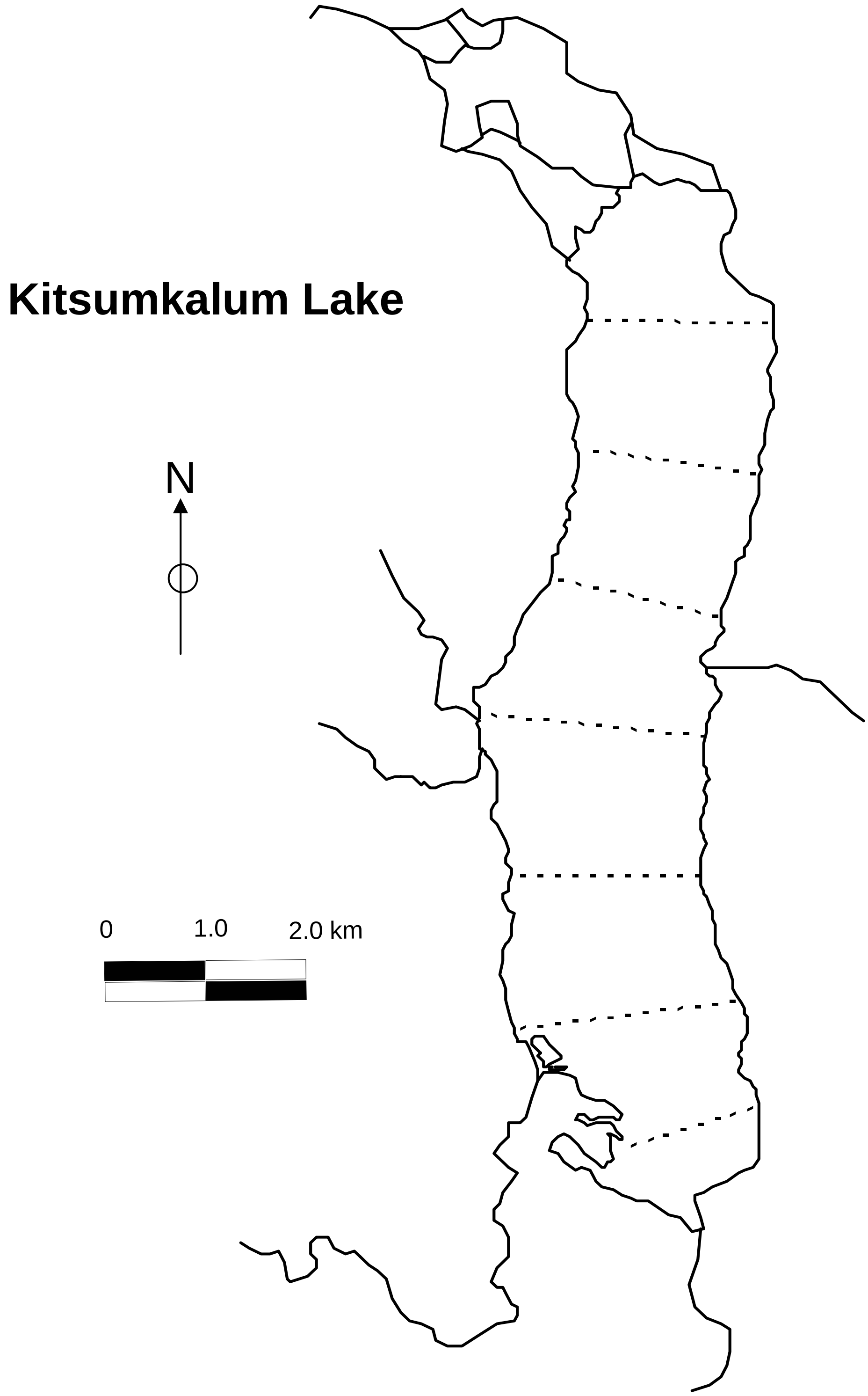

Fig. 7. Outline map of Kitsumkalum Lake showing hydroacoustic transects (dotted lines).

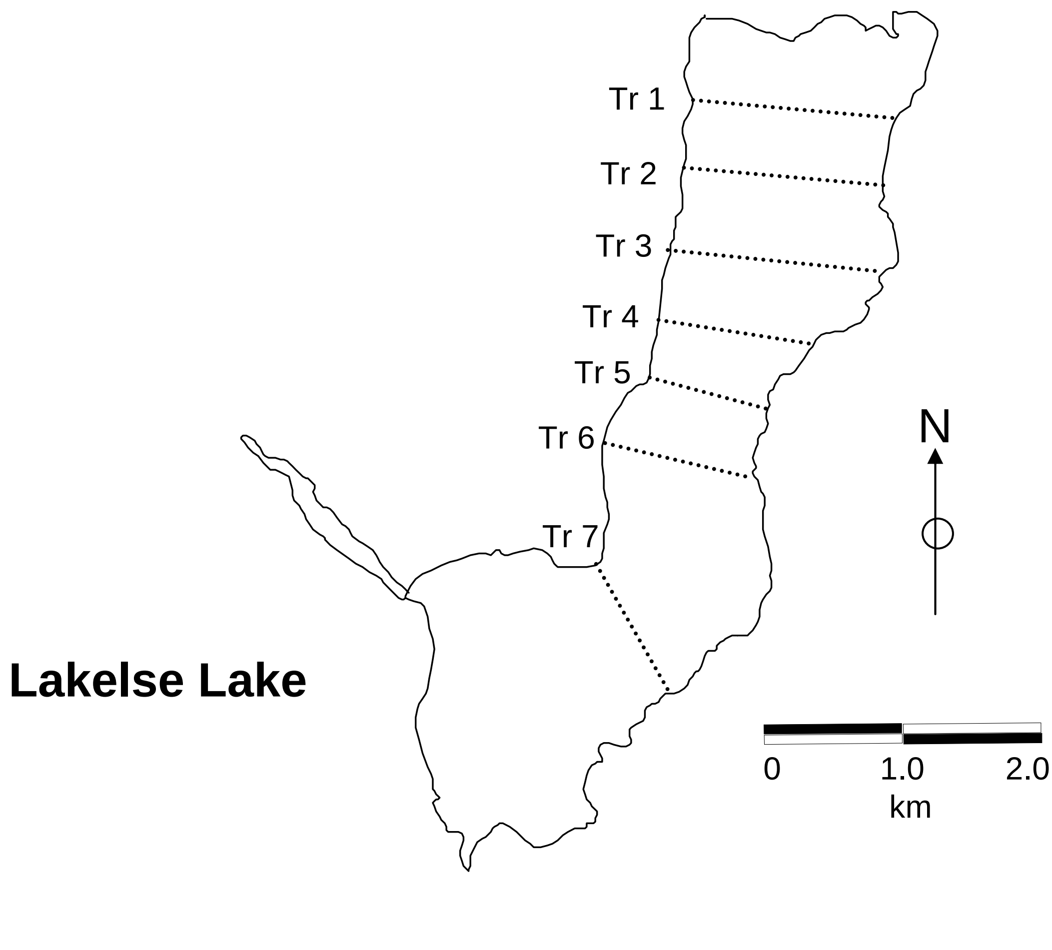

Fig. 8. Outline map of Lakelse Lake showing hydroacoustic transects (dotted lines).

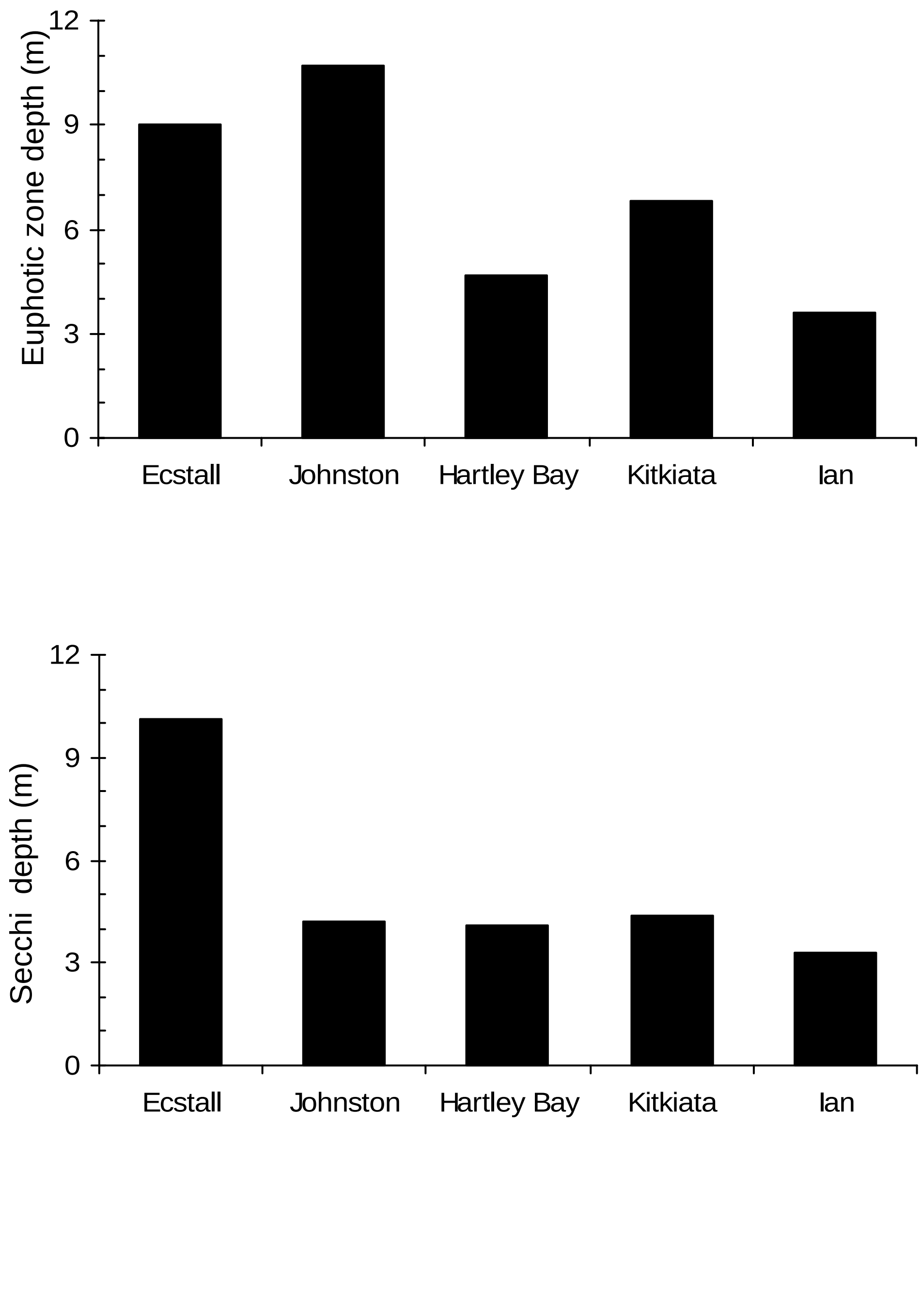

Fig. 9. Variation in euphotic zone and Secchi depth in the lakes surveyed in 2005
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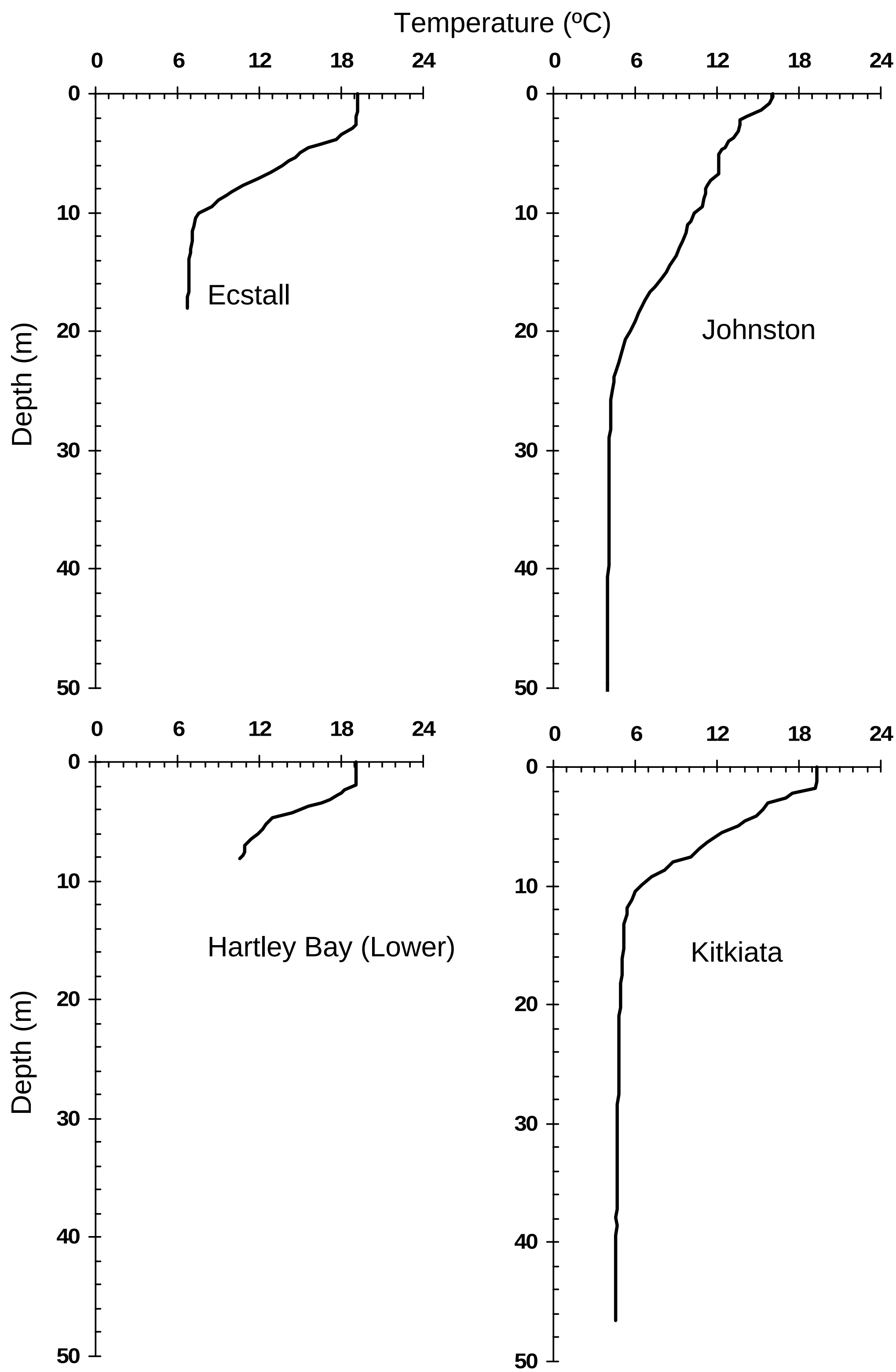

Fig. 10. Temperature profiles obtained during the August, 2005 surveys.

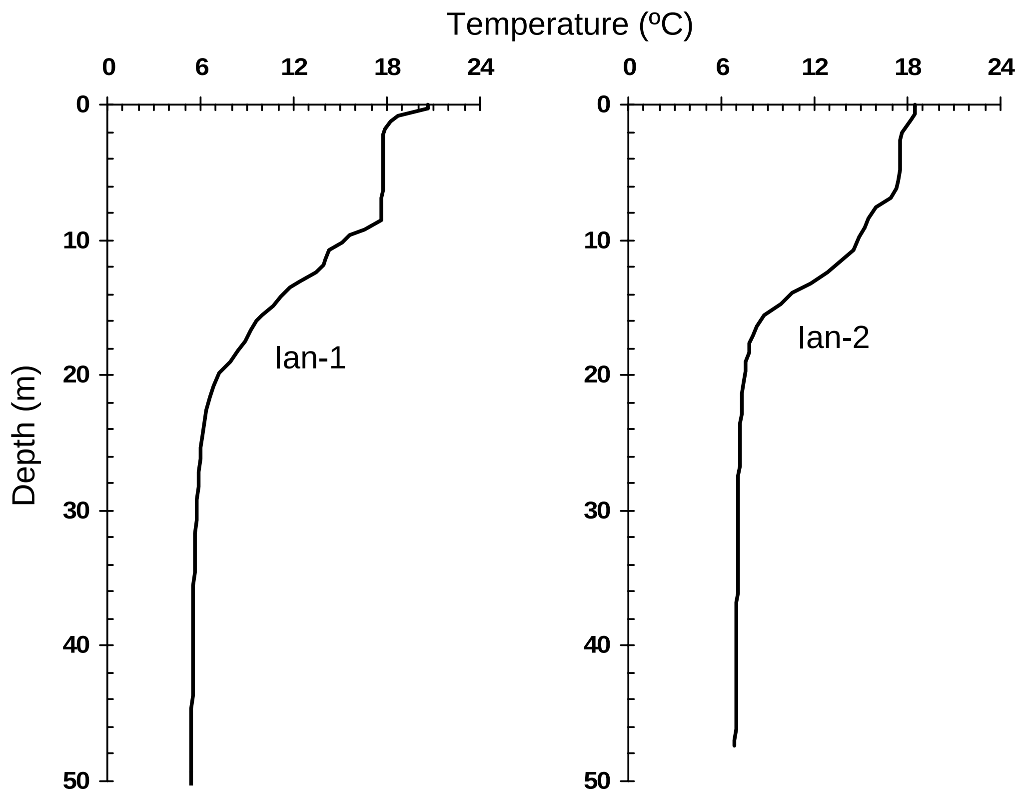

Fig. 11. Temperature profiles obtained during the August, 2005 surveys.

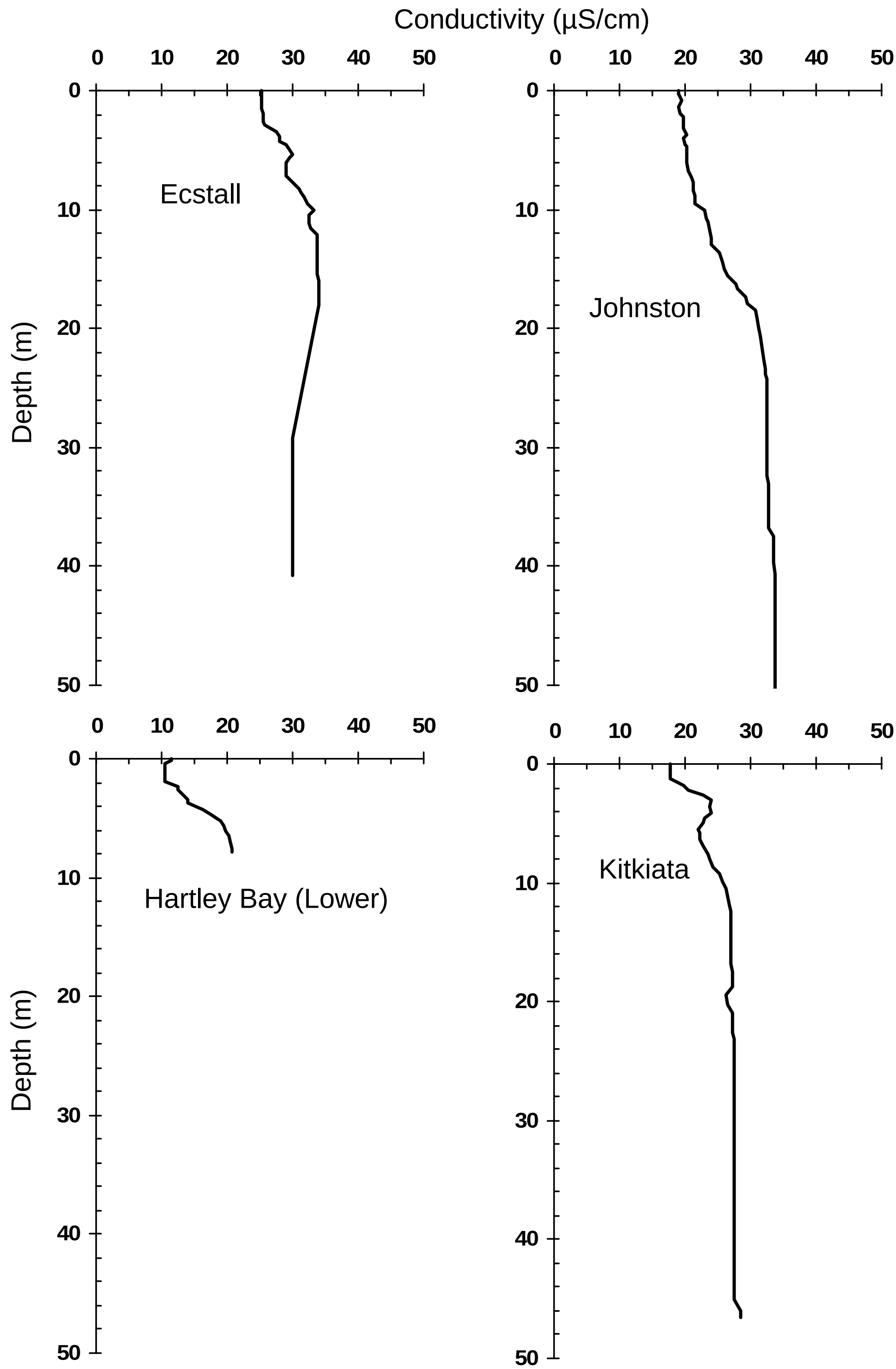

Fig. 12. Conductivity profiles obtained during the August, 2005 surveys.

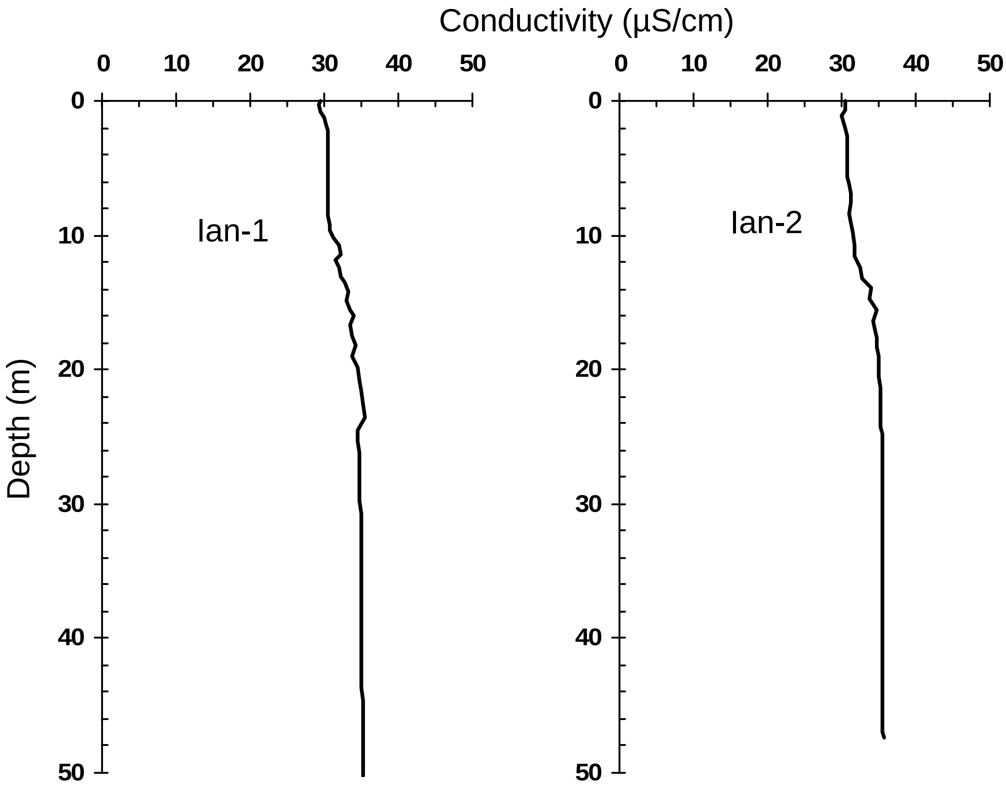

Fig. 13. Conductivity profiles obtained during the August, 2005 surveys.

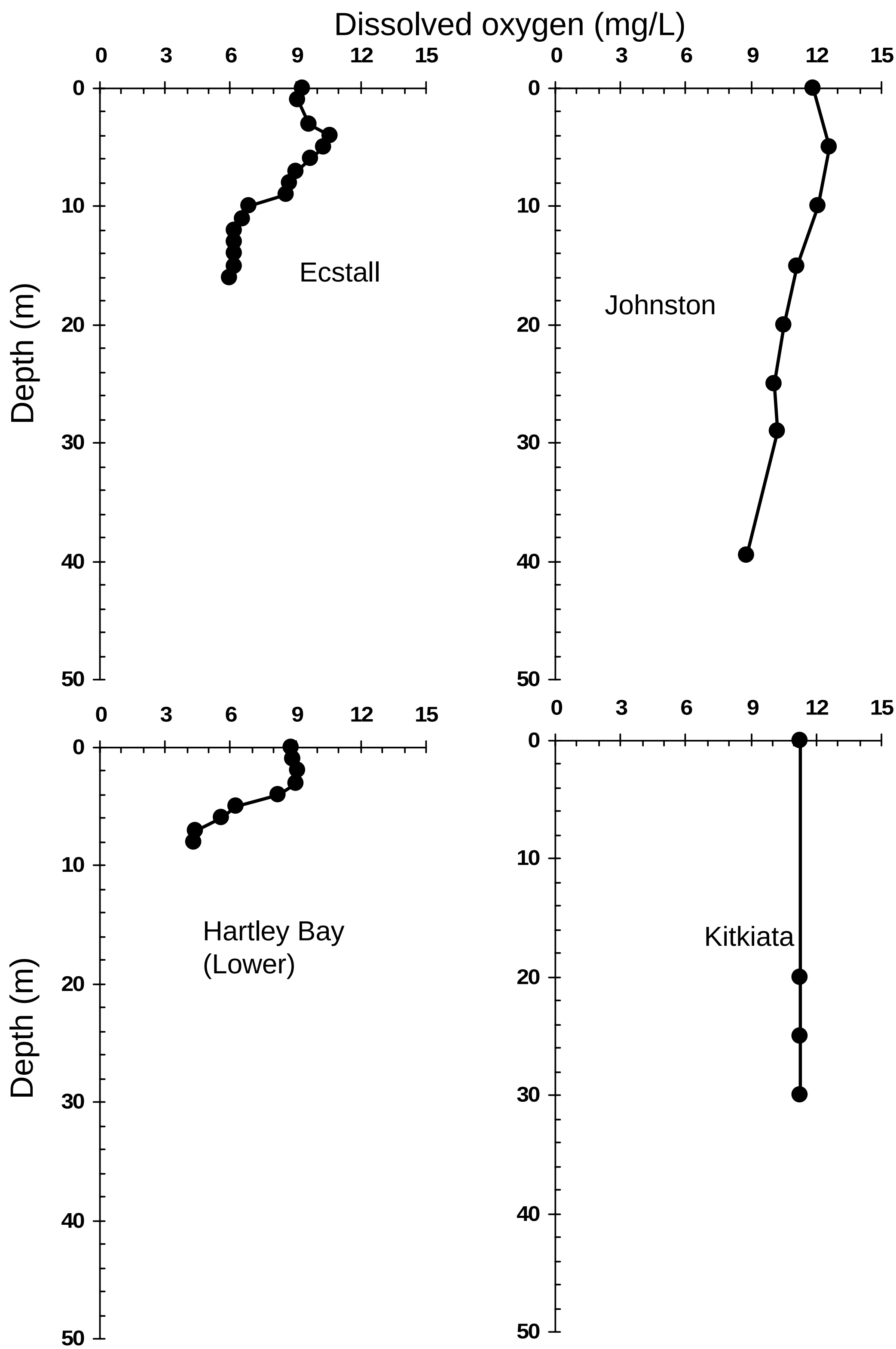

Fig. 14. Dissolved oxygen profiles obtained during the August, 2005 surveys.

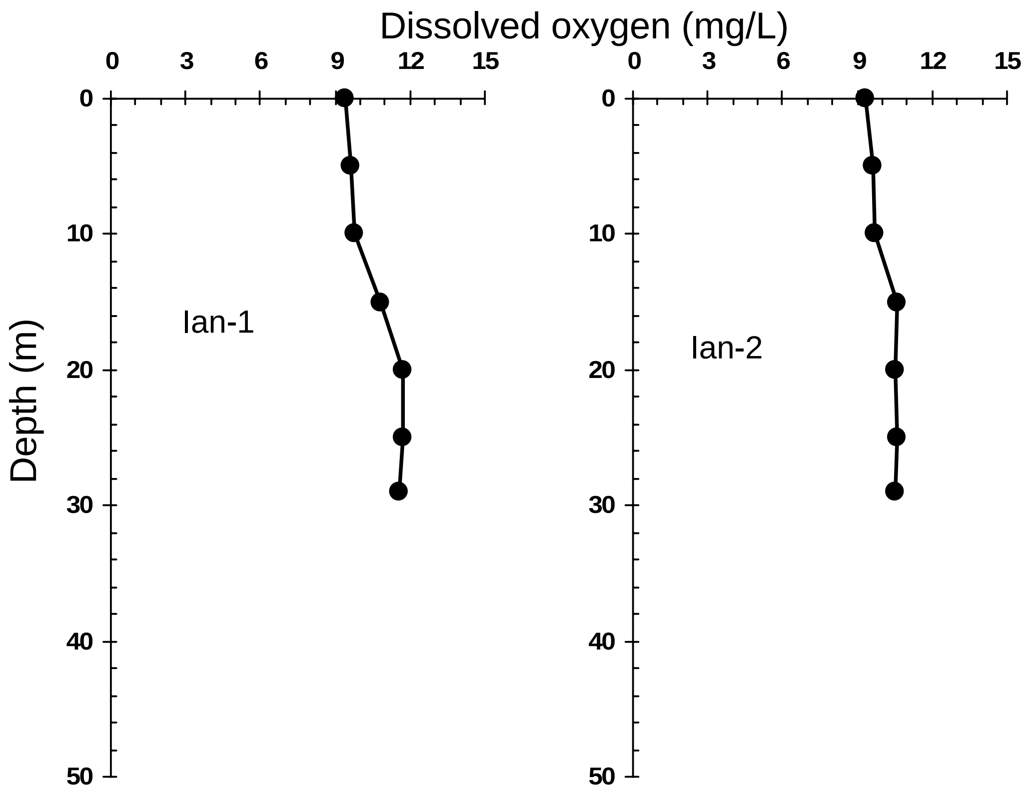

Fig. 15. Dissolved oxygen profiles obtained during the August, 2005 surveys.

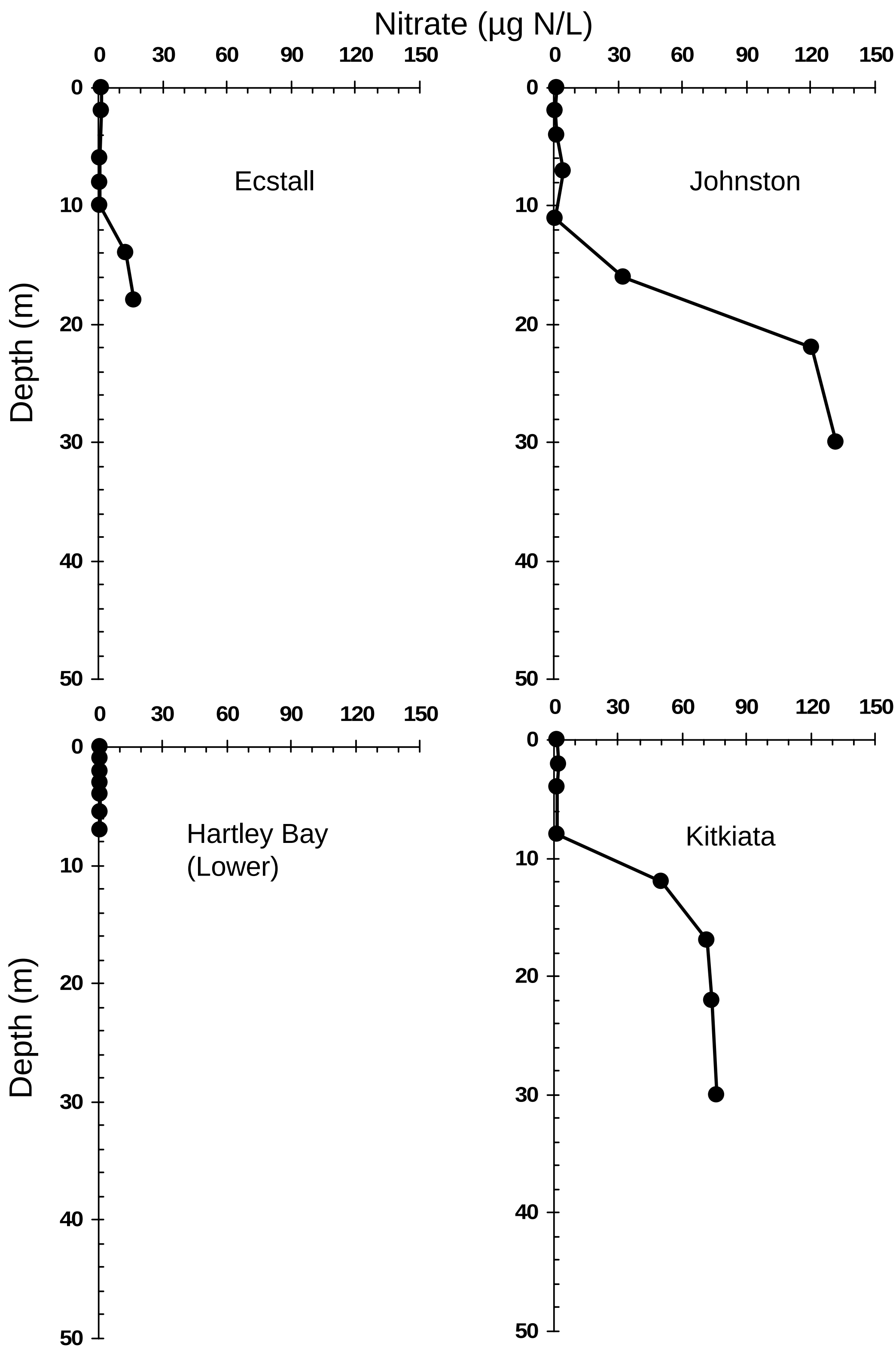

Fig. 16. Nitrate profiles obtained during the August, 2005 surveys.

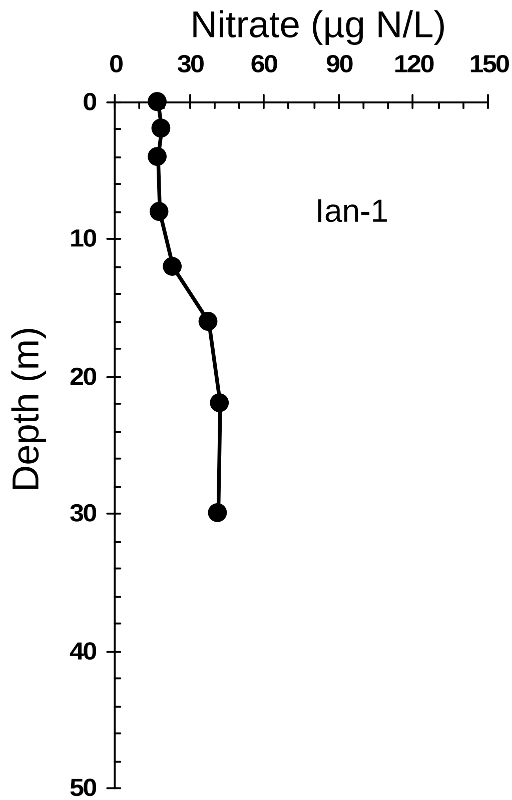

Fig. 17. Nitrate profiles obtained during the August, 2005 surveys.

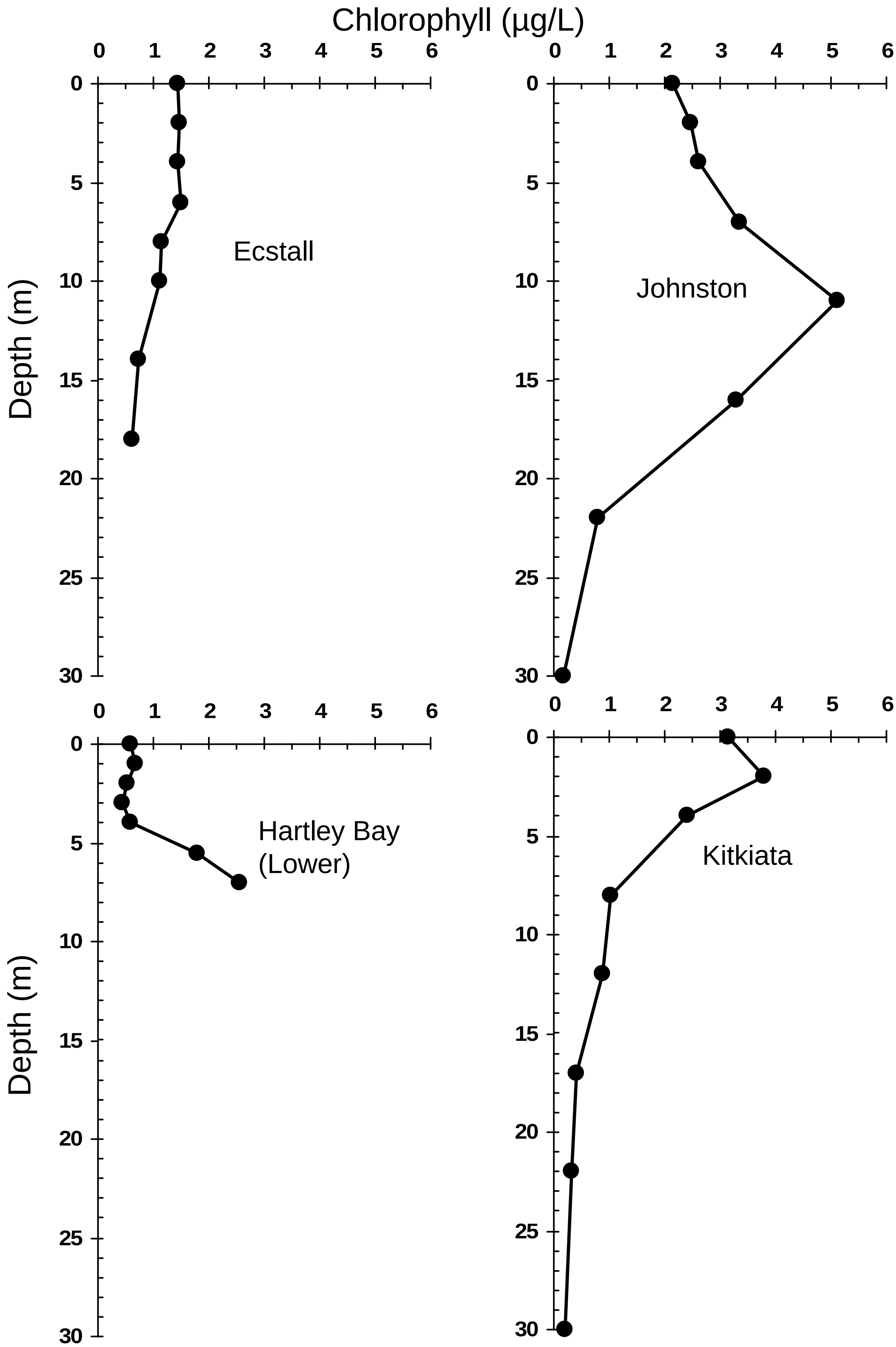

Fig. 18. Vertical profiles of chlorophyll concentrations from the August, 2005 surveys.

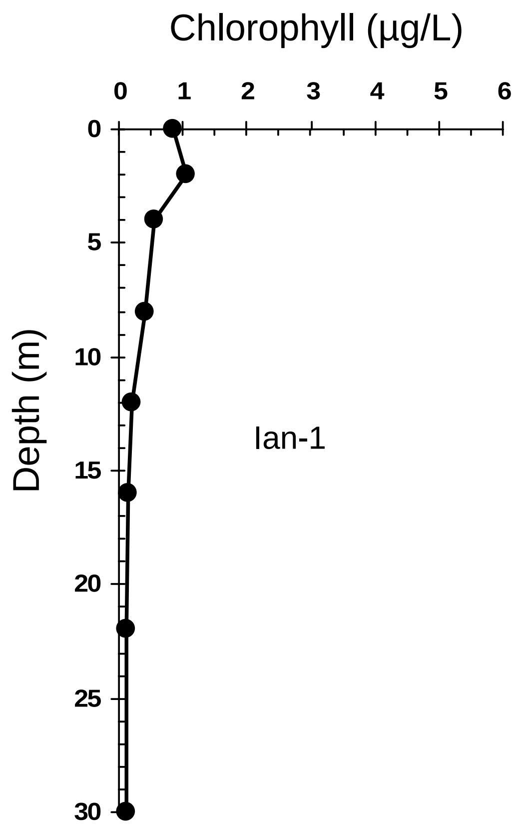

Fig. 19. Vertical profiles of chlorophyll concentrations from the August, 2005 surveys.

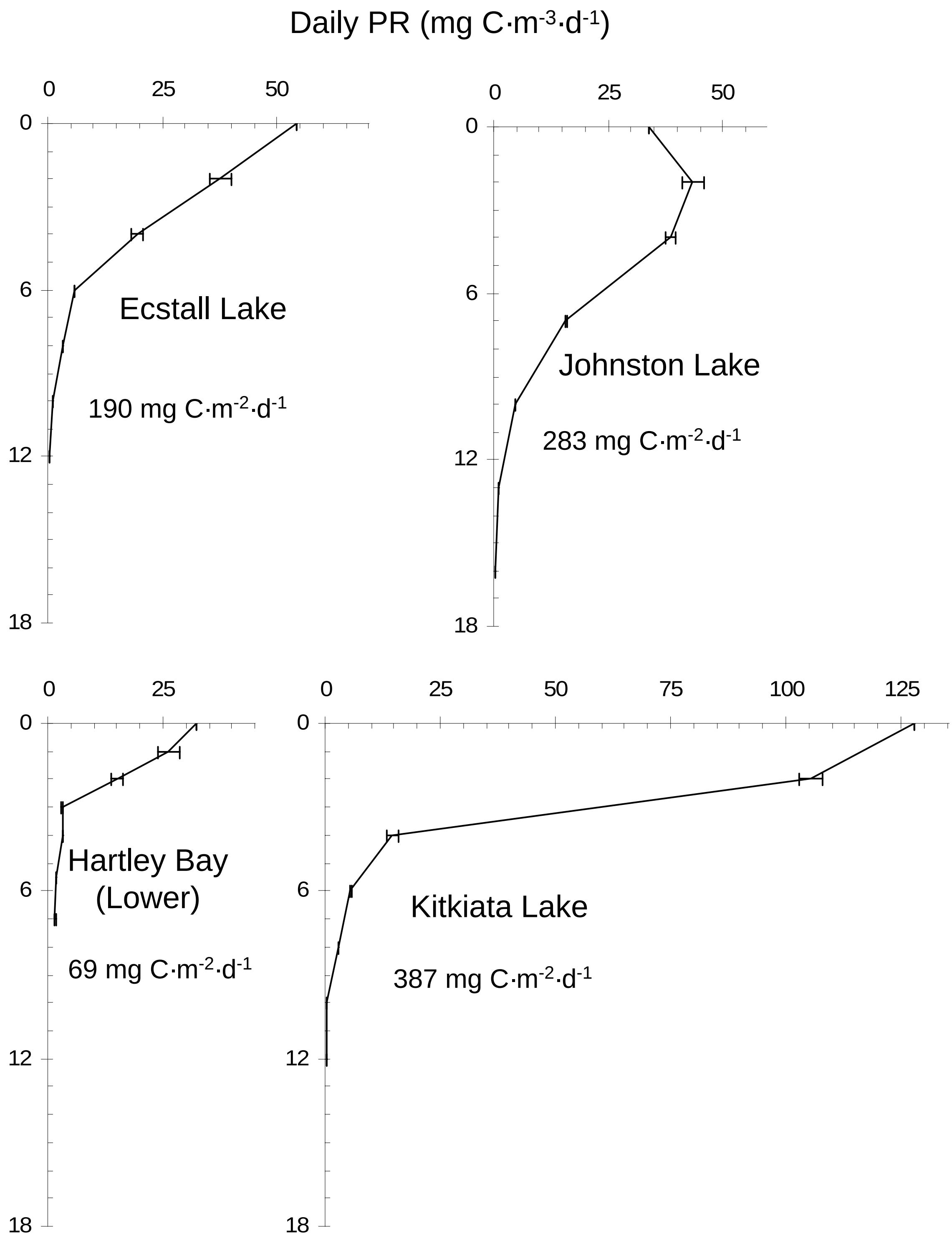

Fig. 20. Vertical profiles of daily photosynthetic rates from the August, 2005 surveys.

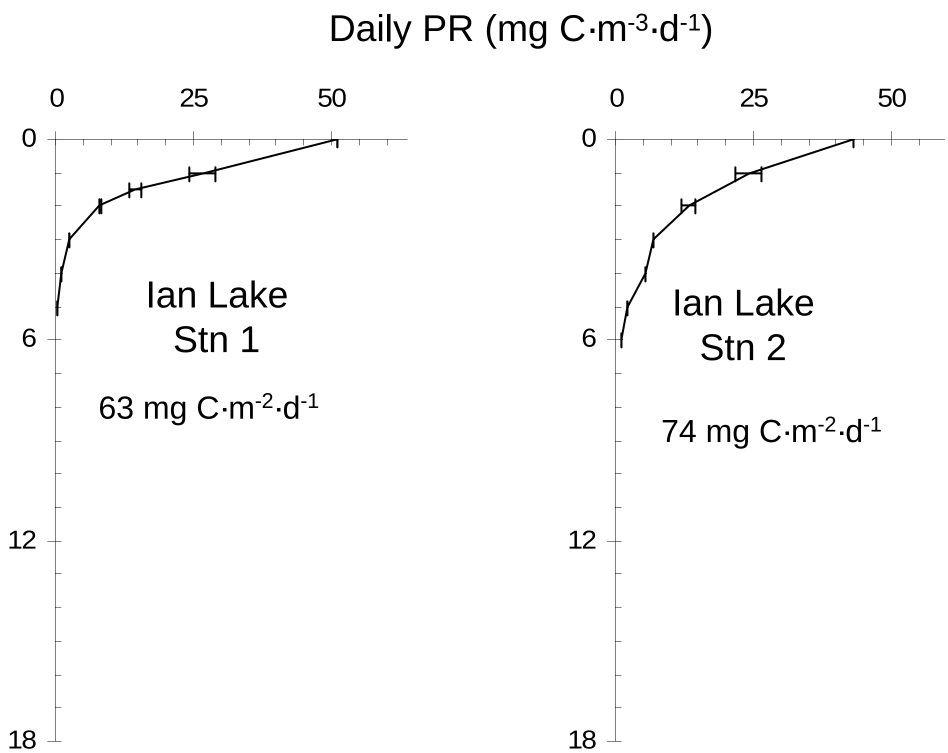

Fig. 21. Vertical profiles of daily photosynthetic rates from the August, 2005 surveys.

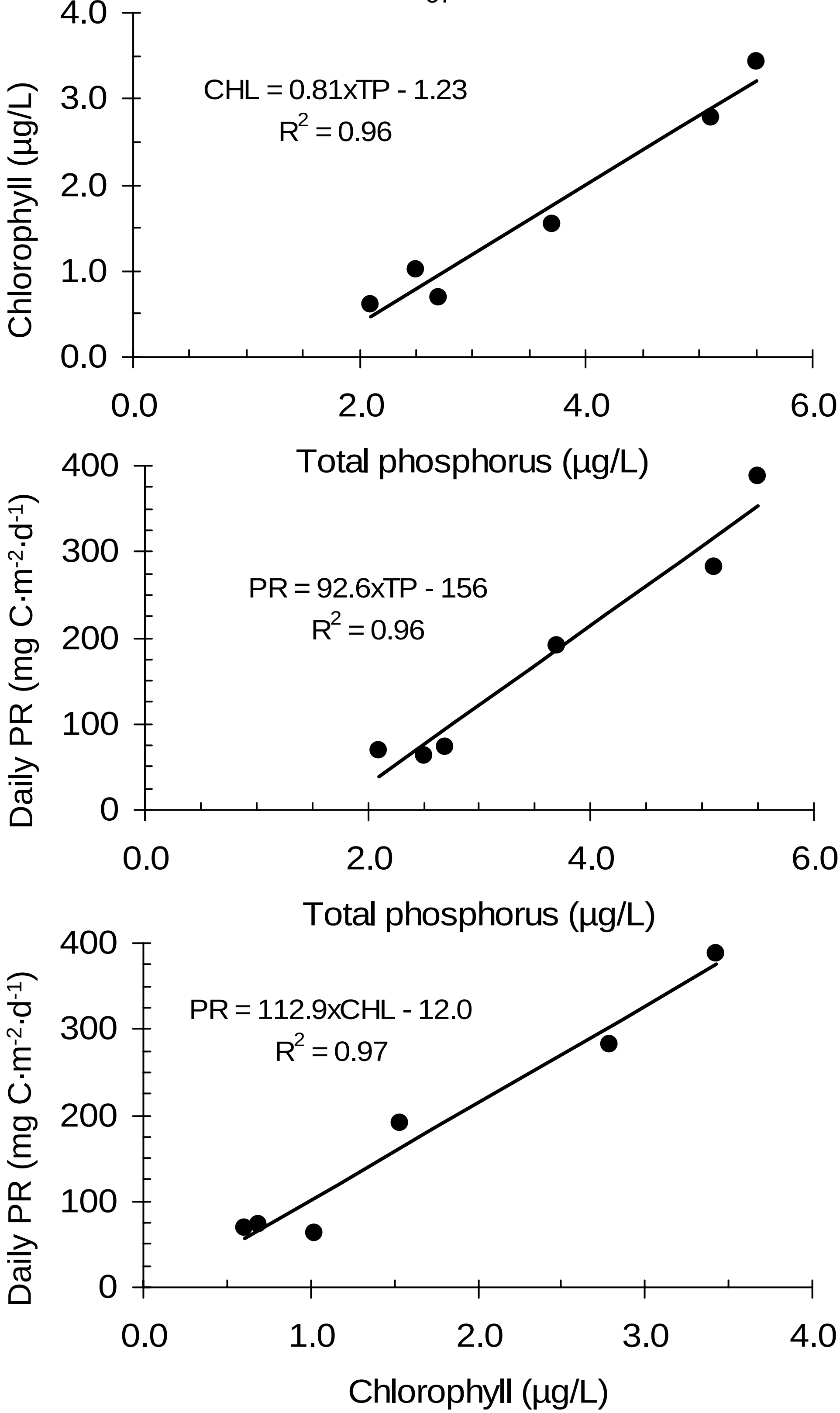

Fig. 22. Correlation between chlorophyll, total phosphorus, and daily photosynthetic rates in the lakes sampled in 2005.

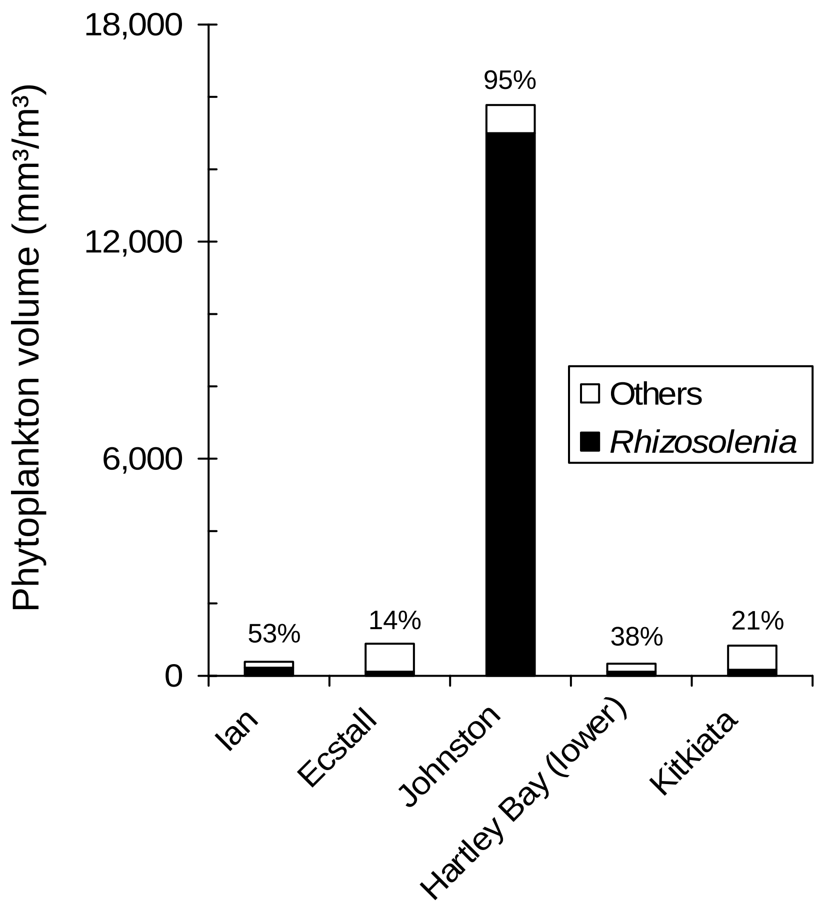

Fig. 23. The contribution of the diatom *Rhizosolenia* sp. to total phytoplankton volume in the lakes sampled in 2005. Numbers above bars represent the percentage of total phytoplankton volume comprised of *Rhizosolenia*.

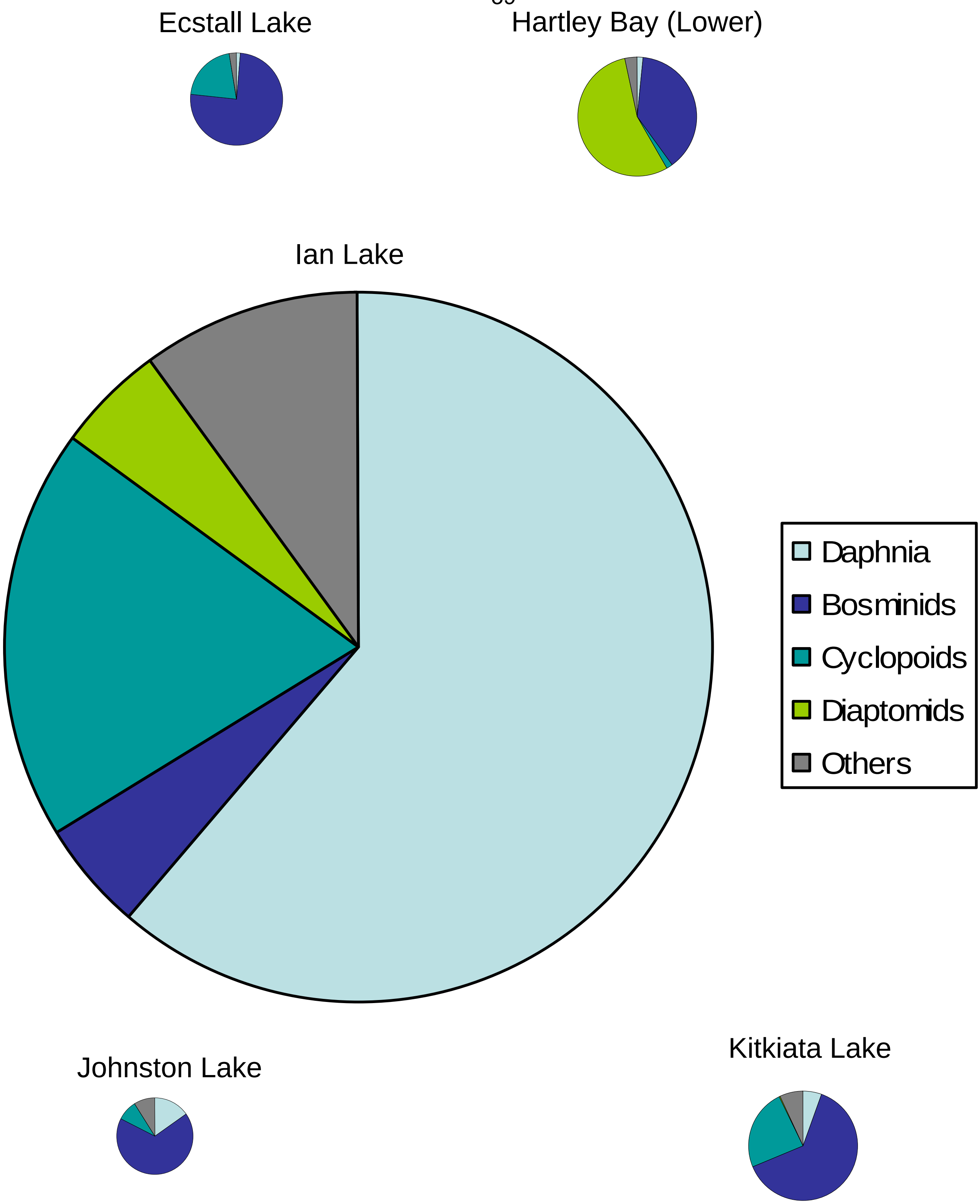

Fig. 24. Variation in zooplankton community structure in lakes sampled in 2005. Area of the pies represents areal biomass (mg dry wt/m^2).

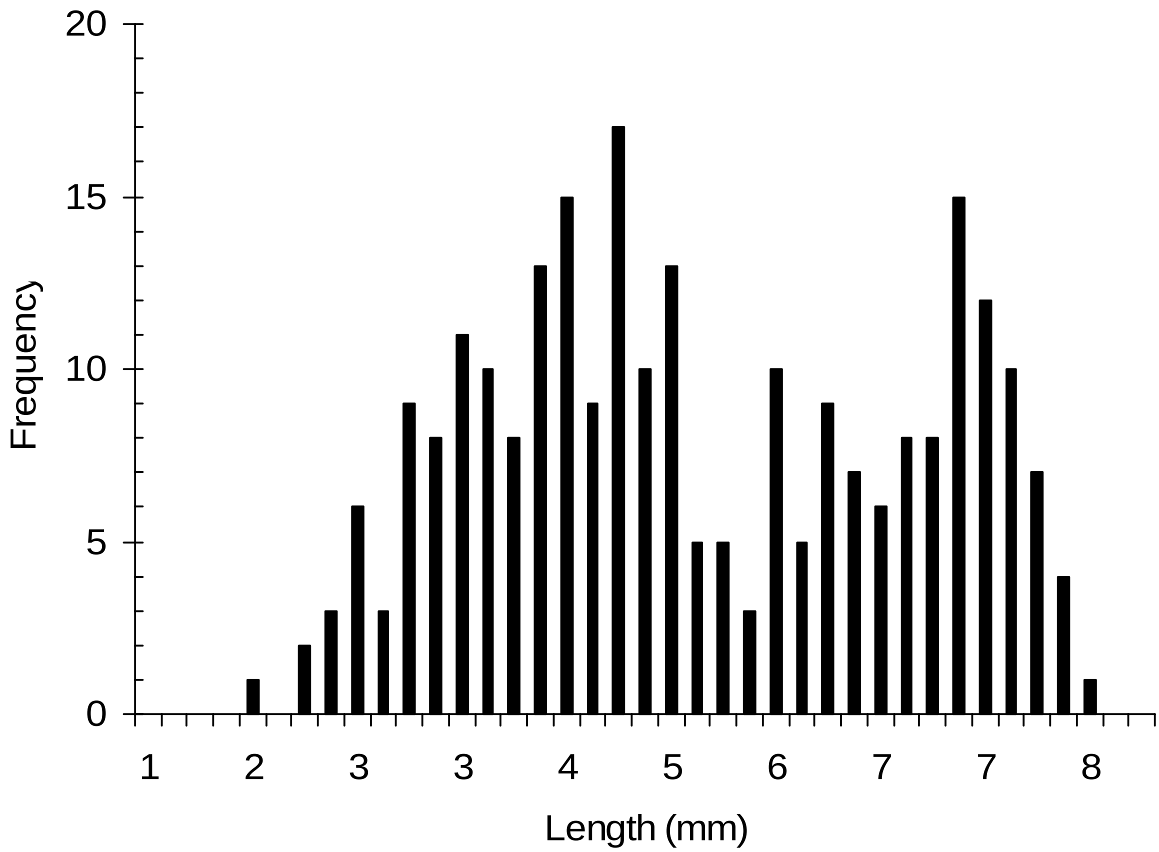

Fig. 25. Length-frequency plot of *Chaoborus* in Hartley Bay (Lower) Lake.