3.0 RESULTS

3.1 LAKE SUBSTRATES: ACOUSTIC DATA ANALYSIS

Substrate samples were taken and described from 10, 7, 4, 22, 15, and 29 locations throughout Lalor, Varnson, Tern, Bur, Fiddle, and Morris Lakes, respectively, for a total of 87 samples to compare with acoustic classes. Cluster analysis of acoustic data in QTC IMPACT demonstrated the presence of three acoustic classes. Based on substrate sample descriptions among the three classes, the acoustic classes were described as:

- Class 1: aquatic vegetation and silt;
- Class 2: coarse sand and gravel; and
- Class 3: soft flocculent sediment (silt/clay).

Results for lakes in the Lalor Lake Study Area are provided below. Results for the Bur Lake Study Area are presented in Gallagher and Cooley (2008).

3.2 WATER AND SEDIMENT QA/QC RESULTS

3.2.1 Water Quality

Results of QA/QC samples (i.e., triplicate samples, trip and field blanks) are provided in Appendix 4. Triplicate samples for routine parameters for which indices of precision could reliably be derived (i.e., PRSD calculations where all values are greater than five times the analytical DL) were generally within the acceptable limits (i.e., PRSD was less than 18%). This was the case for all routine water quality analyses with two exceptions; the triplicate values for dissolved ammonia and total phosphorous in Lalor Lake yielded a PRSD of 23% and 25%, respectively. Blank samples occasionally contained detectable concentrations of some routine water quality parameters although all detections were less than five times the analytical detection limits in field or trip blanks.

Reliable estimates of precision for sample triplicates could not be derived for most metals and major ions as many measurements were near or below analytical detection limits. With the exception of dissolved manganese (PRSD was 27% for LL-2 and 29% for CL-3), PRSDs were within the 18% level of precision where PRSD could be reliably derived for triplicate samples. Metals were occasionally detected in trip and field blanks although no values were greater than five times the detection limit.

Four samples of surface water were analysed in the laboratory for DO to facilitate comparison to *in situ* measurements. All of the samples were in good agreement with the field measurement as the greatest difference observed was equal to 1.1 mg/L and RPMD values were consistently less than 25%.

3.2.2 Sediment Quality

Percent relative standard deviations derived for triplicate samples of sediments indicated that most variables fell within the acceptable level of precision (i.e., < 18%). Exceptions included arsenic, chromium, lead, and titanium at Lalor Lake (Appendix 4). Triplicate sample results for organic and particle size analysis also indicated that all samples fell within the acceptable level of precision.

3.3 LALOR LAKE

Bathymetry and substrate, water and sediment quality, phytoplankton, zooplankton, benthic invertebrates, fish, and fish metal residues were examined in Lalor Lake.

3.3.1 Bathymetry and Substrate

Lalor Lake is shallow (approximate mean and maximum depths of 1.16 m and 2.14 m, respectively) with a relatively small surface area (approximately 0.4 km^2, Figure 8), and a single small island near the centre towards the western shore.

The shoreline vegetation is mainly composed of black spruce with overhanging shrubs and willows. Some areas of the shoreline are not covered by dense trees, revealing the Precambrian shield bedrock. A bog is located along the north shore of the lake at the outlet. Other smaller bog habitat is found along the western shore of the lake. The vegetation, particularly along the northeast shoreline, is composed of bulrush, cattails, sedges and reed grass (*Phragmites* sp.).

Nearshore substrate, especially near the boggy areas, is ultra-fine, unconsolidated soft organic matter. In most cases the shoreline substrate is composed of cobble and coarse and fine woody debris at various stages of decomposition. Vegetation, particularly dead leaves, is also abundant along the shoreline.

Areas deep enough to be surveyed using QTC VIEW V revealed that shallow areas consist mainly of aquatic vegetation and silt with a few small patches of coarse sand and gravel. In the deeper areas of the lake, the bottom consists of soft flocculent material (silt/clay) (Figure 9).

3.3.2 Water Quality

Water quality was measured at three sites in Lalor Lake (Figure 4); surface and bottom samples were taken from two locations (LL-1 and LL-2). A triplicate surface sample was taken at site LL-2 (samples LL2-, LL-4, and LL-5).

Lalor Lake is shallow (Figure 8), clear, slightly alkaline, well-oxygenated, low in phosphorus, and moderately hard; in September 2007 there was no indication of stratification (tables 3 and 4). Ammonia, total phosphorus (TP), DO, and pH were within the Manitoba water quality objectives and guidelines for the protection of aquatic life and nitrate was below the CCME PAL guideline (CCME 1999; updated to 2007).

Compared to other lakes in the Study Area, Lalor Lake has a relatively high dissolved solids content, low colour, and low productivity (Table 4). It is classified as oligotrophic according to the CCME phosphorus guidance framework trophic categorization (Table 5).

In general, concentrations of metals are low in Lalor Lake and a number of metals were not detected, including: antimony; beryllium; cadmium; chromium; cobalt; mercury; silicon; silver; tellurium; and zinc (Table 6). All metals were within MWQSOGs for the protection of aquatic life. Relative to other lakes and streams in the Study Area, Lalor Lake contains a lower concentration of silicon and a higher concentration of potassium.

3.3.3 Sediment Quality

Sediment quality analysis results for the Study Area are presented in tables 7 and 8. Several substances exceeded Manitoba sediment quality guidelines (SQG). Arsenic and copper exceeded the MB SQGs in most or all samples and a single sample exceeded the SQGs for chromium and cadmium. Relative to other lakes, Lalor Lake contains higher concentrations of arsenic and molybdenum in sediments.

Comparison of sediment quality results for Lalor Lake to Ontario sediment quality guidelines (Persaud et al. 1993) indicates that average concentrations of nickel and total phosphorous exceeded the lowest effect level (LEL). Furthermore, total nitrogen[1] and total organic carbon (TOC) from all Lalor Lake samples exceeded Ontario's severe effect levels (SELs).

3.3.4 Phytoplankton

A phytoplankton sample was collected from Lalor Lake on September 8, 2007. The total phytoplankton biomass was 311 mg/m^3 and consisted of 22 taxa (Table 9, Figure 10). In general, the biomass was relatively low but higher than Tern or Maw lakes (Figure 10). On the basis of chlorophyll *a* (range between <1 and 1 µg/L), Lalor Lake had an extremely low productivity at the time it was sampled and notably lower chlorophyll *a* than other Study Area lakes (Table 4). Therefore, there appears to be some discrepancy between chlorophyll *a* and phytoplankton biomass measured in the Study Area.

[1] Concentrations of TN in sediments were compared to the Ontario sediment quality guidelines for TKN for context.

The most abundant species were the cyanophytes *Coelosphaerium* sp. and *Pseudoanabaena* sp., which accounted for 64.29 % and 24.17 %, respectively, of the total biomass in the lake. Both of these genera are toxin producers.

3.3.5 Zooplankton

A single zooplankton sample was collected across a depth of approximately 2 m near the centre of Lalor Lake (at water quality site LL-2, Table 10). The only adult zooplankton species detected in Lalor Lake was *Diaptomus oregonensis*. The density of the *D. oregonensis* was estimated to be 197 individuals/m^3. The remainder of the zooplankton community included juvenile *Diaptomus* sp. (copepodites) that numbered approximately 119 individuals/m^3. Lalor Lake contained the lowest diversity of copepod species among the four lakes sampled.

3.3.6 Benthic Invertebrates

Benthic invertebrate samples were collected at water depths between 1.2 and 1.9 m where sediments were generally characterized as organic, soft, and ultra-fine with some instances of aquatic vegetation (Table 11). No samples required splitting in the laboratory.

Benthic invertebrate density ranged between 391 (LL-4B) and 7,478 (LL-2B) individuals/m^2. Larval diptera was the most abundant invertebrate group collected from the lake while other, less abundant, invertebrates included annelids (aquatic worms), amphipods (scuds) and molluscs (clams) (Table 12). Most invertebrates were found at the majority of sites.

3.3.7 Fish Community

Fish collections were conducted in Lalor Lake between September 7 and 8, 2007. Three experimental gill nets were deployed in similar habitat throughout the lake and left overnight (Table 13). No large-bodied fish were captured. Three forage fish species were collected in Lalor Lake using a Swedish gill net and minnow traps.

The species captured in Lalor Lake were brook stickleback (*Culea inconstans*), fathead minnow (*Pimephales promelas*), and central mudminnow (*Umbra limi*). In the northern portions of their ranges, these species are often associated with one another, particularly in bog habitats. The CPUE of each species is presented in Table 14 while the mean lengths, weights, and condition factors of each species captured in Lalor Lake are summarized in Table 15. The linear equation of the relationship between logarithmically transformed length-weight of brook stickleback and fathead minnow is presented in Table 16. The most abundant species captured, regardless of sampling gear, was the brook stickleback; only a single central mudminnow was collected.

3.3.8 Metal Residues in Fish

A total of 20 brook stickleback (10 males and 10 females) and 20 fathead minnow (sex unidentified) captured in Lalor Lake were submitted for analysis of whole-body metal concentrations (individual tissues could not be analysed due to the small size of the fish). Results are summarized in Table 17 and detailed results are presented in Appendix 5. A number of substances were not detected in forage fish, including: antimony; beryllium; bismuth; boron; chromium; molybdenum; nickel; selenium; silver; thallium; tin; titanium; uranium; and vanadium. Concentrations of arsenic, lead, and mercury were below the Manitoba aquatic life tissue residue guidelines for human consumers in all samples (Appendix 5).

3.4 MAW LAKE

Bathymetry and substrate, water and sediment quality, phytoplankton, zooplankton, benthic invertebrates, fish, and fish metal residues were examined in Maw Lake.

3.4.1 Bathymetry and Substrate

Maw Lake is a shallow circular lake with a mean depth of 0.74 m and a maximum depth of 1.37 m (Figure 11). The lake has an area of 0.16 km^2 and a volume of 100,918 m^3. Shoreline vegetation is similar to Lalor Lake; shrub willow is the predominant vegetation overhanging the lake's shoreline. There are three narrow bog areas (two in the north and one in the southwest) along the shore that are mainly shrub willow with sparse trees and cattails. A single high and narrow outcrop of bedrock is situated on the northeast shore. Nearshore substrates are ultra-fine, soft, and organic in most areas although cobble and woody debris are also widely distributed. Shoreline vegetation was similar to Lalor Lake. Based on visual assessment, the bottom of the lake is soft organic silt/clay with some dense clusters of submerged aquatic vegetation.

3.4.2 Water Quality

Three water quality sites were sampled in Maw Lake (Table 1). Maw Lake is small and shallow (the deepest site to effectively take *in situ* readings was one meter; Figure 11) with no evidence of stratification at the time of sampling.

Like Lalor Lake, Maw Lake is clear, slightly alkaline, well-oxygenated (at the time of sampling), and low in phosphorus (tables 3 and 4). The lake is slightly softer than Lalor Lake and is classified as "soft" (CCREM 1987). Ammonia, TP, DO, and pH were within the Manitoba water quality objectives or guidelines for the protection of aquatic life (Williamson 2002) and nitrate was below the CCME PAL guideline (CCME 1999; updated to 2007).

Compared to other lakes in the Study Area and similar to Lalor Lake, Maw Lake is characterized by low productivity (on the basis of chlorophyll *a*; Table 4). Furthermore, Maw Lake is classified as oligotrophic/mesotrophic according to the CCME phosphorus guidance framework trophic categorization (Table 5).

In general, concentrations of metals were low in Maw Lake and a number of metals were not detected, including: antimony; beryllium; bismuth; boron; cadmium; cesium; chromium; cobalt; selenium; silver; tellurium; tin; titanium; thallium; uranium; vanadium; zinc; and zirconium (Table 6). All metals were within MWQSOGs for the protection of aquatic life.

3.4.3 Sediment Quality

Three surficial sediment samples were analysed for nutrients and metals from Maw Lake. All samples contained concentrations of chromium, lead, and zinc below the MB SQGs (Table 7). Arsenic, cadmium, and copper exceeded the MB SQG in two of the samples (Table 8).

Iron, manganese, and nickel were below the Ontario LEL. The mean TP exceeded the Ontario LEL while TN and TOC exceeded the SEL. Concentrations of nutrients were similar to those measured in Lalor and Varnson lakes.

3.4.4 Phytoplankton

A sample was collected for analysis of phytoplankton biomass and taxonomic composition from Maw Lake on September 9, 2007. The total biomass was 174 mg/m^3 and was composed of 22 taxa (Table 9). The most abundant group were cyanophytes (i.e., blue-green algae) and the most abundant genus was overwhelmingly *Microcystis* sp. (58.84%), followed by *Coelosphaerium* sp. (11.03%), *Pseudoanabaena* sp. (7.72%), and *Navicula* sp. (6.80%).

3.4.5 Zooplankton

Similar to Lalor Lake, the two zooplankton tows performed in Maw Lake yielded two species of copepod. The most abundant adult copepod was *Diaptomus oregonensis* (302 individuals/m^3) while *Diaphanosoma leuchtenbergianum* (4 individuals/m^3) was considerably less numerous (Table 10).

3.4.6 Benthic Invertebrates

Benthic invertebrates were sampled at water depths ranging between 0.8 and 1.3 m (Table 11); half of the samples had a strong pungent odour while odourless samples contained aquatic vegetation. Invertebrate density ranged between 348 and 3,043 individuals/m^2 with individuals from the Class Insecta, notably chironomids, comprising the majority of the community (Table 12). Bivalve molluscs (fingernail clams), ostracods (seed shrimp), amphipods, oligochaetes (aquatic worms) and hirudinids (leeches) were also detected in the sample.

3.4.7 Fish Community

A single index and Swedish gill net were each set in Maw Lake for nearly 24 hours on September 9, 2007 (Table 13). Minnow traps were also deployed within the same time period. Similar to Lalor Lake, no large-bodied fish species were captured and the same forage fish species were captured (brook stickleback, fathead minnow, and central mudminnow). Fathead minnow was the most abundant fish captured using Swedish gill nets. Brook stickleback were not abundant in Swedish gill nets or minnow traps yet many (>50) juveniles and adults were captured using a seine. Only a single central mudminnow was captured in a minnow trap. The catch statistics and biological data for each species are given in tables 14 and 15, respectively. Additional biological information regarding the length-weight relationship of brook stickleback and fathead minnow is given in Table 16.

3.4.8 Metal Residues in Fish

Twenty brook stickleback (10 males and 10 females) and 20 fathead minnow (four females and 16 males) captured in Maw Lake were analyzed for metal residues (whole-body) (Table 17). Similar to other lakes, a number of substances were not detected in forage fish, including: antimony; arsenic; beryllium; bismuth; boron; chromium; cobalt; lead; molybdenum; nickel; selenium; silver; thallium; tin; titanium; uranium; and vanadium. Concentrations of arsenic, lead, and mercury were below the Manitoba aquatic life tissue residue guidelines for human consumers in all samples (Appendix 5).

3.5 UNNAMED CREEK 1

Unnamed Creek 1, the stream draining Lalor Lake and ultimately entering Varnson Lake, was sampled for water and sediment quality at one location downstream of Maw Lake (figures 4 and 5). Additionally, seining was conducted at one site in Unnamed Creek 1 to determine fish presence/absence and the community composition (Figure 7).

3.5.1 Water Quality

Water quality was examined at a single site in Unnamed Creek 1 between Maw and Varnson lakes (Table 1). This site was relatively deep (1.5 m) and exhibited some differences in water quality relative to the lakes in the drainage. Total dissolved solids (TDS), pH, and TKN for example, were lower in the creek than in the lakes upstream or in Varnson Lake downstream, while hardness and alkalinity were intermediate between Varnson and Maw lakes and Lalor Lake (Table 4). Conversely, some water quality parameters (e.g., TP, turbidity, total suspended solids [TSS], colour, chlorophyll *a*) were relatively similar in the creek and lakes in the drainage. On the basis of TP, Unnamed Creek 1 would be considered oligotrophic (Table 5).

Dissolved oxygen was also relatively low at this site (5.12 mg/L) and did not meet the most stringent MWQSOG for cool-water species (6.0 mg/L; Table 3). All other routine variables were within MWQSOGs for the protection of aquatic life and nitrate was below the CCME PAL guideline.

Concentrations of metals in Unnamed Creek 1 were similar to the lakes in the drainage and all were below MWQSOGs for the protection of aquatic life (Table 6).

3.5.2 Sediment Quality

Sediment quality in Unnamed Creek 1 was similar to Maw, Varnson, and Lalor lakes. The two exceptions were copper, which was higher than the lakes, and sodium, which was lower than the lakes (Table 7). Of the metals, cadmium and copper exceeded the MB SQGs. As observed in the nearby lakes, TN and TOC exceeded the Ontario SEL and TP exceeded the LEL.

3.5.3 Fish community

Unnamed Creek 1 is a low velocity stream that drains into Varnson Lake. The presence of fish was examined by seining along a stretch of approximately 15 m in Unnamed Creek 1 near Varnson Lake to determine whether the creek provided habitat for fish. The creek was estimated to be 2 m wide and 1.5 m deep, with a velocity under 0.5 m/s (visual assessment) near the area that was fished. The shores of the creek were very unstable due to the hummocky terrain. The creek channel flows through a wide bog area that is predominantly composed of sedges. Only two fish, a central mudminnow and a fathead minnow, were captured in Unnamed Creek 1.

3.6 VARNSON LAKE

Bathymetry and substrate, water and sediment quality, phytoplankton, zooplankton, benthic invertebrates, fish, and fish metal residues were examined in Varnson Lake.

3.6.1 Bathymetry and Substrate

Varnson Lake has a larger surface area (approximately 0.7 km^2; Figure 12) and greater mean depth (1.73 m) than Lalor or Maw lakes. The volume of the lake is estimated as approximately 1,229,410 m^3 and the maximum recorded depth was 2.57 m. A small island is located near the centre towards the east shore of the lake.

Black and white spruce, jack pine, tamarack and willow shrub are found along the west and east shores of Varnson Lake. The inlet and outlet of the lake are situated at the south and north shores, respectively. These areas have large expanses of bog mainly composed of grasses and hummocky terrain. Other smaller bogs are situated along the west and east shores of the lake. There are many areas where the bedrock is exposed at the shoreline, which produce short cliffs. Much of the shallow area is populated by bulrush and sedges growing several meters offshore along much of the shoreline, particularly in the west. The nearshore substrate is either cobble, smooth bedrock, or ultra-fine organic material with wood detritus.

Areas of the lake deep enough to be surveyed using QTC VIEW V revealed that the dominant substrate was aquatic vegetation and silt. Small pockets of coarse sand and gravel were also detected although these appeared to be situated close to the shore. Patches of soft, flocculent (silt/clay) sediments were found more often near the middle of the lake (Figure 13).

3.6.2 Water Quality

Water quality was measured at three sites in Varnson Lake but due to shallow depths and lack of stratification, no bottom samples were collected for laboratory analysis. Like Lalor and Maw lakes, Varnson Lake was clear, slightly alkaline, well-oxygenated (at the time of sampling), and relatively low in phosphorus (tables 3 and 4). Water hardness was similar to Maw Lake (i.e., "soft") and lower than Lalor Lake. Ammonia, TP, DO, and pH were within the Manitoba water quality objectives or guidelines for the protection of aquatic life (Williamson 2002) and nitrate was below the CCME PAL guideline (CCME 1999; updated to 2007).

Varnson Lake had a slightly higher TP concentration than Maw or Lalor lakes and was classified as mesotrophic according to the CCME phosphorus guidance framework trophic categorization (Table 5). Additionally, chlorophyll *a* concentrations were higher than Lalor or Maw lakes but relatively low compared to Cook, Tern, and Squall lakes or Snow Lake Narrows (Table 4).

As observed in other lakes in the Study Area, concentrations of most metals were low in Varnson Lake and a number of metals were not detected, including: antimony; beryllium; bismuth; boron; cadmium; cesium; chromium; cobalt; mercury; selenium; silver; tellurium; tin; thallium; uranium; zinc; and zirconium (Table 6). All metals were within MWQSOGs for the protection of aquatic life.

3.6.3 Sediment Quality

Sediment quality was examined at one site in Varnson Lake (VL-2). With one exception, all metals/metalloids for which there are Manitoba or Ontario sediment quality guidelines were below the guidelines. The sole exception was for nickel which exceeded the Ontario LEL (Table 7). Nutrients also exceeded Ontario guidelines with both TN and TOC exceeding the SEL and TP exceeding the LEL.

3.6.4 Phytoplankton

Total phytoplankton biomass in Varnson Lake (451 mg/ m^3) was higher than the other three lakes examined and was composed of 35 taxa (Table 9). The relative abundance of major classes was similar to Maw and Lalor lakes, with cyanophytes dominating the community (Figure 10). However, chlorophytes comprised a greater fraction of the overall abundance than in the other lakes.

The most abundant species were the cyanophyte *Coelosphaerium* sp. (225 mg/ m^3) and the chlorophyte *Dictyosphaerium pulchellum* (129.60 mg/ m^3). Collectively, these two species comprised approximately 80% of the phytoplankton community.

3.6.5 Zooplankton

The zooplankton community of Varnson Lake was similar to those observed in Maw and Lalor lakes as it was dominated by *Diaptomus* copepods (Table 10). However, the community in Varnson Lake was more diverse as it also contained daphnia, copepods, and aquatic arachnids. The daphnia species included *Holopedium gibberum* (13 individuals/m^3) and *Diaphanosoma leuchtenbergianum* (9 individuals/m^3).

3.6.6 Benthic Invertebrates

Benthic invertebrate samples were collected at six sites in Varnson Lake from water depths ranging between 1.2 and 1.8 m (Table 11). Sediments were visually described as organic, soft, and ultra-fine with aquatic vegetation present at all sites; a single site (VL-3B) also contained woody debris. Foul odours were not detected from any of the samples.

Benthic invertebrate density varied widely across sites in Varnson Lake, ranging from 0 to 20,343 individuals/ m^2 (Table 12). Organisms from the Class Insecta, particularly from the Order Diptera, were the most abundant invertebrates detected in the lake; with densities ranging from 174 and 17,565 individuals/m^2. With the exception of site VL-4B, where no invertebrates were found, bivalves were captured at all sites and gastropods were abundant at sites VL-1B and VL-2B. Remaining invertebrates were found sporadically throughout the lake.

3.6.7 Fish Community

Two index gill nets (Table 13) and two Swedish gill nets were set overnight in Varnson Lake. Consistent with the other waterbodies sampled in the drainage basin, no large-bodied fish were captured. Also consistent with results from other lakes, three species of forage fish were captured (brook stickleback, fathead minnow, and central mudminnow). CPUE and biological data for fish captured in Varnson Lake are presented in tables 14-16.

3.6.8 Metal Residues in Fish

Central mudminnow (nine females and 11 males) and fathead minnow (12 females and seven males) were analysed for whole-body concentrations of metals (Table 17). Results were similar to those obtained for other lakes in the area and many substances were below analytical detection limits.

With one exception, concentrations of mercury, arsenic, and lead were below MB aquatic life tissue residue guidelines for human consumers. The exception was a single female fathead minnow which contained mercury at the guideline level (0.5 µg/g w.w., Appendix 5).

3.7 COOK LAKE

Cook Lake is a relatively large and deep lake west of Lalor Lake (Figure 1). Samples were collected to describe the lake water and sediment quality only.

3.7.1 Water Quality

Water quality samples were taken at three sites in Cook Lake (Table 1); samples were collected at the surface and at depth. Similar to adjacent lakes, Cook Lake is relatively clear, slightly alkaline, well-oxygenated (at the time of sampling), moderately hard, and was not stratified at the time of sampling (tables 3 and 4). Results for TDS and conductivity were inconsistent; lab and *in situ* conductivities were relatively high and approximated those measured in Lalor Lake. Conversely, TDS concentrations were among the lowest measured in the Study Area. Ammonia, TP (lake-wide mean), DO, and pH were within the Manitoba water quality objectives or guidelines for the protection of aquatic life (Williamson 2002) and nitrate was below the CCME PAL guideline (CCME 1999; updated to 2007). One sample contained TP above the MB narrative guideline for lakes (0.025 mg/L).

Unlike the adjacent lakes, Cook Lake is more phosphorus-rich (mean lake concentration of 0.024 mg/L) and is classified as meso-eutrophic according to the CCME phosphorus guidance framework trophic categorization (Table 5). Similarly, Cook Lake contained a relatively high concentration of chlorophyll *a* (lake-wide mean of 9 µg/L), indicating relatively high productivity.

In general, concentrations of metals are low in Cook Lake and all metals were within MWQSOGs for the protection of aquatic life.

3.7.2 Sediment Quality

Sediment quality, which was examined at three sites in Cook Lake (Table 1), was similar to that measured throughout the Study Area. The exception was TP which was somewhat higher in sediments in Cook Lake than other nearby lakes and streams. One sample contained concentrations of chromium, copper, and iron above the MB SQG and all samples contained nickel and TP above the Ontario LEL and TOC and TN above the SEL (Table 7).

3.8 UNNAMED LAKE 1

Unnamed Lake 1 is a small, shallow lake located east of Cook Lake. Water and sediment quality were measured at a single site near the center of the basin; three benthic grabs were collected to evaluate the abundance and community composition of benthic invertebrates.

3.8.1 Water Quality

Water quality of Unnamed Lake 1 is similar to Cook Lake and other nearby lakes and is relatively clear, slightly alkaline, and well-oxygenated (at the time of sampling). The lake is soft and is classified as oligotrophic (Table 5). The concentration of chlorophyll *a* was lower than in Cook Lake but higher than in Maw, Lalor, or Varnson lakes (Table 4). Ammonia, TP (lake-wide mean), DO, and pH were within the Manitoba water quality objectives or guidelines for the protection of aquatic life (Williamson 2002) and nitrate was below the CCME PAL guideline (CCME 1999; updated to 2007).

As observed in Cook Lake, concentrations of metals are low in Unnamed Lake 1 and all metals were within MWQSOGs for the protection of aquatic life.

3.8.2 Sediment Quality

Sediment quality in Unnamed Lake 1 was similar to that observed in Cook Lake and in other lakes in the adjacent drainage. Relative to Cook Lake, sediments contained lower concentrations of a number of substances, including aluminum, nickel, potassium, magnesium, chromium, cobalt, sodium, and a higher concentration of other substances, including calcium and manganese (Table 7). All metals were within MB SQGs. Manganese and TP exceeded the Ontario LEL and TN and TOC exceeded the SEL.

3.8.3 Benthic Invertebrates

Benthic invertebrates were sampled at sites ranging in water depths between 0.9 and 1.5 m (Table 11). Similar to other lakes, the three sediment samples were described as organic, soft, and ultra-fine. Vegetation was present at site UL1-1B and the sediments had a pungent odour.

Unnamed Lake 1 had the lowest abundance of benthic invertebrates in the Study Area with values ranging between 0 and 522 individuals/m^2 (Table 12). Oligochaetes, ostracods, amphipods (Talitridae), bivalves clams (Pisidiidae), trichopterans, and chironomids were detected at site UL1-1B. Chironomid larvae were the only invertebrates found at site UL1-3B. No invertebrates were found in the samples from site UL1-2B.

3.9 SQUALL LAKE

Squall Lake is a relatively large and deep lake that drains to Snow Creek and Snow Lake to the southeast. Water and sediment quality were examined in Squall Lake.

3.9.1 Water Quality

Water quality of Squall Lake can be generally described in similar terms as the lakes to the southwest; it is slightly alkaline, well-oxygenated (at the time of study), and soft. Other parameters were somewhat different than the other lakes, including TSS/turbidity and chlorophyll *a*, which were higher in Squall Lake. There was no indication of stratification at the four sites examined, although *in situ* measurements could not be collected at depth at three of the sites due to the length of the meter cord.

Squall Lake is moderately nutrient-rich with the lake-wide average total phosphorous concentration (0.017 mg/L) representative of a mesotrophic status (Table 5). Ammonia, TP (lake-wide mean), DO, and pH (tables 3 and 4) were within the Manitoba water quality objectives or guidelines for the protection of aquatic life (Williamson 2002) and nitrate was below the CCME PAL guideline (CCME 1999; updated to 2007).

Like other lakes discussed thus far, metals/metalloids were generally low in Squall Lake and most were present at concentrations below the MWQSOGs for the protection of aquatic life (Table 6). The exceptions occurred in the same sample (SL-1) where aluminum and selenium both slightly exceeded the water quality guidelines for the protection of aquatic life.

Water quality data collected at a site in the northeast arm of Squall Lake in September 2000 (Bezte and Fazakas 2001) were compared with lake-wide means obtained from this study (Table 18). The data collected in 2000 represent a surface grab that was collected at a nearshore site with a depth of 1.8 m. Most water quality parameters were similar between years; the notable exceptions were iron, which was higher in 2007, and zinc, which was lower in 2007.

3.9.2 Sediment Quality

Sediment quality in Squall Lake was similar to that observed in Snow Lake Narrows. Chromium exceeded the Manitoba SQG and iron, manganese, nickel, TOC, and TP (except in one sample) exceeded the Ontario LELs (Table 7). Additionally, TN exceeded the Ontario SEL for TKN. Some parameters were highest in Squall Lake sediments of all the waterbodies examined (with the possible exception of site SLN-1), including: aluminum; barium; cobalt; iron; magnesium; manganese; and potassium.

Sediment quality measured at a site in Squall Lake in 2000 (the sampling site was consistent with the water quality site discussed in Section 3.9.1) was compared with the lake-wide mean measured in 2007 (Table 19). A number of parameters were qualitatively higher in sediments collected in 2007, including: aluminum; arsenic; barium; calcium; chromium; copper; iron; lead; magnesium; manganese; nickel; titanium; vanadium; and zinc. This qualitative comparison may reflect actual changes, spatial variability, changes in analytical methodologies, and/or the sediment fraction analysed (i.e., in 2000 the upper 10 cm were analysed whereas only the upper 5 cm were analysed in 2007).

3.10 SNOW CREEK

Water and sediment quality were examined at two sites in Snow Creek: (1) one site approximately mid-way between Squall Lake and Snow Lake Narrows (approximately 20 m upstream of the power line crossing); and (2) a second site near the mouth of the creek (approximately 275 m upstream of the mouth) as it drains into Snow Lake Narrows.

3.10.1 Water Quality

Most routine water quality parameters were similar in Snow Creek to Squall Lake upstream. However, TP, hardness, specific conductance and colour were higher and TSS and chlorophyll *a* were lower than in Squall Lake. The stream would be classified as meso-eutrophic on the basis of TP (Table 5). Ammonia, TP, DO, and pH were within the Manitoba water quality objectives or guidelines for the protection of aquatic life (Williamson 2002) and nitrate was below the CCME PAL guideline (CCME 1999; updated to 2007).

Several metals were notably higher at the upstream site in Snow Creek than either the downstream site in the creek, Squall Lake, or Snow Lake Narrows, including: aluminum; barium; iron; and titanium. In particular, aluminum and iron were much higher in the creek and measurements from both sites exceeded the water quality guidelines for the protection of aquatic life. All other substances were within the Manitoba water quality objectives or guidelines.

3.10.2 Sediment Quality

In contrast to water quality results, most sediment quality parameters were higher in Snow Creek near the mouth than upstream although in general, concentrations were lower than sites upstream in Squall Lake or downstream in Snow Lake Narrows. This may be a result, at least in part, of the relatively higher concentration of organic carbon and higher fraction of silt and clay in sediments from the site near the mouth (SC-2). Sediments near the mouth exceeded the Ontario LEL for nickel, TP, TOC, and manganese and the SEL for TKN, while sediments upstream only exceeded the Ontario LEL for TKN and TOC.

3.11 SNOW LAKE NARROWS

Water and sediment quality were examined at three sites in Snow Lake Narrows (Table 1).

3.11.1 Water Quality

Overall, Snow Lake Narrows is well-oxygenated (at the time of sampling), slightly alkaline, soft, and relatively nutrient-rich. There was no indication of stratification at the time of sampling. However, *in situ* readings could not be obtained at depth at site SLN-1 due to the length of the meter cord. The lake would be classified as meso-eutrophic on the basis of the lake-wide mean TP concentration measured at the time of the study (Table 5). All measurements of TP exceeded the Manitoba guideline for the prevention of nuisance plant and algal growth. Other routine variables were within Manitoba water quality objectives and guidelines and nitrate was well below the CCME guideline for the protection of aquatic life. The lake exhibited relatively high productivity with a lake-wide mean chlorophyll *a* concentration of.10 µg/L (Table 4).

Most metals were relatively low and only iron exceeded the Manitoba water quality PAL guideline at site SLN-1. Iron, manganese, and TP exhibited a gradient across the sites, decreasing from west to east, whereas other parameters were generally similar across sites (Table 6).

3.11.2 Sediment Quality

All sediment quality parameters which exceeded analytical detection limits by a reasonable margin exhibited a gradient of decreasing concentrations from west to east in Snow Lake Narrows. This may reflect the differences in organic carbon content and the fraction of silt and clay in the sediment samples, as all three of these parameters also exhibited a decreasing gradient from site 1 to 3. Site SNL-3 was in fact largely composed of sand, which may account for the lower concentrations of metals.

Manitoba SQGs were exceeded for arsenic at SLN-1 and SLN-2 and for chromium and copper at SLN-1 (Table 7). There were a number of samples that exceeded Ontario SQGs:

- Iron exceeded the LEL at SLN-1;
- Manganese, TP and nickel exceeded the LEL at SLN-1 and SLN-2;
- TOC exceeded the LEL at all sites; and
- TN exceeded the LEL for TKN at SLN-2 and SLN-3 while TN exceeded the SEL at SLN-1 (Table 7).

3.12 TERN CREEK

Tern Creek drains north to Snow Lake Narrows. Water and sediment quality were examined at a single site in the stream (figures 3, 4, and 5).

3.12.1 Water Quality

Tern Creek is slightly alkaline, coloured, clear, moderately hard, and relatively nutrient-poor. The stream is classified as oligotrophic on the basis of TP (Table 5), which is supported by the low chlorophyll *a* concentration. Ammonia, TP, DO, and pH (tables 3 and 4) were within the Manitoba water quality objectives and guidelines for the protection of aquatic life (Williamson 2002) and nitrate was below the CCME PAL guideline (CCME 1999; updated to 2007). Although DO was somewhat reduced at this site, it remained above the most stringent water quality objective for the protection of cool-water aquatic life.

All metals/metalloids were present at concentrations below MWQSOGs for the protection of aquatic life and in general, concentrations were similar to those observed at other sites in the Study Area (Table 6).

3.12.2 Sediment Quality

Sediment quality in Tern Creek was similar to that observed in Tern Ditch and other sites in the Study Area (Table 7). Most parameters were below Manitoba or Ontario SQGs; exceptions included arsenic which exceeded the Manitoba probable effect level (PEL), TN and TOC which exceeded the Ontario SEL, and TP, which exceeded the Ontario LEL.

3.13 TERN DITCH

Tern Ditch drains north to Tern Lake. Water and sediment quality were examined at a single site in the stream (figures 3, 4 and 5).

3.13.1 Water Quality

Water quality of Tern Ditch is considerably different than that of other streams or lakes in the Study Area and many parameters are notably higher in this system. Overall, the ditch is nutrient-rich, containing high concentrations of TOC, TP, and TKN, contains a moderately high concentration of TDS and TSS, and is highly coloured. Tern Ditch also contained a particularly high concentration of chlorophyll *a* (47 μg/L), indicating very high productivity. On the basis of TP, the system would be classified as eutrophic (Table 5). Ammonia, DO, and pH were within the Manitoba water quality objectives or guidelines for the protection of aquatic life (Williamson 2002) and nitrate was below the CCME PAL guideline (CCME 1999; updated to 2007). TP, however, exceeded the Manitoba guideline for streams (0.050 mg/L).

As observed in Snow Creek, only two metals (iron and aluminum) exceeded the MWQSOGs for the protection of aquatic life in Tern Ditch. However, many metals/inorganics, most notably aluminum, arsenic, barium, calcium, iron, manganese, magnesium strontium, and titanium, were the highest observed in the Study Area (Table 6).

3.13.2 Sediment Quality

Sediment quality in Tern Ditch was similar to that observed in Tern Creek and most parameters were below Manitoba or Ontario SQGs (Table 7). The notable exception was arsenic, which exceeded the Manitoba PEL. Additionally, similar to observations across the Study Area, TN and TOC were relatively high and both exceeded the Ontario SEL. Unlike the high TP concentration observed in water, sediments contained a relatively low concentration of phosphorus that was within Ontario SQGs.

3.14 TERN LAKE

Bathymetry and substrate, water and sediment quality, phytoplankton, zooplankton, benthic invertebrates, fish, and fish metal residues were examined in Tern Lake.

3.14.1 Lake Bathymetry and Substrate

Tern Lake is a small (0.15 km^2), circular, shallow lake with an average and maximum depth of 1.61 and 2.24 m, respectively (Figure 14). Tern Lake is surrounded by mainly softwood trees although a relatively narrow band of bog habitat consisting predominantly of grass surrounds the lake. Two separate small outcrops of Precambrian shield bedrock interrupt the bog habitat at the southern end of the lake.

The substrate survey revealed that, similar to the other lakes, the dominant substrate around the margins of the lake consists of vegetation and silt. Sporadic patches of coarse sand/gravel are found among the vegetation and silt substrate. Areas near the middle of the lake are composed primarily of soft flocculent (silt/clay) sediments (Figure 15).

3.14.2 Water Quality

Tern Lake is slightly alkaline, relatively clear, moderately hard, and moderately nutrient-rich (Table 4). The lake is classified as mesotrophic on the basis of TP (Table 5). The trophic status, TP, and chlorophyll *a* concentrations of Tern Lake were nearly identical to those observed in Squall Lake. Other parameters were somewhat different, however, including TKN, TOC, TDS, hardness, and colour, all of which were higher in Tern Lake than in Squall Lake or Snow Lake Narrows. This likely reflects the size of the lake and its drainage; elevated concentrations of these parameters were noted in Tern Creek and Tern Ditch.

Ammonia, TP, DO, and pH were within the Manitoba water quality objectives or guidelines for the protection of aquatic life (Williamson 2002) and nitrate was below the CCME PAL guideline (CCME 1999; updated to 2007). All metals/metalloids were present at concentrations below MWQSOGs for the protection of aquatic life and in general, concentrations were similar to those observed at other sites in the Study Area.

3.14.3 Sediment Quality

Sediment quality in Tern Lake was similar to that observed elsewhere in the Study Area, although some parameters were lower than observed in Squall Lake or Snow Lake Narrows. Most parameters were below Manitoba or Ontario SQGs; the sole exceptions were for nutrients, where TN and TOC exceeded the Ontario SELs.

3.14.4 Phytoplankton

Tern Lake had a relatively high concentration of chlorophyll *a* (11 μg/L) but the lowest total biomass of phytoplankton (125 mg/m^3) of the four lakes examined (Table 9). The community composition differed from the other lakes, with chrysophytes followed by cryptophytes dominating in terms of biomass (Figure 10). The most abundant species were unidentified chrysophytes (41%) followed by the cryptophyte *Rhodomonas minuta* (21%) and the chlorophyte *Monoraphidium* sp. (19%).

3.14.5 Zooplankton

Of the four lakes examined, Tern Lake had the most diverse zooplankton community and the highest density of zooplankton at the time of sampling (Table 10). The most abundant zooplankton was the copepod *Diaptomus oregonensis* (2,019 individuals/m^3).

3.14.6 Benthic Invertebrates

Benthic invertebrate samples were collected at three sites in Tern Lake at water depths ranging between 1.1 and 1.6 m (Table 11). Sediment from all three samples was described as organic, soft, and ultra-fine while two contained vegetation and one had a pungent odour.

Tern Lake had the highest average benthic invertebrate density of the lakes examined in the Study Area, with abundances ranging between 913 and 29,391 individuals/m^2 (Table 12). The highest total density was observed at site TL-3B. The most abundant invertebrates were larval dipterans (chironomids, non-biting midges). Tern Lake was the only site where crustaceans were not detected.

3.14.7 Fish Community

A single index gill net, two Swedish gill nets and four minnow traps were set for nearly 48 hours each on September 11, 2007. No large-bodied fish and only 20 brook stickleback were captured. The catch statistics and summarized biological data are presented in tables 14 and 15, respectively.

3.14.8 Metal Residues in Fish

Metals analyses were performed on the twenty brook stickleback (eight females and 12 males) captured in Tern Lake. Concentrations of arsenic, lead, and mercury were below the Manitoba aquatic life tissue guidelines for human consumers in all samples (Table 17 and Appendix 5).

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