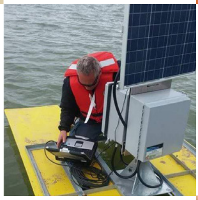
Coordinated Aquatic Monitoring Program



# Six Year Summary Report

## Technical Document 5: Upper Churchill River Region

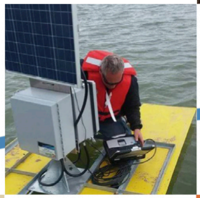
2008-2013

Submitted to:
Manitoba/Manitoba Hydro MOU Working Group

2017

**Report Citation:**

Coordinated Aquatic Monitoring Program (CAMP). 2017. Six Year Summary Report (2008-2013). Report prepared for Manitoba/Manitoba Hydro MOU Working Group by North/South Consultants Inc., Winnipeg, MB.



## TECHNICAL DOCUMENT 1:
Introduction, Background, and Methods

- Introduction and background
- CAMP regional descriptions
- Sampling and laboratory methods
- Reporting approach and data analysis methods

## TECHNICAL DOCUMENT 2:
Winnipeg River Region Results

- Introduction
- Hydrology
- Water quality
- Sediment quality
- Benthic macroinvertebrates
- Fish community
- Mercury in fish

## TECHNICAL DOCUMENT 3:
Saskatchewan River Region Results

- Introduction
- Hydrology
- Water quality
- Sediment quality
- Benthic macroinvertebrates
- Fish community
- Mercury in fish
- Aquatic habitat

## TECHNICAL DOCUMENT 4:
Lake Winnipeg Region Results

- Introduction
- Hydrology
- Water quality
- Sediment quality
- Benthic macroinvertebrates
- Fish community
- Mercury in fish

## TECHNICAL DOCUMENT 5:
Upper Churchill River Region

- Introduction
- Hydrology
- Water quality
- Sediment quality
- Benthic macroinvertebrates
- Fish community
- Mercury in fish
- Aquatic habitat

## TECHNICAL DOCUMENT 6:
Lower Churchill River Region Results

- Introduction
- Hydrology
- Water quality
- Sediment quality
- Benthic macroinvertebrates
- Fish community
- Mercury in fish

## TECHNICAL DOCUMENT 7:
Churchill River Diversion Region Results

- Introduction
- Hydrology
- Water quality
- Sediment quality
- Benthic macroinvertebrates
- Fish community
- Mercury in fish

## TECHNICAL DOCUMENT 8:
Upper Nelson River Region Results

- Introduction
- Hydrology
- Water quality
- Sediment quality
- Benthic macroinvertebrates
- Fish community
- Mercury in fish
- Aquatic habitat

## TECHNICAL DOCUMENT 9:
Lower Nelson River Region Results

- Introduction
- Hydrology
- Water quality
- Sediment quality
- Benthic macroinvertebrates
- Fish community
- Mercury in fish

# SIX YEAR SUMMARY REPORT (2008-2013)

## Technical Document 5:

## Upper Churchill River Region Results

by

North/South Consultants Inc.
83 Scurfield Blvd.
Winnipeg, MB R3Y 1G4
Tel: (204) 284-3366 Fax: (204) 477-4173
Email: info@nscons.ca

2017

CAMP

# TABLE OF CONTENTS

**Page**

**Page**

**Page**

# LIST OF TABLES

**Page**

**Page**

# LIST OF FIGURES

**Page**

**Page**

**Page**

**Page**

**Page**

**Page**

**Page**

**Page**

**Page**

**Page**

# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| ASL | Above sea level |
| BMI | Benthic macroinvertebrate(s) |
| CAMP | Coordinated Aquatic Monitoring Program |
| CCME | Canadian Council of Ministers of the Environment |
| CL | Confidence limit |
| cms | Cubic metres per second |
| CPUE | Catch-per-unit-effort |
| CRD | Churchill River Diversion |
| CS | Control structure(s) |
| DO | Dissolved oxygen |
| DOC | Dissolved organic carbon |
| DL | Detection Limit |
| EPT | Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies) |
| EPT:C | Ratio of the combined abundances of Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies) to the abundance of Chironomidae (non-biting midges) |
| FL | Fork length |
| GAU | Gauer Lake |
| GRV | Granville Lake |
| ISQG | Interim sediment quality guideline |
| $K_F$ | Condition Factor |
| LCRR | Lower Churchill River Region |
| LEL | Lowest effect level |
| LWCNRSB | Lake Winnipeg, Churchill and Nelson Rivers Study Board |
| MWQSOGs | Manitoba Water Quality Standards, Objectives, and Guidelines |
| MWS | Manitoba Water Stewardship |
| OPACH | Opachuanau Lake |
| PAL | Protection of aquatic life |
| PEL | Probable effect level |
| ppm | Parts per million |
| RCEA | Regional cumulative effects assessment |
| SAC | Sediment alert concentration |
| SE | Standard error of the mean |
| SEL | Severe effect level |
| SIL | Southern Indian Lake |
| SQG | Sediment quality guidelines |
| TDS | Total dissolved solids |
| TKN | Total Kjeldahl nitrogen |
| TN | Total nitrogen |
| TOC | Total organic carbon |
| TP | Total phosphorus |
| TSS | Total suspended solids |

| | |
|---|---|
| UCRR | Upper Churchill River Region |
| WL (GN) | Average water level during the gillnetting program |
| WSL | Water surface level |

# 1.0 INTRODUCTION

The following presents a description of results of monitoring conducted under the Coordinated Aquatic Monitoring Program (CAMP) for years 1 through 6 (i.e., 2008/2009 through 2013/2014) in the Upper Churchill River Region (UCRR). As described in Technical Document 1, Section 2.4.1, the UCRR is composed of the Churchill River watershed extending from the Saskatchewan/Manitoba border downstream to the natural outlet of Southern Indian Lake at Missi Falls (i.e., the Missi Falls Control Structure [CS]) and the man-made outlet at South Bay. It includes Granville, Opachuanau, and Southern Indian lakes. Granville Lake is considered an off-system waterbody, because water levels are not affected by the Churchill River Diversion (CRD) the majority of the time; a measureable backwater effect occurs less than 10 percent of the time when low flows occur on the upper Churchill River (and consequently low Granville Lake levels) in conjunction with Southern Indian Lake being near its maximum operating limit. Historical studies of Southern Indian Lake typically divided the lake into seven areas (Areas 1-7) and three of these areas (1, 4, and 6) are monitored under CAMP. Monitoring areas in the UCRR include the following:

- Granville Lake (off-system);
- Opachuanau Lake;
- Southern Indian Lake – Area 1;
- Southern Indian Lake – Area 6; and
- Southern Indian Lake – Area 4.

Monitoring results for an off-system lake (i.e., Gauer Lake) are also considered in the following presentation of results; while Gauer Lake is formally considered part of the Lower Churchill River Region (LCRR) under CAMP, this site is intended to provide contextual information for the interpretation of monitoring results for both the UCRR and the LCRR.

Descriptions of the region and waterbodies monitored under CAMP are provided in Technical Document 1, Section 2.4. As described in Technical Document 1, Section 1.2.2.1, sampling of on-system waterbodies addresses the primary objective of CAMP – to monitor aquatic ecosystem health along Manitoba Hydro's hydraulic operating system. The off-system waterbodies were included in CAMP to provide regional information collected in a manner consistent with monitoring of on-system waterbodies that will assist in interpreting any observed environmental changes over time. Such comparisons are intended to help distinguish between hydroelectric-related effects and other external factors (e.g., climate change) in each CAMP region.

A summary of monitoring conducted by waterbody or river reach is provided in Table 1-1 and monitoring areas are shown in Figure 1-1. As noted in Table 1-1, monitoring was conducted annually in some areas and on a three-year rotation at other sites. Components monitored in the UCRR over this time period include hydrology, aquatic habitat, water quality, sediment quality, phytoplankton, benthic macroinvertebrates (BMI), fish community, and mercury in fish.

Results presented below include a discussion of hydrology, water quality, sediment quality, BMI, fish community, and fish mercury for key metrics, as described in Technical Document 1. Observations of note for additional metrics are also provided in the following for the water quality, BMI, and fish community components. Results of an aquatic habitat survey completed in Southern Indian Lake – Area 4 (surveyed in 2013) are also provided below.

The terms of reference for the six year summary report specified that the reporting would include an exploratory analysis of available data for key indicators and metrics to:

- provide a preliminary evaluation of potential trends within the six year monitoring period; and
- provide an initial review of data to explore potential relationships between biological and chemical metrics and hydrological conditions.

It is recognized that although a large quantity of data was acquired over the initial six years of CAMP, these data are relatively limited in terms of monitoring for long-term trends and/or relationships with physical (and other) variables due to the short temporal period. As noted in Technical Document 1, six years of data may be insufficient to detect trends over time, notably long-term trends. Additionally, any indications of potential trends over the six year period do not necessarily imply a long-term trend is occurring, as apparent trends over this interval may simply reflect the relatively limited time period assessed in conjunction with inter-annual variability in a metric. Consideration of a longer period of record is required to evaluate for long-term trends.

In addition, many of the regions experienced high flows/water levels for most of the six year monitoring period and the lower range of the hydrographs was generally underrepresented or lacking altogether. This further limited the ability to explore broad-scale relationships between hydrological conditions and chemical and biological metrics. In addition, it is cautioned that identification of significant correlations between chemical or biological and hydrological metrics does not infer a causal relationship (i.e., correlations simply indicate that two metrics are related). Lastly, the scope of these initial analyses was limited to a relatively high-level exploratory approach. For these reasons, discussions of trends and relationships with hydrological conditions discussed herein are considered exploratory/preliminary and are expected to be revised and updated as additional data are acquired.

Table 1-1. Overview of CAMP sampling in the Upper Churchill River Region: 2008/2009-2013/2014.

| Waterbody/Area | Site Abbreviation | On-system | Off-system | Annual | Rotational | Sampling Years[1] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 2008/09 | 2009/10 | 2010/11 | 2011/12 | 2012/13 | 2013/14 |
| Granville Lake | GRV | | X | X | | X | X | X | X | X | X |
| Opachuanau Lake | OPACH | X | | | X | | | | X | | |
| Southern Indian Lake – Area 1 | SIL-1 | X | | | X | | X | | | X | |
| Southern Indian Lake – Area 6 | SIL-6 | X | | | X | | | X | | | X |
| Southern Indian Lake – Area 4 | SIL-4 | X | | X | | X | X | X | X | X | X |
| Gauer Lake[2] | GAU | | X | X | | X | X | X | X | X | X |

[1] Note that not all components were sampled at the frequency indicated for all waterbodies/areas. See descriptions provided for each monitoring component for details.

[2] Site formally included in the LCRR; included here for discussion of results for the UCRR.

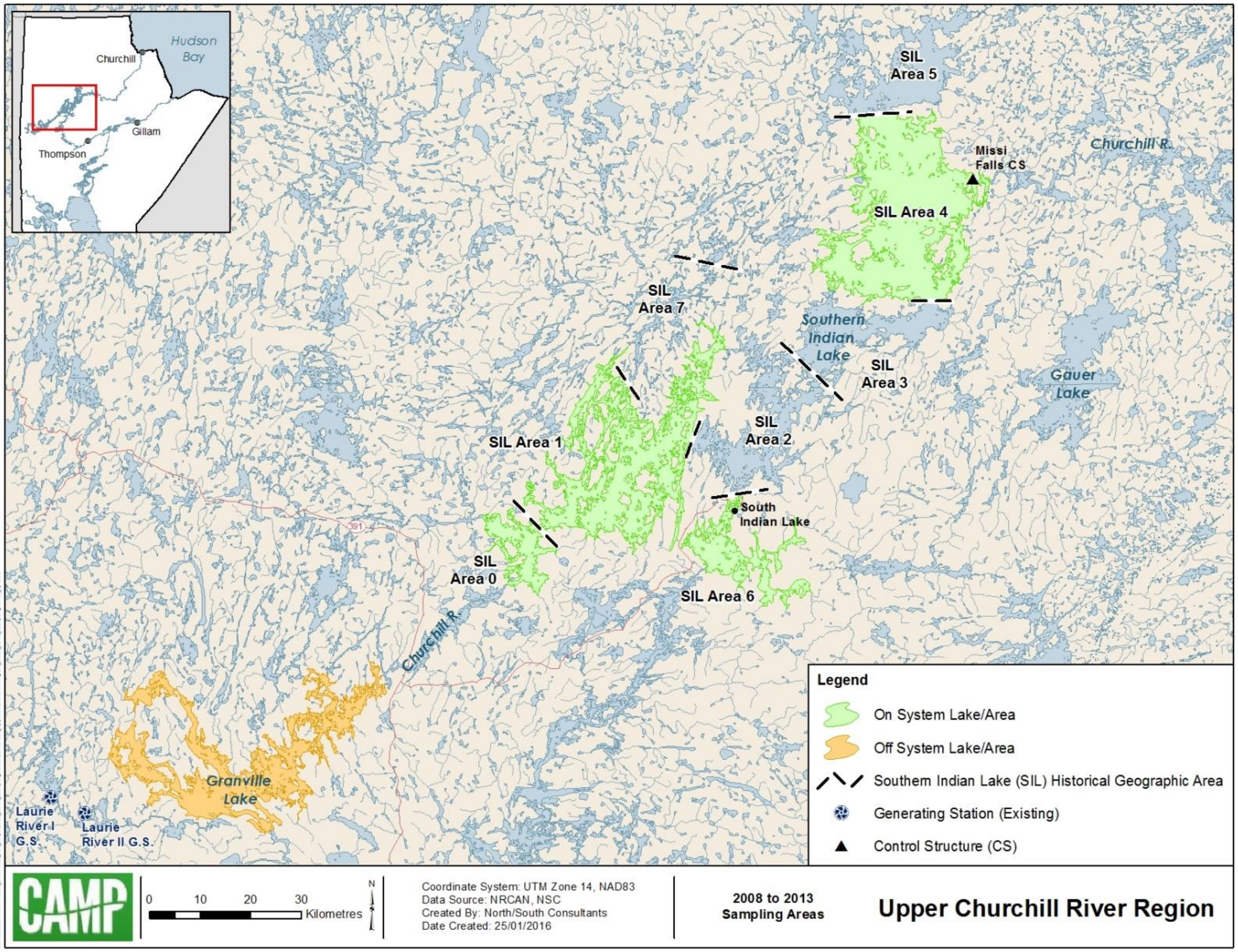



Figure 1-1. On-system and off-system waterbodies and river reaches sampled under CAMP in the Lower Churchill River Region: 2008/2009-2013/2014.

# 2.0 HYDROLOGY

Upper Churchill River flows entering Manitoba are influenced by run-off from snow-melt and precipitation across the Churchill River drainage basin, which begins in Alberta and covers a large portion of northwestern Saskatchewan. The drainage basin includes several large lakes which act as reservoirs, the largest being Reindeer Lake along the Manitoba-Saskatchewan border. Between 2008 and 2013, CAMP monitoring occurred on Southern Indian Lake and Opachuanau Lake, which act together as a hydroelectric reservoir for Manitoba Hydro as part of CRD. Monitoring also occurred on Granville Lake as the off-system waterbody for this region. Flows for the UCRR are reported based on a gauge at Granville Falls upstream from Granville Lake.

Winter flows on the upper Churchill River were typically within the narrow range between the lower and upper quartile between 2008 and 2013. The exceptions were the winters of 2009/2010 and 2012/2013 where precipitation later in the preceding year led to flows well above the upper quartile throughout the winter. Flows were generally more variable during the open-water season. Peak flows above the upper quartile early in the open-water season occurred in 2008, 2009, and 2012 due to above average snowpack in the basin. High rainfall led to flow peaks above the upper quartile later in the year in 2011 and 2013, as well as a second and large peak in 2009 and a late peak in 2012. Flows remained below average during most of the 2010 open-water season (Figure 2-1).

Southern Indian Lake is a controlled reservoir with water levels typically following a predictable pattern each year. In spring, water levels typically rise because of both increased inflows with the spring freshet and reduced outflows at the Notigi CS related to reduced energy demand. Summer outflows from Southern Indian Lake are managed depending on precipitation conditions and inflows, such that water levels peak in late summer/fall each year. Southern Indian Lake water levels then typically decline steadily through the winter as inflows drop off and discharge at the Notigi CS are maximized to meet Manitoba's higher winter energy requirements. From 2008 to 2013, water levels generally followed this typical trend with the exception that levels remained at near record highs through the winters of 2009/2010 and 2012/2013. This occurred because of high precipitation late in the preceding year despite maintaining outflows at the Notigi CS, and therefore Southern Indian Lake outflows at South Bay, at the *Water Power Act* licensed maximum. Water levels also increased in Southern Indian Lake earlier than normal in the spring of 2012 and later than normal in the springs of 2008 and 2011. In early 2014, water levels decreased but remained above the upper quartile from January through March (Figure 2-2).

Granville Lake water levels followed a similar trend as the upper Churchill River flows from 2008 to 2013. Winter water levels on Granville Lake were typically within a narrow range, and within the lower and upper quartile (259.4 to 260.0 m) between 2008 and 2013. The exceptions were the winters of 2009/2010 and 2012/2013 where precipitation later in the preceding year led to inflows and water levels well above the upper quartile throughout the winter. Granville Lake water levels were generally more variable during the open-water season. Peak water levels above the upper quartile earlier in the open-water season occurred in 2008, 2009 and 2012, due to above-average snowpack in the basin. High open-water season precipitation led to peak water levels above the upper quartile later in the year in 2011 and 2013, as well as a second and large peak in 2009 and a late peak in 2012. Water levels remained close to or below average during most of the 2010 open-water season. Granville Lake levels were also above the upper quartile from January through March of 2014 (Figure 2-3).

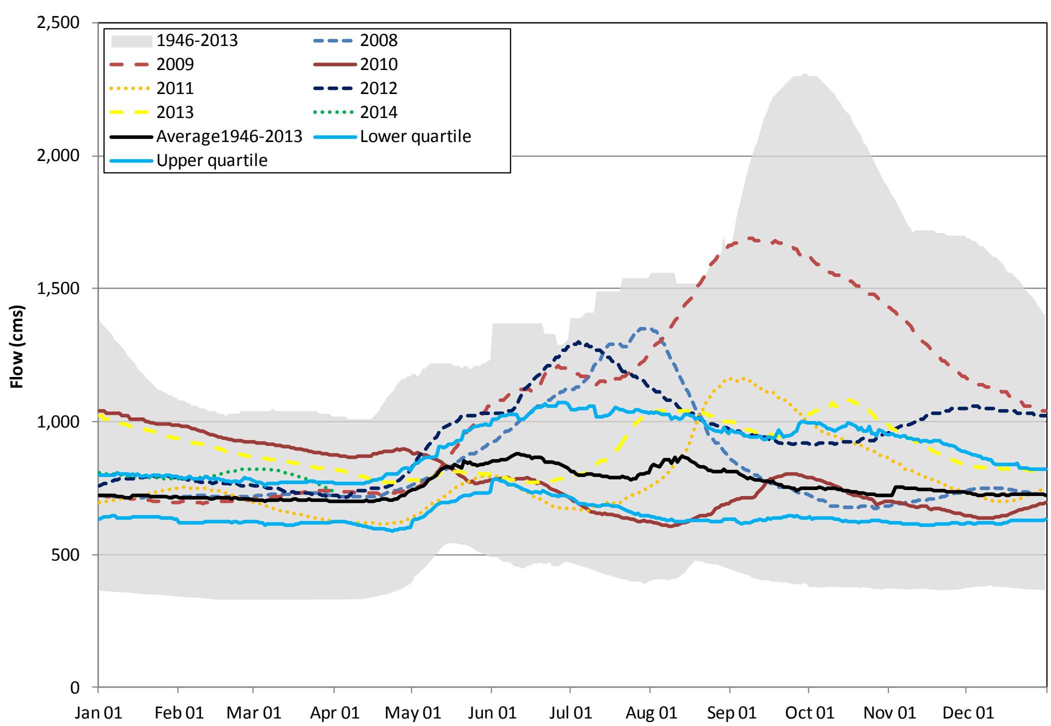



Figure 2-1. Upper Churchill River flow at Granville Falls (06EC006): 2008-2013.

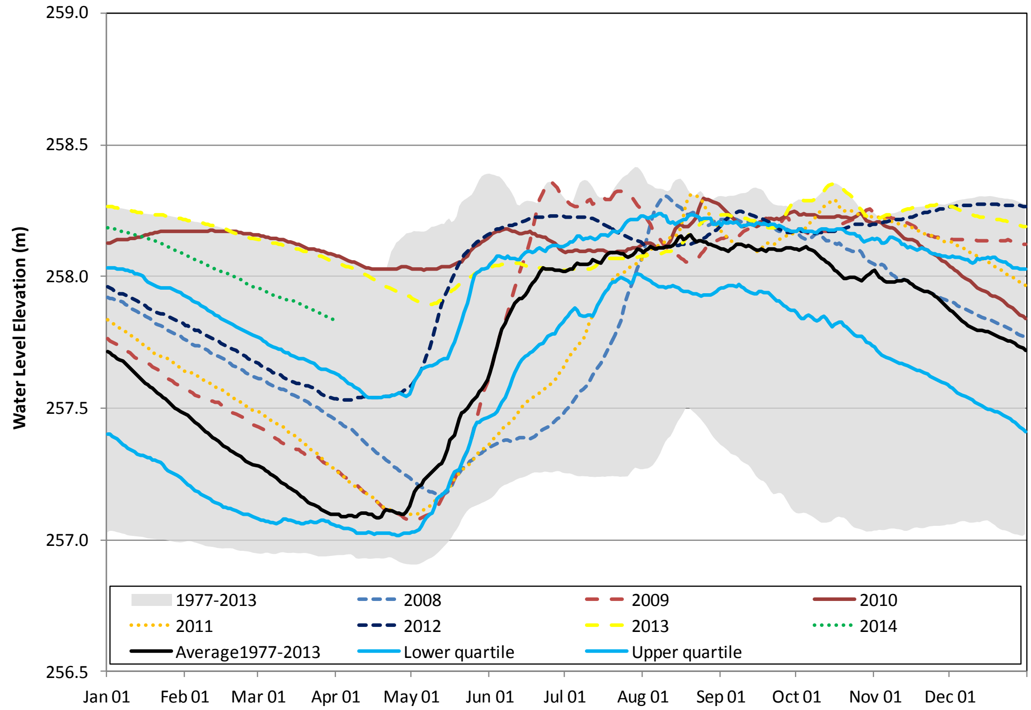



Figure 2-2. Southern Indian Lake average water level elevation: 2008-2013.

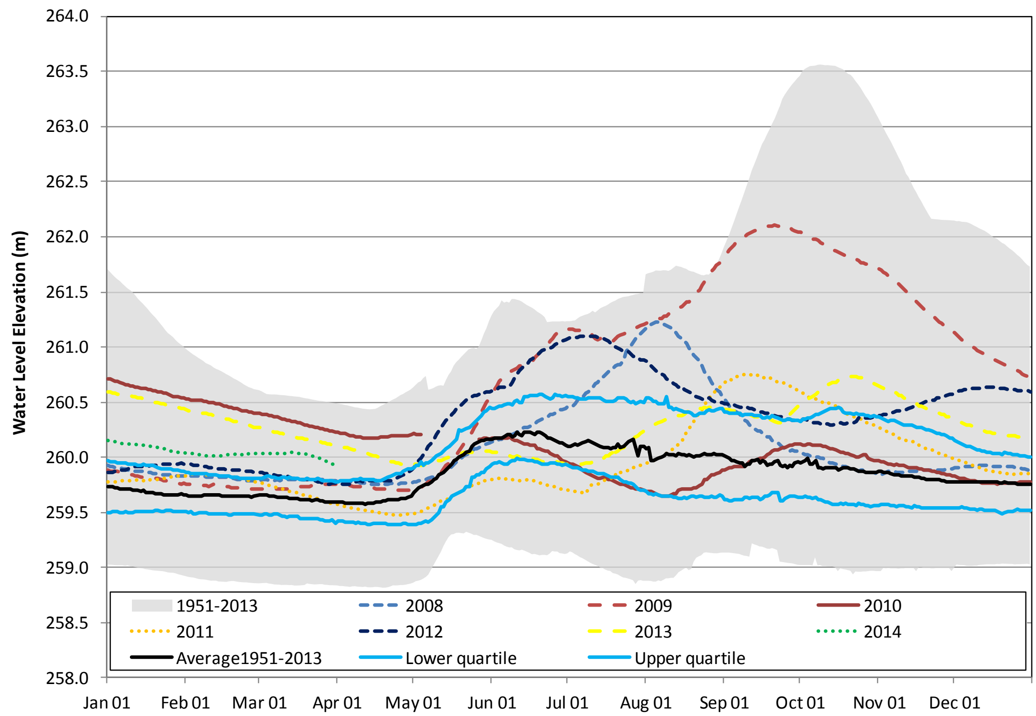



Figure 2-3. Granville Lake water level elevation (06EB002): 2008-2013.

# 3.0 WATER QUALITY

## 3.1 INTRODUCTION

The following provides an overview of water quality conditions for key metrics measured over years 1-6 of CAMP in the UCRR. Waterbodies/river reaches sampled annually for water quality included one on-system area (Southern Indian Lake – Area 4) and one off-system lake (Granville Lake; Table 3-1; Figure 3-1). Three additional on-system areas were sampled on a rotational basis including Opachuanau Lake and Southern Indian Lake – Areas 1 and 6. Sampling was completed at all locations and sampling periods as planned, though the sampling location in Area 4 was moved to the lee of the island as needed for safety and logistical reasons.

A detailed description of the program design and sampling methods is provided in Technical Document 1, Section 3.3. In brief, the CAMP water quality program includes four sampling periods per year (referred to as spring, summer, fall, and winter) at a single location within each monitoring waterbody or area of a waterbody/river reach.

### 3.1.1 Objectives and Approach

The key objectives of the analysis of CAMP water quality data, which were directed in the terms of reference for preparation of this report, were to:

- evaluate whether water quality conditions are suitable for aquatic life;
- evaluate whether there are indications of temporal trends in water quality metrics; and
- provide an initial review of linkages between water quality metrics and key drivers, notably hydrological conditions, where feasible.

The first objective was addressed through comparisons to Manitoba Water Quality Standards, Objectives, and Guidelines (MWQSOGs) for the protection of aquatic life (PAL) to evaluate overall ecosystem health (Manitoba Water Stewardship [MWS] 2011).

The second objective (analysis of temporal changes or trends) was addressed through two approaches: (1) statistical analyses were undertaken to assess whether there were significant differences between years at sites monitored annually; and (2) trends were examined visually through graphical plots for sites monitored annually. As noted in Technical Document 1, six years of data may be insufficient to detect trends over time, notably long-term trends, and the assessment was therefore restricted to qualitative assessment of the available data for sites monitored annually. Additionally, any indications of potential trends over the six year period do not necessarily imply a long-term trend is occurring, as apparent trends over this interval may simply reflect the relatively limited time period assessed in conjunction with inter-annual variability in a metric. Consideration of a longer period of record is required to evaluate for long-term trends.

The third objective was addressed through statistical analysis of hydrological (flow and water level) and water quality metrics to evaluate correlations. Statistically significant relationships between hydrological (water level or discharge) and water quality metrics (chlorophyll *a*, dissolved oxygen [DO], total suspended solids [TSS], alkalinity, hardness, specific conductance, calcium, magnesium, and potassium) were observed in Manitoba Hydro and the Province of Manitoba's (2015) recent regional cumulative effects assessment (RCEA) of changes in Southern Indian and Opachuanau lakes as a result of CRD.

Statistical analyses undertaken for this component are inherently limited by the quantity of data, notably the frequency of sampling, and the absence of statistically significant differences may reflect the relatively limited amount of data. Furthermore, factors other than hydrological conditions, notably climatological conditions such as air temperature and wind, affect water quality. For these reasons, these analyses are considered to be exploratory in nature. In addition, it is cautioned that identification of significant correlations between water quality and hydrological metrics does not infer a causal relationship (i.e., correlations simply indicate that two metrics are related).

A detailed description of the approach and methods applied for analysis and reporting is provided in Technical Document 1, Section 4.3. Figures illustrating results for all sites sampled in the UCRR in the following present data in an upstream to downstream direction. Site abbreviations applied in tables and figures are defined in Table 1-1.

### 3.1.2 Indicators

Although CAMP measures over 65 water quality parameters, results presented below focus upon three key indicators selected at CAMP workshops: dissolved oxygen (and the supporting metric water temperature); water clarity; and nutrients/trophic status. Metrics for these indicators include DO and temperature, total nitrogen (TN), total phosphorus (TP), chlorophyll *a*, TSS, turbidity, and Secchi disk depth. A detailed description of key indicators is provided in Technical Document 1, Section 4.3.1.

Manitoba Hydro and the Province of Manitoba's (2015) recent RCEA identified several effects of CRD on water quality in the upper Churchill River area. TN and turbidity exhibited long-term decreases and increases, respectively, in Southern Indian Lake – Area 4 as a result of CRD. Long-term (i.e., permanent) effects also included increases in conductivity (a measure of the amount of dissolved substances in water), hardness, calcium, and magnesium in Southern Indian Lake – Area 4; these parameters concurrently decreased in Area 6. Observed effects were due to the change in the influence of the Churchill River in each area (i.e., reduced influence in Area 4 and increased influence in Area 6). As noted above, these metrics were also correlated to discharge (as measured on the Churchill River upstream of Southern Indian Lake). Results of CAMP monitoring for parameters in addition to the key metrics were reviewed and summarized in Section 3.3 where of particular note (e.g., where there was evidence of temporal trends or where a metric did not meet MWQSOGs for PAL).

## 3.2 KEY INDICATORS

### 3.2.1 Dissolved Oxygen

Concentrations of dissolved oxygen are affected by water temperature, both in terms of the absolute amount of oxygen that can be contained in water (the capacity of water to hold oxygen is temperature-dependent) and because thermal stratification (i.e., layering of water of different temperatures) in a lake can affect the introduction and distribution of oxygen from the atmosphere. Thermal stratification can limit or prevent mixing of the water column and lead to oxygen deficits, notably near the bottom of the water column. When water near the surface of the water column cools in the fall and warms in the spring, layers of water isolated due to temperature and density differences are turned over, and the water column is mixed. For these reasons, water temperature conditions are monitored and considered when interpreting DO results.

#### *3.2.1.1 Upper Churchill River*

Opachuanau Lake was isothermal during all sampling periods in 2011/2012 (Figure 3-2) and sampling sites monitored in Southern Indian Lake were isothermal in fall and winter during all monitoring periods (Table 3-2; Figures 3-3 to 3-5). However, each area monitored in Southern Indian Lake was stratified during a minimum of one spring/summer period as follows: Area 1 was weakly thermally stratified in spring 2012 (thermocline at 1-2 m; Figure 3-3); Area 6 was stratified in spring 2010 (at 7-8 m) and summer 2013 (at 0-1 m; Figure 3-4); and Area 4 was stratified in spring 2008 (thermocline at 0-1 m), 2012 (at 1-3 m), and 2013 (at 6-8 m), and summer 2008 (at 14-15 m; Figure 3-5). Thermal stratification was also observed in in the off-system Granville and Gauer lakes during some of these periods (Figures 3-6 and 3-7), indicating some potential regional influences (e.g., climatological conditions).

All sampling areas along the upper Churchill River were well-oxygenated year-round and DO concentrations consistently exceeded the most stringent Manitoba PAL objectives for cool-water and cold-water aquatic life (5.5 and 9.5 mg/L, respectively) across the water column over the six years of monitoring (Figures 3-8 to 3-11)[1]. Open-water DO conditions in Southern Indian Lake – Area 4 were higher than those measured concurrently in Opachuanau Lake or the other areas of Southern Indian Lake (Figures 3-9 to 3-13).

#### *3.2.1.2 Off-system Waterbodies: Granville and Gauer Lakes*

Similar to the on-system sampling areas, Granville and Gauer lakes were generally isothermal throughout the year. However, both lakes were thermally stratified in spring 2008, and Gauer Lake was also stratified during summer 2013 (Figures 3-6 and 3-7). With one exception (Gauer Lake in winter 2008/2009), the off-system lakes were well-oxygenated across depth and DO concentrations exceeded the most stringent Manitoba PAL objectives for cool-water and cold-water aquatic life (5.5 and 9.5 mg/L, respectively; Figures 3-14 and 3-15).

DO may decrease in north temperate ecosystems that experience long periods of ice cover due to the lack of an oxygen source from the atmosphere (i.e., no or minimal reaeration due to ice). In winter 2008/2009 DO concentrations decreased across the water column and concentrations dropped below the PAL objective for cold-water species at approximately 3 m from the surface, and the PAL objective for cool-water species at approximately 6 m from the surface, in Gauer Lake. This is in contrast to Opachuanau and Southern Indian lakes where DO was consistently within PAL objectives over the first six years of CAMP. Because sampling conducted in Gauer Lake in winters other than 2008/2009 was done at shallower depths, it is unknown if DO depletion may have occurred at deeper sites in other winters.

#### *3.2.1.3 Temporal Comparisons and Trends*

Examination of 2008/2009-2013/2014 data for the annual on-system monitoring site (Southern Indian Lake – Area 4) indicates concentrations or percent saturation of DO (open-water season) were not significantly different between years (Figure 3-13). Similarly, no statistical inter-annual differences were noted for the off-system Granville or Gauer lakes. There was also no indication of an increasing or decreasing trend in oxygen conditions over the six year monitoring period at either on- or off-system sites.

[1] DO conditions measured in the upper Churchill River in fall 2013 and the winters of 2011/2012 and 2013/2014 were removed from the analysis as a result of issues with the water quality meter.

### 3.2.2 Water Clarity

Water clarity is measured under CAMP as total suspended solids, turbidity, and Secchi disk depth. While typically related, each of these metrics measures water clarity in a different way and therefore provides somewhat different information on this key indicator.

#### *3.2.2.1 Upper Churchill River*

TSS concentrations were low to moderate in the region, with 25% of samples from Opachuanau Lake and Southern Indian Lake – Areas 1 and 6 at concentrations below the analytical detection limit of 2 mg/L; the lowest concentrations occurred in winter. Annual averages of TSS were less than 6 mg/L at all sites but the mean annual concentration in Southern Indian Lake – Area 4 was lower than other on-system sites during each respective year (Figure 3-16). At Southern Indian Lake – Area 4, 54% of samples collected over the six years of monitoring were below the detection limit; these samples were collected across seasons. Turbidity was also lower at Southern Indian Lake – Area 4 than other on-system sites (Figure 3-17).

With one exception (2010/2011), annual mean open-water Secchi disk depths were greater than 1 m at Southern Indian Lake – Area 4, though notable inter-annual variability was observed (open-water means ranged from 0.75 to 2.0 m; Figure 3-18). As with TSS and turbidity, Secchi disk depth also indicated higher clarity (i.e., higher Secchi disk depth) in Southern Indian Lake – Area 4 compared to Opachuanau Lake and Southern Indian Lake – Areas 1 and 6, where mean Secchi disk depths were consistently less than 1 m.

Based on the available CAMP data, TSS and turbidity were lower, and Secchi disk depth was higher, in Southern Indian Lake – Area 4 compared to the other on-system sites (Figures 3-16 to 3-19).

#### *3.2.2.2 Off-system Waterbodies: Granville and Gauer Lakes*

Water clarity was similar to or greater in Granville Lake, and notably higher in Gauer Lake, relative to on-system sites located along the main flow path of the upper Churchill River (i.e., Opachuanau Lake and Southern Indian Lake – Area 6; Figures 3-16 to 3-18). Conditions were more similar between the off-system sites and Southern Indian Lake – Area 4 for these metrics. . However, as discussed in Technical Document 1, Section 1.2.2.1, it is recognized that off-system waterbodies monitored under CAMP may fundamentally differ from on-system waterbodies and would not necessarily be expected to exhibit similar chemical or biological characteristics.

#### *3.2.2.3 Temporal Comparisons and Trends*

The lowest TSS concentrations at the annual on-system site (Southern Indian Lake – Area 4) occurred in 2008 when all samples were below the analytical detection limit (Figure 3-16). Though there were no statistically significant inter-annual differences observed for this site, this may reflect the relatively limited amount of data and/or the relatively high frequency of censored data (i.e., values below the analytical detection limit).

Visual examination of data does not suggest increasing or decreasing trends in these metrics over the six-year monitoring program. Similarly, no significant or qualitative trends were observed for either of the two off-system sites (Gauer and Granville lakes). As discussed in Section 3.4, TSS concentrations measured at Southern Indian Lake – Area 4 were positively and significantly related to annual mean water level of the lake.

### 3.2.3 Nutrients, Chlorophyll *a*, and Trophic Status

Trophic status is a means for describing or classifying the productivity of a waterbody and it is commonly defined based on the concentrations of major nutrients (total phosphorus and total nitrogen) and chlorophyll *a* (a measure of algal abundance). Trophic status is typically defined in categories intended to be indicative of the level of productivity as follows: low (ultra-oligotrophic or oligotrophic); moderate to moderately high (mesotrophic or meso-eutrophic); high (eutrophic); and very high (hyper-eutrophic) productivity. Trophic status may vary within a waterbody depending on the metric used to describe it.

#### *3.2.3.1 Upper Churchill River*

Lakes located along the upper Churchill River were oligotrophic to meso-eutrophic on the basis of mean open-water season TP concentrations, and oligotrophic to mesotrophic based on open-water TN and chlorophyll *a* (Table 3-3 and Figures 3-20 to 3-22).

With one exception, mean TP concentrations were below the Manitoba narrative nutrient guideline (0.025 mg/L for lakes, reservoirs and streams near the inflows to waterbodies; MWS 2011) in each year of monitoring at the on-system sites (Figure 3-23). The exception occurred in Southern Indian Lake – Area 6, where the mean open-water TP concentration (0.26 mg/L) marginally exceeded the guideline in 2010. However, occasional exceedances were also observed in all three areas of Southern Indian Lake (25% in Area 1, 4% in Area 4, and 38% in Area 6); no exceedances occurred in Opachuanau Lake. No samples collected at on-system sites along the upper Churchill River exceeded the CAMP trigger of 10 µg/L for chlorophyll *a* in the open-water season (Table 3-3).

Based on the first six years of monitoring data, neither TP nor TN was significantly correlated to chlorophyll *a* at the annual monitoring site (Southern Indian Lake-Area 4; Figure 3-24). This suggests that nutrients are not the primary factor limiting phytoplankton growth, but may also be a reflection of the relatively limited amount of data. Most on-system waterbodies sampled annually under CAMP showed either a weak or lack of a correlation between nutrients and chlorophyll *a* for the six year monitoring period. The ratio of chlorophyll *a* to total phosphorus (which ranged from 0.15 to 0.29 in this region) - an indicator of the efficiency with which algae assimilate phosphorous - suggests that on-system lakes along the upper Churchill River produce a relatively low amount of chlorophyll *a* per unit phosphorus. Values were also similar to those in the off-system Granville Lake (mean ratio of 0.28), but were lower than ratios calculated for Gauer Lake (mean ratio of 0.42; Figure 3-25).

Similar to the water clarity metrics, TP was lower in Southern Indian Lake – Area 4 than other sites along the upper Churchill River (Figure 3-20 to 3-22 and 3-26).

#### *3.2.3.2 Off-system Waterbodies: Granville and Gauer Lakes*

In terms of mean open-water TP and TN concentrations, the trophic status of Granville and Gauer lakes was similar to on-system lakes on the upper Churchill River (i.e., mesotrophic to meso-eutrophic based on TP, and oligotrophic to mesotrophic based on TN; Table 3-3 and Figures 3-20 and 3-21). Trophic status based on average chlorophyll *a* concentrations was also similar between Granville Lake and the on-system sites (mesotrophic), but a broader range of concentrations was observed in Gauer Lake (oligotrophic to eutrophic; Figure 3-22). As was observed for the annual on-system monitoring site, TN and TP were not correlated to chlorophyll *a* in Granville or Gauer lakes (Figure 3-24). As previously noted, the lack of a significant correlation may indicate factors other than nutrients are limiting to phytoplankton growth but may also reflect the relatively limited data available for examination of inter-relationships between metrics.

The mean open-water TP concentrations measured each year in Granville and Gauer lakes were within the narrative guideline for lakes and reservoirs (0.025 mg/L; Figure 3-23). Two samples from Granville Lake (8% of samples, both collected in 2010), and three from Gauer Lake (13% of samples, collected in 2008, 2010, and 2011), exceeded the guideline. This frequency of exceedance is within range of that observed for the upper Churchill River sites.

#### *3.2.3.3 Temporal Comparisons and Trends*

Only one statistically significant inter-annual difference for TP, chlorophyll *a*, or TN was observed at any of the annual monitoring sites and none of the metrics exhibited an increasing or decreasing trend over the six years of monitoring. TP measured at the annual sampling site in Southern Indian Lake – Area 4 was highest in the 2010 open-water season and was statistically significantly higher than in 2008 and 2013 (Figures 3-20 and 3-23).

Exploratory analyses comparing hydrologic metrics (river discharge and lake water level) and nutrient and chlorophyll *a* metrics did not indicate any overt relationships for Southern Indian Lake – Area 4. However, the lack of significant relationships may reflect the relatively limited amount of data and/or that any correlations, should they exist, may relate to other hydrological metrics.

## 3.3 ADDITIONAL METRICS AND OBSERVATIONS OF NOTE

Other water quality metrics measured under CAMP, as described in Technical Document 1, Section 3.3.1, were also reviewed to assess trends and to compare to water quality objectives and guidelines for the protection of aquatic life. A number of parameters measured at Southern Indian Lake – Area 4 were either higher (dissolved phosphorous, total organic carbon) or lower (total and bicarbonate alkalinity, specific conductance, hardness, and calcium) during the 2010 open-water season compared to other monitoring years (Figures 3-27 to 3-33). However, though discharge at Granville Falls was below average in 2010, none of these water quality metrics were significantly correlated to water level or discharge (see Section 3.4).

Using a longer period of record (1972-2013), Manitoba Hydro and the Province of Manitoba's RCEA indicated that water quality of the upper Churchill River is more dilute than local sources and that turbidity, total alkalinity, specific conductance, hardness, calcium, and magnesium tend to increase in Area 4 when hydrologic influence of the river is reduced (i.e., under low flow conditions; Manitoba Hydro and the Province of Manitoba 2015).

No trends or unusual conditions were observed for other water quality metrics at the annual off-system monitoring sites (Granville and Gauer lakes) over the period of 2008-2013 (see Technical Document 1, Section 3.3 for a list of additional metrics).

pH, ammonia, and nitrate remained within PAL guidelines/objectives at all sites and times, both on- and off-system. Additionally, most metals were within Manitoba water quality PAL objectives and guidelines. Exceptions included aluminum, which was above the PAL guideline (0.1 mg/L) in 88-100% of samples from the on-system upper Churchill River sites (Table 3-4). Exceedances of this metal were also observed in the off-system Granville Lake (92%) but not in Gauer Lake. Other PAL guideline exceedances occurred for iron (0.3 mg/L) at Opachuanau Lake (25% of samples) and Southern Indian Lake – Area 1 (38% of samples), Area 4 (4% of samples), and Area 6 (63% of samples); for lead (site-specific objective) in Southern Indian Lake – Area 1

(25% of samples); and for selenium at Granville Lake (8% of samples) and Southern Indian Lake – Area 4 (4% of samples; Table 3-4). The detection limit (DL) for selenium is equivalent to the PAL guideline, however, and measurements that are at or near the DL are associated with relatively high uncertainty. In such instances (i.e., when a measurement is near a DL), there is low confidence that an actual exceedance of a PAL guideline has occurred. These exceedances of PAL objectives and guidelines are common in northern Manitoba lakes and rivers and are also observed in lakes and rivers unaffected by hydroelectric development (Ramsey 1991; Keeyask Hydropower Limited Partnership [KHLP] 2012; Manitoba Hydro and the Province of Manitoba 2015), including off-system CAMP waterbodies.

Chloride was within the Canadian Council of Ministers of the Environment (CCME 1999; updated to 2017) PAL guideline and sulphate remained within the British Columbia Ministry of the Environment (BCMOE) PAL guideline (128-309 mg/L; Meays and Nordin 2013) at all on- and off-system sites monitored in this region.

## 3.4 RELATIONSHIPS WITH HYDROLOGICAL METRICS

Statistically significant inter-annual differences in water quality for the annual on-system site (Southern Indian Lake – Area 4) included peak concentrations of TP, dissolved phosphorous, total organic carbon, and some metals in 2010, while other parameters (total and bicarbonate alkalinity, specific conductance, hardness, and calcium) exhibited the lowest concentrations in that year. Hydrological conditions were somewhat different in 2010 relative to the remaining years, which may have contributed to the observed inter-annual differences. Firstly, flows on the upper Churchill River were particularly low in the open-water season of 2010 and Southern Indian Lake – Area 4 would therefore have experienced a relatively smaller influence of the Churchill River on water quality. Secondly, although the water level of Southern Indian Lake was approximately average in the open-water season of 2010, water level had been relatively high in the lake over a prolonged period (i.e., spring 2009 through fall 2010). Exploratory analyses were conducted to provide an initial evaluation of potential linkages between hydrological metrics and water quality for this site. As the water residence time of Southern Indian Lake – Area 4 has been estimated as 1.4 years (under mean discharge; McCullough 1981), exploratory analyses were conducted using annual means (as rolling averages) of water discharge and level.

Exploratory regression analyses found a small number of statistically significant correlations between annual lake water level and/or annual upper Churchill River discharge and water quality metrics (Table 3-5). The strongest correlations were observed for TSS (Figure 3-34). Weaker positive correlations were also observed for turbidity and dissolved organic carbon (DOC) and the annual mean discharge of the upper Churchill River (Figure 3-35).

Conceptually, TSS and turbidity in Southern Indian Lake may be affected by inflow (which supplies TSS to the lake) and/or water level (which can affect shoreline erosion and/or resuspension). The positive relationships observed between annual water level and inflow and TSS could be explained by the aforementioned linkages. Likewise, organic carbon may be influenced by both inflow rates (which affect loading/supply to the lake and water residence times) and water level (which may affect DOC through flooding). However, the available information is inadequate to properly assess whether these metrics are related to hydrology and if so, to what specific hydrological metrics and in what direction. It is further acknowledged that other factors such as climate may affect water quality. TSS, in particular, may be strongly affected by wind conditions and may be affected by combinations of factors such as high water levels in conjunction with high wind. However, analysis of climatological factors as drivers of water quality conditions was excluded from the scope of the reporting.

## 3.5 SUMMARY

Analysis of the six years of CAMP monitoring data collected in the UCRR indicates that most water quality metrics were within PAL objectives and guidelines, and metrics that exceeded PAL guidelines in this region (notably TP, aluminum, and iron) are commonly above these benchmarks in other northern Manitoba lakes and rivers, including off-system sites monitored under CAMP. Some differences in water quality were observed from Granville Lake (upstream, off-system site) through Opachuanau Lake and the three areas of Southern Indian Lake. Notably, water clarity and dissolved oxygen were higher, and total phosphorous was lower, in Area 4 of Southern Indian Lake than at the other sites.

None of the metrics appear to have undergone an increasing or decreasing trend over the six year period, though some parameters were significantly higher (e.g., total phosphorous, total organic carbon) or lower (e.g., alkalinity, specific conductance, hardness) in 2010 compared to other CAMP monitoring periods. Despite below average flows in 2010 and above average discharge in all other years, water levels were relatively stable during the open-water season and preliminary exploratory relationships revealed a few significant relationships between water quality and hydrologic metrics (i.e., water level or discharge).

Table 3-1. Inventory of water quality sampling completed in the UCRR: 2008/2009-2013/2014.

| **Waterbody/Area** | **Site Abbreviation** | **Site ID** | **On-system** | **Off-system** | **Annual** | **Rotational** | **Sampling Years** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | **2008/2009** | **2009/2010** | **2010/2011** | **2011/2012** | **2012/2013** | **2013/2014** |
| Granville Lake | GRV | EBS 043 | | X | X | | X | X | X | X | X | X |
| Opachuanau Lake | OPACH | EBS 046 | X | | | X | | | | X | | |
| Southern Indian Lake – Area 1 | SIL-1 | ECS 006 | X | | | X | | X | | | X | |
| Southern Indian Lake – Area 6 | SIL-6 | ECS 001 | X | | | X | | | X | | | X |
| Southern Indian Lake – Area 4 | SIL-4 | ECS 004 | X | | X | | X | X | X | X | X | X |
| Gauer Lake [1] | GAU | FAS 007 | | X | X | | X | X | X | X | X | X |

[1] Site formally included in the LCRR; included here for discussion of results.

Table 3-2. Summary of water quality conditions measured in the Upper Churchill River Region over the period of 2008/2009 to 2013/2014. Values represent means.

| **Metric** | | **Waterbody** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **GRV** | **OPACH** | **SIL-1** | **SIL-6** | **SIL-4** | **GAU** |
| Years Sampled | | 2008/09-2013/14 | 2010/11 | 2009/10, 2012/13 | 2010/11, 2013/14 | 2008/09-2013/14 | 2008/09-2013/14 |
| TP | (mg/L) | 0.0170 | 0.0184 | 0.0185 | 0.0209 | 0.0140 | 0.0171 |
| | Trophic Status | Mesotrophic | Mesotrophic | Mesotrophic | Meso-eutrophic | Mesotrophic | Mesotrophic |
| TN | (mg/L) | 0.36 | 0.36 | 0.31 | 0.26 | 0.31 | 0.42 |
| | Trophic Status | Mesotrophic | Mesotrophic | Oligotrophic | Oligotrophic | Oligotrophic | Mesotrophic |
| TKN | (mg/L) | 0.34 | 0.35 | 0.30 | 0.25 | 0.29 | 0.40 |
| Chlorophyll *a* | (µg/L) | 3.85 | 4.08 | 2.66 | 1.79 | 2.31 | 5.30 |
| | Trophic Status | Mesotrophic | Mesotrophic | Mesotrophic | Oligotrophic | Oligotrophic | Mesotrophic |
| TN:TP | - | 50 | 44 | 42 | 31 | 53 | 60 |
| DOC | (mg/L) | 7.6 | 7.3 | 7.7 | 7.1 | 6.6 | 8.6 |
| Nitrate/nitrite | (mg N/L) | 0.0210 | 0.0135 | 0.0180 | 0.0224 | 0.0202 | 0.0206 |
| Ammonia | (mg N/L) | 0.018 | 0.005 | 0.014 | 0.009 | 0.016 | 0.008 |
| Dissolved Phosphorus | (mg/L) | 0.008 | 0.010 | 0.010 | 0.010 | 0.008 | 0.007 |
| DO Lower than MWQSOGs for PAL | (Y/N) | No | No | No | No | No | Yes (Winter 2008/2009) |
| DO - open-water season (surface) | (mg/L) | 9.68 | 9.51 | 9.80 | 10.4 | 10.5 | 10.01 |
| DO - open-water season (bottom) | (mg/L) | 9.39 | 9.11 | 9.85 | 10.5 | 10.8 | 9.84 |
| DO - ice-cover season (surface) | (mg/L) | 15.9 | n/r | 15.7 | 14.7 | 15.2 | 14.15 |
| DO - ice-cover season (bottom) | (mg/L) | 15.3 | n/r | 14.7 | 14.0 | 14.5 | 11.23 |
| Thermal Stratification | (Y/N) | Yes (spring 2008) | No | Yes (spring 2012) | Yes (spring 2010 and summer 2013) | Yes (spring 2008, 2012 and 2013; and, summer 2008) | Yes (spring 2008, summer 2013) |
| Secchi Disk Depth | (m) | 1.29 | 0.79 | 0.95 | 0.71 | 1.49 | 1.87 |
| TSS | (mg/L) | 3.8 | 4.2 | 3.7 | 4.8 | 2.3 | 2.6 |
| Turbidity | (NTU) | 4.19 | 6.65 | 7.87 | 10.3 | 5.17 | 1.64 |
| True Colour | (TCU) | 15.2 | 12.6 | 20.6 | 12.8 | 14.3 | 19.2 |
| Specific Conductance | (µmhos/cm) | 90.1 | 92.5 | 86.5 | 99.0 | 124 | 156 |
| TDS | (mg/L) | 61.8 | 58.5 | 58.5 | 69.2 | 79.8 | 101.8 |
| Hardness | (mg/L) | 40.6 | 42.7 | 39.5 | 45.4 | 61.2 | 83.4 |
| Hardness Category | - | Soft | Soft | Soft | Soft | Moderately Soft/Hard | Moderately Soft/Hard |
| pH | - | 7.81 | 7.85 | 7.87 | 7.89 | 8.07 | 8.14 |
| Total Alkalinity | (mg/L) | 42.5 | 44.3 | 40.9 | 46.2 | 62.0 | 81.5 |
| Metals > MWQSOGs for PAL | - | Al, Se | Al, Fe | Al, Fe, Pb | Al, Fe | Al, Fe, Se | - |
| Aluminum | (mg/L) | 0.199 | 0.324 | 0.435 | 0.523 | 0.223 | 0.021 |
| Iron | (mg/L) | 0.174 | 0.246 | 0.369 | 0.418 | 0.120 | 0.041 |
| Mercury (<26 ng/L DL only) | (ng/L) | <20 | - | <20 | <20 | <20 | <20 |
| Mercury (≤1 ng/L DL only) | (ng/L) | 1.3 | - | <1.0 | 1.7 | 1.2 | 1.0 |
| Calcium | (mg/L) | 10.0 | 10.7 | 9.8 | 11.5 | 16.8 | 24.0 |
| Magnesium | (mg/L) | 3.82 | 3.86 | 3.66 | 4.08 | 4.68 | 5.68 |
| Potassium | (mg/L) | 1.27 | 1.23 | 1.30 | 1.33 | 1.10 | 0.770 |
| Sodium | (mg/L) | 3.27 | 3.18 | 3.08 | 3.10 | 2.62 | 1.59 |
| Chloride | (mg/L) | 1.07 | 1.03 | 0.97 | 0.98 | 1.16 | 0.72 |
| Sulphate | (mg/L) | 2.97 | 2.21 | 4.15 | 2.44 | 2.78 | 1.92 |

TKN = total Kjeldahl nitrogen; DOC = dissolved organic carbon; TDS = total dissolved solids; DL = detection limit.

Table 3-3. Summary of water quality conditions measured in the Upper Churchill River Region in the open-water season: 2008-2013. Values represent means.

| Indicator | Metric | | Unit | Waterbody | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | GRV | OPACH | SIL-1 | SIL-6 | SIL-4 | GAU |
| Nutrients | TP | Mean | (mg/L) | 0.0179 | 0.0195 | 0.0205 | 0.0210 | 0.0136 | 0.0184 |
| | | Trophic Status | - | Mesotrophic | Mesotrophic | Meso-eutrophic | Meso-eutrophic | Mesotrophic | Mesotrophic |
| | TN | Mean | (mg/L) | 0.35 | 0.34 | 0.27 | 0.21 | 0.26 | 0.41 |
| | | Trophic Status | - | Mesotrophic | Oligotrophic | Oligotrophic | Oligotrophic | Oligotrophic | Mesotrophic |
| | Chlorophyll *a* | Mean | (µg/L) | 4.76 | 5.34 | 3.42 | 2.29 | 2.75 | 6.68 |
| | | Trophic Status | - | Mesotrophic | Mesotrophic | Mesotrophic | Oligotrophic | Mesotrophic | Mesotrophic |
| | TN:TP | Mean | - | 46 | 39 | 29 | 26 | 47 | 53 |
| | | Nutrient Limitation | - | P-Limitation | P-Limitation | P-Limitation | P-Limitation | P-Limitation | P-Limitation |
| | Chlorophyll *a*:TP | Mean | - | 0.28 | 0.29 | 0.17 | 0.15 | 0.22 | 0.42 |
| | Chlorophyll *a*:TN | Mean | - | 0.016 | 0.016 | 0.016 | 0.017 | 0.013 | 0.019 |
| | Algal Bloom Frequency (Chlorophyll *a* >10 µg/L) | - | (%) | 0 | 0 | 0 | 0 | 0 | 22 |
| Dissolved Oxygen | DO Lower than MWQSOGs for PAL | - | (Y/N) | No | No | No | No | No | No |
| | DO | Surface | (mg/L) | 9.68 | 9.51 | 9.80 | 10.4 | 10.5 | 10.01 |
| | | Bottom | (mg/L) | 9.39 | 9.11 | 9.85 | 10.5 | 10.8 | 9.84 |
| | Thermal Stratification | - | (Y/N) | Yes (spring 2008) | No | Yes (spring 2012) | Yes (spring 2010 and summer 2013) | Yes (spring 2008, 2012 and 2013; and, summer 2008) | Yes (spring 2008, summer 2013) |
| Water Clarity | Secchi Disk Depth | Mean | (m) | 1.29 | 0.79 | 0.95 | 0.71 | 1.49 | 1.87 |
| | TSS | Mean | (mg/L) | 4.3 | 5.2 | 4.6 | 6.0 | 2.7 | 3.1 |
| | Turbidity | Mean | (NTU) | 4.83 | 8.04 | 9.76 | 12.00 | 5.34 | 1.95 |

Table 3-4. Frequency of exceedances of MWQSOGs for metals, the CCME PAL guideline for chloride, and the BCMOE PAL guideline for sulphate measured in the Upper Churchill River Region: 2008-2013. Values in red indicate exceedances occurred at a given site.

| | | MWQSOGs PAL | | | | | | | | | | | | | | | | CCME PAL | BCMOE PAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Waterbody** | | **Aluminum** | **Arsenic** | **Boron** | **Cadmium** | **Chromium** | **Copper** | **Iron** | **Lead** | **Mercury[1]** | **Molybdenum** | **Nickel** | **Selenium** | **Silver** | **Thallium** | **Uranium** | **Zinc** | **Chloride** | **Sulphate** |
| Objective or Guideline (mg/L) | | 0.1 | 0.15 | 1.5 | 0.000103 – 0.000281 | 0.0297 – 0.0899 | 0.00307 – 0.00975 | 0.3 | 0.000607 – 0.0034 | 0.000026 | 0.073 | 0.0173 – 0.0545 | 0.001 | 0.0001 | 0.0008 | 0.015 | 0.0398 – 0.125 | 120 | 128 - 309 |
| Granville Lake | n | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 |
| | # Exceedances | **22** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **2** | 0 | 0 | 0 | 0 | 0 | 0 |
| | % Exceedance | **92** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **8** | 0 | 0 | 0 | 0 | 0 | 0 |
| Opachuanau Lake | n | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| | # Exceedances | **4** | 0 | 0 | 0 | 0 | 0 | **1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | % Exceedance | **100** | 0 | 0 | 0 | 0 | 0 | **25** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Southern Indian Lake-Area 1 | n | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| | # Exceedances | **8** | 0 | 0 | 0 | 0 | 0 | **3** | **2** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | % Exceedance | **100** | 0 | 0 | 0 | 0 | 0 | **38** | **25** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Southern Indian Lake-Area 6 | n | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| | # Exceedances | **8** | 0 | 0 | 0 | 0 | 0 | **5** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | % Exceedance | **100** | 0 | 0 | 0 | 0 | 0 | **63** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Southern Indian Lake-Area 4 | n | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 |
| | # Exceedances | **21** | 0 | 0 | 0 | 0 | 0 | **1** | 0 | 0 | 0 | 0 | **1** | 0 | 0 | 0 | 0 | 0 | 0 |
| | % Exceedance | **88** | 0 | 0 | 0 | 0 | 0 | **4** | 0 | 0 | 0 | 0 | **4** | 0 | 0 | 0 | 0 | 0 | 0 |
| Gauer Lake | n | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 |
| | # Exceedances | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | % Exceedance | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

[1] Only measurements made with an analytical detection limit of <0.000026 mg/L included.

Table 3-5. Linear regressions between water quality metrics measured in Southern Indian Lake – Area 4 and water level of the lake and discharge of the upper Churchill River. Hydrology metrics represent annual rolling averages. Values in red indicate significant correlations.

| Parameter | Units | Water Level vs. Water Quality | | | River Discharge vs. Water Quality | | |
|---|---|---|---|---|---|---|---|
| | | $R^2$ | p Value | Direction of Relationship | $R^2$ | p Value | Direction of Relationship |
| Total Suspended Solids | mg/L | 0.345 | 0.01 | + | 0.416 | 0.004 | + |
| Total Suspended Solids – Detected Values Only[1] | mg/L | 0.606 | 0.005 | + | 0.573 | 0.007 | + |
| Laboratory Turbidity | NTU | NS | NS | NA | 0.236 | 0.041 | + |
| *In Situ* Turbidity | NTU | NS | NS | NA | 0.292 | 0.031 | + |
| Dissolved Organic Carbon | mg/L | NS | NS | NA | 0.274 | 0.026 | + |

[1] Values reported below the analytical detection limit were omitted.
NS = no significant difference; NA = not applicable.

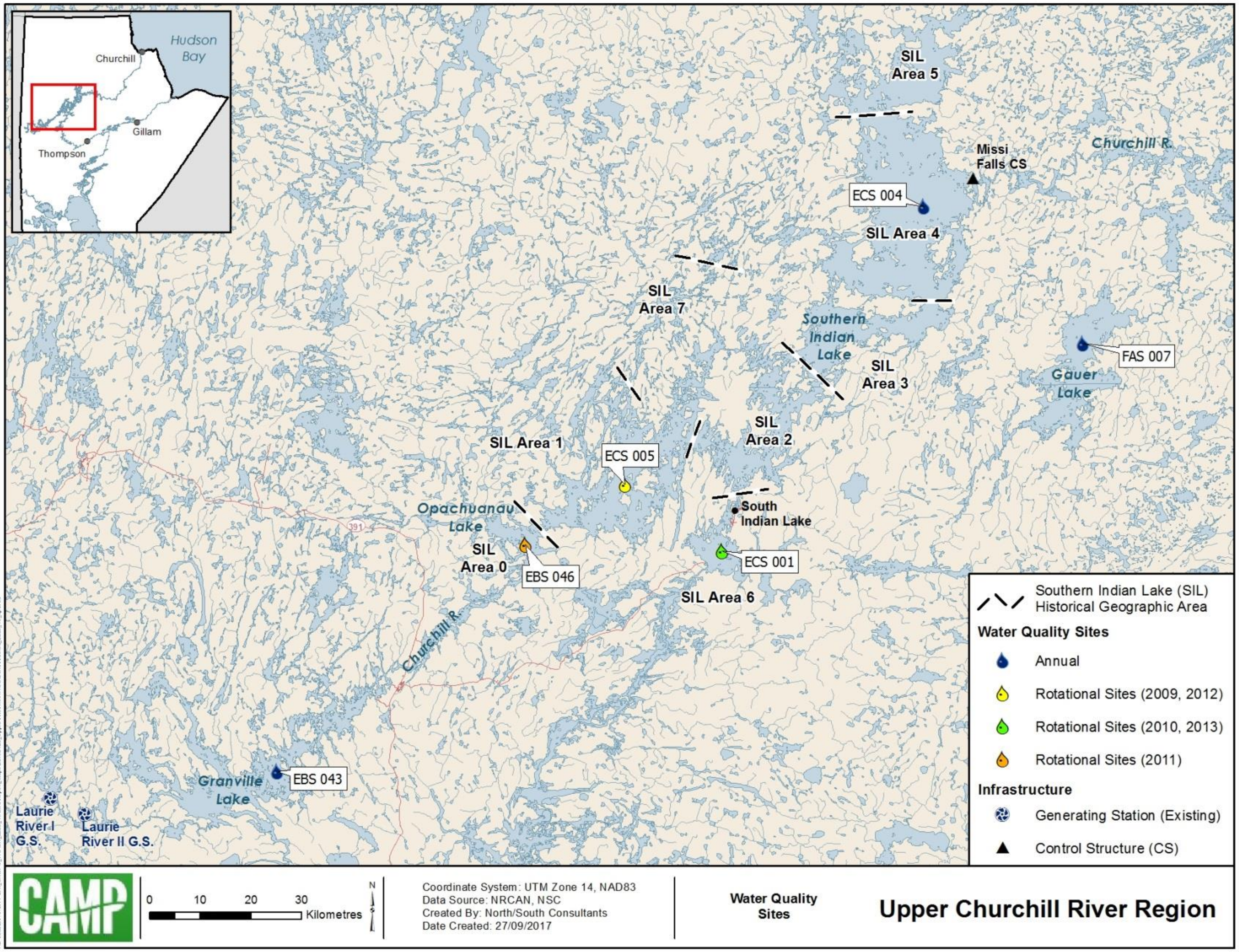



Figure 3-1. Water quality sampling sites in the Upper Churchill River Region: 2008/2009-2013/2014.

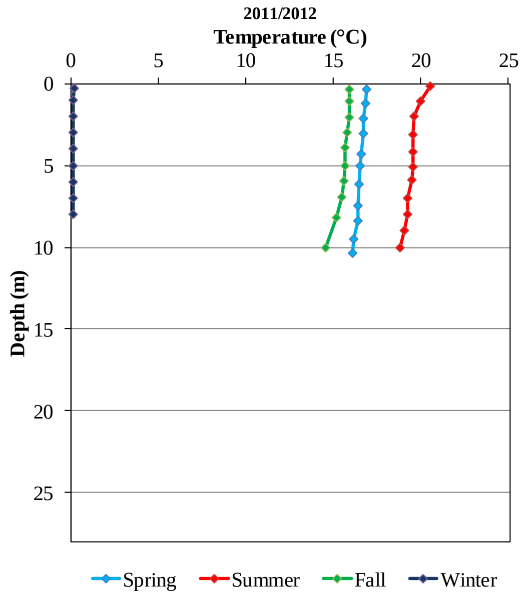
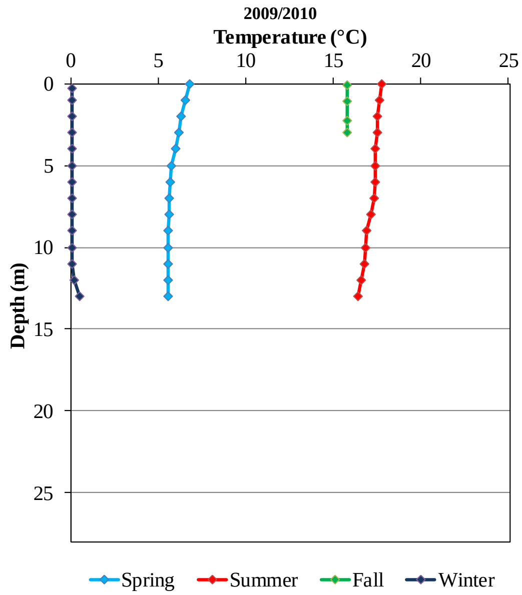



Figure 3-2. Temperature depth profiles in Opachuanau Lake: 2008/2009-2013/2014.



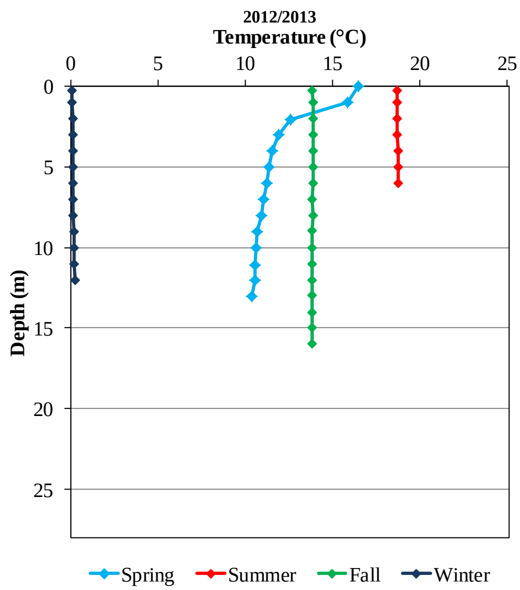
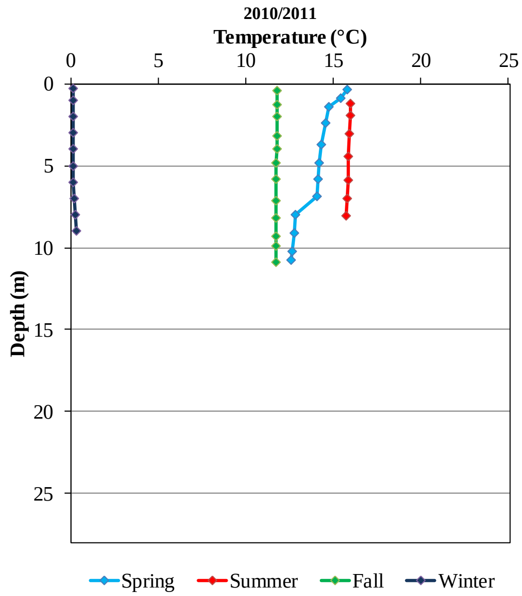




Figure 3-3. Temperature depth profiles in Southern Indian Lake-Area 1: 2008/2009-2013/2014.



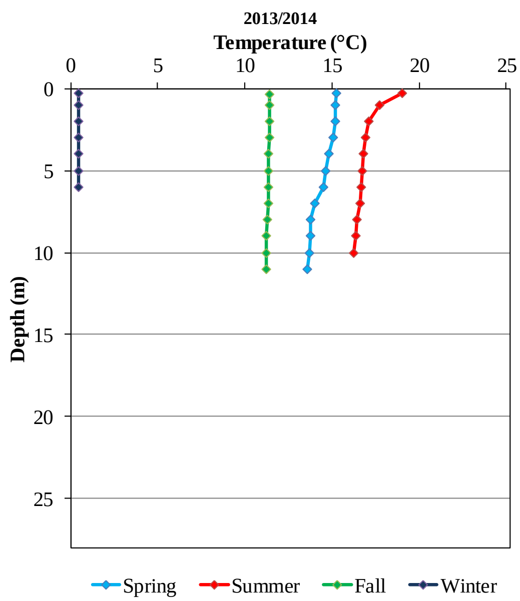




Figure 3-4. Temperature depth profiles in Southern Indian Lake-Area 6: 2008/2009-2013/2014.

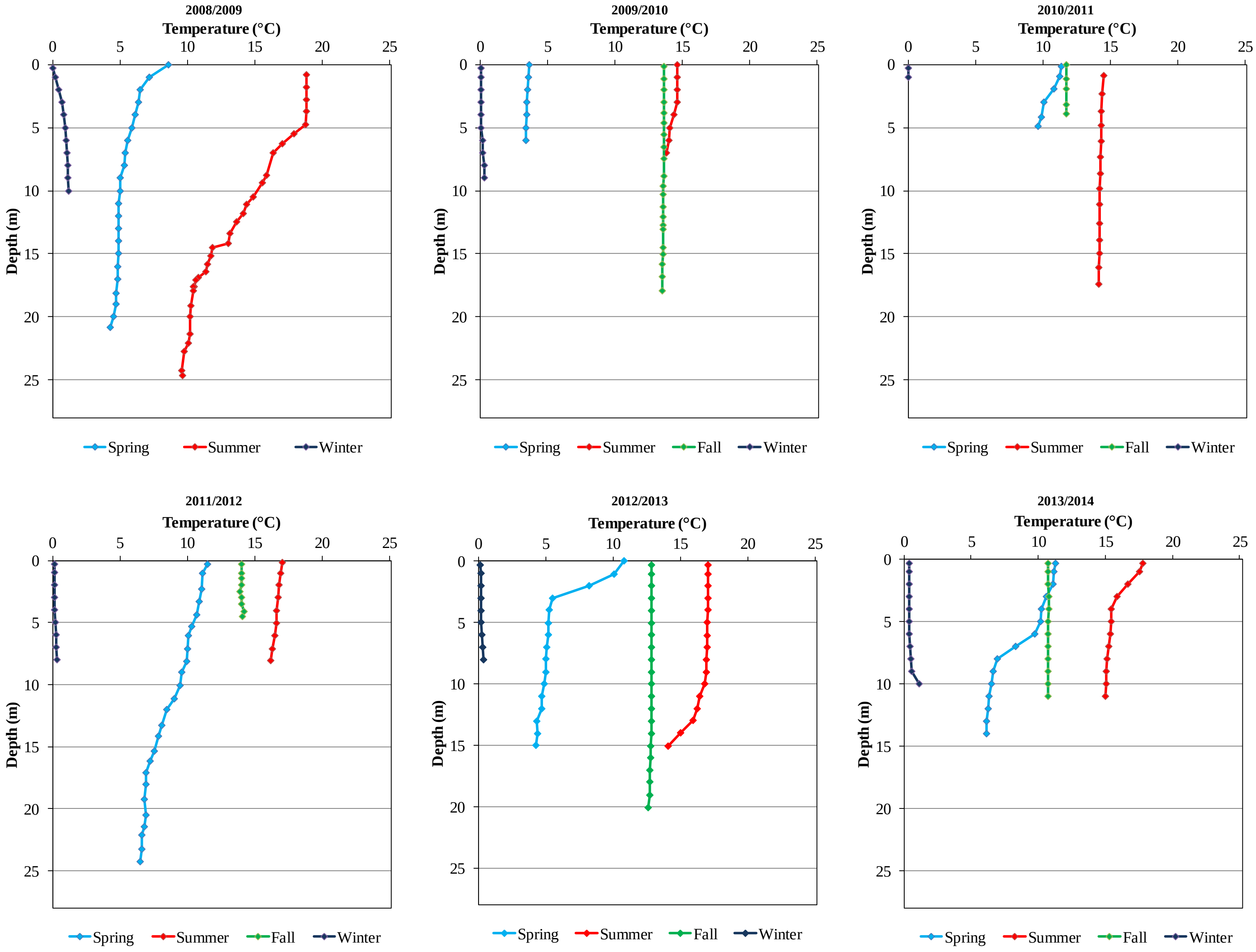



Figure 3-5. Temperature depth profiles in Southern Indian Lake-Area 4: 2008/2009-2013/2014

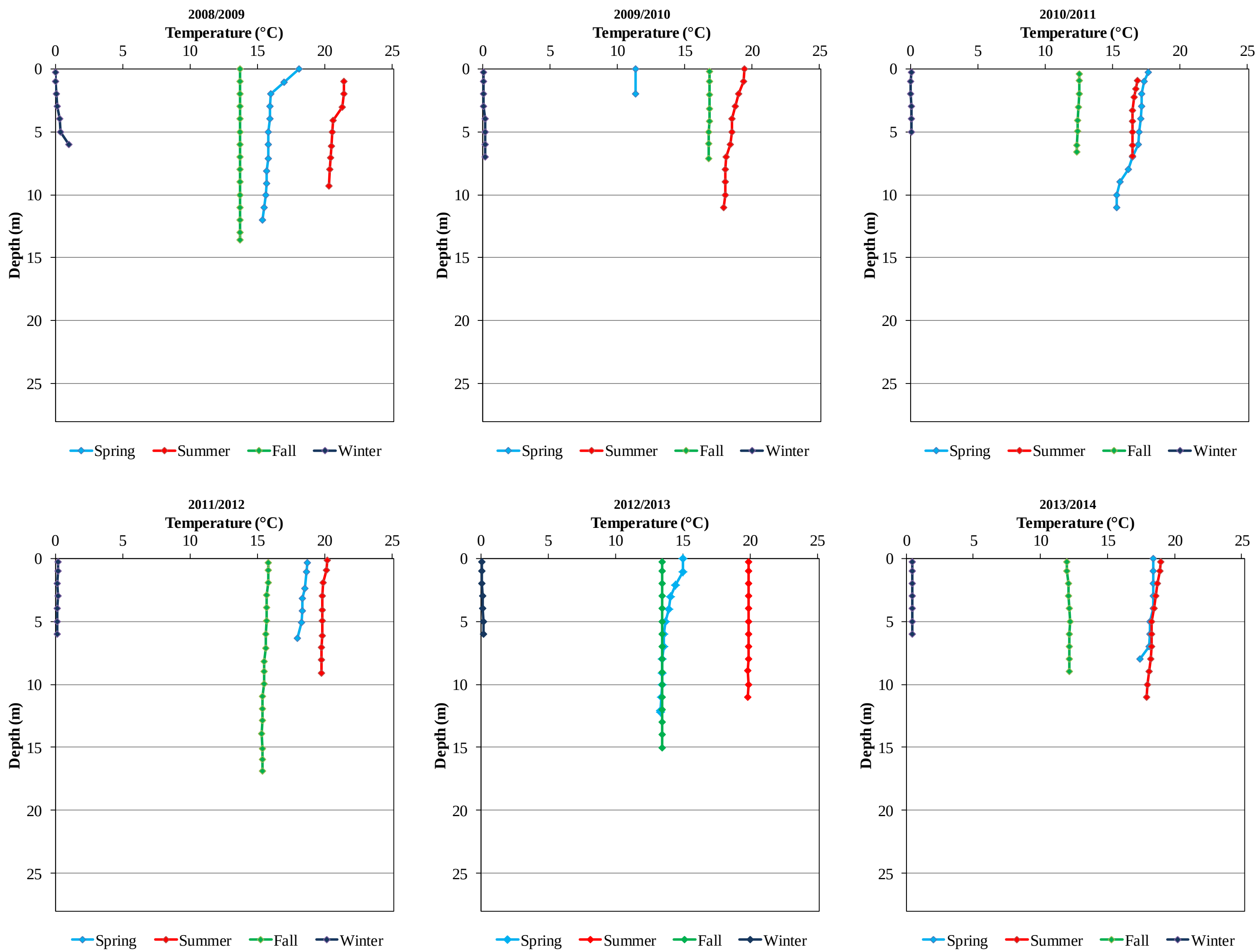



Figure 3-6. Temperature depth profiles in the off-system Granville Lake: 2008/2009-2013/2014

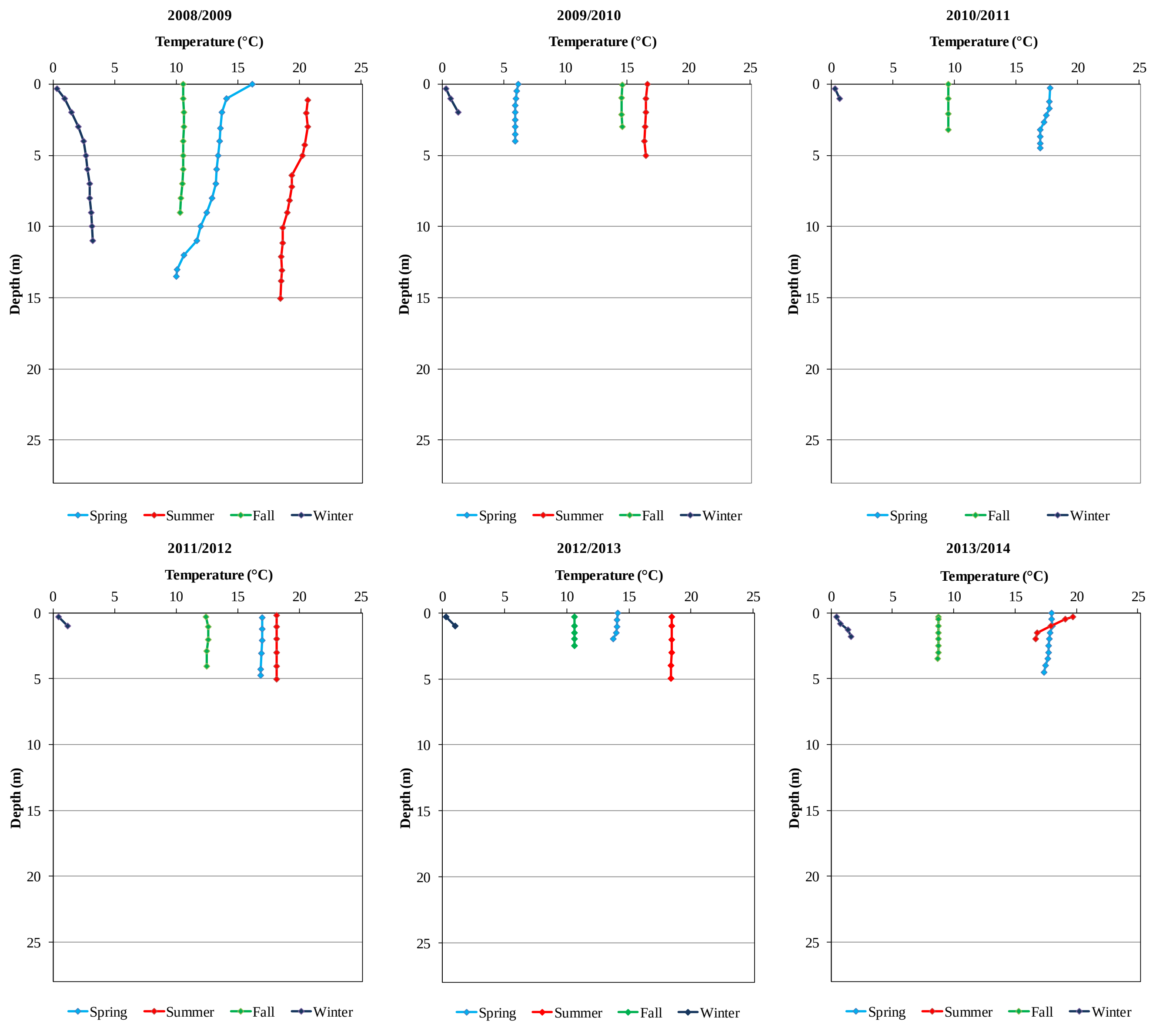



Figure 3-7. Temperature depth profiles in the off-system Gauer Lake: 2008/2009-2013/2014.

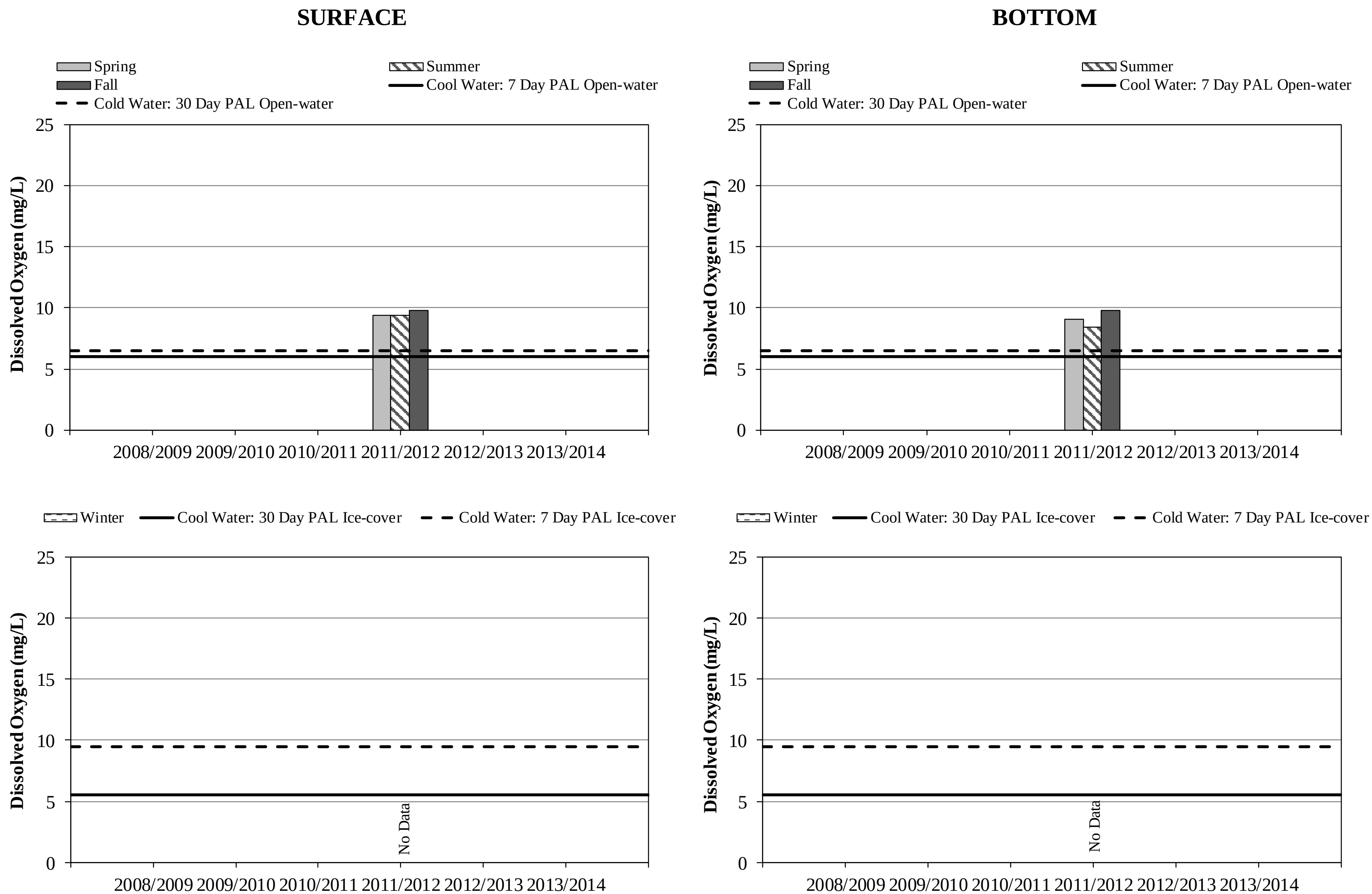



Figure 3-8. Dissolved oxygen measured near the surface and bottom of the water column in Opachuanau Lake and comparison to MB PAL objectives: 2008/2009-2013/2014.

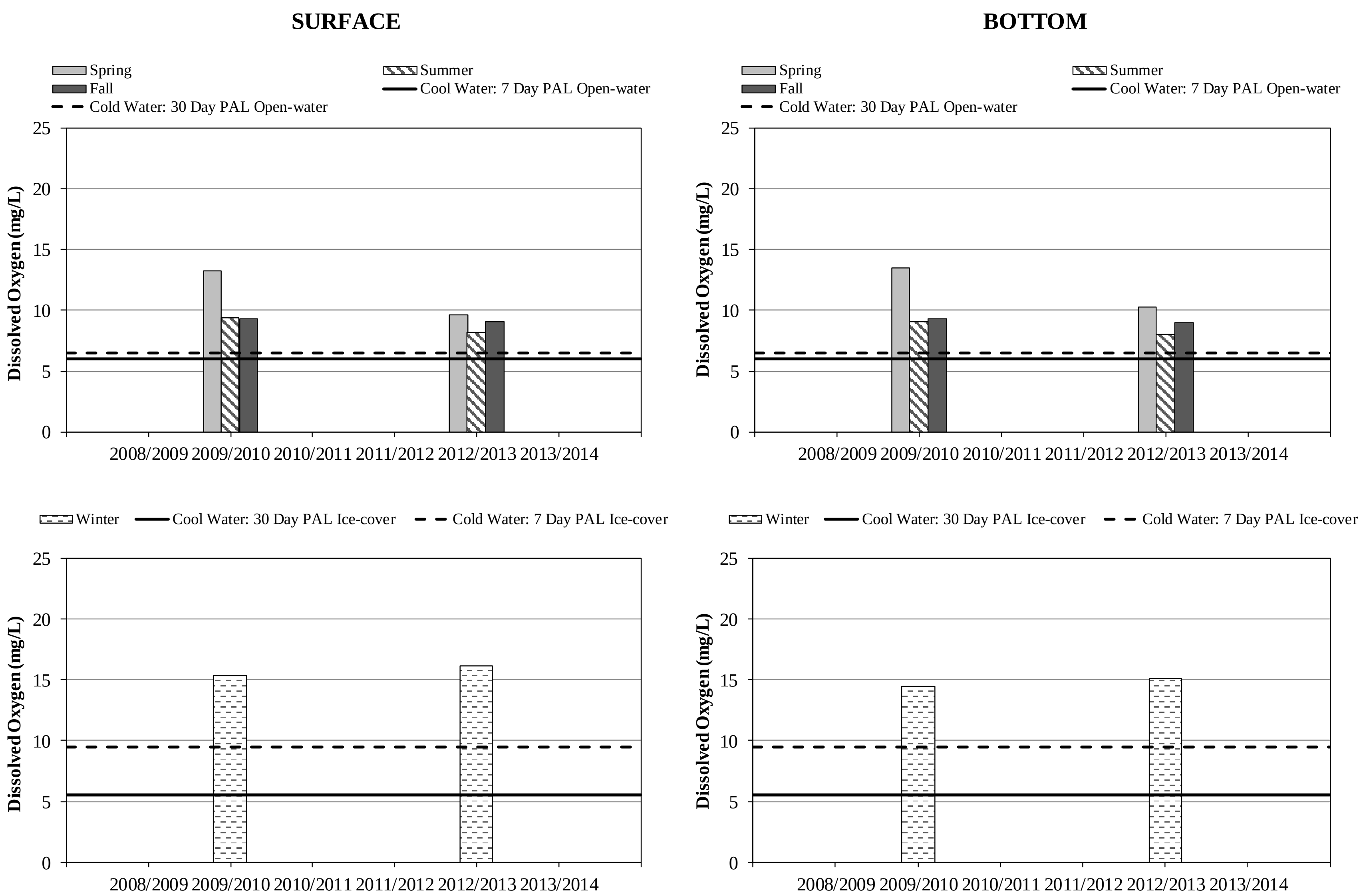



Figure 3-9. Dissolved oxygen measured near the surface and bottom of the water column in Southern Indian Lake-Area 1 and comparison to MB PAL objectives: 2008/2009-2013/2014.

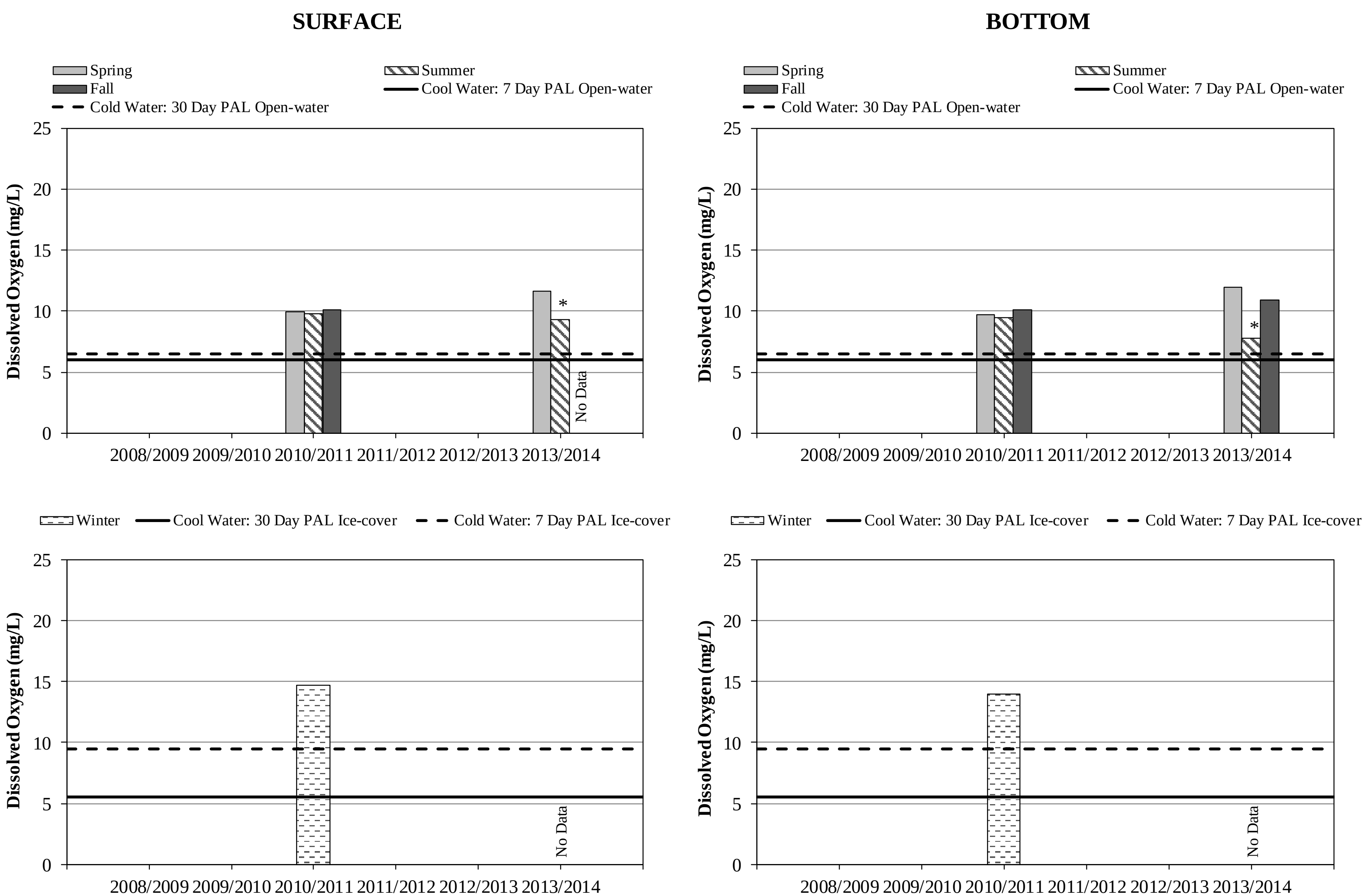



Figure 3-10. Dissolved oxygen measured near the surface and bottom of the water column in Southern Indian Lake-Area 6 and comparison to MB PAL objectives: 2008/2009-2013/2014. Values indicated with an asterisk are considered suspect.

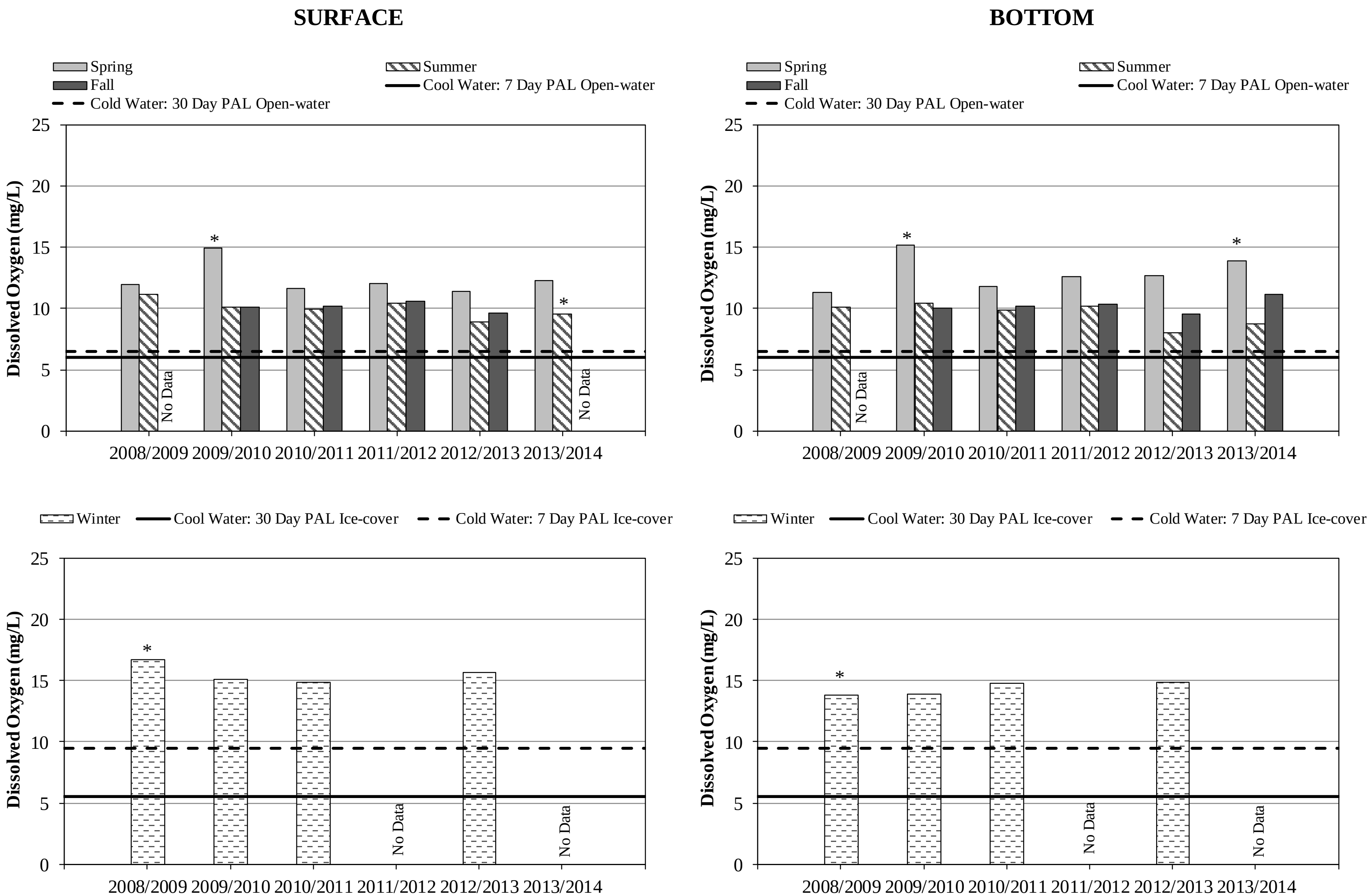
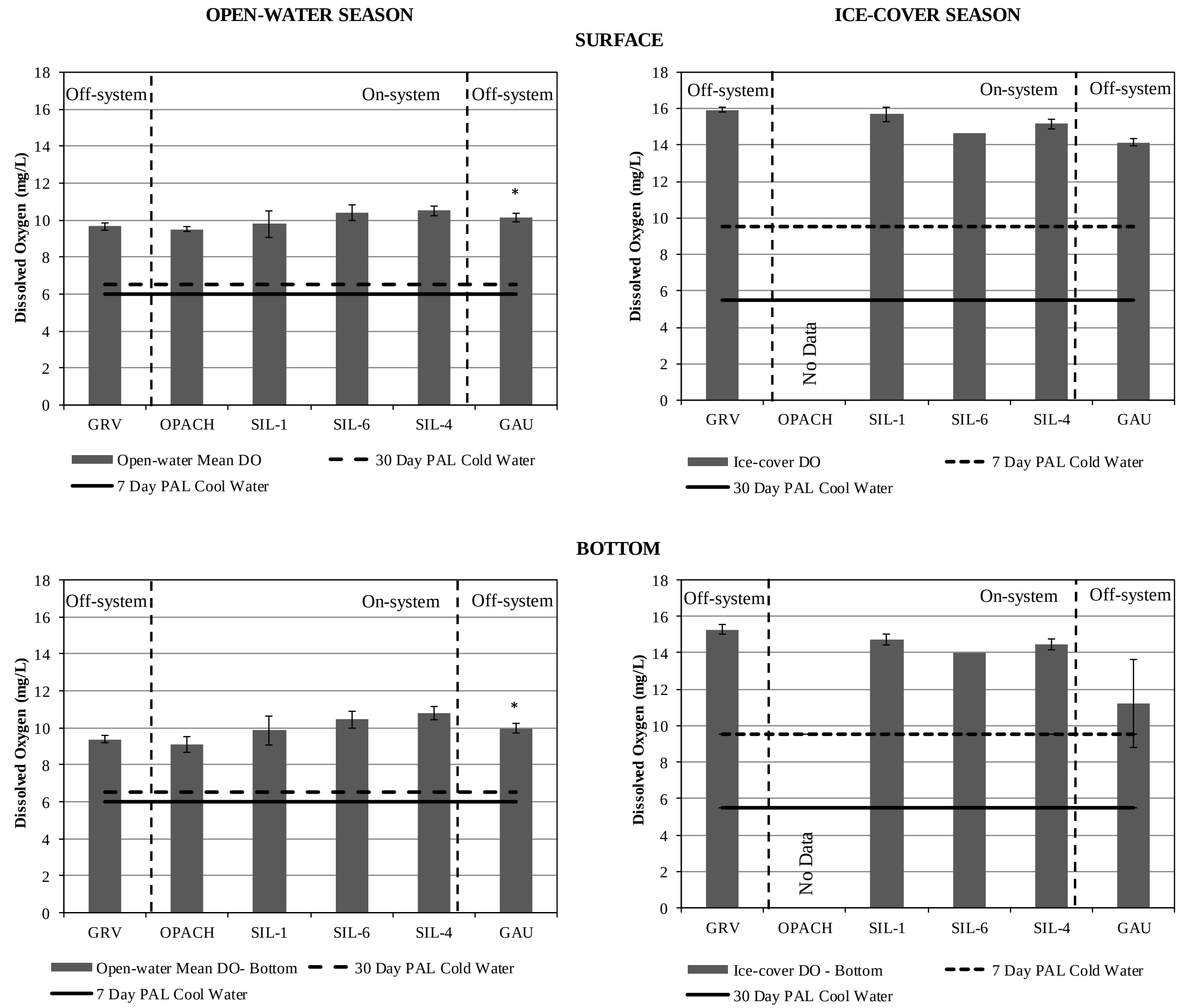
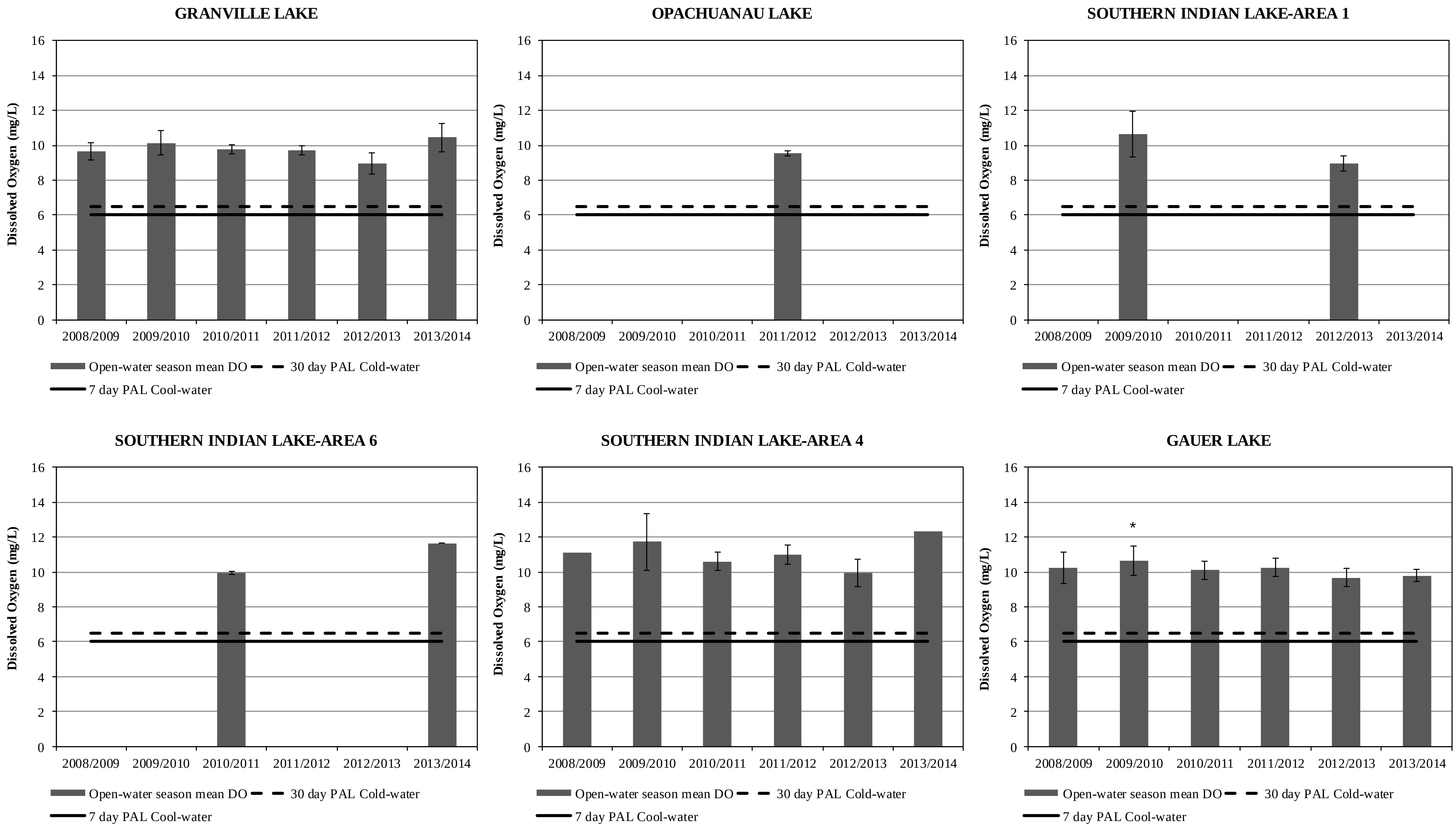



Figure 3-11. Dissolved oxygen measured near the surface and bottom of the water column in Southern Indian Lake-Area 4 and comparison to MB PAL objectives: 2008/2009-2013/2014. Values indicated with an asterisk are considered suspect.




* Includes data that are considered suspect. Concentrations may be overestimated.

Figure 3-12. Dissolved oxygen (mean±SE) measured near the surface and bottom of the water column in the upper Churchill River and off-system waterbodies (Granville and Gauer lakes): 2008/2009-2013/2014.




* Data are considered suspect. Concentrations may be overestimated.

Figure 3-13. Open-water season dissolved oxygen concentrations (mean±SE) in the upper Churchill River and off-system waterbodies (Granville and Gauer lakes). No statistically significant inter-annual differences were observed between the open-water seasons in the annual monitoring sites (SIL-Area 4 and Granville and Gauer lakes).

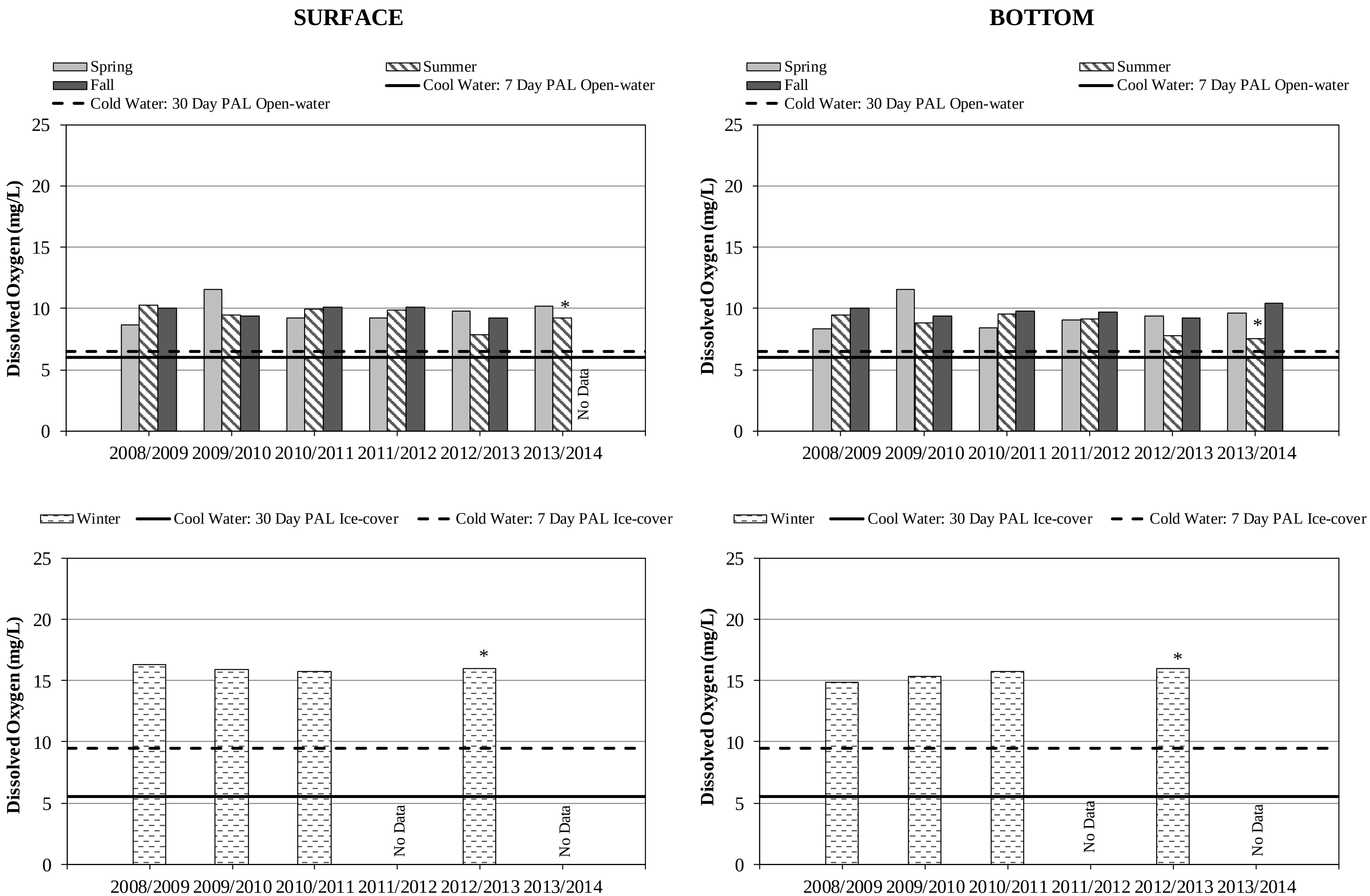
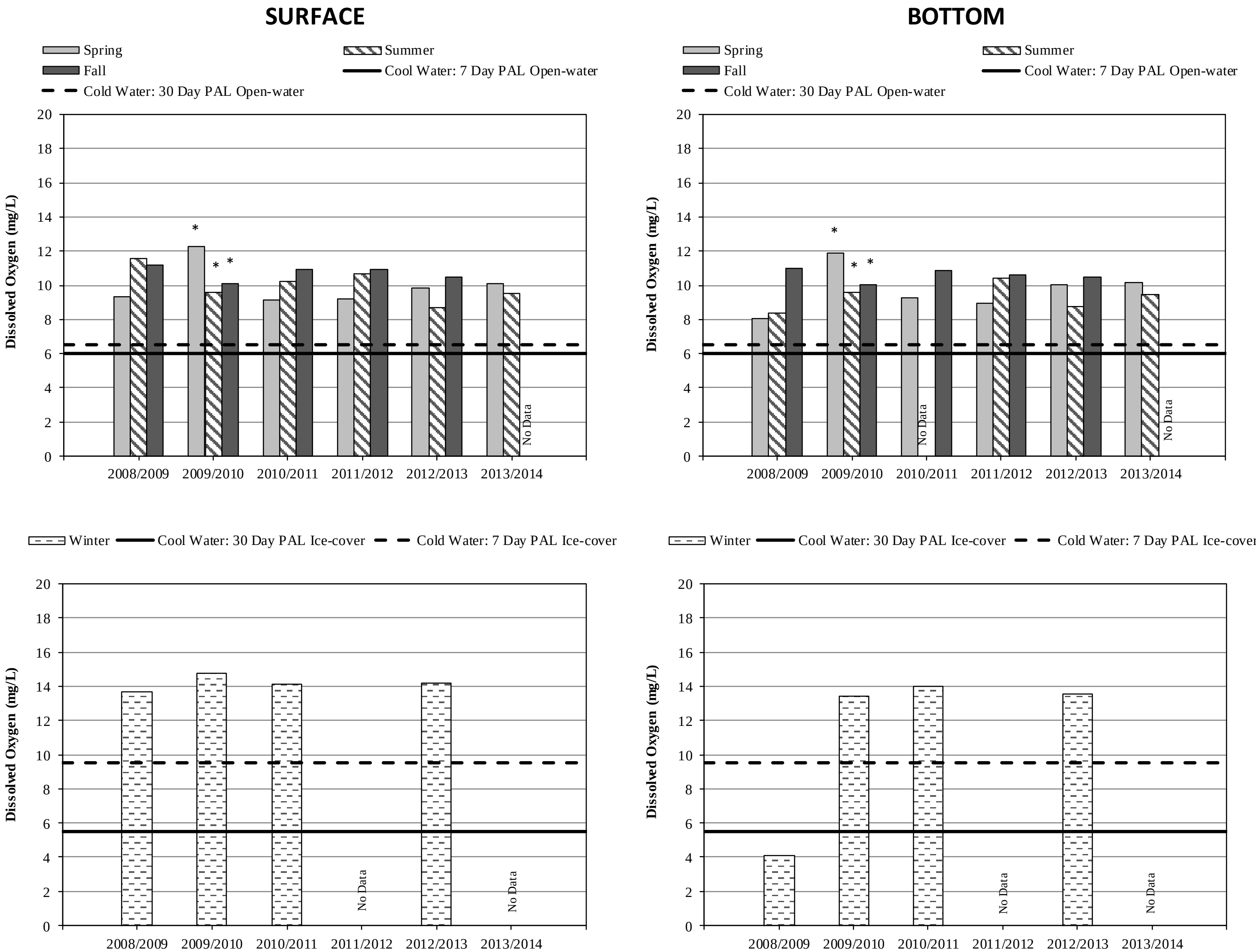



Figure 3-14. Dissolved oxygen measured near the surface and bottom of the water column in the off-system Granville Lake and comparison to MB PAL objectives: 2008/2009-2013/2014. Values indicated with an asterisk are considered suspect.




* Data are considered suspect. Concentrations may be overestimated.

Figure 3-15. Dissolved oxygen measured near the surface and bottom of the water column in the off-system Gauer Lake and comparison to MB PAL objectives: 2008/2009-2013/2014.

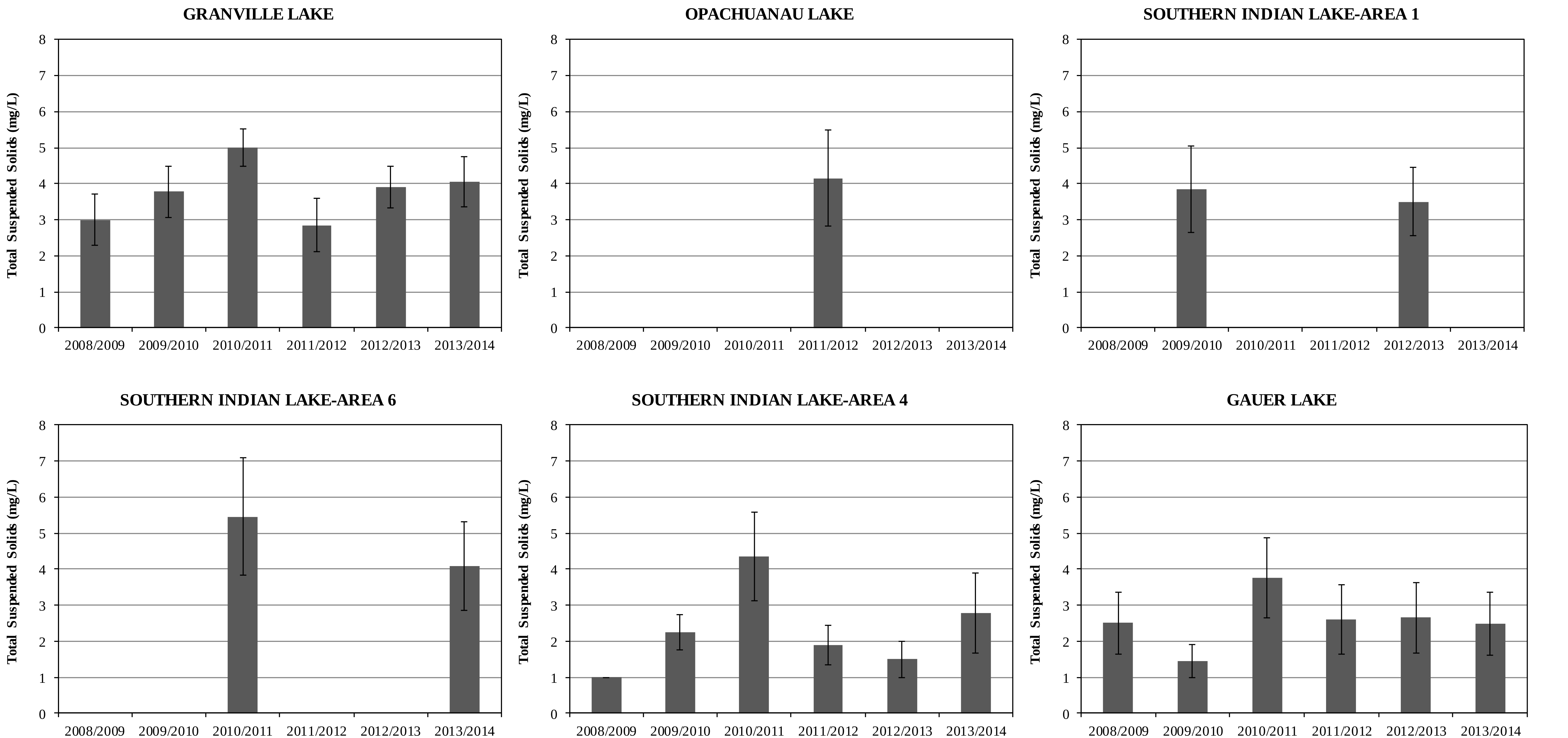



Figure 3-16. Total suspended solids (mean±SE) measured in the upper Churchill River and off-system waterbodies (Granville and Gauer lakes): 2008/2009-2013/2014. No statistically significant inter-annual differences were observed between the open-water seasons in the annual monitoring sites (SIL-Area 4 and Granville and Gauer lakes).

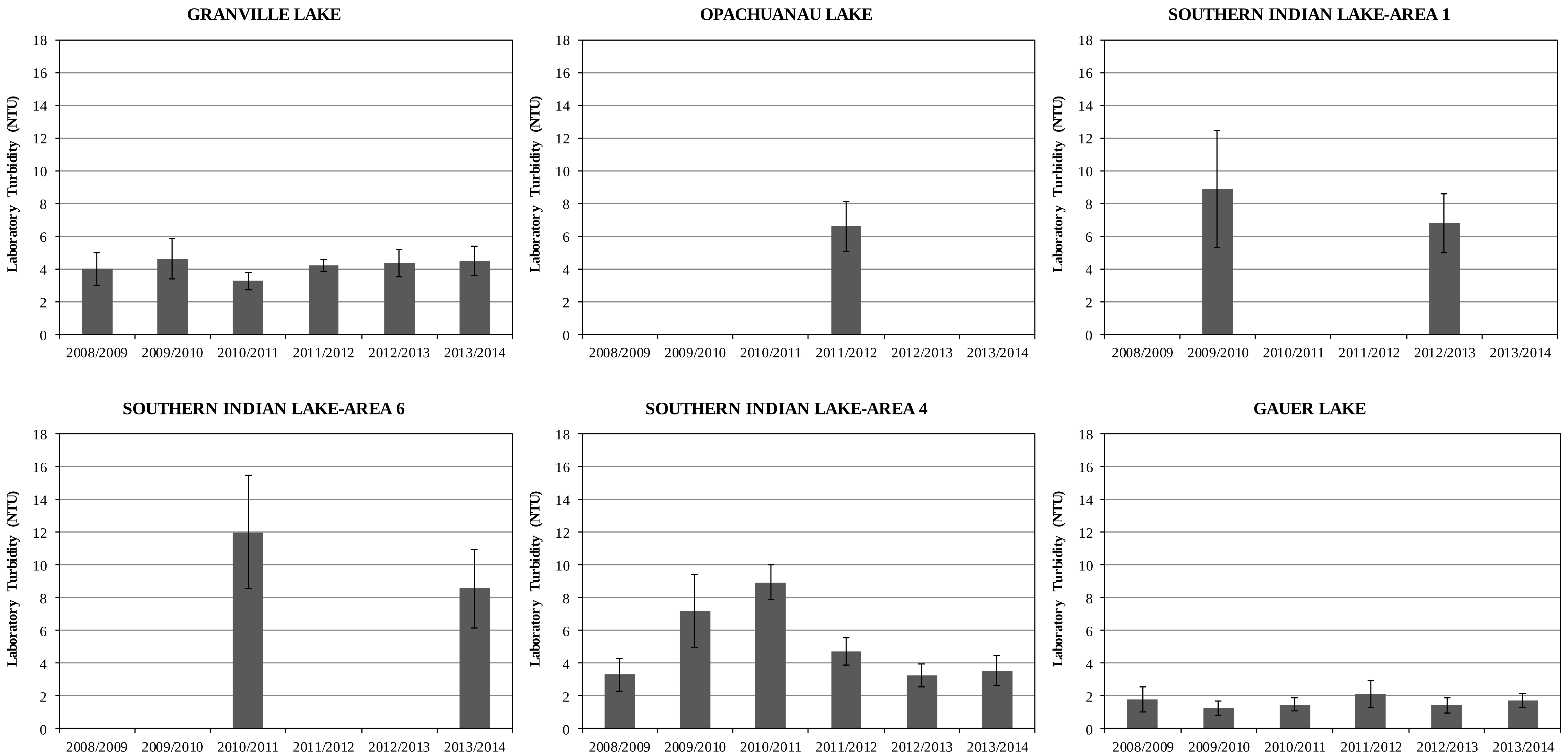



Figure 3-17. Laboratory turbidity (mean±SE) measured in the upper Churchill River and off-system waterbodies (Granville and Gauer lakes): 2008/2009-2013/2014. No statistically significant inter-annual differences were observed between the open-water seasons in the annual monitoring sites (SIL-Area 4 and Granville and Gauer lakes).

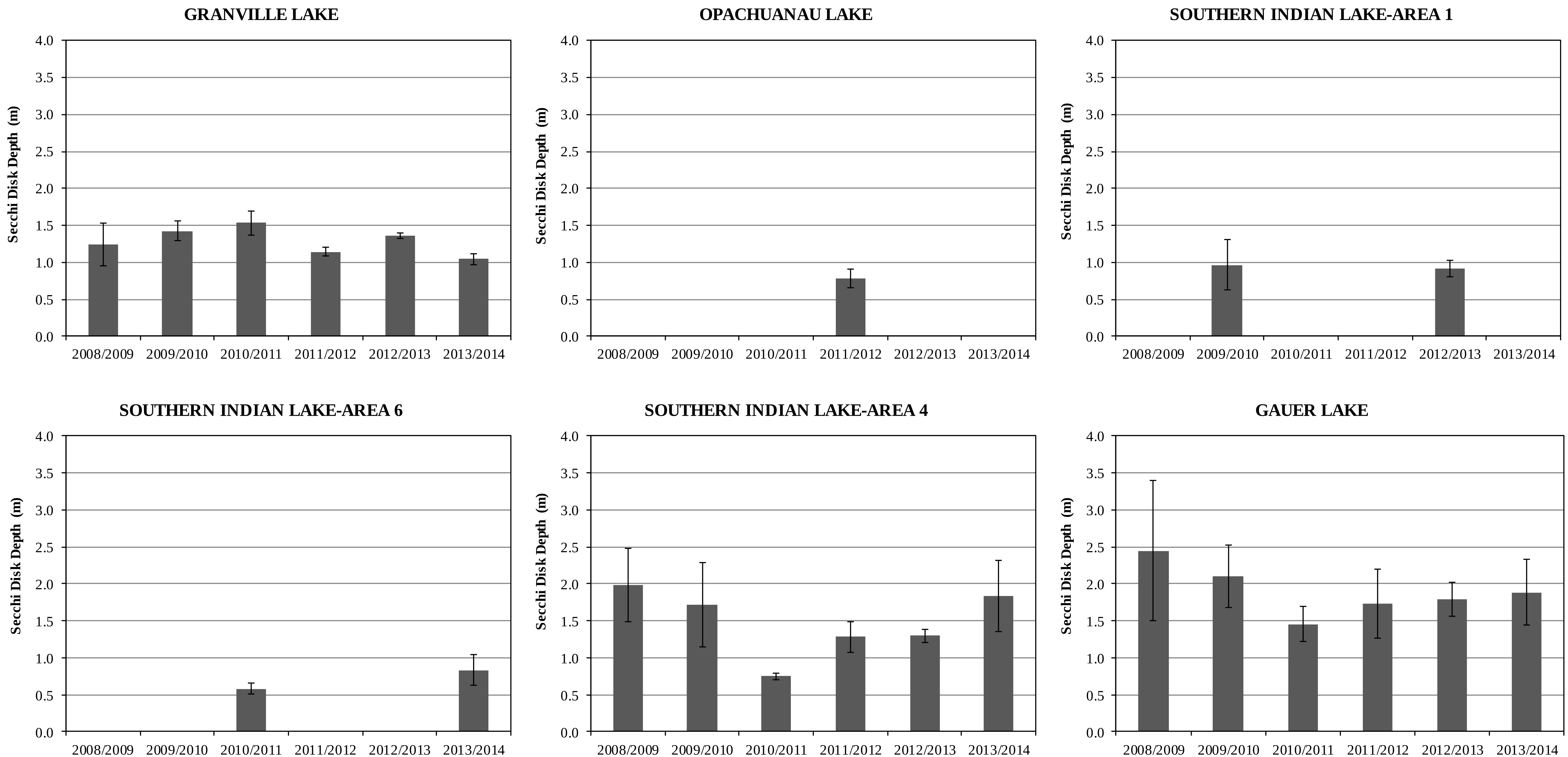



Figure 3-18. Secchi disk depths (mean±SE) measured in upper Churchill River and off-system waterbodies (Granville and Gauer lakes: 2008/2009-2013/2014 (open-water season). No statistically significant inter-annual differences were observed between the open-water seasons in the annual monitoring sites (SIL-Area 4 and Granville and Gauer lakes).

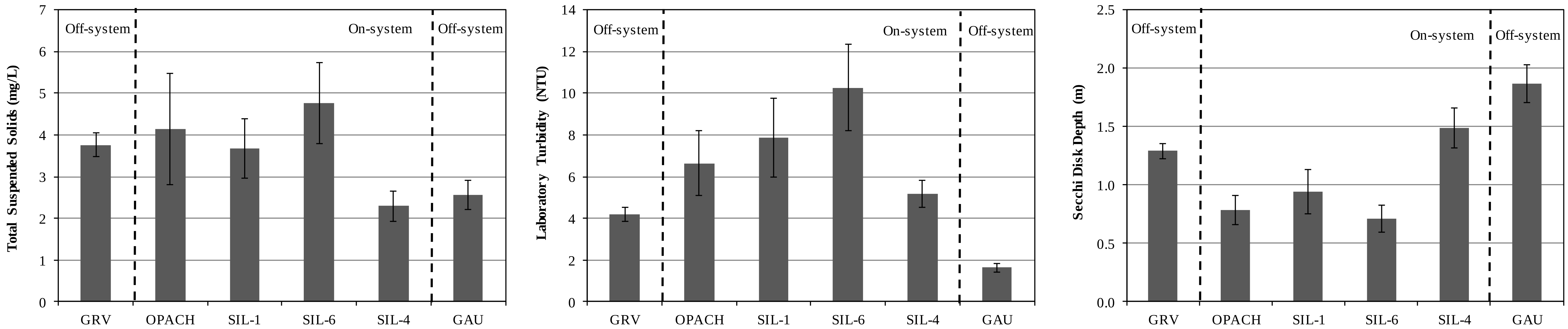



Figure 3-19. TSS, laboratory turbidity, and Secchi disk depths (mean±SE) measured in the upper Churchill River and off-system waterbodies (Granville and Gauer lakes): 2008/2009-2013/2014.

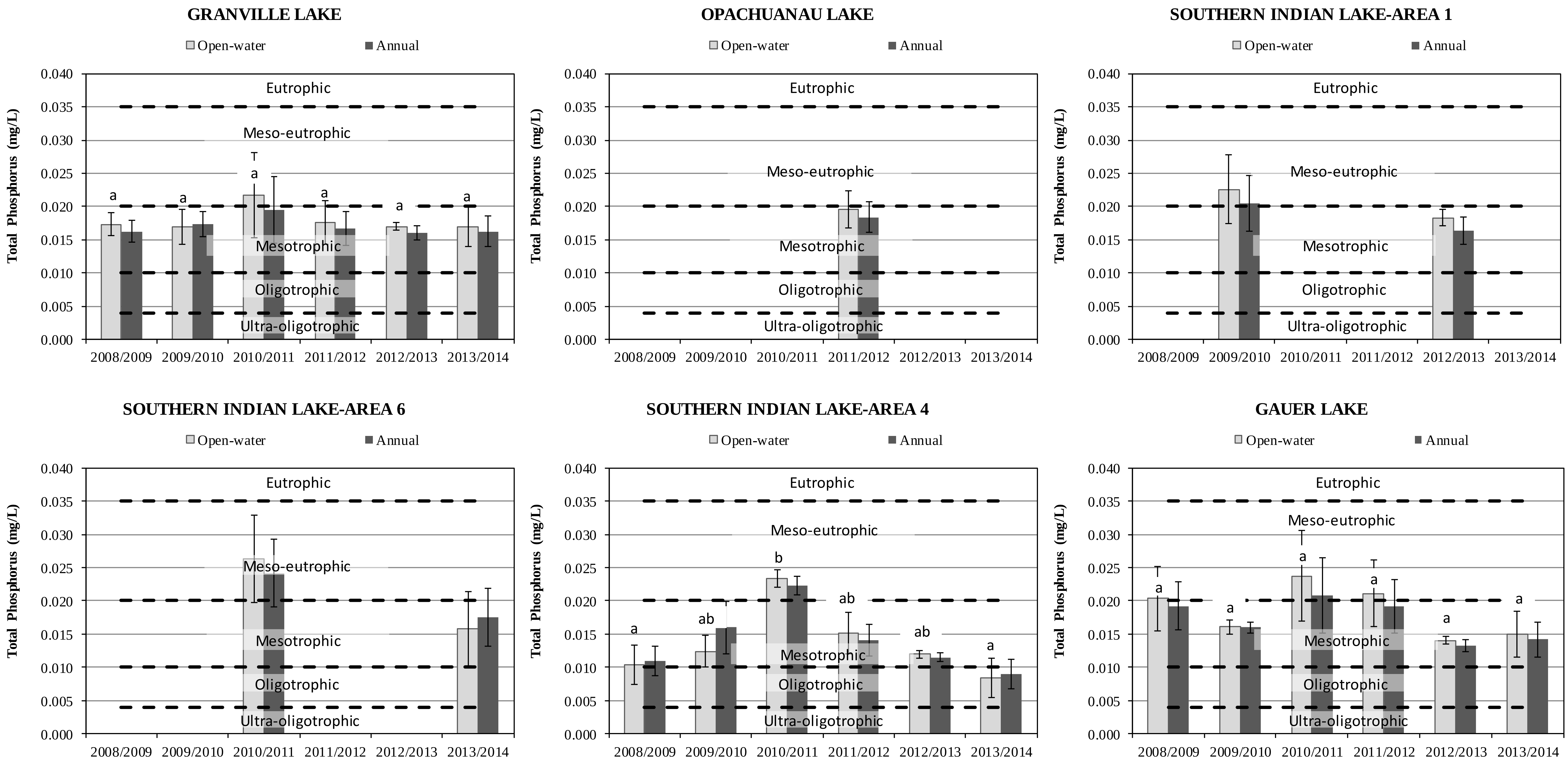



Figure 3-20. Total phosphorous (mean±SE) measured in the upper Churchill River and off-system waterbodies (Granville and Gauer lakes) and comparison to trophic categories: 2008/2009-2013/2014. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

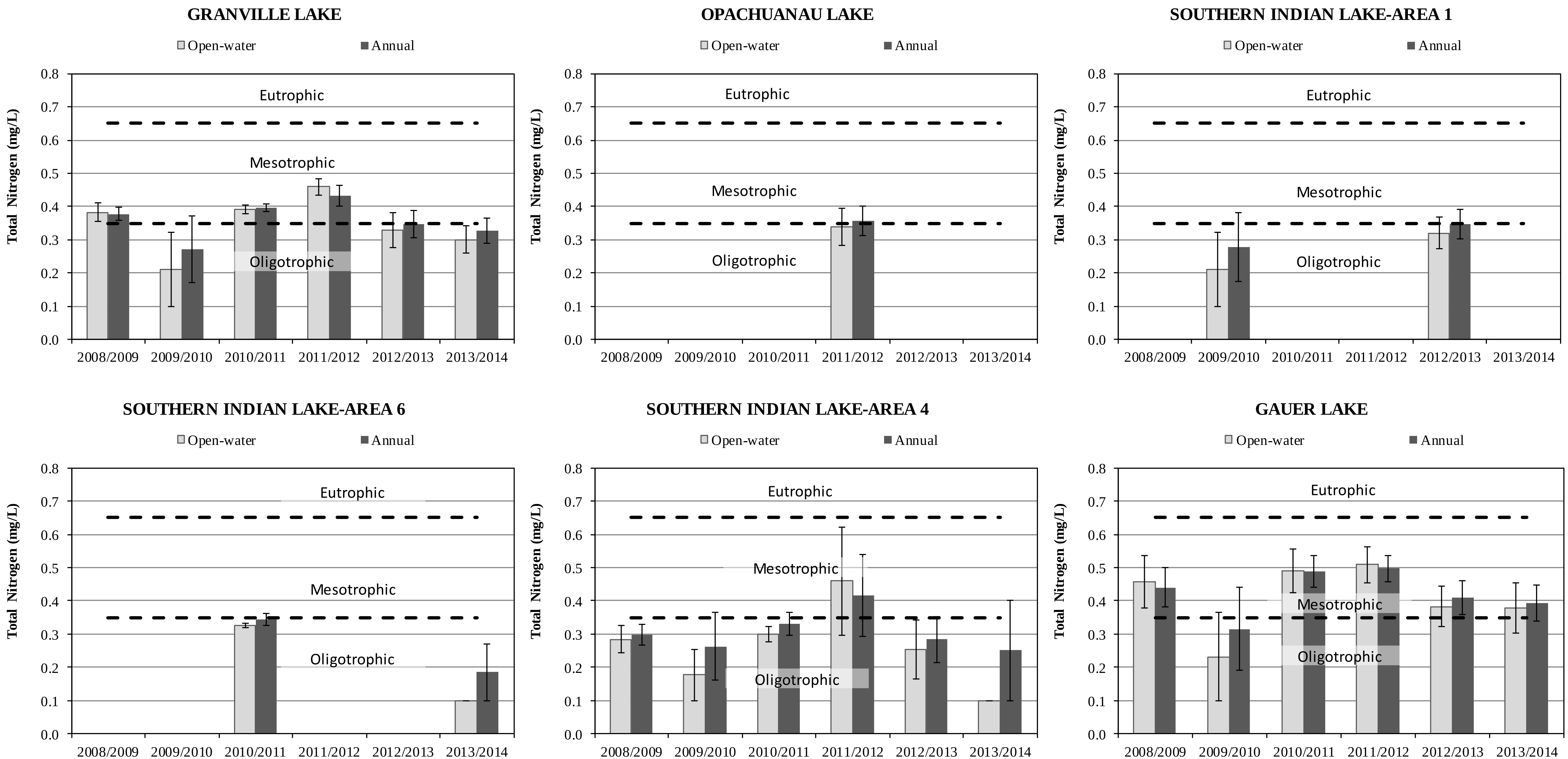



Figure 3-21. Total nitrogen (mean±SE) measured in the upper Churchill River and off-system waterbodies (Granville and Gauer lakes) and comparison to trophic categories: 2008/2009-2013/2014. No statistically significant inter-annual differences were observed between the open-water seasons in the annual monitoring sites (SIL-Area 4 and Granville and Gauer lakes).

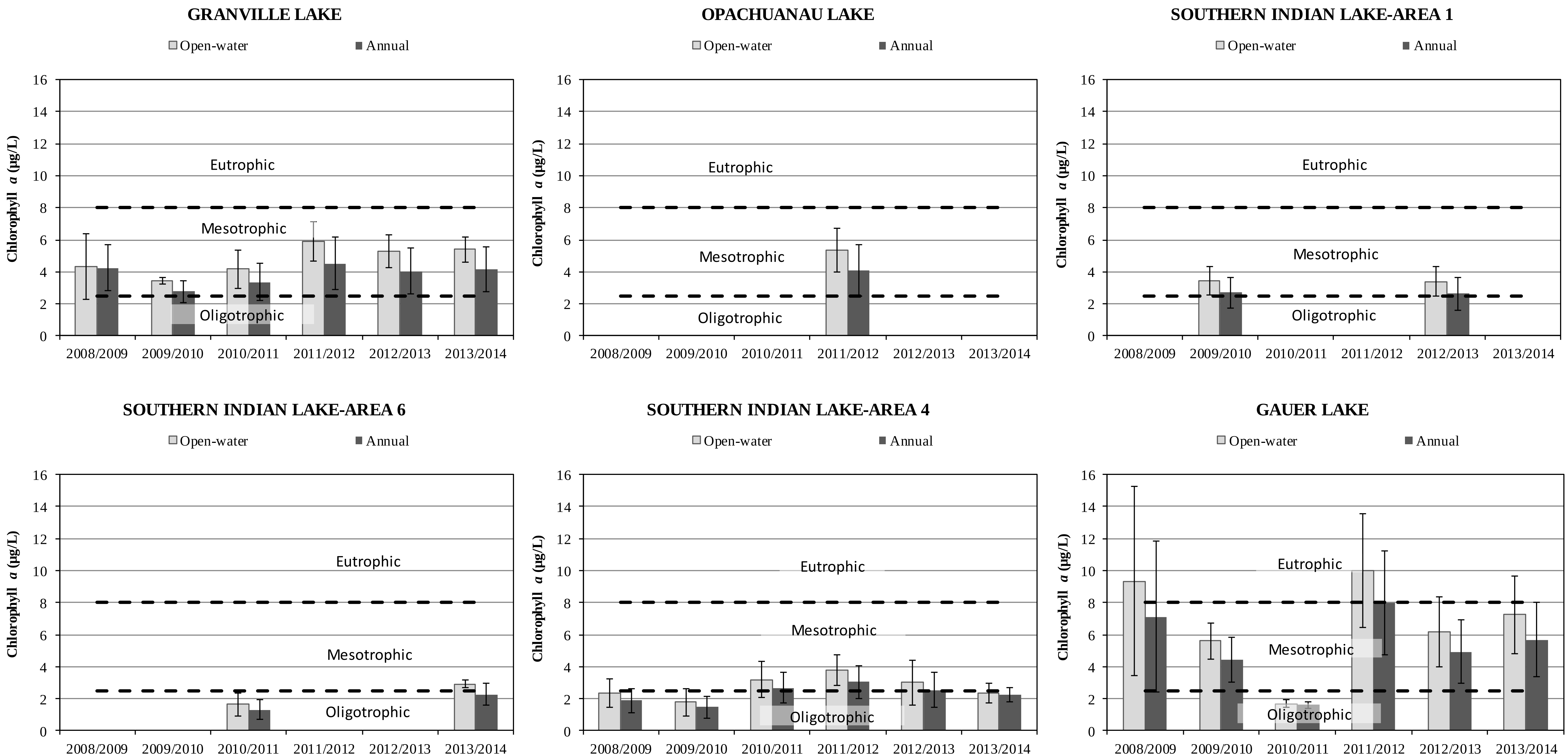



Figure 3-22. Chlorophyll *a* (mean±SE) measured in the upper Churchill River and off-system waterbodies (Granville and Gauer lakes) and comparison to trophic categories: 2008/2009-2013/2014. No statistically significant inter-annual differences were observed between the open-water seasons in the annual monitoring sites (SIL-Area 4 and Granville and Gauer lakes).

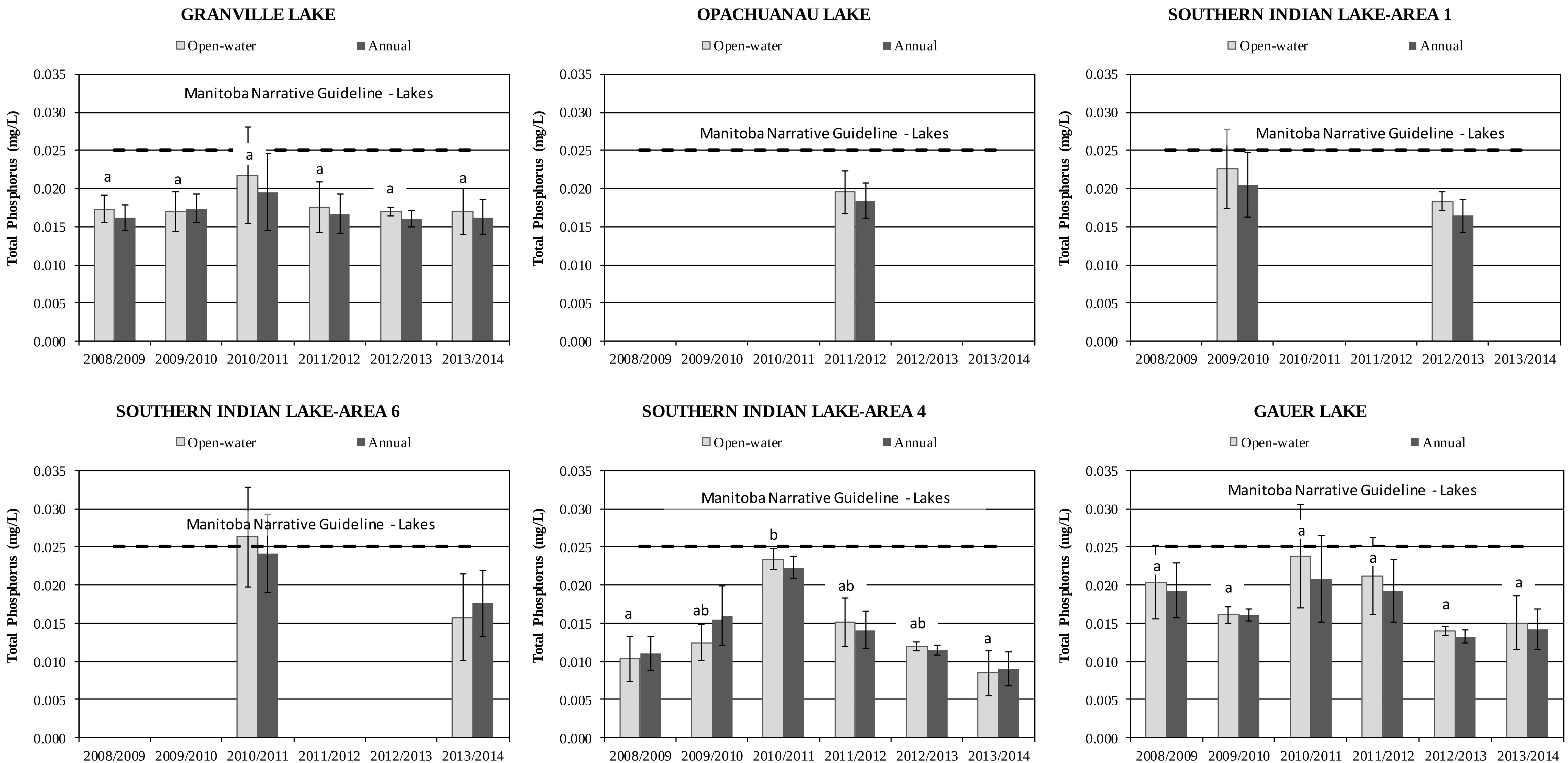



Figure 3-23. Total phosphorous (mean±SE) measured in the upper Churchill River and off-system waterbodies (Granville and Gauer lakes) and comparison to the Manitoba narrative nutrient guidelines: 2008/2009-2013/2014. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

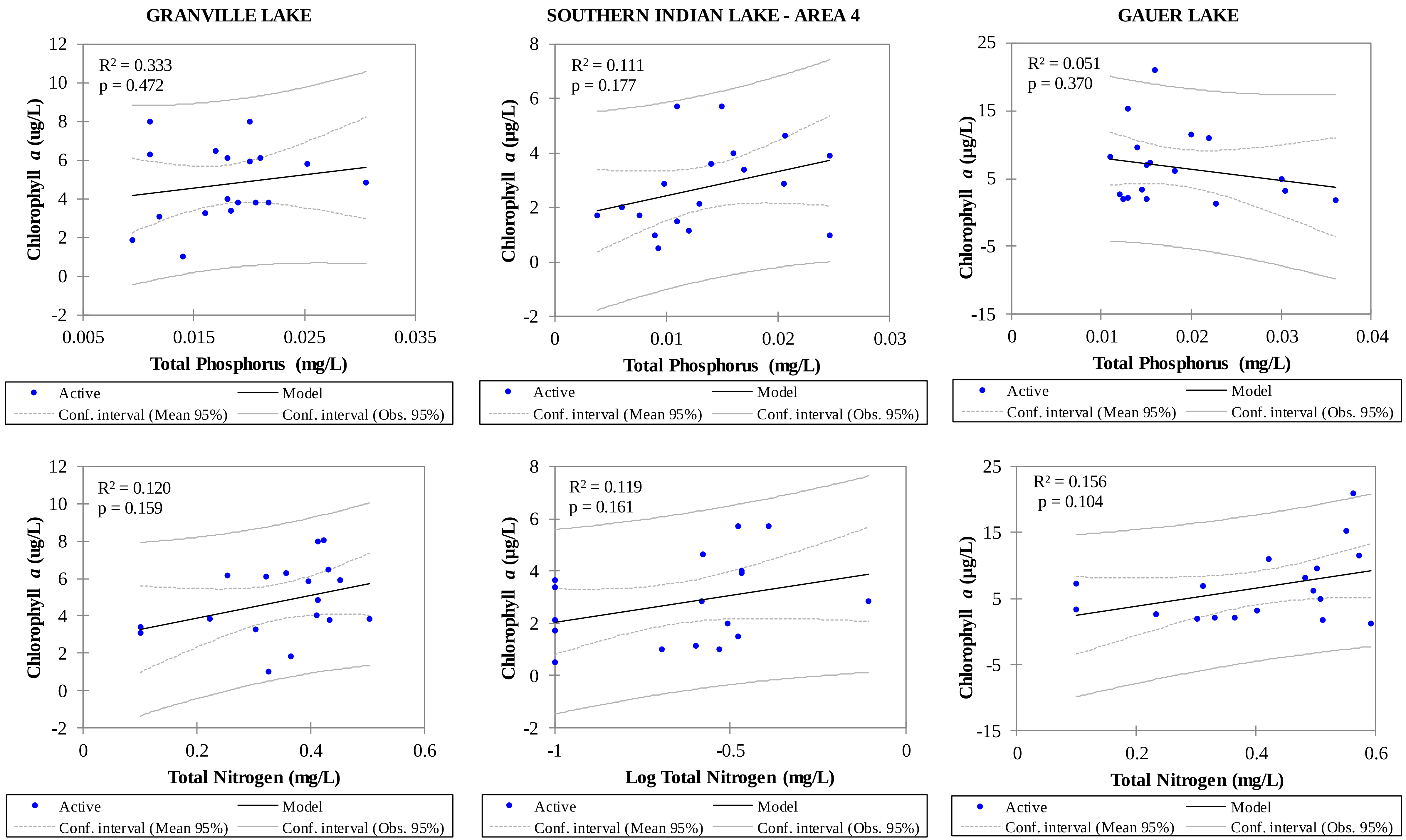



Figure 3-24. Linear regression between total phosphorus or total nitrogen and chlorophyll *a* in on-system (Southern Indian Lake-Area 4) and off-system (Granville and Gauer lakes): open-water seasons 2008-2013.

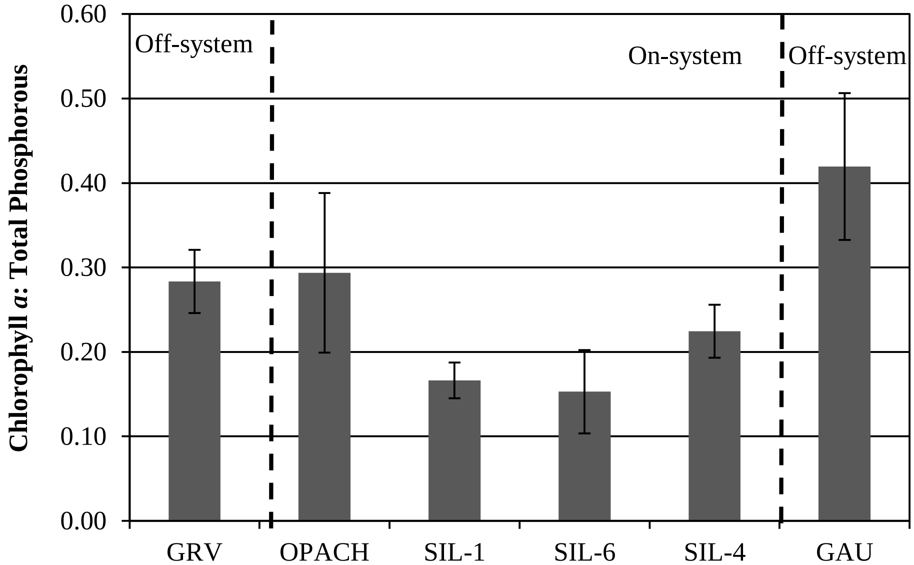



Figure 3-25. Chlorophyll *a* to total phosphorus ratios (mean±SE) measured in the upper Churchill River and off-system waterbodies (Granville and Gauer lakes): open-water seasons 2008-2013.

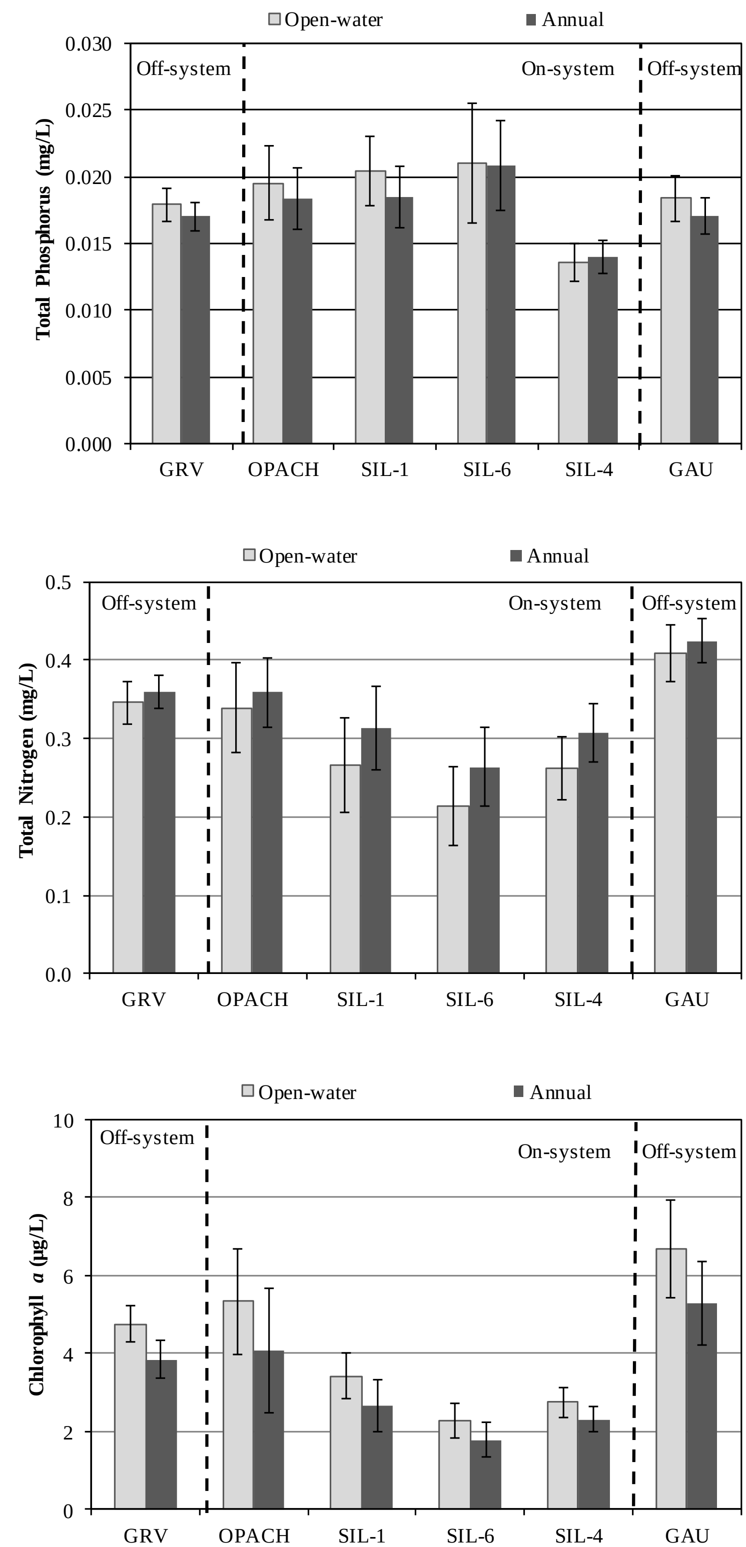



Figure 3-26. Total phosphorus, total nitrogen, and chlorophyll *a* (mean±SE) measured in the upper Churchill River and off-system waterbodies: 2008/2009-2013/2014.

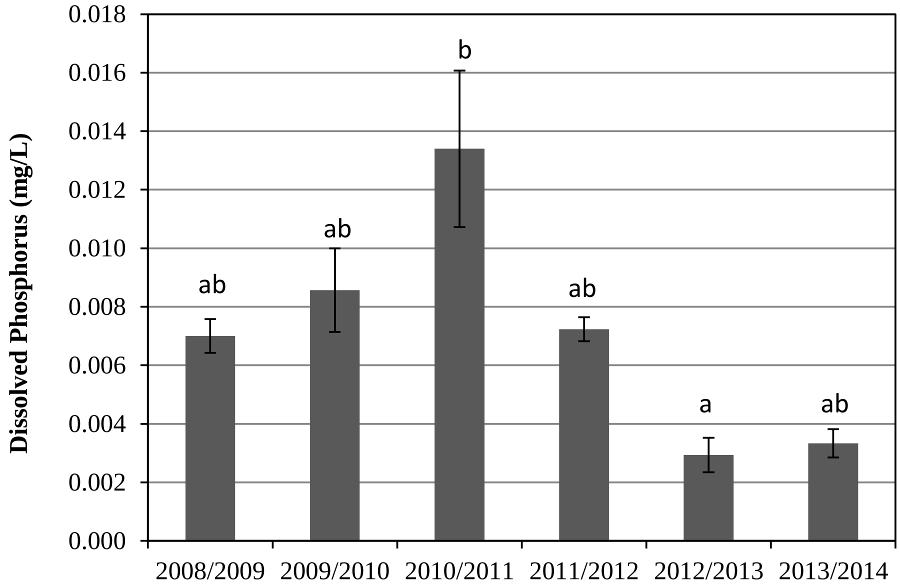



Figure 3-27. Open-water season dissolved phosphorous (mean±SE) at the annual on-system (Southern Indian Lake – Area 4). Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

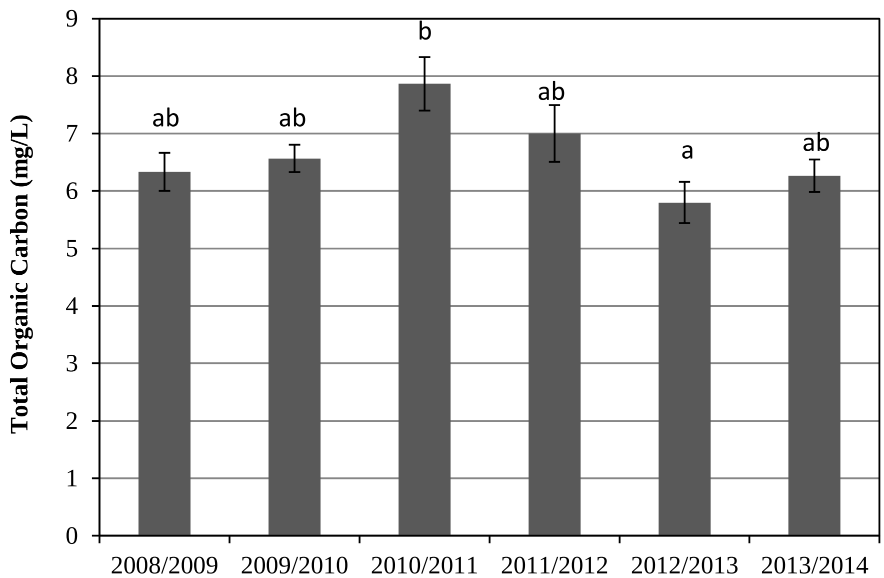



Figure 3-28. Open-water season total organic carbon (mean±SE) at the annual on-system (Southern Indian Lake – Area 4). Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

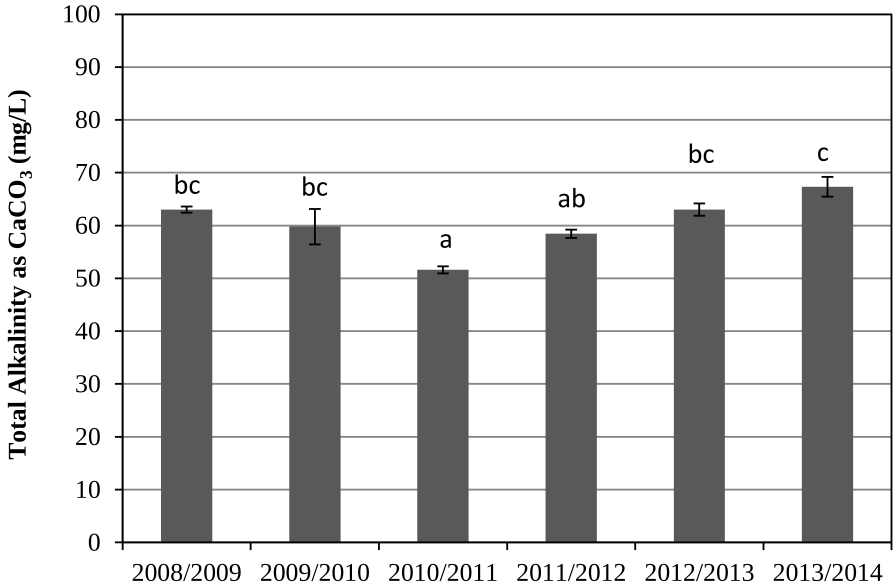



Figure 3-29. Open-water season total alkalinity (mean±SE) at the annual on-system (Southern Indian Lake – Area 4). Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

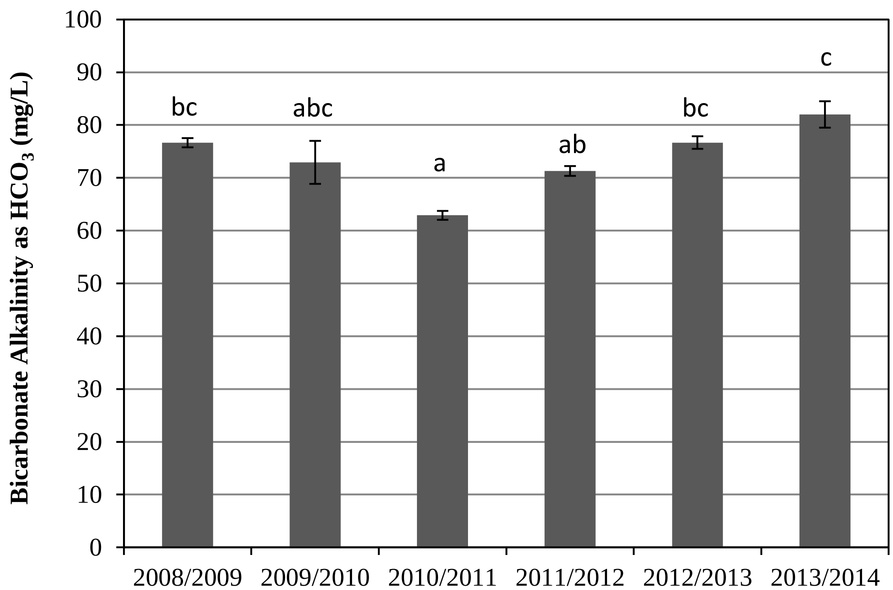



Figure 3-30. Open-water season bicarbonate alkalinity (mean±SE) at the annual on-system (Southern Indian Lake – Area 4). Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

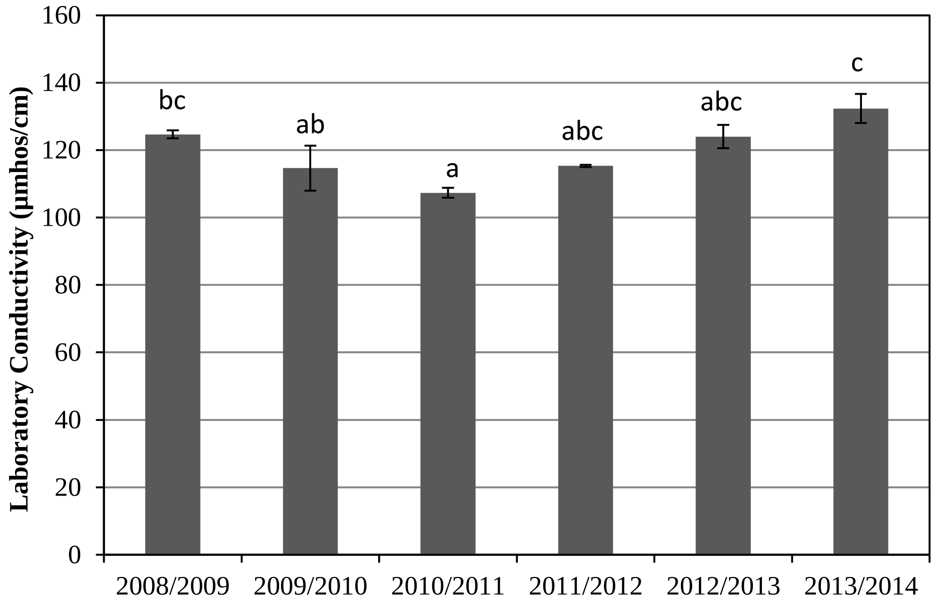



Figure 3-31. Open-water season laboratory specific conductance (mean±SE) at the annual on-system (Southern Indian Lake – Area 4). Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

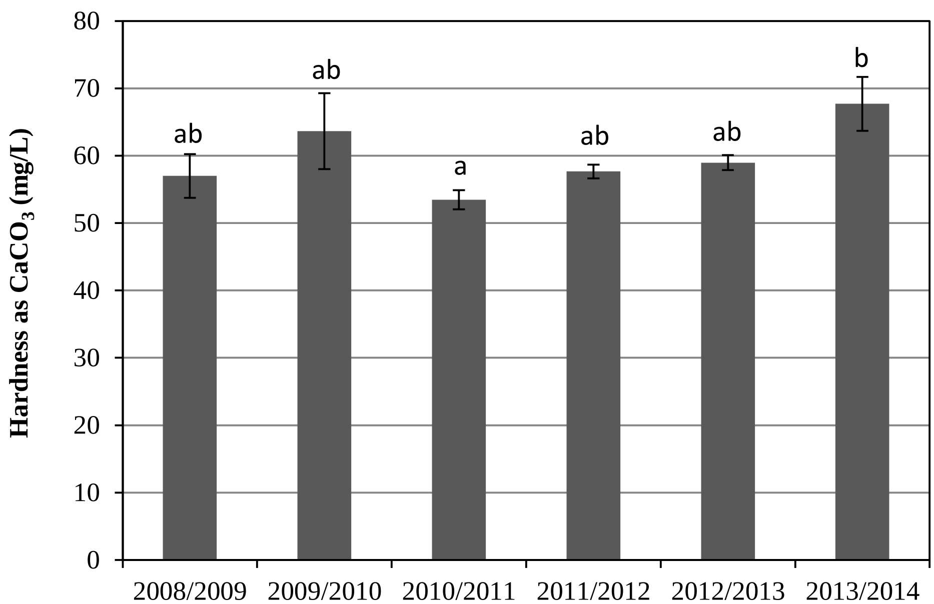



Figure 3-32. Open-water season hardness (mean±SE) at the annual on-system (Southern Indian Lake – Area 4). Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

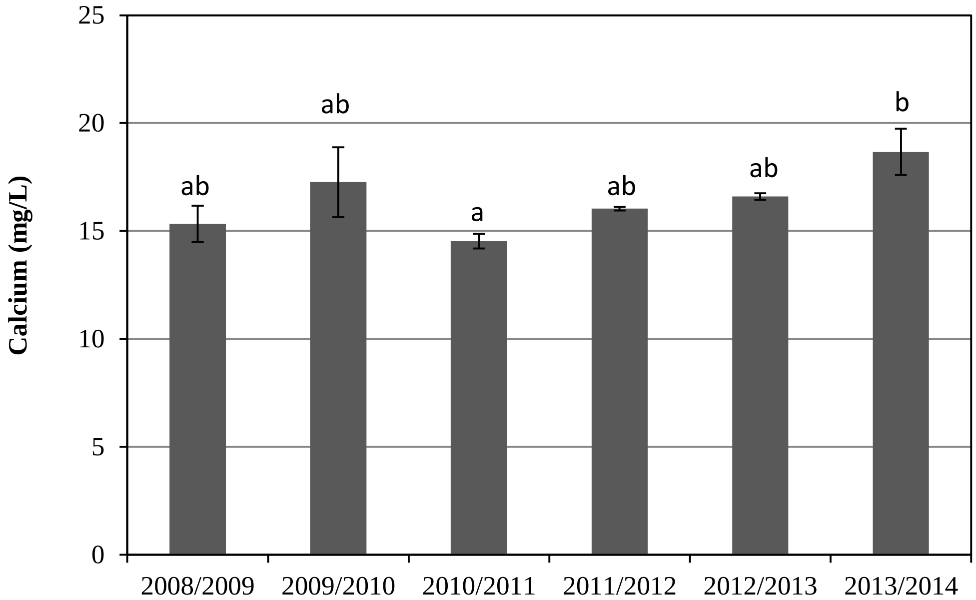



Figure 3-33. Open-water season calcium (mean±SE) at the annual on-system (Southern Indian Lake – Area 4). Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

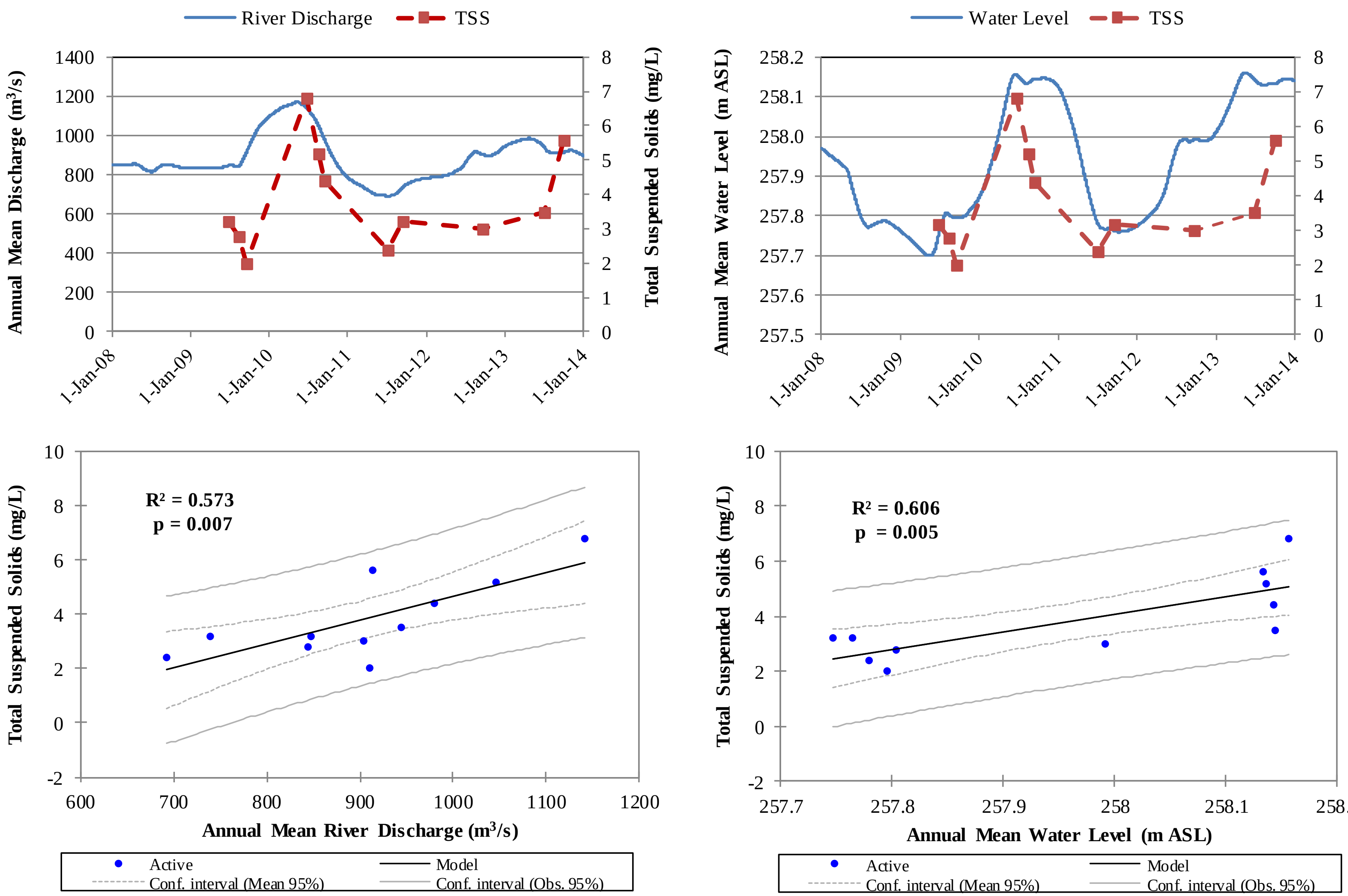



Figure 3-34. Open-water season total suspended solids (detected values only) at the annual on-system (Southern Indian Lake – Area 4) versus water level of the lake and discharge of the upper Churchill River.

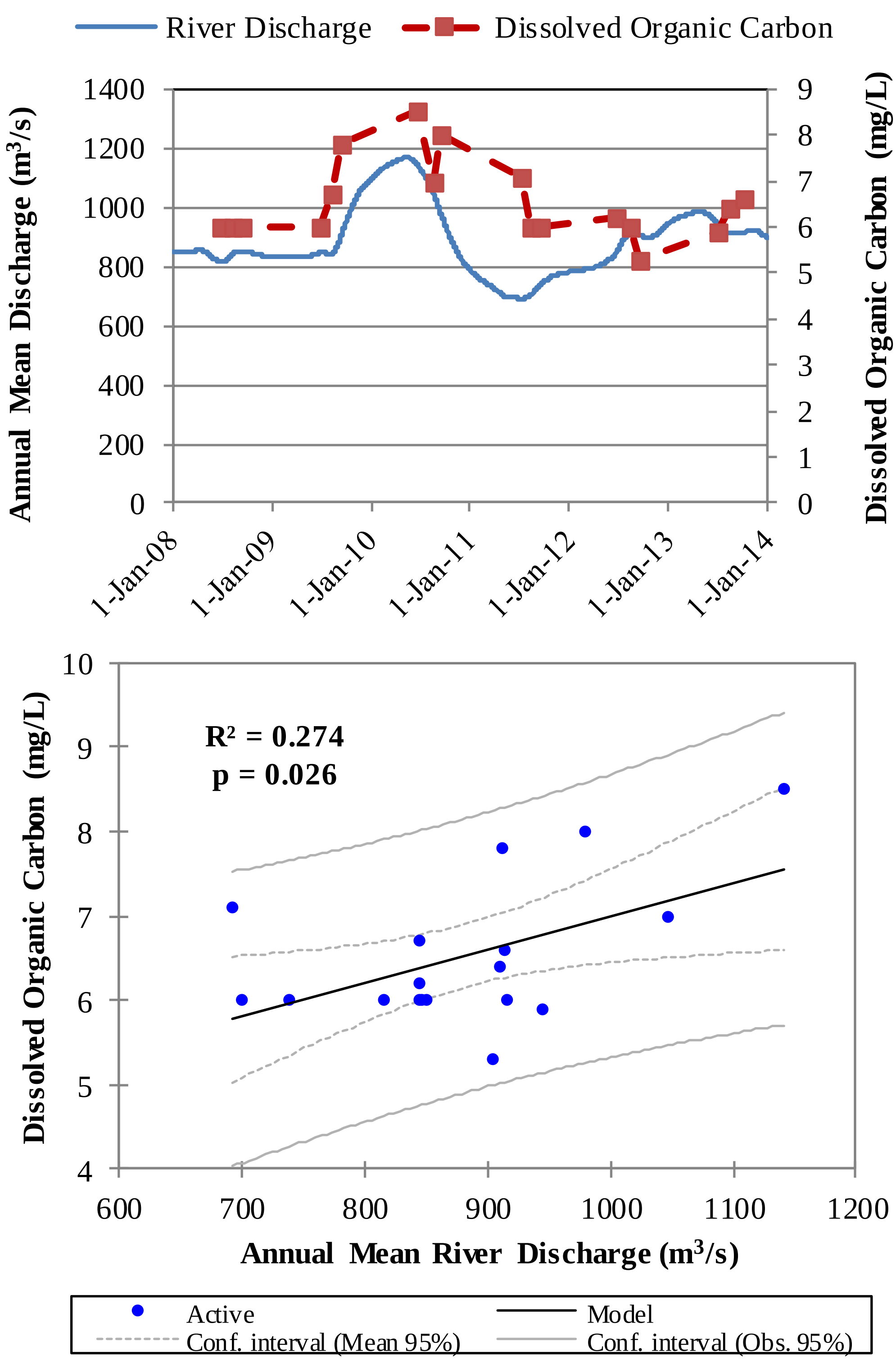



Figure 3-35. Open-water season dissolved organic carbon at the annual on-system (Southern Indian Lake – Area 4) versus water level of the lake and discharge of the upper Churchill River.

# 4.0 SEDIMENT QUALITY

## 4.1 INTRODUCTION

The following provides an overview of sediment quality conditions measured under CAMP in the UCRR over the period of 2008 through 2013; a description of the sediment quality program sampling methods is provided in Technical Document 1, Section 3.4.1. In brief, sediment quality is monitored in surficial sediments (upper 5 cm) on a six year rotational basis, beginning in 2011, at selected sites under CAMP. Three samples (i.e., a triplicate) were collected at each site. Sediment quality was measured in 2011 in Granville Lake and Southern Indian Lake – Area 4 in the UCRR (Figure 4-1). For context, results obtained from Gauer Lake – the off-system lake in the Lower Churchill River Region – are also included. As described in Technical Document 6, two sites were sampled in Gauer Lake - one predominantly sand and the other predominantly silt/clay.

### 4.1.1 Objectives and Approach

The key objective of the analysis of CAMP sediment quality data was to evaluate whether conditions are suitable for aquatic life. As described in Technical Document 1, Section 4.4, the key objective was addressed through comparisons to sediment quality guidelines (SQGs) for the protection of aquatic life. SQGs that were applied include the Manitoba SQGs (MWS 2011) where available, supplemented with Ontario SGQs (Persaud et al. 1993; Fletcher et al. 2008) and the British Columbia sediment alert concentration (SAC) for selenium (BCMOE 2014, 2017), recently adopted as an interim sediment quality guideline (ISQG) by Alberta Environment and Sustainable Resource Development (2014). There are two values specified for both Manitoba and Ontario SQGs with similar intended interpretations: SQG (Manitoba) and lowest effect level (LEL; Ontario) are values below which adverse effects to biota are expected to occur rarely; and the probable effect level (PEL; Manitoba) and severe effect level (SEL; Ontario) which are levels above which adverse effects are expected to occur frequently. Concentrations lying between the SQG/LEL and the PEL/SEL reflect a condition of increased risk of adverse effects. As only one year of data is available for sediment quality, inter-annual differences and temporal trends could not be examined for this component.

### 4.1.2 Indicators

Key sediment quality indicators have not yet been identified for CAMP reporting. Sediment quality was described for those metrics for which there are SQGs as summarized above and described in greater detail in Technical Document 1, Section 4.4.

## 4.2 UPPER CHURCHILL RIVER

Surficial sediment samples from Southern Indian Lake – Area 4 were dominated by sand (85%; Figure 4-2) and had relatively low levels of total organic carbon (TOC; Figure 4-3). The particle size and TOC content were similar to that observed at the site comprised predominantly of sand in the off-system Gauer Lake (see Section 4.3) but differed from Granville Lake located upstream on the upper Churchill River which was dominated by silt and clay and had a higher TOC fraction.

TOC (Figure 4-3) in Southern Indian Lake – Area 4 was marginally below the Ontario LEL SQG but TP (Figure 4-4) and total Kjeldahl nitrogen (TKN; Figure 4-5) exceeded the LELs. TOC and TKN results were similar to those observed at the sandy site in the off-system Gauer Lake, although TP concentrations in surficial sediments of Southern Indian Lake – Area 4 were notably higher than those in Granville or Gauer lakes. In fact, the mean concentration of TP measured in Southern Indian Lake sediments was the highest measured of all the CAMP monitoring sites.

Nickel (Figure 4-6) in surficial sediments from Southern Indian Lake – Area 4 exceeded the Ontario LEL, but not the SEL, whereas iron (Figure 4-7) and manganese (Figure 4-8) both exceeded the Ontario SELs. As observed for arsenic, the concentrations of iron and manganese in Southern Indian Lake – Area 4 were notably higher than those measured in either of the off-system waterbodies (Granville or Gauer lakes) and were the highest measured at any of the CAMP sites.

Selenium was not detected in surficial sediments from Southern Indian Lake-Area 4 (Figure 4-9) and the analytical detection limit (0.5 µg/g) was below the BC SAC and the AB ISQG (2.0 µg/g). All but one metal (arsenic), including cadmium, chromium, copper, lead, mercury, and zinc, were within the Manitoba SQGs (Figures 4-10 to 4-16).

The key finding of the sediment quality program conducted in the UCRR was the high concentrations of arsenic, iron, manganese, and phosphorus, found in the offshore sediments of Southern Indian Lake – Area 4. Arsenic exceeded the Manitoba SQG and PEL in Southern Indian Lake – Area 4 (Figure 4-10); this concentration (mean of 43.5 µg/g) was notably higher than either of the off-system waterbodies (Granville or Gauer lakes) or any other site monitored under CAMP (Table 4-1). Concentrations above a sediment quality SEL are typically interpreted to be those frequently associated with adverse biological effects. However, actual risks to aquatic life associated with metals, in general, are dependent upon many factors, including bioavailability.

For context, the Geological Survey of Canada reported under the National Geochemical Reconnaissance program (Friske and Hornbrook 1991 in CCME 1999) that mean background concentrations of arsenic in Canadian lake and stream sediments are 2.5 µg/g and 10.7 µg/g, respectively.

Arsenic has a high affinity for iron and manganese oxides (CCME 1999); sediments from this site contained iron (12.5%) and manganese (13.5%) at concentrations an order of magnitude higher than all other sites sampled under CAMP (Table 4-1). These results suggest the presence of iron and manganese oxides at this location. In addition, sediments collected from this site contained nodules (Figure 4-17); nodules were also observed at several sites sampled during the aquatic habitat survey of Southern Indian Lake – Area 4 conducted in 2013 and during the BMI monitoring programs (Figure 4-18).

Iron and manganese nodules have been reported in a number of lakes, including lakes in Canada (e.g., Grand and Ship Harbour lakes, Nova Scotia and Mosque Lake, Ontario [Harris and Troup 1970]). Iron to manganese ratios, as well as the composition of other metals in nodules, varies across sites. In general, nodules or precipitates of iron and manganese have a high affinity for cations due to the presence of large numbers of binding sites. Nodules commonly contain relatively high concentrations of other metals including copper, nickel, and cobalt and can adsorb phosphorus (Post 1999). High concentrations of arsenic have also been reported in nodules from other freshwater lakes, including Lake Michigan (Edgington and Callender 1970).

Previous studies conducted in this area as part of the Lake Winnipeg, Churchill and Nelson Rivers Study Board (LWCNRSB) studies in the early 1970s prior to CRD also noted the presence of nodules in the sediments of Area 4 and other areas (Areas 2, 6, and 7) of the lake, as well Opachuanau Lake (Hecky 1974). Examination of these formations indicated they were "ferro-manganese nodules….formed by the precipitation of iron and manganese oxides on a pre-existing nucleus such as a sand grain."

McTavish (1952) also noted from a survey of Southern Indian Lake in 1952: "A type of bottom that is hard to describe. At first glance it appears to be pebbles of rock, but on examination could be crushed by the fingers. Under the hand lens it consisted of black and brown sand, with a greasy quality to it…This bottom was found in nearly all areas where current was present, and extended for miles in Area 3 going toward the Missi Falls." Ayles and Koshinsky (1974) incidentally noted the presence of "iron nodules" in the stomachs of fish (species not specified) in fisheries investigations conducted in 1972 (prior to CRD) as part of the LWCNRSB studies.

Collectively, the available information suggests that the high concentrations of arsenic, iron, manganese, and phosphorus found in the offshore sediments of Southern Indian Lake – Area 4 are a reflection of iron and manganese nodules which, at this particular site, are associated with high concentrations of arsenic and phosphorus. Sediments from this site also contained notably higher concentrations of barium, cobalt, molybdenum, and tungsten (Table 4-2)

## 4.3 OFF-SYSTEM WATERBODIES: GRANVILLE AND GAUER LAKES

The physical and chemical composition of surficial sediments in the two off-system sites differed markedly from one another and from sediment in Southern Indian Lake – Area 4. Samples from Granville Lake were dominated by silt/clay (99%; Figure 4-2), while sediments were 74% silt/clay at the fine textured site from Gauer Lake and 99% sand from the coarse textured site. Concentrations of nutrients and metals were generally low at the Gauer Lake site composed predominantly of sand, and notably lower than at the fine texture sampling site (Figures 4-2 to 4-16). Further, nutrients and metals were often higher in Granville Lake compared to the fine textured site in Gauer Lake.

With the exception of TKN, which marginally exceeded the Ontario LEL (Figure 4-5), the low concentrations of nutrients and metals measured at the sandy site in Gauer Lake were all within the sediment quality benchmarks (Figures 4-3 to 4-16).

Exceedances of sediment quality benchmarks in Granville Lake and the fine textured site in Gauer Lake were generally similar to those observed in Southern Indian Lake – Area 4 (i.e., generally, the same metrics exceeded benchmarks at the on- and off-system sites). Exceptions included chromium, which was above the Manitoba SQG and higher in Granville Lake and the silt/clay site in Gauer Lake than Southern Indian Lake – Area 4, and arsenic, which was lower at the off-system sites and below the Manitoba SQG.

## 4.4 SUMMARY

Approximately half of sediment quality metrics were within sediment quality benchmarks in Southern Indian Lake – Area 4 and with one key exception, metrics that exceeded benchmarks were also above these benchmarks in many waterbodies monitored under CAMP (Table 4-1). The key exception was arsenic which was above the upper sediment quality benchmark (the Manitoba SEL), which is considered to be the concentration associated with frequent adverse effects to aquatic biota. Concentrations at this site were the highest (average 43.5 µg/g) of all sites monitored under CAMP and well above those measured at the upstream Granville Lake (5.16 µg/g) or the off-system Gauer Lake (0.56 and 2.53 µg/g at the two sampling Gauer Lake sites). Iron and manganese were also highest at Southern Indian Lake – Area 4 of all the sites monitored under CAMP in 2011 which likely indicates the presence of iron and manganese oxides (nodules), for which arsenic has a high affinity, at this site.

Table 4-1. Sediment quality (means of triplicate samples) monitoring results for key metrics. Shading indicates concentrations at or above a sediment quality benchmark.

| Region | Waterbody | Sand (%) | Silt (%) | Clay (%) | TKN (µg/g) | TP (µg/g) | TOC (%) | Arsenic (µg/g) | Cadmium (µg/g) | Chromium (µg/g) | Copper (µg/g) | Iron (µg/g) | Lead (µg/g) | Manganese (µg/g) | Mercury (µg/g) | Nickel (µg/g) | Selenium (µg/g) | Zinc (µg/g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WRR | PDB | 88.1 | 7.56 | 4.35 | 717 | 370 | 0.50 | 1.76 | 0.028 | 11.6 | 4.6 | 9450 | 3.78 | 272 | <0.05 | 7.53 | <0.5 | 20 |
| | LDB | 12.2 | 66.7 | 21.1 | 2283 | 735 | 2.15 | 4.49 | 0.171 | 25.2 | 13.8 | 18267 | 8.02 | 1056 | 0.075 | 18.1 | <0.5 | 48 |
| | MANIG | 1.54 | 39.4 | 59.0 | 5983 | 1063 | 5.18 | 5.40 | 0.289 | 43.2 | 25.8 | 31500 | 17.4 | 569 | 0.085 | 31.3 | 0.75 | 80 |
| SRR | CEDAR-SE | 0.60 | 34.6 | 64.8 | 4137 | 910 | 3.92 | 6.58 | 0.335 | 33.7 | 24.6 | 31700 | 13.0 | 583 | <0.05 | 33.8 | 0.89 | 80 |
| | CORM | 1.12 | 29.5 | 69.4 | 4223 | 850 | 3.29 | 4.34 | 0.606 | 59.2 | 37.3 | 37867 | 20.6 | 877 | 0.083 | 43.1 | 0.67 | 111 |
| LKWPGR | LWPG | - | - | - | 3483 | 667 [1] | - | 5.05 | 0.260 | 57.0 | 32.3 | 31233 | 13.4 | 630 | <0.05 | 44.0 | 0.86 | 78 |
| | LWPGOSIS | 92.9 | 5.41 | 1.68 | 987 | 241 | 0.95 | 1.19 | 0.066 | 7.1 | 4.2 | 4683 | 2.36 | 273 | <0.05 | 5.78 | <0.5 | 12 |
| UCRR | GRV | 1.36 | 39.9 | 58.7 | 3023 | 1188 | 2.16 | 5.16 | 0.434 | 76.5 | 27.1 | 49700 | 18.3 | 3543 | <0.05 | 55.3 | <0.5 | 111 |
| | SIL-4 | 85.1 | 4.97 | 9.92 | 817 | 1790 | 0.99 | 43.5 | 0.330 | 21.0 | 10.6 | 125000 | 16.0 | 13500 | <0.05 | 21.3 | <0.5 | 39 |
| LCRR | NIL | 3.98 | 61.5 | 34.5 | 3393 | 973 | 2.66 | 4.54 | 0.192 | 55.7 | 22.2 | 38967 | 12.6 | 1597 | <0.05 | 35.9 | <0.5 | 78 |
| | GAU-Sand | 99.4 | 0.47 | <0.1 | 657 | 123 | 0.53 | 0.56 | <0.02 | 2.5 | 1.4 | 2480 | 1.15 | 41 | <0.05 | 1.82 | <0.5 | <10 |
| | GAU-Silt/Clay | 26.0 | 47.9 | 26.1 | 6977 | 786 | 5.65 | 2.53 | 0.165 | 44.5 | 22.2 | 28467 | 9.36 | 552 | <0.05 | 30.9 | 0.59 | 74 |
| CRDR | 3PT | 0.33 | 47.1 | 52.7 | 1350 | 775 | 1.11 | 4.94 | 0.160 | 68.3 | 28.5 | 39100 | 13.0 | 2235 | <0.05 | 45.6 | <1.1 | 88 |
| | LEFT | 1.03 | 40.5 | 58.5 | 7003 | 942 | 5.62 | 3.02 | 0.273 | 60.8 | 33.9 | 37000 | 15.6 | 463 | <0.05 | 45.3 | 0.46 | 79 |
| UNRR | CROSS | 1.37 | 55.7 | 42.9 | 3097 | 1005 | 2.75 | 6.48 | 0.199 | 52.0 | 22.8 | 31933 | 12.3 | 804 | <0.05 | 37.6 | 0.67 | 74 |
| | SET | 1.49 | 24.1 | 74.4 | 3937 | 1012 | 3.10 | 5.10 | 0.309 | 80.1 | 28.3 | 51467 | 17.4 | 1303 | <0.05 | 53.6 | <0.5 | 117 |
| LNRR | BURNT | 5.87 | 70.7 | 23.5 | 673 | 604 | 0.88 | 2.12 | 0.104 | 35.5 | 14.6 | 19000 | 6.54 | 493 | <0.05 | 24.8 | <1.1 | 41 |
| | SPLIT | 3.46 | 51.0 | 45.5 | 1053 | 459 | 1.00 | 3.46 | 0.130 | 50.0 | 21.1 | 25733 | 9.63 | 575 | <0.05 | 34.5 | <1.1 | 65 |
| | ASSN | 0.14 | 56.2 | 43.6 | 1280 | 533 | 1.30 | 2.78 | 0.170 | 40.3 | 16.8 | 23933 | 9.57 | 579 | <0.05 | 27.8 | <1.1 | 57 |
| | Mean > MB SQG | | | | | | | 5.9 | 0.6 | 37.3 | 35.7 | | 35 | | 0.17 | | | 123 |
| | Mean > MB PEL | | | | | | | 17 | 3.5 | 90 | 197 | | 91.3 | | 0.486 | | | 315 |
| | Mean > ON LEL | | | | 550 | 600 | 1 | | | | | 20000 | | 460 | | 16 | | |
| | Mean > ON SEL | | | | 4800 | 2000 | 10 | | | | | 40000 | | 1100 | | 75 | | |
| | Mean > BC SAC | | | | | | | | | | | | | | | | 2.0 | |

[1] Data from 2009 (not measured in 2011).

Table 4-2. Sediment quality (means of triplicate samples) monitoring results for other metals.

| Region | Waterbody | Aluminum (µg/g) | Antimony (µg/g) | Barium (µg/g) | Beryllium (µg/g) | Bismuth (µg/g) | Boron (µg/g) | Calcium (µg/g) | Cesium (µg/g) | Cobalt (µg/g) | Magnesium (µg/g) | Molybdenum (µg/g) | Potassium (µg/g) | Rubidium (µg/g) | Silver (µg/g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WRR | PDB | 4327 | <0.10 | 26.7 | <0.10 | <0.02 | 2.4 | 2673 | 0.333 | 3.71 | 1807 | 0.076 | 580 | 6.24 | <0.10 |
| | LDB | 10700 | <0.10 | 86.4 | 0.41 | 0.087 | 8.2 | 7590 | 0.891 | 8.26 | 5753 | 0.183 | 1943 | 21.2 | <0.10 |
| | MANIG | 23333 | 0.24 | 155 | 0.81 | 0.238 | 13.2 | 6117 | 1.27 | 10.5 | 7317 | 0.468 | 3427 | 38.8 | 0.14 |
| SRR | CEDAR-SE | 20133 | 0.45 | 242 | 0.79 | 0.220 | 8.4 | 21300 | 1.30 | 11.3 | 14267 | 0.503 | 3060 | 24.7 | 0.18 |
| | CORM | 27933 | 0.25 | 193 | 0.95 | 0.328 | 15.4 | 26233 | 2.36 | 15.2 | 22667 | 0.369 | 5357 | 51.5 | 0.16 |
| LKWPGR | LWPG | 23967 | 0.41 | 204 | 0.92 | 0.240 [1] | 17.2 | 27433 | 2.41 [1] | 13.6 | 21500 | 0.778 | 5153 | 47.0 [1] | 0.14 |
| | LWPGOSIS | 2767 | <0.10 | 28.6 | <0.10 | 0.037 | 6.0 | 93233 | 0.259 | 2.45 | 26700 | 0.165 | 685 | 4.8 | <0.10 |
| UCRR | GRV | 35333 | 0.13 | 384 | 1.39 | 0.479 | 12.5 | 6220 | 3.96 | 20.9 | 11467 | 0.854 | 7633 | 86.6 | 0.17 |
| | SIL-4 | 10010 | <0.10 | 1280 | 1.40 | 0.242 | 6.2 | 4320 | 1.28 | 44.6 | 2920 | 4.65 | 1783 | 23.0 | <0.10 |
| LCRR | NIL | 26633 | <0.10 | 175 | 1.05 | 0.333 | 12.2 | 6343 | 3.28 | 14.3 | 9967 | 0.319 | 5617 | 61.6 | 0.12 |
| | GAU-Sand | 784 | <0.10 | 5.80 | <0.10 | <0.02 | <3.0 | 810 | 0.065 | 0.79 | 380 | 0.083 | 143 | 1.12 | <0.10 |
| | GAU-Silt/Clay | 20800 | <0.10 | 106 | 0.83 | 0.252 | 10.4 | 6043 | 2.57 | 10.8 | 7780 | 0.362 | 3977 | 45.6 | 0.13 |
| CRDR | 3PT | 28650 | <0.10 | 192 | 0.96 | 0.318 | 13.2 | 7680 | 3.10 | 16.4 | 13300 | 0.339 | 6260 | 67.4 | 0.21 |
| | LEFT | 27567 | 0.12 | 157 | 1.07 | 0.341 | 17.7 | 7723 | 3.10 | 15.1 | 11267 | 0.612 | 5843 | 55.4 | 0.17 |
| UNRR | CROSS | 21033 | 0.23 | 146 | 0.69 | 0.212 | 16.4 | 24767 | 2.02 | 12.5 | 21000 | 0.304 | 4270 | 41.2 | 0.17 |
| | SET | 35633 | 0.17 | 241 | 1.31 | 0.363 | 22.7 | 7373 | 3.70 | 19.6 | 18700 | 0.346 | 7397 | 76.8 | 0.21 |
| LNRR | BURNT | 12633 | <0.10 | 69.5 | 0.51 | 0.135 | 13.0 | 51700 | 1.30 | 8.28 | 30533 | 0.216 | 2620 | 25.6 | 0.14 |
| | SPLIT | 20400 | 0.14 | 128 | 0.75 | 0.191 | 17.1 | 63400 | 1.93 | 11.5 | 28567 | 0.295 | 4373 | 39.9 | 0.21 |
| | ASSN | 16700 | <0.10 | 82.1 | 0.69 | 0.171 | 18.5 | 80900 | 1.67 | 9.87 | 36600 | 0.189 | 3473 | 31.3 | 0.12 |

Table 4-2. continued.

| Region | Waterbody | Sodium (µg/g) | Strontium (µg/g) | Sulfur (µg/g) | Tellurium (µg/g) | Thallium (µg/g) | Tin (µg/g) | Titanium (µg/g) | Tungsten (µg/g) | Uranium (µg/g) | Vanadium (µg/g) | Zirconium (µg/g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WRR | PDB | 116 | 9.26 | <5.0 | <0.10 | <0.10 | <5.0 | 309 | <0.050 | 0.607 | 15.5 | 2.10 |
| | LDB | 147 | 22.4 | <5.0 | <0.10 | 0.11 | <5.0 | 346 | <0.050 | 1.36 | 35.1 | 5.13 |
| | MANIG | 199 | 32.7 | <5.0 | <0.10 | 0.25 | <5.0 | 364 | <0.050 | 2.36 | 61.6 | 7.90 |
| SRR | CEDAR-SE | 294 | 68.2 | 13.3 | <0.10 | 0.25 | <5.0 | 96.8 | <0.050 | 1.54 | 51.7 | 7.24 |
| | CORM | 348 | 38.0 | <5.0 | <0.10 | 0.34 | <5.0 | 736 | 0.078 | 1.17 | 63.2 | 6.84 |
| LKWPGR | LWPG | 464 | 52.3 | 2667 | <0.10 [1] | 0.31 | - | 854 | 0.073 [1] | 1.69 [1] | 65.8 | 10.1 |
| | LWPGOSIS | 462 | 128 | 673 | <0.10 | <0.10 | <5.0 | 145 | <0.050 | 0.328 | 6.99 | 1.09 |
| UCRR | GRV | 327 | 42.0 | <5.0 | <0.10 | 0.54 | <5.0 | 2023 | 0.195 | 4.71 | 83.0 | 13.8 |
| | SIL-4 | 117 | 29.4 | <5.0 | <0.10 | 0.19 | <5.0 | 500 | 0.814 | 3.69 | 66.9 | 3.85 |
| LCRR | NIL | 388 | 31.8 | <5.0 | <0.10 | 0.37 | <5.0 | 1323 | 0.140 | 2.32 | 54.8 | 12.1 |
| | GAU-Sand | 30 | 2.83 | <5.0 | <0.10 | <0.10 | <5.0 | 130 | <0.050 | 0.293 | 3.58 | 1.35 |
| | GAU-Silt/Clay | 303 | 23.2 | <5.0 | <0.10 | 0.28 | <5.0 | 1002 | 0.120 | 2.34 | 42.6 | 11.7 |
| CRDR | 3PT | 409 | 36.2 | <5.0 | <0.10 | 0.37 | <5.0 | 1665 | 0.140 | 1.55 | 65.3 | 20.5 |
| | LEFT | 456 | 32.2 | <5.0 | <0.10 | 0.32 | <5.0 | 1267 | 0.127 | 2.35 | 61.7 | 16.8 |
| UNRR | CROSS | 452 | 42.1 | <5.0 | <0.10 | 0.26 | <5.0 | 985 | 0.098 | 1.29 | 52.7 | 12.3 |
| | SET | 751 | 40.0 | <5.0 | <0.10 | 0.40 | <5.0 | 1510 | 0.119 | 1.79 | 75.7 | 18.4 |
| LNRR | BURNT | 250 | 35.3 | <5.0 | <0.10 | 0.14 | <5.0 | 846 | 0.100 | 0.802 | 33.0 | 14.9 |
| | SPLIT | 362 | 57.0 | 320 | <0.10 | 0.24 | <5.0 | 1081 | 0.077 | 0.959 | 50.3 | 23.7 |
| | ASSN | 279 | 52.5 | <5.0 | <0.10 | 0.19 | <5.0 | 808 | 0.091 | 0.790 | 41.3 | 10.2 |

[1] Data from 2009 (not measured in 2011).

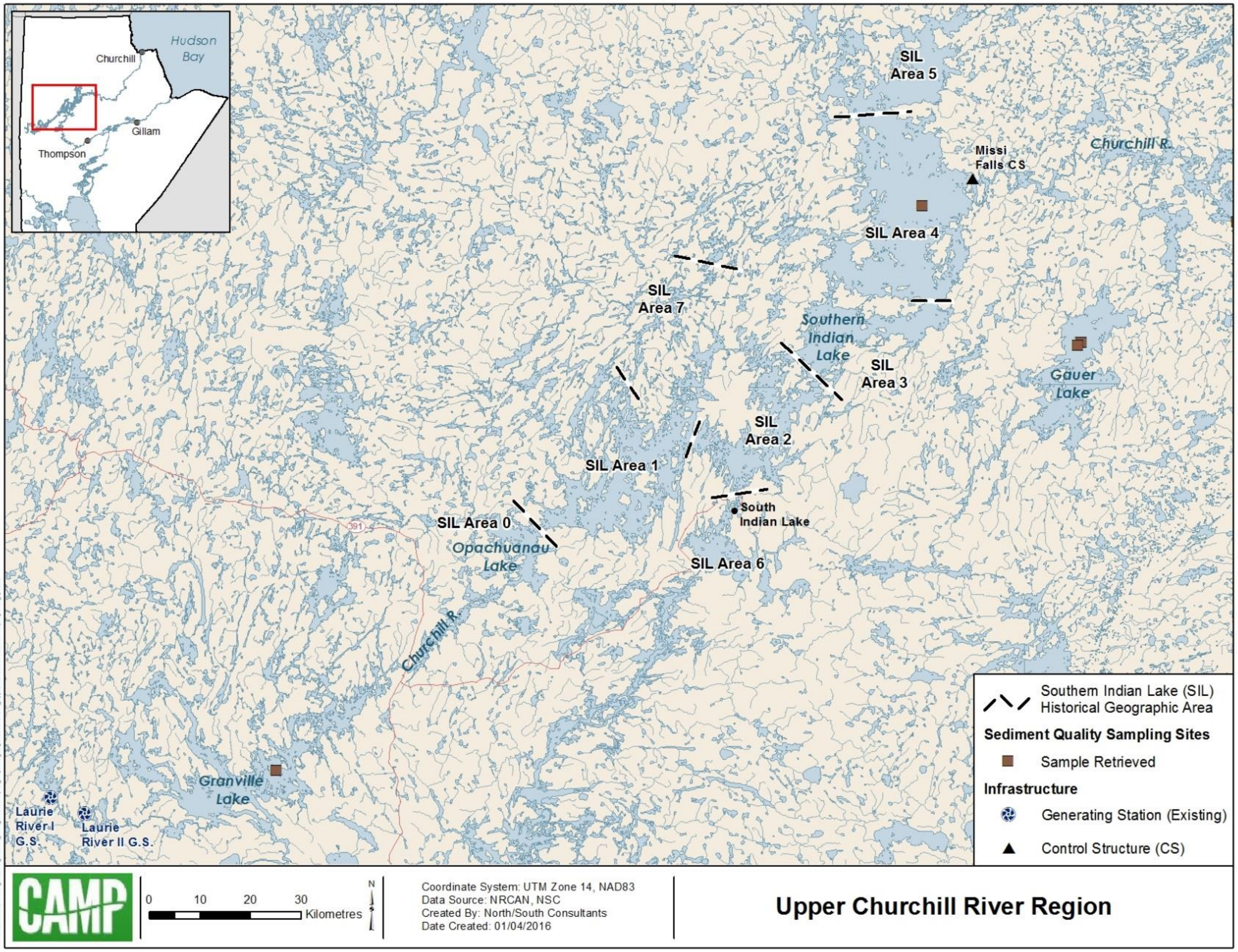



Figure 4-1. Sediment quality sampling sites in the Upper Churchill River Region: 2008-2013.

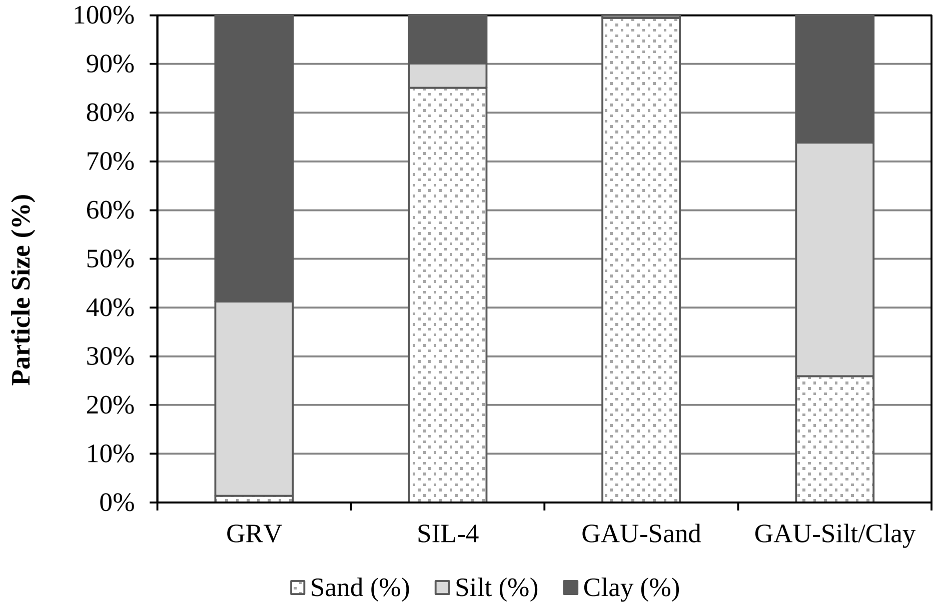



Figure 4-2. Particle size of surficial sediment from Granville Lake (GRV), Southern Indian Lake – Area 4 (SIL-4), and two sites in Gauer Lake (GAU).

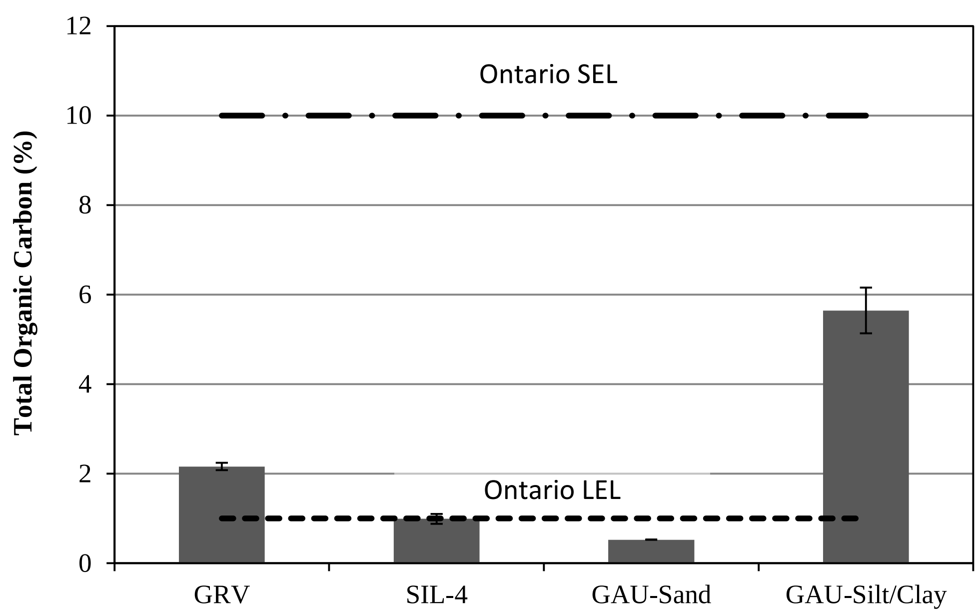



Figure 4-3. Percentage of total organic carbon (mean±SE) in surficial sediment from Granville Lake (GRV), Southern Indian Lake – Area 4 (SIL-4), and two sites in Gauer Lake (GAU), and comparison to Ontario sediment quality guidelines.

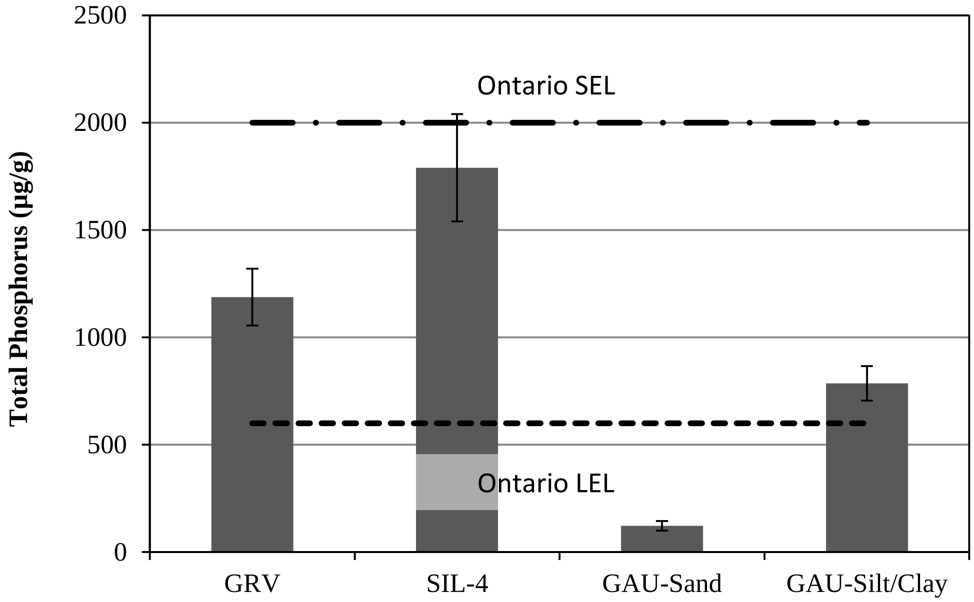



Figure 4-4. Mean (±SE) concentrations of total phosphorus in surficial sediment from Granville Lake (GRV), Southern Indian Lake – Area 4 (SIL-4), and two sites in Gauer Lake (GAU), and comparison to Ontario sediment quality guidelines.

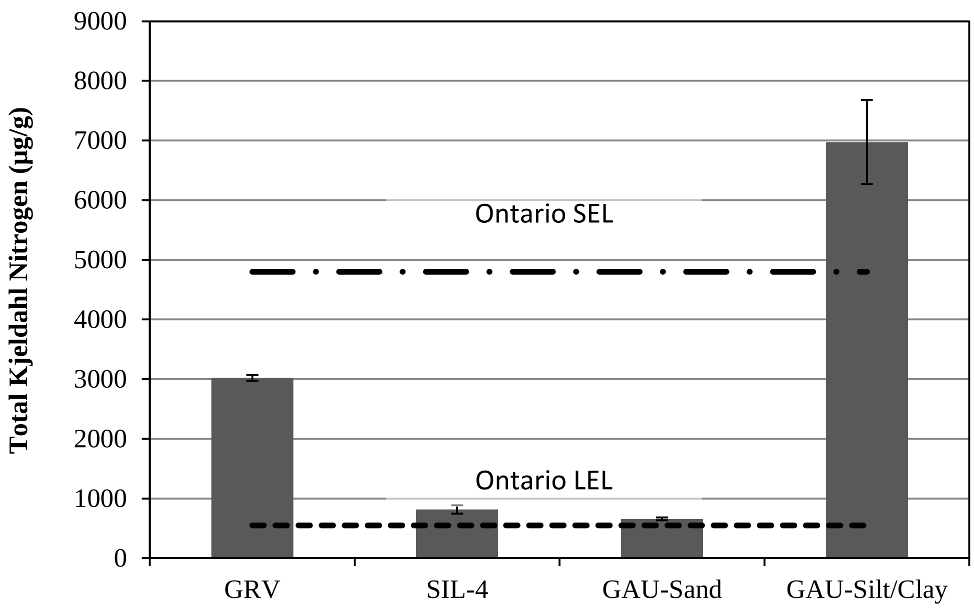



Figure 4-5. Mean (±SE) concentrations of total Kjeldahl nitrogen in surficial sediment from Granville Lake (GRV), Southern Indian Lake – Area 4 (SIL-4), and two sites in Gauer Lake (GAU), and comparison to Ontario sediment quality guidelines.

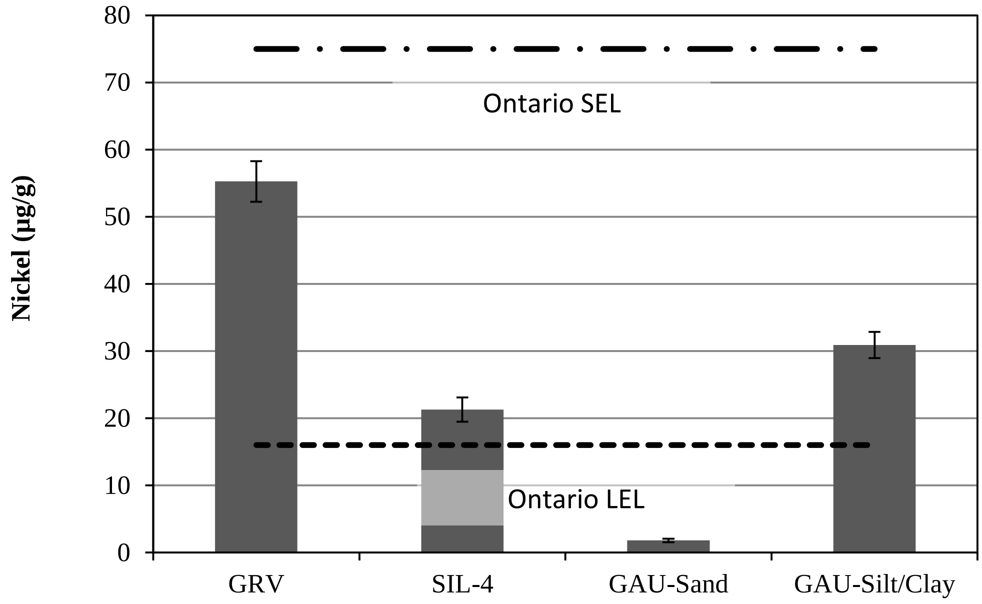



Figure 4-6. Mean (±SE) concentrations of nickel in surficial sediment from Granville Lake (GRV), Southern Indian Lake – Area 4 (SIL-4), and two sites in Gauer Lake (GAU), and comparison to Ontario sediment quality guidelines.

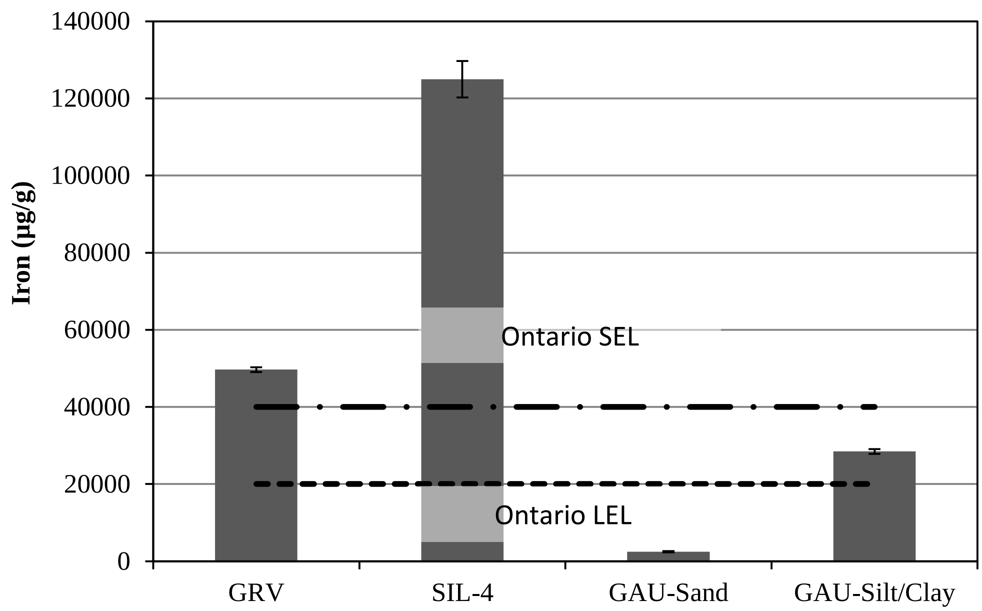



Figure 4-7. Mean (±SE) concentrations of iron in surficial sediment from Granville Lake (GRV), Southern Indian Lake – Area 4 (SIL-4), and two sites in Gauer Lake (GAU), and comparison to Ontario sediment quality guidelines.

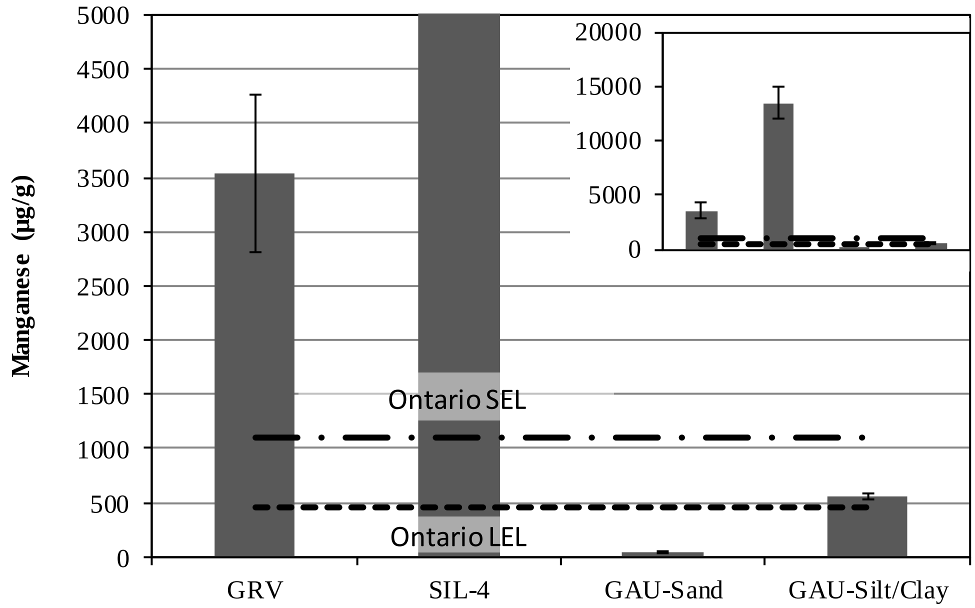



Figure 4-8. Mean (±SE) concentrations of manganese in surficial sediment from Granville Lake (GRV), Southern Indian Lake – Area 4 (SIL-4), and two sites in Gauer Lake (GAU), and comparison to Ontario sediment quality guidelines.

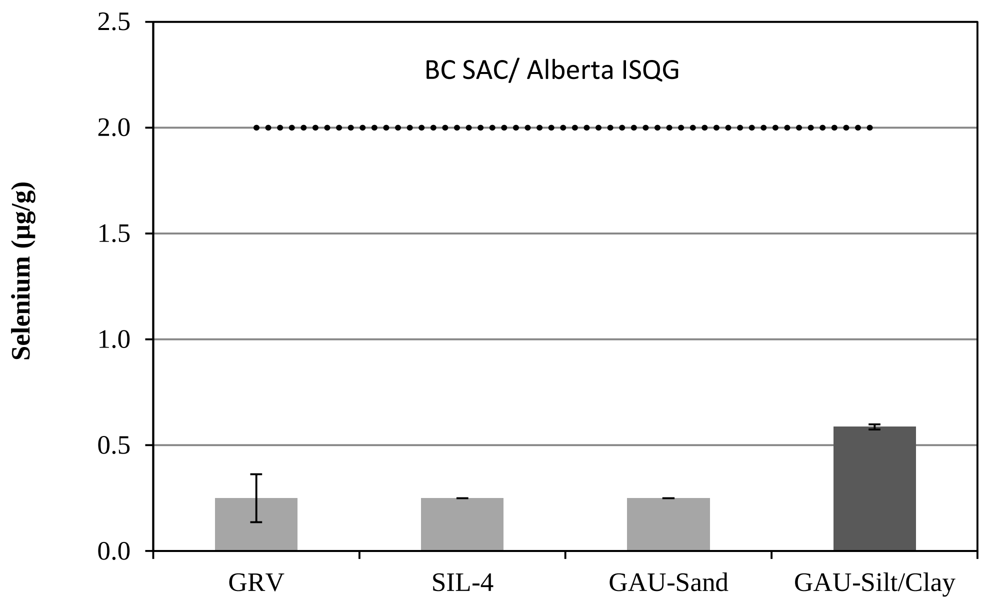



Figure 4-9. Mean (±SE) concentrations of selenium in surficial sediment from Granville Lake (GRV), Southern Indian Lake – Area 4 (SIL-4), and two sites in Gauer Lake (GAU), and comparison to the BC sediment alert concentration and the Alberta ISQG. Means indicated in light grey were below the analytical detection limit.

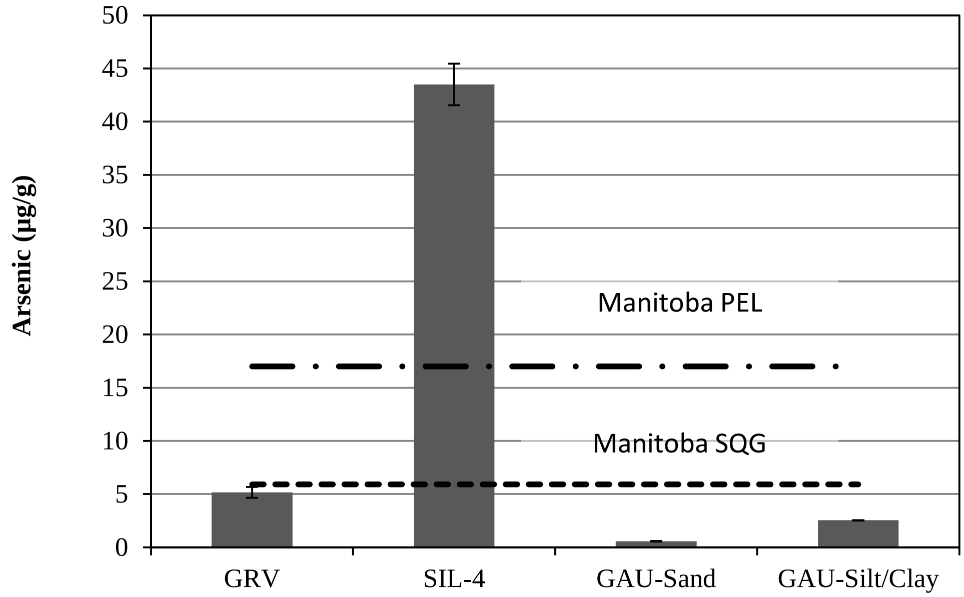



Figure 4-10. Mean (±SE) concentrations of arsenic in surficial sediment from Granville Lake (GRV), Southern Indian Lake – Area 4 (SIL-4), and two sites in Gauer Lake (GAU), and comparison to Manitoba sediment quality guidelines.

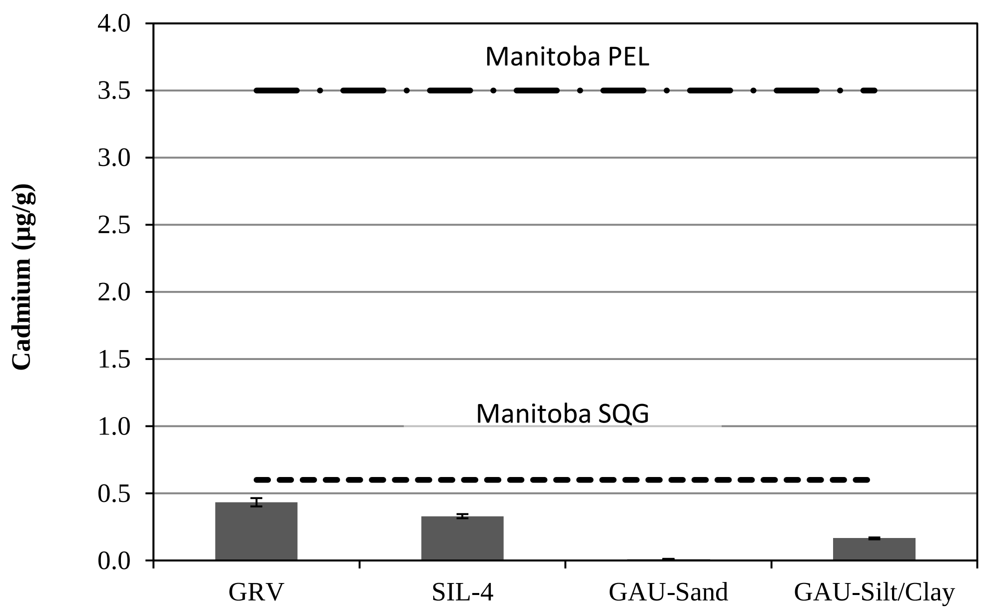



Figure 4-11. Mean (±SE) concentrations of cadmium in surficial sediment from Granville Lake (GRV), Southern Indian Lake – Area 4 (SIL-4), and two sites in Gauer Lake (GAU), and comparison to Manitoba sediment quality guidelines. Means indicated in light grey were below the analytical detection limit.

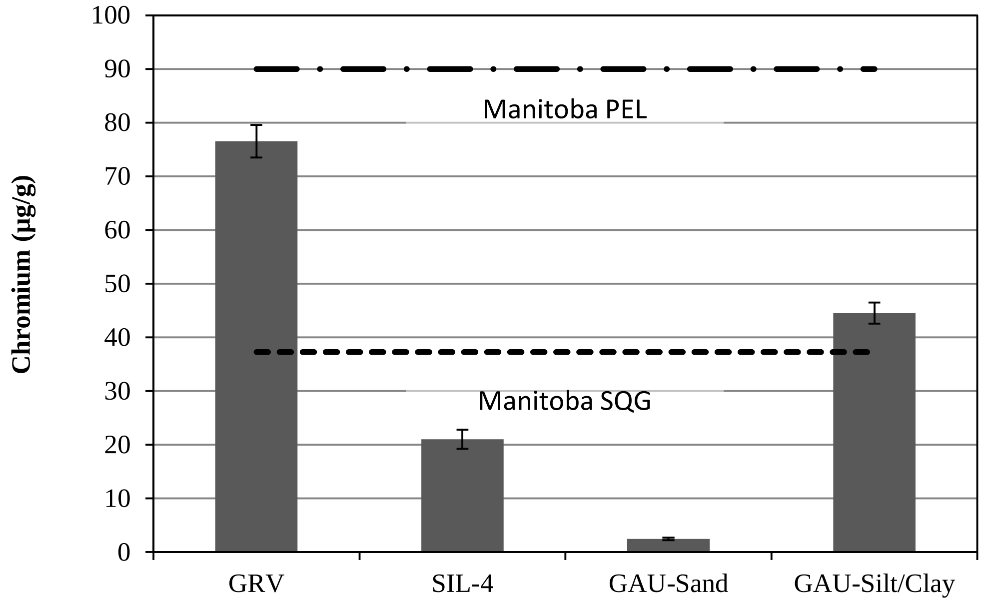



Figure 4-12. Mean (±SE) concentrations of chromium in surficial sediment from Granville Lake (GRV), Southern Indian Lake – Area 4 (SIL-4), and two sites in Gauer Lake (GAU), and comparison to Manitoba sediment quality guidelines.

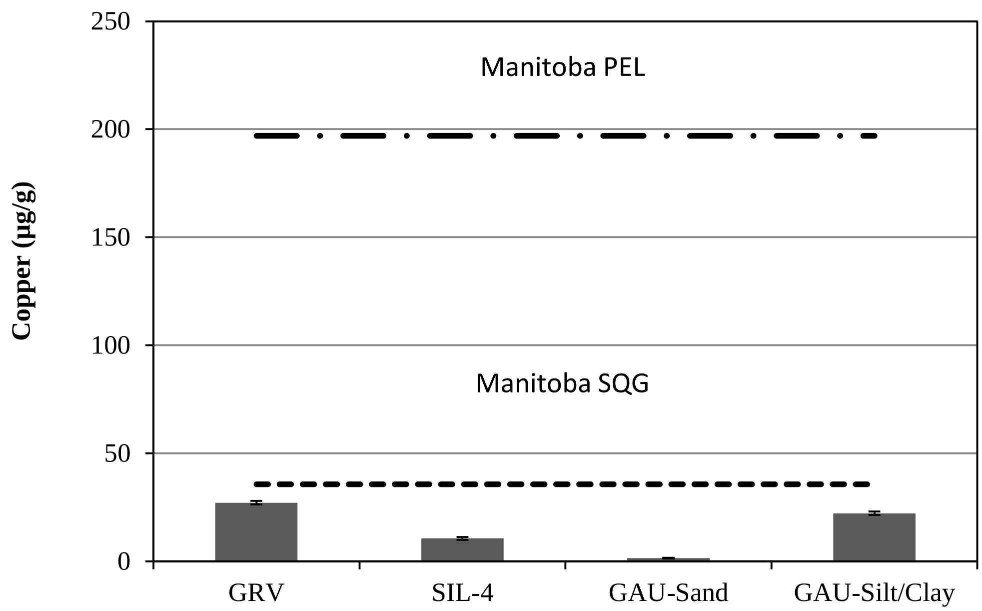



Figure 4-13. Mean (±SE) concentrations of copper in surficial sediment from Granville Lake (GRV), Southern Indian Lake – Area 4 (SIL-4), and two sites in Gauer Lake (GAU), and comparison to Manitoba sediment quality guidelines.

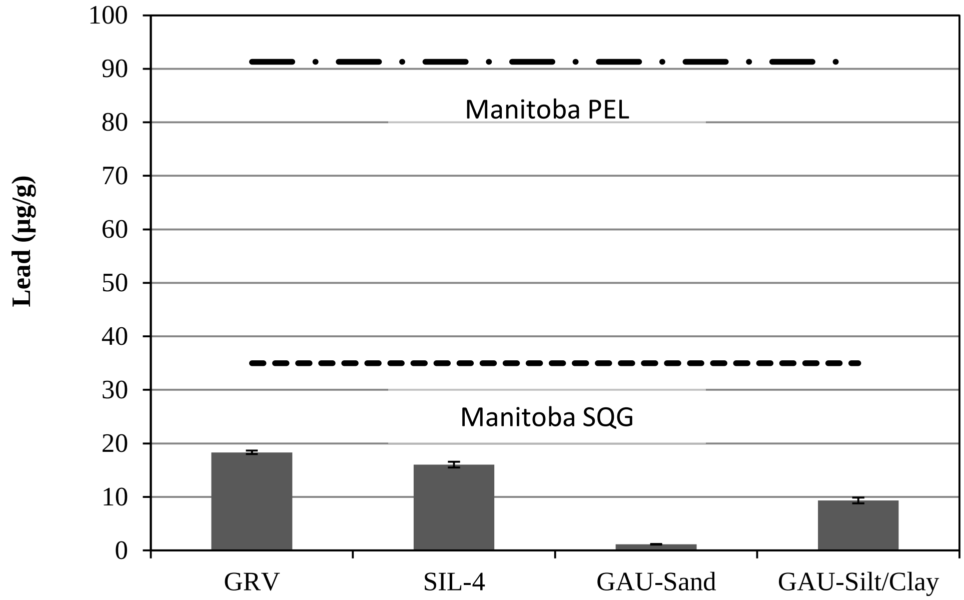



Figure 4-14. Mean (±SE) concentrations of lead in surficial sediment from Granville Lake (GRV), Southern Indian Lake – Area 4 (SIL-4), and two sites in Gauer Lake (GAU), and comparison to Manitoba sediment quality guidelines.

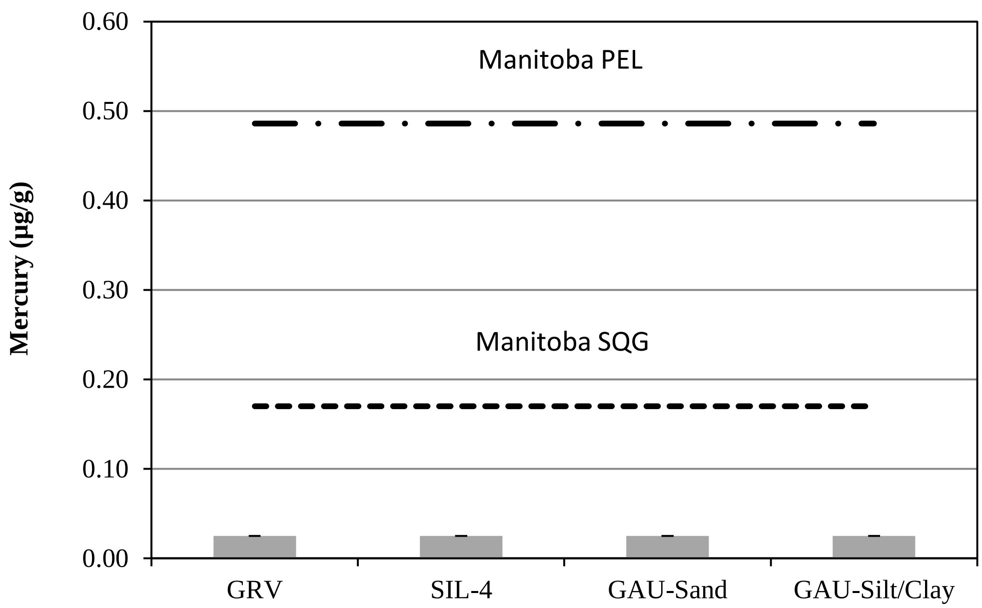



Figure 4-15. Mean (±SE) concentrations of mercury in surficial sediment from Granville Lake (GRV), Southern Indian Lake – Area 4 (SIL-4), and two sites in Gauer Lake (GAU), and comparison to Manitoba sediment quality

guidelines. All measurements were below the analytical detection limit (0.05 µg/g).

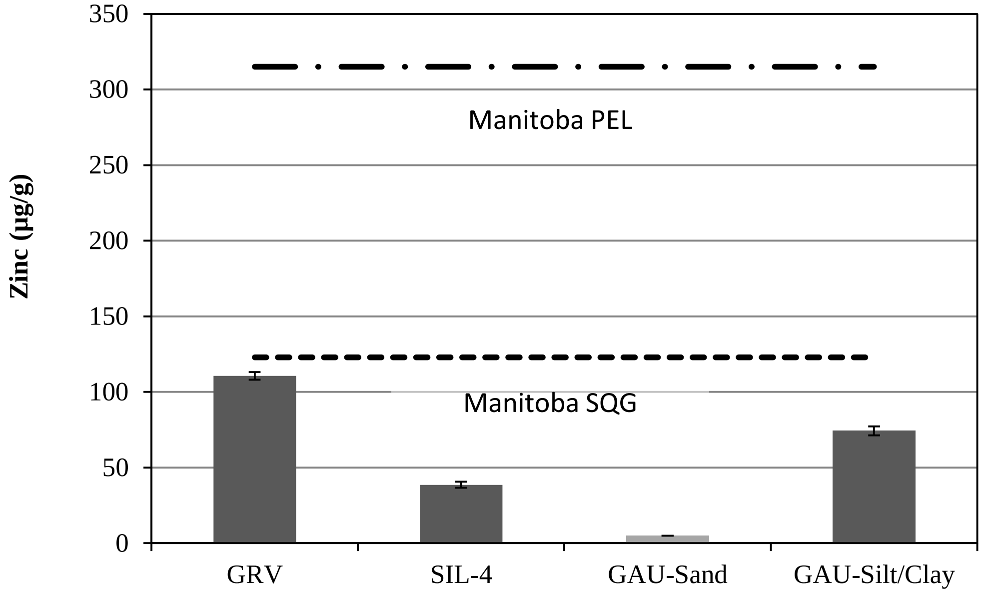



Figure 4-16. Mean (±SE) concentrations of zinc in surficial sediment from Granville Lake (GRV), Southern Indian Lake – Area 4 (SIL-4), and two sites in Gauer Lake (GAU), and comparison to Manitoba sediment quality guidelines. Means indicated in light grey were below the analytical detection limit.


Figure 4-17. Photograph of sediments collected from Southern Indian Lake – Area 4 (sediment quality sampling site) showing nodules (black aggregations).

Figure 4-18. Photographs of sediment grab samples and nodules observed during the aquatic habitat survey of Southern Indian Lake – Area 4 in 2013.

# 5.0 BENTHIC MACROINVERTEBRATES

## 5.1 INTRODUCTION

The following provides an overview of the BMI community for key metrics measured over 2010-2013 under CAMP in the UCRR. Data are restricted to this four-year time-period as the sampling design was modified in 2010 to reduce the inherent variability within the BMI data (Technical Document 1, Section 1.6.3). As noted in Section 1.0, waterbodies/river reaches sampled annually included one on-system lake (Southern Indian Lake-Area 4) and one off-system lake (Granville Lake). Three additional on-system lakes or areas were sampled on a rotational basis, including Opachuanau Lake (2011), Southern Indian Lake-Area 1 (2012), and Southern Indian Lake-Area 6 (2010, 2013; Figure 5-1). While formally part of the LCRR under CAMP, results for the off-system Gauer Lake are included in the following discussion to provide context for the UCRR results (Figure 5-1).

A detailed description of the program design and sampling methods is provided in Technical Document 1, Section 3.5. In brief, the CAMP benthic macroinvertebrate program is comprised of sample collection at nearshore (water depth ≤1 m, sampled with travelling kick/sweep net) and offshore (water depth 5-10m, sampled with Ekman/petite Ponar dredge) habitat sites in the late summer/fall within each monitoring waterbody (annual and rotational). Depending on the water level at time of sampling, sample collection in the nearshore habitat could include sites that are periodically dewatered, the frequency and duration of dewatering depending on the elevation along the shoreline where samples were collected in relation to the hydrograph. Offshore habitats were always permanently wetted.

### 5.1.1 Objectives and Approach

The primary objectives for the analysis of CAMP BMI data, which were directed in the terms of reference for preparation of this report, were to:

- evaluate whether there are indications of temporal trends in key BMI metrics; and
- provide an initial review of linkages between BMI metrics and key drivers, notably hydrological conditions, where feasible.

The first objective (analysis of temporal changes or trends) was addressed through two approaches: (1) statistical analyses were undertaken to assess whether there were significant differences between years at annual sites; and (2) trends were examined visually through graphical plots for annual sites. The mean and standard error (± SE) were calculated to characterize key indicators for each aquatic habitat type sampled for each waterbody. Supporting environmental variables were also described to aid in the understanding of BMI metrics. It should be noted that four years of data are insufficient to detect trends over time, notably long-term trends, and the assessment was therefore restricted to qualitative assessment of the available data for sites monitored annually. Additionally, any indications of potential trends over the four year period do not necessarily imply a long-term trend is occurring, as apparent trends over this interval may simply reflect the relatively limited time period assessed in conjunction with inter-annual variability in a metric. Consideration of a longer period of record is required to evaluate for long-term trends.

The second objective (linkages with hydrological conditions) was addressed through inspection of differences among key indicators in the nearshore and offshore environments and differences in water levels and flow among sampling years. Statistical analyses were not conducted because the four years of data utilizing a consistent sampling design were not considered sufficient to support a statistical analysis.

A detailed description of the approach and methods applied for analysis and reporting is provided in Technical Document 1, Section 4.5. Site abbreviations applied in tables and figures are defined in Table 1-1. Results are presented separately for nearshore and offshore habitats, because these may be affected differently by annual changes in water levels and flows.

### 5.1.2 Indicators

Although a large number of indicators may be used to describe the BMI community, four key BMI indicators were selected at CAMP workshops: abundance/density; composition; taxa richness; and diversity. The metrics presented for these indicators include: total number of invertebrates; the ratio of Ephemeroptera, Plecoptera, and Trichoptera (EPT) to Chironomidae (EPT:C); total taxonomic richness (family-level); EPT richness (family-level); and Simpson's Diversity Index. A detailed description of key indicators and metrics is provided in Technical Document 1, Section 4.5.1.

In addition to descriptions of the key metrics, observations for an additional BMI metric (number of Ephemeroptera taxa) is presented in Section 5.4 to assess whether it should be included in the suite of key metrics.

Section 5.2 describes supporting habitat variables that aid in the interpretation of BMI metrics.

## 5.2 SUPPORTING HABITAT VARIABLES

Supporting habitat variables consisted of: (i) measures related to water depth to enable calculation of where sampling was conducted in the nearshore zone in relation to the annual cycle of wetting and drying; and (ii) characterization of the substrate (Table 5-1). In 2010, relative benchmarks were established along the shore at each waterbody. The distance along the shore from the water level at time of sampling to the benchmark and the high water mark were recorded; a shorter distance indicates a relatively higher water level at the time of sampling (Table 5-1). Additionally, gauged water levels (i.e., elevations) and discharges were provided by Manitoba Hydro for select locations in the UCRR (Section 2.0). Relationships between select BMI and hydrology metrics are described in Section 5.5.

Sediment samples were collected at nearshore and offshore replicate stations for particle size analysis and TOC content to provide a quantitative description of sediment composition. Results for particle size analysis and organic carbon content in the nearshore are provided in Figures 5-2 and 5-3, respectively. Particle size and organic carbon are presented for the offshore environment in Figures 5-4 and 5-5.

### 5.2.1 Upper Churchill River

Substrate distribution maps and overall aquatic habitat characteristics for Southern Indian Lake - Area 4 are presented in Section 8.0. Supporting habitat variables collected in conjunction with the BMI program are described below.

The nearshore habitat of on-system Opachuanau and Southern Indian lakes consisted mainly of coarser, hard substrate (bedrock, boulder, cobble) and, as such, sediment samples were not consistently collected (Table 5-1). Sediment samples from Opachuanau Lake and Southern Indian Lake – Area 1 consisted mainly of silt/clay (60-67%; Figure 5-2), while sediments sampled in Southern Indian Lake – Area 6 and Southern Indian Lake – Area 4 largely consisted of sand (61-96%, Figure 5-2). The TOC content of all sediments sampled was low (average less than 2%; Figure 5-3).

With the exception of Southern Indian Lake – Area 4, the offshore habitat of on-system lakes consisted mainly of silt/clay (Figure 5-4). Southern Indian Lake – Area 4 sediments had a greater proportion of sand than other waterbodies (70-81% sand). The TOC of all sediments sampled was low (less than 2%; Figure 5-5).

### 5.2.2 Off-system Waterbodies: Granville and Gauer Lakes

The nearshore habitat of Granville and Gauer lakes consisted of mainly large, hard substrate (bedrock and boulder with cobble); as such sediment samples were not collected for laboratory analysis (Table 5-1).

Similar to the majority of on-system areas, the offshore habitat of Granville and Gauer lakes consisted mainly of silt and clay (Figure 5-4). TOC content was higher than on-system lakes, particularly for Gauer Lake (7-8%; Figure 5-5).

## 5.3 KEY INDICATORS

### 5.3.1 Total Number of Invertebrates

Differences in the numbers of organisms are influenced by a variety of physical (e.g., substrate type, flow conditions), biological (e.g., benthic algal biomass), and chemical (e.g., dissolved oxygen and nutrient concentrations) factors. As such, the total number of invertebrates measured in a waterbody is a reflection of numerous aquatic habitat variables that have been integrated by the community over time.

Comparative abundances for all sites and years for the nearshore environment are provided in Figure 5-6. Yearly results for the offshore environment are provided in Figure 5-7.

#### *5.3.1.1 Upper Churchill River*

In 2010, Southern Indian Lake – Area 4 was sampled using a grab sampler in the predominantly wetted nearshore habitat. As such, the units (no. per $m^2$) are not comparable to abundances measured in Southern Indian Lake – Area 4 (2011 to 2013) or to other on-system lakes (no. per kicknet; Figure 5-6). The greater abundance measured for Southern Indian Lake – Area 4 is due to high numbers of chironomids and oligochaetes in samples and indicative of the nature of the habitat and substrate sampled in that year (Table 5-1). For the reasons discussed above, the 2010 nearshore data for Southern Indian Lake – Area 4 are not discussed further here.

In Southern Indian Lake – Area 4, the average number of invertebrates per kick net sample was four-fold greater between 2011 and 2012, and was approximately 30% greater in 2013 than 2012. The proportion of insects in Area 4 was higher in 2012 and 2013, with Chironomidae being the most abundant insect in 2011 and Corixidae in 2013. There was a coincident annual decrease in the proportion of Oligochaeta (although it remained the most abundant non-insect taxon in all years).

Total invertebrate abundance in the nearshore of Southern Indian Lake – Area 6 was similar in 2010 and 2013 (Figure 5-6). The dominant taxa were consistent between years, with Amphipoda and Gastropoda the most prevalent non-insects, and Corixidae the most abundant insect. A decrease in the number of Corixidae in 2013 resulted in the samples containing, on average, fewer insects than non-insects, while insects outnumbered non-insects in 2010. Samples collected from the nearshore habitat of Southern Indian Lake – Area 6 in 2013 contained approximately one third of the number in Southern Indian Lake – Area 4 in the same year.

Mean total invertebrate abundances in samples collected from Opachuanau Lake and Area 4 of Southern Indian Lake in 2011 were similar. The dominant non-insect taxon was Oligochaeta (25%), while Ephemeroptera and Corixidae were the most abundant insect taxa, each accounting for 20% of the organisms sampled. High numbers of Ephemeroptera in nearshore samples was unique to Opachuanau Lake in 2012; Ephemeroptera abundance was much lower in the nearshore of all other lakes in all years.

Mean total invertebrate abundances in nearshore samples collected from Area 1 and Area 4 of Southern Indian Lake in 2011 were similar. Insects and non-insects were present in Area 1 samples in roughly equal amounts. Similar to Southern Indian Lake – Area 6, Gastropoda was the dominant non-insect taxon, while the majority of insects in the samples were Corixidae.

The density of invertebrates at offshore sites in Southern Indian Lake – Area 4 varied little between 2010 and 2012, but was more than twice as great (1,847 no./ $m^2$) in 2013 (Figure 5-7). Density in 2013 was statistically significantly higher than in all preceding sampling years. In all years except 2011, samples contained more insects than non-insects, and Chironomidae was the dominant taxon, accounting for more than half of all organisms collected. Oligochaeta and Amphipoda were the most abundant taxa (combining to represent almost 60% of all organisms collected) in the 2011 samples; these two groups comprised the majority of the non-insect invertebrates in most years.

The mean total invertebrate density in Area 4 and Area 6 of Southern Indian Lake were similar in the 2010 and 2013 offshore samples (Figure 5-7). Total invertebrate abundance in Area 6 of Southern Indian Lake in 2013 was more than double what it had been in 2010 (Figure 5-7). The mean proportion of insects in samples was similar in 2010 and 2013 (36% and 37%, respectively), and Chironomidae was the dominant insect taxon, comprising 22% of the organisms in both years. Ephemeroptera comprised the majority of the remaining Insecta in both years. The dominant taxa in the offshore of Area 6 were the same as Area 4, although Amphipoda outnumbered Chironomidae in Area 6. Amphipoda was the most abundant taxon in both 2010 (51%) and 2013 (47%) samples.

In 2011, offshore samples from Opachuanau Lake contained almost four times as many invertebrates as samples from Southern Indian Lake – Area 4 (Figure 5-7). . In fact, the highest mean density among on-system lakes was observed in Opachuanau Lake in 2011 (1,899 no. per $m^2$). Non-insects comprised 89% of the offshore samples, and Amphipoda was the dominant taxon (78% of all organisms collected).

Offshore samples from Southern Indian Lake – Area 1 in 2012 contained, on average, about 60% fewer organisms than samples from Southern Indian Lake – Area 4 in the same year. Insects dominated offshore samples from Southern Indian Lake -Area 1 in 2012, and were comprised of roughly equal proportions of Ephemeroptera and Chironomidae (each 26%). The relatively high proportion of Ephemeroptera in Area 1 offshore samples was unique among the on-system waterbodies, although in absolute numbers Area 6 also had substantial numbers of Ephemeroptera. Amphipoda (30%) comprised the majority of the non-insect catch.

#### *5.3.1.2 Off-system Waterbodies: Granville and Gauer Lakes*

Mean total abundance for the nearshore habitat of Granville Lake was comparable in 2010, 2012, and 2013, but notably lower in 2011 (Figure 5-6). .Mean total abundance in 2011 was statistically significantly lower than that in 2012. In 2010, almost 90% of the BMI sampled were insects, and the majority of these were Corixidae. In 2011-2013, Insecta comprised 50-60% of the catch and Chironomidae and Corixidae were generally the most abundant insects. The predominant non-insect groups varied from year to year, but Oligochaeta, Gastropoda, and Amphipoda were each dominant in some years.

A different temporal pattern was observed in the nearshore of Gauer Lake: abundances were comparable in 2010 and 2011, but then appeared to decrease in 2012 and again in 2013 (Figure 5-6). Abundance in 2013 was significantly lower than in 2010 and 2011. As seen in Granville Lake, insects consistently dominated the nearshore samples. In all years except 2013, Corixidae were extremely abundant in all samples. In 2013, while still present, they were captured in smaller numbers, and the proportion of Trichoptera present increased.

Total density for the offshore habitat of Granville Lake was lowest in 2011 and 2012, intermediate in 2010, and highest in 2013 (Figure 5-7). Density in 2013 was statistically significantly higher than 2011 and 2012. Mean density in Granville Lake was higher than observed densities for on-system areas in 2010 and 2013, while 2011 and 2012, density was within the range observed for on-system areas. The composition of samples collected from Granville Lake was consistent in all years: Amphipoda was the most abundant taxon in samples collected from Granville Lake in all years, comprising 33-62% of the mean total. Chironomidae and Ephemeroptera each comprised at least 10% of the catch in each year and in some years comprised substantially more (e.g., Ephemeroptera comprised 32% of the total in 2012). Granville Lake is similar to Southern Indian Lake – Area 1 and Southern Indian Lake – Area 6, in that Ephemeroptera were present in high numbers in the offshore.

The mean density of BMIs in offshore habitat in Gauer Lake was notably higher than on-system lakes (and Granville Lake) in all years (Figure 5-7). In general, abundance of BMIs increases with the presence of organic matter (i.e., detritus), and the TOC content of offshore sediments in Gauer Lake was higher than any other UCRR waterbody (Section 5.2). In the offshore of Gauer Lake, total density of BMIs was significantly higher in 2013 than in 2011, and 2010 and 2012 were intermediate (Figure 5-7). The proportions of insects and non-insects in offshore samples from Gauer Lake were roughly equal in all years except 2013, when there were slightly more insects. Chironomidae was consistently the most abundant taxon, and when insects outnumbered non-insects in 2013, it was due to an increase in Chironomidae. While the insect composition of samples remained consistent between years, the most abundant non-insect taxon in samples was variable and shifted from Oligochaeta in 2010 and 2011, to Bivalvia in 2012, and back to Oligochaeta in 2013. Contrary to all other UCRR waterbodies, Amphipoda were very rarely collected from Gauer Lake, and were completely absent from 2010 and 2011 samples.

#### *5.3.1.3 Temporal Comparisons and Trends*

Although not significant for all the years 2010-2012, abundance in off shore habitat in 2013 was significantly higher than at least one year for all of the annual water bodies.

No trends were apparent during 2010-2013.

### 5.3.2 Ratio of EPT to Chironomidae

Ephemeroptera, Plecoptera, and Trichoptera are generally considered to be more sensitive, and Chironomidae less sensitive, to environmental stress (e.g., nutrient enrichment, low dissolved oxygen concentrations). Although Chironomidae are often described as being tolerant to adverse conditions, many taxa belong to this group and the perceived tolerance of the group as a whole may be attributable to only a few taxa. Chironomidae are relatively more abundant on fine textured sediments (e.g., silt/clay, sand) than Ephemeroptera, Plecoptera, and Trichoptera. Fine substrates are more common in deeper areas of waterbodies, especially with less water flow; therefore, a low EPT:C ratio may also reflect differences in substrate.

The ratio of EPT:C for all sites and years for the nearshore environment are provided in Figure 5-8.Yearly results for the offshore environment are provided in Figure 5-9.

#### *5.3.2.1 Upper Churchill River*

With the exception of Southern Indian Lake – Area 4 (ratio of less than 0.5), nearshore habitat in on-system areas was dominated by ephemeropterans (ratios of 1.5 to 9.5 at Southern Indian Lake – Area 1 and Southern Indian Lake – Area 6, respectively) (Figure 5-8). Generally, insects such as ephemeropterans show a preference for shallow waters with gravel or coarse substrates, such as those sampled in the on-system areas (Minshall 1984).

The mean EPT:C in offshore habitat varied minimally among years and somewhat among on-system lakes but was near one in most areas (Figure 5-9). In Southern Indian Lake – Area 4, mean EPT:C was zero or near zero for all sampling years due to the absence of ephemeropterans from the majority of samples collected.

#### *5.3.2.2 Off-system Waterbodies: Granville and Gauer Lakes*

Similar to Southern Indian Lake – Area 4, the mean EPT:C ratio in the nearshore habitat of Granville Lake was less than 0.5 indicating a predominance of chironomids in comparison to ephemeropterans for this sampling area (Figure 5-8). With the exception of 2011 (ratio of near one), the EPT:C ratio in the nearshore of Gauer Lake indicated a predominance of ephemeropterans at this site (ratio of 3.7 to 9).

In 2010 and 2013, the EPT:C ratio in the offshore of Granville Lake was near one; however, in 2011 and 2012 the ratio increased to near three and was notably higher than on-system areas (Figure 5-9). Similar to Southern Indian Lake – Area 4, the mean ratio of ephemeropterans to chironomids in the offshore habitat of Gauer Lake was near zero for all sampling years (Figure 5-9).

#### *5.3.2.3 Temporal Comparisons and Trends*

The EPT:C ratio exhibited inter-annual variability; however there were no consistent statistically significant differences (Figures 5-8 and 5-9). No obvious trends were noted over the four year sampling period.

### 5.3.3 Total Richness

The number of unique taxa (total taxonomic richness) reflects habitat diversity, with more diverse habitats typically supporting a richer fauna than less diverse habitats. Richness also provides information about the degree of perturbation (either natural [e.g., increased scouring during high flow events] or anthropogenic [e.g., increased suspended sediments in surface waters related to surface disturbance]) that has occurred at a site, with sampling events associated with more taxa often suggesting that fewer perturbations have recently occurred at that site.

Total richness for all sites and years for the nearshore environment are provided in Figure 5-10. Yearly results for the offshore environment are provided in Figure 5-11.

#### *5.3.3.1 Upper Churchill River*

The mean total richness of BMIs in nearshore habitat ranged from an average of 13-19 taxa, but was generally similar among on-system lakes within the same year (Figure 5-10).

The mean total richness of BMIs in offshore habitat ranged from 4-7 taxa but as with the nearshore habitat, richness was generally similar among lakes in the same year of sampling (Figure 5-11).

#### *5.3.3.2 Off-system Waterbodies: Granville and Gauer Lakes*

The mean total richness of BMIs in the nearshore habitat of off-system Granville and Gauer lakes was typically lower than in on-system lakes (Figure 5-10).The exception was Gauer Lake in 2010 when the total richness of BMIs was within the range observed for on-system areas sampled.

The mean total richness of BMIs in the offshore habitat of Granville and Gauer lakes was marginally higher (Gauer) or comparable (Granville) to that of on-system lakes (Figure 5-11).

#### *5.3.3.3 Temporal Comparisons and Trends*

Total taxa richness exhibited inter-annual variability, but no consistent statistically significant differences (Figures 5-10 and 5-11). No trends were apparent.

### 5.3.4 Ephemeroptera, Plecoptera, and Trichoptera Richness

EPT richness is the total number of distinct taxa (family-level) within the groups, Trichoptera, Ephemeroptera, and Plecoptera. EPT richness as an indicator of aquatic health is based on the premise that high-quality waterbodies typically have the greatest richness.

EPT richness for all sites and years for the nearshore environment are provided in Figure 5-10. Yearly results for the offshore environment are provided in Figure 5-11.

#### *5.3.4.1 Upper Churchill River*

The mean EPT richness (family-level) in nearshore habitat of on-system lakes followed a pattern similar to that for total richness (Figure 5-10).

The mean EPT richness in offshore habitat was very similar among years and on-system lakes, with approximately one family represented for the majority of areas sampled (Figure 5-11).

#### *5.3.4.2 Off-system Waterbodies: Granville Lake and Gauer Lake*

In the nearshore of Granville Lake, mean EPT richness was lower in comparison to on-system areas in 2010, 2011, and 2012, but increased and was within the range observed in 2013 (Figure 5-10). The mean EPT richness in the nearshore habitat of Gauer Lake varied among years and was typically within the range of the number of taxa observed in on-system lakes (Figure 5-10).

Similar to the majority of on-system lakes, the mean EPT richness in the offshore habitat of Granville and Gauer lakes varied between one and two families represented (Figure 5-11).

#### *5.3.4.3 Temporal Comparisons and Trends*

EPT richness differed among years and statistical tests indicated no consistent statistically significant differences (Figures 5-10 and 5-11). No obvious increasing or decreasing trends were noted for the annual sites over the four year sampling period.

### 5.3.5 Simpson's Diversity Index

Simpson's Diversity Index may provide more information about benthic macroinvertebrate community structure than abundance or richness alone. Simpson's Diversity Index summarizes the relative abundance of various taxa and provides an estimate of the probability that two individuals in a sample belong to the same taxa. Simpson's Diversity Index de-emphasizes rare taxa, while highlighting common taxa and evenness among taxa (i.e., similarity of population sizes of different species; Mandaville 2002). The higher the index, the less likely it is that two individuals belong to the same taxa and indicates that the taxa present are similar in relative abundance (Magurran 1988, 2004). Simpson's Diversity Index values range from zero (indicating a low level of diversity) to one (indicating a high level of diversity).

Simpson's Diversity Index for all sites and years for the nearshore environment are provided in Figure 5-12, and results for each site are summarized in Figure 5-12. Yearly results for the offshore environment are provided in Figure 5-13.

#### *5.3.5.1 Upper Churchill River*

Simpson's Diversity Index for the nearshore BMI community generally ranged from approximately 0.7-0.8 among on-system lakes, and was generally comparable among lakes within a given year (Figure 5-12). Diversity in 2010 in Opachuanau Lake was slightly lower.

Similar to nearshore habitat, Simpson's Diversity Index for the offshore BMI community varied among years and typically less so among on-system lakes for a given sampling year; the exception was Opachuanau Lake in 2011 when the diversity index was notably lower (0.33) in comparison to Southern Indian Lake – Area 4 (0.68; Figure 5-13).

#### *5.3.5.2 Off-system Waterbodies: Granville and Gauer Lakes*

For the off-system Granville Lake, diversity in the nearshore in 2010 was notably lower than the on-system areas, whereas in 2011, 2012, and 2013 diversity was comparable (Figure 5-12). With the exception of 2013, Simpson's Diversity Index for the nearshore community in Gauer Lake was notably lower than on-system lakes (Figure 5-12).

Diversity in the offshore habitats of Granville and Gauer lakes was generally similar among years (although some differences were statistically significant) and generally within the range observed at on-system sites (Figure 5-13).

#### *5.3.5.3 Temporal Comparisons and Trends*

Simpson's Diversity Index exhibited notable inter-annual variability; however there were no consistent statistically significant differences (Figures 5-12 and 5-13). No temporal trends were apparent.

## 5.4 ADDITIONAL METRICS AND OBSERVATIONS OF NOTE

Ephemeroptera have been identified as being sensitive to environmental disturbances (e.g., increased shoreline erosion, increased frequency in water level fluctuation; Mandaville 2002; Merritt and Cummins 1996). Ephemeroptera richness (genus-level) was examined as this metric may be useful over time for describing trends at sites and illustrating linkages to hydrology, as well as to other physical (i.e., habitat) and chemical (i.e., surface water quality) metrics as additional data are acquired through CAMP.

### 5.4.1 Ephemeroptera Richness

#### *5.4.1.1 Upper Churchill River*

Mean Ephemeroptera richness (genus-level) in nearshore habitat of on-system lakes was generally low, ranging from two to four taxa (Figure 5-14). The mean richness measured for Opachuanau Lake in 2011 (6 genera) was higher in comparison to other on-system sites.

The mean Ephemeroptera richness in offshore habitat was one in all lakes, with the exception of Southern Indian Lake – Area 4 where ephemeropterans were absent from all samples collected in 2010-2012 and from the majority of samples collected in 2013 (Figures 5-15).

#### *5.4.1.2 Off-system Waterbodies: Granville and Gauer Lakes*

With the exception of 2011 (lower), the mean ephemeropteran richness in the nearshore habitat of Granville Lake was comparable to that for on-system areas (Figure 5-14). In contrast, the mean Ephemeroptera richness in the nearshore habitat of Gauer Lake was typically lower than on-system lakes along the upper Churchill River (Figure 5-14).

The mean Ephemeroptera richness in the offshore habitat of Granville and Gauer lakes was comparable to the majority of on-system areas with one genus represented (Figure 5-15).

#### *5.4.1.3 Temporal Comparisons and Trends*

Ephemeroptera richness exhibited inter-annual variability, but too few genera area present for meaningful statistical analysis (Figures 5-14 and 5-15). No obvious increasing or decreasing trends were noted for annual sites over the four year sampling period.

## 5.5 RELATIONSHIPS WITH HYDROLOGICAL METRICS

Changes in water level will primarily affect benthic communities in the shallow margins of waterbodies. Typically, chironomids and oligochaetes are able to tolerate the conditions of periodic exposure in the upper littoral zone as well as be able to rapidly take advantage of newly wetted habitat, colonizing bare substrates within a month (Fisher and Lavoy 1972; Scheifhacken et al. 2007). Other invertebrate groups are less tolerant of exposure, resulting in reduced species diversity in habitats that are frequently dewatered. In riverine habitats, changes in discharge can also affect aquatic invertebrate assemblages by causing an increase in drift, whereby organisms leave the substrate and are carried downstream.

Water level and discharge may also affect the offshore invertebrate community through indirect means, such as increased sedimentation occurring after high water levels or discharge erode shorelines and mobilize sediments. Hydrology may also affect trophic conditions (e.g., nutrients) and other factors such as water temperature.

Given that only four years of benthic invertebrate data were collected from the annual sites using the current sampling design, statistical analyses comparing average water levels and flows during the open water season prior to invertebrate sample collection (i.e., the “growing season” for a particular sampling event) and key indicators for which the preceding statistical analysis showed significant between year differences (i.e., total abundance, richness and diversity) was not conducted. However, both nearshore and offshore data were inspected in relation to average water levels and flows to determine whether a relationship might be present that would merit further examination when more data are available.

Examination of the seasonal hydrographs indicated considerable variation over the growing season, with little consistency among years (i.e., in some years lowest levels occurred in spring and water levels increased through the growing season, in others water levels declined during summer, while in others there were erratic peaks). Given the importance of dewatering and the duration of wetting to invertebrate colonization of nearshore habitat, seasonal hydrographs were inspected to determine whether the duration of wetting could have contributed to observed inter-annual differences.

### 5.5.1 Summary of Seasonal Water Levels and Flows on UCRR Waterbodies, 2010-2013

During the open water season of 2010-2013, flows on the upper Churchill River were generally at the lower quartile for the initial part of the growing season in 2010, 2011 and 2013 but increased late in 2011 and 2013 (Section 2). Flows in 2012 were above the upper quartile for the entire open water season. Water levels on Granville Lake are not regulated and, therefore, the nearshore BMI sampling location was directly affected by variations in inflow. Nearshore samples collected in 2012 were at a higher elevation than the remaining years, which were all sampled at a similar elevation. Assuming that water level at the BMI sapling site was not affected by wind, the nearshore sampling zone would have been wetted for most of the 2010 and 2012 growing seasons but only partially wetted in the other two years, in particular in 2011.

Water levels at the on-system sampling locations are all regulated by outflow at the Missi and Notigi CSs and the water elevation at all sites is comparable. There was little difference in the sampling elevation in each year. However, in 2010 and 2012 the nearshore sites were wetted throughout the growing season, and in 2013 the nearshore was wetted for much of the open water season, while in 2011 it was only wetted for a portion of the open water season.

The Gauer River is unregulated and flows respond to local precipitation and Gauer Lake water levels. From 2010-2013, Gauer River flows from January to the beginning of August were below average (1979-2013); Section 2.0). In both 2012 and 2013, below-average flow levels persisted through the whole year, but in 2010 and 2011, there was a dramatic increase in discharge in mid-to-late August. There is no information on water levels at the BMI sampling site, but potentially the increased levels in 2010 and 2011 would have resulted in sampling areas that were not wetted throughout the open water season.

### 5.5.2 Potential Relationships between BMI Monitoring Results and Seasonal Water Levels and Flows

The higher abundance of BMI in the nearshore of Southern Indian Lake – Area 4 in 2012 and 2013 in comparison to 2011 could be due to the shorter period of wetting during the open water season in 2011. None of the other metrics were clearly affected by this difference. Similarly, the relatively low BMI abundance in 2011 in Granville Lake could be related to the shorter period of wetting.

As noted above, based on Gauer River discharge, levels in Gauer Lake may have increased in late 2010 and 2011 while levels in 2012 and 2013 would have been more stable. However, assuming that river discharge is directly linked to lake level, inter-annual differences in BMI abundance in the nearshore are not linked to the duration of wetting during the open water season, as abundance was lowest in 2013.

No relationship between average water levels and flows during the “growing” season and any of the key indicators in the nearshore environment was apparent (Table 5-2). Based on data collected to date, the duration of exposure immediately prior to sampling, rather than an average over the growing season is more important. However, as more data are collected over a greater range of hydrological conditions, a relationship may become apparent.

In general, abundance in offshore habitat was higher in 2013 than other years in Granville Lake and Southern Indian Lake –Area 4. Abundance was also greatest in 2013 in Gauer Lake and in Southern Indian Lake- Area 6 (though 2010 was the only other year sampled). No relation to water levels and flows is apparent in inspection of graphs relating abundance, richness or diversity to average water levels or flows during the “growing season” for any of the annual waterbodies (Figures 5-16 to 5-18).

## 5.6 SUMMARY

Nearshore habitat within the UCRR was predominantly cobble/boulder. The nearshore BMI community was generally comprised equally of insects and non-insects, with Corixidae, Oligochaeta, Gastropoda and Amphipoda being most abundant. Offshore substrate at all locations with the exception of Southern Indian Lake – Area 4 was predominantly silt/clay. In Southern Indian Lake – Area 4, sand formed a major part of the sediment. Insects dominated in Southern Indian Lake – Area 1 and Southern Indian Lake – Area 6, while non-insects dominated in Southern Indian Lake – Area 4 and Opachuanau Lake. Despite this, dominant taxa were the same for all sites (Chironomidae, Amphipoda and Oligochaeta). Ephemeroptera distribution was irregular: they comprised a high proportion of nearshore samples from Opachuanau Lake and offshore samples from Southern Indian Lake – Area 1, but were rare in the nearshore and completely absent from Southern Indian Lake – Area 4 offshore samples in 2010-2012, and only rarely present in 2013.

The shorelines of the off-system waterbodies were also dominated by rock substrate (bedrock in Granville Lake, boulder in Gauer Lake). In the nearshore environment of both lakes, insects outnumbered non-insects, and Corixidae was the dominant taxon. Gastropoda and Oligochaeta were also captured in high numbers in Granville Lake. Offshore sites in both off-system lakes had a combination of silt/clay sediments, although the substrate in Granville Lake contained a higher proportion of clay. The mean density of BMIs in offshore habitat in Gauer Lake was notably higher than any other UCRR waterbody, which is possibly related to the high TOC content of offshore sediments. Granville Lake samples were dominated by Amphipoda, while samples from Gauer Lake contained high numbers of Chironomidae.

The nearshore invertebrate community was affected by variable water levels during the open water season. BMI abundance in the nearshore was lower in 2011 than in 2012 and 2103 in both Southern Indian Lake – Area 4 and in Granville Lake, which could be related to the shorter duration of wetting. Offshore habitats also exhibited notable inter-annual differences, but the cause could not be readily determined. In particular, abundance in the offshore was higher in 2013 than other years in Granville Lake and Southern Indian Lake – Area 4. Abundance was also greatest in 2013 in Gauer Lake and in Southern Indian Lake- Area 6 (though 2010 was the only other year sampled).

Overall, analysis of the four years of CAMP BMI monitoring data collected in the UCRR indicated that the key metrics, including the additional metric Ephemeroptera richness, did not show a consistent increasing or decreasing trend over this time period. Statistically significant inter-annual differences included lower abundance in 2011 in nearshore habitats of Granville Lake and Southern Indian Lake – Area 4 and higher abundance in the offshore habitats of the same two waterbodies in 2013.

.

Table 5-1. Supporting variables measured in the nearshore and offshore habitats of the Upper Churchill River Region: 2010 – 2013.

| Waterbody | Date | Nearshore | | | | Offshore | | | | Relative Water Level | | Gauged Water Level[3] (daily mean) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Water Depth (mean max, m) | Water Velocity (mean, category) | Benthic Substrate Type/Description[1] | Benthic Substrate Texture/Analysis[1, 2] | Water Depth (mean, m) | Water Velocity (mean, category) | Benthic Substrate Type/Description (predominant)[1] | Benthic Substrate Texture/Analysis[1] | Current (m) | High (m) | (WSL m) | (Q $m^3$/s) |
| GRV | 25-Aug-10 | 0.6 | standing | bedrock, boulder | -- | 9.1 | standing | clay, organic matter | silt loam | 3.97 | 1.73 | 259.80 | 661.00 |
| SIL-6 | 19-Aug-10 | 0.5 | standing | boulder, gravel | -- | 9.2 | standing | clay | silty clay (sandy loam) | 2.90 | 0.84 | 258.19 | -- |
| SIL-4 | 13-Aug-10 | 1.0 | standing | boulder | -- | 8.9 | standing | silt, gravel | sandy loam, loamy sand | 1.75 | n.r. | 258.16 | -- |
| GAU | 20-Aug-10 | 0.5 | standing | boulder | -- | 6.2 | standing | clay, silt | silty clay loam | 1.97 | 0.95 | 29.02 | 24.00 |
| GRV | 22-Aug-11 | 1.1 | standing | bedrock (boulder, cobble) | -- | 9.7 | standing | clay, silt | silty clay | 2.90 | 1.70 | 260.40 | 1070.00 |
| OPACH | 26-Aug-11 | 0.9 | standing | boulder, cobble (gravel, sand, silt) | sandy loam, clay | 9.0 | standing | clay, silt | silty clay (clay) | 2.69 | 2.23 | 258.26 | -- |
| SIL-4 | 23-Aug-11 | 0.9 | standing | boulder (organic matter) | sand, sandy clay loam | 9.3 | standing | sand, gravel (silt, clay) | sandy loam, sandy clay loam | 1.70 | 1.10 | 258.30 | -- |
| GAU | 18-Aug-11 | 0.8 | standing | cobble, boulder | -- | 6.8 | standing | silt, clay | silty clay (silty clay loam) | 3.10 | 2.20 | 29.37 | 57.10 |
| GRV | 21-Aug-12 | 0.9 | standing | bedrock | -- | 9.9 | standing | clay, silt, gravel, sand | silty clay (silt clay loam) | 3.24 | n.r. | 260.55 | 1000.00 |
| SIL-1 | 19-Aug-12 | 0.8 | standing | bedrock, organic matter (silt) | sandy clay | 7.0 | standing | clay, silt | clay (sandy clay loam) | 2.35 | 2.20 | 258.12 | -- |
| SIL-4 | 14-Aug-12 | 1.0 | standing | bedrock, boulder (cobble, sand, gravel) | sand, clay | 9.0 | standing | sand, clay (gravel) | loamy sand (sand) | 1.94 | 1.30 | 258.12 | -- |
| GAU | 22-Aug-12 | 0.8 | standing | boulder (cobble, gravel) | -- | 6.5 | standing | silt, clay | silt loam | 1.86 | n.r. | 29.05 | 28.00 |
| GRV | 20-Aug-13 | 1.0 | standing | bedrock | -- | 9.8 | standing | clay, silt | silty clay (clay) | 2.65 | n.r. | 260.45 | 1040.00 |
| SIL-6 | 26-Aug-13 | 1.0 | standing | boulder (sand, gravel) | sand | 9.1 | standing | silt, clay | silty clay | 3.43 | n.r. | 258.22 | -- |
| SIL-4 | 23-Aug-13 | 1.0 | standing | bedrock (cobble, gravel, sand) | sand (sandy loam) | 9.2 | standing | silt, clay (sand) | sandy loam (loamy sand) | 1.88 | n.r. | 258.19 | -- |
| GAU | 24-Aug-13 | 1.0 | standing | boulder | -- | 6.4 | standing | silt, clay | silty clay (silty clay loam) | 1.25 | n.r. | 28.95 | 16.00 |

[1] Substrate type and texture: parentheses indicate present to a lesser extent.
[2] -- Indicates habitat type not sampled (due to high water velocity) or no sediment sample collected (due to predominantly hard substrate).
[3] Relative water level is the distance up the shore to the benchmark installed for the BMI program.
n.r means data was not recorded.

Table 5-2. Average abundance, total richness, Simpson's Diversity, and hydrological metrics (average water level and discharge for the "growing season") in Gauer, SIL– Area 4, and Granville lakes, 2010 to 2013.

**Granville Lake**

| Year | Abundance (Number/Kicknet or Number/m$^2$) | Richness | Diversity | Water Level (m ASL) | Discharge (m$^3$/s) |
|---|---|---|---|---|---|
| Nearshore | | | | | |
| 2010 | 968 | 11.20 | 0.38 | 259.9 | 685.5 |
| 2011 | 258 | 12.40 | 0.76 | 259.9 | 756.0 |
| 2012 | 1179 | 13.00 | 0.78 | 260.9 | 1153.2 |
| 2013 | 1026 | 14.80 | 0.84 | 260.1 | 886.8 |
| Offshore | | | | | |
| 2010 | 1766 | 8.00 | 0.72 | 259.9 | 685.5 |
| 2011 | 1033 | 5.40 | 0.57 | 259.9 | 756.0 |
| 2012 | 721 | 5.80 | 0.64 | 260.9 | 1153.2 |
| 2013 | 2557 | 7.00 | 0.57 | 260.1 | 886.8 |

**Southern Indian Lake – Area 4**

| Year | Abundance | Richness | Diversity | Water Level | Discharge |
|---|---|---|---|---|---|
| Nearshore | | | | | |
| 2010 | no data | no data | no data | no data | no data |
| 2011 | 313 | 13.40 | 0.72 | 257.9 | 758.6 |
| 2012 | 1298 | 19.00 | 0.82 | 258.1 | 1190.5 |
| 2013 | 1721 | 16.80 | 0.75 | 258.0 | 913.3 |
| Offshore | | | | | |
| 2010 | 785 | 5.20 | 0.66 | 258.1 | 671.2 |
| 2011 | 491 | 4.40 | 0.68 | 257.9 | 758.6 |
| 2012 | 788 | 5.60 | 0.70 | 258.1 | 1190.5 |
| 2013 | 1847 | 6.80 | 0.76 | 258.0 | 913.3 |

**Gauer Lake**

| Year | Abundance | Richness | Diversity | Water Level | Discharge |
|---|---|---|---|---|---|
| Nearshore | | | | | |
| 2010 | 541 | 13.20 | 0.29 | 238.9 | 14.3 |
| 2011 | 541 | 7.20 | 0.24 | 239.2 | 39.3 |
| 2012 | 332 | 13.00 | 0.42 | 239.3 | 53.9 |
| 2013 | 126 | 14.80 | 0.70 | 239.0 | 27.9 |
| Offshore | | | | | |
| 2010 | 3930 | 8.00 | 0.75 | 238.9 | 14.3 |
| 2011 | 3136 | 6.40 | 0.76 | 239.2 | 39.3 |
| 2012 | 3780 | 8.40 | 0.77 | 239.3 | 53.9 |
| 2013 | 5079 | 8.20 | 0.70 | 239.0 | 27.9 |

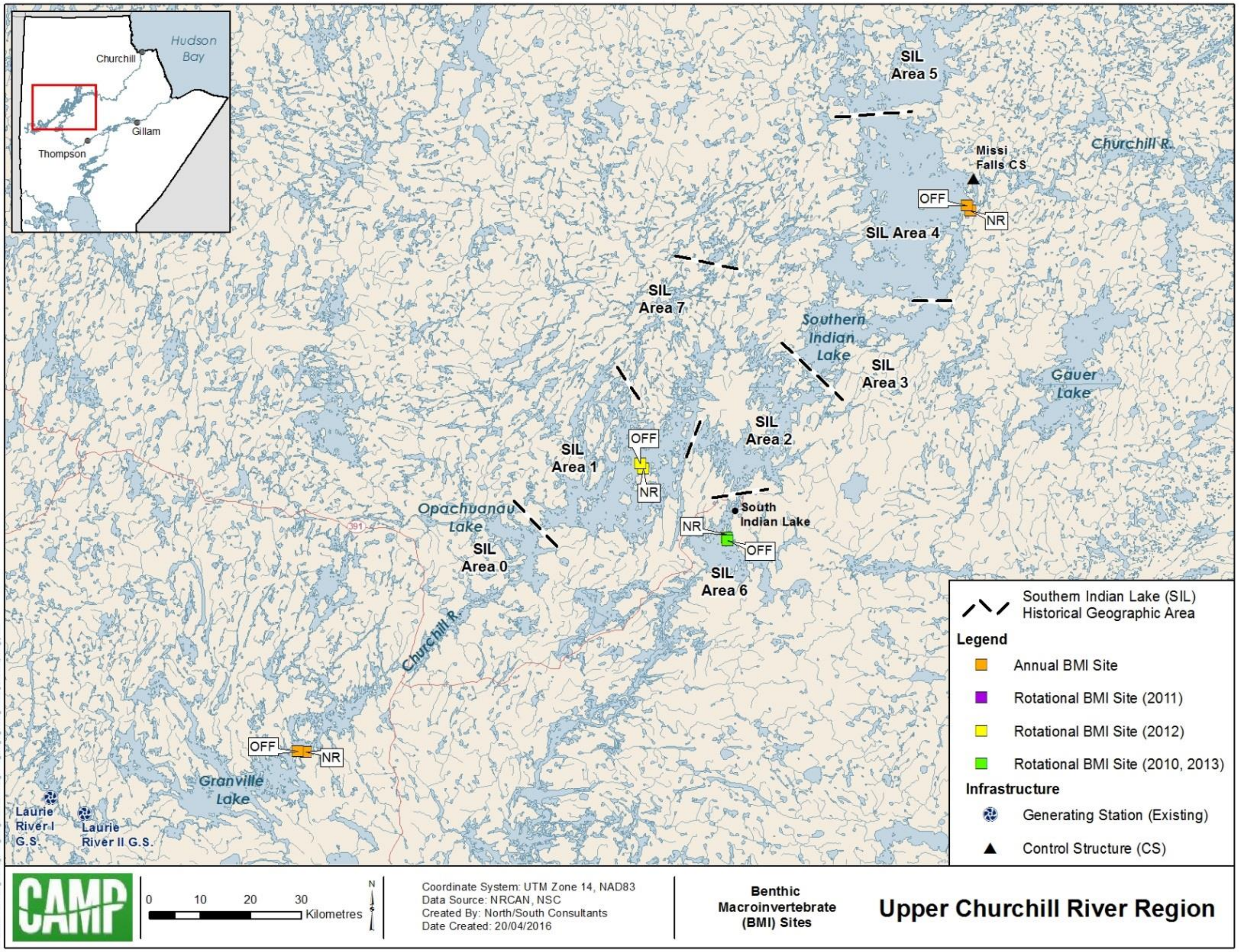
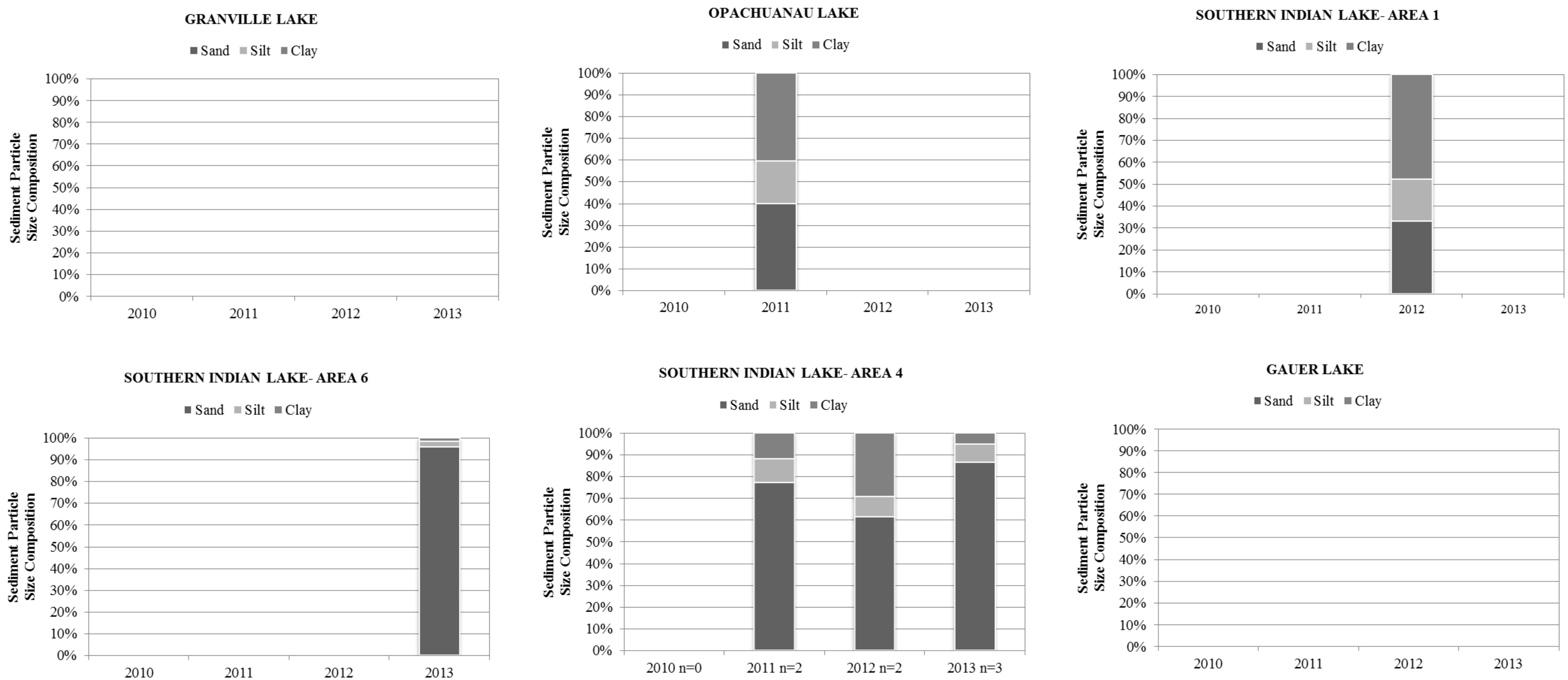


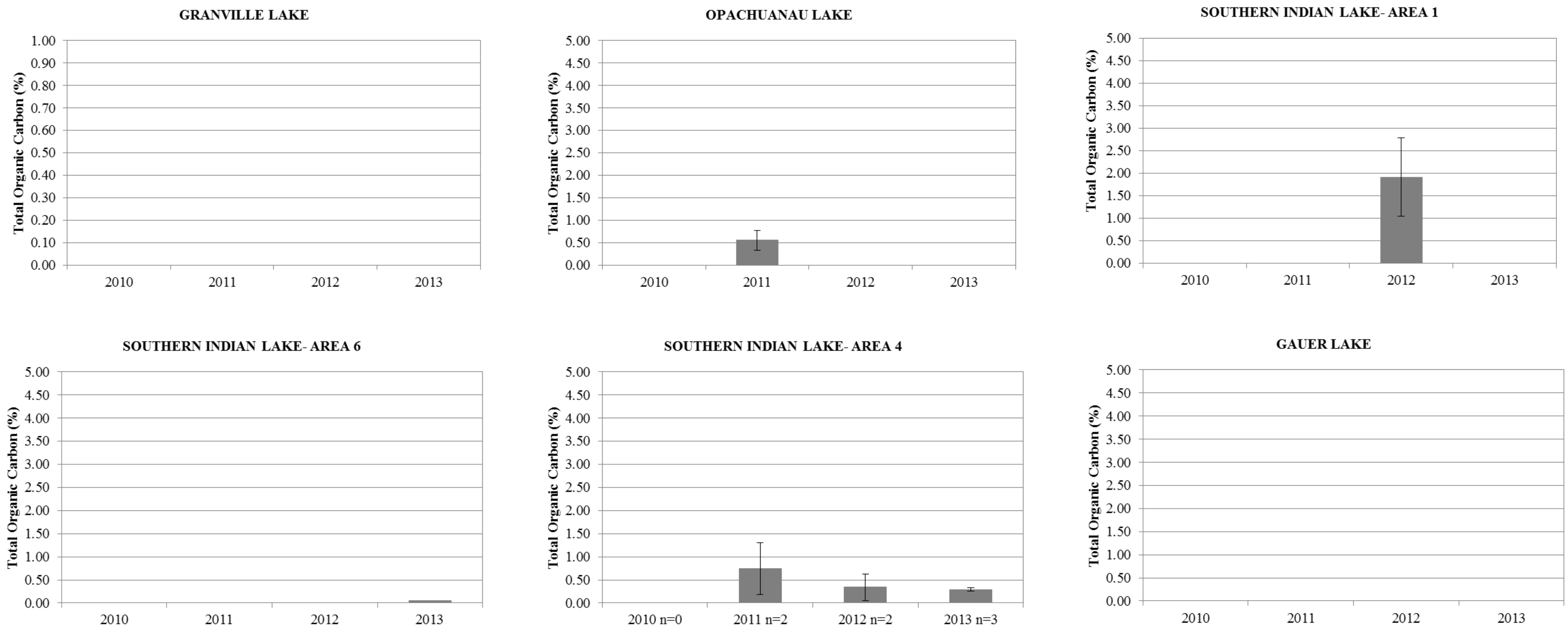

Figure 5-1. Benthic macroinvertebrate sampling sites in the Upper Churchill River Region: 2010 – 2013.




No sediment samples collected at:

- Granville Lake due to predominantly hard substrate.
- Opachuanau Lake (2011 n = 2) due to predominantly hard substrate.
- Southern Indian Lake Area 1 (2012 n = 2); Area 6 (2013 n = 1); and Area 4 (2011 to 2013 n = 7) due to predominantly hard substrate.
- Gauer Lake (2010 to 2013) due to predominantly hard substrate (gravel).

Figure 5-2. Sediment particle size composition (mean % of sand, silt, clay) in the nearshore habitat of the Upper Churchill River Region, by year: 2010 – 2013.




No sediment samples collected at:

- Granville Lake due to predominantly hard substrate.
- Opachuanau Lake (2011 n = 2) due to predominantly hard substrate.
- Southern Indian Lake Area 1 (2012 n = 2); Area 6 (2013 n = 1); and Area 4 (2011 to 2013 n = 7) due to predominantly hard substrate.
- Gauer Lake (2010 to 2013) due to predominantly hard substrate (gravel).

Figure 5-3. Total organic carbon (mean % ± SE) in the nearshore habitat of the Upper Churchill River Region, by year: 2010 – 2013.

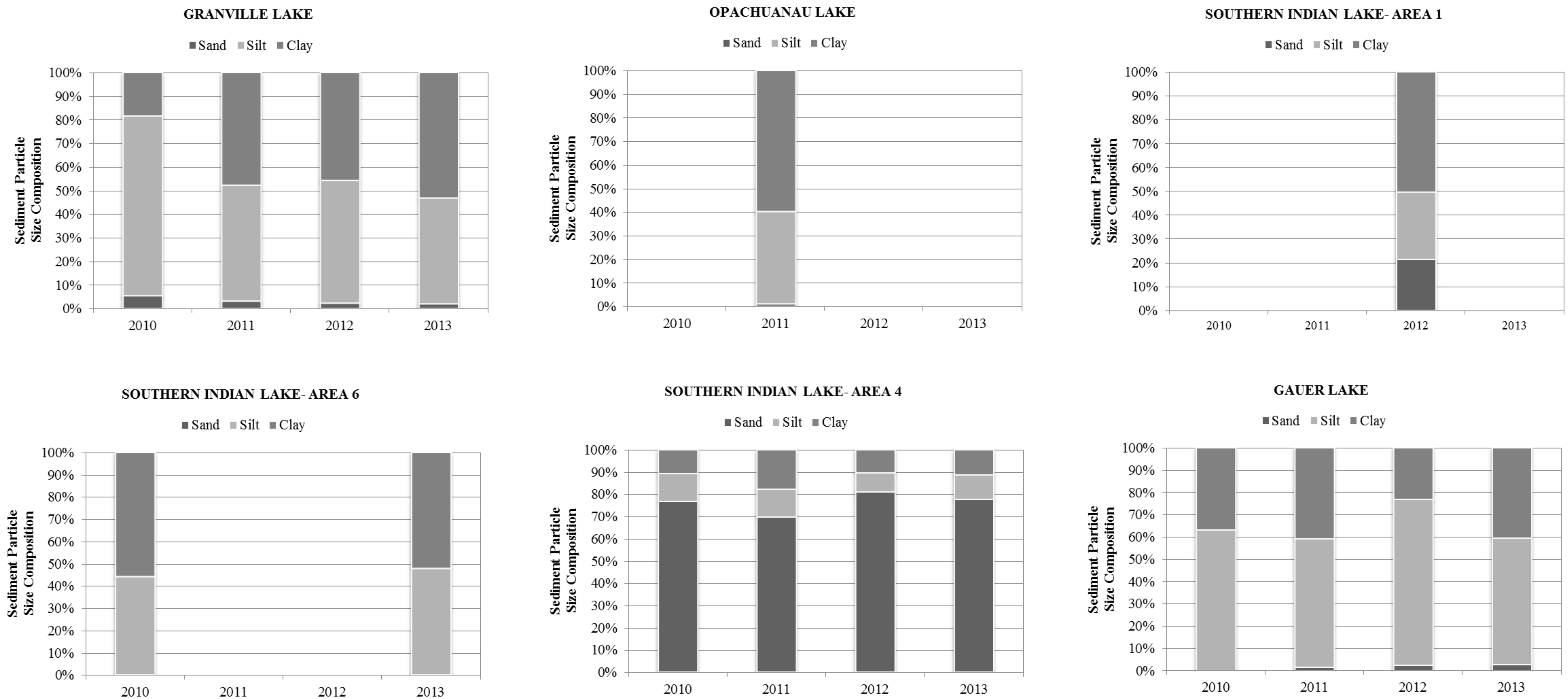



Figure 5-4. Sediment particle size composition (mean % of sand, silt, clay) in the offshore habitat of the Upper Churchill River Region, by year: 2010 – 2013.

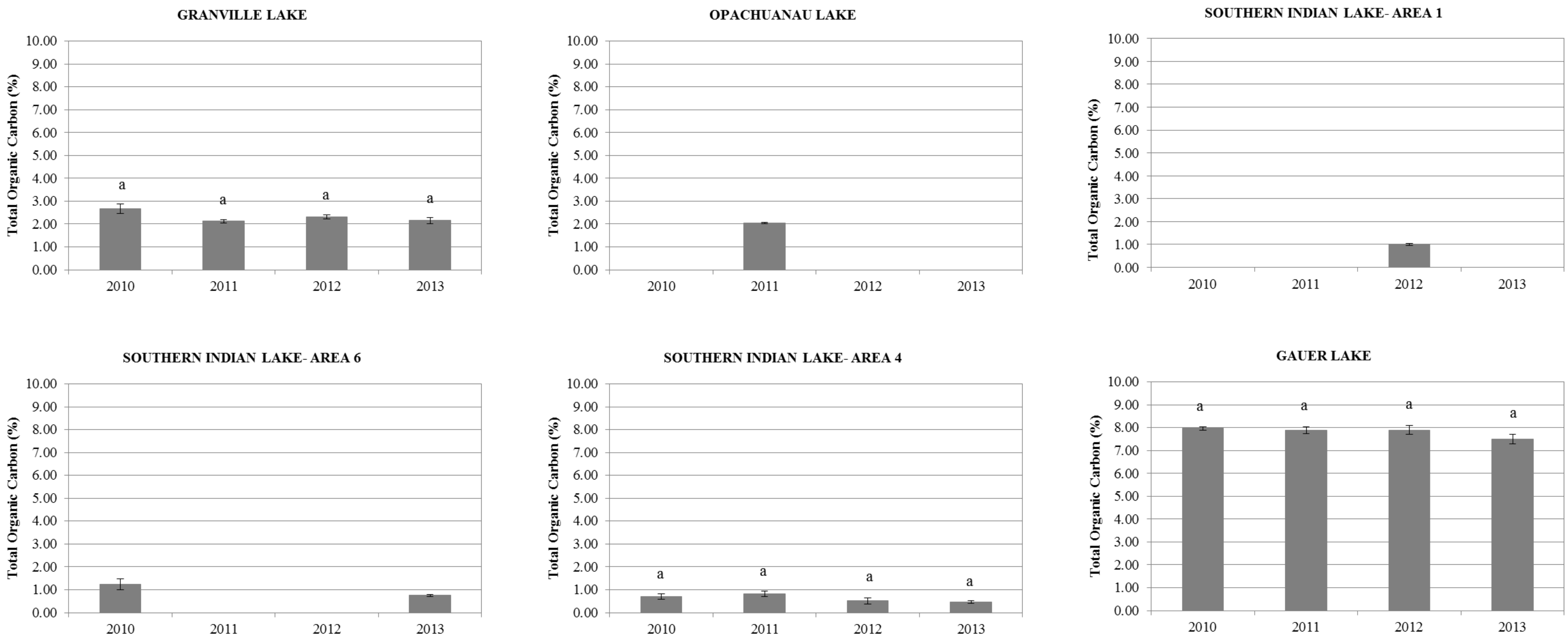
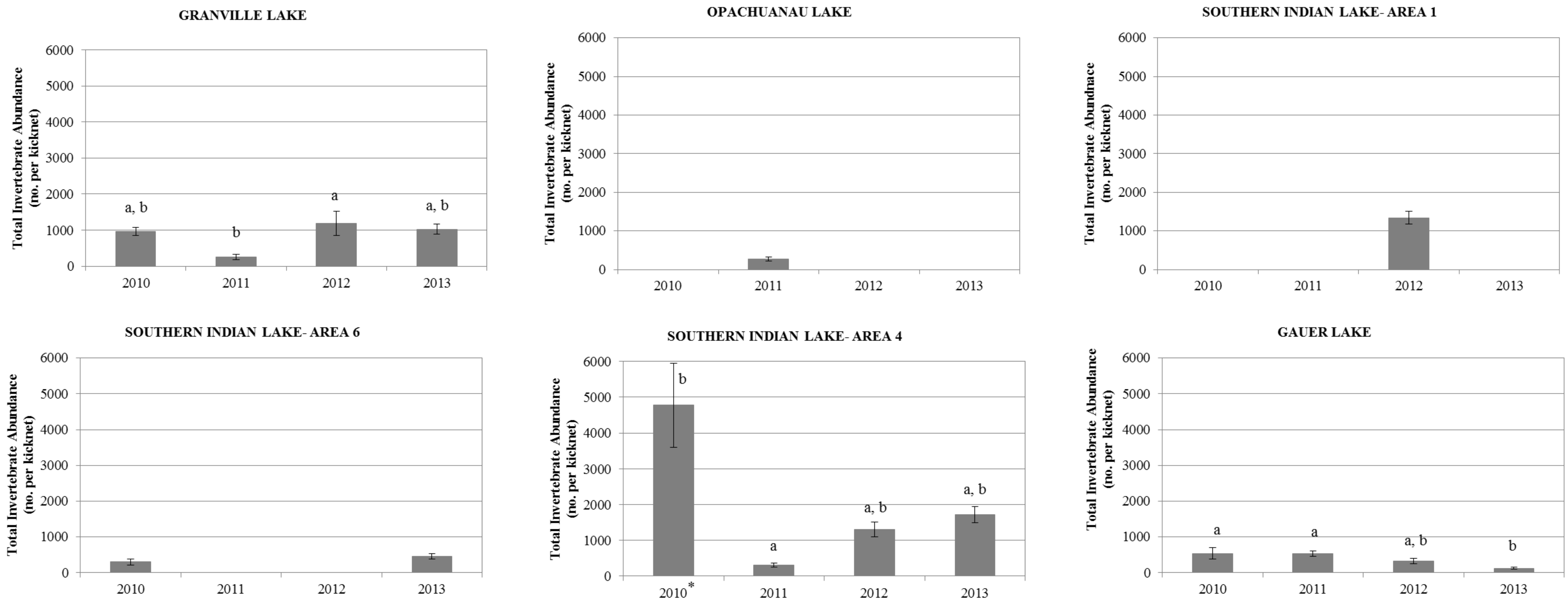



Figure 5-5. Total organic carbon (mean % ± SE) in the offshore habitat of the Upper Churchill River Region, by year: 2010 – 2013. No statistically significant inter-annual differences were observed in the annual monitoring sites (Southern Indian Lake – Area 4 and Granville and Gauer lakes).




*In 2010, the nearshore habitat at Southern Indian Lake – Area 4 was sampled using a grab sampler, units are no. per $m^2$.

Figure 5-6. Total invertebrate abundance (mean ± SE) in the nearshore habitat of the Upper Churchill River Region, by year: 2010 – 2013. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

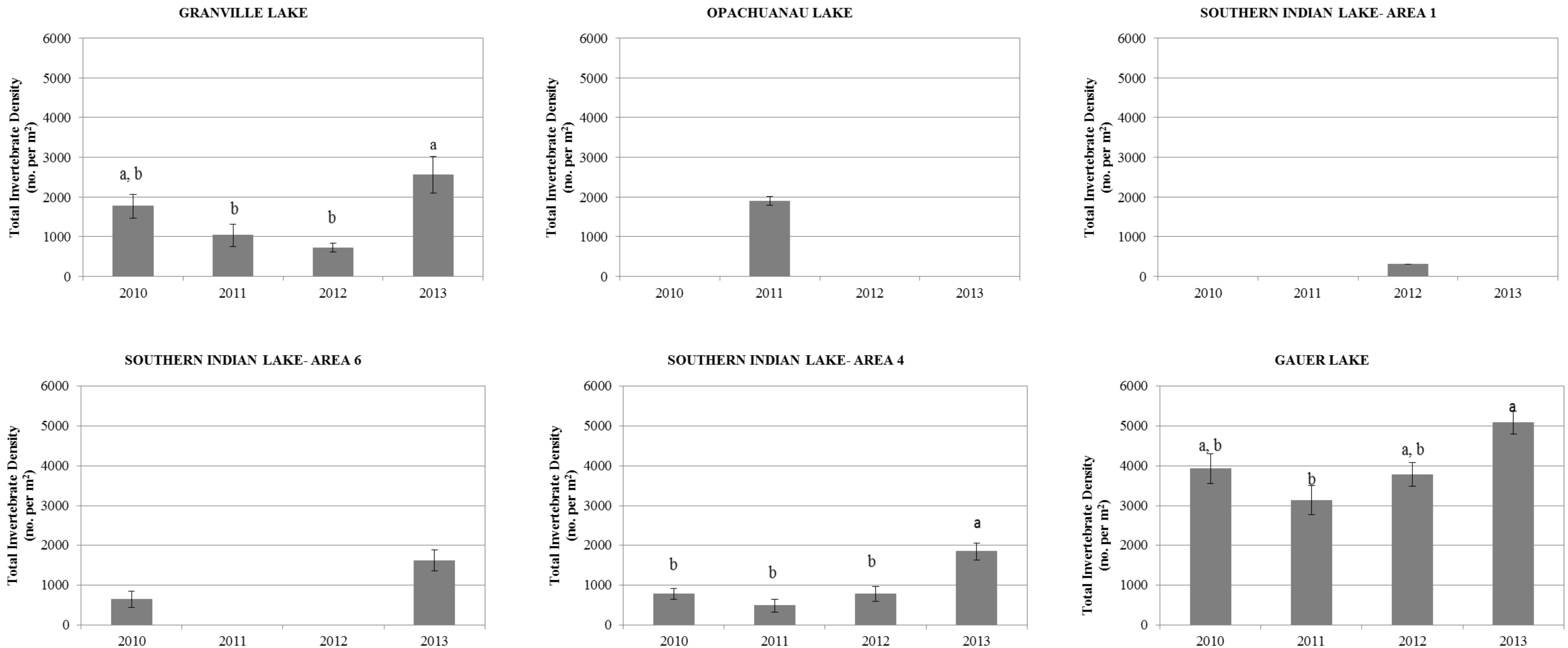



Figure 5-7. Total invertebrate density (mean ± SE) in the offshore of the Upper Churchill River Region, by year: 2010 – 2013. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

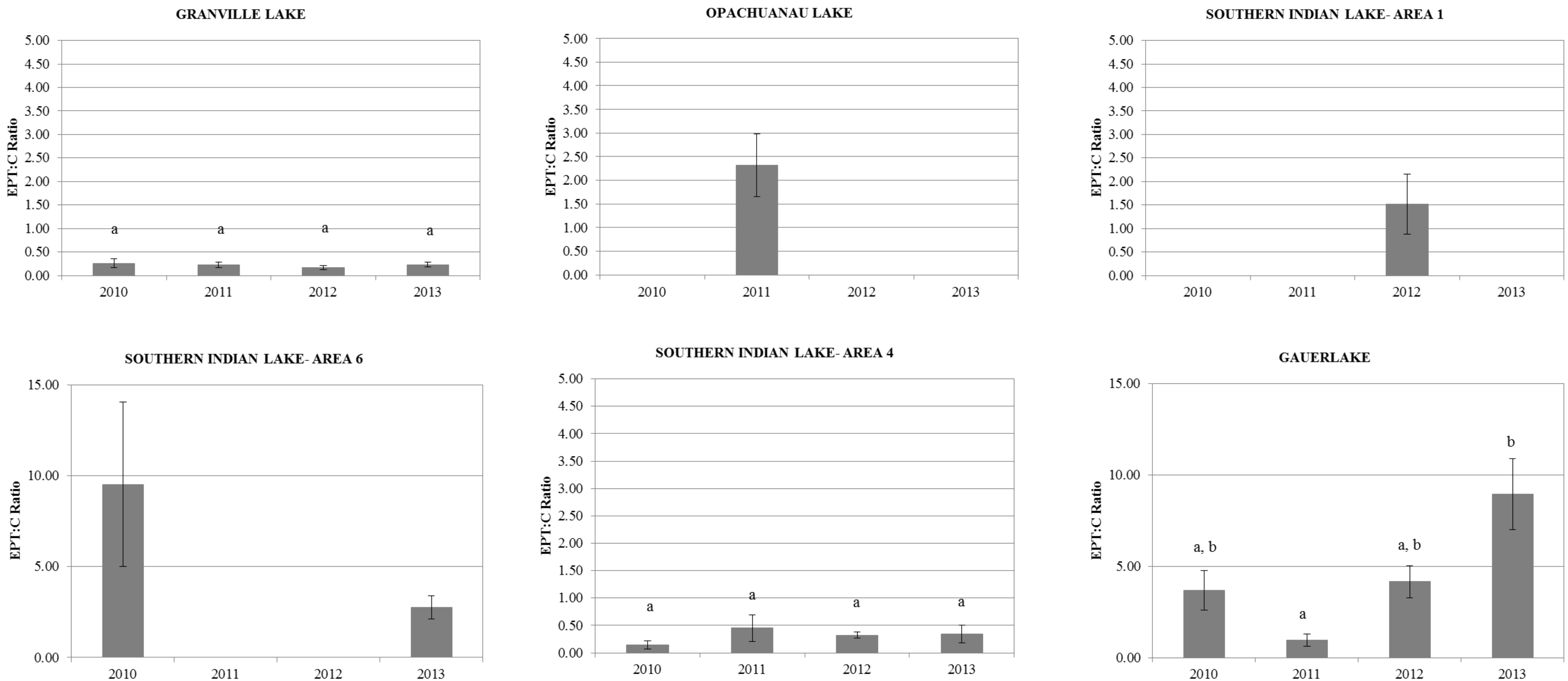



Figure 5-8. EPT:C ratio (mean ± SE) in the nearshore habitat of the Upper Churchill River Region, by year: 2010 – 2013. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

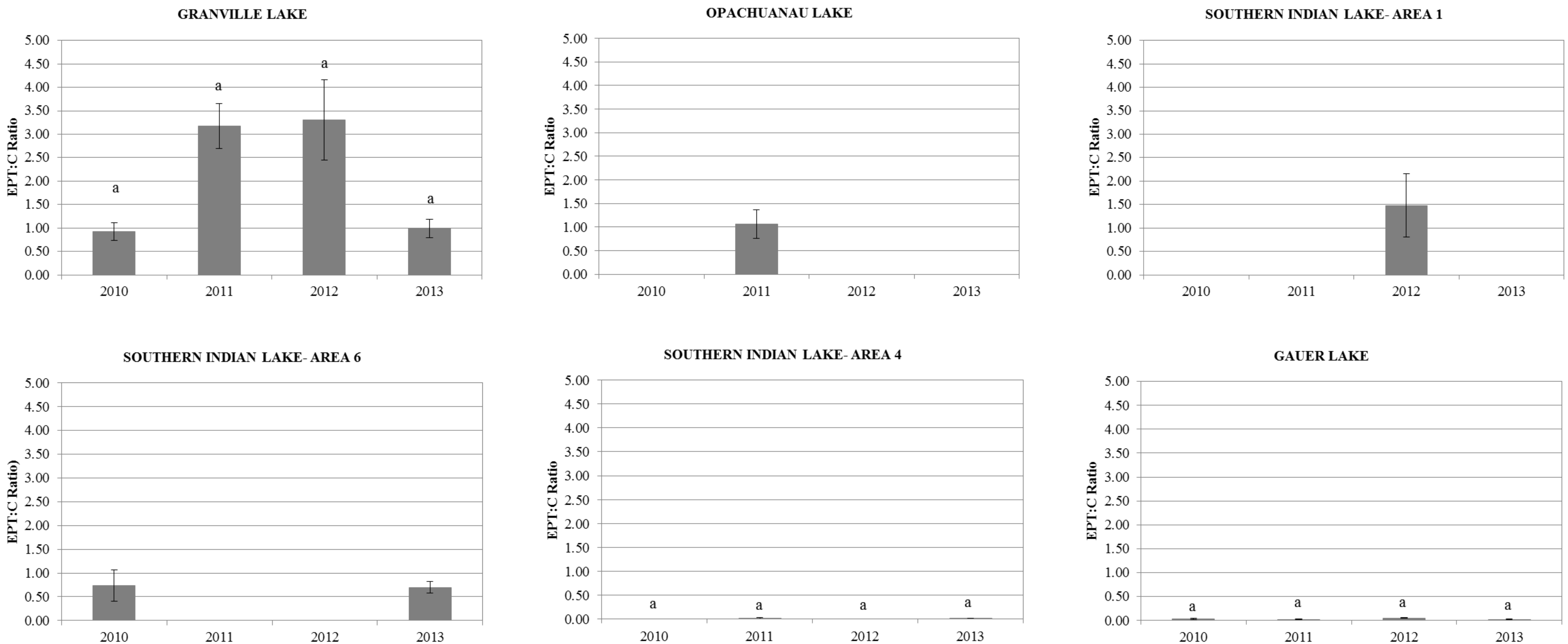



Figure 5-9. EPT:C ratio (mean ± SE) in the offshore habitat of the Upper Churchill River Region, by year: 2010 – 2013. No statistically significant inter-annual differences were observed in the annual monitoring sites (Southern Indian Lake – Area 4 and Granville and Gauer lakes).

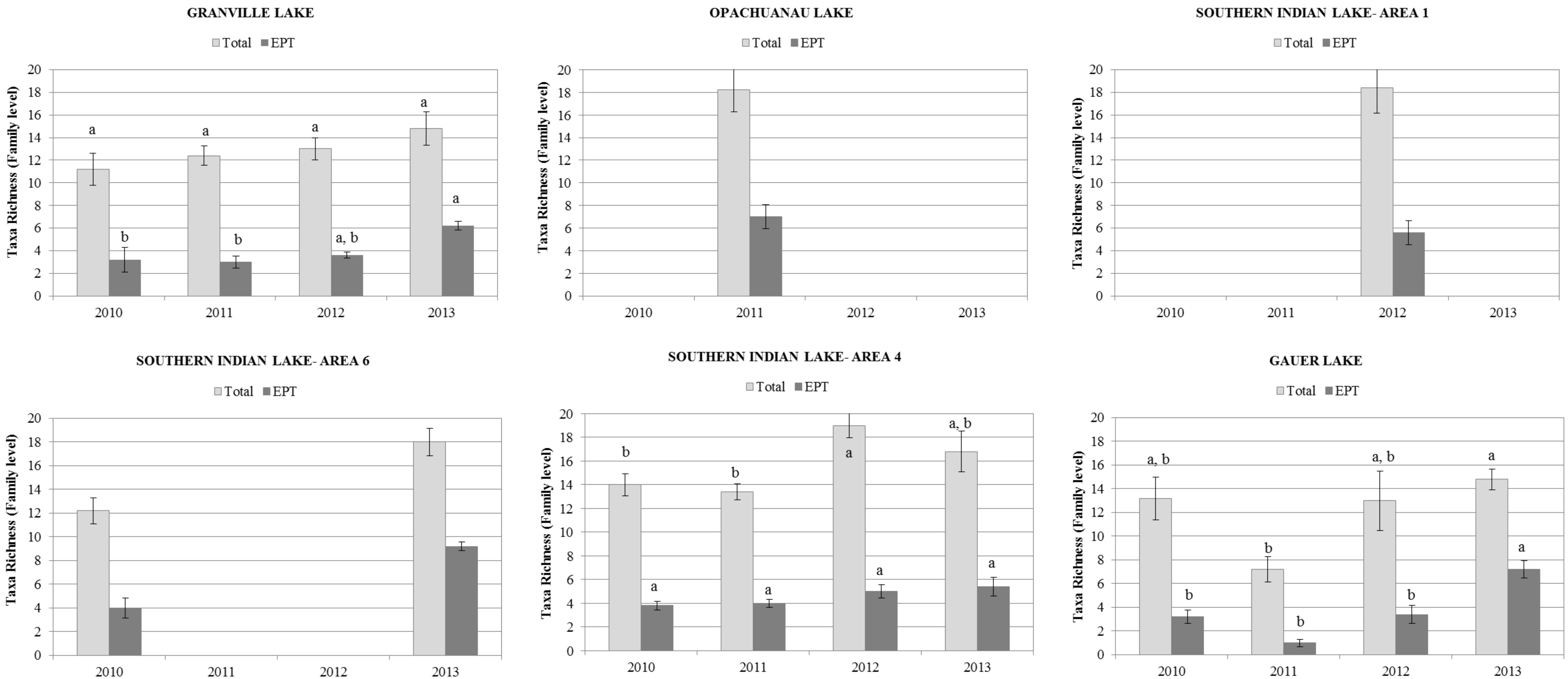



Figure 5-10. Taxonomic richness (total and EPT to family level; mean ± SE) in the nearshore habitat of the Upper Churchill River Region, by year: 2010 – 2013. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

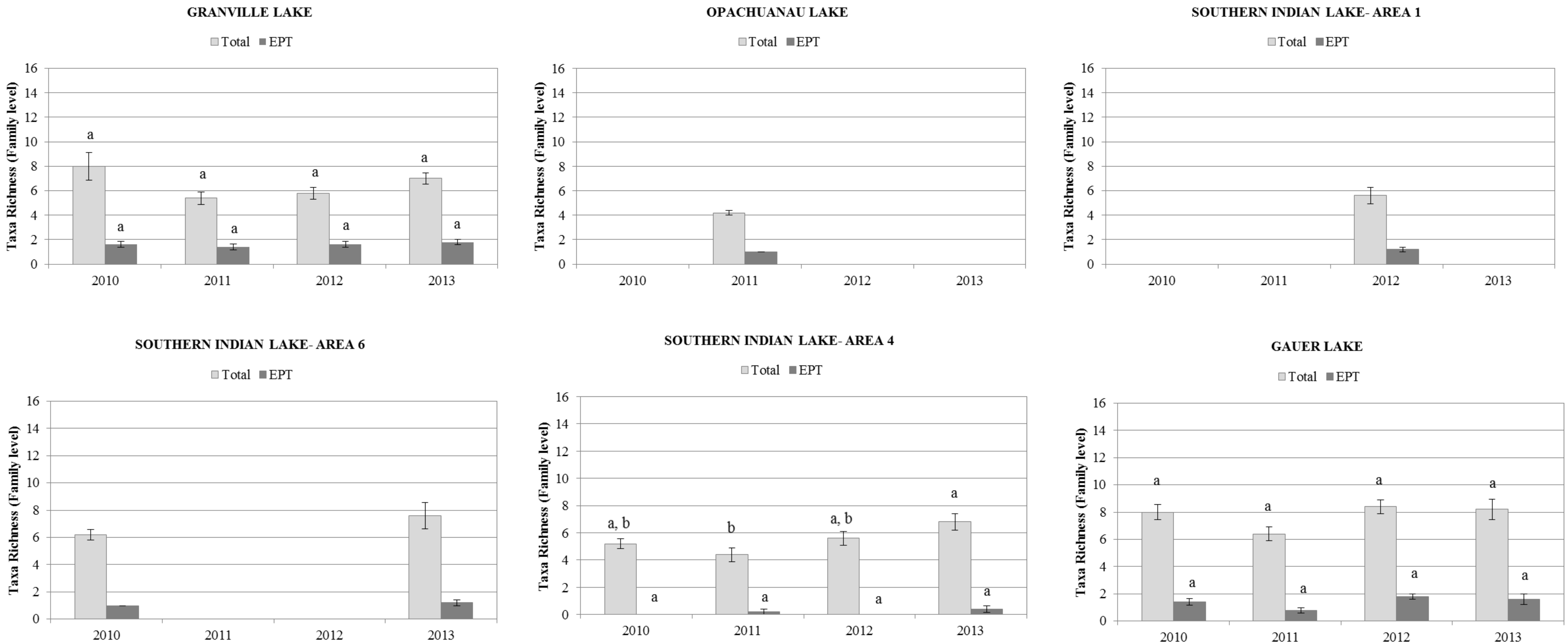



Figure 5-11. Taxonomic richness (total and EPT to family level; mean ± SE) in the offshore habitat of the Upper Churchill River Region, by year: 2010 – 2013. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

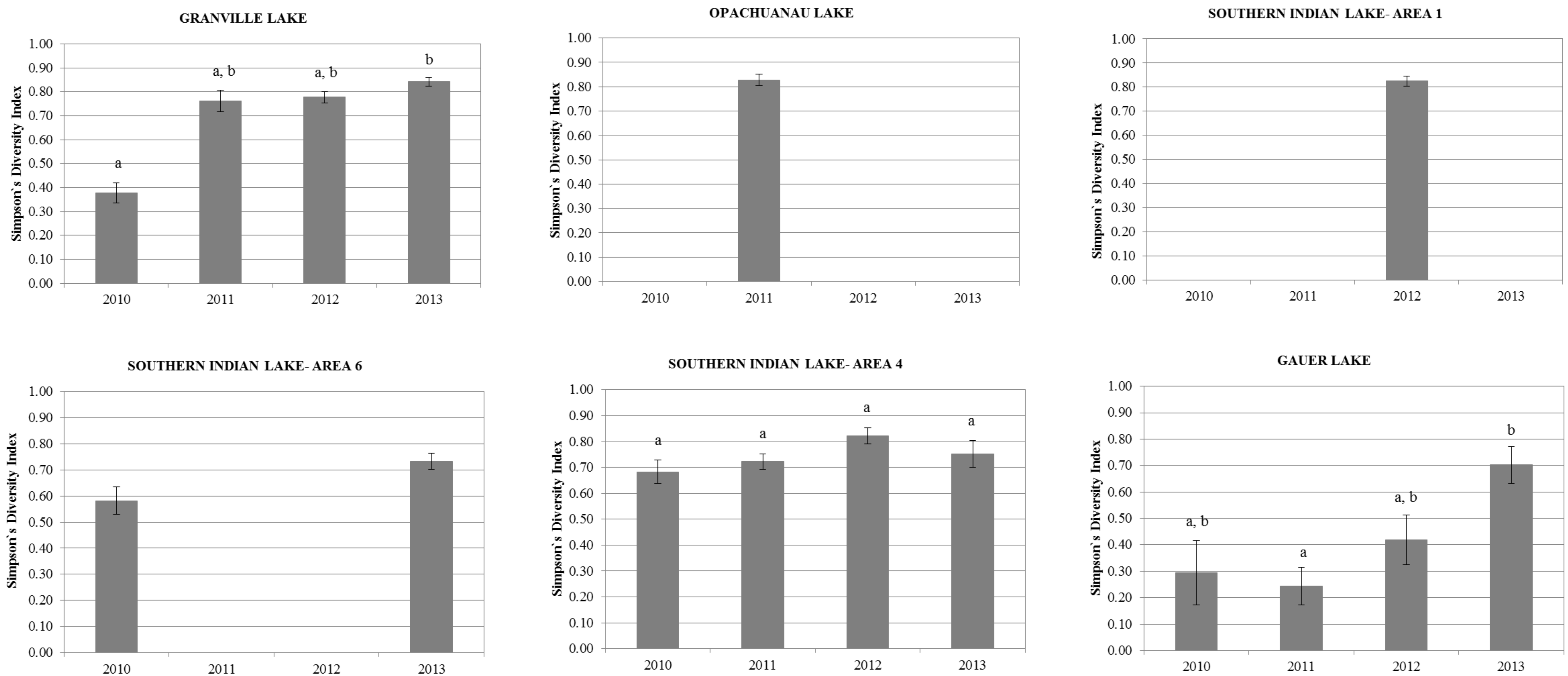



Figure 5-12. Simpson's Diversity Index (mean ± SE) in the nearshore habitat of the Upper Churchill River Region, by year: 2010 – 2013. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

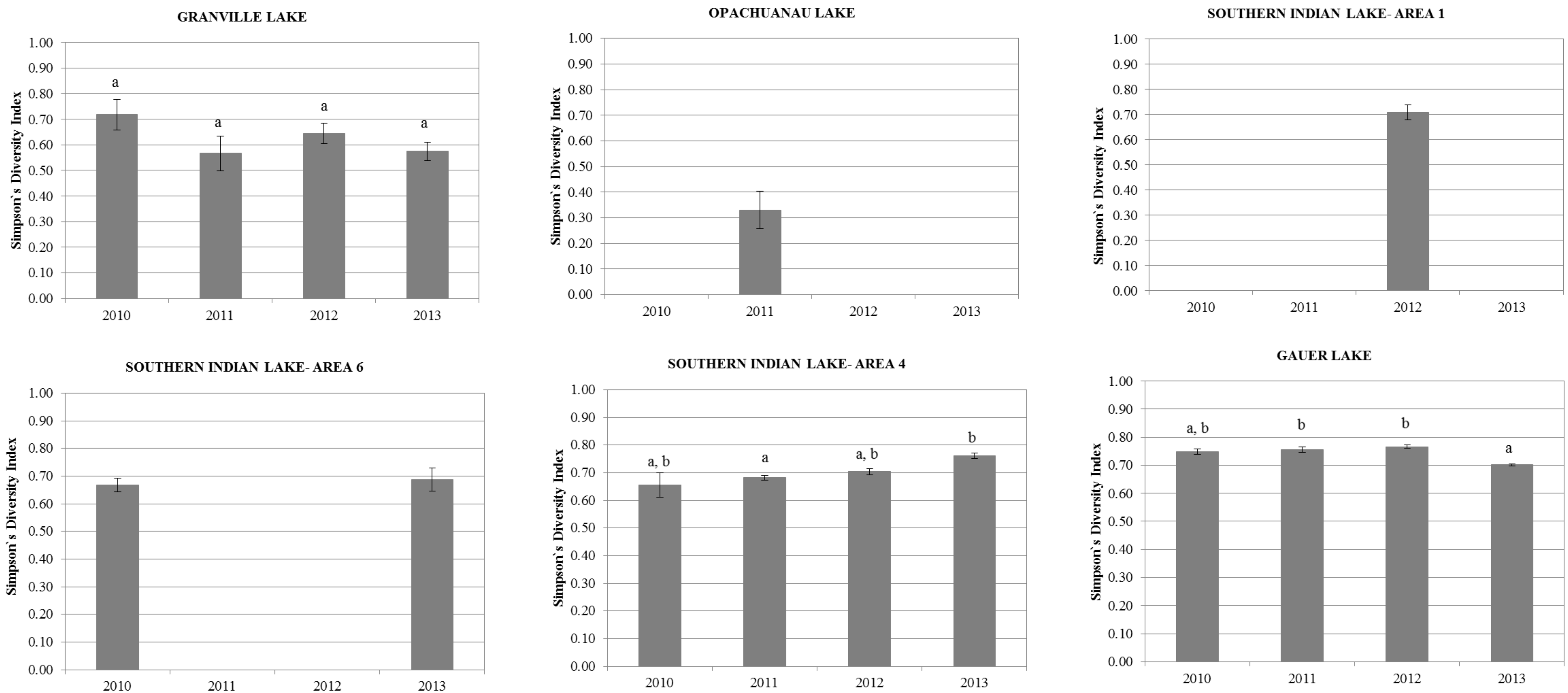



Figure 5-13. Simpson's Diversity Index (mean ± SE) in the offshore habitat of the Upper Churchill River Region, by year: 2010 – 2013. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

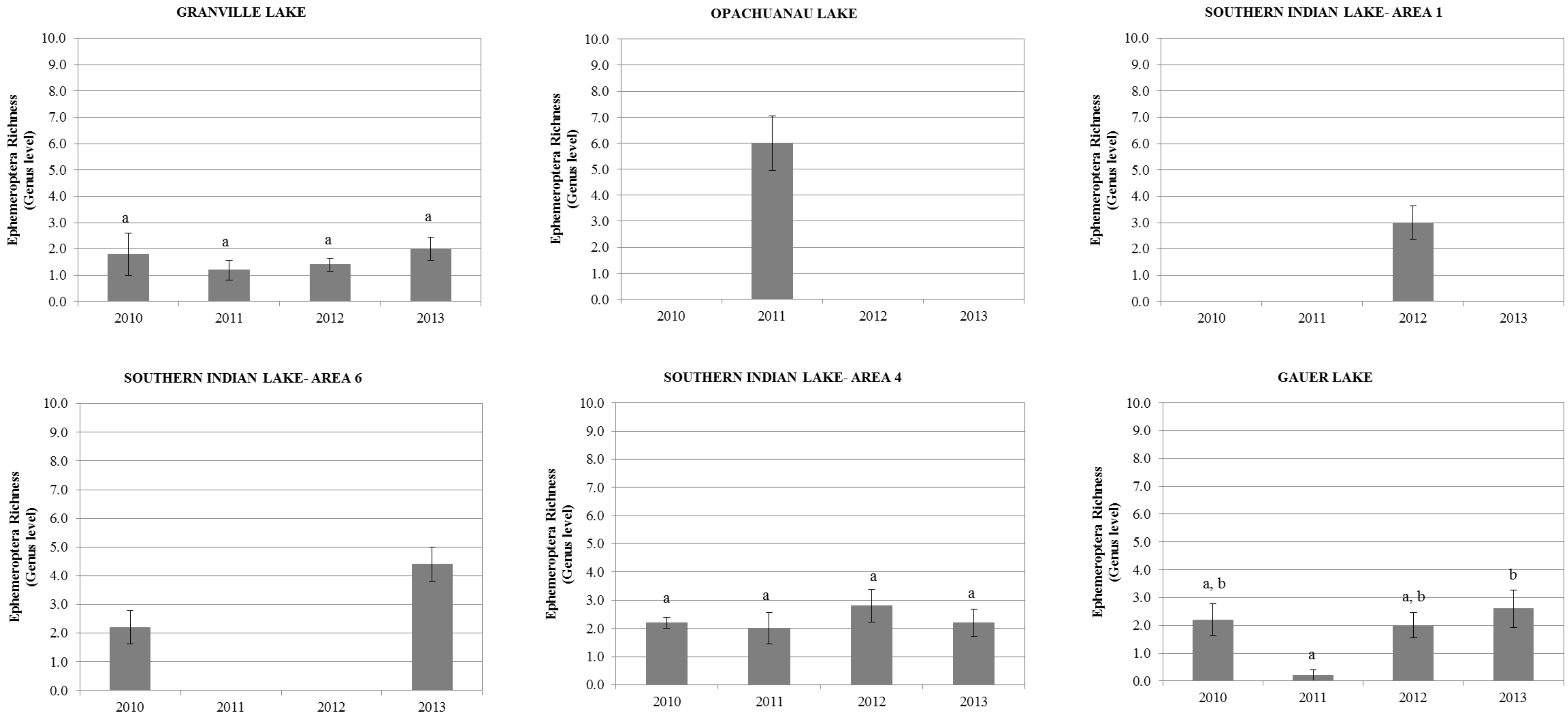



Figure 5-14. Ephemeroptera richness (genus level; mean ± SE) in the nearshore habitat of the Upper Churchill River Region, by year: 2010 – 2013. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

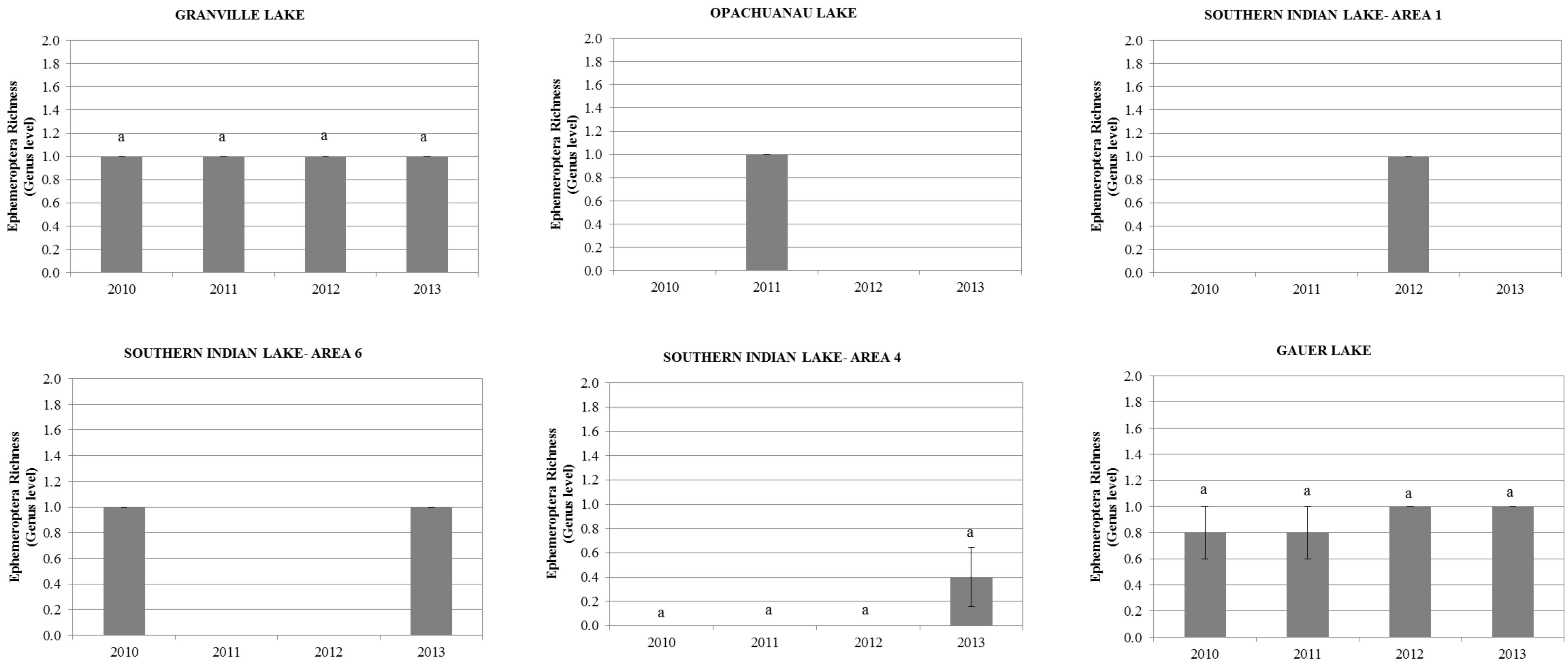



Figure 5-15. Ephemeroptera richness (genus level; mean ± SE) in the offshore habitat of the Upper Churchill River Region, by year: 2010 – 2013. No statistically significant inter-annual differences were observed in the annual monitoring sites (Southern Indian Lake – Area 4 and Granville and Gauer lakes).

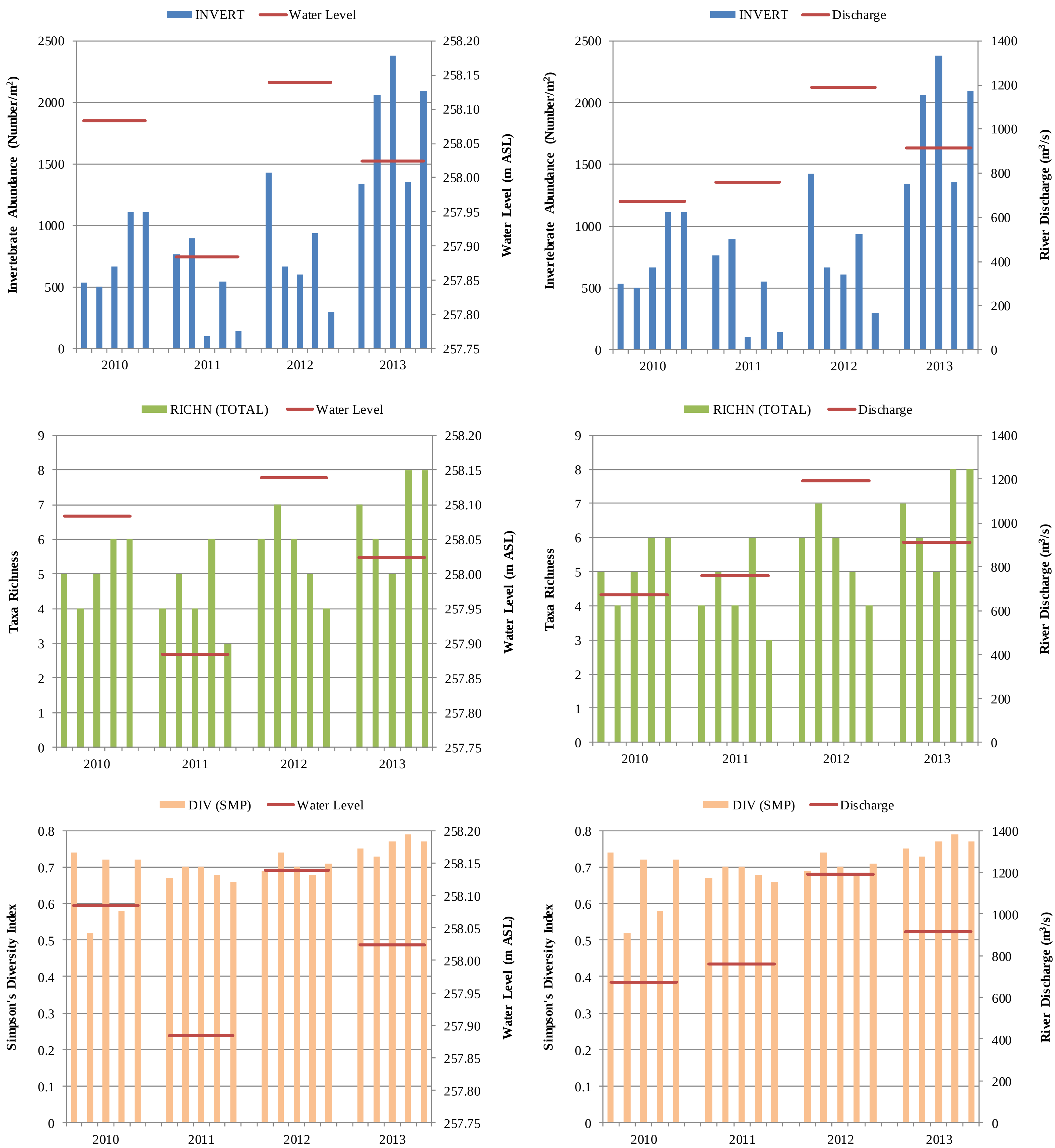



Figure 5-16. Invertebrate abundance, total richness, and Simpson's diversity index for replicate samples collected at the offshore Southern Indian Lake – Area 4 site: 2010 to 2013. The average water level and discharge during the "growing season" are shown.

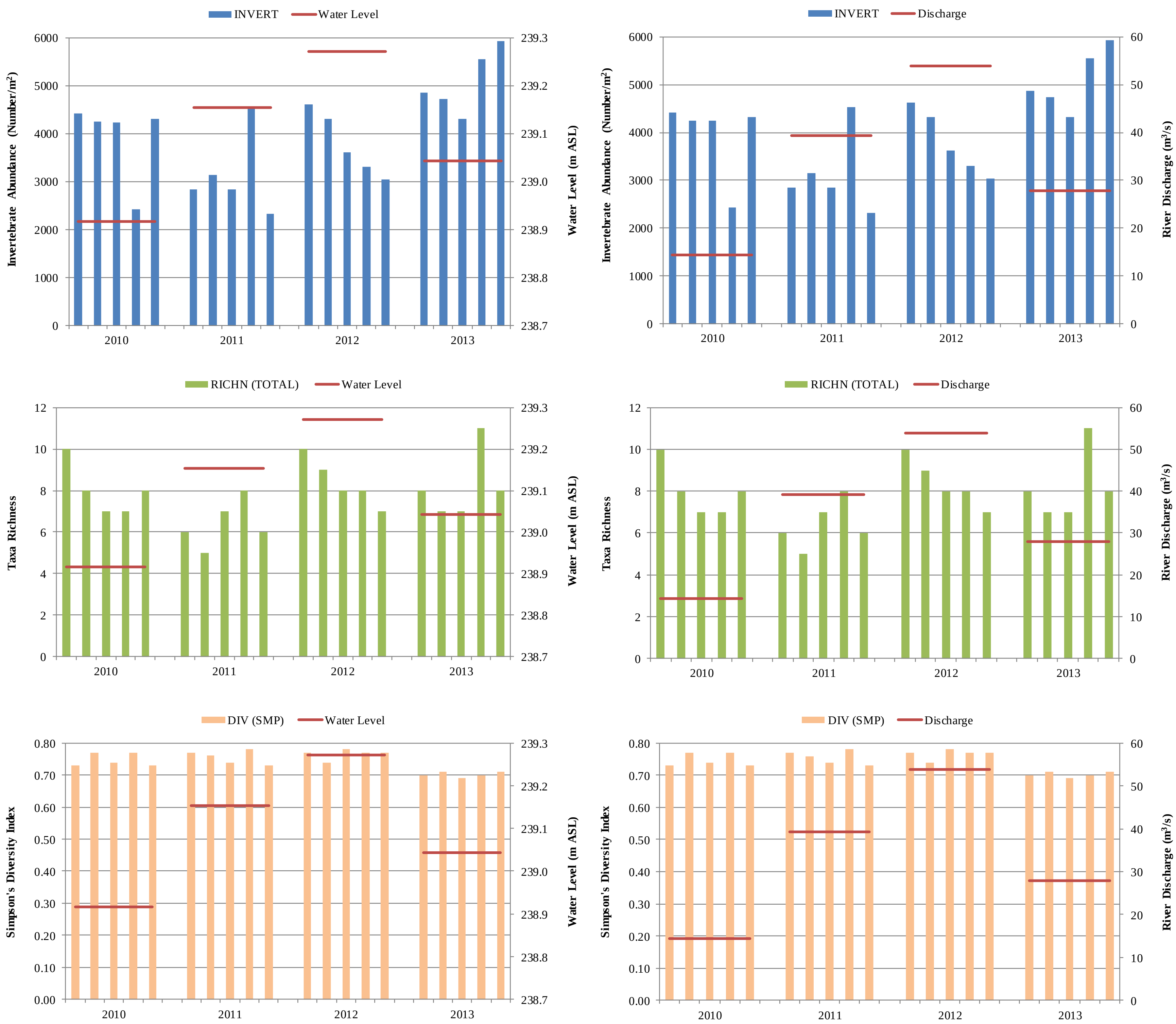



Figure 5-17. Invertebrate abundance, total richness, and Simpson's diversity index for replicate samples collected at the offshore Gauer Lake site: 2010 to 2013. The average water level and discharge during the "growing season" are shown.

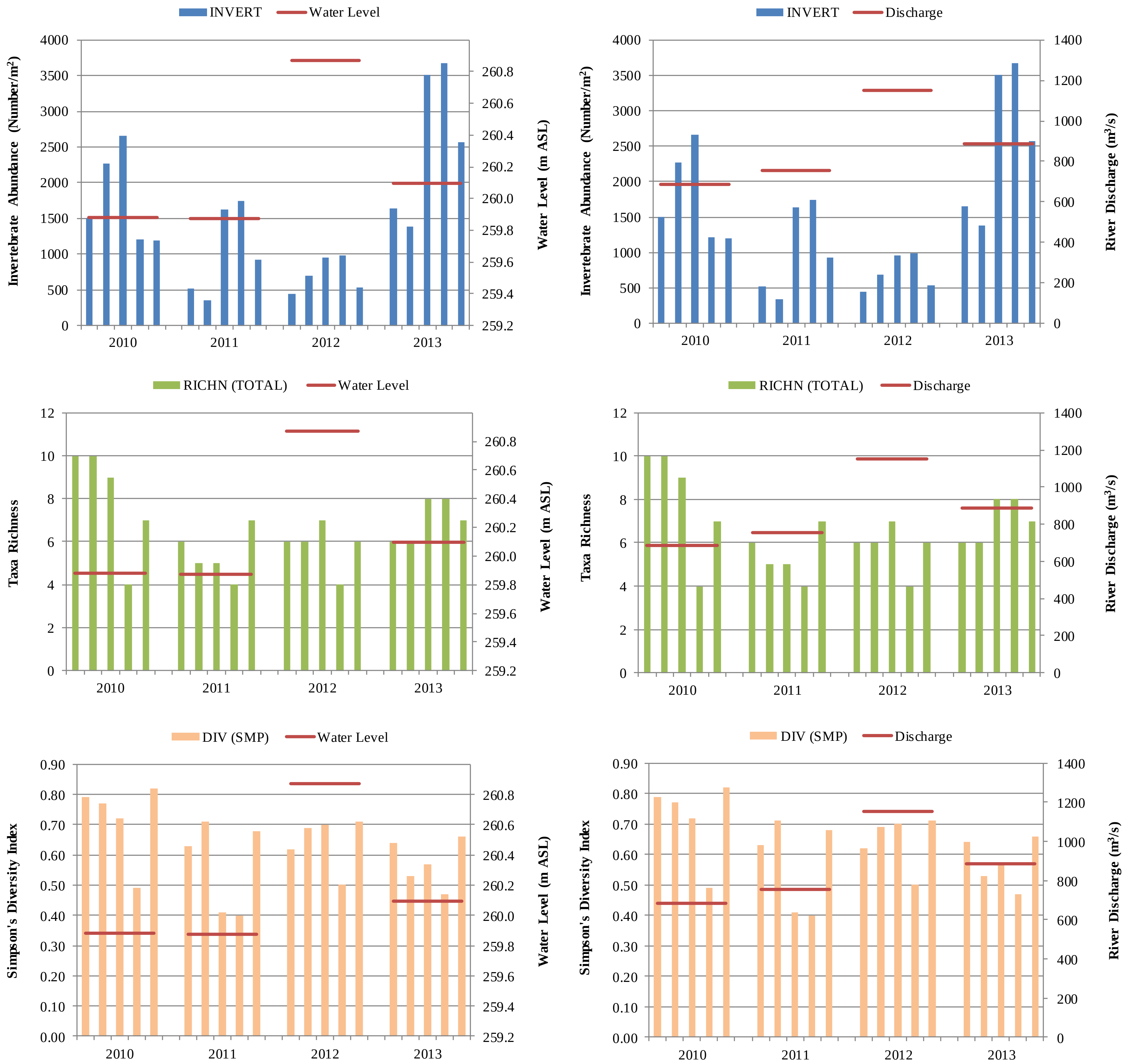



Figure 5-18. Invertebrate abundance, total richness, and Simpson's diversity index for replicate samples collected at the offshore Granville Lake site: 2010 to 2013. The average water level and discharge during the "growing season" are shown.

# 6.0 FISH COMMUNITY

## 6.1 INTRODUCTION

The following provides an overview of the fish community component of CAMP using key metrics measured over years 1 to 6 in the UCRR. As noted in Section 1.0, waterbodies sampled annually included one on-system location (Southern Indian Lake – Area 4) and one off-system lake (Granville Lake). While formally part of the LCRR under CAMP, results for the annual off-system Gauer Lake are included in the following discussion to provide context for the UCRR results. Three additional on-system waterbodies or areas were sampled on a rotational basis, including Opachuanau Lake and Southern Indian Lake – Area 1 and Southern Indian Lake – Area 6 (Table 6-1; Figure 6-1). Descriptions of the region and waterbodies monitored under CAMP are provided in Technical Document 1, Section 2.4 and the abbreviations for the sampling locations used in the tables and figures are provided in Table 6-1.

Sampling was completed at all locations and in most cases was conducted at the same general time period each year. All analyses presented below have been conducted on the results of annual or rotational index gillnetting studies. A detailed description of the sampling methods is presented in Section 3.6 of Technical Document 1. A complete list of all fish species captured in standard gang and small mesh index gill nets set in UCRR waterbodies (2008-2013) is presented in Table 6-2.

### 6.1.1 Objectives and Approach

The key objectives for the analysis of CAMP fish community data, which were directed in the terms of reference for preparation of this report, were to:

- evaluate whether there are indicators of temporal changes or trends in fish community metrics; and
- provide an initial review of potential linkages between fish metrics and key drivers, notably hydrological conditions, where feasible.

The first objective (analysis of temporal changes or trends) was addressed through two approaches: (1) statistical analyses were undertaken, where possible, to assess whether there were significant differences between years at annual locations; and (2) graphical plots for annual sites were examined visually for trends. As noted in Technical Document 1, six years of data may be insufficient to detect trends over time, notably long-term trends, and the assessment was therefore restricted to a qualitative assessment of the available data for sites monitored annually. Additionally, any indications of potential trends over the six year period do not necessarily imply a long-term trend is occurring, as apparent trends over this interval may simply reflect the relatively limited time period assessed in conjunction with inter-annual variability in a metric. Consideration of a longer period of record is required to evaluate for long-term trends.

The second objective was addressed by regression analysis of hydrological (discharge and/or water level) data and selected fish community metrics where potential linkages were considered meaningful. Statistical analyses undertaken for this component are inherently limited by the quantity of data and the absence of statistically significant differences may reflect the relatively limited amount of data. Furthermore, factors other than hydrological conditions, notably abiotic and biotic variables such as water quality, habitat quantity and quality, benthos production, and predator/prey interactions, affect the fish community. For these reasons, these analyses are considered to be exploratory in nature. In addition, it is cautioned that the identification of significant correlations between fish community metrics and hydrological variables does not infer a causal relationship (i.e., correlations simply indicate that two metrics are related).

### 6.1.2 Indicators

The following sections describe four key fish community indicators: diversity; abundance; condition; and growth. The metrics presented for these indicators include: Hill's effective species richness index (Hill's index); catch-per-unit-effort (CPUE) for both standard gang and small mesh index gillnets; Fulton's condition factor ($K_F$); and length-at-age. A description of and the rationale for the selection of the metrics and indicators is provided in Section 4.6.1 of Technical Document 1.

Manitoba Hydro and the Province of Manitoba's (2015) RCEA identified several effects of hydroelectric development on fish communities along the upper Churchill River and its associated lakes (particularly Southern Indian Lake), although a paucity of pre-development data limited a direct comparison of data for key CAMP metrics. Declines in total CPUE, Lake Whitefish (*Coregonus clupeaformis*) CPUE, and commercial catches since the establishment of CRD were observed for most areas of Southern Indian Lake (Manitoba Hydro and the Province of Manitoba 2015). The key conclusion from the RCEA was that changes in spawning habitat, emigration, food availability, and the effects of the commercial fishery were affecting the fish community of Southern Indian Lake.

## 6.2 KEY INDICATORS

### 6.2.1 Diversity (Hill's Index)

Changes in aquatic habitat can result in a shift in species composition. The Hill's Index is a mathematical measure of species diversity in a community based on how many different species (i.e., species richness) and how abundant each species (i.e., evenness) is in the community. The diversity index increases with an increase in the number of species and, for a given number of species, is maximized when all of the species are equally abundant. Generally, diverse communities are indicators of ecosystem health as more diversity increases the ability of the community to respond to environmental stressors.

#### *6.2.1.1 Upper Churchill River Region*

A total of 16 fish species were caught in Upper Churchill River on-system waterbodies between 2008 and 2013 (Table 6-2). The mean annual Hill's effective species richness (i.e., Hill's index number) ranged from a high of 7.7 in Southern Indian Lake – Area 1 to a low of 5.3 in Southern Indian Lake – Area 4 (Figure 6-2; Table 6-3). Overall, Hill's effective species richness in Southern Indian Lake – Area 1 was higher than in all other on-system waterbodies (Figure 6-2). The higher Hill's value calculated for this waterbody was a result of both a higher average number of species caught per year, and more even relative abundances (as measured by CPUE; Figure 6-3). In contrast, the other on-system waterbodies had a lower average number of species detected per year, and catches were typically dominated by a smaller number of species. For example, White Sucker (*Catostomus commersonii*) accounted for over 40% of the catch in Opachuanau Lake. Within Southern Indian Lake, the Hill's number was similar in Area 6 (6.1) and Area 4 (5.3), with the only difference in species composition being three sculpin species (family Cottidae) captured in Area 4 that were not captured in Area 6, likely a result of the higher sampling effort expended in Area 4 (six versus two years of sampling).

#### *6.2.1.2 Off-system Waterbodies: Granville and Gauer Lakes*

The mean annual Hill's number was 7.7 in Gauer Lake and 5.9 in Granville Lake (Table 6-3; Figure 6-2). The value calculated for Gauer Lake was similar to that observed in Southern Indian Lake – Area 1, while the value calculated for Granville Lake was similar to those calculated for the other on-system sites.

#### *6.2.1.3 Temporal Comparisons and Trends*

Although the Hill's numbers calculated for sites sampled annually showed variability among sampling years, some potential trends were observed (Figure 6-2; Table 6-3). A gradual increase in Hill's number over time was observed in Southern Indian Lake – Area 4 which was a result of an increase in species richness; nine species were captured in 2008, eight in 2009, 11 in 2010 and 2011, 12 in 2012, and 13 in 2013.

The gradual decrease in Hill's number observed for Gauer Lake over time appears to be a result of one or a combination of: (1) a slight decrease in the number of species caught in the area over time; and/or (2) an increase in the number of Walleye (*Sander vitreus*) and a decrease in the number of Lake Whitefish (especially in 2013) caught in the waterbody.

### 6.2.2 Abundance (Catch-Per-Unit-Effort)

The abundance of fish in a waterbody is influenced by a variety of physical (e.g., substrate type, flow conditions), biological (e.g., benthos production, predator/prey interactions), and chemical (e.g., dissolved oxygen) factors. Fish abundance is difficult to quantify as the number and type of fish species captured is affected by the type of sampling equipment as a result of size selectivity of the gear and the types of habitat that can be effectively sampled. CPUE is a measure of the abundance of fish captured in a standardized length of net over a fixed amount of time.

#### *6.2.2.1 Upper Churchill River Region*

<u>Fish Community</u>

In standard gangs, mean CPUE calculated for the upper Churchill River on-system waterbodies ranged from a high of 63 fish/100 m/24 h in Opachuanau Lake to a low of 40 fish/100 m/24 h in Southern Indian Lake – Area 1 (Table 6-3). The CPUE of large-bodied fish in Southern Indian Lake – Area 4 was higher than in Southern Indian Lake – Area 1 and Southern Indian Lake – Area 6, but lower than in Opachuanau Lake, as indicated by the lack of overlap of interquartile ranges between Southern Indian Lake – Area 4 and the other three areas (Figure 6-4). The most abundant large-bodied species varied by area: White Sucker dominated the catch in Opachuanau Lake; Lake Whitefish and Cisco (*Coregonus artedi*) were generally abundant in all areas of Southern Indian Lake; Sauger (*Sander canadensis*) was most abundant in Southern Indian Lake – Area 6; Longnose Sucker (*Catostomus catostomus*) was particularly abundant in Southern Indian Lake – Area 4 while White Sucker were not common; and Northern Pike (*Esox lucius*) and Walleye were not overly abundant in any area (Figure 6-3).

In small mesh gangs, mean CPUE ranged from a high of 97 fish/30 m/24 h in Southern Indian Lake – Area 6 to a low of 7 fish/30 m/24 h in Southern Indian Lake – Area 1 (Table 6-3). Few small-bodied species were captured in small mesh gill nets in most on-system waterbodies; where small-bodied species were captured, Spottail Shiner (*Notropis hudsonius*), Trout-perch (*Percopsis omiscomaycus*), and Emerald Shiner (*Notropis atherinoides*), along with Cisco and Sauger, were among the more commonly captured species (Figure 6-3).

Lake Whitefish

Lake Whitefish mean annual CPUE ranged from a high of 13 fish/100 m/24 h in Southern Indian Lake – Area 4 to a low of 4 fish/100 m/24 h in Southern Indian Lake – Area 6 (Table 6-3; Figure 6-5). Lake Whitefish were more abundant in Southern Indian Lake – Areas 1 and 4 compared to Southern Indian Lake – Area 6, as indicated by the lack of overlap in interquartile ranges (Figure 6-5). However, CPUE in Southern Indian Lake – Area 4 was notably more variable than in the other on-system areas (Figure 6-5).

Northern Pike

Northern Pike mean annual CPUE was higher in Southern Indian Lake (Areas 1, 6 and 4) than in Opachuanau Lake, though data for Opachuanau Lake are limited to a single sampling year (Figure 6-6). In Southern Indian Lake, Northern Pike CPUE was similar among areas, ranging from a mean of 3 fish/100 m/24 h in Area 1 and Area 6 to a high of 5 fish/100 m/24 h in Area 4; pike CPUE was <1 fish/100 m/24 h in Opachuanau Lake (Table 6-3; Figure 6-6).

Walleye

Walleye mean CPUE ranged from a high of 4 fish/100 m/24 h in Opachuanau Lake to a low of <1 fish/100 m/24 h in Southern Indian Lake – Area 6 and Area 4 (Table 6-3; Figure 6-7). Walleye catches were consistently low in on-system waterbodies along the upper Churchill River, and there was little difference in Walleye abundance among the on-system areas (Figure 6-7).

White Sucker

White Sucker mean CPUE in standard gangs ranged from a high of 41 fish/100 m/24 h in Opachuanau Lake to a low of <1 fish in Southern Indian Lake – Area 4 (Table 6-3; Figure 6-8).

White Sucker CPUE was considerably higher in Opachuanau Lake than in all areas of Southern Indian Lake, though as noted above Opachuanau Lake was only sampled in one year (2011; Figure 6-8). Within Southern Indian Lake, Area 1 had the highest White Sucker CPUE.

#### *6.2.2.2 Off-system Waterbodies: Granville and Gauer Lakes*

Fish Community

In standard gang index gill nets, mean CPUE was 80 fish/100 m/24 h in Gauer Lake and 78 fish/100 m/24 h in Granville Lake (Table 6-3; Figure 6-4). The most abundant large-bodied fish species in Gauer Lake were White Sucker, Walleye, and Lake Whitefish, while the large-bodied fish community in Granville Lake was dominated by White Sucker, with smaller numbers of Walleye and Sauger (Figure 6-3).

In small mesh index gill nets, the mean CPUE was 134 fish/30 m/24 h in Gauer Lake and 85 fish/30 m/24 h in Granville Lake (Table 6-3). The small-bodied fish community in Gauer Lake was dominated by Spottail Shiner, with smaller numbers of Trout-perch, Yellow Perch (*Perca flavescens*), and Emerald Shiner, while the abundance of Emerald Shiner, Spottail Shiner, Trout-perch, and Yellow Perch in Granville Lake were approximately equal in abundance (Figure 6-3).

Catches in the off-system waterbodies were comparable as the interquartile ranges overlapped. However, based on the available data, catches in the off-system lakes were higher than those at the on-system locations (Figure 6-4).

### Lake Whitefish

Lake Whitefish had a mean CPUE in standard gangs of 18 fish/100 m/24 h in Gauer Lake and 3 fish/100 m/24 h in Granville Lake (Table 6-3; Figure 6-5). Lake Whitefish CPUE in Gauer Lake was higher than in the on-system waterbodies, with the exception of the high catch in Southern Indian Lake – Area 4 in 2008 (Figure 6-5). In Granville Lake, Lake Whitefish CPUE was comparable to that in Southern Indian Lake – Area 6, and lower than in all other areas.

### Northern Pike

Northern Pike had a mean CPUE in standard gangs of 11 fish/100 m/24 h in Gauer Lake and 3 fish/100 m/24 h in Granville Lake (Table 6-3; Figure 6-6). Northern Pike CPUE in the off-system Granville Lake was in the range observed in the three areas of Southern Indian Lake, but was higher than in Opachuanau Lake (Figure 6-6). Northern Pike CPUE in the off-system Gauer Lake was higher than in all the other areas in the UCRR.

### Walleye

Walleye had a mean CPUE in standard gangs of 19 fish/100 m/24 h in Gauer Lake and 9 fish/100 m/24 h in Granville Lake (Table 6-3; Figure 6-7). Walleye CPUE was higher in both off-system lakes than in all on-system locations, although Walleye CPUE in each of the off-system lakes was quite variable from year-to-year (Figure 6-7).

### White Sucker

White Sucker had a mean CPUE in standard gangs of 21 fish/100 m/24 h in Gauer Lake and 48 fish/100 m/24 h in Granville Lake (Table 6-3; Figure 6-8), both of which were considerably higher than the values for Southern Indian Lake. White Sucker CPUE appeared to decrease moving down the Churchill River from Granville Lake to Opachuanau Lake and ultimately to Southern Indian Lake (Figure 6-8). White Sucker CPUE in the off-system waterbodies was notably higher than the catches observed in all areas of Southern Indian Lake (Figure 6-3).

#### *6.2.2.3 Temporal Comparisons and Trends*

Fish Community

Temporal comparisons and evaluations of trends were undertaken for all UCRR waterbodies sampled annually (i.e., Granville Lake, Southern Indian Lake – Area 4, and Gauer Lake).

Based on the available data, total CPUE (Figure 6-9) was significantly higher in 2008 than in all other years in Southern Indian Lake – Area 4 primarily due to a large catch of Lake Whitefish in that year. Data are insufficient to ascertain if this represents a downward trend or simply a single year with a significantly higher catch of Lake Whitefish. No trends in total CPUE were observed in Granville Lake or Gauer Lake.

Lake Whitefish

Lake Whitefish CPUE was significantly higher in 2008 (28 fish/100 m/24 h) than in other years (range of 7-15 fish/100 m/24 h) in Southern Indian Lake – Area 4 (Figure 6-10). Data are insufficient to ascertain if this represents a downward trend or simply a single year with a significantly larger catch of Lake Whitefish. Explanations for the large catch of Lake Whitefish in Southern Indian Lake – Area 4 in 2008 are not known. A change in sampling locations or timing of sampling do not appear to be responsible for the difference between the large 2008 catch and the lower catches in the years that follow as site locations and the timing of sampling typically changed little from year-to-year in Southern Indian Lake – Area 4.

There were few statistical differences between years (Figure 6-10), and no apparent increasing or decreasing trend in Lake Whitefish abundance in Granville and Gauer lakes.

Northern Pike

Northern Pike CPUE in Southern Indian Lake – Area 4 has been relatively consistent over the sampling period, ranging from 3 fish/100 m/24 h in 2010 to 7 fish/100 m/24 h in 2008 (Figure 6-6). There were no statistically significant differences among years and there were no apparent increasing or decreasing trends in Northern Pike abundance in Southern Indian Lake – Area 4 or the off-system lakes (Figure 6-11).

## Walleye

The mean CPUE in Southern Indian Lake – Area 4 was lowest in 2008 and 2009 when no Walleye were captured and highest in 2013 at 1 fish/100 m/24 h (Figure 6-7). There were no significant inter-annual differences in CPUE in this area (Figure 6-12), and no indication of an increasing or decreasing trend over the six-year sampling period.

Walleye CPUE was higher and more variable between years at the off-system lakes (Figure 6-7). There was some evidence of a slight increasing trend in Walleye abundance in Granville Lake over the six-year monitoring period with the CPUE value in 2013 statistically higher than in 2009 and 2011 (Figure 6-12). Walleye CPUE in Gauer Lake also increased over the six-year monitoring period and was statistically highest in 2013 (Figure 6-12).

## White Sucker

White Sucker CPUE in Southern Indian Lake – Area 4 was low in all years (Figure 6-8). Catches ranged between <1 fish/100 m/24 h in 2009 to just over 1 fish/100 m/24 h in 2012 and 2013 (Figure 6-8). There was no statistical difference among years or trends in CPUE over time (Figure 6-13).

CPUE values for Granville Lake (ranging from a high of 59 fish/100 m/24 h in 2012 to a low of 30 fish/100 m/24 h in 2013) were relatively consistent from 2008-2012, but were notably lower in 2013 (Figure 6-13). Data are not sufficient to determine if this represents a long-term trend or short-term variation. A decrease in White Sucker CPUE was observed in Gauer Lake over the first two years followed by an increase over the last four years (Figure 6-8). However, there were no significant differences among years and the data are not sufficient to delineate a long-term trend (Figure 6-13).

### 6.2.3 Condition (Fulton's Condition Factor)

Condition is a measure of an individual fish's health calculated from the relationship between its weight and length. Fulton's condition factor ($K_F$) is a mathematical equation that quantitatively describes the girth or "fatness" of a fish. The condition factor differs among fish species, and for a given species, can be influenced by the age, sex, season, stage of maturity, and amount of fat and muscular development. Generally, fish in better condition (more full-bodied/fatter) are assumed to have better nutritional and health status. Lack of food, poor water quality, or disease can cause stress that results in lower condition.

#### *6.2.3.1 Upper Churchill River Region*

Lake Whitefish

The condition of Lake Whitefish was similar among the on-system areas, except in Southern Indian Lake – Area 4 where the mean condition of fish (1.31) was lower than the other on-system areas (means ranged from 1.53 to 1.65; Figure 6-14). Conceptually, lower condition of Lake Whitefish in Southern Indian Lake – Area 4 relative to Areas 1 and 6 of Southern Indian Lake or Opachuanau Lake may reflect differences in the abundance and/or types of BMIs (the typical food source of Lake Whitefish) among the areas. Data collected under CAMP indicate that total abundance of BMIs in Area 4 were similar to or higher than in Areas 1 and 6 (nearshore and offshore habitat; see Section 5.3.1). Data for Opachuanau Lake are insufficient for comparison as only one year of monitoring was conducted. However, differences in the composition of the BMI community were observed among the areas; Area 4 offshore habitat contained fewer amphipods and a near absence of Ephemeroptera (i.e., mayflies) for the period of 2010-2013, which differed from the other on-system areas (Section 5).

Northern Pike

Mean Fulton's condition factor for Northern Pike was extremely consistent among the three areas of Southern Indian Lake (0.65 in Area 1, 0.66 in Area 6, and 0.67 in Area 4; Figure 6-15). There was an insufficient number of Northern Pike caught in Opachuanau Lake to compare condition with the other on-system areas.

Walleye

The condition of Walleye was generally consistent among the on-system waterbodies, with the possible exception of Southern Indian Lake – Area 1 (Figure 6-16). The mean condition of Walleye in Area 1 was 1.08, compared to 1.16 in Opachuanau Lake, and 1.20 in Southern Indian Lake – Area 4. However, it should be noted that few Walleye were captured at the on-system sites and the dataset was comprised of a maximum of two years of data for each of the sites.

White Sucker

The condition of White Sucker in Southern Indian Lake – Area 4 was lower than those of all other on-system sites (Figure 6-17). The condition of White Sucker in Opachuanau Lake (1.58) was similar to Southern Indian Lake – Area 1 (1.56) and within the range observed in Southern Indian Lake – Area 4 (1.49) and Southern Indian Lake – Area 6 (1.64; Figure 6-17).

#### *6.2.3.2 Off-system Waterbodies: Granville and Gauer Lakes*

Lake Whitefish

The condition of Lake Whitefish in Granville Lake (1.59) and Gauer Lake (1.50) was within the range of those observed in most on-system waterbodies, but higher than those in Southern Indian Lake – Area 4 (Figure 6-14).

Northern Pike

Mean Fulton's condition factor for Northern Pike in Gauer Lake (0.67) and Granville Lake (0.68) was within the range observed for the on-system areas (Figure 6-15).

Walleye

Walleye condition in Gauer Lake (1.13) and Granville Lake (1.12) was similar, but slightly lower than in Opachuanau Lake and Southern Indian Lake – Area 4, and higher than in Southern Indian Lake – Area 1 (Figure 6-16).

White Sucker

With the exception of Southern Indian Lake – Area 4, condition of White Sucker in Gauer Lake (1.54) and in Granville Lake (1.55) was similar to or lower than the on-system sites (Figure 6-17). White Sucker condition was notably lower in Southern Indian Lake – Area 4 than all other sites, including the off-system lakes (Figure 6-17).

#### *6.2.3.3 Temporal Comparisons and Trends*

Lake Whitefish

For the three sites that were sampled annually, there was limited variability in condition among sampling years (Figure 6-14). However, some significant differences were observed between years at Southern Indian Lake – Area 4 and Gauer Lake (Figure 6-18). Mean condition was statistically higher in 2008 compared to all other years, and statistically lower in 2010, 2011, and 2012 compared to all other years in Southern Indian Lake – Area 4 (Figure 6-18). Data are insufficient to determine if a long-term trend is occurring.

In Gauer Lake, mean condition was statistically lower in 2010 than in all other years, but was relatively similar for each other year of study. No increasing or decreasing trend in Lake Whitefish condition was apparent in Gauer Lake (Figure 6-18). There were an insufficient number of years with large enough sample sizes to conduct statistical analyses or assess temporal trends for Lake Whitefish in Granville Lake.

### Northern Pike

The annual mean condition of Northern Pike in Southern Indian Lake – Area 4 was relatively consistent over the 6-year sampling period (ranging from 0.65 in 2009 to 0.67 in 2011), except in 2010 when the mean condition was significantly higher (0.71; Figure 6-19). There were no significant inter-annual differences in the condition of Northern Pike in Granville or Gauer lakes and no indication of trends (Figure 6-19).

### Walleye

The condition of Walleye in Southern Indian Lake – Area 4 was 1.19 in 2012 and 1.20 in 2013; the only two years in which greater than 20 Walleye were captured (Figure 6-16). There were insufficient data to conduct statistical analyses or assess temporal trends for Southern Indian Lake – Area 4.

Over the six-year period, the condition of fish in Gauer Lake showed a gradual increase from 2008-2010 (1.11 in all three years) to 2012 and 2013 (1.16 in both years), and the differences were statistically significant (Figure 6-20). In Granville Lake, mean condition (1.09-1.16) was significantly highest in 2011 and no trends were apparent for this lake (Figure 6-20).

### White Sucker

There were an insufficient number of years with large enough sample sizes to conduct statistical analyses or assess temporal trends for White Sucker condition in Southern Indian Lake – Area 4 (Figure 6-21).

In Gauer Lake, mean condition in 2010 was statistically lower than mean condition in 2012 and 2013, and there appeared to be a gradual increase in White Sucker condition over time, though data are insufficient to determine if this represents a true trend rather than inter-annual variability (Figure 6-21). The condition of White Sucker in Granville Lake decreased significantly from 1.60 in 2011 to 1.47 in 2013, and based on the available data, suggested a decreasing trend in condition over the latter half of the 6-year sampling period (Figure 6-21).

## 6.2.4 Growth (Length-at-age)

Changes in the age or size distribution of a fish population can be caused by changes in growth, adult mortality, or recruitment success. The study of growth is the determination of body length as a function of age. Growth rates will differ for each species, and within a species, successive cohorts may grow differently depending on environmental conditions. Growth was characterized from length–at-age and focused on the length distribution of fish of a given age-class selected for each species based on the following:

- when the species was large enough to be recruited into the gear;
- young enough to be prior to, or at, the age of first maturity; and
- enough fish in the year class to be able to conduct statistical analyses.

#### *6.2.4.1 Upper Churchill River Region*

Lake Whitefish

Lake Whitefish in Southern Indian Lake – Area 4 ranged from 2-20 years of age, with the majority of fish aged between 5 and 15 years (Figure 6-22). Growth was slow in the first few years, and increased between 6 and 9 years when mean fork length increased from 244 mm at age 6 to 299 mm at age 9. Mean fork length calculated for fish older than nine years increased consistently, though marginally, in each year until age 17-18 (range of 327 mm at age 10 to a maximum mean fork length of 418 mm at age 19; Figure 6-22).

Both length-at-age 4 and length-at-age 5 varied considerably between on-system sites. Size-at-age (age 4 and 5) was lowest in Southern Indian Lake – Area 4 (219 and 229 mm, respectively) and highest in Southern Indian Lake – Area 6 (314 and 368 mm, respectively; Figures 6-23 and 6-24) although in some cases results were based on very small sample sizes.

Northern Pike

Northern Pike in Southern Indian Lake – Area 4 ranged from 2-17 years of age, with the majority of fish aged between 6 and 11 years (Figure 6-25). Growth appeared to be slow and linear across years, steadily increasing almost every year until maximum mean length reached 722 mm at the maximum age of 17 (Figure 6-25).

Like Lake Whitefish, four-year-old pike were shorter in Southern Indian Lake – Area 4 (mean length-at-age 4 of 422 mm) than Southern Indian Lake – Area 6 (mean length-at-age 4 of 496 mm; Figure 6-26). Too few Northern Pike were captured at the other on-system sites to warrant analysis.

Walleye

Walleye in Southern Indian Lake – Area 4 ranged from 2-15 years of age, with the majority of fish aged between 4 and 10 years (Figure 6-27). Growth appeared to be fairly rapid during the early years, with mean length at age increasing from 225 mm at age 2 to 437 mm at age 9. After age 9, growth jumped to 482 mm at age 10, but then plateaued until maximum mean length reached 536 mm at age 15 (Figure 6-27).

Small sample sizes precluded detailed analysis of Walleye growth, using the length-at-age 3 metric, for the on-system sites.

#### *6.2.4.2 Off-system Waterbodies: Granville and Gauer Lakes*

Lake Whitefish

Lake Whitefish in Granville Lake ranged from 2 to 18 years of age with the majority of fish aged between 2 and 8 years, while Lake Whitefish in Gauer Lake ranged from 1 to 30 years of age with the majority of fish aged between 3 and 11 years (Figure 6-22). Lake Whitefish grew faster and were consistently larger at a given age in Granville Lake compared to Gauer Lake. This faster rate of growth observed in Granville Lake appeared to slow after age 9, after which mean fork length fluctuated between 431 mm at age 10 to 504 mm at age 18. Growth was slower in Gauer Lake, but the number of older fish and maximum age (30 years) in Gauer Lake was considerably higher than in Granville Lake (18 years) and in Southern Indian Lake – Area 4 (20 years). Maximum mean size (506 mm) was not attained in Gauer Lake until 21 years-of-age versus Granville Lake where maximum mean size (504 mm) was attained at 18 years-of-age.

Based on a comparison of inter-quartile ranges, age 4 and 5 Lake Whitefish in Granville Lake (290 mm and 317 mm, respectively) and Gauer Lake (272 mm and 304 mm, respectively) were larger than whitefish from Southern Indian Lake – Area 4, and smaller than fish from Southern Indian Lake – Area 6 (Figures 6-23 and 6-24).

Northern Pike

Northern Pike in Granville Lake ranged from 2-14 years of age, with the majority of fish aged between 3 and 10 years (Figure 6-25). Growth appeared to be slow and uniform (linear) from age 2, when mean fork length equalled 400 mm, to age 10 when maximum mean fork length equalled 695 mm.

Northern Pike in Gauer Lake ranged from 0-16 years, with the majority of fish aged between 3 and 10 years (Figure 6-25). Northern Pike in Gauer Lake also grew at a uniform rate from a mean length of 135 mm at age 0 to a maximum mean length of 1024 mm at age 16. Although younger Northern Pike (i.e., 2-4 years) appear to be smaller and grow at a slower rate in Gauer Lake compared to Granville Lake and Southern Indian Lake – Area 4, older (4+) pike in Gauer Lake appear to be larger and grow at a faster rate compared to the pike populations from the other two annual sites (Figure 6-25).

The length-at-age 4 of Northern Pike in Granville (457 mm) and Gauer (444 mm) lakes was within the range observed in the on-system lakes where sufficient data were available for comparison (Figure 6-26).

Walleye

Walleye in Granville Lake ranged from 2 to 18 years of age with the majority of fish aged between 3 and 11 years, while Walleye in Gauer Lake ranged from 1 to 19 years of age with the majority of fish aged between 4 and 15 years (Figure 6-27). Considerably more fish greater than 10 years of age were caught in Gauer Lake (n = 332) compared to Granville Lake (n = 81).

Walleye in Granville Lake increased from a mean length of 216 mm at age 2 to 437 mm at age 11, after which growth appeared to slow considerably (Figure 6-27). In comparison, Walleye in Gauer Lake increased from a mean length of 132 mm at age 1 to 453 mm at age 13 after which mean length-at-age ranged from 446 mm to 484 mm. Similar to what was observed for Northern Pike, younger Walleye (approximately 2-11 years of age) in Granville Lake were longer-at-age and grew at a faster rate than Walleye in Gauer Lake. However, older (12+) Walleye in Gauer Lake were larger and grew at a faster rate compared to Walleye in Granville Lake (Figure 6-27).

The mean length-at-age 3 was calculated to be 248 mm for Walleye in Granville Lake and 235 mm in Gauer Lake (Figure 6-28). A comparison to the on-system waterbodies was not possible as insufficient numbers of 3-year-old Walleye were obtained for the on-system waterbodies.

#### *6.2.4.3 Temporal Comparisons and Trends*

Lake Whitefish

The annual mean length-at-age of Lake Whitefish in Southern Indian Lake – Area 4, the on-system site that was monitored annually, ranged from 196 mm in 2011 to 244 mm in 2012 for 4 year olds and 226 mm in 2012 to 230 mm in 2013 for 5 year olds (Figures 6-23 and 6-24). Age 4 Lake Whitefish in Southern Indian Lake – Area 4 were statistically shorter in 2011 compared to 2012 (Figure 6-29). There were no significant differences in mean length among years for age 5 Lake Whitefish in Southern Indian Lake – Area 4 (Figure 6-30). Based on the available data, no increasing or decreasing trends in length at age 4 or 5 for Lake Whitefish in Southern Indian Lake – Area 4 were apparent.

There were no statistical differences in the length-at-age of either 4- or 5-year-old fish among years in Granville Lake or Gauer Lake (Figures 6-29 and 6-30). No increasing or decreasing trends were apparent in length-at-age 4 or 5 for Lake Whitefish in Gauer Lake and in Granville Lake.

Northern Pike

An insufficient number of 4-year-old Northern Pike were captured in 2008-2010 to calculate length-at-age in Southern Indian Lake – Area 4, the on-system waterbody that was monitored annually. There has been some variation in the annual mean length-at-age 4 of Northern Pike in Southern Indian Lake – Area 4 since 2010 (Figure 6-26). The length-at-age increased over this period, ranging from 399 mm in 2011 to 451 mm in 2013. However, the difference in length of 4 year olds among years was not statistically significant (Figure 6-31).

The fork length-at-age 4 for Northern Pike in the off-system lakes showed a similar range of inter-annual variation as in the on-system waterbody over the 6-year sampling period (Figure 6-26). Four year olds in Granville Lake ranged from an average of 414 mm in 2009 to 485 mm in 2012, and four year olds in Gauer Lake ranged from an average of 390 mm in 2012 to 484 mm in 2008 (Figure 6-26). Length-at-age 4 was not statistically different between years in Granville Lake, whereas length-at-age 4 was statistically lower in Gauer Lake in 2012 than in 2008, 2010, and 2013 (Figure 6-31). There was no indication of an increasing trend in Northern Pike fork length-at-age 4 in Granville or Gauer lakes (Figure 6-31).

Walleye

There were an insufficient number of 3-year-old Walleye captured in Southern Indian Lake – Area 4 and Gauer Lake to facilitate an analysis of inter-annual differences or temporal trends. There was no statistical difference in Walleye length-at-age 3 between years in Granville Lake, nor was there an increasing or decreasing trend apparent, for the years with sufficient data for analysis (i.e., 2008, 2010, and 2012-2013; Figure 6-32).

## 6.3 ADDITIONAL METRICS AND OBSERVATIONS OF NOTE

The other fish community metric measured under CAMP, as described in Technical Document 1, Section 4.6, that was reviewed to assess trends was relative abundance. The relative abundance of fish species captured in standard gang index gill nets was assessed to provide information on the overall composition of the fish community (Figure 6-33). This metric was assessed because the analyses conducted for RCEA on a longer term dataset indicated that a shift in species composition may have occurred in several hydro-affected waterbodies over time (Manitoba Hydro and the Province of Manitoba 2015). Catches in the off-system Granville Lake and on-system Opachuanau Lake, both located upstream of Southern Indian Lake, consisted primarily of White Sucker, followed by considerably lower catches of Sauger and Walleye

(Figure 6-33). The species composition in Areas 1, 4, and 6 of Southern Indian Lake differed somewhat from these upstream waterbodies in that Lake Whitefish and Cisco were typically more abundant. There were some differences in species composition among areas: White Sucker and Burbot (*Lota lota*) were common in Southern Indian Lake – Area 1; Sauger were abundant in Southern Indian Lake – Area 6; and Longnose Sucker were common in Southern Indian Lake – Area 4. Catches in Gauer Lake, the second off-system waterbody, consisted primarily of White Sucker, Lake Whitefish and Walleye, and contained fewer Cisco than catches in Southern Indian Lake.

## 6.4 RELATIONSHIPS WITH HYDROLOGICAL METRICS

While it is recognized that fish community indicators/metrics are influenced by many abiotic and biotic variables (e.g., water quality, water levels and flows, habitat quantity and quality, benthos production, and predator/prey interactions), relationships between hydrological variables and fish community metrics were examined, where potential linkages were considered meaningful, as defined by the terms of reference for this report. These analyses are considered to be exploratory in nature. In addition, it is cautioned that identification of significant correlations between fish community metrics and hydrological variables does not infer a causal relationship.

A quantitative consideration of hydrological conditions (using water level data from a gauge on Southern Indian Lake near the community of South Indian Lake and discharge data from the Churchill River above Granville Falls provided by Manitoba Hydro) and fish community metrics indicated some statistically significant relationships between CPUE and discharge and/or water level during the sampling period for Southern Indian Lake – Area 4 (Table 6-4). No statistically significant relationships were found for fish condition and discharge and/or water level during the open-water period at Southern Indian Lake – Area 4.

While water levels were generally typical for much of the 2008-2013 period, water levels increased earlier than normal in the spring of 2012, and later than normal in the spring of 2008 and 2011 (see Section 2.0 for details).

The relatively large 2008 Northern Pike catch in Southern Indian Lake – Area 4 was coincident with the lowest water levels during the sampling period for the six-year period of record (Figure 6-34). Similarly, a significant negative relationship between water level during the sampling period and Northern Pike and total CPUE was observed (Table 6-4, Figure 6-34). The total CPUE vs. water level relationship was likely influenced by the negative relationship between Northern Pike CPUE and water level in Southern Indian Lake – Area 4.

Gear effectiveness typically decreases with increasing discharge and/or water level. However, there was at least one additional factor that may, at least in part, have contributed to the notably higher catches of Lake Whitefish and Northern Pike and total CPUEs in 2008. The fish community monitoring program was conducted earlier (last week of July) in 2008 than all other years (sampling dates varied from August 6 to September 23 in the remaining years).

## 6.5 SUMMARY

A number of spatial differences were noted across locations in the UCRR including:

- Hill's effective species richness in Southern Indian Lake – Area 1 was higher than that of all other on-system waterbodies. The higher calculated Hill's value in Southern Indian Lake – Area 1 was a result of both a higher number of species, and more even relative abundances between species.
- The abundance of fish captured in standard gang index gill nets was higher in Opachuanau Lake (though only one year of data are available) and Southern Indian Lake – Area 4 (50 to 60 fish/100 m/24 h) compared to Areas 1 and 6 (about 40 fish/100 m/24 h). There were differences in the abundance of large-bodied species among on-system sites: White Sucker were the dominant species in Opachuanau Lake, Lake Whitefish and Cisco were relatively abundant in all areas of Southern Indian Lake, Sauger were abundant in Southern Indian Lake – Area 6, and Longnose Sucker were the most commonly captured species in Southern Indian Lake – Area 4.
- The mean condition of Lake Whitefish was lower in Southern Indian Lake – Area 4 (1.31) than in all other on-system locations within the UCRR (1.53 to 1.65). Likewise, the condition of White Sucker (1.49) was somewhat lower in Southern Indian Lake – Area 4 compared to the other on-system locations (1.56-1.64). Northern Pike and Walleye generally had similar condition factors throughout the region (0.65-0.67 and 1.08-1.20, respectively).
- The fork lengths of 4- and 5-year-old Lake Whitefish were considerably lower in Area 4 of Southern Indian Lake (219 and 229 mm, respectively) compared to all other on-system locations (257-318 mm and 314-368 mm). Very few 4-year old Northern Pike and 3-year old Walleye were captured in the region which limited the detailed analyses that could be undertaken.

Analysis of the six years of data revealed a number of temporal trends or substantive inter-annual variability for the fish community metrics. A gradual increase in Hill's effective species richness over time was observed in Southern Indian Lake – Area 4, and appears to be a result of an increase in the number of species captured in the waterbody over time. In contrast, a gradual decrease in the Hill's number was observed in Gauer Lake over time, which appears to be a result of one or a combination of: (1) a slight decrease in the number of species captured in the area over time, and/or (2) an increase in the number of Walleye and a decrease in the number of Lake Whitefish (especially in 2013) captured.

With the exception of Southern Indian Lake – Area 4, total CPUE values remained relatively consistent over the six year period. Total CPUE, Northern Pike CPUE, and Lake Whitefish CPUE were highest in 2008 in this area. Whether this reflects an actual trend, versus substantive short-term inter-annual variability, is not known. In contrast to Area 4, total CPUE values in Gauer Lake have remained relatively high and may have increased slightly since 2008.

Analysis of the six years of data did not reveal any obvious trends in Northern Pike, Walleye or White Sucker condition over the 2008-2013 period. Similarly, no obvious trends in Lake Whitefish, Northern Pike, or Walleye length-at-age were observed over the 2008-2013 period.

Significant correlations were observed between hydrological variables and some fish community metrics. Total CPUE, as well as CPUE for Northern Pike, showed a negative relationship with water levels at Southern Indian Lake – Area 4. The relationships between water level and total and Northern Pike CPUE were largely driven by the relatively large Northern Pike catch in 2008 which coincided with a relatively low water level during the period of sampling.

Table 6-1. Inventory of fish community sampling completed in the UCRR: 2008-2013.

| **Location** | **Site Abbreviation** | **On-system** | **Off-system** | **Annual** | **Rotational** | **Sampling Years** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** |
| Granville Lake | GRV | | X | X | | X | X | X | X | X | X |
| Opachuanau Lake | OPACH | X | | | X | | | | X | | |
| Southern Indian Lake – Area 1 | SIL-1 | X | | | X | | X | | | X | |
| Southern Indian Lake – Area 6 | SIL-6 | X | | | X | | | X | | | X |
| Southern Indian Lake – Area 4 | SIL-4 | X | | X | | X | X | X | X | X | X |
| Gauer Lake[1] | GAU | | X | X | | X | X | X | X | X | X |

[1] Site formally included in the LCRR; included here for discussion of results.

Table 6-2. Fish species captured in standard gang index and small mesh index gill nets set in Upper Churchill River Region waterbodies, 2008-2013.

| **Species** | **Species Abbreviation** | **GRV ($n_Y$ = 6)** | **OPACH ($n_Y$ = 1)** | **SIL-1 ($n_Y$ = 2)** | **SIL-6 ($n_Y$ = 2)** | **SIL-4 ($n_Y$ = 6)** | **GAU ($n_Y$ = 6)** |
|---|---|---|---|---|---|---|---|
| Lake Chub | LKCH | | | | | | X* |
| Northern Pearl Dace | NPDC | | | | | | X* |
| Emerald Shiner | EMSH | X | X | X* | X | X* | X |
| Spottail Shiner | SPSH | X | X | | X | X* | X |
| Longnose Sucker | LNSC | X | X | X | X | X | X |
| White Sucker | WHSC | X | X | X | X | X | X |
| Shorthead Redhorse | SHRD | X | | | | | |
| Northern Pike | NRPK | X | X | X | X | X | X |
| Cisco | CISC | X | X | X | X | X | X |
| Lake Whitefish | LKWH | X | X | X | X | X | X |
| Trout-perch | TRPR | X | X | X | X | X | X |
| Burbot | BURB | X | X | X | X | X | X |
| Mottled Sculpin | MTSC | | | | | X* | |
| Slimey Sculpin | SLSC | X* | | X* | | X* | |
| Spoonhead Sculpin | SPSC | | | | | X* | |
| Yellow Perch | YLPR | X | X | X | X | X* | X |
| Log Perch | LGPR | X* | | X* | | | X* |
| Sauger | SAUG | X | X | X | X | X | |
| Walleye | WALL | X | X | X | X | X | X |

*species is observed infrequently in catches (i.e., in fewer than 80% of sampling years).
$n_Y$ = number of years sampled.

Table 6-3. Summary of fish community metrics, including Hill's index, catch-per-unit-effort (CPUE), Fulton's condition factor ($K_F$), and fork length-at-age (mm), calculated for Upper Churchill River Region waterbodies: 2008-2013.

| Component | Waterbody | Hills Index | | | CPUE[1] | | | $K_F$[2] | | | FL-at-age[3] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $n_Y$ | Mean | SE | $n_F$ | Mean | SE | $n_F$ | Mean | SE | $n_F$ | Mean | SE |
| Biodiversity | GRV | 6 | 5.9 | 0.23 | - | - | - | - | - | - | - | - | - |
| | OPACH | 1 | 5.6 | - | - | - | - | - | - | - | - | - | - |
| | SIL-1 | 2 | 7.7 | 0.02 | - | - | - | - | - | - | - | - | - |
| | SIL-6 | 2 | 6.1 | 0.35 | - | - | - | - | - | - | - | - | - |
| | SIL-4 | 6 | 5.3 | 0.26 | - | - | - | - | - | - | - | - | - |
| | GAU | 6 | 7.7 | 0.15 | - | - | - | - | - | - | - | - | - |
| Standard gang | GRV | - | - | - | 5673 | 78.2 | 8.8 | - | - | - | - | - | - |
| | OPACH | - | - | - | 796 | 63.4 | 18.1 | - | - | - | - | - | - |
| | SIL-1 | - | - | - | 895 | 39.5 | 65.9 | - | - | - | - | - | - |
| | SIL-6 | - | - | - | 1031 | 41.5 | 52.8 | - | - | - | - | - | - |
| | SIL-4 | - | - | - | 7977 | 53.6 | 16.0 | - | - | - | - | - | - |
| | GAU | - | - | - | 4710 | 80.4 | 16.1 | - | - | - | - | - | - |
| Small mesh | GRV | - | - | - | 1653 | 84.8 | 19.6 | - | - | - | - | - | - |
| | OPACH | - | - | - | 135 | 37.2 | 52.8 | - | - | - | - | - | - |
| | SIL-1 | - | - | - | 52 | 7.3 | 29.1 | - | - | - | - | - | - |
| | SIL-6 | - | - | - | 711 | 96.7 | 395.8 | - | - | - | - | - | - |
| | SIL-4 | - | - | - | 604 | 16.1 | 9.1 | - | - | - | - | - | - |
| | GAU | - | - | - | 2343 | 133.7 | 41.2 | - | - | - | - | - | - |
| Lake Whitefish | GRV | - | - | - | 216 | 3.1 | 0.6 | 124 | 1.57 | 0.04 | 29 | 295 | 12 |
| | | | | | | | | | | | 27 | 336 | 12 |
| | OPACH | - | - | - | 78 | 5.9 | - | 59 | 1.53 | 0.01 | 4 | 257 | - |
| | | | | | | | | | | | 38 | 316 | - |
| | SIL-1 | - | - | - | 180 | 8.2 | 1.0 | 126 | 1.65 | 0.07 | 14 | 277 | 2 |
| | | | | | | | | | | | 17 | 308 | 0.25 |
| | SIL-6 | - | - | - | 90 | 3.6 | 0.9 | 50 | 1.56 | 0.01 | 19 | 314 | 3 |
| | | | | | | | | | | | 8 | 355 | 9 |
| | SIL-4 | - | - | - | 1882 | 13.0 | 3.0 | 1408 | 1.31 | 0.02 | 29 | 214 | 7 |
| | | | | | | | | | | | 75 | 227 | 4 |
| | GAU | - | - | - | 1085 | 18.4 | 2.1 | 787 | 1.50 | 0.02 | 107 | 272 | 4 |
| | | | | | | | | | | | 134 | 304 | 3 |
| Northern Pike | GRV | - | - | - | 252 | 3.4 | 0.3 | 185 | 0.68 | 0.01 | 26 | 457 | 11 |
| | OPACH | - | - | - | 6 | 0.5 | - | 6 | 0.64 | - | 2 | 443 | - |
| | SIL-1 | - | - | - | 72 | 3.3 | 0.7 | 66 | 0.65 | 0.01 | 2 | 480 | - |
| | SIL-6 | - | - | - | 67 | 2.7 | 0.4 | 67 | 0.66 | 0.01 | 6 | 459 | 26 |
| | SIL-4 | - | - | - | 678 | 4.5 | 0.6 | 463 | 0.67 | 0.01 | 20 | 433 | 10 |
| | GAU | - | - | - | 650 | 10.8 | 0.6 | 548 | 0.67 | 0.005 | 64 | 437 | 14 |
| Walleye | GRV | - | - | - | 623 | 8.8 | 2.2 | 528 | 1.13 | 0.01 | 28 | 244 | 5 |
| | OPACH | - | - | - | 47 | 3.8 | - | 40 | 1.16 | 0.02 | 1 | 150 | - |
| | SIL-1 | - | - | - | 44 | 1.8 | 0.4 | 45 | 1.12 | 0.04 | 1 | 204 | - |
| | SIL-6 | - | - | - | 13 | 0.5 | 0.1 | 10 | 1.07 | 0.03 | - | - | - |
| | SIL-4 | - | - | - | 80 | 0.7 | 0.2 | 72 | 1.21 | 0.02 | 1 | 292 | - |
| | GAU | - | - | - | 1109 | 19.2 | 3.0 | 999 | 1.13 | 0.01 | 13 | 221 | 4 |
| White Sucker | GRV | - | - | - | 3471 | 47.7 | 3.7 | 2060 | 1.55 | 0.03 | - | - | - |
| | OPACH | - | - | - | 505 | 40.6 | - | 473 | 1.58 | 0.01 | - | - | - |
| | SIL-1 | - | - | - | 151 | 6.1 | 2.6 | 106 | 1.56 | - | - | - | - |
| | SIL-6 | - | - | - | 78 | 3.1 | 0.2 | 71 | 1.64 | 0.04 | - | - | - |
| | SIL-4 | - | - | - | 100 | 0.6 | 0.2 | 59 | 1.49 | 0.02 | - | - | - |
| | GAU | - | - | - | 1247 | 21.4 | 1.8 | 730 | 1.53 | 0.01 | - | - | - |

[1] CPUE = fish/100 m/24 h except for small mesh gangs where it is fish/30 m/24 h

[2] Fork lengths analyzed for $K_F$ were 300-499 mm for Lake Whitefish, Walleye, and White Sucker, and 400-699 mm for Northern Pike

[3] Ages analyzed are 3 years for Walleye, 4 years for Northern Pike; 4 and 5 years for Lake Whitefish

$n_Y$ = number of years sampled

$n_F$ = number of fish: caught (CPUE), measured for length and weight ($K_F$), aged and measured for length-at-age

SE = standard error

Table 6-4. Significant results from linear regressions of fish community metrics (catch-per-unit-effort [CPUE] and Fulton's condition factor [$K_F$]) against hydrological metrics for Southern Indian Lake – Area 4 (2008 - 2013).

| Metric | Species | Waterbody | Hydrology Metric | df | F | p | $R^2$ | Direction |
|---|---|---|---|---|---|---|---|---|
| CPUE | NRPK | SIL-4 | WL (GN) | 4 | 15.83 | 0.02 | 0.80 | - |
| | Total | SIL-4 | WL (GN) | 4 | 16.66 | 0.02 | 0.81 | - |

WL (GN) = average water level (m ASL) during the gillnetting program

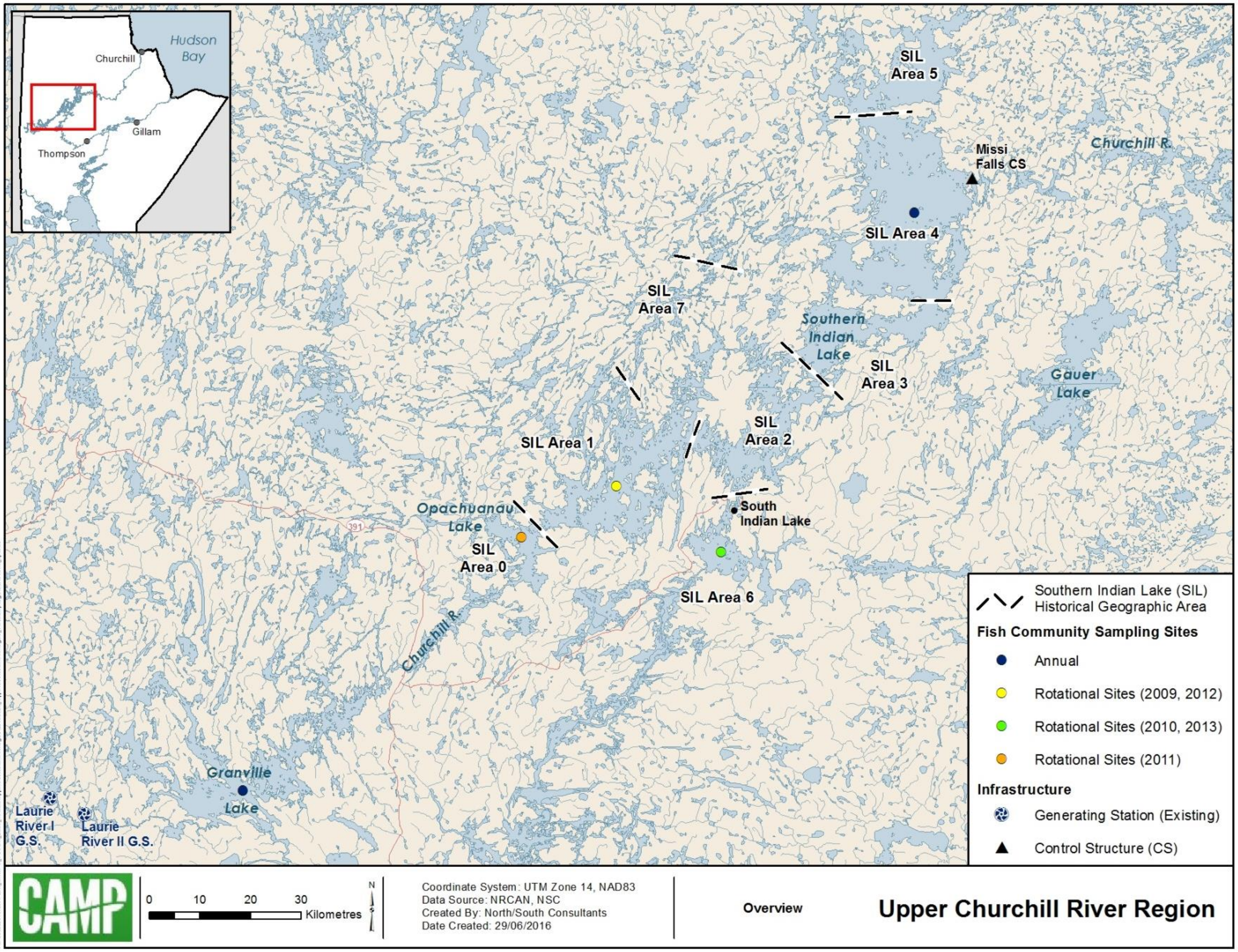



Figure 6-1. Waterbodies sampled in the Upper Churchill River Region: 2008-2013.

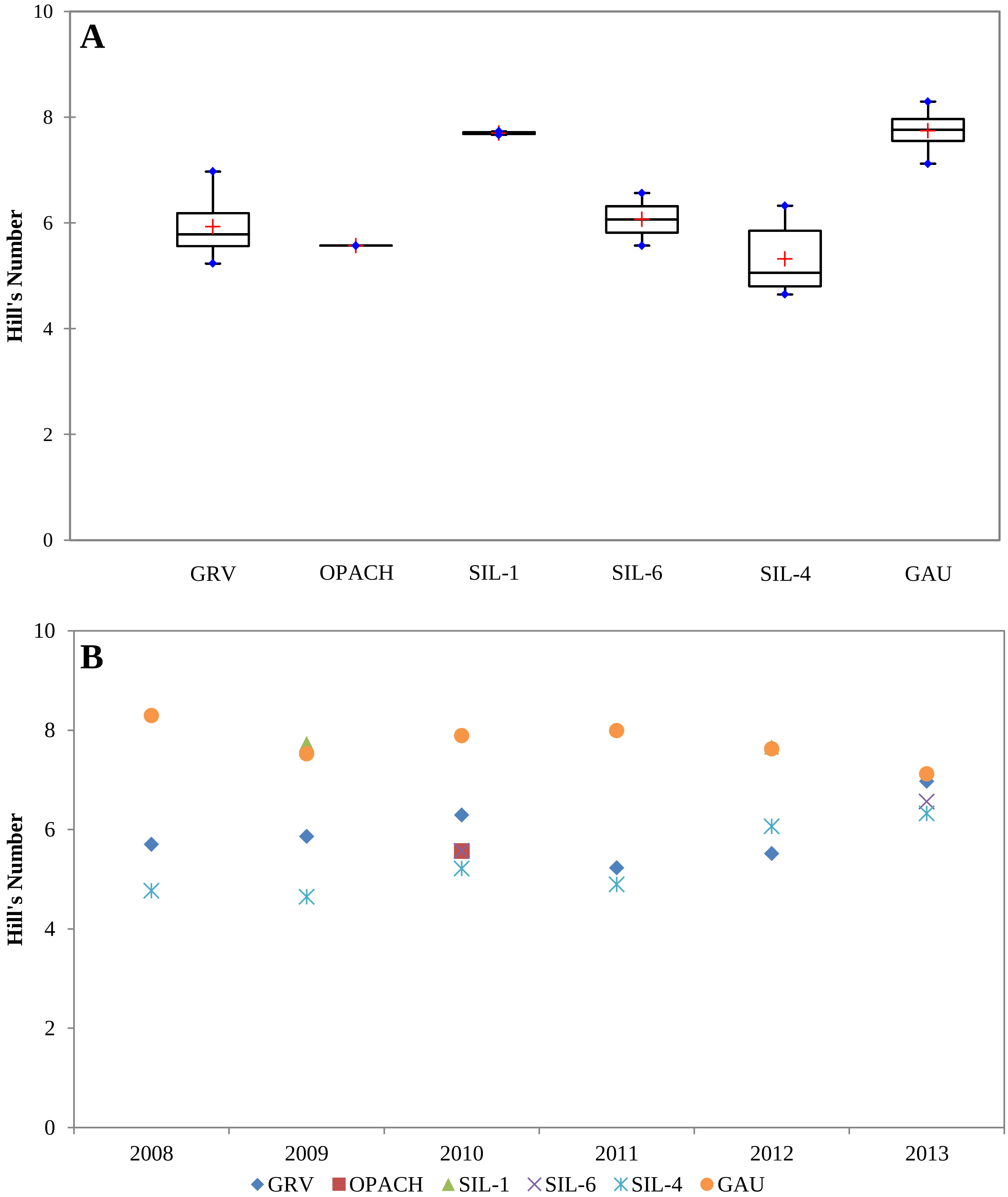



Figure 6-2. Annual mean Hill's effective species richness index (Hill number) for standard gang and small mesh index gill nets set in Upper Churchill River Region waterbodies, 2008-2013 by waterbody (A) and year (B).

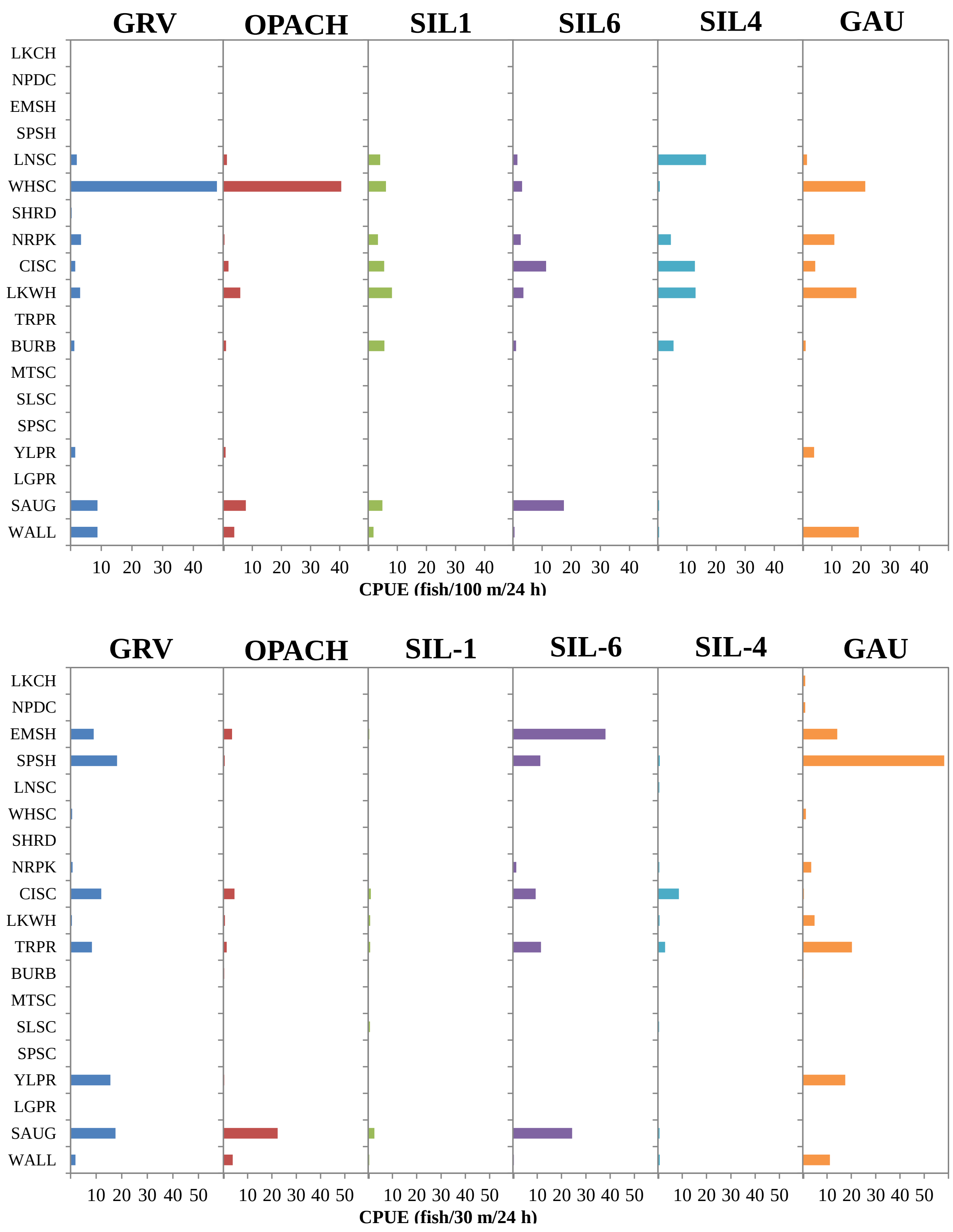



Figure 6-3. Mean catch-per-unit-effort in (A) standard gang (fish/100 m/24 h) and (B) small mesh (fish/30 m/24 h) index gill nets set in Upper Churchill River Region waterbodies, 2008-2013.

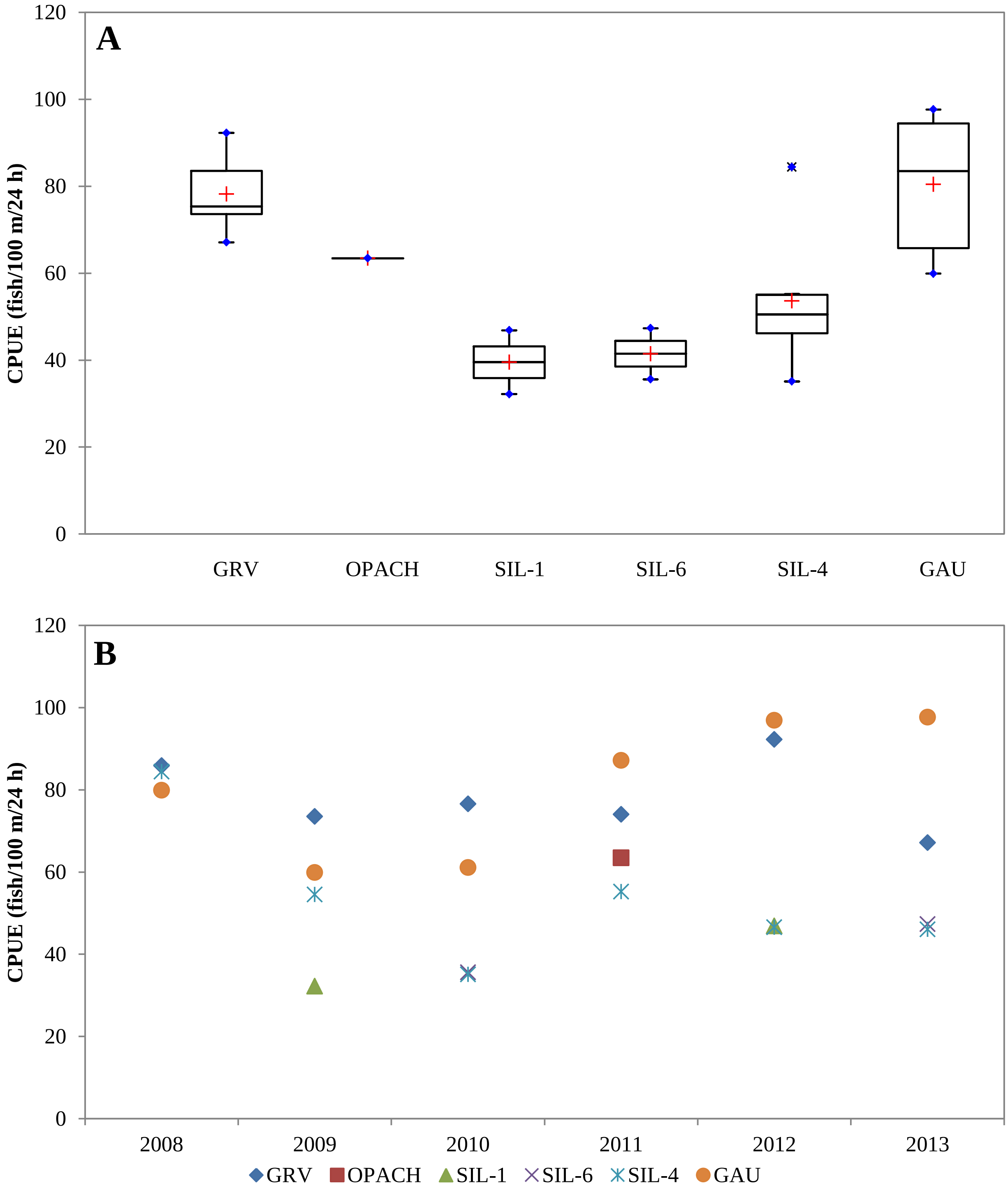



Figure 6-4. Annual mean catch-per-unit-effort (CPUE) calculated for the total catch in standard gang index gill nets set in Upper Churchill River Region waterbodies, 2008-2013 by waterbody (A) and by year (B).

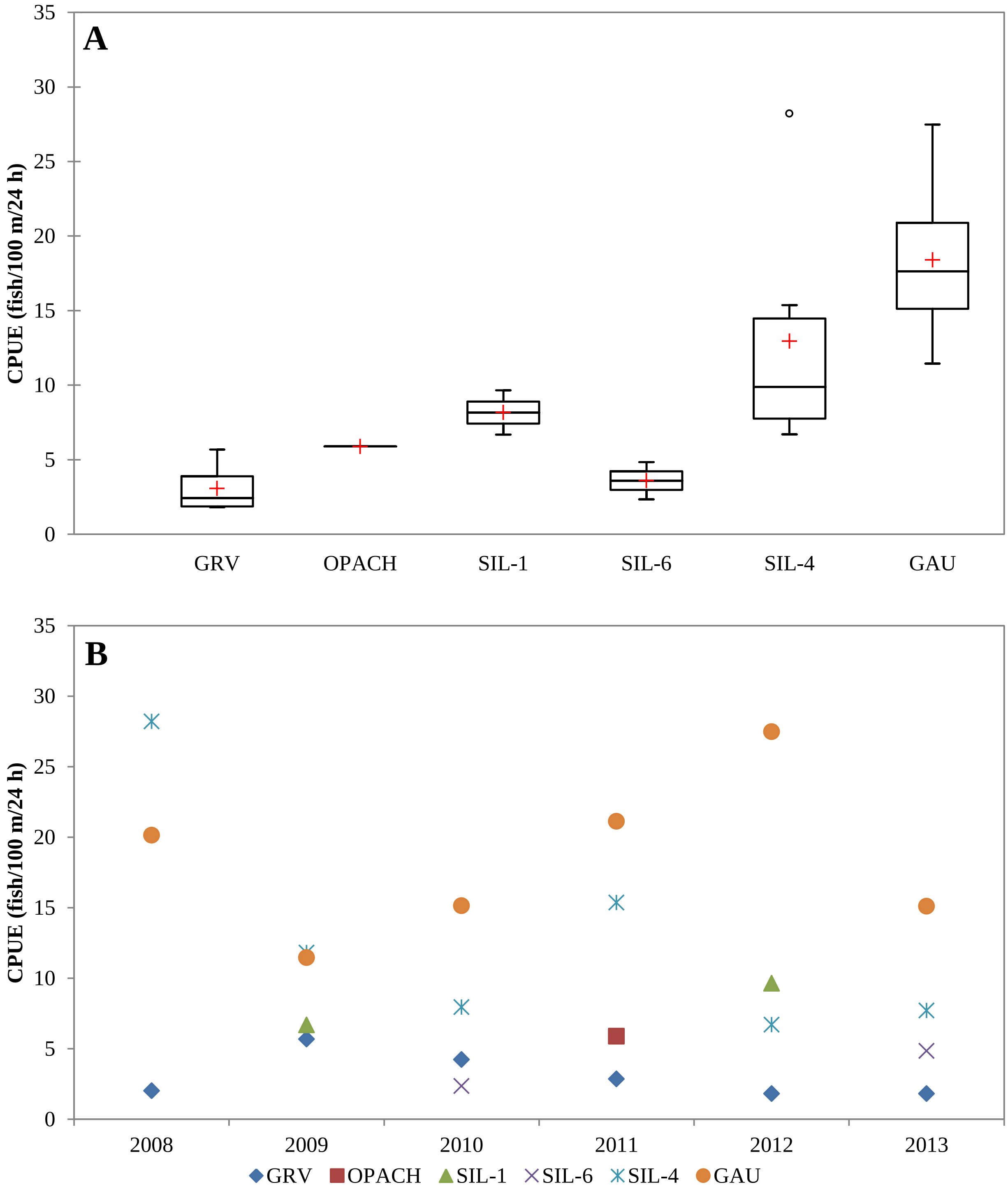



Figure 6-5. Annual mean catch-per-unit-effort (CPUE) calculated for Lake Whitefish captured in standard gang index gill nets set in Upper Churchill River Region waterbodies, 2008-2013 by waterbody (A) and by year (B).

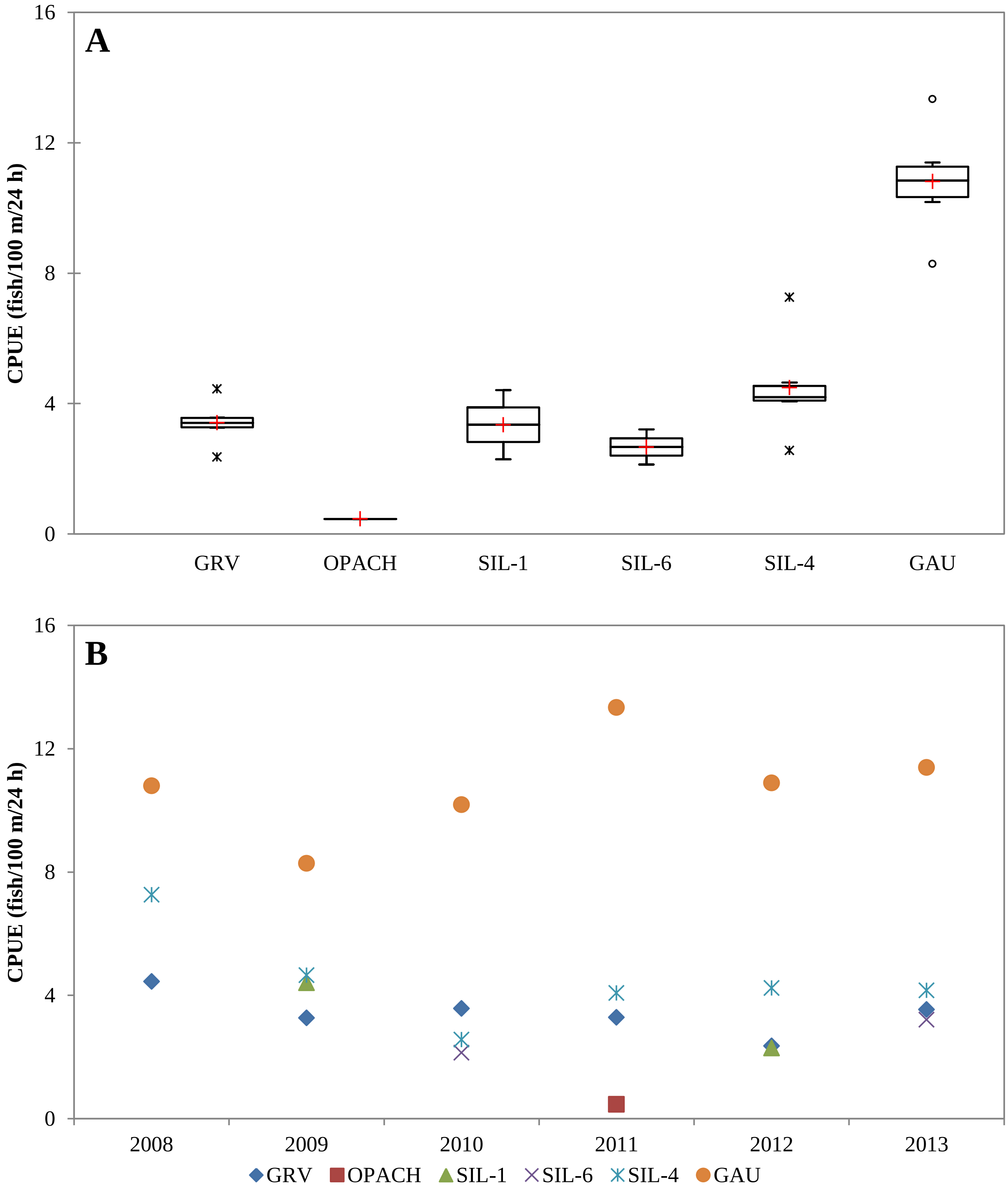



Figure 6-6. Annual mean catch-per-unit-effort (CPUE) calculated for Northern Pike captured in standard gang index gill nets set in Upper Churchill River Region waterbodies, 2008-2013 by waterbody (A) and by year (B).

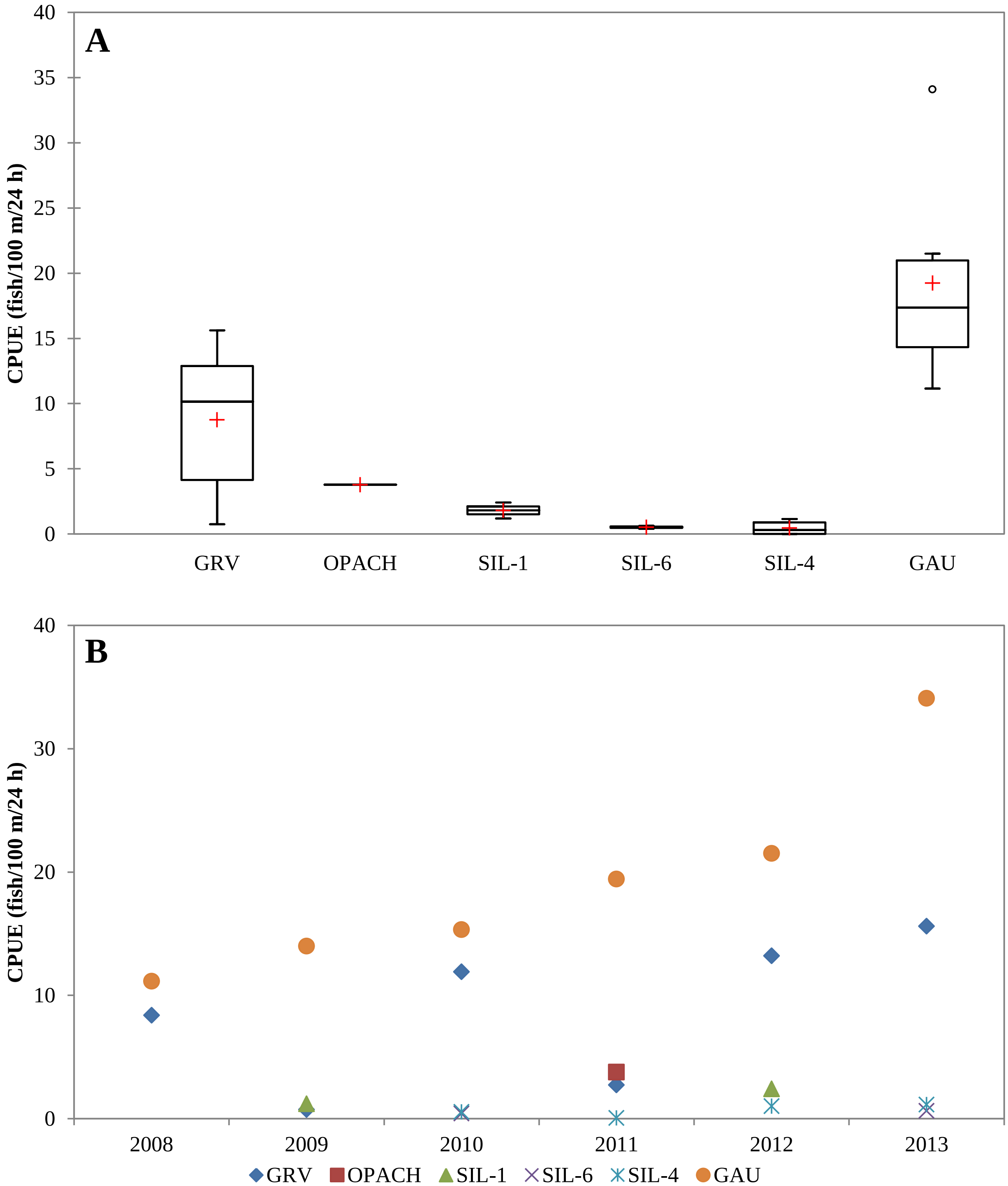



Figure 6-7. Annual mean catch-per-unit-effort (CPUE) calculated for Walleye captured in standard gang index gill nets set in Upper Churchill River Region waterbodies, 2008-2013 by waterbody (A) and by year (B).

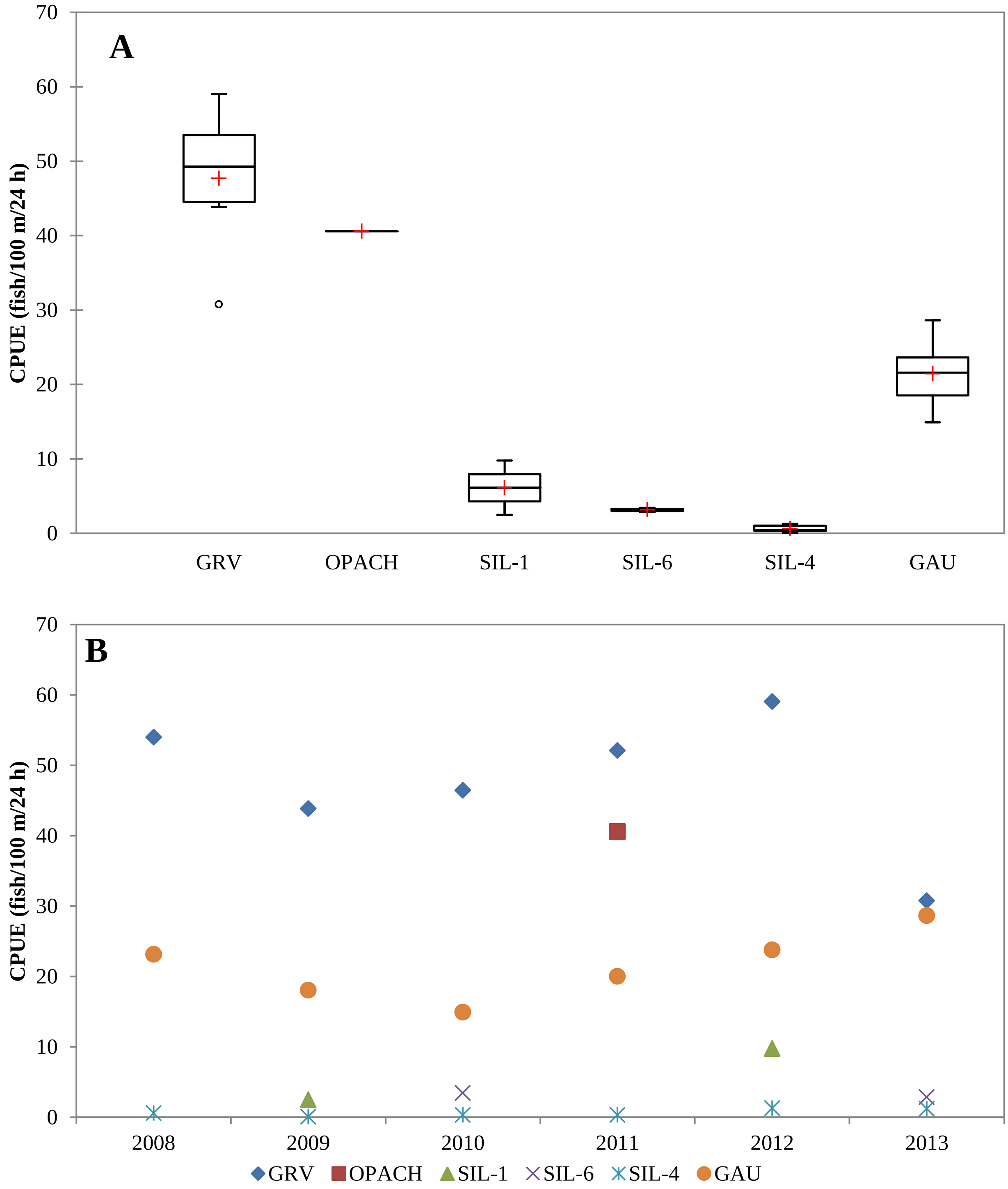



Figure 6-8. Annual mean catch-per-unit-effort (CPUE) calculated for White Sucker captured in standard gang index gill nets set in Lower Churchill River Region waterbodies, 2008-2013 by waterbody (A) and by year (B).

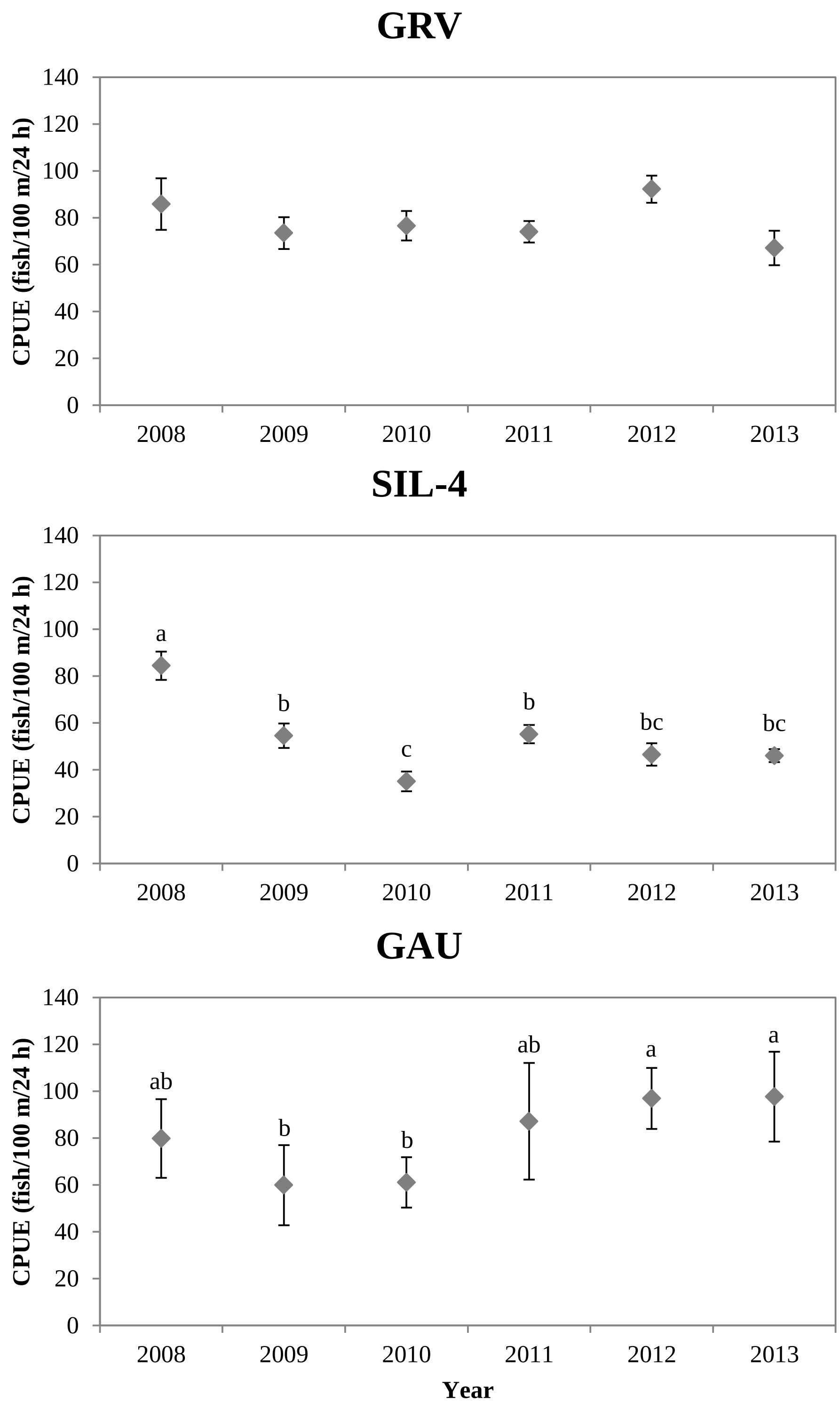



Figure 6-9. Total catch-per-unit-effort (CPUE; mean ± SE) in standard gang index gill nets set at annual on-system (SIL-4) and off-system (GRV and GAU) locations. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts, or lack of superscripts, denote no statistically significant difference.

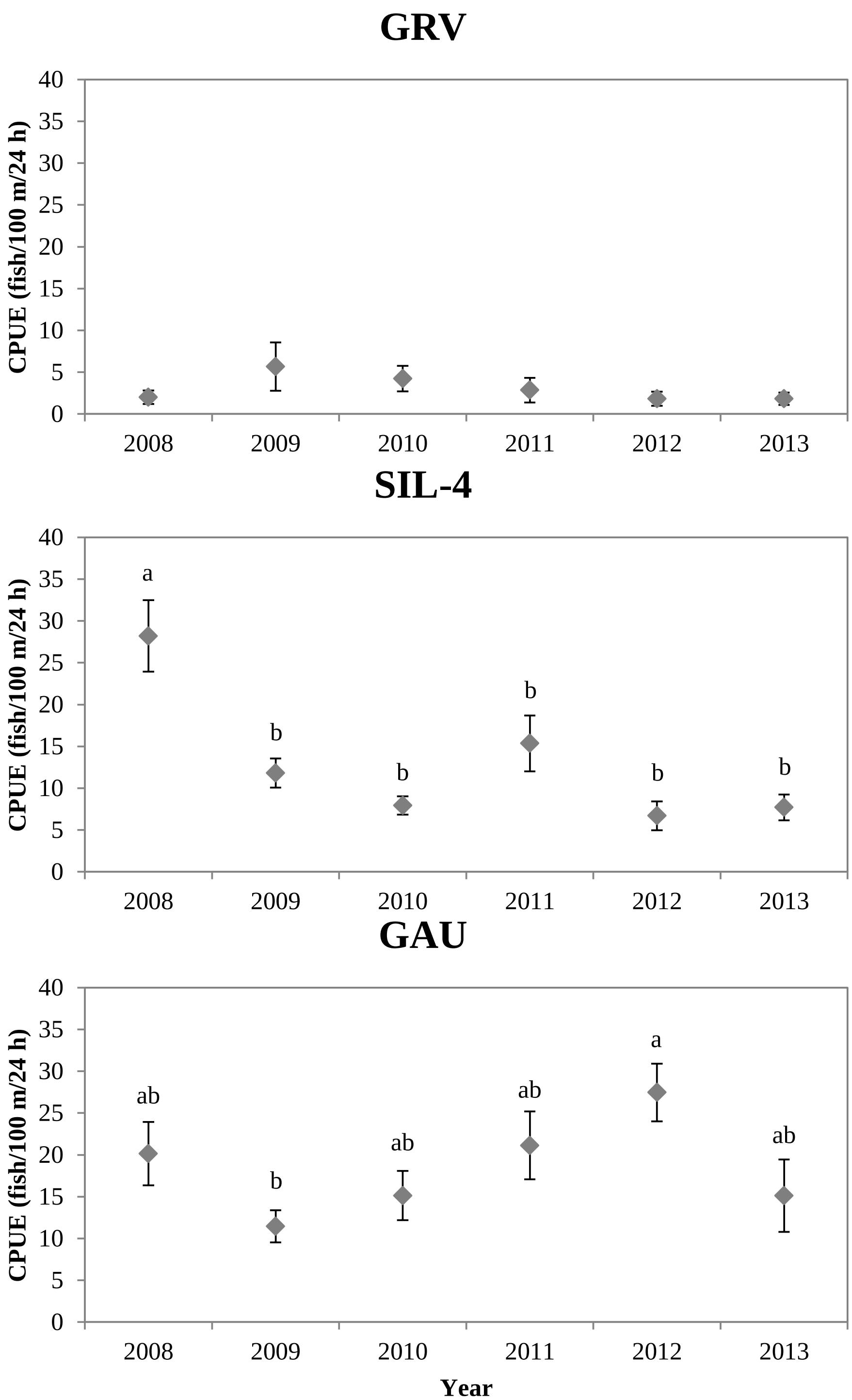



Figure 6-10. Lake Whitefish catch-per-unit-effort (CPUE; mean ± SE) in standard gang index gill nets set at annual on-system (SIL-4) and off-system (GRV and GAU) locations. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts, or lack of superscripts, denote no statistically significant difference.

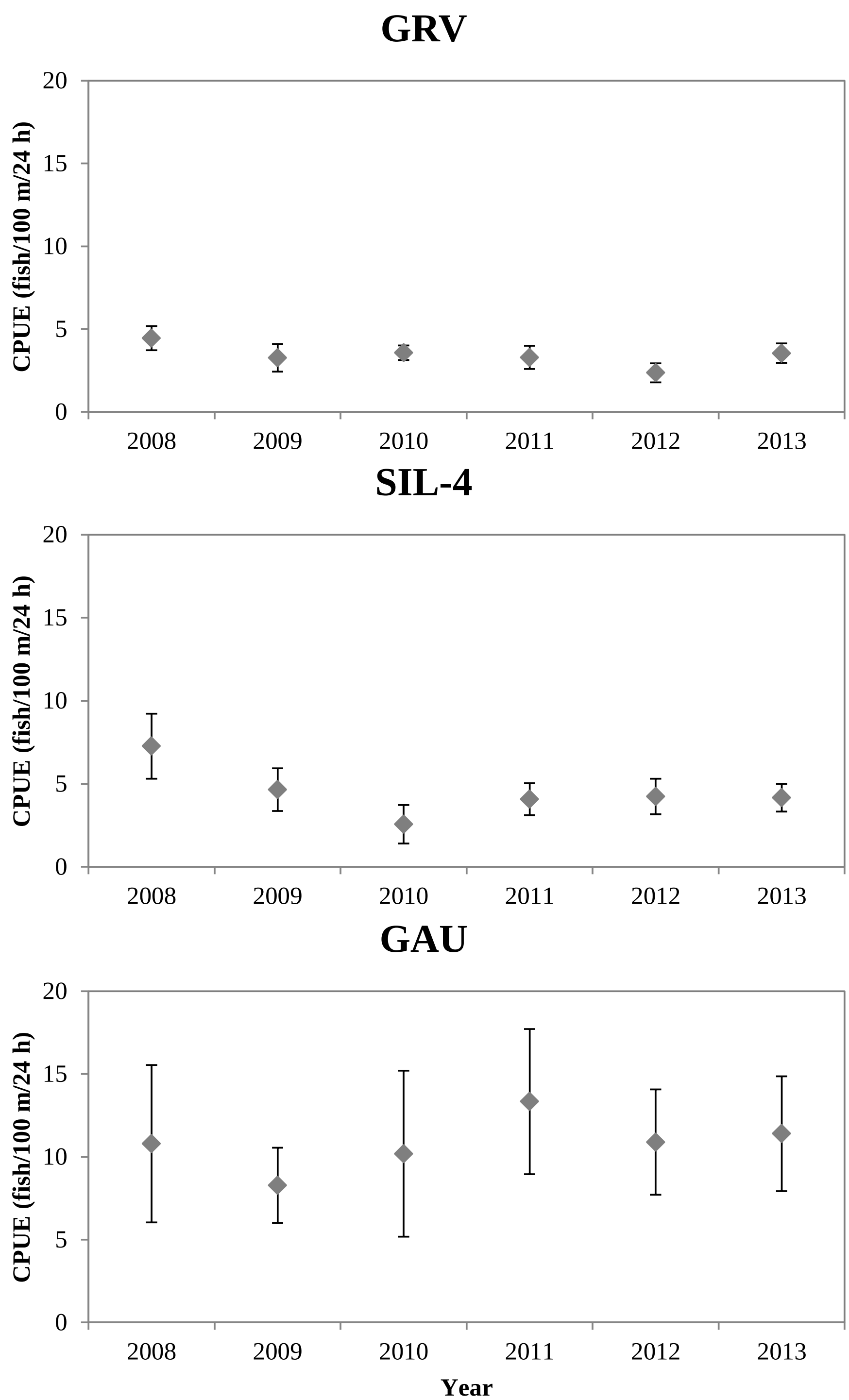



Figure 6-11. Northern Pike catch-per-unit-effort (CPUE; mean ± SE) in standard gang index gill nets set at annual on-system (SIL-4) and off-system (GRV and GAU) locations. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts, or lack of superscripts, denote no statistically significant difference.

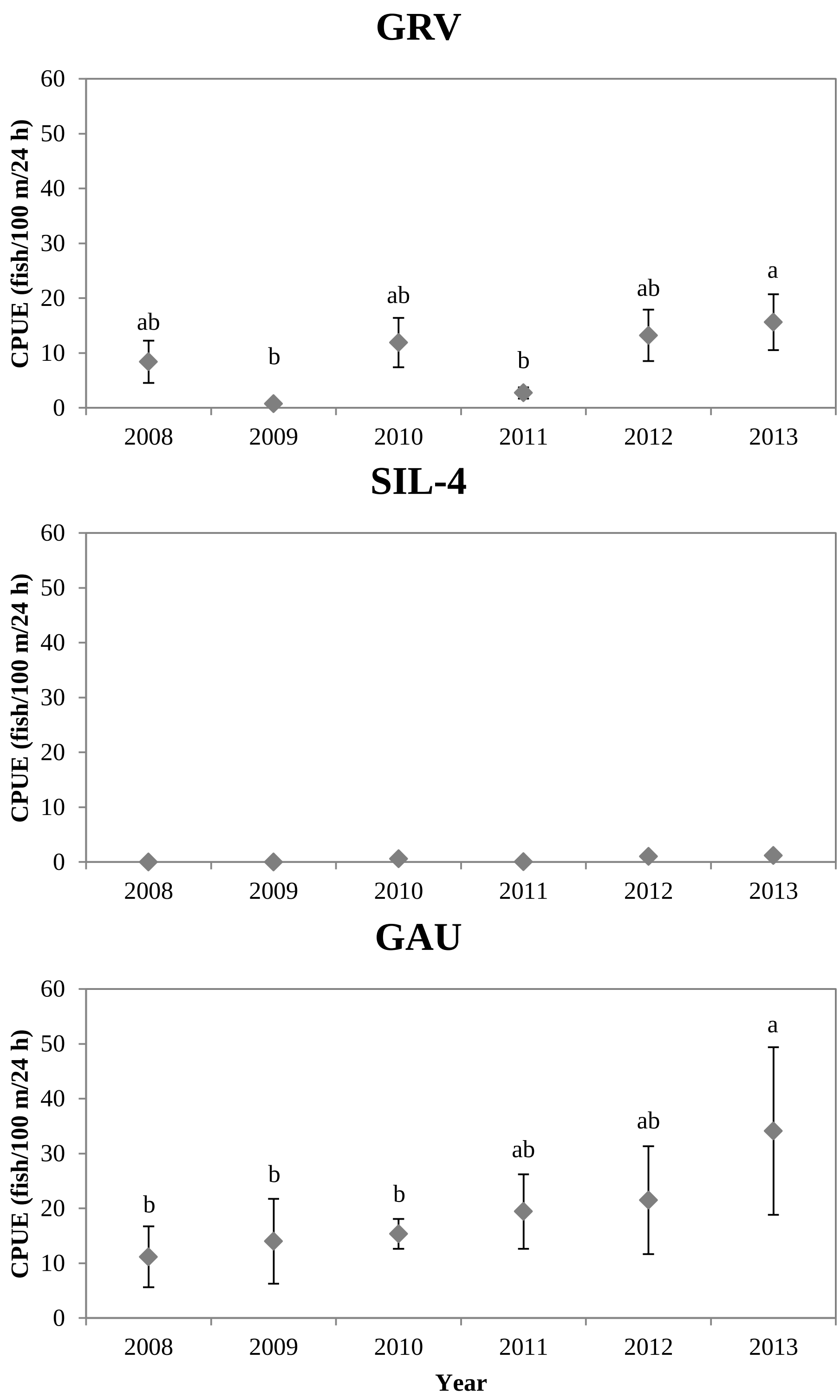



Figure 6-12. Walleye catch-per-unit-effort (CPUE; mean ± SE) in standard gang index gill nets set at annual on-system (SIL-4) and off-system (GRV and GAU) locations. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts, or lack of superscripts, denote no statistically significant difference.

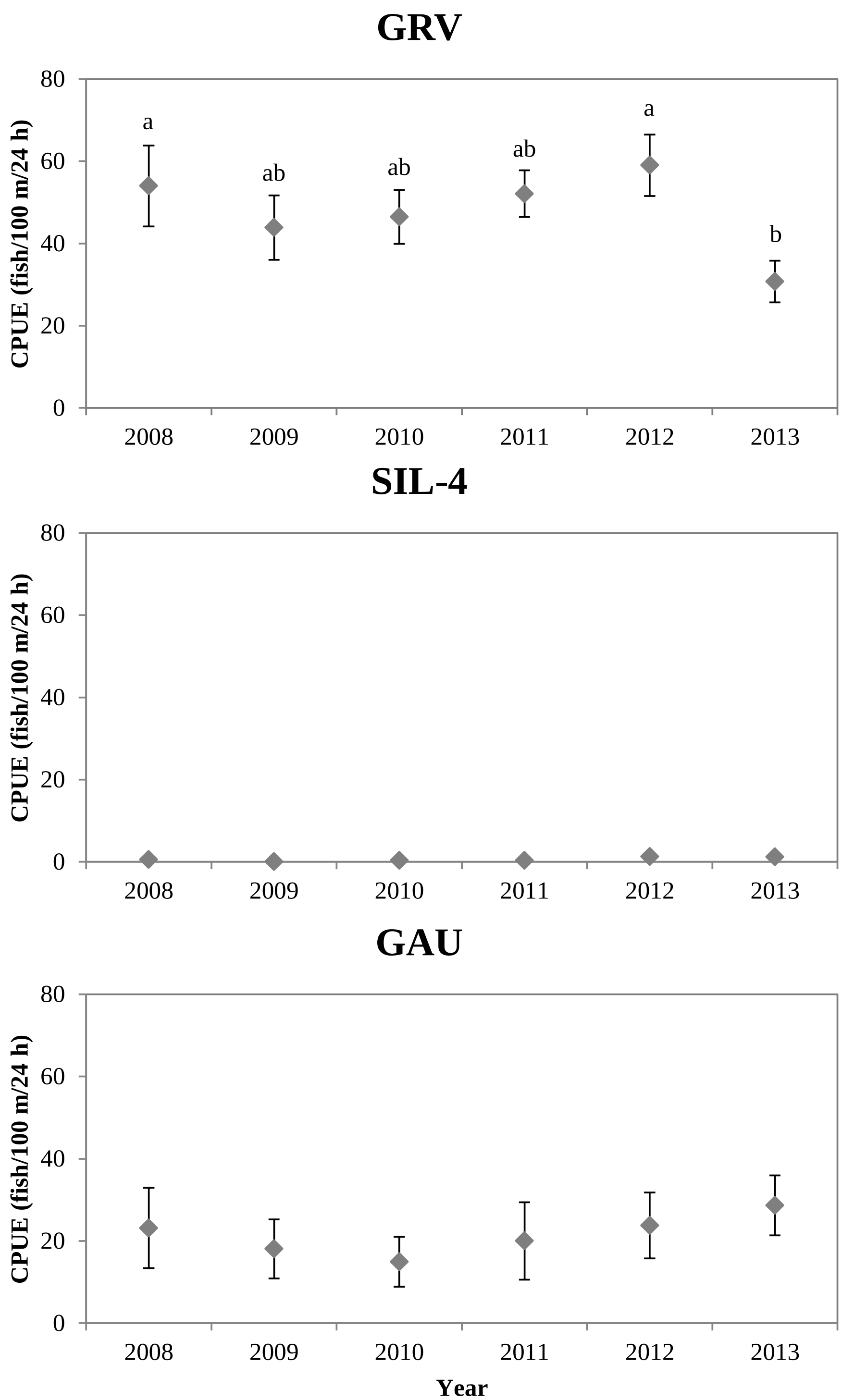



Figure 6-13. White Sucker catch-per-unit-effort (CPUE; mean ± SE) in standard gang index gill nets set at annual on-system (SIL-4) and off-system (GRV and GAU) locations. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts, or lack of superscripts, denote no statistically significant difference.

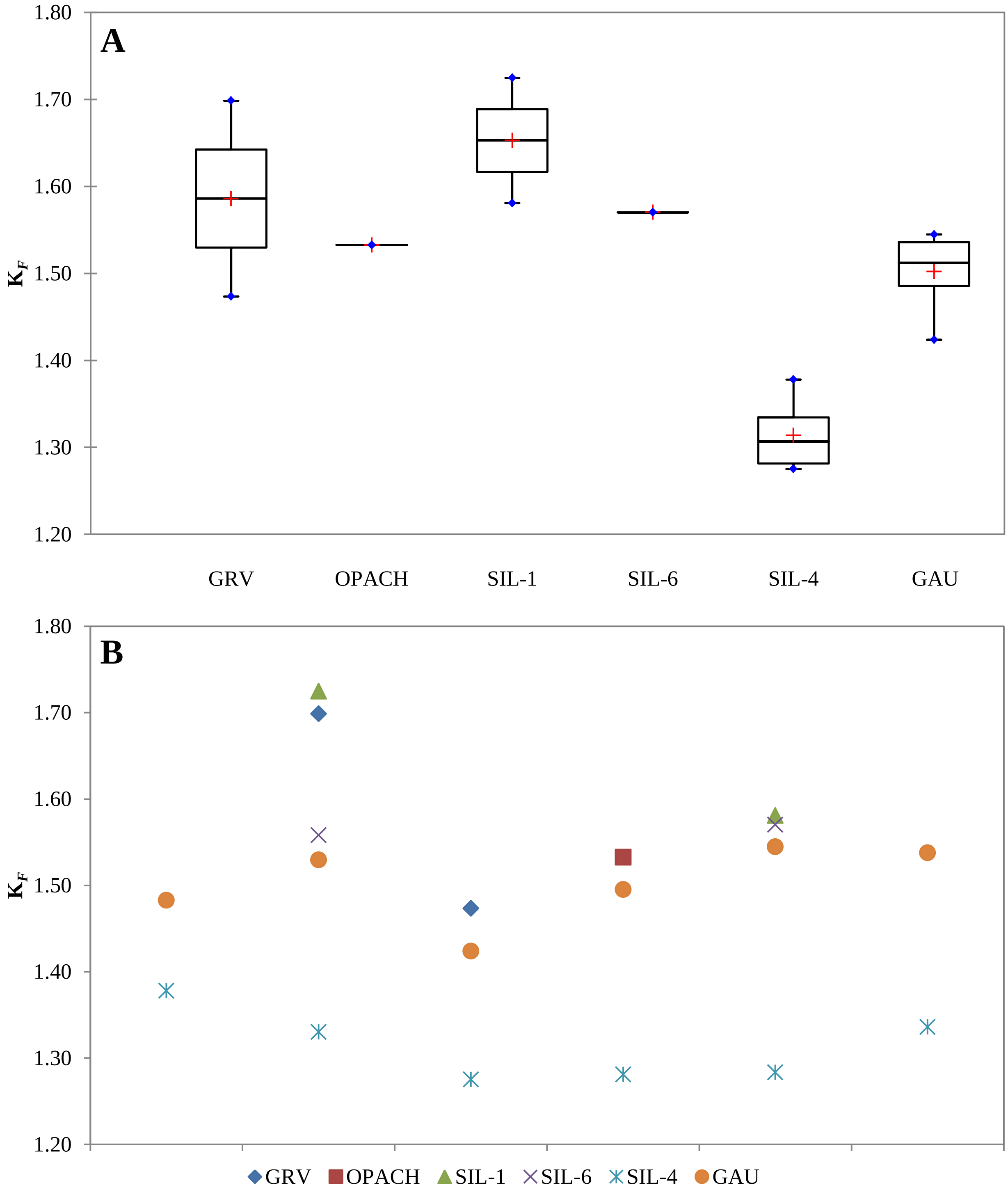



Figure 6-14. Annual mean Fulton's condition factor ($K_F$) calculated for Lake Whitefish between 300 and 499 mm in fork length captured in gill nets set in Upper Churchill River Region waterbodies, 2008-2013 by waterbody (A) and by year (B). Years in which fewer than 20 individuals were caught were excluded from analysis.

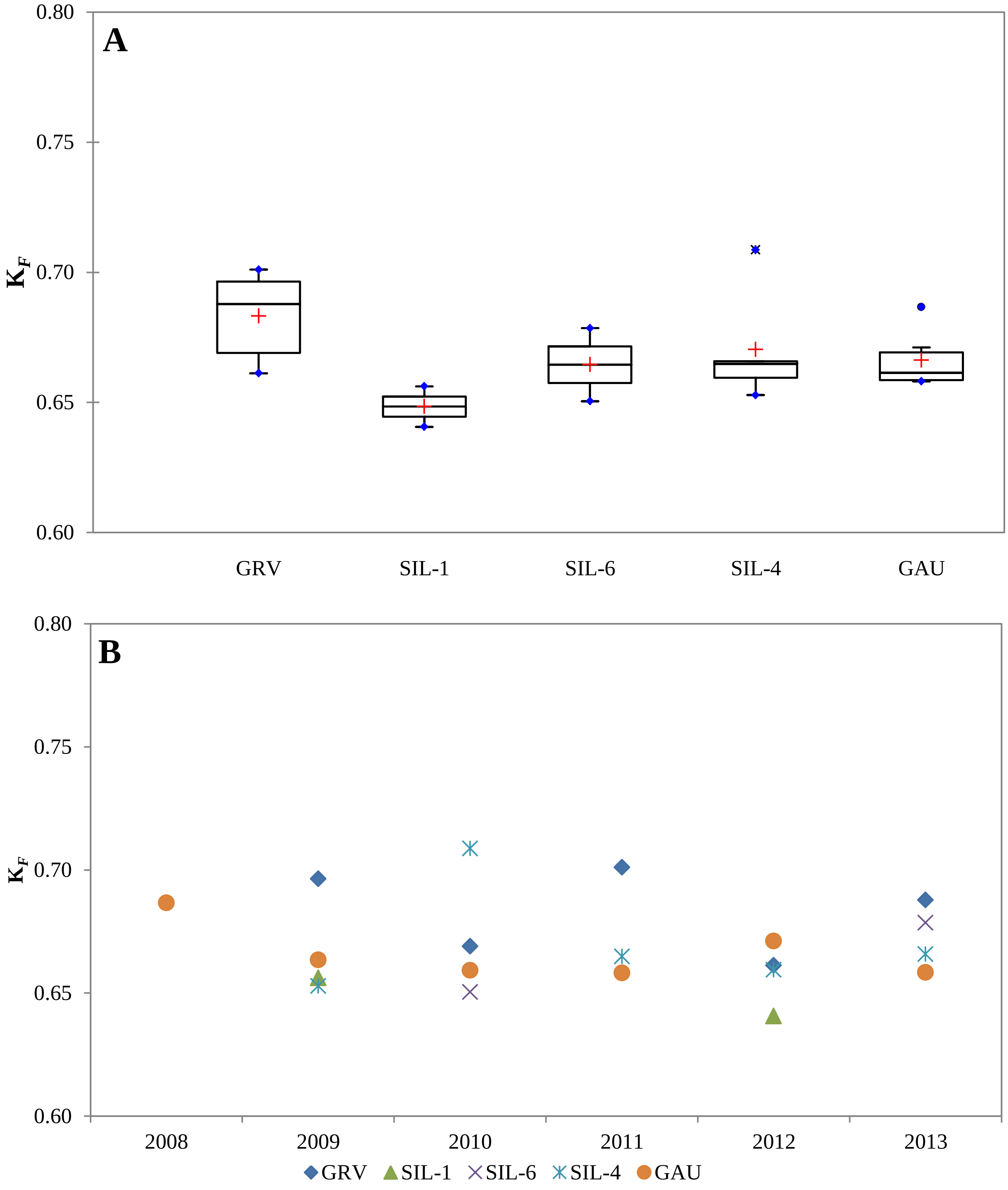
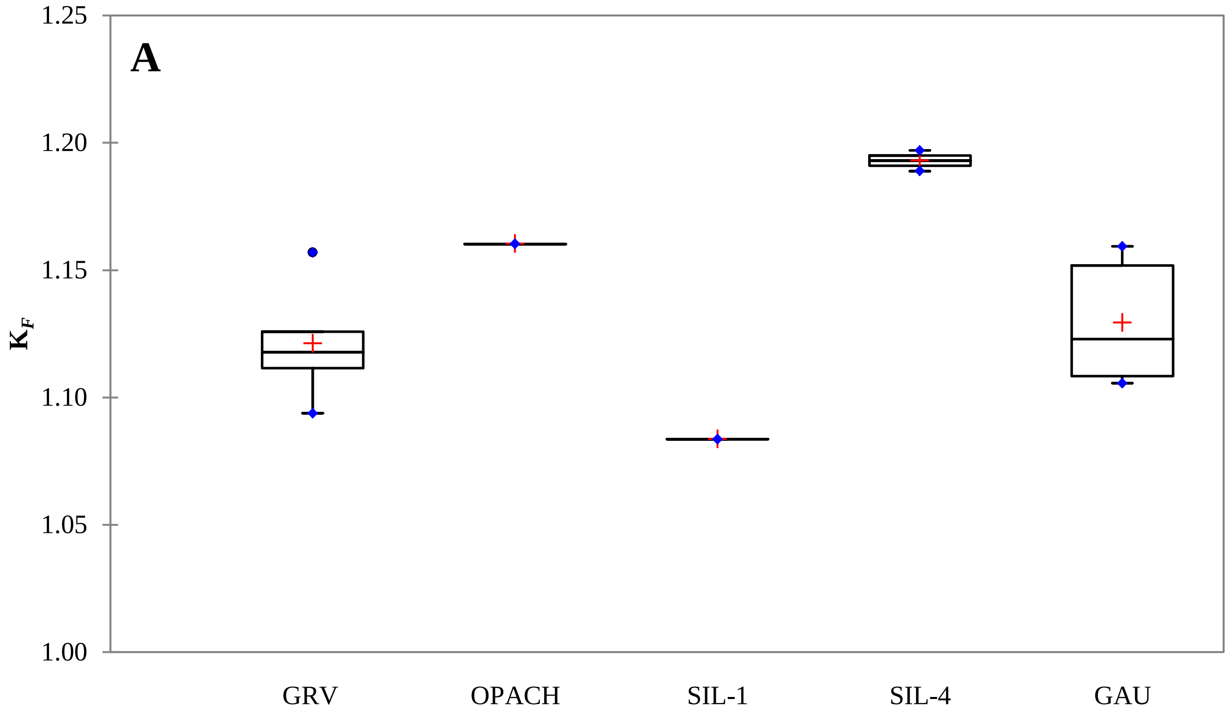



Figure 6-15. Annual mean Fulton's condition factor ($K_F$) calculated for Northern Pike between 400 and 699 mm in fork length captured in gill nets set in Upper Churchill River Region waterbodies, 2008-2013 by waterbody (A) and by year (B). Too few fish were captured in Opachuanau Lake to present for analysis. Years in which fewer than 20 individuals were caught were excluded from analysis.



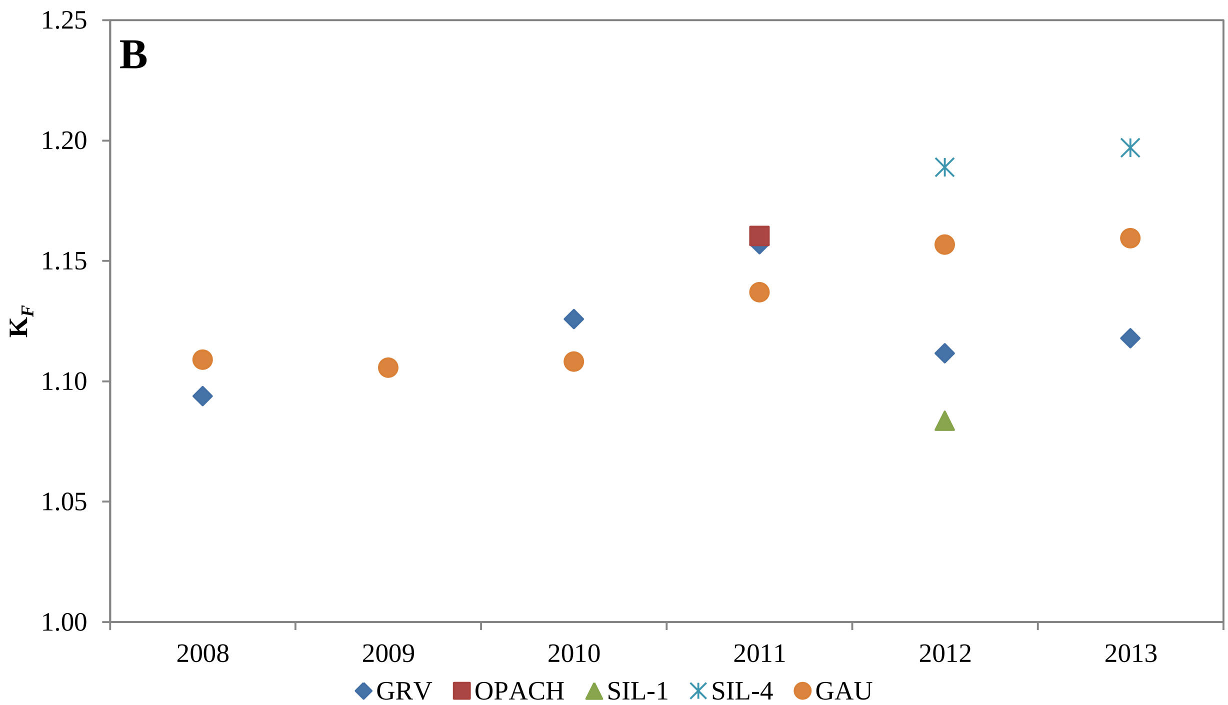




Figure 6-16. Annual mean Fulton's condition factor ($K_F$) calculated for Walleye between 300 and 499 mm in fork length captured in gill nets set in Upper Churchill River Region waterbodies, 2008-2013 by waterbody (A) and by year (B). Years in which fewer than 20 individuals were caught were excluded from analysis.

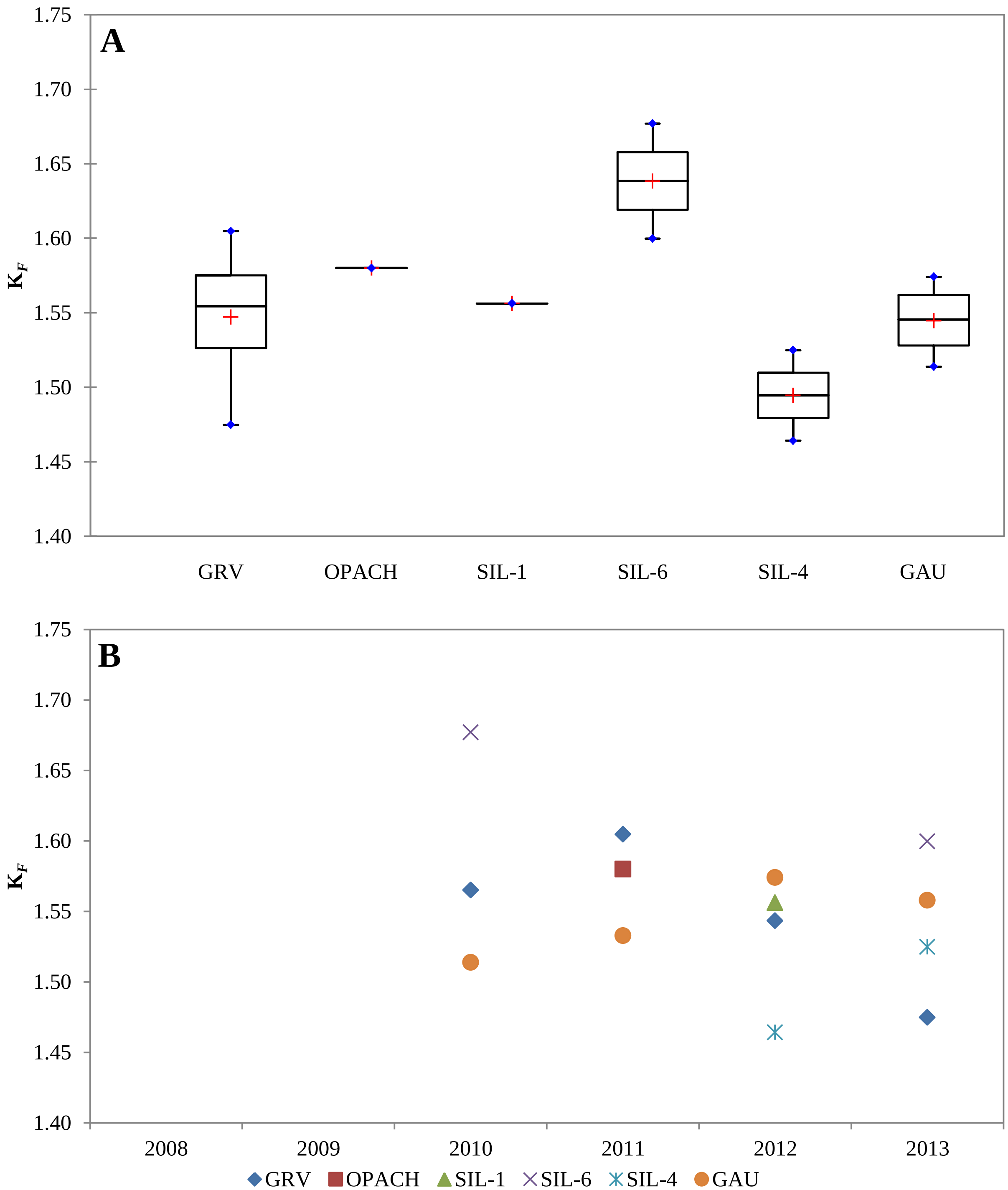



Figure 6-17. Annual mean Fulton's condition factor ($K_F$) calculated for White Sucker between 300 and 499 mm in fork length captured in gill nets set in Upper Churchill River Region waterbodies, 2008-2013 by waterbody (A) and by year (B). Condition factor was not calculated for White Sucker caught in 2008 and 2009 because they were measured for weight only. Years in which fewer than 20 individuals were caught were excluded from analysis.

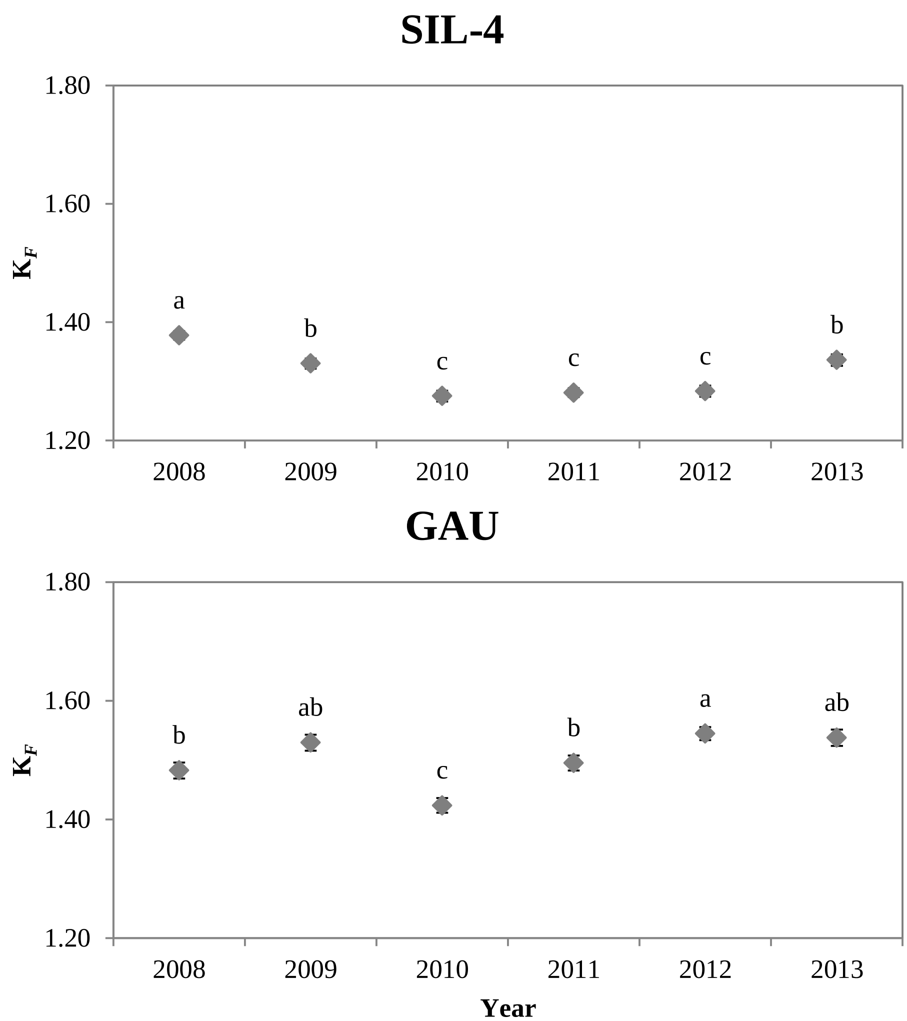



Figure 6-18. Fulton's condition factor ($K_F$; mean ± SE) of Lake Whitefish between 300 and 499 mm in fork length captured at annual on-system (SIL-4) and off-system (GAU) locations. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts, or lack of superscripts, denote no statistically significant difference. There were insufficient data from Granville Lake for detailed analysis of this metric.

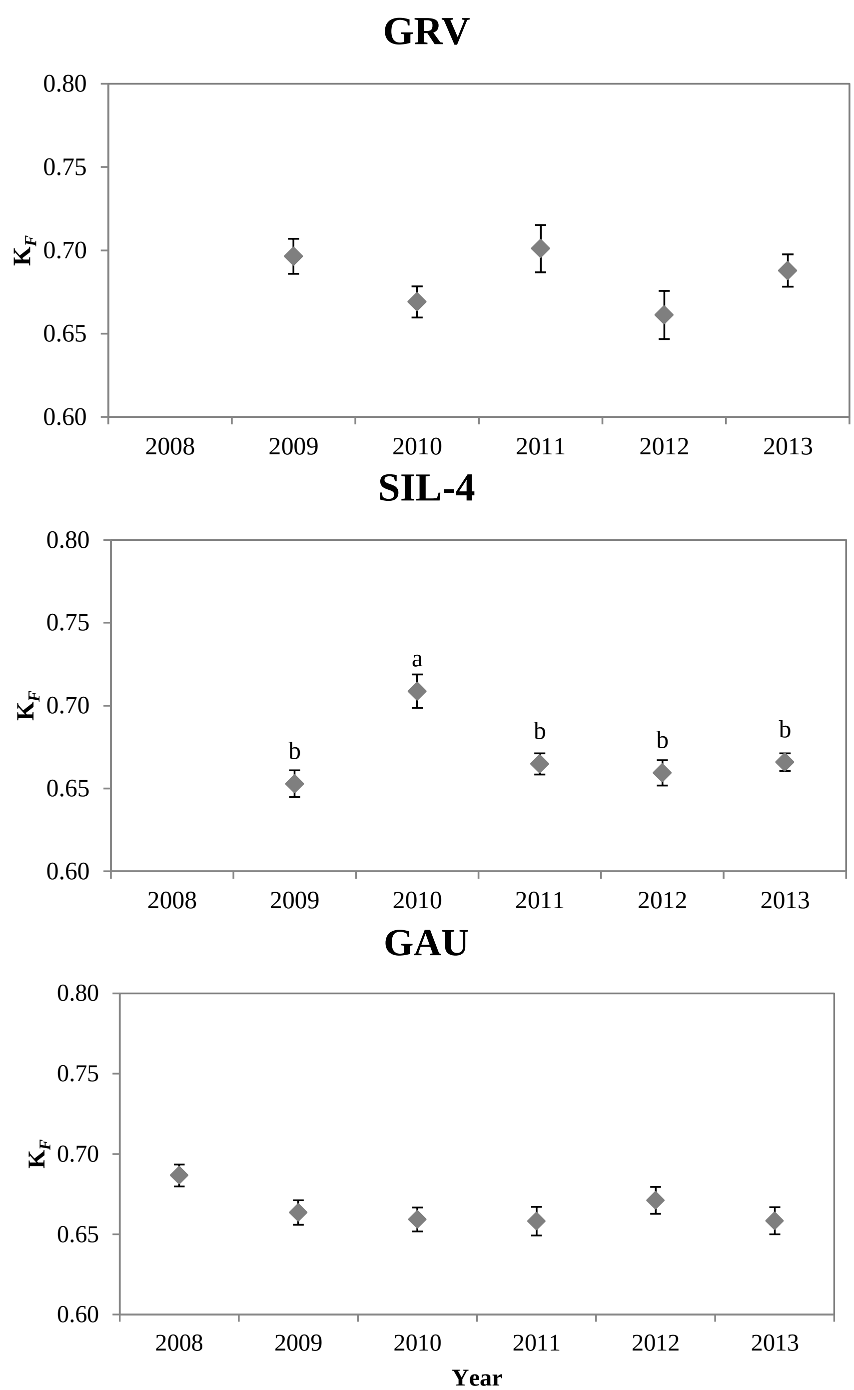



Figure 6-19. Fulton's condition factor ($K_F$; mean ± SE) of Northern Pike between 400 and 699 mm in fork length captured at annual on-system (SIL-4) and off-system (GRV and GAU) locations. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts, or lack of superscripts, denote no statistically significant difference. Condition factor was not calculated for Northern Pike caught in Granville Lake and Southern Indian Lake – Area 4 in 2008 because they were measured for weight only.

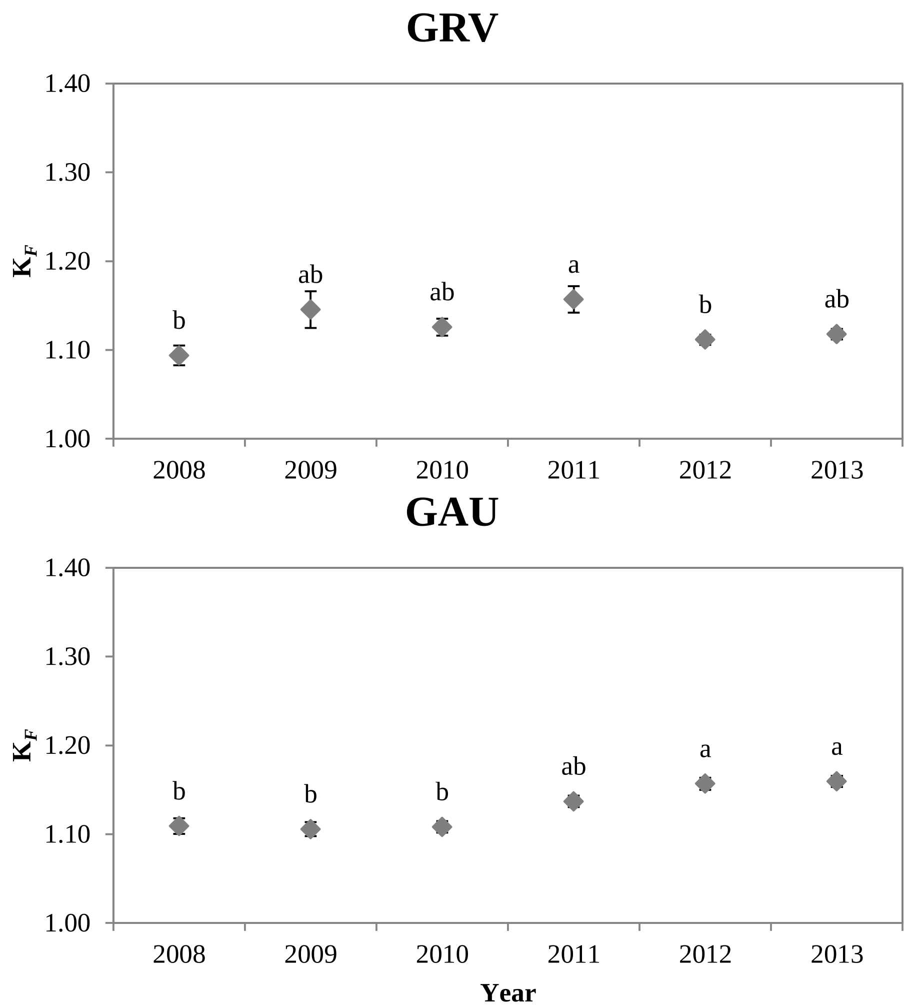



Figure 6-20. Fulton's condition factor ($K_F$; mean ± SE) of Walleye between 300 and 499 mm in fork length captured at annual off-system (GAU and GRV) locations. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts, or lack of superscripts, denote no statistically significant difference. There were insufficient data from Southern Indian Lake – Area 4 for detailed analysis of this metric.

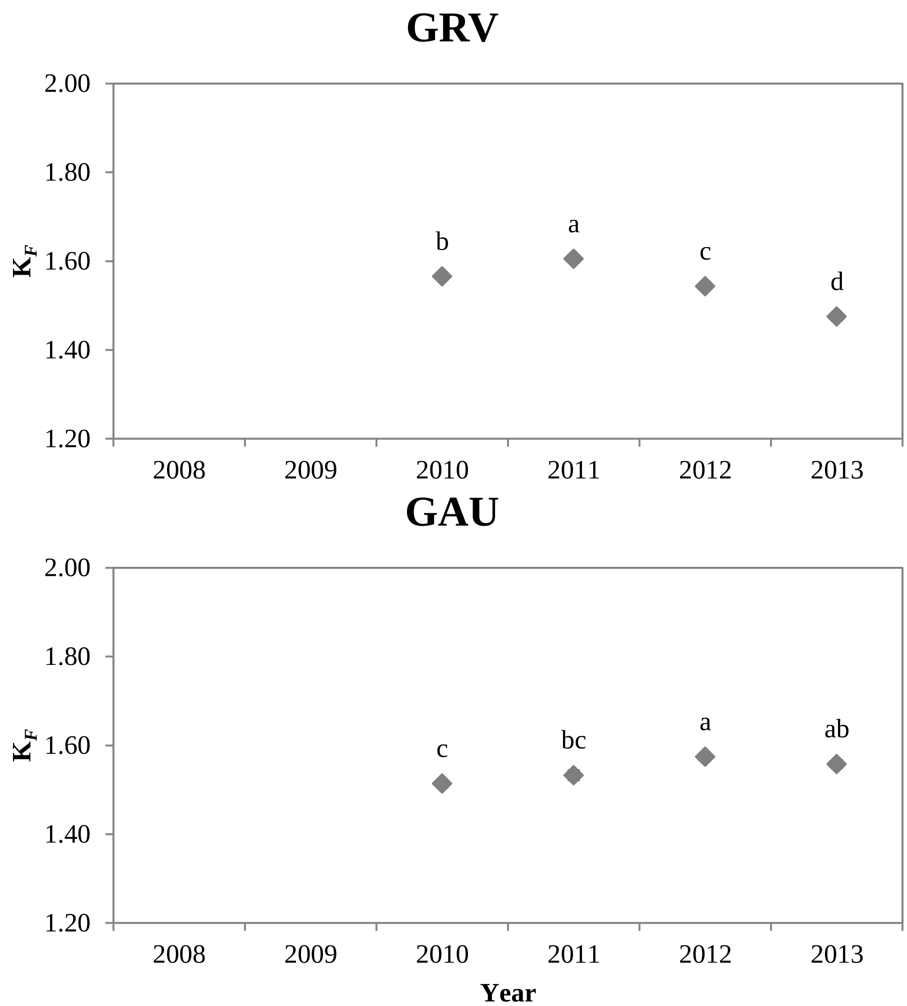



Figure 6-21. Fulton's condition factor ($K_F$; mean ± SE) of White Sucker between 300 and 499 mm in fork length captured at off-system (GAU and GRV) locations. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts, or lack of superscripts, denote no statistically significant difference. There were insufficient data from Southern Indian Lake – Area 4 for detailed analysis of this metric. Condition factor was not calculated for White Sucker caught in Gauer Lake in 2008 and 2009 because they were measured for weight only.

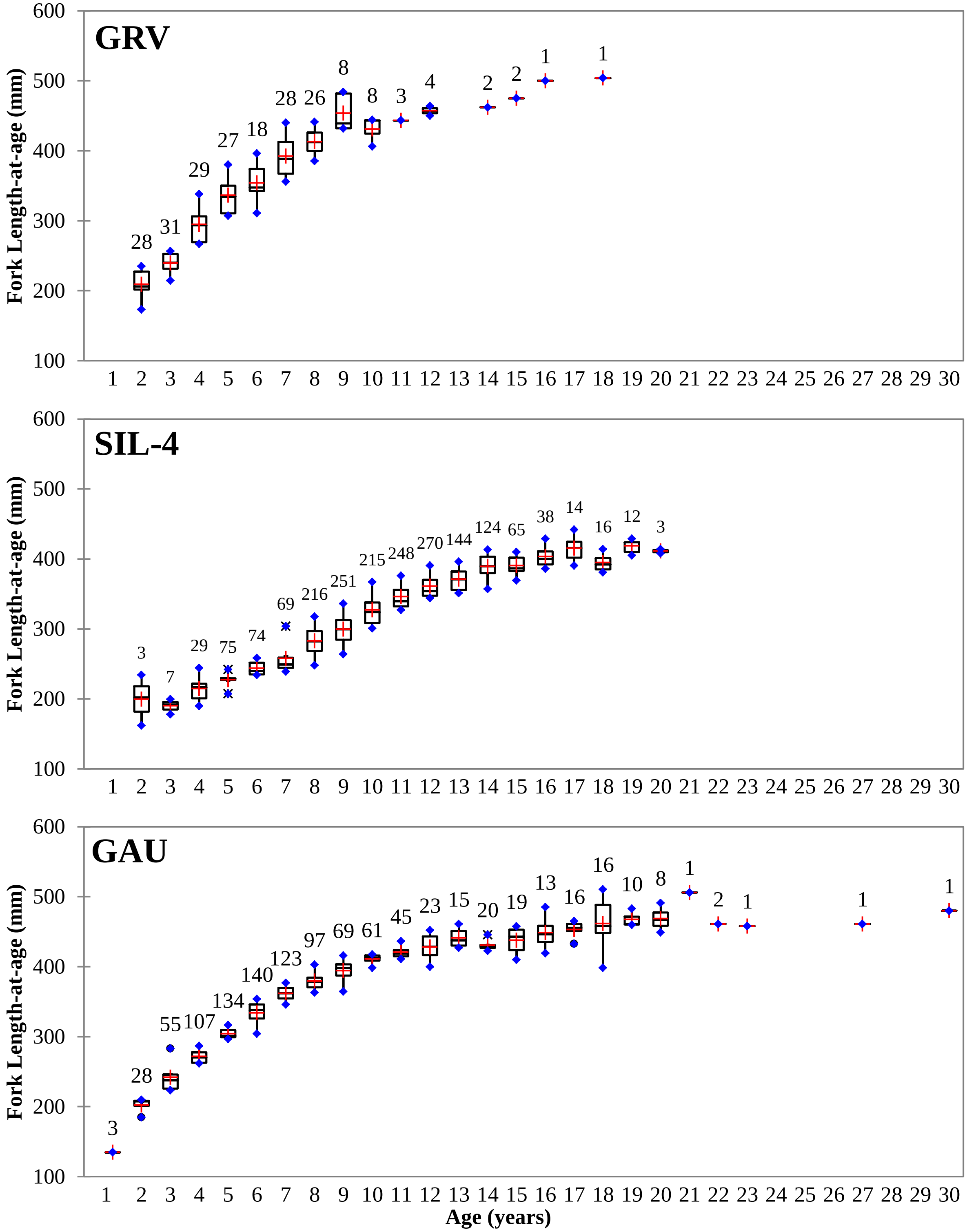



Figure 6-22. Annual mean length-at-age (mm) of Lake Whitefish captured in standard gang and small mesh index gill nets set at annual sampling locations in the Upper Churchill River Region, 2008-2013. The number of fish captured over the 6-year sampling period is shown above the box for each age.

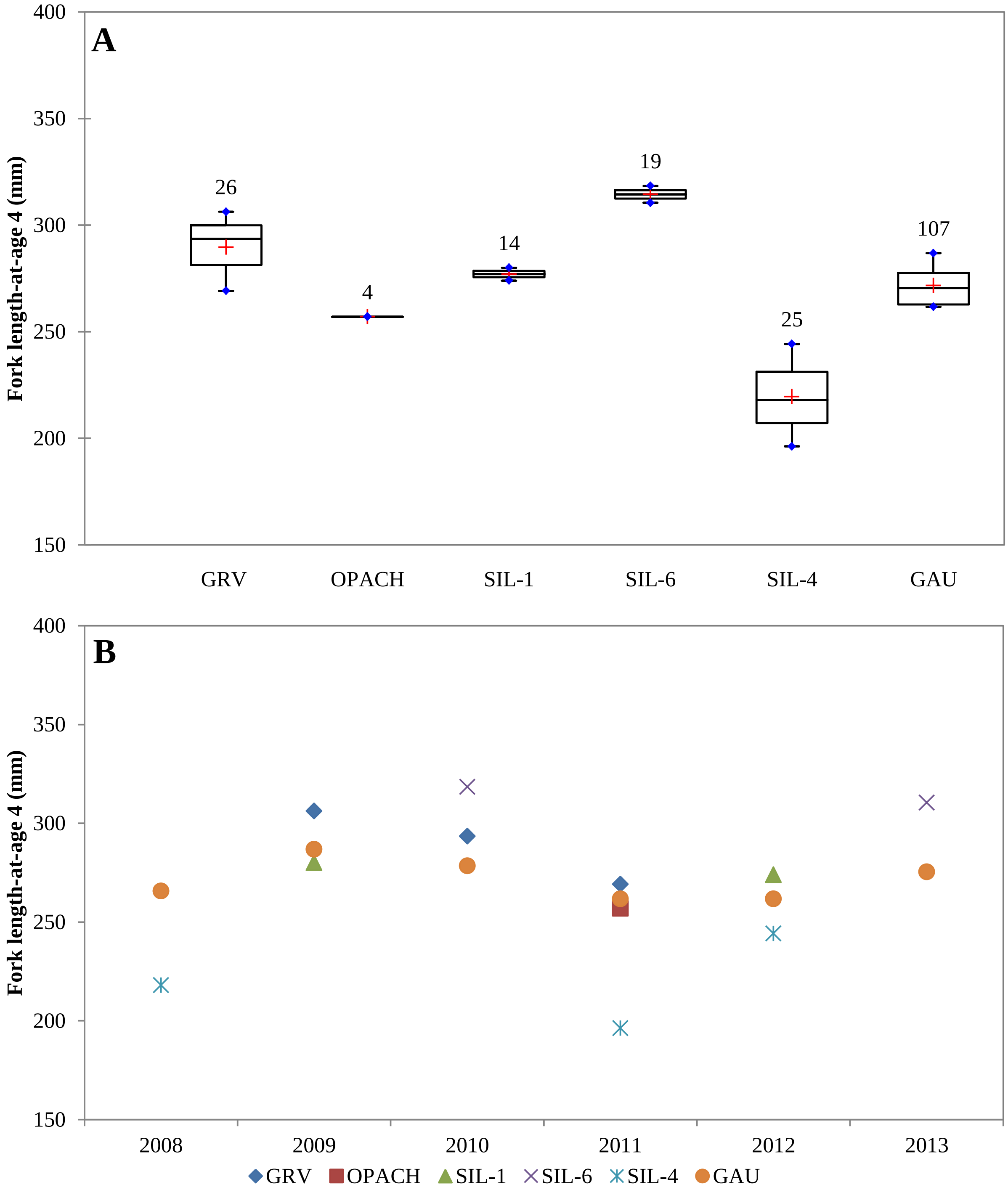
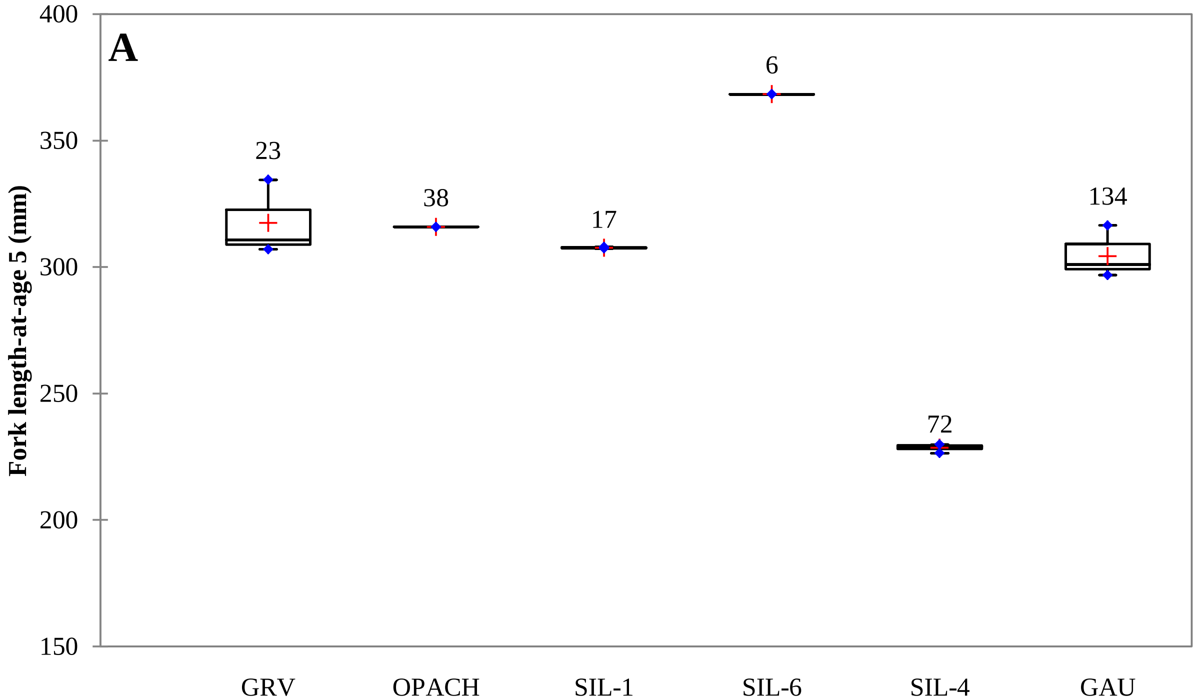



Figure 6-23. Annual mean fork length- at-age 4 (mm) of Lake Whitefish captured in standard gang and small mesh index gill nets set in Upper Churchill River Region waterbodies, 2008-2013 by waterbody (A) and year (B). The number of fish captured over the 6-year sampling period is shown above the box for each age. Years in which fewer than three individuals were caught were excluded from analysis.



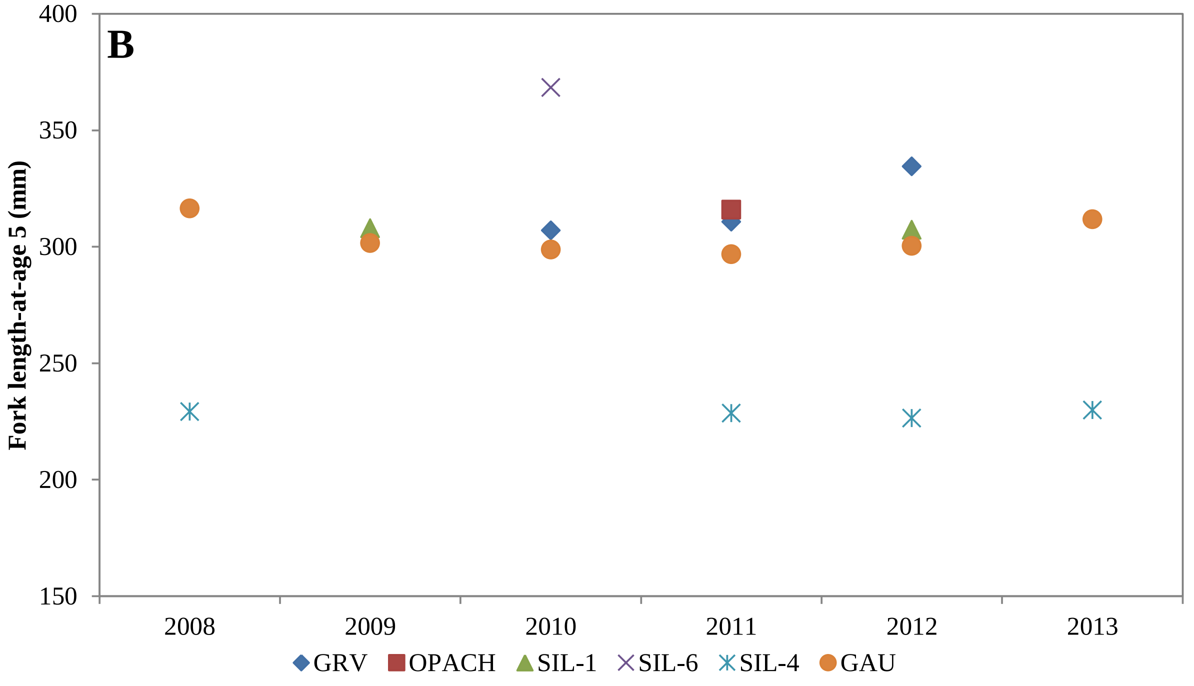




Figure 6-24. Annual mean fork length-at-age 5 (mm) of Lake Whitefish captured in standard gang and small mesh index gill nets set in Upper Churchill River Region waterbodies, 2008-2013 by waterbody (A) and year (B). The number of fish captured over the 6-year sampling period is shown above the box for each age. Years in which fewer than three individuals were caught were excluded from analysis.

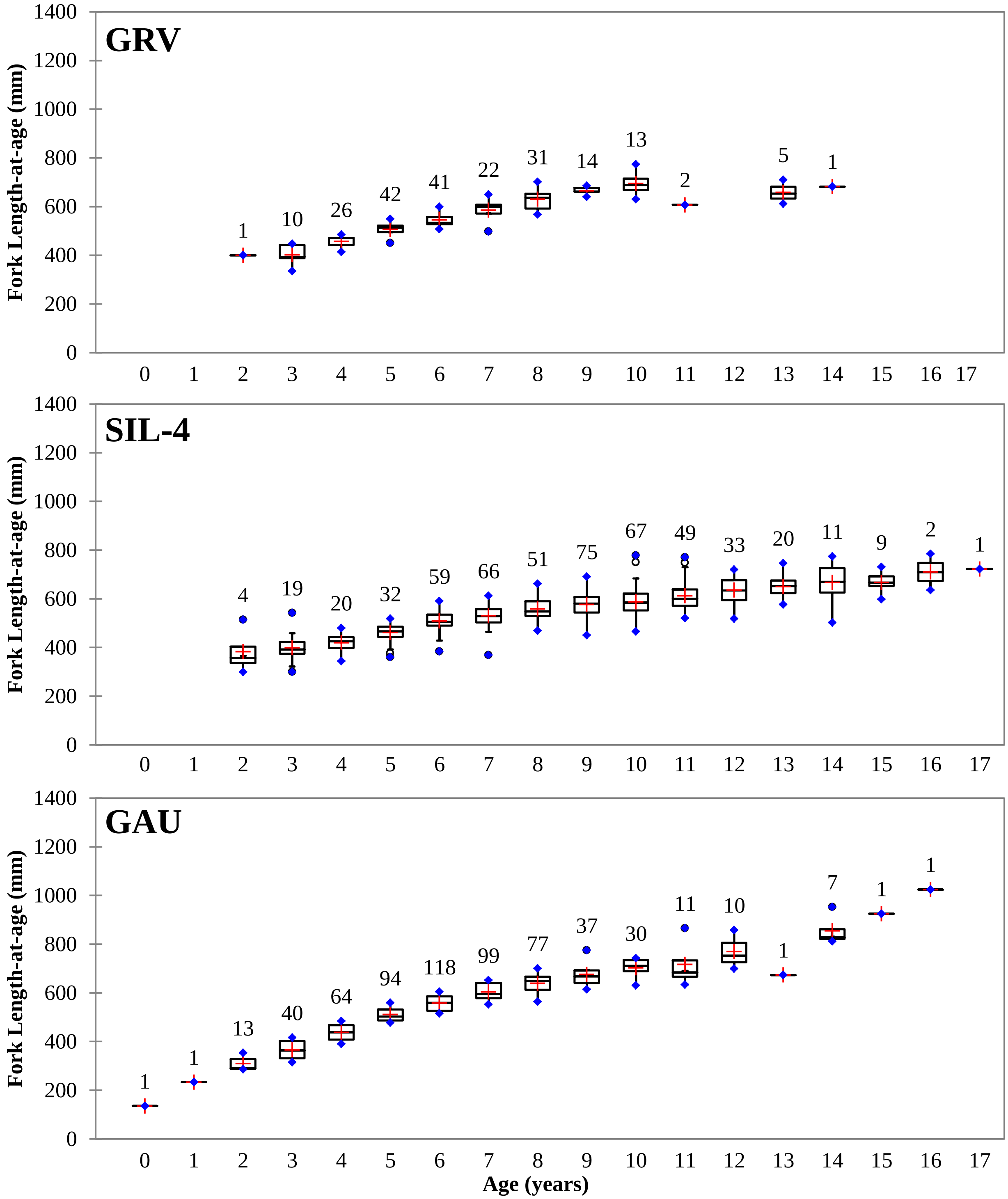



Figure 6-25. Annual mean length-at-age (mm) of Northern Pike captured in standard gang and small mesh index gill nets set at annual sampling locations in the Upper Churchill River Region, 2008-2013. The number of fish captured over the 6-year sampling period is shown above the box for each age. Northern Pike caught in Granville Lake and Southern Indian Lake – Area 4 in 2008 were not included because they were measured for weight only.

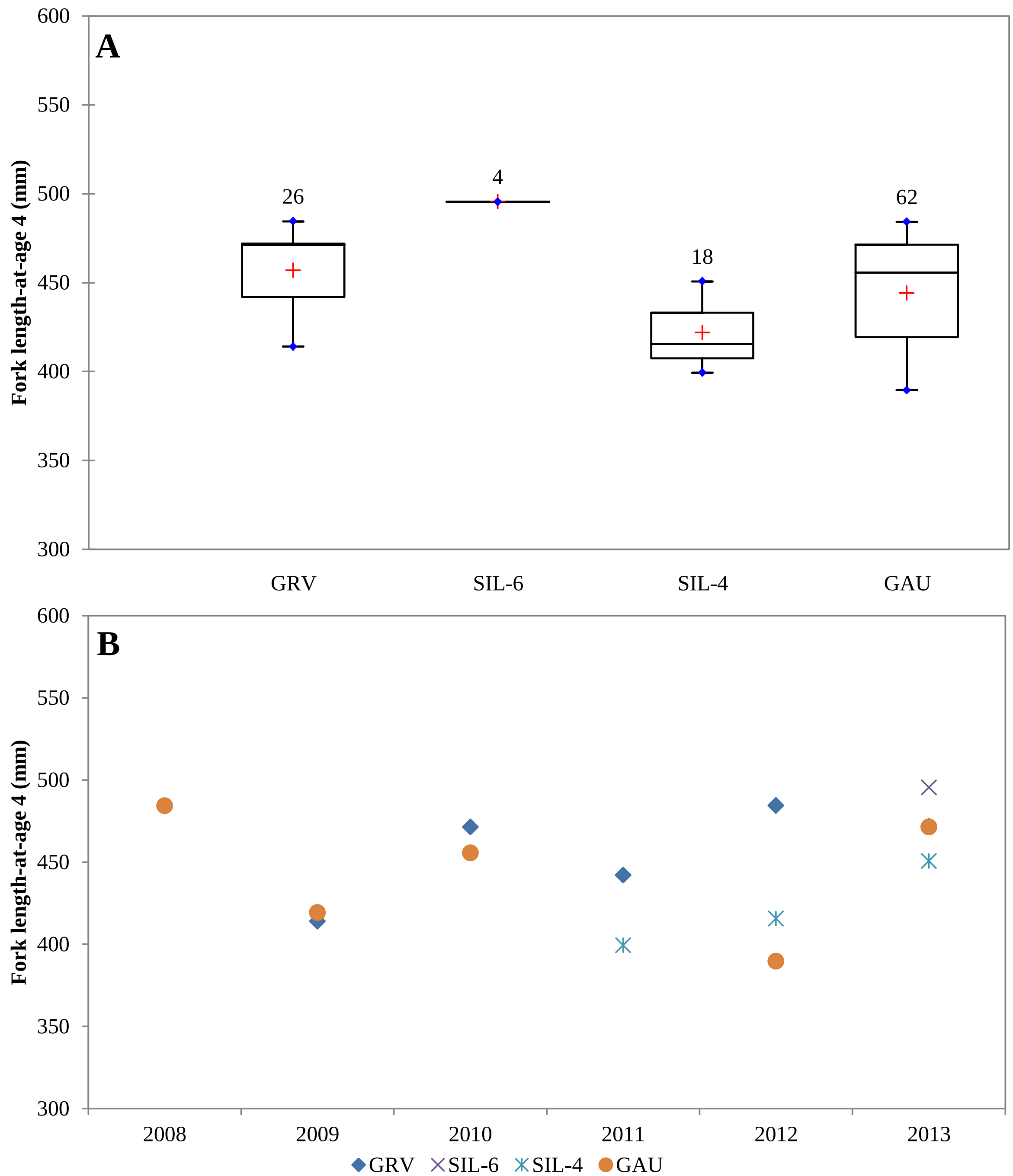



Figure 6-26. Annual mean fork length-at-age 4 (mm) of Northern Pike captured in standard gang and small mesh index gill nets set in Upper Churchill River Region waterbodies, 2008-2013 by waterbody (A) and year (B). The number of fish captured over the 6-year sampling period is shown above the box for each age. Years in which fewer than three individuals were caught were excluded from analysis. Northern Pike caught in Granville Lake and Southern Indian Lake – Area 4 in 2008 were not included because they were measured for weight only.

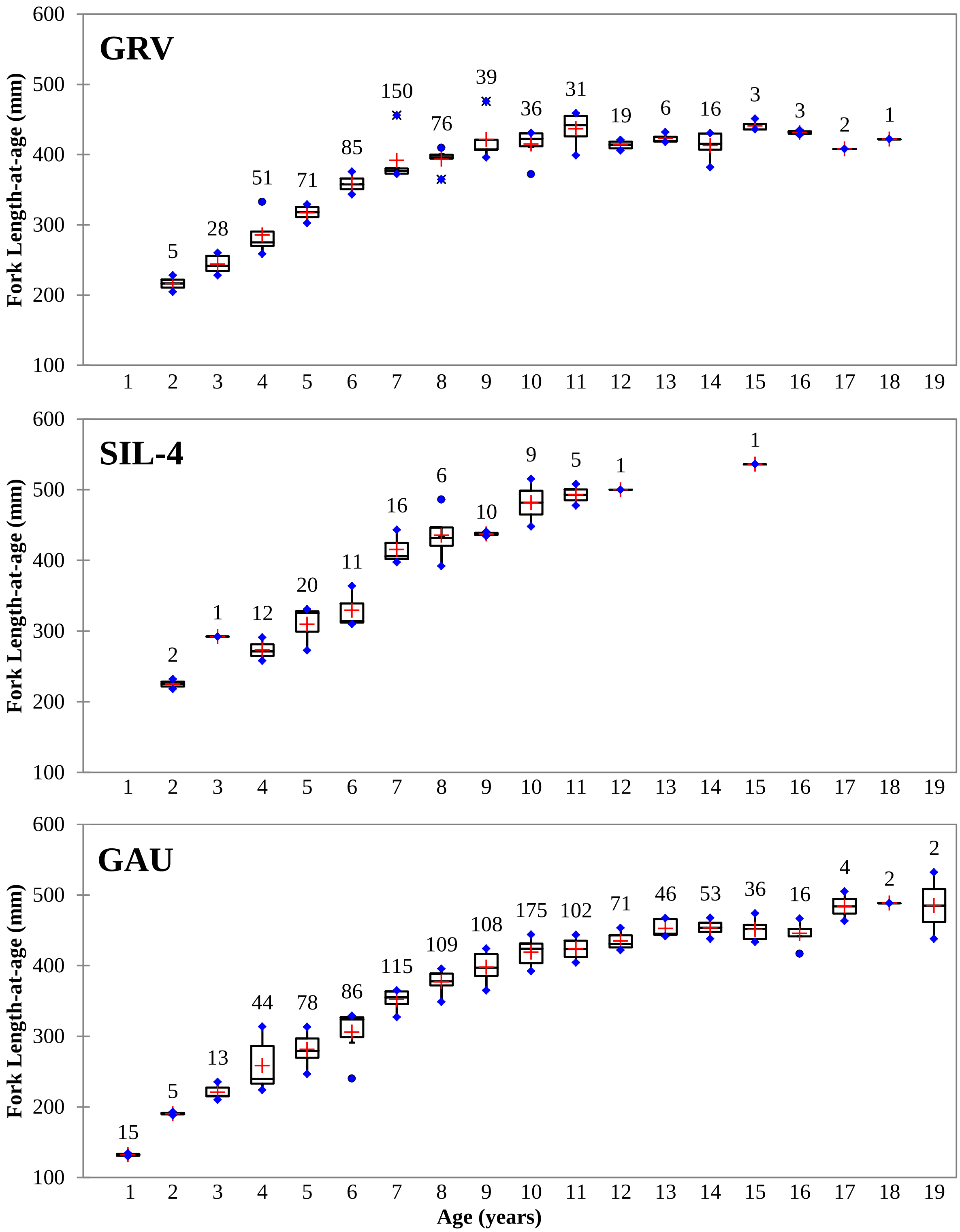



Figure 6-27. Annual mean length-at-age (mm) of Walleye captured in standard gang and small mesh index gill nets set at annual sampling locations in the Upper Churchill River Region, 2008-2013. The number of fish captured over the 6-year sampling period is shown above the box for each age.

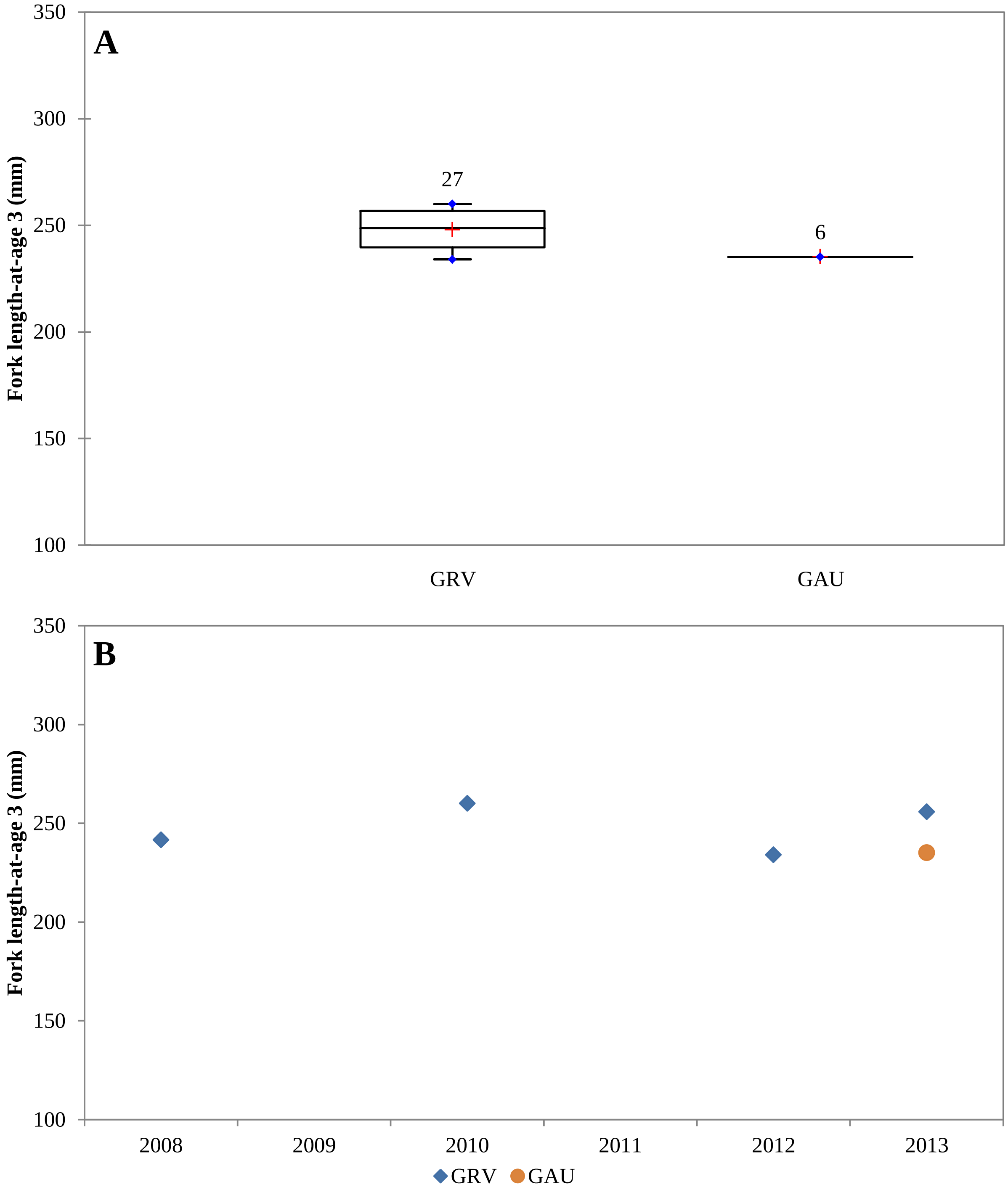



Figure 6-28. Annual mean fork length-at-age 3 (mm) of Walleye captured in standard gang and small mesh index gill nets set in Upper Churchill River Region waterbodies, 2008-2013 by waterbody (A) and year (B). The number of fish captured over the 6-year sampling period is shown above the box for each age. Years in which fewer than three individuals were caught were excluded from analysis.

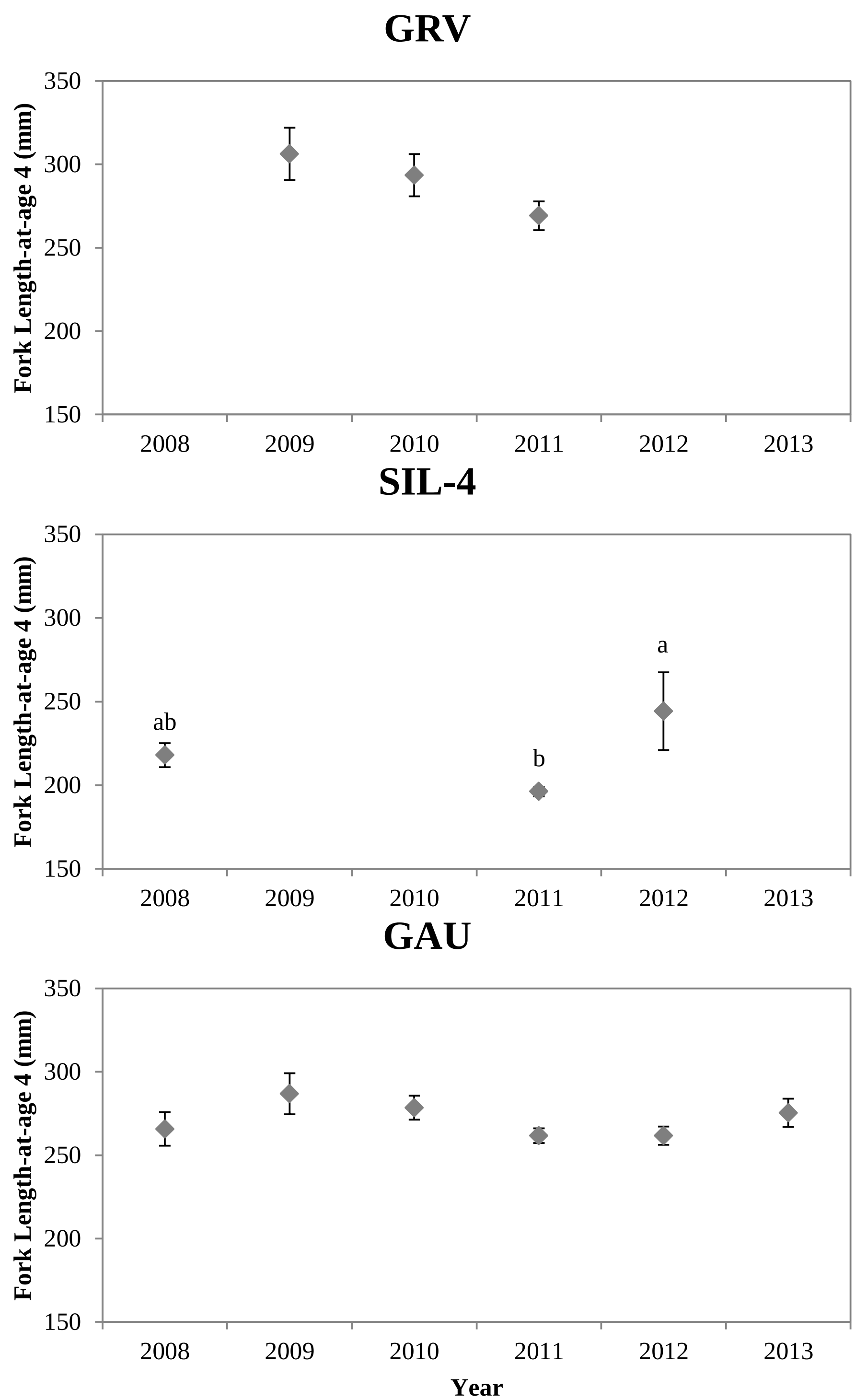



Figure 6-29. Fork length-at-age 4 (mean ± SE) calculated for Lake Whitefish captured at annual on- and off-system locations. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts, or lack of superscripts, denote no statistically significant difference. Years in which fewer than three individuals were caught were excluded from analysis.

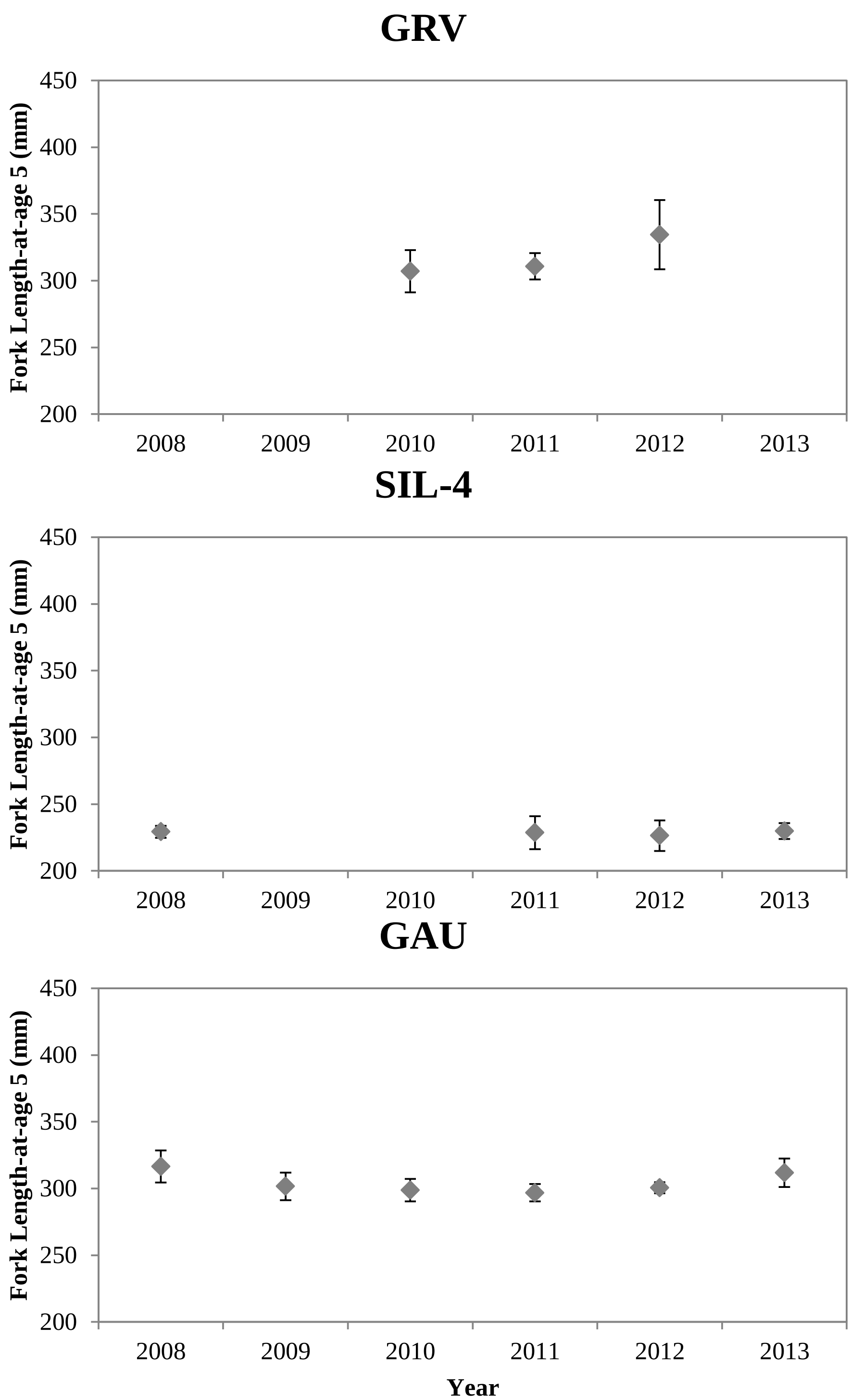



Figure 6-30. Fork length-at-age 5 (mean ± SE) calculated for Lake Whitefish captured at annual on- and off-system locations. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts, or lack of superscripts, denote no statistically significant difference. Years in which fewer than three individuals were caught were excluded from analysis.

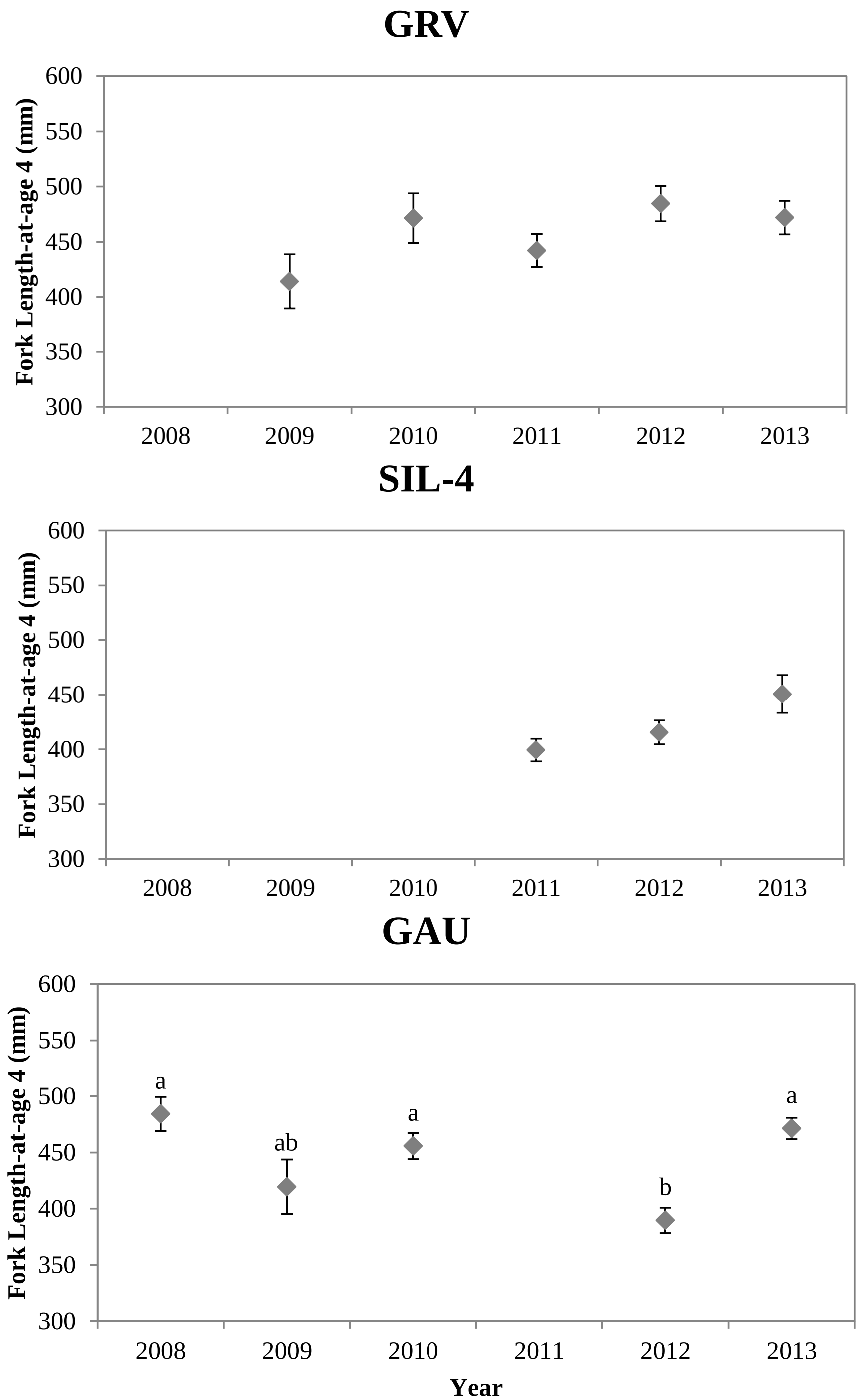



Figure 6-31. Fork length-at-age 4 (mean ± SE) calculated for Northern Pike captured at annual on- and off-system locations. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts, or lack of superscripts, denote no statistically significant difference. Years in which fewer than three individuals were caught were excluded from analysis. Northern Pike caught in Granville Lake and Southern Indian Lake – Area 4 in 2008 were not included because they were measured for weight only.

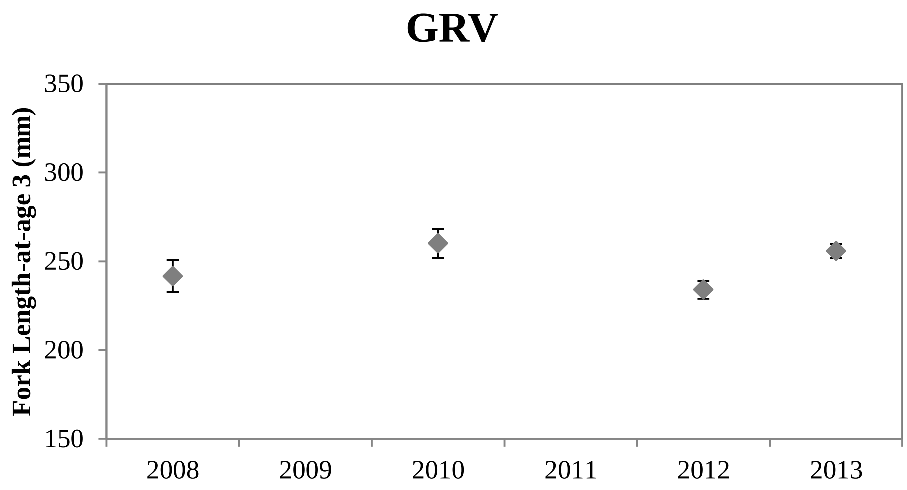



Figure 6-32. Fork length-at-age 3 (mean ± SE) calculated for Walleye captured at Granville Lake, an off-system location. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts, or lack of superscripts, denote no statistically significant difference. Years in which fewer than three individuals were caught were excluded from analysis. There were insufficient data from Southern Indian Lake – Area 4 and Gauer Lake for detailed analysis of this metric.

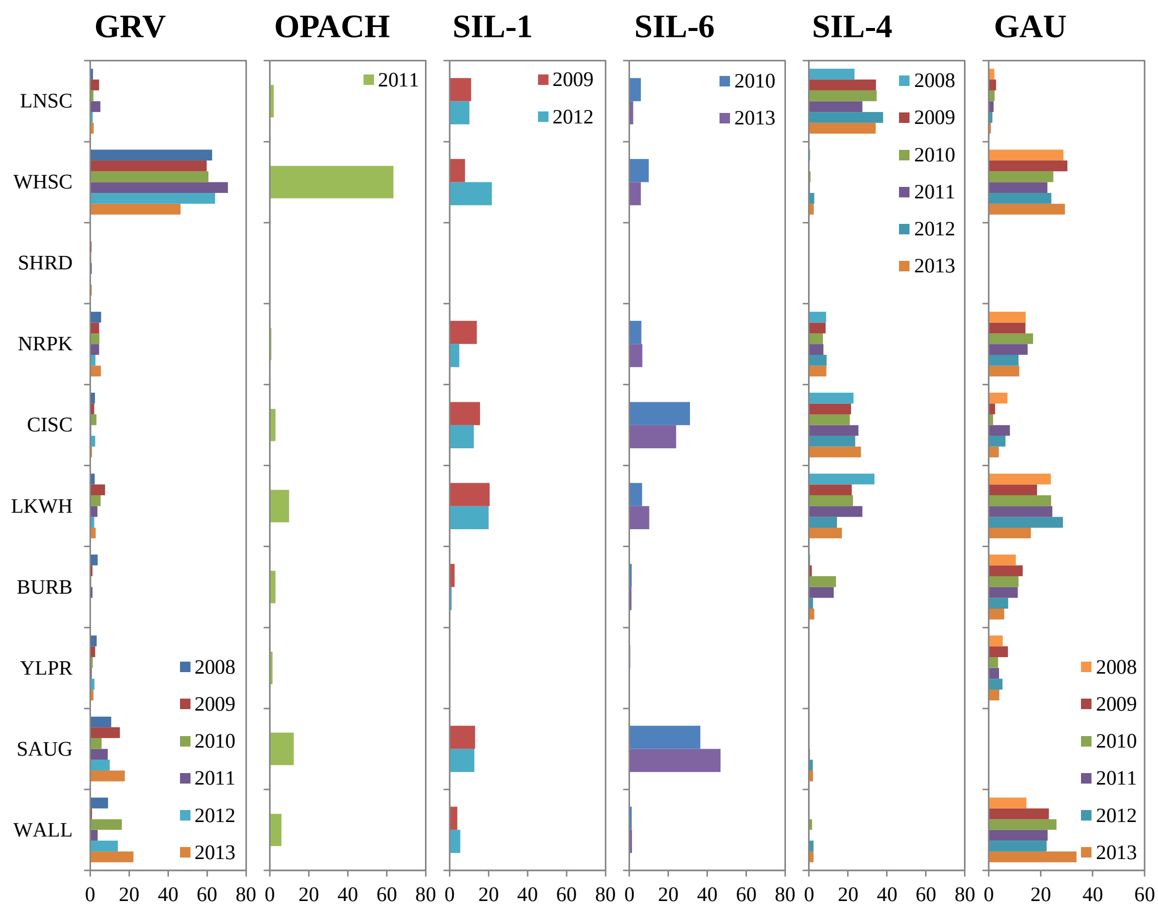
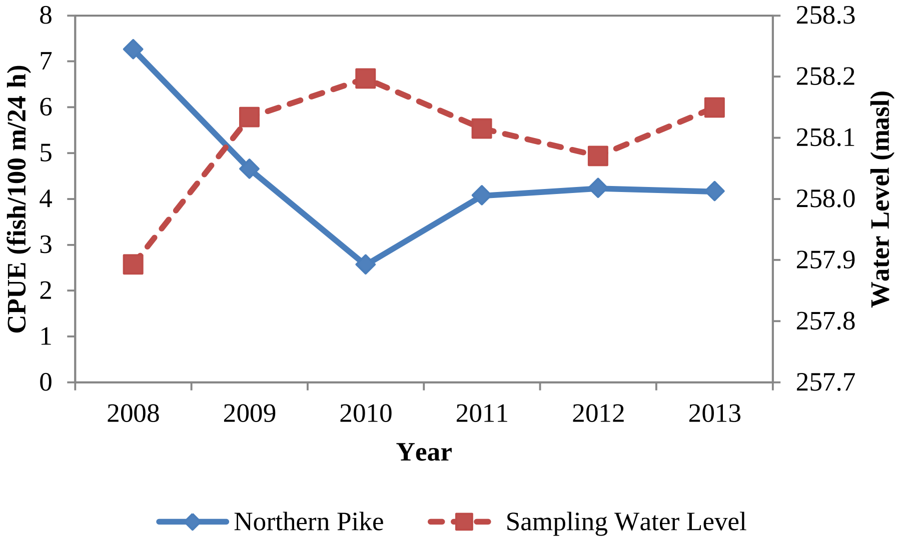



Figure 6-33. Relative abundance of fish species captured in standard gang index gill nets in Upper Churchill River Region waterbodies, 2008-2013.



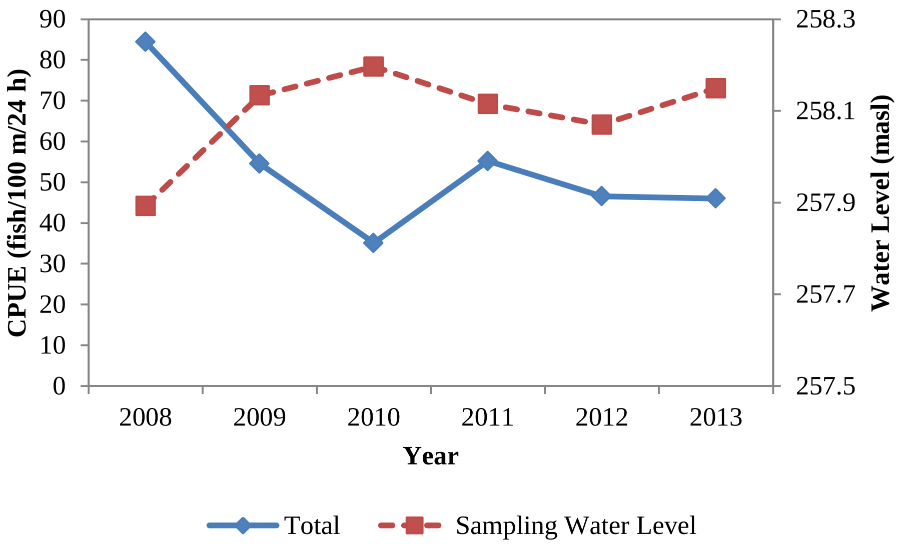




Figure 6-34. Abundance of Northern Pike (top) and total catch (bottom) in gillnet catches in Southern Indian Lake – Area 4 as measured by CPUE in relation to the average water level at the community of South Indian Lake during the gillnetting period: 2008-2013.

# 7.0 FISH MERCURY

## 7.1 INTRODUCTION

The following provides an overview of the results of fish mercury monitoring conducted in the UCRR under CAMP in the first six years of the program. Fish mercury sampling was conducted on a three-year rotation (2010 and 2013) in Southern Indian Lake – Area 4 and Area 6 and the off-system Granville Lake. While formally part of the LCRR under CAMP, results for the off-system Gauer Lake were also considered in the interpretation of fish mercury data for the UCRR. Additional sampling was conducted in 2011 for waterbodies where sample sizes obtained in 2010 were substantially below target numbers.

A detailed description of the program design and sampling methods is provided in Technical Document 1, Section 4.7. In brief, mercury was analysed in the trunk muscle of Northern Pike, Lake Whitefish, and Walleye selected from a range of fork lengths. Sampling also targeted capture of 1-year-old Yellow Perch for analysis of mercury in the whole carcass with the head, pelvic girdle, pectoral girdle, and caudal fin removed. The latter are included in CAMP as a potential early-warning indicator of changes in mercury in the food web.

### 7.1.1 Objectives and Approach

The key objectives of the analysis of CAMP fish mercury data were to:

- evaluate the suitability of fish for domestic, recreational and commercial fisheries; and
- evaluate whether there are indications of temporal differences in fish mercury concentrations.

The first objective was addressed through comparisons to the Health Canada standard for commercial marketing of freshwater fish in Canada (Health Canada 2007a,b) and the Manitoba aquatic life tissue residue guideline for human consumers (MWS 2011) for the three target species (Lake Whitefish, Northern Pike, and Walleye).

The second objective (temporal differences) was addressed through statistical comparisons between years for a given waterbody or riverine area where more than one year of data were available. Trend analysis and assessment of potential relationships with hydrological metrics could not be undertaken for fish mercury because only two years of monitoring data were available for this region.

A detailed description of the approach and methods applied for analysis and reporting is provided in Technical Document 1, Section 4.7. Site abbreviations applied in tables and figures are defined in Table 1-1.

### 7.1.2 Indicators

Results presented below focus upon one key indicator (fish mercury concentrations) and two key metrics: absolute or arithmetic mean mercury concentrations; and length-standardized mean mercury concentrations (also referred to as "standard mean(s)"). Fish mercury concentrations are typically positively correlated to fish length and standardization to a single fish length for a given species is commonly done to enable comparisons among waterbodies and over time. As CAMP targets a specific age class of perch, fish captured for this component are inherently of a limited size range; therefore, length-standardization for this species was not undertaken.

## 7.2 KEY INDICATOR: MERCURY CONCENTRATIONS IN FISH

### 7.2.1 Upper Churchill River: Southern Indian Lake – Areas 4 and 6

A total of 358 fish were analyzed for mercury from Areas 4 and 6 of Southern Indian Lake (Table 7-1). In Southern Indian Lake – Area 6, the number of fish available for mercury analysis was often below the target sample size for all species (Table 7-1). In contrast, target samples sizes were mostly obtained in Southern Indian Lake – Area 4 except for Walleye, where the number sampled in 2010 was considerably less than the sample target size (Table 7-1).

Mean length-standardized mercury concentrations for Northern Pike and Walleye from Areas 4 and 6 generally approached or slightly exceeded the 0.5 parts per million (ppm) standard for commercial marketing of fish in Canada (Health Canada 2007a,b) and the Manitoba aquatic life tissue residue guideline for human consumers (MWS 2011). Although a length-standardized mean could not be established, the arithmetic mean mercury concentration of Walleye from Area 6 in 2013 approached 0.5 ppm (Table 7-1). Mean length-standardized mercury concentrations for Lake Whitefish were consistently below the 0.5 ppm guideline for both areas and years (Table 7-1). Similarly, arithmetic means for mercury concentrations measured in Yellow Perch tissue were also well below the Health Canada standard (Health Canada 2007a,b).

The percentage of Walleye exceeding the 0.5 ppm standard varied from none in Area 4 to 33% in Area 6 of Southern Indian Lake (Figure 7-1). The higher frequency of exceedances of 0.5 ppm in Area 6 may be related to relatively small sample size obtained for Walleye in 2013 in conjunction with the relatively high proportion of larger fish in that sample (Table 7-2; Figure 7-1).

Approximately 38-40% of individual pike sampled from the two areas of Southern Indian Lake exceeded the standard. A maximum concentration of 1.62 ppm was measured in a female pike measuring 690 mm in length.

All of the Lake Whitefish and Yellow Perch sampled from both areas had mercury concentrations substantially lower than 0.5 ppm, with maxima for whitefish of 0.15 ppm and 0.02 ppm for perch (Figures 7-1 and 7-2).

### 7.2.2 Off-system Waterbodies: Granville and Gauer Lakes

A total of 474 fish from Granville and Gauer lakes were analyzed for mercury, including ten 1-year-old Walleye captured in 2013 that were analyzed in addition to the regular sample of larger and older fish (Table 7-1). Except for Lake Whitefish in 2013, sample sizes for all three large-bodied species were close or equal to the target sample size of 36 fish in both waterbodies and monitoring years. Yellow Perch were sampled at approximately two thirds of the target sample size of 25 fish (Table 7-1).

Mean length-standardized mercury concentrations were consistently below the 0.5 ppm Health Canada standard for commercial marketing of fish in Canada (Health Canada 2007a,b) and the Manitoba aquatic life tissue residue guideline for human consumers (MWS 2011) for all species sampled from Granville and Gauer lakes (Table 7-1). Both Walleye and Northern Pike sampled from Granville Lake in 2010 had a mean length-standardized concentration of 0.441 ppm, the highest concentrations observed in the two waterbodies during the monitoring period (Table 7-1).

Based on mercury concentrations in individual fish, the percentage of Walleye sampled in 2010 and 2013 that exceeded the 0.5 ppm Health Canada standard ranged from 1.4% in Gauer Lake to 14% in Granville Lake (Figure 7-3). Similarly, the proportion of individual Northern Pike sampled from Gauer Lake that exceeded the 0.5 ppm standard (5.6%) was lower than observed for Northern Pike sampled from Granville Lake (28.8%; Figure 7-3). None of the Lake Whitefish or Yellow Perch sampled from either waterbody exceeded 0.5 ppm (Figure 7-2; Figure 7-3).

### 7.2.3 Temporal Comparisons

No significant differences in mercury concentrations were observed between years for Northern Pike or Lake Whitefish from either area of Southern Indian Lake (Figure 7-4). Inter-annual comparisons could not be undertaken for Walleye in either area due to the lack of a significant correlation between fish length and mercury concentration (i.e., data could not be length-standardized) for one of the two sampling years.

Conversely, Northern Pike from Granville Lake, Walleye from Gauer and Granville lakes, and perch from Gauer Lake contained mercury concentrations that were significantly higher in 2010 than 2013 (Figure 7-4).

## 7.3 SUMMARY

Mean length-standardized mercury concentrations for most species and years were below the 0.5 ppm Health Canada standard for commercial marketing of freshwater fish (Health Canada 2007a,b) and the Manitoba aquatic life tissue residue guideline for human consumers (MWS 2011) in on-system and off-system waterbodies. Only the mean length-standardized mercury concentration of Northern Pike marginally exceeded the standard in Southern Indian Lake – Area 6 in 2010.

Based on concentrations in individual fish, some of the Northern Pike and Walleye from Southern Indian Lake exceeded the standard, though there was variability observed between the two areas of the lake. No Walleye analysed from Area 4 contained mercury above 0.5 ppm, whereas 33% of Walleye from Area 6 exceeded this level. The higher frequency of exceedances of 0.5 ppm in Area 6 may be related to relatively small sample size obtained for Walleye in Area 6 in 2013 in conjunction with the relatively high proportion of larger fish in that sample. On the other hand, about the same proportion of Northern Pike (38-40%) from both areas of Southern Indian Lake exceeded the 0.5 ppm standard. These percentages were similar to those observed in Granville Lake but lower than Gauer Lake.

All of the Lake Whitefish and Yellow Perch sampled from both areas had mercury concentrations substantially lower than 0.5 ppm in Southern Indian, Granville, and Gauer lakes.

No inter-annual differences were observed for Northern Pike or Lake Whitefish from either area of Southern Indian Lake. Comparisons could not be made for Walleye, as data were inadequate for standardization to a common fish length. Conversely, Northern Pike from Granville Lake, Walleye from Gauer and Granville lakes, and Yellow Perch from Gauer Lake contained mercury concentrations that were significantly higher in 2010 than 2013.

Table 7-1. Arithmetic mean (±SE) and length-standardized (95% confidence limits, CL) mercury concentrations (ppm) for Lake Whitefish, Northern Pike, Walleye, and Yellow Perch from the Upper Churchill River Region: 2010-2013.

| Waterbody | Year | Species | n | Mercury Concentration (ppm) | | | |
|---|---|---|---|---|---|---|---|
| | | | | Arithmetic Mean | SE | Standard Mean | 95% CL |
| Granville Lake | 2010 | Pike | 37 | 0.513 | 0.038 | 0.441 | 0.392 - 0.497 |
| | | Walleye | 35 | 0.416 | 0.026 | 0.441 | 0.401 - 0.485 |
| | | Whitefish | 36 | 0.047 | 0.003 | 0.052 | 0.048 - 0.056 |
| | 2013 | Pike | 36 | 0.342 | 0.034 | 0.309 | 0.275 - 0.347 |
| | | Walleye | 36 | 0.289 | 0.022 | 0.278 | 0.251 - 0.309 |
| | | Walleye, 1-yr | 10 | 0.044 | 0.004 | 0.035 | 0.029 - 0.042 |
| | | Whitefish | 22 | 0.047 | 0.005 | 0.046 | 0.040 - 0.052 |
| | | Perch | 19 | 0.019 | 0.004 | - | - |
| Southern Indian Lake - Area 4 | 2010 | Pike | 36 | 0.408 | 0.026 | 0.371 | 0.330 - 0.417 |
| | | Walleye | 12 | 0.217 | 0.011 | NS | 0.194 - 0.240 |
| | | Whitefish | 37 | 0.07 | 0.003 | 0.072 | 0.066 - 0.079 |
| | 2013 | Pike | 36 | 0.476 | 0.028 | 0.414 | 0.363 - 0.473 |
| | | Walleye | 36 | 0.207 | 0.015 | 0.193 | 0.177 - 0.211 |
| | | Whitefish | 36 | 0.068 | 0.006 | 0.07 | 0.062 - 0.079 |
| | | Perch | 20 | 0.017 | 0.001 | - | - |
| Southern Indian Lake - Area 6 | 2010 | Pike | 28 | 0.499 | 0.053 | 0.52 | 0.443 - 0.610 |
| | | Walleye | 7 | 0.421 | 0.137 | 0.457 | 0.271 - 0.771 |
| | | Whitefish | 29 | 0.026 | 0.002 | 0.028 | 0.025 - 0.030 |
| | 2013 | Pike | 36 | 0.475 | 0.053 | 0.443 | 0.380 - 0.493 |
| | | Walleye | 8 | 0.479 | 0.049 | NS | 0.364 - 0.594 |
| | | Whitefish | 35 | 0.028 | 0.002 | 0.031 | 0.028 - 0.035 |
| | | Perch | 2 | 0.011 | 0.003 | - | - |
| Gauer Lake | 2010 | Pike | 36 | 0.238 | 0.022 | 0.202 | 0.182 - 0.224 |
| | | Walleye | 33 | 0.249 | 0.017 | 0.246 | 0.222 - 0.272 |
| | | Whitefish | 36 | 0.041 | 0.003 | 0.036 | 0.032 - 0.040 |
| | 2011 | Perch | 15 | 0.018 | 0.002 | - | - |
| | 2013 | Pike | 36 | 0.271 | 0.026 | 0.195 | 0.171 - 0.223 |
| | | Walleye | 36 | 0.182 | 0.016 | 0.18 | 0.162 - 0.201 |
| | | Whitefish | 36 | 0.033 | 0.003 | 0.034 | 0.030 - 0.037 |
| | | Perch | 15 | 0.009 | 0.001 | - | - |

NS = Not significant

Table 7-2. Mean (±SE) fork length, round weight, condition ($K_F$), and age of Lake Whitefish, Northern Pike, Walleye, and Yellow Perch from the Upper Churchill River Region: 2010-2013.

| Waterbody | Year | Species | n | Length (mm) | Weight (g) | $K_F$ | Age (years) |
|---|---|---|---|---|---|---|---|
| Granville Lake | 2010 | Pike | 375 | 588.9 ± 16.6 | 1577.3 ± 169.1 | 0.69 ± 0.01 | 7.0 ± 0.4 |
| | | Walleye | 356 | 376.4 ± 11.0 | 623.7 ± 49.7 | 1.07 ± 0.01 | 8.7 ± 0.5 |
| | | Whitefish | 367 | 308.3 ± 15.7 | 563.6 ± 86.5 | 1.42 ± 0.03 | 5.7 ± 0.6 |
| | 2013 | Pike | 36 | 545.6 ± 15.0 | 1229.2 ± 110.9 | 0.70 ± 0.01 | 5.7 ± 0.3 |
| | | Walleye | 368 | 394.8 ± 8.1 | 711.4 ± 41.8 | 1.11 ± 0.01 | 8.0 ± 0.4 |
| | | Whitefish | 229 | 341.6 ± 19.7 | 740.5 ± 123.1 | 1.51 ± 0.02 | 6.5 ± 0.7 |
| | | Perch | 2010 | 78.9 ± 2.1 | 7.2 ± 0.6 | 1.39 ± 0.02 | 1 – 2 |
| Southern Indian Lake - Area 4 | 2010 | Pike | 36 | 562.2 ± 14.9 | 1352.5 ± 110.2 | 0.71 ± 0.01 | 8.1 ± 0.5 |
| | | Walleye | 12 | 343.3 ± 17.7 | 549.2 ± 96.7 | 1.20 ± 0.03 | 5.5 ± 0.4 |
| | | Whitefish | 37 | 325.0 ± 10.1 | 480.8 ± 40.5 | 1.25 ± 0.02 | 11.1 ± 0.5 |
| | 2013 | Pike | 36 | 576.7 ± 13.5 | 1359.7 ± 102.7 | 0.67 ± 0.01 | 8.9 ± 0.5 |
| | | Walleye | 362 | 401.4 ± 15.5 | 869.4 ± 93.6 | 1.13 ± 0.02 | 7.3 ± 0.5' |
| | | Whitefish | 36 | 329.7 ± 9.9 | 518.6 ± 40.2 | 1.33 ± 0.02 | 12.4 ± 0.7 |
| | | Perch[3] | 204 | 76.7 ± 2.0 | 6.1 ± 0.5 | 1.31 ± 0.02 | 01-Feb |
| Southern Indian Lake - Area 6 | 2010 | Pike | 28 | 517.9 ± 15.8 | 987.1 ± 95.4 | 0.65 ± 0.01 | 7.2 ± 0.5 |
| | | Walleye | 7 | 337.4 ± 48.7 | 540.0 ± 189.0 | 1.07 ± 0.04 | 5.7 ± 1.1 |
| | | Whitefish | 291 | 324.1 ± 11.5 | 568.6 ± 58.9 | 1.55 ± 0.02 | 4.3 ± 0.3 |
| | 2013 | Pike | 36 | 537.5 ± 18.7 | 1193.6 ± 120.0 | 0.69 ± 0.01 | 6.6 ± 0.5 |
| | | Walleye | 8 | 443.0 ± 12.0 | 972.5 ± 77.3 | 1.10 ± 0.01 | 10.0 ± 0.6 |
| | | Whitefish | 35 | 309.1 ± 10.4 | 493.4 ± 60.2 | 1.46 ± 0.02 | 4.1 ± 0.3 |
| | | Perch | 2 | 86.0 ± 2.0 | 8.8 ± 0.4 | 1.38 ± 0.02 | - |
| Gauer Lake | 2010 | Pike | 36 | 572.8 ± 20.9 | 1492.8 ± 234.5 | 0.68 ± 0.01 | 6.2 ± 0.4 |
| | | Walleye | 3311 | 390.2 ± 10.2 | 682.9 ± 49.4 | 1.08 ± 0.02 | 10.4 ± 0.6 |
| | | Whitefish | 3612 | 372.7 ± 11.8 | 824.9 ± 79.6 | 1.41 ± 0.02 | 10.1 ± 1.1 |
| | 2011 | Perch | 15 | 78.3 ± 1.8 | 6.8 ± 0.5 | 1.39 ± 0.05 | - |
| | 2013 | Pike | 36 | 588.4 ± 22.6 | 1578.8 ± 176.1 | 0.68 ± 0.01 | 6.2 ± 0.4 |
| | | Walleye | 36 | 381.8 ± 16.4 | 781.7 ± 86.8 | 1.15 ± 0.02 | 8.9 ± 0.7 |
| | | Whitefish | 3613 | 333.1 ± 12.7 | 658.9 ± 78.7 | 1.50 ± 0.03 | 7.2 ± 0.8 |
| | | Perch | 1514 | 75.1 ± 1.4 | 4.9 ± 0.3 | 1.15 ± 0.03 | 1 |

[1] n=28 for weight; [2] n=30 for age; [3] measurements from frozen fish; [4] n=11 for age; [5] n=25 for age; [6] n=34 for age; [7] n=29 for age; [7] n=10 for age; [8] n=35 for age; [9] n=35 for age; [10] n=21 for age; [11] n=32 for age; [12] n=33 for age; [13] n=34 for age; [14] n=6 for age.

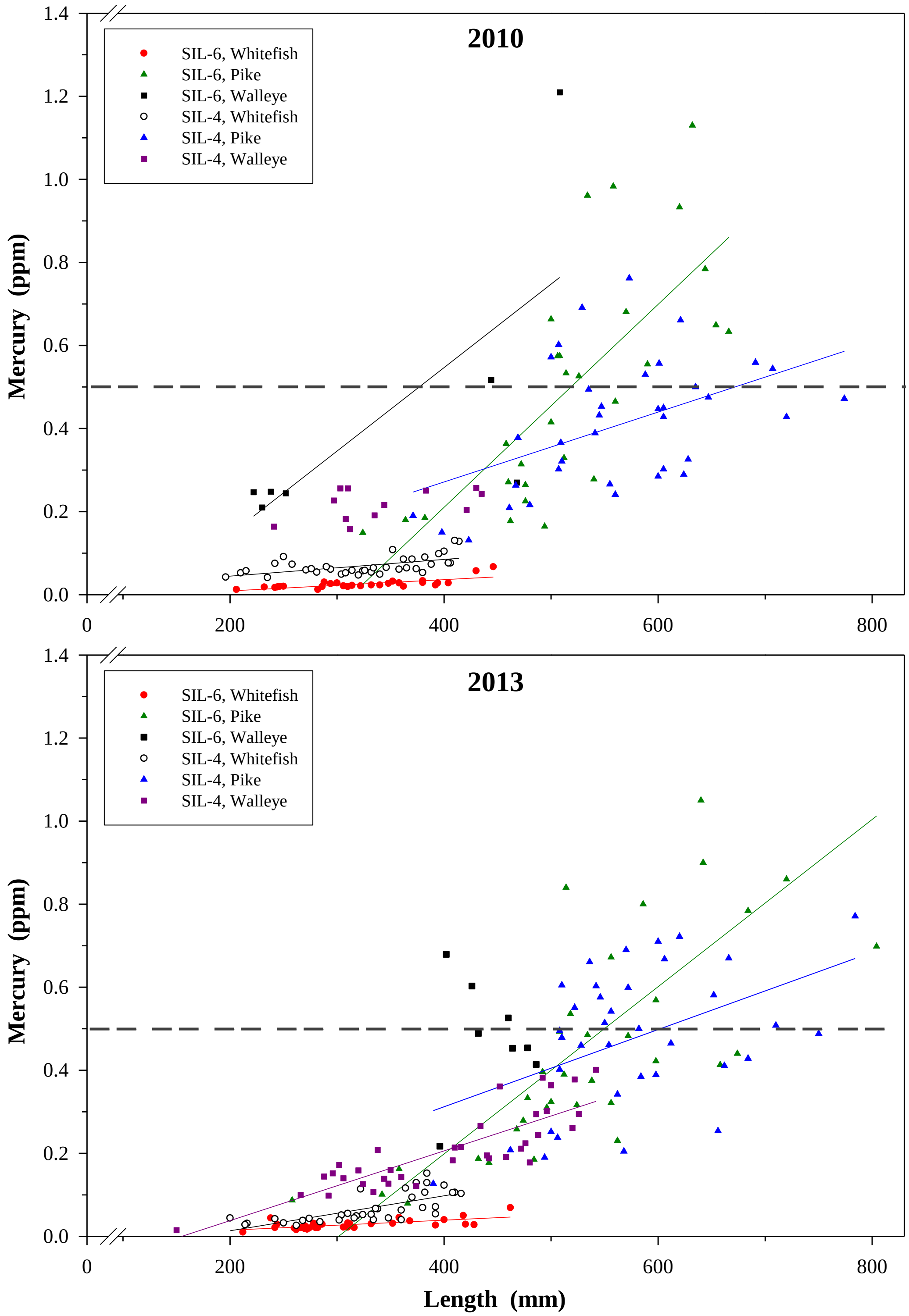



Figure 7-1. Relationship between mercury concentration and fork length for Lake Whitefish, Northern Pike, and Walleye from Southern Indian Lake – Areas 4 and 6 of in 2010 and 2013. Significant linear regression lines are shown. Dashed lines represent the Health Canada standard for retail fish.

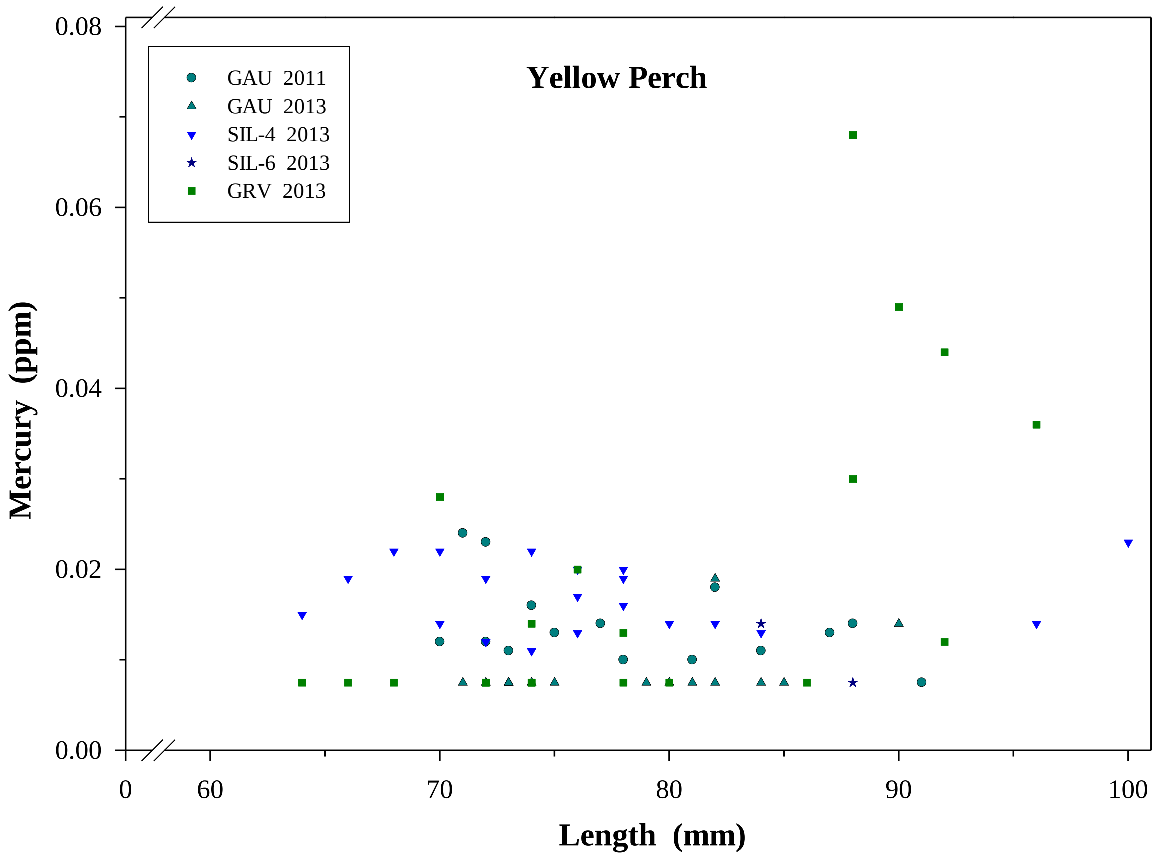



Figure 7-2. Relationship between mercury concentration and fork length for Yellow Perch from Gauer, Southern Indian, and Granville lakes from 2011-2013.

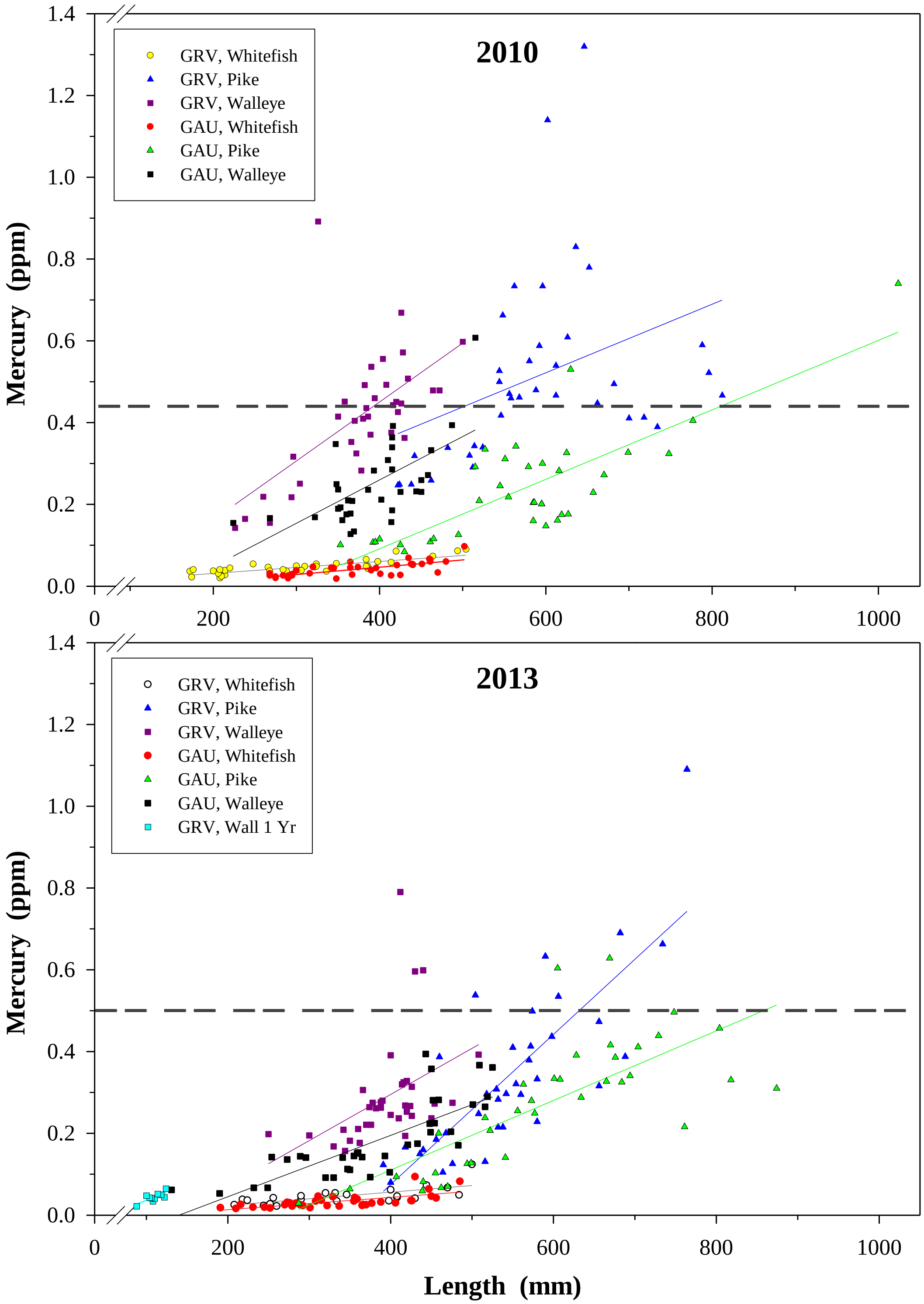
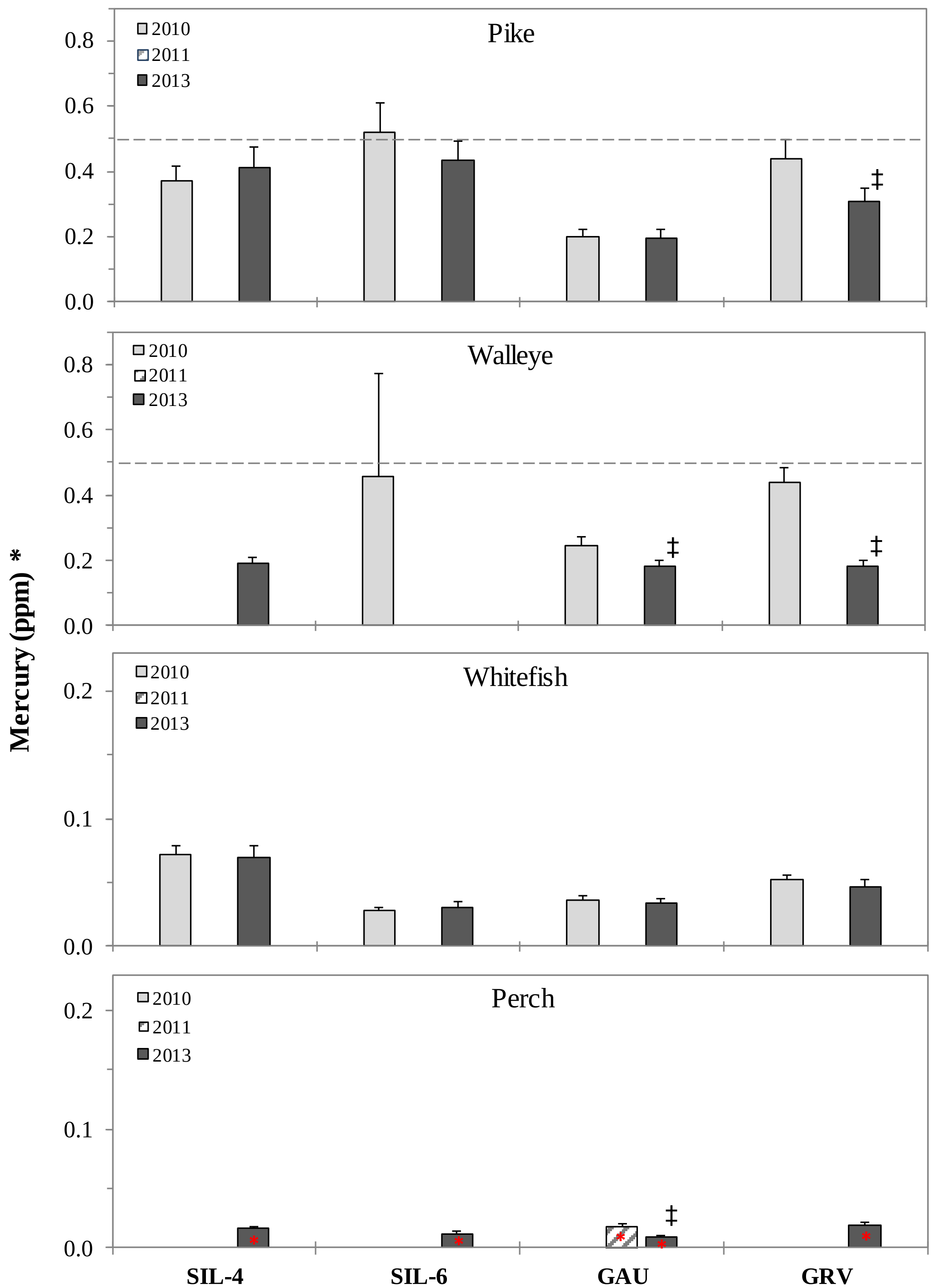



Figure 7-3. Relationship between mercury concentration and fork length for Lake Whitefish, Northern Pike, and Walleye (Wall) from Gauer and Granville lakes in 2010 and 2013. Significant linear regression lines are shown. Dashed lines represent the Health Canada standard for retail fish.




* Note differences in mercury scale among species.

Figure 7-4. Standard or arithmetic (asterisk) mean (upper 95% CL) mercury concentrations of Northern Pike, Walleye, Lake Whitefish, and Yellow Perch from the Upper Churchill River Region: 2010-2013. Significant differences between years are indicated by † (higher than 2010) or ‡ (lower than 2010). Dashed lines represent the 0.5 ppm standard for retail fish.

# 8.0 AQUATIC HABITAT INVENTORY

## 8.1 INTRODUCTION

The primary objective of the CAMP aquatic habitat inventories is to create depth and substrate distribution maps, which are two common habitat variables used in aquatic habitat assessments. A detailed description of the program design and sampling method is provided in Technical Document 1, Section 3.2. In brief, the CAMP aquatic habitat inventory program consists of hydroacoustic bottom surveys and collection of physical samples to validate the hydroacoustic data, and data analysis to create habitat maps.

Aquatic habitat inventory surveys were conducted in the UCRR on Area 4 of Southern Indian Lake in July and August of 2013 (Figure 8-1). The data collected during the surveys were used to produce depth and substrate distribution habitat maps, which were used to describe the depth, substrate, and overall aquatic habitat characteristics of Southern Indian Lake – Area 4 (referred to as Area 4 below).

## 8.2 BATHYMETRY

Southern Indian Lake – Area 4 is a large deep waterbody with over 92% of its area greater than 3 m in depth (Figures 8-2 and 8-3). Its mean depth is 13.49 m, and its average bed slope is 1.96% (Table 8-1). The maximum depth in the waterbody is 35.08 m relative to the average survey water surface elevation of 258.09 m (GS of CGVD28 Local 1969 Adj.). Area 4 is deep and flat throughout its central portions. One of the deeper areas that was surveyed in Area 4 (~ 35 m at its deepest) is Loon Narrows (~ 500 m at its widest) to the north of Loon Island. Loon Narrows also has steeply sloped banks/shorelines. The maximum bed slope in Area 4 is 33%. Deep drop-offs also occur to the east and west of Sheppard Island and offshore of a few other unnamed islands east of Sheppard Island. The largest continuous deep areas of the lake occur in the central portion of the waterbody. The wide channel connecting Area 3 in the south with Area 4 on the east side of Long Point is deep relative to the narrower channel on the west side. The transition from Area 4 to Area 5 in the north is shallower than the transition from Area 3 to Area 4. The total volume of Area 4, including Kame Hills Lake in the northwest, is 9,522,138,000 $m^3$.

## 8.3 SUBSTRATE

Southern Indian Lake – Area 4 is largely composed of silt and clay substrates (Table 8-2; Figure 8-4). Silt/Clay substrates comprise 31% and clay substrates comprise 16% of the area. Mixed sand/silt/clay loam substrates occupy 30% of Area 4. The shore zone is often rocky with varying degrees of embedded materials between fine substrates. Sand (12%) substrates are found intermittently throughout the nearshore areas. Rock substrates consisting of bedrock, and boulder and cobble sized material are often found throughout the shallow nearshore areas and comprise 10% of the overall substrate composition. Bedrock and rock shoals range from large gravel to boulder sized material. The deep offshore areas of the waterbody are typically of a soft silt/clay depositional nature. The typical offshore mud-bottomed Ponar grab sample was a base layer of compact grey clay substrate covered by a thick layer of light brown silt.

## 8.4 AQUATIC HABITAT SUMMARY

Southern Indian Lake – Area 4 is deep and voluminous. Substrate is fine in offshore areas but varies in the nearshore area. Rocky shoals are found throughout the nearshore areas of the waterbody and sand beaches are common. Macrophytes were not observed in any appreciable quantity during surveys, although timing of the surveys was targeted to avoid full aquatic plant bloom. The presence of a thick layer of brown silt in the upper layers of offshore sediments may reflect increased deposition following CRD.

Table 8-1. Summary of depth, slope, and volume statistics of Southern Indian Lake – Area 4 resulting from aquatic habitat surveys and mapping conducted in July and August 2013.

| **Area** | **Area[1] (ha)** | **Maximum Depth (m)** | **Mean Depth (m)** | **Maximum Slope (%)** | **Mean Slope (%)** | **Volume ($m^3$)** |
|---|---|---|---|---|---|---|
| Southern Indian Lake - Area 4 | 70,572 | 35.08 | 13.49 | 33 | 2 | 9,522,138,000 |

[1] A total of 202 ha of Southern Indian Lake – Area 4 were not mapped for bathymetry relative to the substrate mapping area.

Table 8-2. Summary of substrate distribution for Southern Indian Lake – Area 4 resulting from aquatic habitat surveys and mapping conducted in July and August 2013.

| **Substrate** | **Area (ha)** | **Total Area (%)** |
|---|---|---|
| Bedrock/Boulder/Cobble | 7,313 | 10 |
| Sand | 8,754 | 12 |
| Sand/Silt/Clay Loam | 20,996 | 30 |
| Silt/Clay | 22,213 | 31 |
| Clay | 11,139 | 16 |
| Organic | 320 | 0.5 |
| Not Classified | 38 | <0.5 |
| Total | 70,774 | 100 |

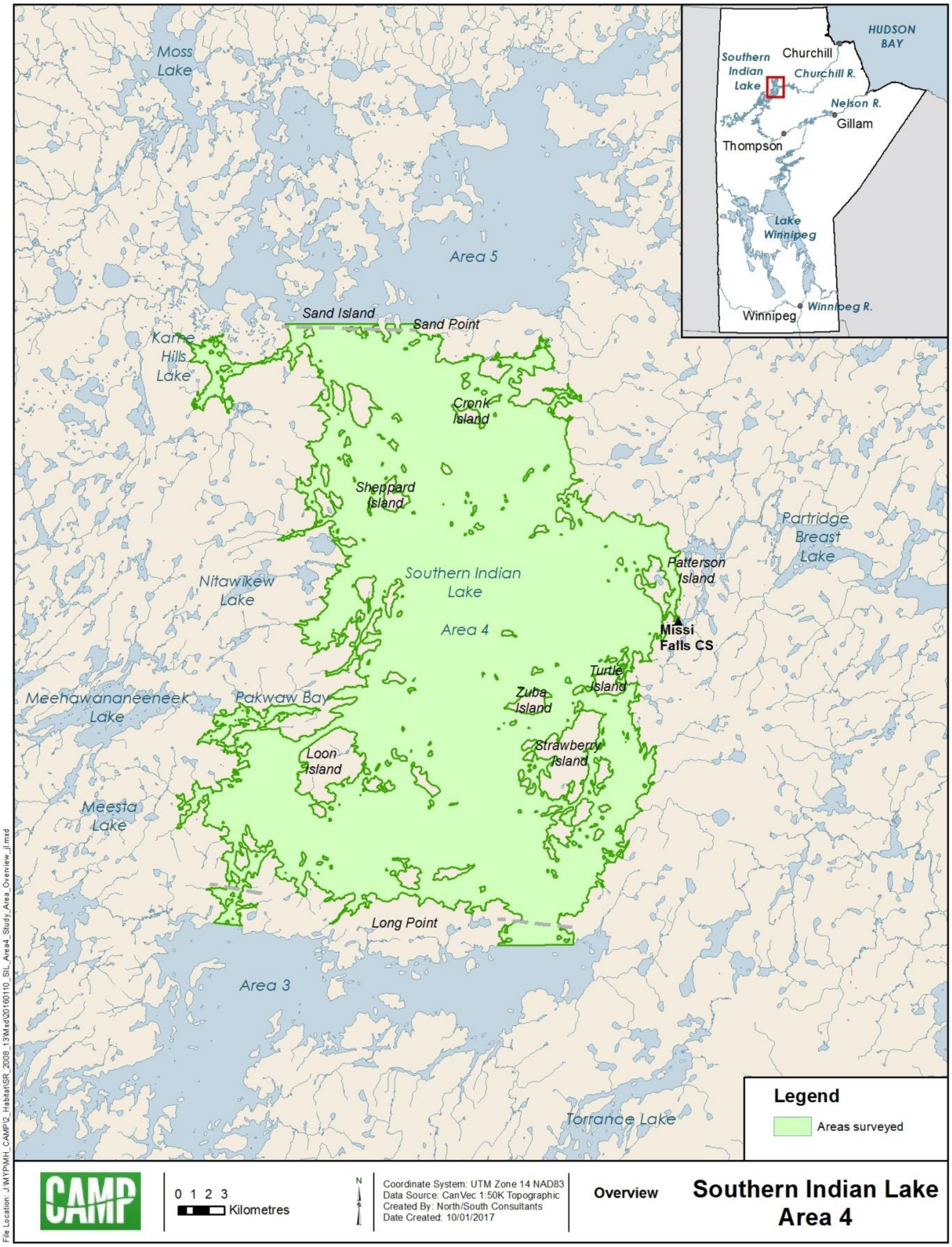



Figure 8-1. Area of habitat surveys on Area 4 of Southern Indian Lake.

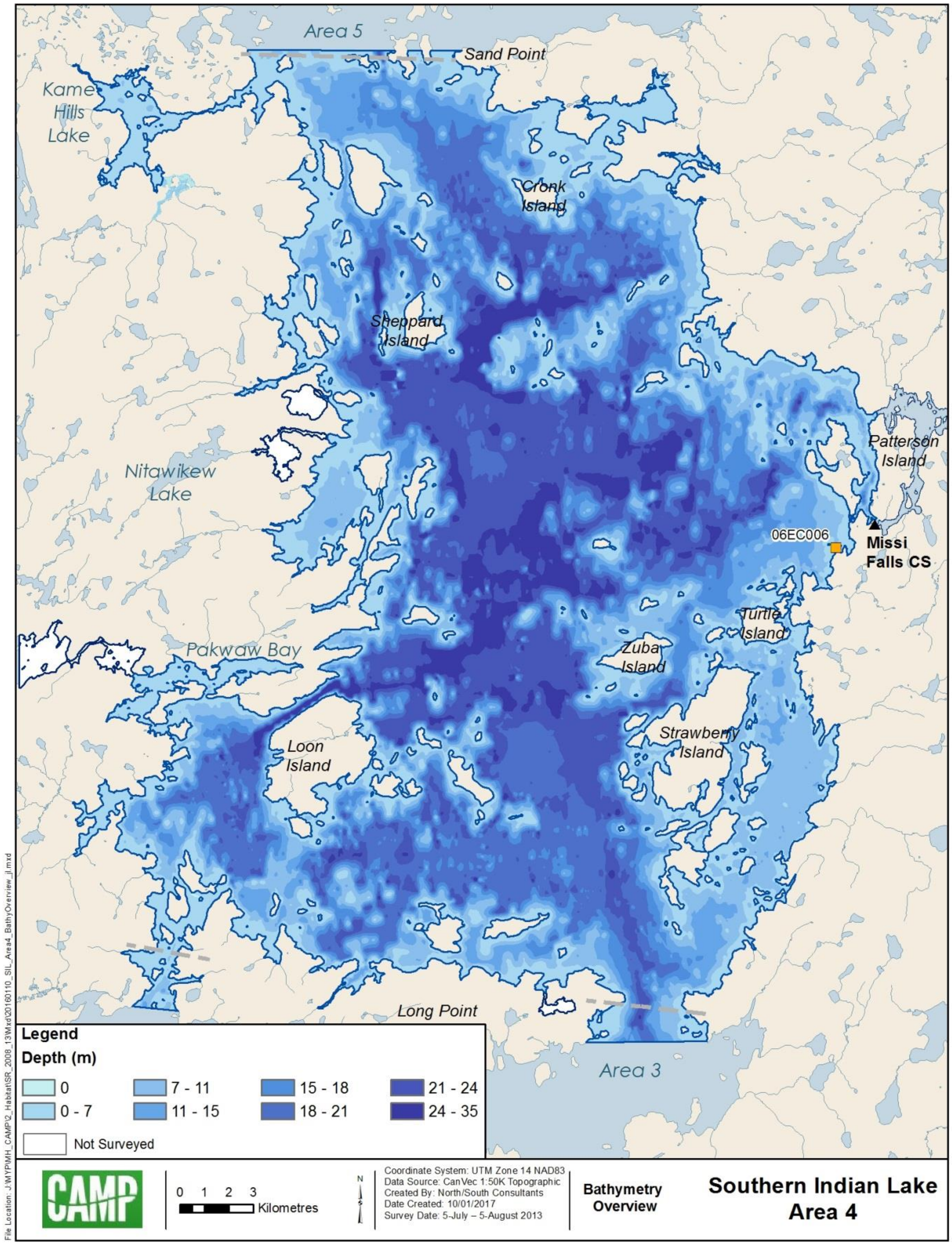



Figure 8-2. Overview bathymetric map of Southern Indian Lake Area 4 relative to a mean survey water surface elevation of 258.09 m (GS of CGVD28, 1969 Adj.).

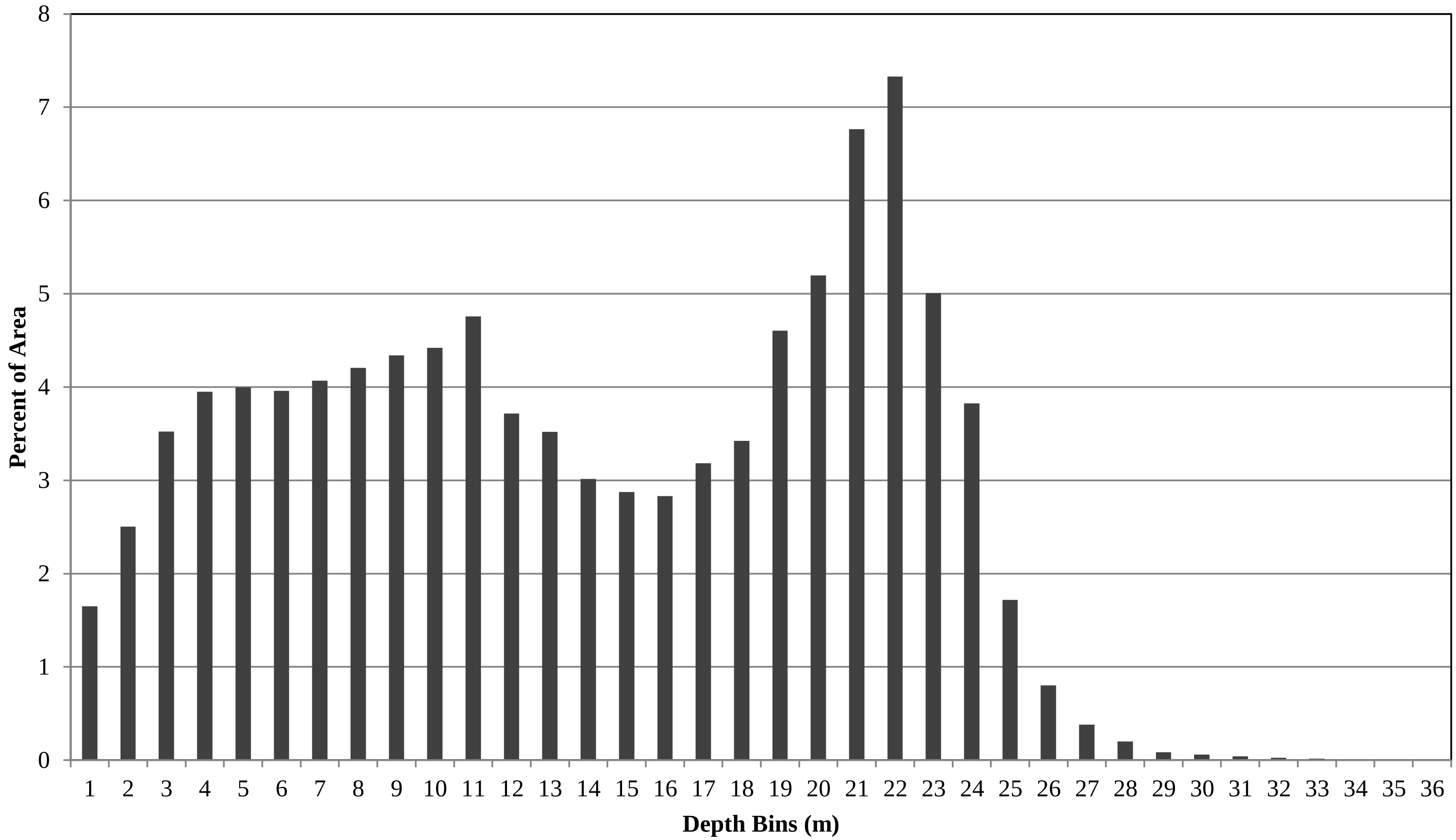



Figure 8-3. Depth distribution histogram depicting 1 m depth intervals by percentage of area covered in Southern Indian Lake Area 4 based on the July and August 2013 survey when mean water surface elevation was relative to the average survey water surface elevation of 258.09 m (GS of CGVD28 Local 1969 Adj.).

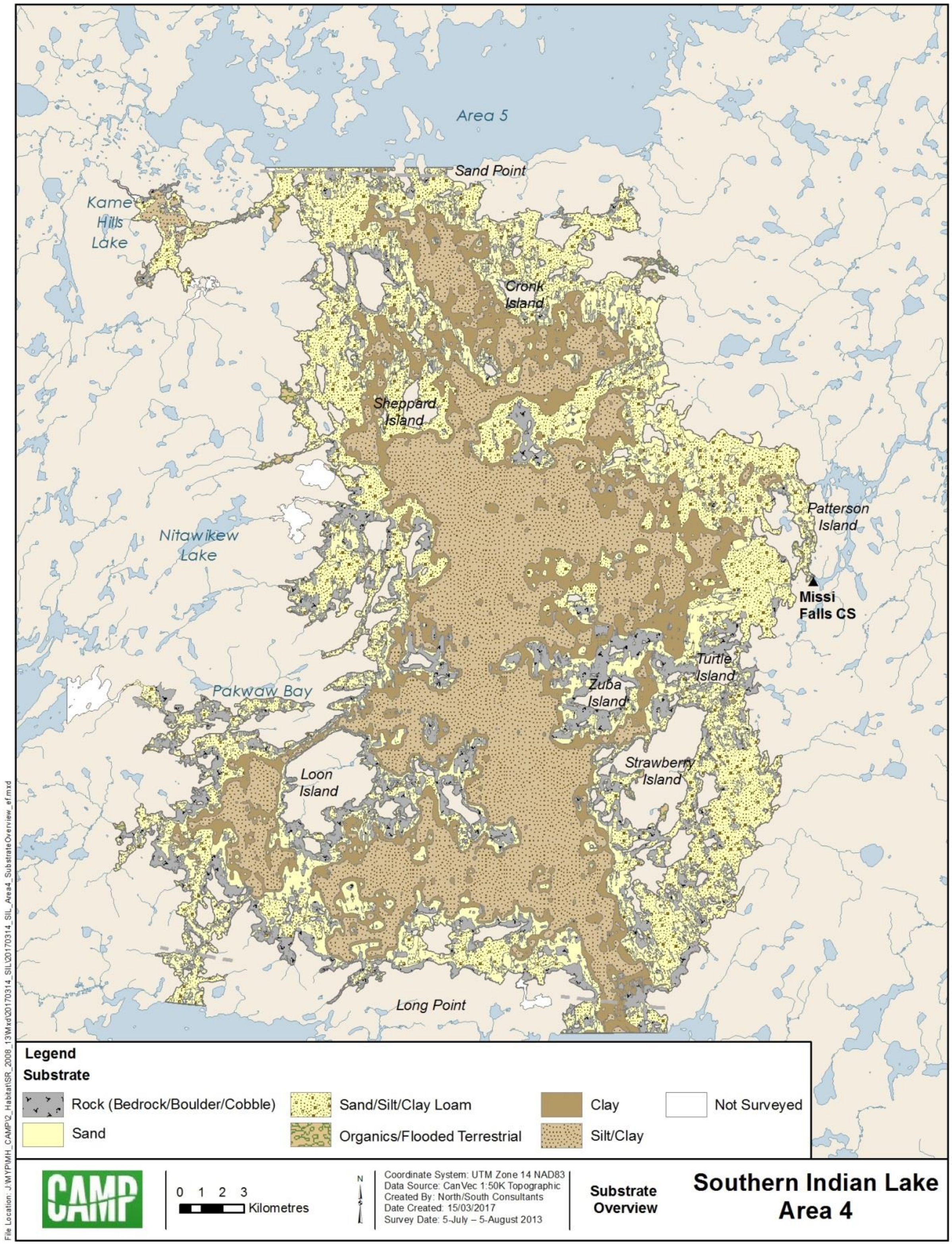



Figure 8-4. Overview substrate map of Southern Indian Lake – Area 4 produced from the 2013 habitat inventory surveys.

# 9.0 LITERATURE CITED


Alberta Environment & Sustainable Resource Development. 2014. Environmental quality guidelines for Alberta surface waters. Water Policy Branch, Policy Division, Edmonton. 48 pp.

Ayles, H.A., and Koshinsky, G.D. 1974. The fisheries of Southern Indian Lake: Present conditions and implications of hydroelectric development. Lake Winnipeg, Churchill and Nelson Rivers Study Board Technical Report, Appendix 5, Volume 1, Section H. 118 pp.

British Columbia Ministry of Environment (BCMOE). 2014. Ambient Water Quality Guidelines for Selenium: Technical Report Update. Water Protection and Sustainability Branch, Environmental Sustainability and Strategic Policy Division, April 2014.

BCMOE. 2017. British Columbia Approved Water Quality Guidelines: Aquatic Life, Wildlife & Agriculture. Summary Report. Water Protection & Sustainability Branch, January 2017.

Canadian Council of Ministers of the Environment (CCME). 1999. Canadian sediment quality guidelines for the protection of aquatic life: Arsenic. *In*: Canadian environmental quality guidelines, 1999, CCME, Winnipeg. 5 pp.

Canadian Council of Ministers of the Environment (CCME). 1999; updated to 2017. Canadian environmental quality guidelines. Canadian Council of Ministers of the Environment, Winnipeg, MB.

Edgington, D.N. and E. Callender. 1970. Minor element geochemistry of Lake Michigan ferromanganese nodules. Earth Planet. Sci. Lett. 8: 97-100.

Fisher, S.G. and Lavoy, A. 1972. Differences in littoral fauna due to fluctuating water levels below a hydroelectric dam. J. Fish. Res. Board Can. 29: 1472-1476.

Fletcher, R., P. Welsh, and T. Fletcher. 2008. Guidelines for identifying, assessing and managing contaminated sediments in Ontario: An integrated approach. Ontario Ministry of the Environment, May 2008.107 pp.

Harris, R.C. and A.G. Troup. 1970. Chemistry and origin of freshwater ferromanganese concretions. Limnol. Oceanogr. 15: 702-712.

Health Canada. 2007a. Human health risk assessment of mercury in fish and health benefits of fish consumption. Health Canada: Bureau of Chemical Safety, Food Directorate, Health Products and Food Branch, Ottawa, ON. 48 pp.

Health Canada. 2007b. Updating the existing risk management strategy for mercury in fish. Health Canada: Bureau of Chemical Safety, Food Directorate, Health Products and Food Branch, Ottawa, ON, 30 pp.

Hecky, R.E. 1974. Southern Indian Lake: sedimentary environments, recent basin history and implications of inundations and diversion. Lake Winnipeg, Churchill and Nelson Rivers Study Board technical report, Appendix 5, Volume 1, Section D. 60 pp.

Keeyask Hydropower Limited Partnership (KHLP). 2012. Keeyask Generation Project: Environmental impact statement, supporting volume: Aquatic environment. Keeyask Hydropower Limited Partnership, Winnipeg, MB.

Magurran, A. E. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, New Jersey. 189 pp.

Magurran, A. E. 2004. Measuring biological diversity. Blackwell. Malden Massachusetts.

Mandaville, S.M. 2002. Benthic invertebrates in freshwaters – taxa tolerance values, metrics, and protocols. Project H-1. Soil and Water Conservation Society of Metro Halifax. 48 pp. + Appendices.

Manitoba Hydro and the Province of Manitoba. 2015. Regional cumulative effects assessment for hydroelectric developments on the Churchill, Burntwood and Nelson river systems: Phase II Report. Winnipeg, MB. xxx + 4459 pp.

Manitoba Water Stewardship (MWS). 2011. Manitoba Water Quality Standards, Objectives, and Guidelines. Water Science and Management Branch, MWS. MWS Report 2011-01, November 28, 2011. 67 pp.

McCullough, G.K. 1981. Water budgets for Southern Indian Lake, Manitoba, before and after impoundment and Churchill River Diversion, 1972–1979. Can. Man. Rep. Fish. Aquat. Sci. 1620: 22 pp.

McTavish, W.B. 1952. A biological investigation of Southern Indian Lake, summer 1952. Manitoba Department of Mines and Natural Resources, Winnipeg, MB. 9 pp.

Meays, C. and R. Nordin. 2013. Ambient water quality guidelines for sulphate. Technical Appendix: Update April 2013. Water Protection & Sustainability Branch Environmental Sustainability and Strategic Policy Division, British Columbia Ministry of Environment.

Merritt R.W. and K.W. Cummins. 1996. Aquatic insects of North America. Kendall/Hunt Publishing Company. Dubuque, Iowa. 862 pp.

Minshall, G.W. 1984. Aquatic insect-substratum relationships. In The ecology of aquatic insects. Edited by Resh, V.H. and D.M. Rosenberg. Praeger Publishers, New York, NY. 358-400 pp.

Persaud, D., R. Jaagumagi, and A. Hayton. 1993. Guidelines for the protection and management of aquatic sediment quality in Ontario. Ontario Ministry of the Environment, Water Resources Branch, ISBN 0-7724-9248-7.

Post, J.E. 1999. Manganese oxide minerals: Crystal structures and economic environmental significance. Proc. Natl. Acad. Sci. USA 96: 3447-3454.

Ramsey, D.J. 1991. Federal ecological monitoring program: Final water quality report. Federal Ecological Monitoring Program, Technical Appendix, Volume 2. 320 pp.

Scheifhacken, N., C. Fiek, and K.-O. Rothhaupt. 2007. Complex spatial and temporal patterns of littoral benthic communities interacting with water level fluctuations and wind exposure in the littoral zone of a large lake. Fundamental and Applied Limnology 169: 115-129.

CAMP

Coordinated Aquatic Monitoring Program

www.campmb.com