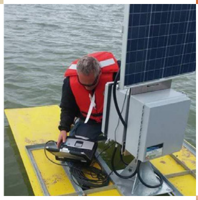
Coordinated Aquatic Monitoring Program



Six Year Summary Report

Technical Document 4: Lake Winnipeg Region

2008-2013

Submitted to:
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Introduction, Background, and Methods

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

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Winnipeg River Region Results

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- Water quality
- Sediment quality
- Benthic macroinvertebrates
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SIX YEAR SUMMARY REPORT (2008-2013)

Technical Document 4:

Lake Winnipeg 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

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ABBREVIATIONS AND ACRONYMS

ASL	Above sea level
BCMOE	British Columbia Ministry of Environment
BMI	Benthic macroinvertebrate(s)
CAMP	Coordinated Aquatic Monitoring Program
CCME	Canadian Council of Ministers of the Environment
CL	Confidence limit
CPUE	Catch-per-unit-effort
DL	Detection Limit
DO	Dissolved oxygen
EC	Environment Canada
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
FL-at-age	Fork-length-at age
GS(s)	Generating station(s)
ISQG	Interim sediment quality guideline
K_F	Condition Factor
KHLP	Keeyask Hydropower Limited Partnership
LEL	Lowest effect level
LKWPGR	Lake Winnipeg Region
LW-GR	Lake Winnipeg – Grand Rapids
LW-MB	Lake Winnipeg – Mossy Bay
LW-ST	Lake Winnipeg – Sturgeon Bay
LWR	Lake Winnipeg Regulation
MSD	Manitoba Sustainable Development
MWQSOGs	Manitoba Water Quality Standards, Objectives, and Guidelines
MWS	Manitoba Water Stewardship
n_F	Number of fish
n_Y	Number of years sampled
PAL	Protection of aquatic life
PEL	Probable effect level
ppm	Parts per million
Q (OW)	Average discharge during the open water period
Q (GN)	Average discharge during the gillnetting program
SAC	Sediment alert concentration
SE	Standard error of the mean
SEL	Severe effect level
SQG	Sediment quality guideline
SRR	Saskatchewan River Region

TDS	Total dissolved solids
TKN	Total Kjeldahl nitrogen
TN	Total nitrogen
TOC	Total organic carbon
TP	Total phosphorus
TSS	Total suspended solids
WL (OW)	Average water level during the open water period
WL (GN)	Average water level during the gillnetting program
WPGOSIS	Lake Winnipegosis
WPGOSIS-1	Lake Winnipegosis – Site 1
WPGOSIS-2	Lake Winnipegosis – Site 2
WPGOSIS-3	Lake Winnipegosis – Site 3
WPGOSIS-4	Lake Winnipegosis – Site 4
WPGOSIS-5	Lake Winnipegosis – Site 5
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 Lake Winnipeg Region (LKWPGR). As described in Technical Document 1, Section 2.8.1, the LKWPGR is composed of the north basin of Lake Winnipeg and the off-system Lake Winnipegosis. Monitoring occurs in one to three areas of the north basin of Lake Winnipeg, depending on the monitoring component:

- Grand Rapids area;
- Sturgeon Bay area; and
- Mossy Bay area.

Descriptions of the region and waterbodies monitored under CAMP are provided in Technical Document 1, Section 2.8. 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 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 each lake. Results presented below include a discussion of hydrology, water quality, sediment quality, benthic macroinvertebrates (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.

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 Lake Winnipeg 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
Lake Winnipeg – Sturgeon Bay	LW-SB [2,3]	X		X [2]		X	X	X	X	X	X
Lake Winnipeg – Grand Rapids	LW-GR	X		X [2]		X [4]	X	X	X	X	X
Lake Winnipeg – Mossy Bay	LW-MB [2]	X		X		X [4]	X	X	X	X	X
Lake Winnipegosis	WPGOSIS		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] Water quality is not monitored at this site.
[3] BMI are not monitored at this site.
[4] BMI sampling initiated at this site in 2013.

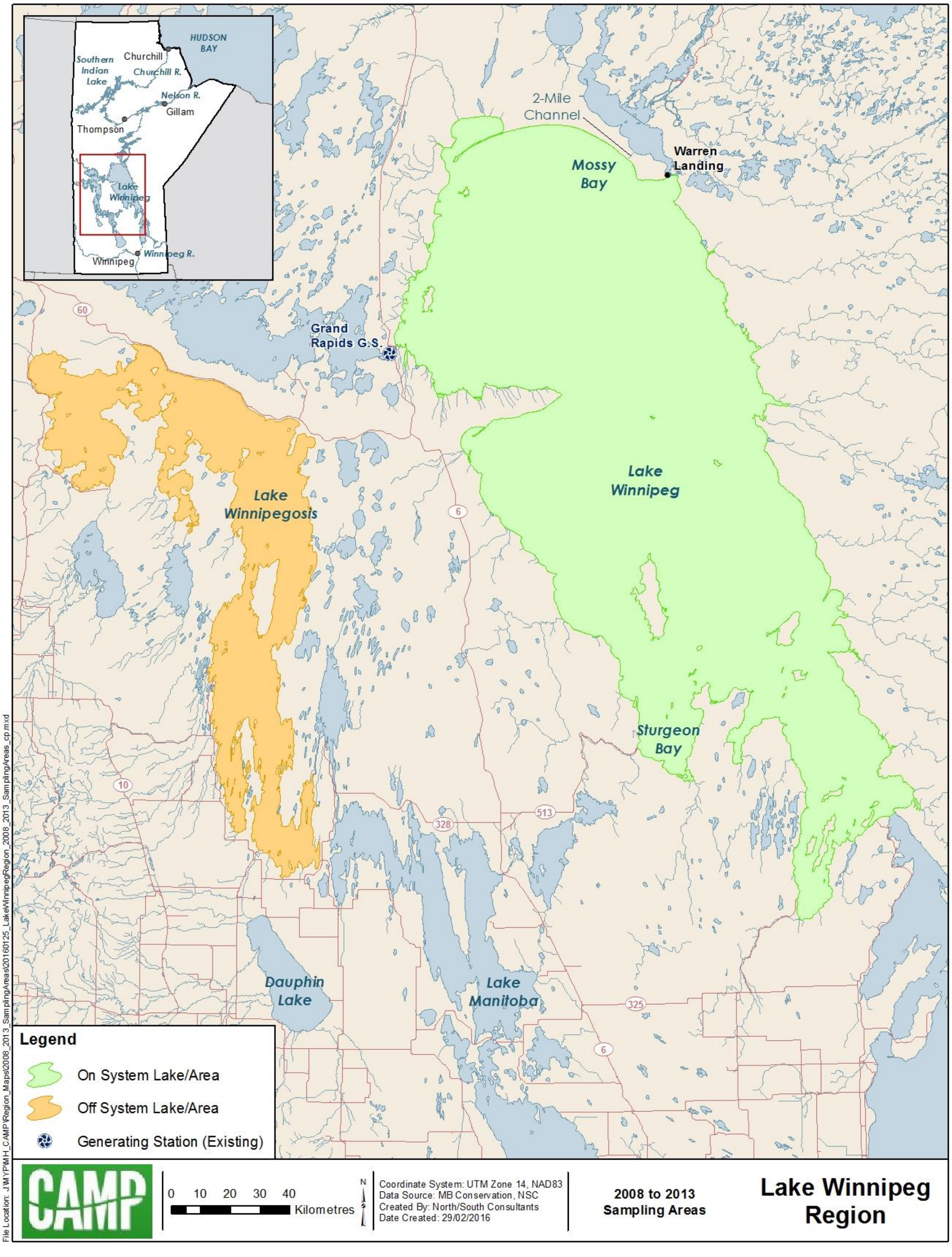


Figure 1-1. On-system and off-system waterbodies and river reaches sampled under CAMP in the Lake Winnipeg Region: 2008/2009-2013/2014.

2.0 HYDROLOGY

The Lake Winnipeg drainage basin covers an area of approximately 953,000 km^2, and is the second largest drainage basin in Canada. Water levels on Lake Winnipeg depend primarily on inflows from three major tributaries - the Winnipeg River, the Saskatchewan River, and the Red River. Water levels are also influenced by outflows which have been regulated by the Jenpeg Generating Station (GS) since 1976 for power production, flood reduction, and drought support. Other inflows come from smaller rivers such as the Dauphin, Berens, and Poplar rivers. Lake Winnipegosis is the off-system waterbody for this region and is located upstream within the Lake Winnipeg drainage basin, draining through Lake Manitoba into Lake Winnipeg.

From 2008 to 2013, water levels on Lake Winnipeg were generally above average due to above average precipitation in the Lake Winnipeg drainage basin. Water levels reached record highs for the period since Lake Winnipeg Regulation (LWR) became operational (i.e., post-1976) in late 2010 and through much of 2011. Water levels were above-average in each open-water season over the six year monitoring period with the lowest peak levels occurring in 2012. High water levels resulted in maximum discharge operations at the Jenpeg GS for parts of each open-water season from 2008 to 2011 and 2013 (Figure 2-1). Table 2-1 below provides the average annual inflow to Lake Winnipeg as well as the percent contribution from each of the major tributaries. The combined percent contribution from all east side and local tributaries is also provided.

Similar to Lake Winnipeg, water levels on Lake Winnipegosis remained above average for the entire period from 2008 to 2013 and were above the upper quartile most of the time. The only time water levels fell below the upper quartile was the second half of 2009 and the first half of 2010. In contrast to Lake Winnipeg, the lowest water levels in Lake Winnipegosis for the open-water season occurred in 2009. Water levels were also at record high in late 2010 and all of 2011 (Figure 2-2).

Table 2-1. Average annual Lake Winnipeg inflow and percent contribution from major tributaries.

Year	Annual Average Inflow to Lake Winnipeg (m^3/day)	Contribution from Tributary (%)				
		Winnipeg River	Saskatchewan River	Dauphin River	Red River	Eastern and Other Local Tributaries
2008	3260	41	18	5	7	30
2009	4045	38	10	4	14	34
2010	3768	30	17	4	15	32
2011	3806	24	28	11	20	17
2012	2618	28	29	12	6	25
2013	3090	33	29	7	12	19

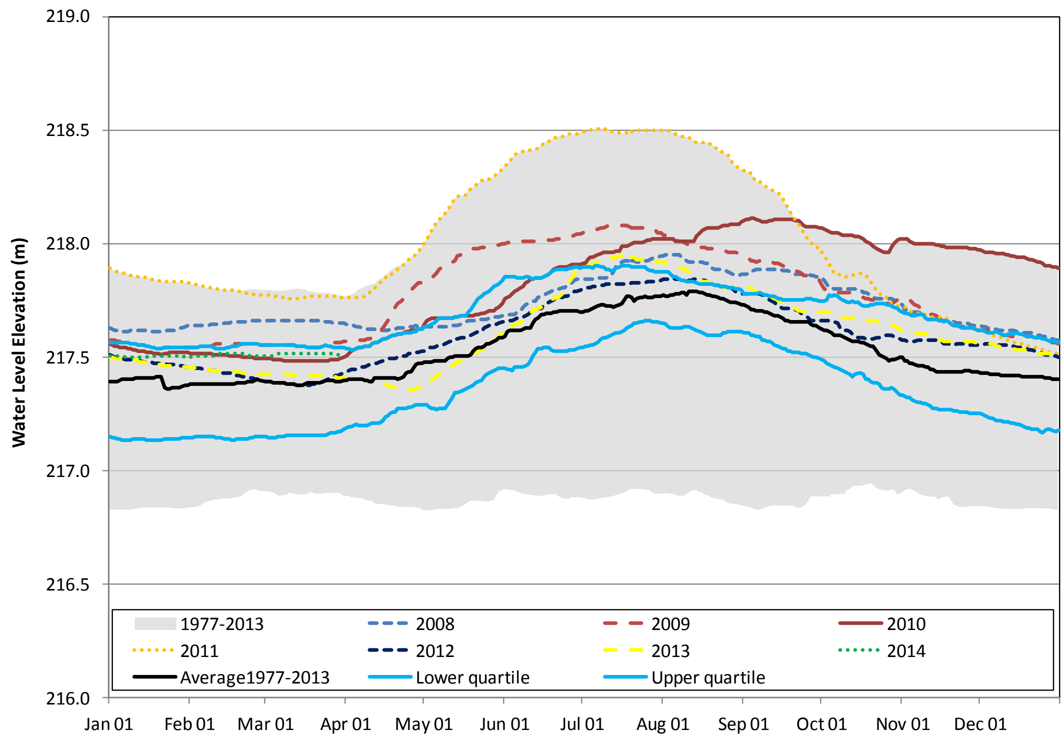


Figure 2-1. 2008-2013 Lake Winnipeg wind-eliminated water level elevation.

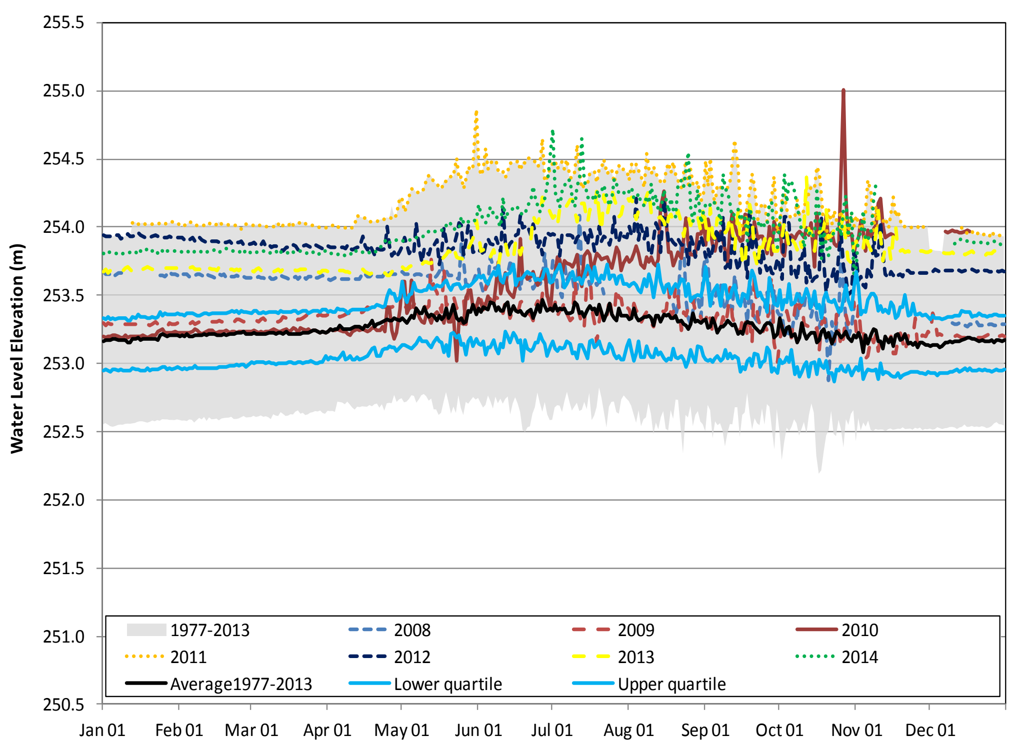


Figure 2-2. 2008-2013 Lake Winnipegosis (05LH001) water level elevation.

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 LKWPGR. While extensive water quality monitoring is conducted by Manitoba Sustainable Development (MSD) in the north basin of Lake Winnipeg, results included in this report are restricted to a single sampling station in the lake (referred to as "Lake Winnipeg – Grand Rapids"), located east of the Grand Rapids GS (Table 3-1; Figure 3-1). Water quality monitoring conducted in the off-system waterbody – Lake Winnipegosis – has been modified since CAMP was initiated; the program initially included monitoring at five sites, but was reduced to three sites in 2011, and ultimately to one site in 2013. Water quality monitoring conducted in the Lake Winnipeg outlets (Two-Mile Channel and the Nelson River) under CAMP is discussed in Technical Document 8: Upper Nelson River Region.

Sampling was mostly completed as intended at the two annual sampling sites. However, two exceptions occurred:

- Lake Winnipeg – Grand Rapids: sampling not completed in winter 2014 due to difficulty securing air transportation; and
- Lake Winnipegosis Site 3: sampling was not completed in spring 2009 due to issues with access (i.e., high winds).

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).

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 annual sites; 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 (annual mean water level) and water quality metrics to evaluate correlations.

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 LKWPGR 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 (DO; 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*, total suspended solids (TSS), turbidity, and Secchi disk depth. A detailed description of key indicators is provided in Technical Document 1, Section 4.3.1.

Results for parameters in addition to the key metrics were also 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 Lake Winnipeg

While *in situ* depth profile data, including measurement of DO and temperature, were collected at the Lake Winnipeg – Grand Rapids site, data were not available at the time of preparation of this report. As a consequence, information is insufficient to evaluate the occurrence of thermal stratification. However, measurements of temperature and DO near the surface and near the bottom of the water column, which were typically collected, were available for inclusion in this report. These data indicate relatively substantive differences in water temperature (i.e., up to 5 to 6 ^{o}C) between the top and bottom of the water column (total water depth was approximately 13-14 m) during a number of sampling events, that suggests this site may have been stratified.

Dissolved oxygen, which was measured at an analytical laboratory rather than in the field with a water quality meter, was typically above PAL objectives in the open-water season (Figure 3-2). DO was below one or both of the PAL objectives (i.e., 6.5 mg/L for cold-water aquatic life and 6.0 mg/L for cool-water aquatic life) in two summers near the surface (2008 and 2010) and near the bottom of the water column (2010 and 2012). Concentrations were below 5 mg/L, which is the instantaneous minimum objective for cool-water aquatic life and the 7-day minimum for cold-water aquatic life, at the bottom in summer 2010 and 2012. Lower DO conditions were observed in one winter (2011/2012) when DO was 3.4 mg/L near the bottom of the water column.

3.2.1.2 Off-system Waterbody: Lake Winnipegosis

Thermal stratification was observed at each of the five water quality sampling sites in Lake Winnipegosis in most winters and in some spring and/or summer periods at four of the five sites (all but site 5; Table 3-2).

Dissolved oxygen was typically lower at the bottom of the water column in winter and concentrations were below PAL objectives in the hypolimnion in the summers of 2010 and 2012. DO was lower at depth and concentrations were below the most stringent DO objective (9.5 mg/L for cold-water aquatic life) in each winter at a minimum of one site (Figures 3-3 to 3-8); concentrations were also below the PAL objective for cool-water aquatic life (5.5 mg/L) at depth in several winters. Oxygen depletion is more likely to develop in lakes during long periods of stratification, notably near the bottom of the water column over winter. Similar to the Lake Winnipeg site, DO was also below one or more PAL objectives at depth at two sites (Site 1 and Site 5) in one or two summers, indicating depletion is not restricted to the ice-cover season in this lake.

3.2.1.3 Temporal Comparisons and Trends

There were no statistically significant differences in concentrations or percent saturation of DO (open-water season) between years at the Lake Winnipeg – Grand Rapids site or at the annual monitoring site (Site 3) in the off-system Lake Winnipegosis. In addition, there was no indication of an increasing or decreasing trend in oxygen conditions over the six year monitoring period at either site.

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 Lake Winnipeg

TSS concentrations (Figure 3-9) and *in situ* turbidity levels (turbidity was not measured in the laboratory at this site; Figure 3-10) were relatively low at the Lake Winnipeg – Grand Rapids site over the six years of monitoring (mean TSS = 6.2 mg/L and *in situ* turbidity = 3.9 NTU). Both metrics were similar to those measured upstream of the Grand Rapids GS in Cedar Lake (see Technical Document 3, Section 3.2.2.1), as well as the off-system Lake Winnipegosis. Secchi disk depths (range of 1.1 to 3.5 m) were also comparable to those measured upstream in

Cedar Lake or the off-system waterbody (Figure 3-11). Of the three metrics, Secchi disk depth, followed by turbidity, was the least variable.

3.2.2.2 Off-system Waterbody: Lake Winnipegosis

Water clarity in Lake Winnipegosis was generally similar to that observed at the Lake Winnipeg monitoring site (Figures 3-9 to 3-11). The highest mean open-water season TSS and laboratory turbidity occurred in 2012.

3.2.2.3 Temporal Comparisons and Trends

Statistical comparisons of water clarity metrics between years at the annual on-system site in Lake Winnipeg indicate no significant differences for any the three water quality metrics over the six year period. Qualitative examination of the data for the six-year period does not suggest increasing or decreasing trends in TSS or turbidity over the six year monitoring period; as Secchi disk depth was not measured in 2012 and 2013, trend analysis could not be undertaken.

Significant inter-annual differences were observed for laboratory turbidity, which was highest in 2012, at the annual site monitored in the off-system waterbody (i.e., Lake Winnipegosis - Site 3; Figure 3-12). Laboratory turbidity was not measured in Lake Winnipeg.

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 (TP and TN) 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 Lake Winnipeg

The single site in the north basin of Lake Winnipeg near Grand Rapids incorporated into CAMP indicates this area was nutrient-rich (meso-eutrophic to eutrophic based on TP [Figure 3-13] and mesotrophic to eutrophic based on TN [Figure 3-14]) and supported a relatively high concentration of phytoplankton (mesotrophic to eutrophic based on chlorophyll *a*; Figure 3-15). Of the three metrics, chlorophyll *a* was the most variable and exhibited a higher variability than the off-system sites monitored in Lake Winnipegosis.

Unlike most on-system lakes monitored under CAMP, over the period of 2008-2013 a significant positive correlation between TP and chlorophyll *a* was found for the monitoring site in the north basin of Lake Winnipeg (Figure 3-16). This is in contrast to the annual site in the off-system waterbody (Lake Winnipegosis - Site 3), where no significant relationship was observed for this period. TN was not correlated to chlorophyll *a* in either the on- or off-system waterbody (Figure 3-16).

On average, TP concentrations were in excess of the Manitoba narrative nutrient guideline for lakes, ponds, and reservoirs and streams near the point of entry to these waterbodies (0.025 mg/L) in all but one year (2013) of monitoring at the Lake Winnipeg site (Figure 3-17). Exceedance of this guideline was observed in other CAMP regions and is commonly observed in other more southern lakes and streams in Manitoba, including Lake Winnipeg (Environment Canada [EC] and MWS 2011). The highest average TP concentrations occurred in 2008 which reflects an atypically high measurement (0.086 mg/L) collected in the summer sampling period. This high concentration of TP co-occurred with a high TSS measurement (39 mg/L) and was largely comprised of particulate phosphorus (63%). Chlorophyll *a* was not measured during this sampling event.

The ratio of chlorophyll *a* to TP (average of 0.29) - an indicator of the efficiency of assimilating phosphorus into algae - was in the range observed at the off-system Lake Winnipegosis (mean ratios of 0.24 to 0.39; Table 3-3). Twenty-eight percent of chlorophyll *a* measurements collected in the open-water season exceeded 10 µg/L (the level identified under CAMP as indicative of an algal bloom).

3.2.3.2 Off-system Waterbody: Lake Winnipegosis

The off-system waterbody (Lake Winnipegosis) was also moderately to highly nutrient-rich, but concentrations of nutrients varied across sites. TP (Figure 3-13) and chlorophyll *a* (Figure 3-15) were highest, and most similar to the Lake Winnipeg – Grand Rapids site, at Site 1 near the north end of the lake. TN concentrations were more similar across sites in Lake Winnipegosis but were somewhat higher relative to Lake Winnipeg (Figure 3-14).

Neither TN nor TP were correlated to chlorophyll *a* at the annual monitoring site in Lake Winnipegosis (Figure 3-16). This may indicate factors other than nutrients are limiting to phytoplankton growth and/or that nutrients are of limited bioavailablity to algae and/or or that bioavailability of nutrients is limited, but may also reflect the relatively limited data acquired for examination of inter-relationships among metrics.

On average, TP concentrations were below the Manitoba guideline for TP for lakes (0.025 mg/L) at four sites (sites 2-5) but exceeded the guideline at Site 1 near the north end of the lake (Table 3-3). Exceedance frequencies ranged from 0% at Sites 2 and 4 to 67% at Site 1. A higher number of chlorophyll *a* measurements at Site 1 (73%) exceeded 10 µg/L, relative to other sites in the lake or for the site in Lake Winnipeg.

3.2.3.3 Temporal Comparisons

There were no statistically significant inter-annual differences for nitrogen, phosphorus, or chlorophyll *a* at the annual monitoring sites in Lake Winnipeg (Grand Rapids) or Lake Winnipegosis (Site 3). However, as previously noted, chlorophyll *a* was highly variable in most years in Lake Winnipeg which limits the statistical power of the data set. The lowest mean chlorophyll *a* concentration, and the lowest degree of variability of the data, measured in Lake Winnipeg occurred in the open-water season of 2009/2010. The open-water season mean was also notably lower than the annual mean in this year – an occurrence that was not observed in any other year. Though this coincided with a period of low discharge from the Grand Rapids GS (see Technical Document 3, Section 2.0), data are too limited for detailed exploration of potential causes. None of the metrics appeared to experience an increasing or decreasing trend over the six years of monitoring in Lake Winnipeg or Lake Winnipegosis.

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. There were no strong indications of trends for non-key water quality metrics for the Lake Winnipeg site over the period of 2008-2013. However, several non-key metrics were highest in 2013, including:

- total alkalinity (Figure 3-18);
- specific conductance (Figure 3-19);
- sulphate (Figure 3-20); and
- hardness (Figure 3-21).

Though these observations may suggest a trend has recently begun to develop since the inception of CAMP (i.e., since 2008), additional data are required to truly determine if these observations reflect inter-annual, or short-term variability, relative to long-term trends. While significant inter-annual differences for these metrics were also observed at the off-system site

(Lake Winnipegosis – Site 3), conditions did not follow the same temporal pattern as those in Lake Winnipeg.

Specific conductance, hardness, and sulphate also indicated a slight increase in Cedar Lake (southeast) over the monitoring period; as the Saskatchewan River is the largest tributary to the north basin Lake Winnipeg and the monitoring site in Lake Winnipeg is relatively close to the Grand Rapids GS, these observations may be indicative, at least in part, of Saskatchewan River influence. However, a more comprehensive analysis would be required to assess potential influences on water quality in the north basin of Lake Winnipeg as a whole.

Ammonia, nitrate/nitrite, and pH remained within PAL guidelines/objectives at all sites and times, both on- and off-system. Most metals, excepting aluminum, iron, and selenium, were also consistently within Manitoba water quality PAL objectives and guidelines at the Lake Winnipeg site. Aluminum was above the PAL guideline (0.1 mg/L) in 43% of samples and iron exceeded the PAL guideline (0.3 mg/L) in 4% of samples at this site (Table 3-4). While neither aluminum nor iron exceeded PAL guidelines at any of the sites in Lake Winnipegosis, exceedances are common in northern Manitoba lakes and rivers and are also observed in other lakes and rivers unaffected by hydroelectric development, including off-system sites monitored under CAMP (Ramsey 1991; Keeyask Hydropower Limited Partnership [KHLP] 2012; Manitoba Hydro and the Province of Manitoba 2015). One measurement of selenium (representing 4% of samples) also marginally exceeded the PAL guideline (0.001 mg/L) in summer 2011 in Lake Winnipeg; exceedances of this guideline were also observed at each Lake Winnipegosis site with exceedance frequencies ranging from 4-25% of measurements.

Chloride is relatively high in Lake Winnipegosis and 65 to 100% of measurements collected across the five monitoring sites exceeded the Canadian Council of Ministers of the Environment (CCME 1999; updated to 2017) PAL guideline (Table 3-4). No exceedances were observed in Lake Winnipeg. Sulphate remained within the British Columbia Ministry of the Environment (BCMOE) PAL guidelines (128-429 mg/L; Meays and Nordin 2013) in both the on- and off-system lakes monitored in this region.

3.4 RELATIONSHIPS WITH HYDROLOGICAL METRICS

Water quality conditions vary spatially within Lake Winnipeg, including within the north basin of the lake (EC and MWS 2011). Unlike many of the on-system lakes monitored under CAMP, Lake Winnipeg has a relatively long water residence time (approximately 2.5-7 years; Manitoba Hydro 2014) and water quality is affected by inflows over a broader time frame than lakes with shorter residence times. In addition, water quality differs between the various tributaries to Lake Winnipeg and the relative flow (i.e., contribution) of these tributaries varies over time.

Therefore, an examination of relationships between hydrological conditions and water quality in the north basin of Lake Winnipeg is complex and must consider a broader dataset for the lake itself, as well as discharge and water quality conditions of the various inflows. As such, a comprehensive analysis is outside of the scope of CAMP. As CAMP captures only a single monitoring site in the north basin of the lake, relationships between water quality and hydrological conditions was limited to an exploratory analysis based on lake water level and data collected for this single site.

Significant relationships were found between annual mean water level, calculated as a rolling average, and a number of water quality metrics at the Lake Winnipeg CAMP site (Table 3-5). TN (Figure 3-22), dissolved phosphorus (Figure 3-23), and the fraction of TP in dissolved form (Figure 3-24) were significantly positively correlated to the annual mean water level at this site. Conversely, specific conductance (Figure 3-25), total dissolved solids ([TDS] Figure 3-26), and magnesium (Figure 3-27) were negatively correlated to annual mean lake water level.

As described in Section 2.0, the first six years of CAMP occurred during a wet cycle in the Lake Winnipeg drainage basin. Lake water level was above average during each open-water season and was at record levels in late 2010 and most of 2011. Therefore, the lower end of the hydrograph is not represented within the time period presented in this report and relationships with water level or other hydrological metrics may vary with inclusion of a wider range of water levels and hydrological conditions, as well as additional monitoring data. Further, as noted above, water quality in Lake Winnipeg is affected by a complexity of factors including relative contribution of flows and loading from the various tributaries, as well as in-lake processes. In addition, the analyses were conducted using data collected from a single site in the north basin of the lake. For these reasons, the results of the preliminary analyses of relationships between hydrological and water quality metrics should be considered as an initial exploratory exercise.

3.5 SUMMARY

Analysis of the six years of CAMP monitoring data collected in the north basin of Lake Winnipeg indicated that most water quality metrics were within PAL objectives and guidelines and metrics that exceeded PAL guidelines in this region are commonly above these benchmarks in northern Manitoba lakes and rivers.

Dissolved oxygen concentrations were below chronic objectives for the protection of aquatic life at the Lake Winnipeg site in three summers and one winter. For comparison, low DO conditions occurred more regularly in the off-system Lake Winnipegosis. Lake Winnipeg was nutrient-rich (mesotrophic to eutrophic) and had a relatively high water clarity. Water quality varied across sites in Lake Winnipegosis and TP and chlorophyll *a* were highest, and most similar to the Lake Winnipeg site, in the northern area of the lake.

Unlike most on-system lakes monitored under CAMP, over the period of 2008-2013 TP and chlorophyll *a* were positively correlated for the monitoring site in the north basin of Lake Winnipeg, while no significant relationship was observed for Lake Winnipegosis. This relationship, while typically observed in lakes, was not commonly observed for CAMP waterbodies over the six-year period possibly owing to the limited data and/or range of conditions measured.

Several non-key metrics were highest in 2013, including total alkalinity, specific conductance, sulphate, and hardness and some water quality metrics were found to be significantly correlated to lake water level. Specific conductance, TDS, and magnesium were negatively correlated, whereas several nutrient metrics (TN, dissolved phosphorus, and the fraction of TP in dissolved form) were positively correlated, to lake water level. However, the first six years of CAMP coincided with a period of relatively high water levels in Lake Winnipeg and relationships with hydrological metrics observed for this time period and this data set (i.e., at this location) may not be representative of the north basin of the lake as a whole or of relationships that may exist over a broader range of hydrological conditions. Furthermore, relationships between hydrological conditions and water quality in the north basin of Lake Winnipeg must consider a broader dataset for the lake itself, as well as discharge and water quality conditions of the various inflows. As such, a comprehensive analysis is outside of the scope of CAMP. Relationships with hydrological metrics and evaluation of longer-term patterns in the data (i.e., trend analysis) will be further explored as additional data are acquired through CAMP.

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

Site	Site Abbreviation	Site ID	On-system	Off-system	Annual	Rotational	Sampling Years					
							2008/09	2009/10	2010/11	2011/12	2012/13	2013/14
Lake Winnipeg – Grand Rapids	LW-GR	SHS 004	X		X		X	X	X	X	X	X
Lake Winnipegosis – Site 1	WPGOSIS-1	LFS 003		X	X		X	X	X	X	X	
Lake Winnipegosis – Site 2	WPGOSIS-2	LFS 004		X	X		X	X	X			
Lake Winnipegosis – Site 3	WPGOSIS-3	LFS 005		X	X		X	X	X	X	X	X
Lake Winnipegosis – Site 4	WPGOSIS-4	LGS 016		X	X		X	X	X			
Lake Winnipegosis – Site 5	WPGOSIS-5	LHS 003		X	X		X	X	X	X	X	

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

Metric		Waterbody					
		LW-GR	WPGOSIS-1	WPGOSIS-2	WPGOSIS-3	WPGOSIS-4	WPGOSIS-5
Years Sampled		2008/09-2013/14	2008/09-2012/13	2008/09-2010/11	2008/09-2013/14	2008/09-2010/11	2008/09-2012/13
TP	(mg/L)	0.0335	0.0271	0.0176	0.0129	0.0155	0.0214
	Trophic Status	Meso-eutrophic	Meso-eutrophic	Mesotrophic	Mesotrophic	Mesotrophic	Meso-eutrophic
TN	(mg/L)	0.53	0.76	0.63	0.68	0.76	0.84
	Trophic Status	Mesotrophic	Eutrophic	Mesotrophic	Eutrophic	Eutrophic	Eutrophic
Chlorophyll *a*	(µg/L)	8.55	9.78	4.33	3.27	3.24	6.11
	Trophic Status	Eutrophic	Eutrophic	Mesotrophic	Mesotrophic	Mesotrophic	Mesotrophic
TKN	(mg/L)	0.51	0.74	0.61	0.66	0.73	0.81
TN:TP	-	42	75	88	146	111	117
DOC	(mg/L)	-	12.3	12.2	11.8	11.4	14.4
Nitrate/nitrite	(mg N/L)	0.0235	0.0192	0.0165	0.0230	0.0256	0.0337
Ammonia	(mg N/L)	0.012	0.017	0.023	0.016	0.038	0.027
Dissolved Phosphorus	(mg/L)	0.018	0.010	0.009	0.006	0.008	0.011
DO Lower than MWQSOGs for PAL	(Y/N)	Summer (2008, 2010, 2012); winter (2011/12)	Summer at depth (2010); winter at depth (2008/09, 2009/10, 2011/12, 2012/13)	Winter at depth (2008/09, 2009/10)	Winter at depth (2009/10, 2011/12, 2012/13, and 2013/14)	Winter at depth (2008/09, 2009/10)	Summer at depth (2010, 2012); winter at depth (2008/09, 2009/10, 2012/13)
DO - open-water season (surface)	(mg/L)	9.43	9.72	9.20	9.52	8.84	9.87
DO - open-water season (bottom)	(mg/L)	8.81	8.32	8.71	9.39	8.45	8.95
DO - ice-cover season (surface)	(mg/L)	12.35	15.15	14.75	15.42	14.64	15.25
DO - ice-cover season (bottom)	(mg/L)	8.44	4.34	3.64	7.63	2.99	5.13
Thermal Stratification	(Y/N)	IS	Yes (spring 2008; summer 2010, 2011; each winter)	Yes (spring 2008, 2010; winter 2008/09, 2009/10, 2010/11)	Yes (spring 2010, 2013; each winter)	Yes (spring 2010; winter 2008/09, 2009/10, 2010/11)	Yes (winter 2008/09, 2009/2010, 2011/12)
Secchi Disk Depth (open-water)	(m)	2.06	1.66	2.09	1.57	1.78	1.19
TSS	(mg/L)	6.2	5.2	3.3	4.2	3.7	5.8
Turbidity	(NTU)	-	2.8	2.2	2.9	2.6	4.4
True Colour	(TCU)	17.9	16.6	8.6	5.6	6.3	8.8
Specific Conductance	(µmhos/cm)	366	877	1142	1120	1353	1121
TDS	(mg/L)	224	523	672	650	792	662
Hardness	(mg/L)	151	229	225	229	242	257
Hardness Category	-	Hard	Very Hard	Very Hard	Very Hard	Very Hard	Very Hard
pH	-	-	8.50	8.48	8.45	8.47	8.43
Total Alkalinity	(mg/L)	124	185	181	178	171	188
Metals/Major Ions > MWQSOGs for PAL	-	Al, Fe, Se	Cl, Se, Ag	Cl, Se, Ag	Cl, Hg, Se	Cl, Se	Cl, Se
Aluminum	(mg/L)	0.130	0.019	0.015	0.022	0.015	0.024
Iron	(mg/L)	0.125	0.029	0.017	0.020	0.018	0.028
Mercury (<26 ng/L DL only)	(mg/L)	-	<20	<20	<20	<20	<20
Mercury (1 ng/L DL only)	(mg/L)	-	<1	-	5.2	-	<1
Calcium	(mg/L)	35.9	54.9	51.4	50.9	50.6	54.5
Magnesium	(mg/L)	14.83	22.23	23.55	24.74	28.18	29.28
Potassium	(mg/L)	3.14	6.76	7.82	7.82	9.12	8.54
Sodium	(mg/L)	20.7	96.9	147	146	188	143
Chloride	(mg/L)	20.2	147	233	224	288	218
Sulphate	(mg/L)	40.2	50.2	52.3	53.5	59.3	66.6

TKN = total Kjeldahl nitrogen; DOC = dissolved organic carbon; IS = Insufficient data; TDS = total dissolved solids; DL = detection limit

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

Indicator	**Metric**		**Units**	**Waterbody**					
				LW-GR	**WPGOSIS-1**	**WPGOSIS-2**	**WPGOSIS-3**	**WPGOSIS-4**	**WPGOSIS-5**
Nutrients	TP	Mean	(mg/L)	0.0339	0.0315	0.0187	0.0135	0.0157	0.0209
		Trophic Status	-	Meso-eutrophic	Meso-eutrophic	Mesotrophic	Mesotrophic	Mesotrophic	Meso-eutrophic
	TN	Mean	(mg/L)	0.52	0.79	0.62	0.68	0.75	0.82
		Trophic Status	-	Mesotrophic	Eutrophic	Mesotrophic	Eutrophic	Eutrophic	Eutrophic
	Chlorophyll *a*	Mean	(µg/L)	9.24	12.2	5.34	3.75	3.76	7.06
		Trophic Status	-	Eutrophic	Eutrophic	Mesotrophic	Mesotrophic	Mesotrophic	Mesotrophic
	TN:TP	Mean	-	40	60	84	139	111	113
		Nutrient Limitation		P-Limitation	P-Limitation	P-Limitation	P-Limitation	P-Limitation	P-Limitation
	Chlorophyll *a*:TP	Mean	-	0.29	0.39	0.28	0.33	0.24	0.37
	Chlorophyll *a*:TN	Mean	-	0.021	0.017	0.009	0.007	0.007	0.010
	Algal Bloom Frequency (Chlorophyll *a* >10 µg/L)	-	(%)	28	73	14	0	0	20
Dissolved Oxygen	DO Lower than MWQSOGs for PAL	-	(Y/N)	Summer (2008, 2010, 2012)	Summer at depth (2010)	No	No	No	Summer at depth (2010, 2012)
	DO	Surface	(mg/L)	9.43	9.72	9.20	9.52	8.84	9.87
		Bottom	(mg/L)	8.81	8.32	8.71	9.39	8.45	8.95
	Thermal Stratification	-	(Y/N)	NA	Yes (spring 2008; summer 2010, 2011)	Yes (spring 2008, 2010)	Yes (spring 2010, 2013)	Yes (spring 2010)	No
Water Clarity	Secchi Disk Depth	Mean	(m)	2.06	1.66	2.09	1.57	1.78	1.19
	TSS	Mean	(mg/L)	7.3	6.5	4.0	5.3	4.5	7.4
	Turbidity	Mean	(NTU)	-	3.39	2.91	3.75	3.29	5.42

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 Lake Winnipeg 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	0.000277 - 0.000745	0.0883 - 0.2638	0.00957 - 0.02998	0.3	0.00330 - 0.01811	0.000026	0.073	0.0535 - 0.1657	0.001	0.0001	0.0008	0.015	0.123 - 0.381	120	309 - 429
Lake Winnipeg-Grand Rapids	n	23	23	23	23	23	23	23	23	0	23	23	23	23	23	23	23	23	23
	# Exceedances	**10**	0	0	0	0	0	**1**	0	-	0	0	**1**	0	0	0	0	0	0
	% Exceedance	**43**	0	0	0	0	0	**4**	0	-	0	0	**4**	0	0	0	0	0	0
Lake Winnipegosis-Site 1	n	20	20	20	20	20	20	20	20	3	20	20	20	20	20	20	20	20	20
	# Exceedances	0	0	0	0	0	0	0	0	0	0	0	**1**	**1**	0	0	0	**13**	0
	% Exceedance	0	0	0	0	0	0	0	0	0	0	0	**5**	**5**	0	0	0	**65**	0
Lake Winnipegosis-Site 2	n	10	10	10	10	10	10	10	10	3	10	10	10	10	10	10	10	10	10
	# Exceedances	0	0	0	0	0	0	0	0	0	0	0	**1**	**1**	0	0	0	**10**	0
	% Exceedance	0	0	0	0	0	0	0	0	0	0	0	**10**	**10**	0	0	0	**100**	0
Lake Winnipegosis-Site 3	n	23	23	23	23	23	23	23	23	7	23	23	23	23	23	23	23	23	23
	# Exceedances	0	0	0	0	0	0	0	0	0	0	0	**1**	0	0	0	0	**23**	0
	% Exceedance	0	0	0	0	0	0	0	0	0	0	0	**4**	0	0	0	0	**100**	0
Lake Winnipegosis-Site 4	n	12	12	12	12	12	12	12	12	3	12	12	12	12	12	12	12	12	12
	# Exceedances	0	0	0	0	0	0	0	0	0	0	0	**3**	0	0	0	0	**12**	0
	% Exceedance	0	0	0	0	0	0	0	0	0	0	0	**25**	0	0	0	0	**100**	0
Lake Winnipegosis-Site 5	n	20	20	20	20	20	20	20	20	11	20	20	20	20	20	20	20	20	20
	# Exceedances	0	0	0	0	0	0	0	0	**1**	0	0	**4**	0	0	0	0	**17**	0
	% Exceedance	0	0	0	0	0	0	0	0	**9**	0	0	**20**	0	0	0	0	**85**	0

[1] Only measurements made with an analytical detection limit of <26 ng/L included.

Table 3-5. Linear regressions between annual mean water level in Lake Winnipeg and water quality measured at the CAMP monitoring site in the north basin of Lake Winnipeg in the open-water season: 2008-2013. Only significant correlations are presented.

Metric	Units	R^2	p-value	Direction
Total Nitrogen	(mg/L)	0.361	0.008	+
Dissolved Phosphorus	(mg/L)	0.330	0.013	+
Dissolved Fraction of Phosphorus	(%)	0.412	0.004	+
Laboratory Specific Conductance	(µmhos/cm)	0.487	0.001	-
Total Dissolved Solids	(mg/L)	0.336	0.012	-
Magnesium	(mg/L)	0.223	0.048	-

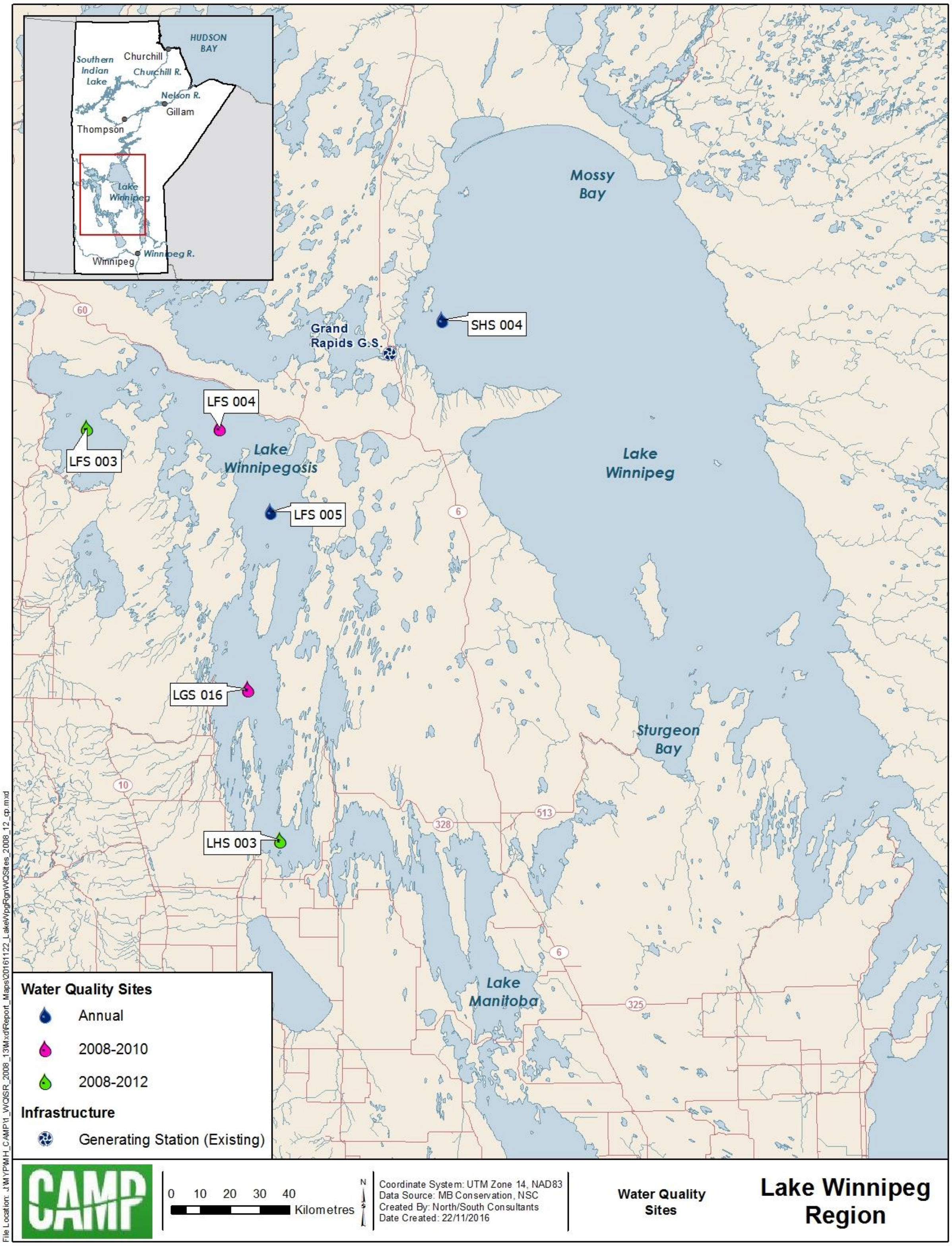


Figure 3-1. Water quality sampling sites in the Lake Winnipeg Region: 2008/2009-2013/2014.

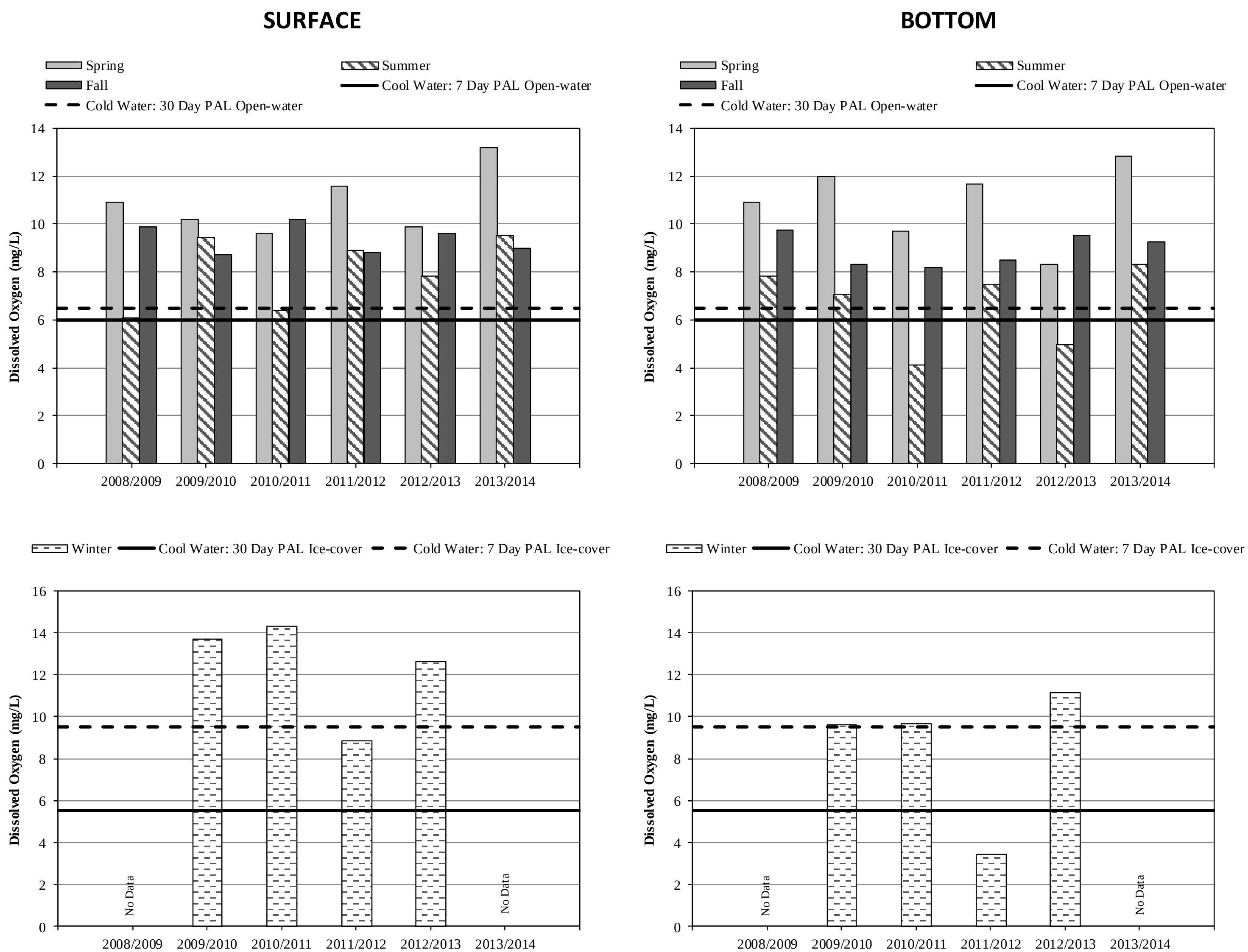


Figure 3-2. Dissolved oxygen measured near the surface and bottom of the water column in Lake Winnipeg near Grand Rapids and comparisons to MB PAL objectives: 2008/2009-2013/2014.

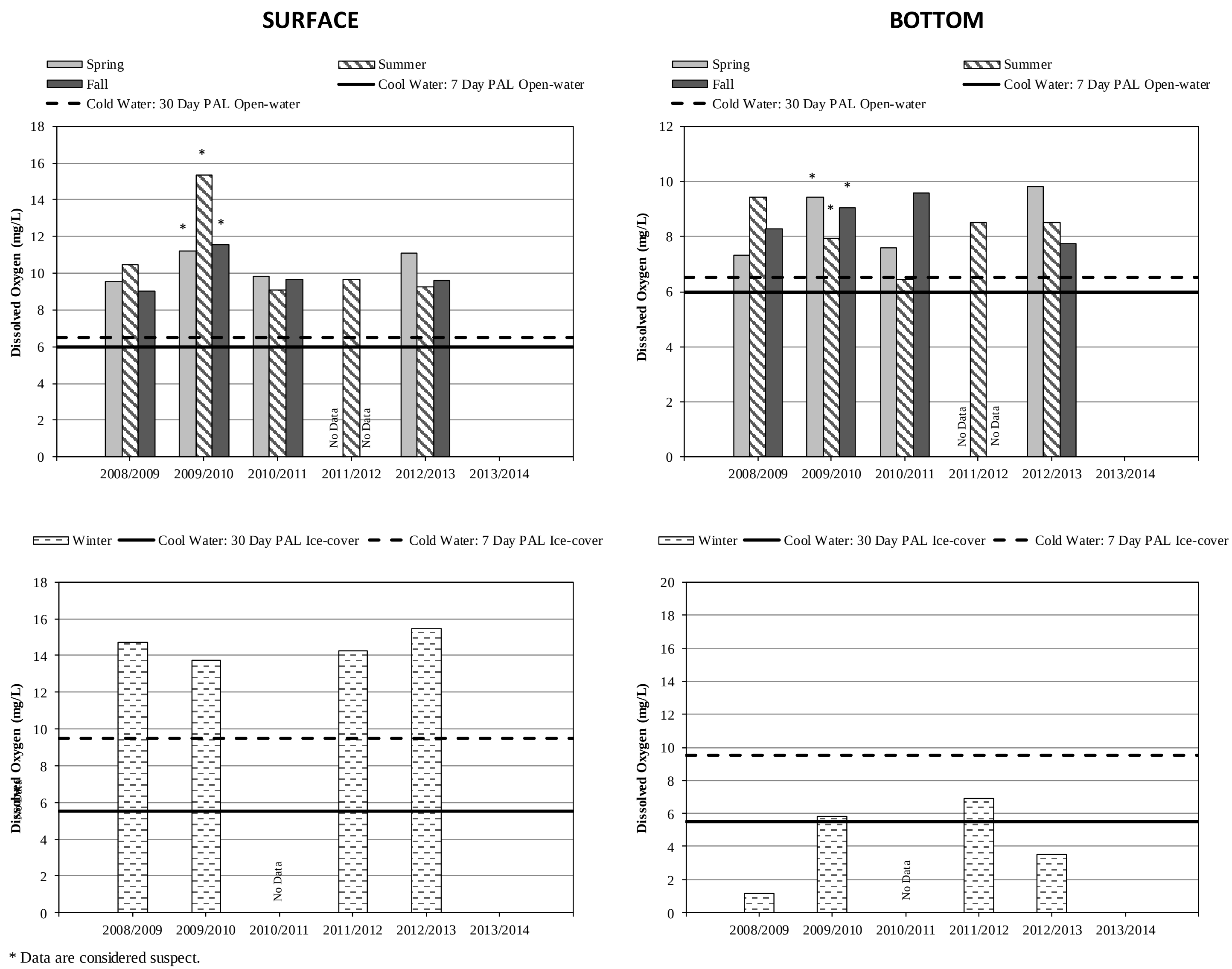
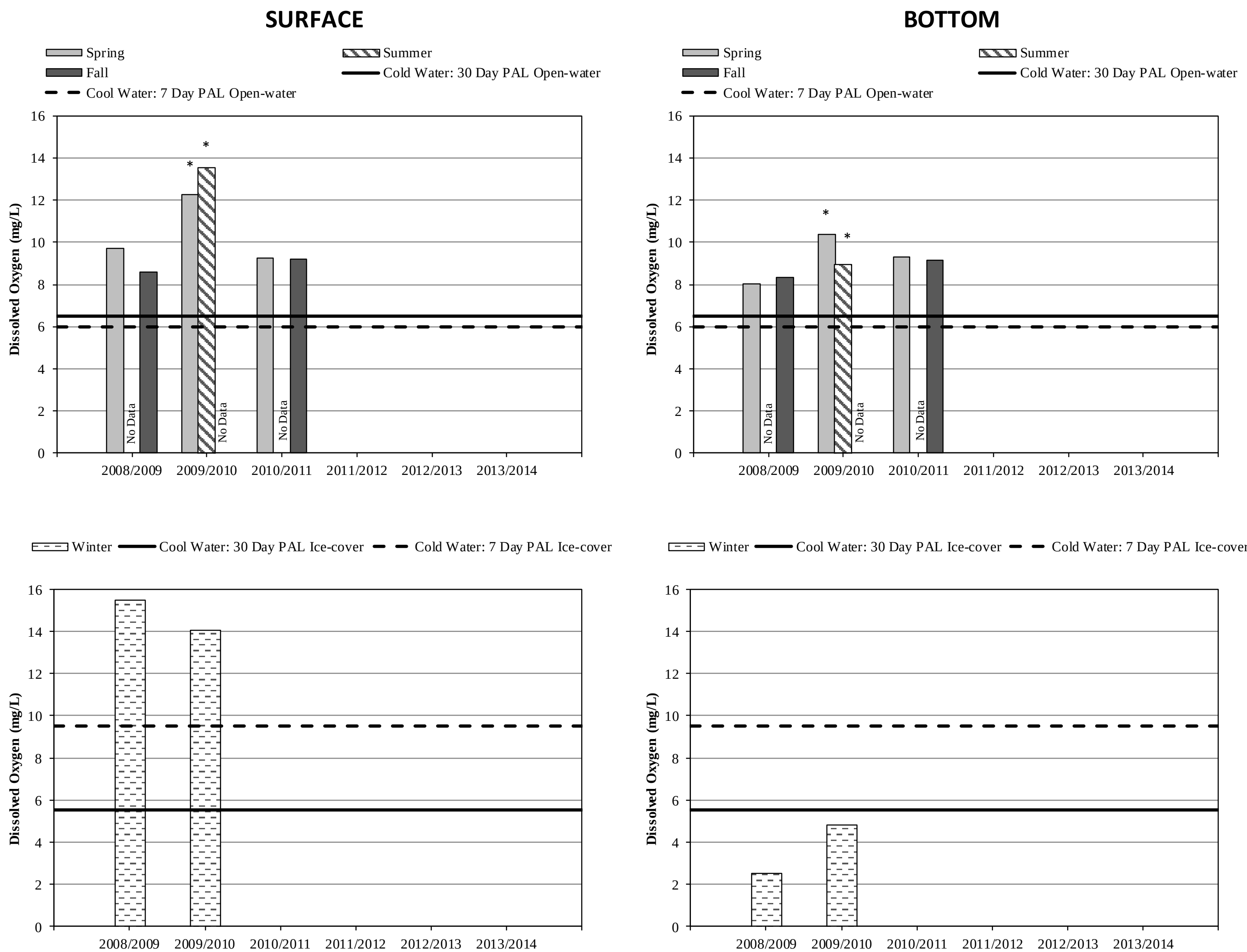
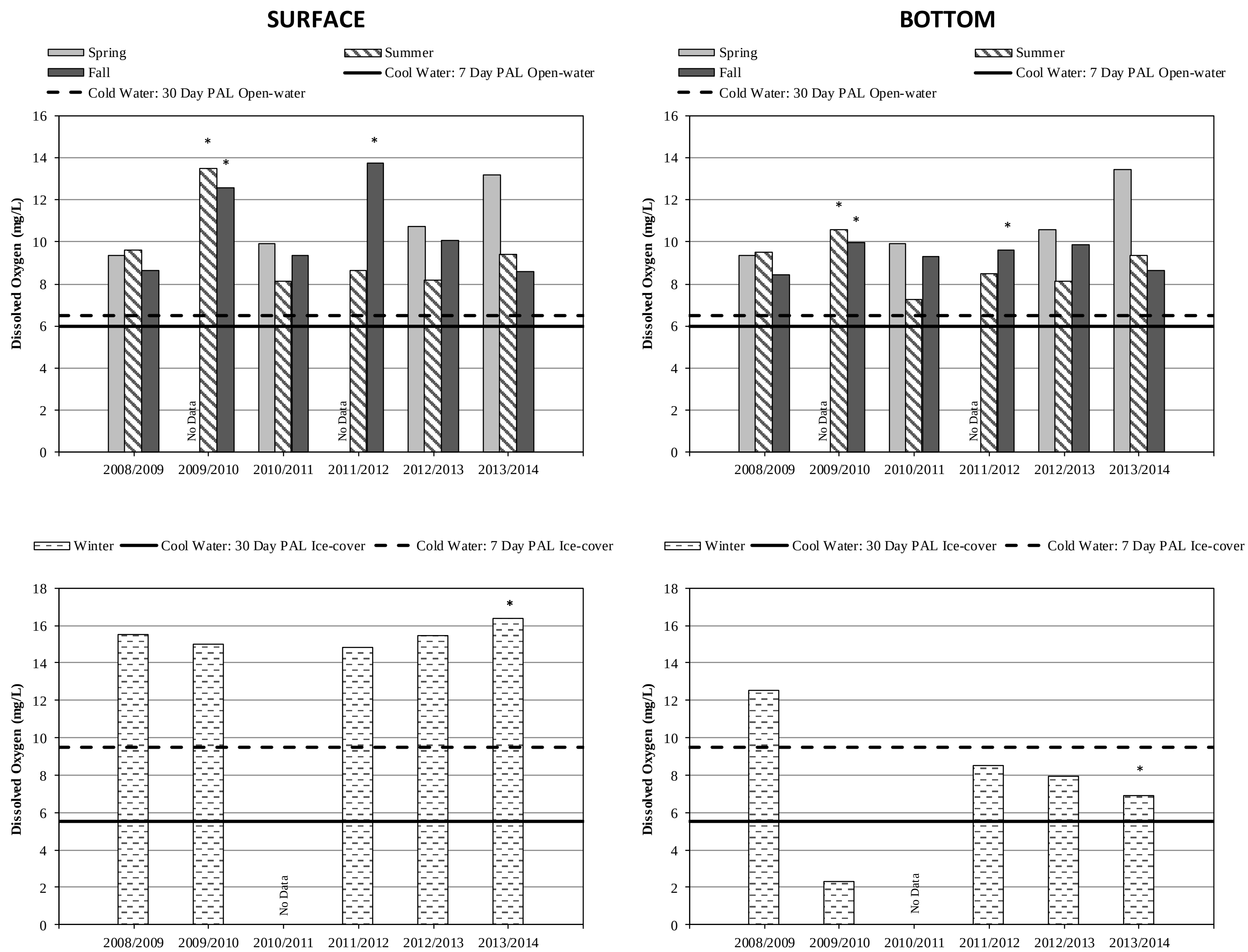


Figure 3-3. Dissolved oxygen measured near the surface and bottom of the water column in Lake Winnipegosis Site 1 and comparisons to MB PAL objectives: 2008/2009-2013/2014.



* Data are considered suspect.

Figure 3-4. Dissolved oxygen measured near the surface and bottom of the water column in Lake Winnipegosis Site 2 and comparisons to MB PAL objectives: 2008/2009-2013/2014.



* Data are considered suspect.

Figure 3-5. Dissolved oxygen measured near the surface and bottom of the water column in Lake Winnipegosis Site 3 and comparisons to MB PAL objectives: 2008/2009-2013/2014.

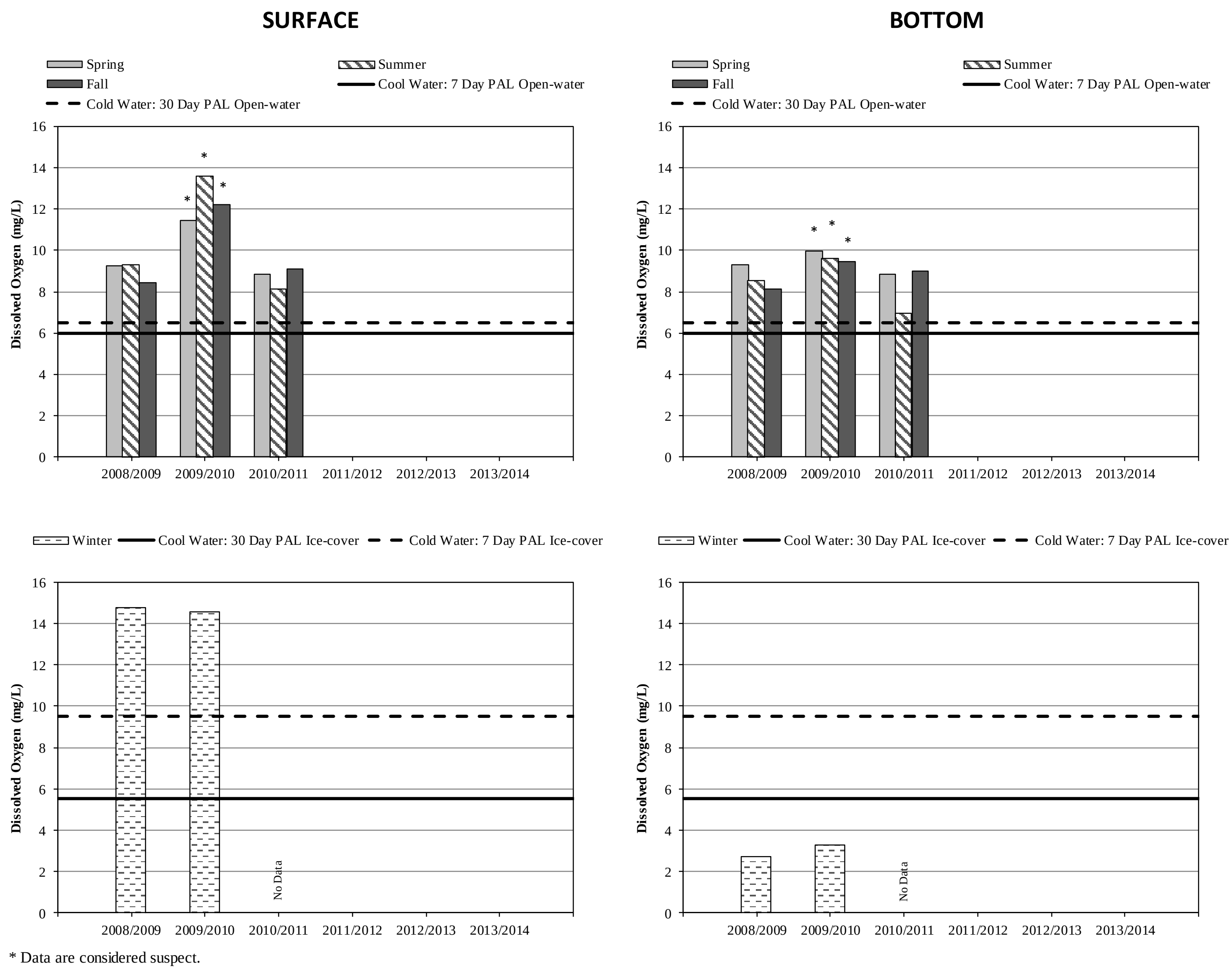
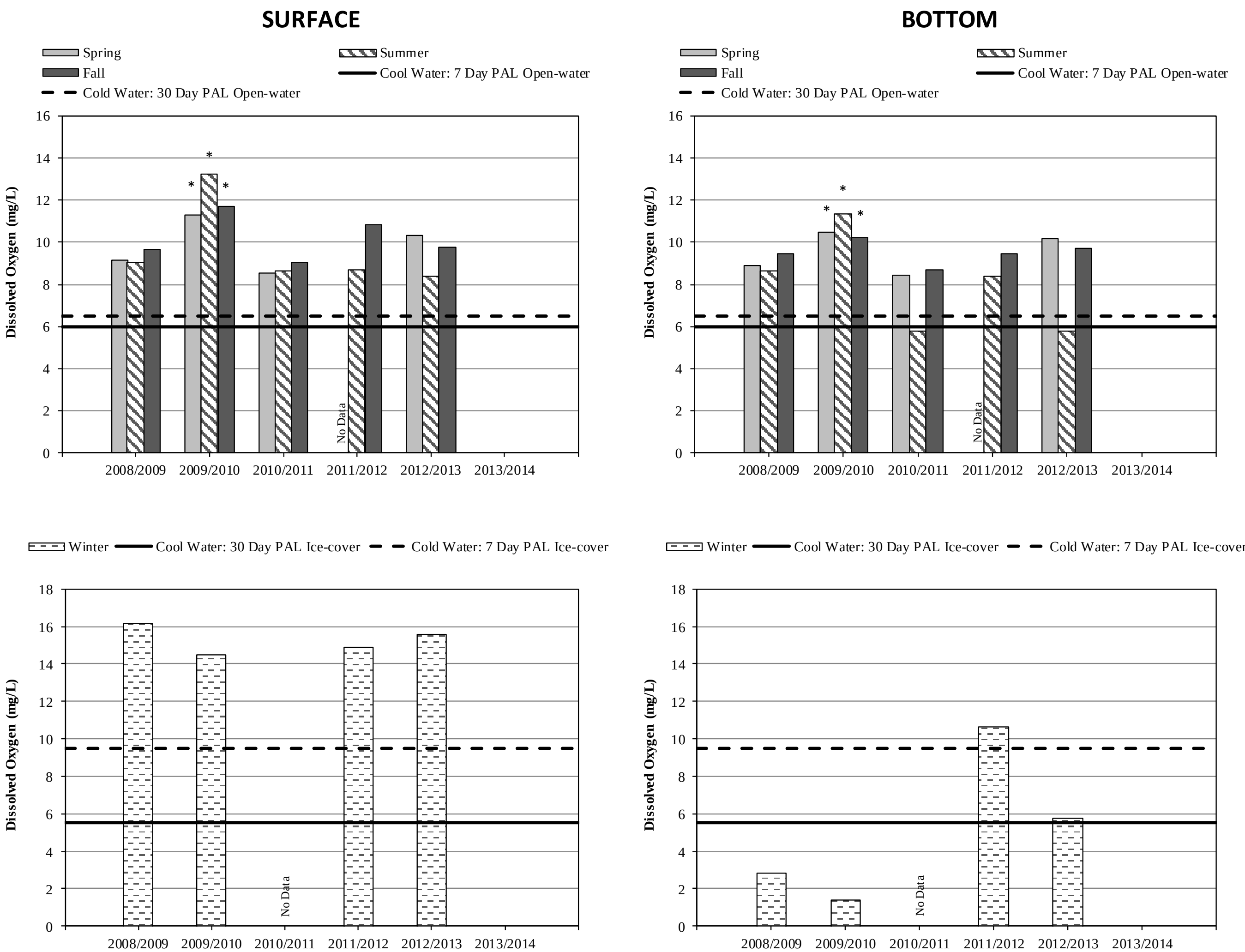


Figure 3-6. Dissolved oxygen measured near the surface and bottom of the water column in Lake Winnipegosis Site 4 and comparisons to MB PAL objectives: 2008/2009-2013/2014.



* Data are considered suspect.

Figure 3-7. Dissolved oxygen measured near the surface and bottom of the water column in Lake Winnipegosis Site 5 and comparisons to MB PAL objectives: 2008/2009-2013/2014.

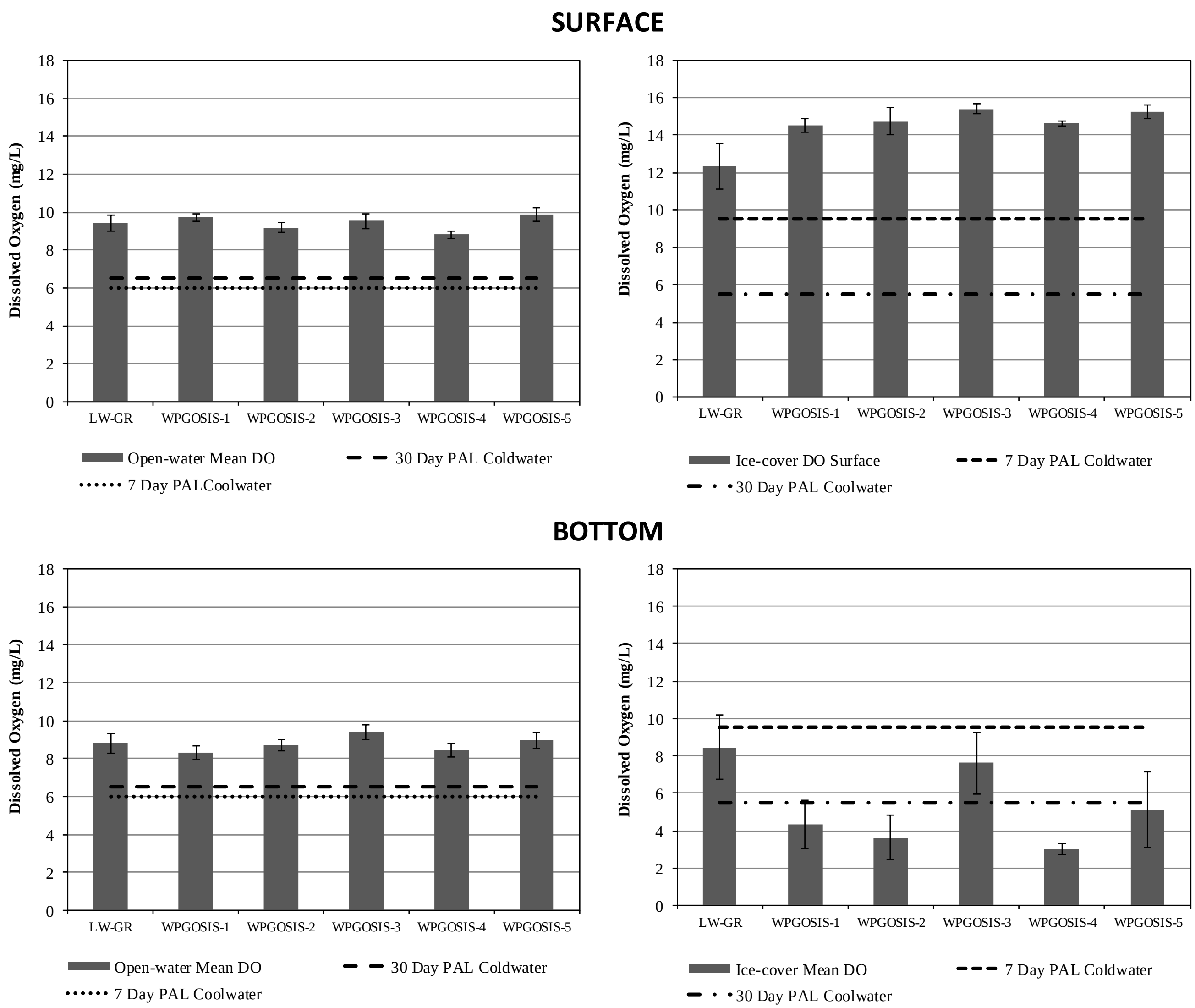


Figure 3-8. Dissolved oxygen (mean±SE) measured in the Lake Winnipeg Region in the open-water and ice-cover seasons: 2008/2009-2013/2014.

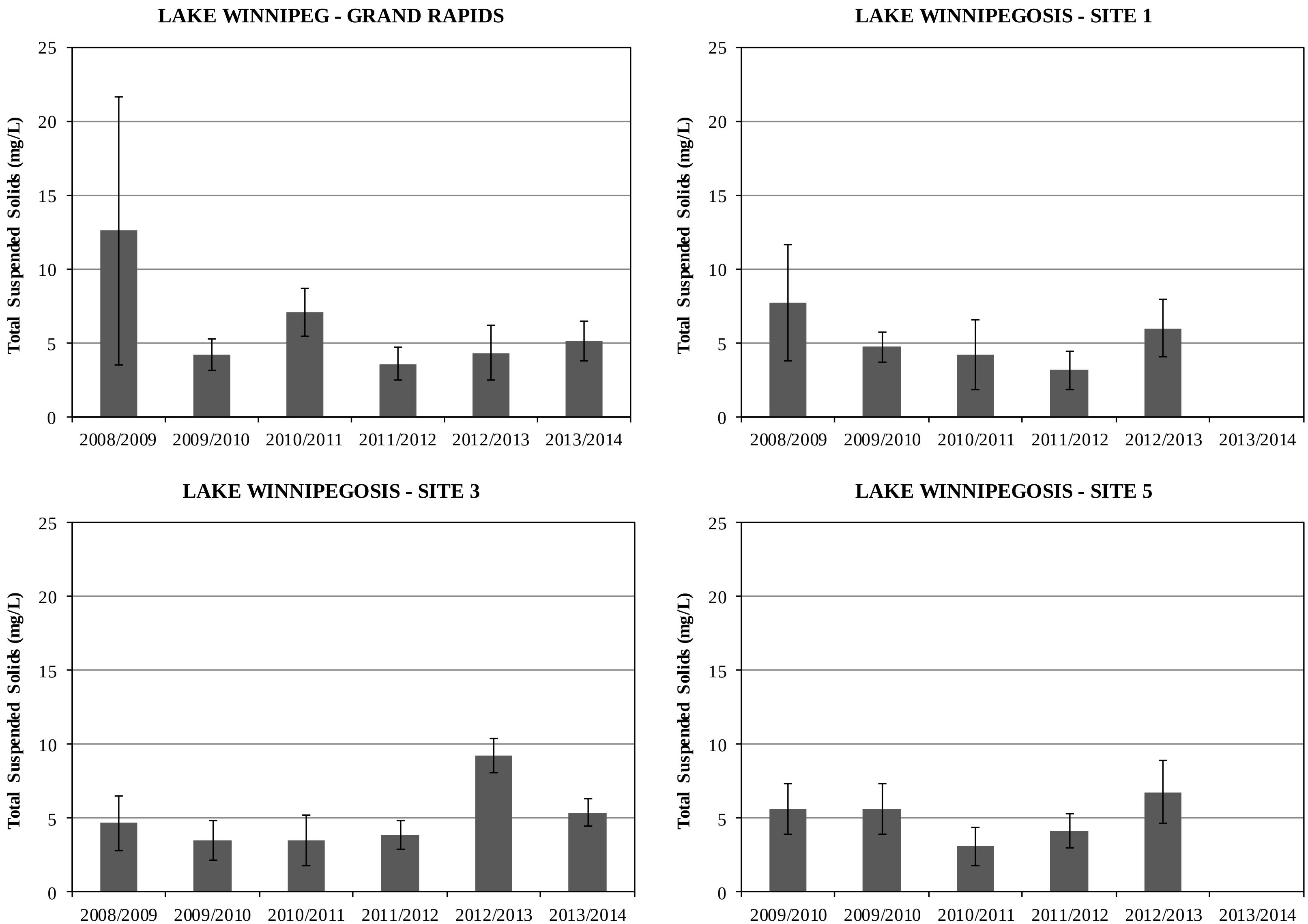


Figure 3-9. Total suspended solids (mean±SE) measured in the Lake Winnipeg Region: 2008/2009-2013/2014.

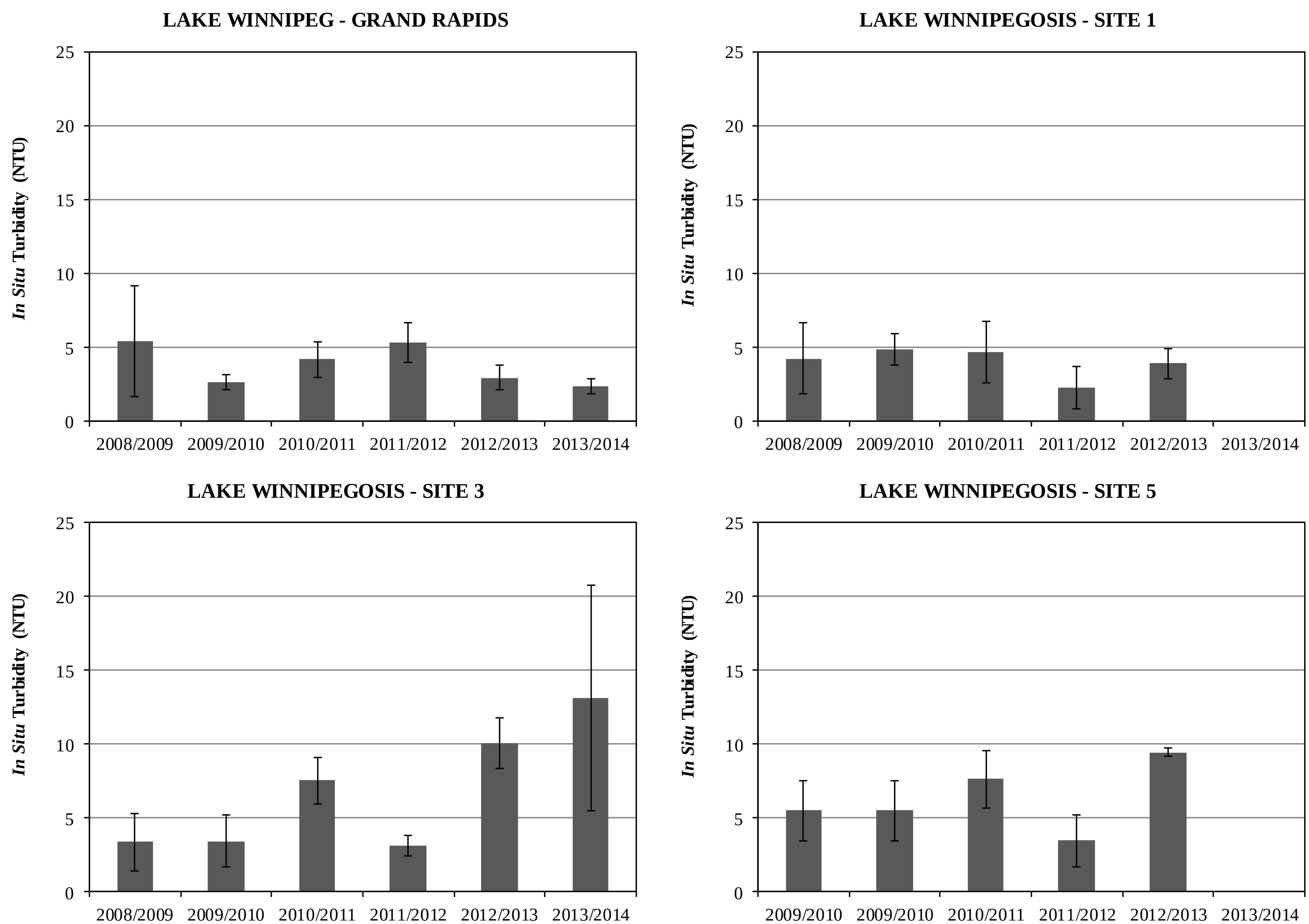


Figure 3-10. *In situ* turbidity (mean±SE) measured in the Lake Winnipeg Region: 2008/2009-2013/2014. Note that readings are not necessarily comparable between Lake Winnipeg and Lake Winnipegosis due to use of different turbidity sensors.

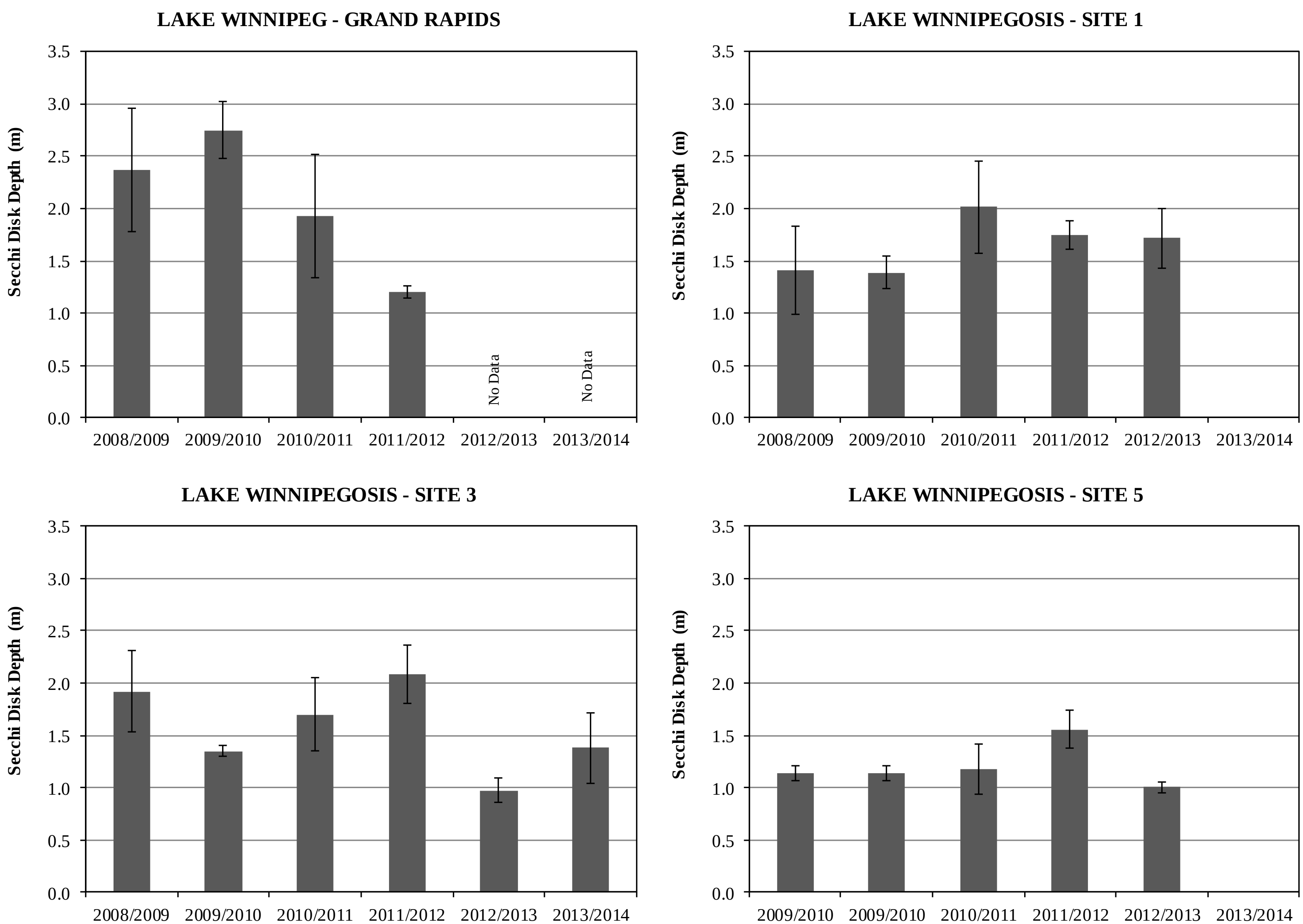


Figure 3-11. Secchi disk depth (mean±SE) measured in the Lake Winnipeg Region: open-water seasons 2008/2009-2013/2014.

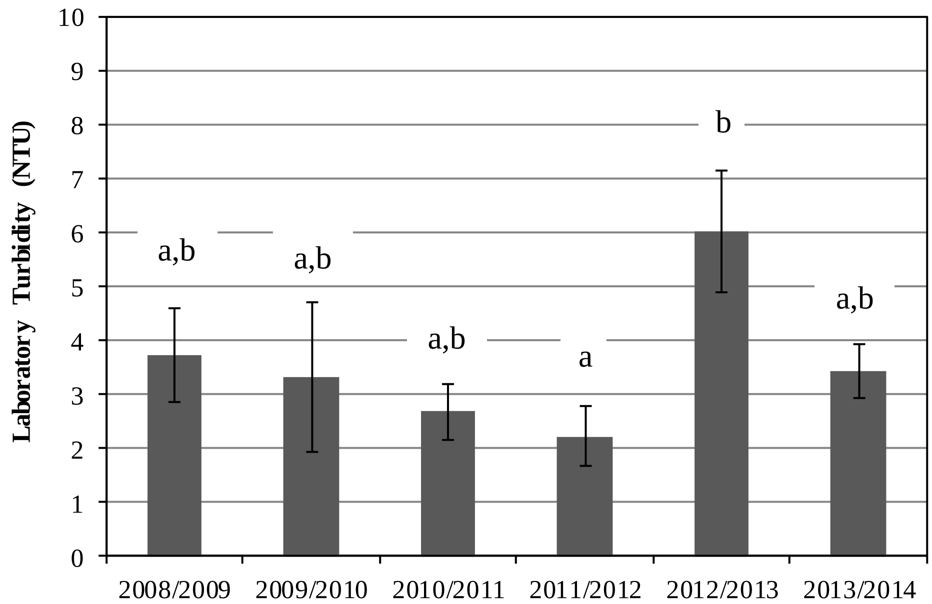


Figure 3-12. Open-water season laboratory turbidity measured at the annual off-system site (Site 3) in Lake Winnipegosis. Laboratory turbidity was not measured at the Lake Winnipeg water quality site. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

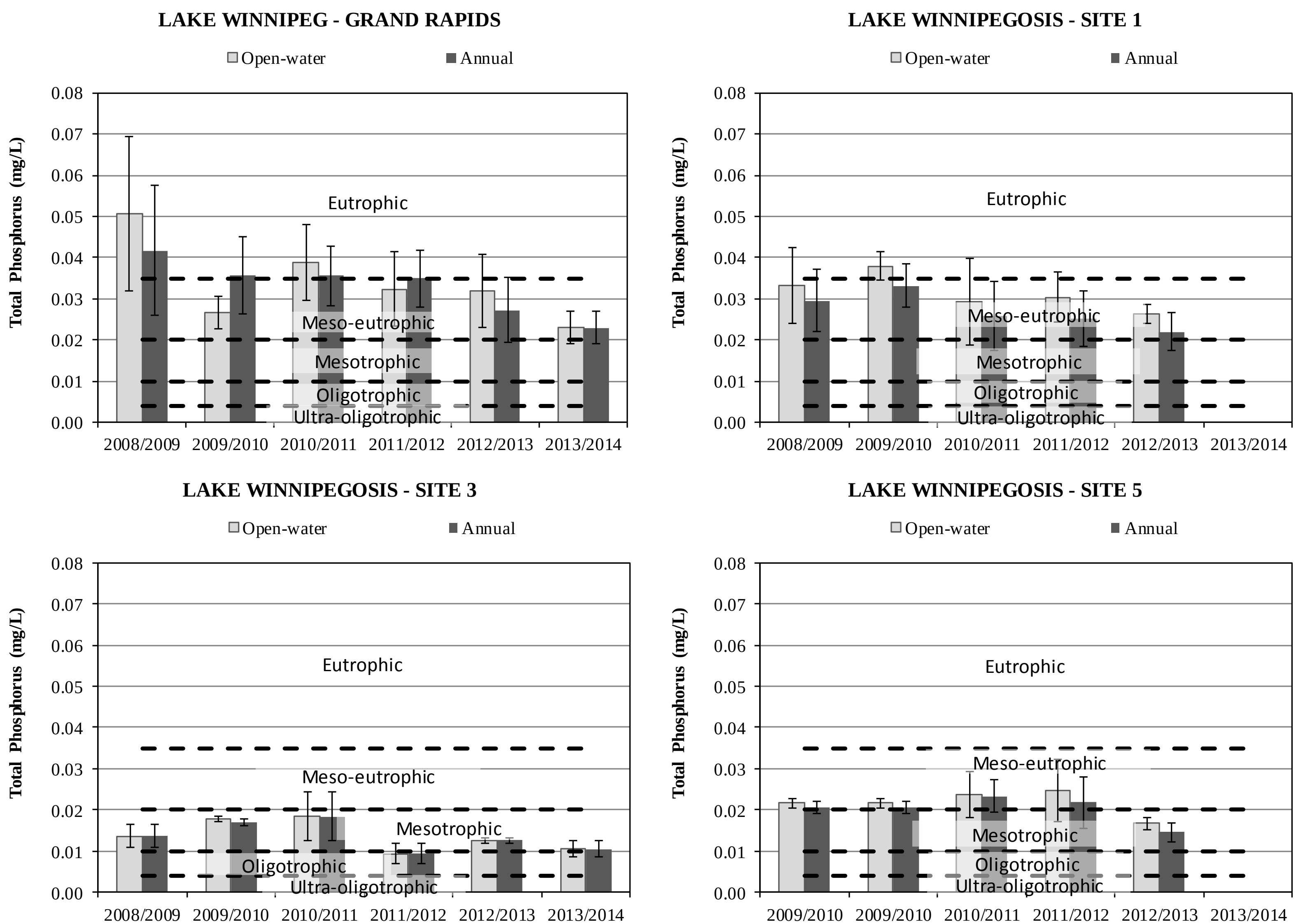


Figure 3-13. Total phosphorus (mean±SE) measured in the Lake Winnipeg Region and comparison to trophic categories: 2008/2009-2013/2014.

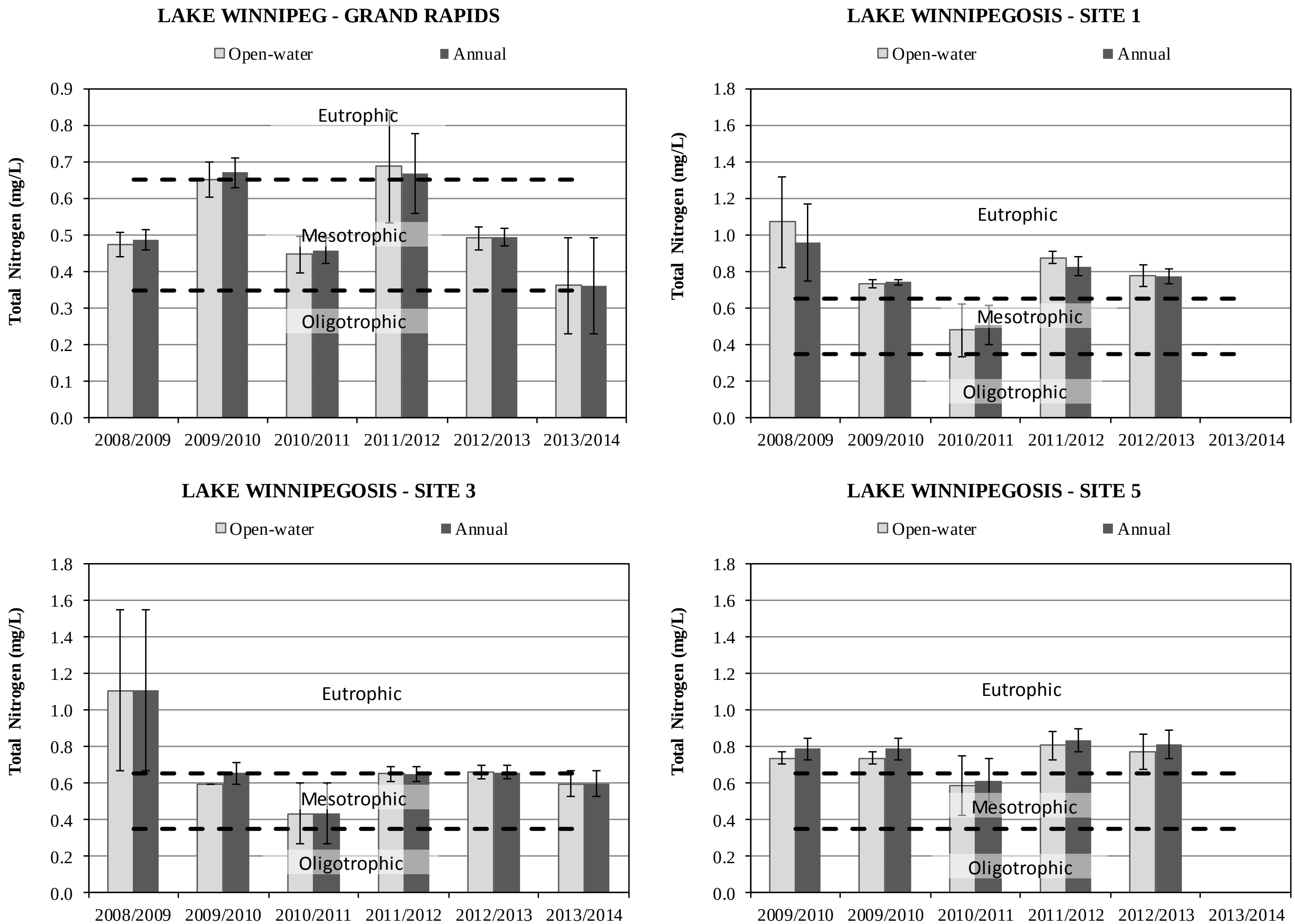


Figure 3-14. Total nitrogen (mean±SE) measured in the Lake Winnipeg Region and comparison to trophic categories: 2008/2009-2013/2014.

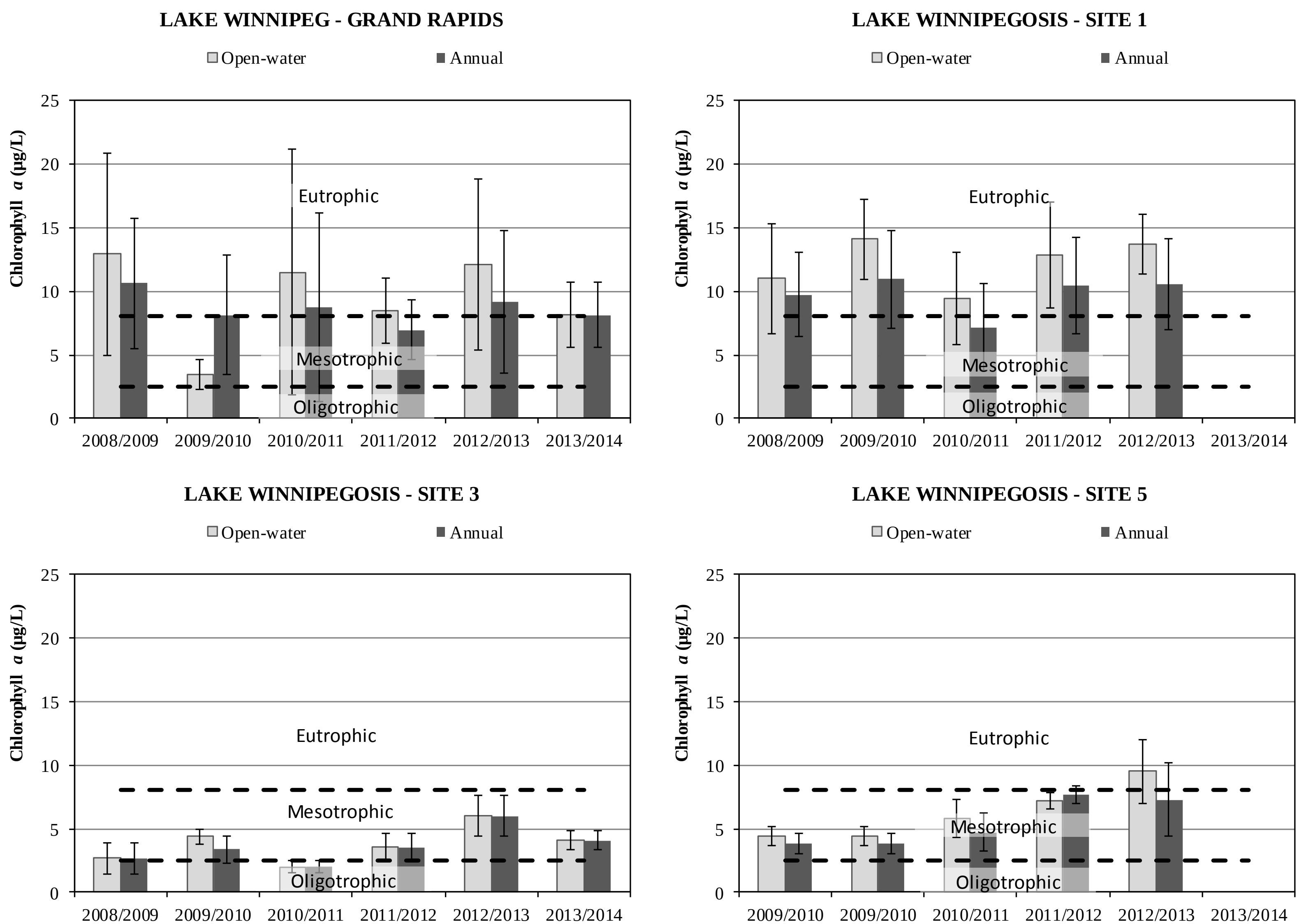


Figure 3-15. Chlorophyll *a* (mean±SE) measured in the Lake Winnipeg Region and comparison to trophic categories: 2008/2009-2013/2014.

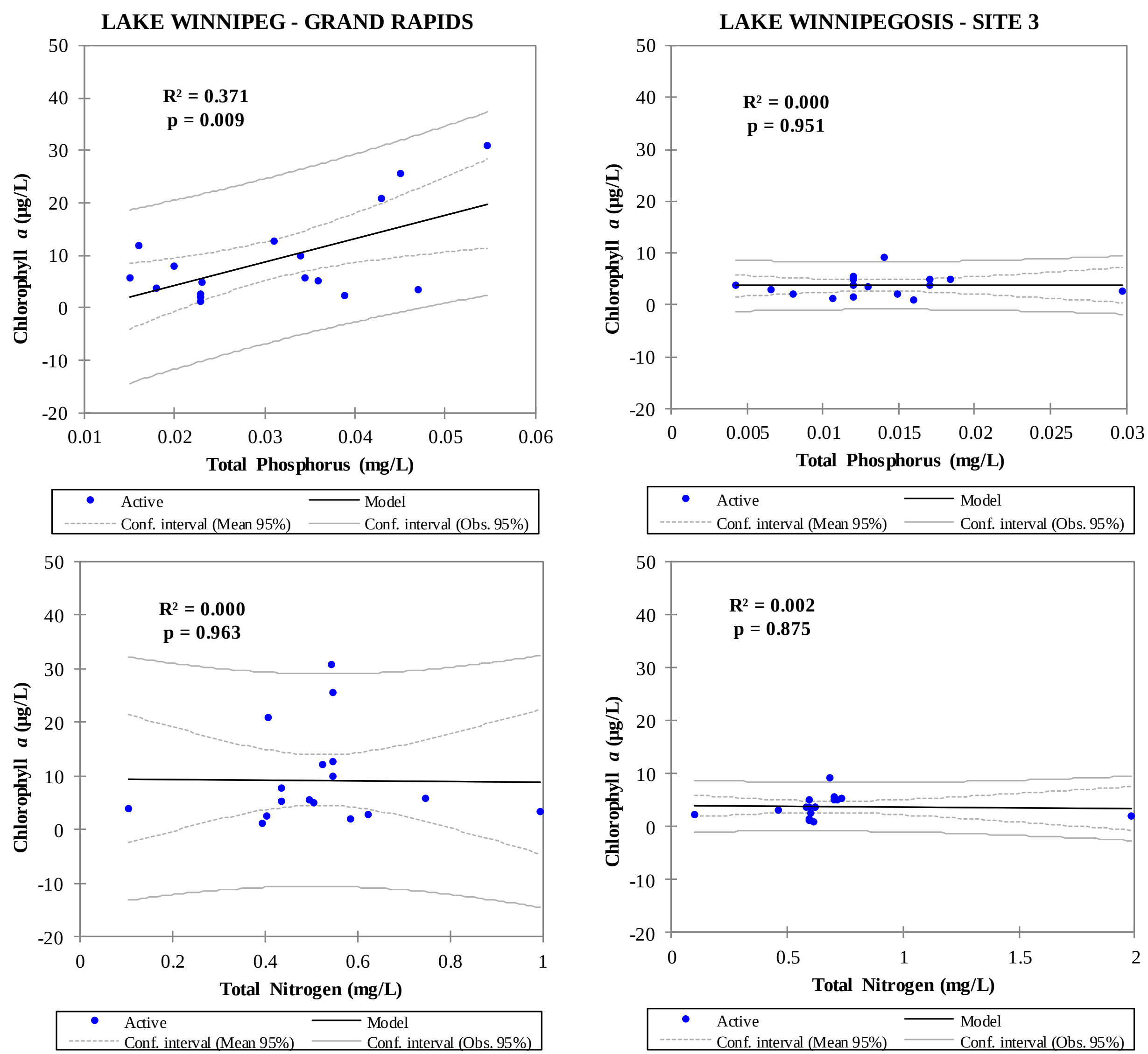


Figure 3-16. Linear regression between total phosphorus and total nitrogen and chlorophyll *a* in Lake Winnipeg – Grand Rapids (on-system) and Lake Winnipegosis – Site 3 (off-system): open-water seasons 2008-2013.

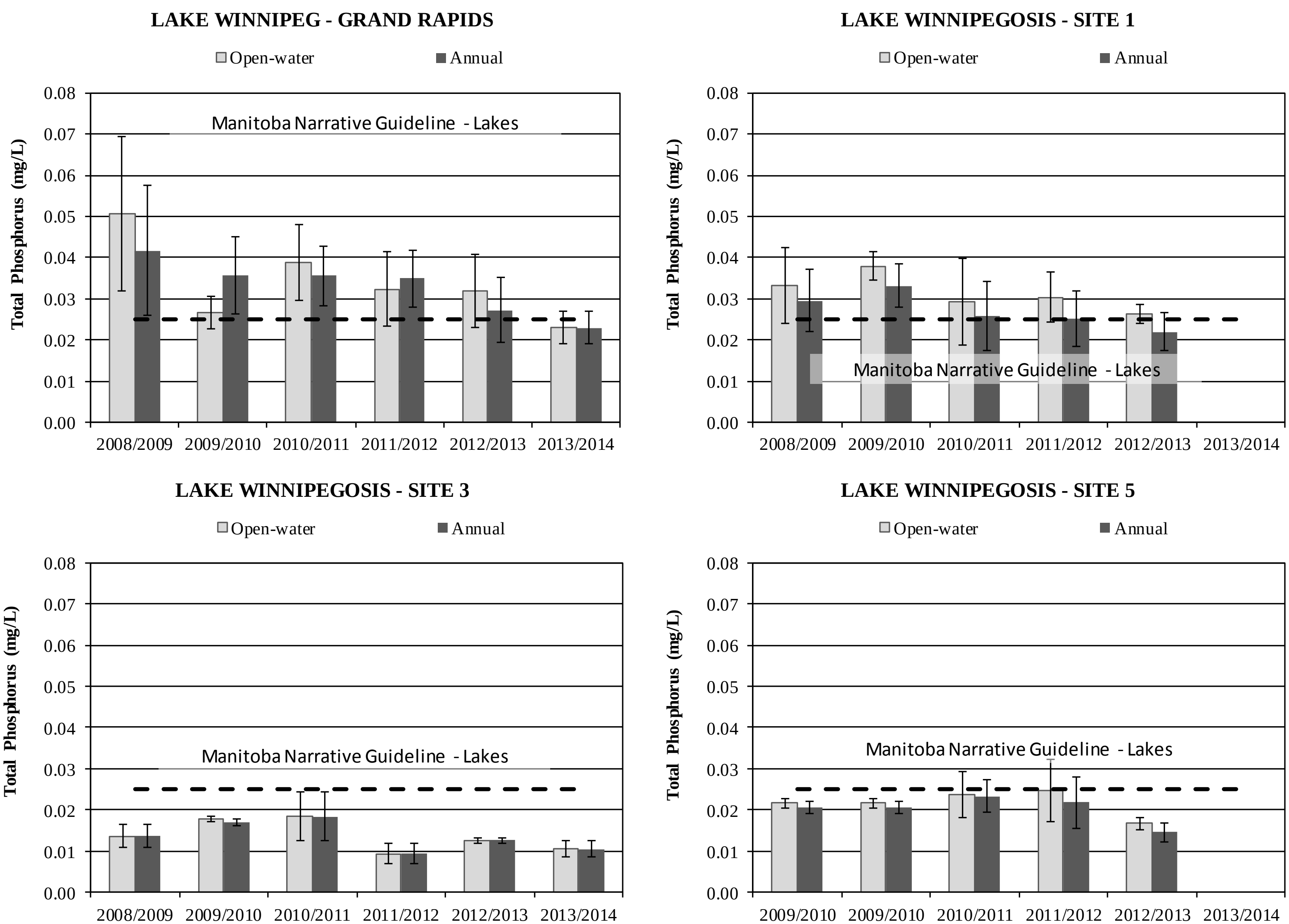


Figure 3-17. Total phosphorus (mean±SE) measured in the Lake Winnipeg Region and comparison to the Manitoba narrative nutrient guidelines: 2008/2009-2013/2014.

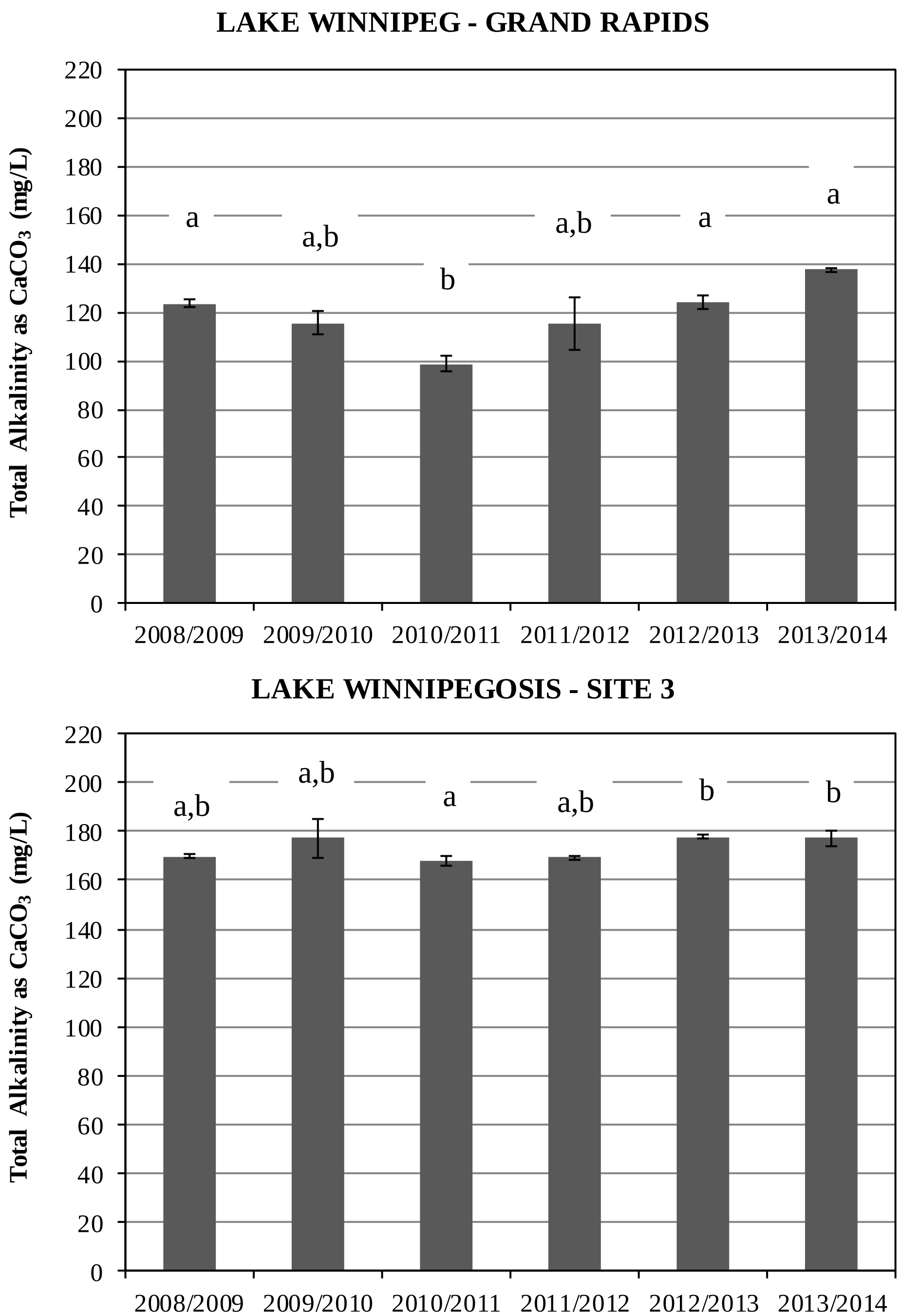


Figure 3-18. Open-water season total alkalinity (mean±SE) at the annual on-system (Lake Winnipeg – Grand Rapids) and off-system (Lake Winnipegosis – Site 3) sites. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

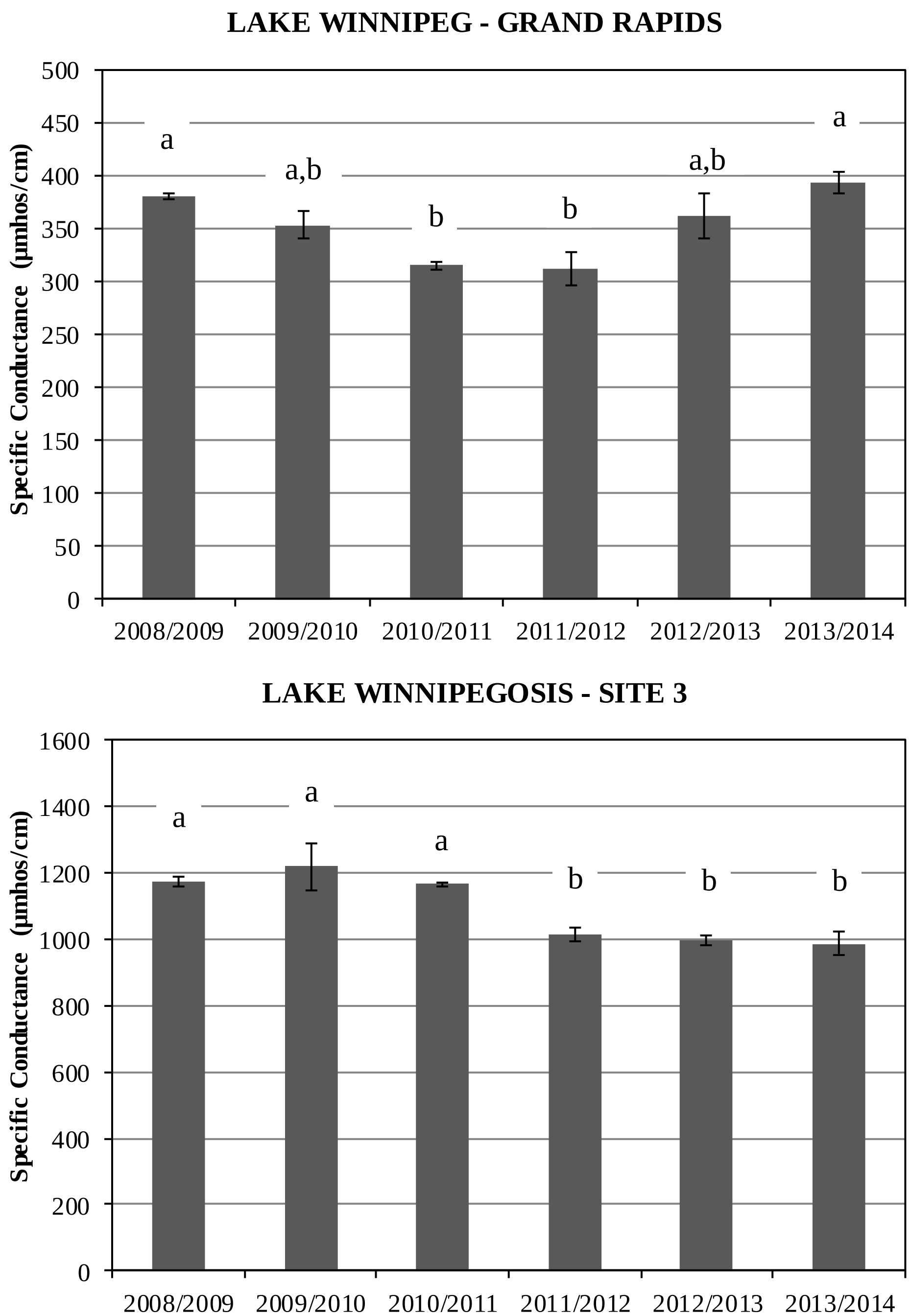


Figure 3-19. Open-water season laboratory specific conductance (mean±SE) at the annual on-system (Lake Winnipeg – Grand Rapids) and off-system (Lake Winnipegosis – Site 3) sites. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

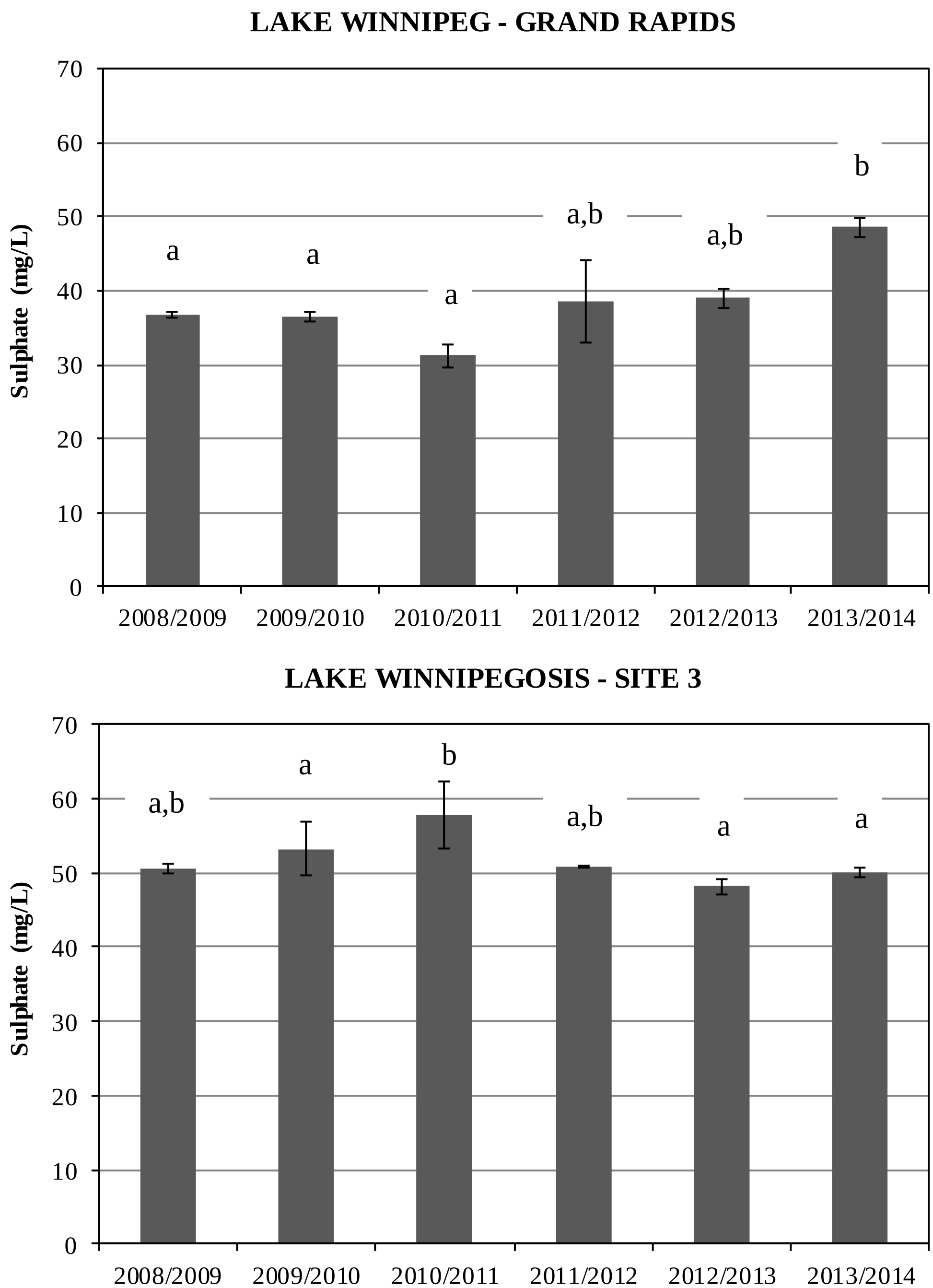


Figure 3-20. Open-water season sulphate concentrations (mean±SE) at the annual on-system (Lake Winnipeg – Grand Rapids) and off-system (Lake Winnipegosis – Site 3) sites. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

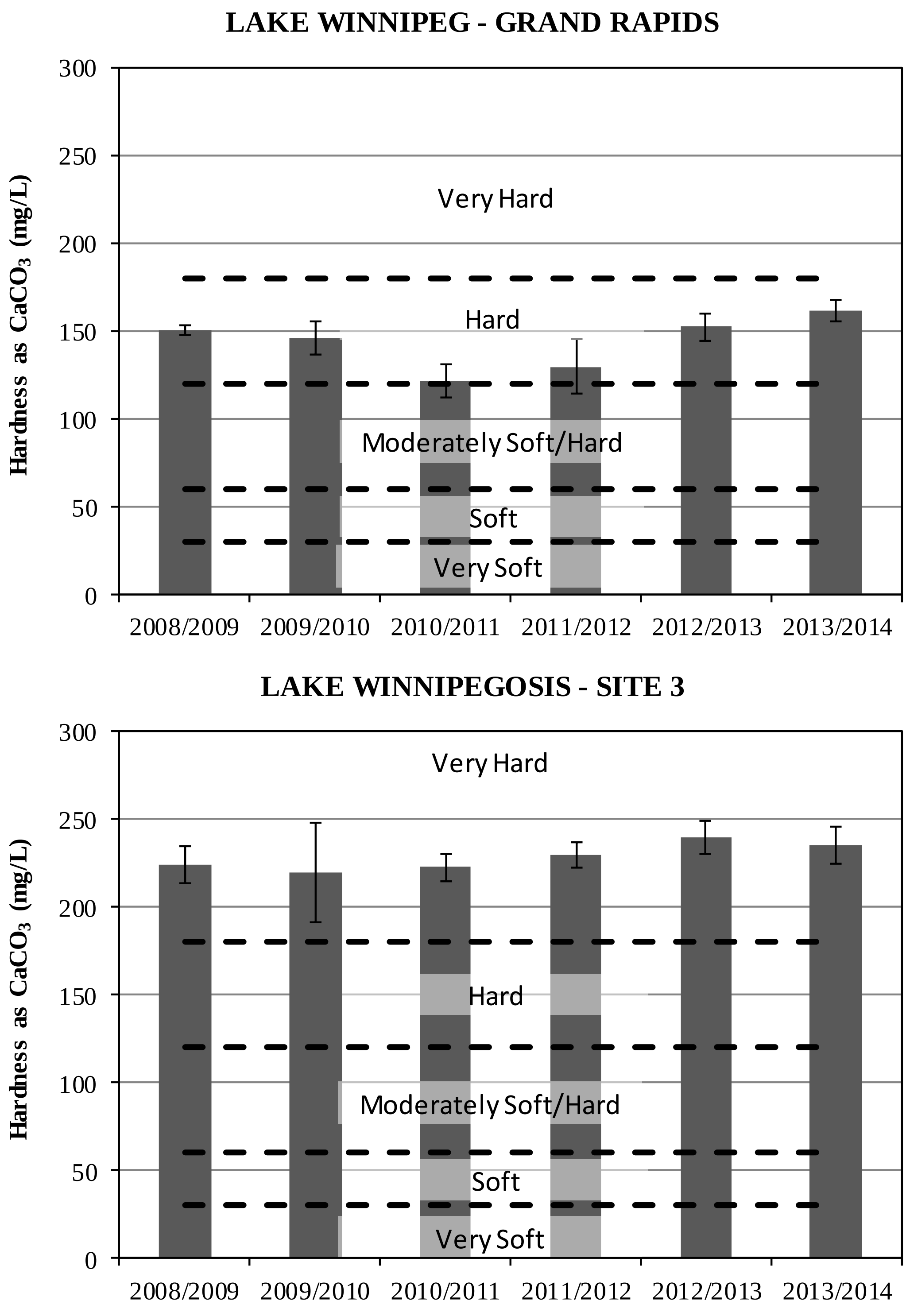
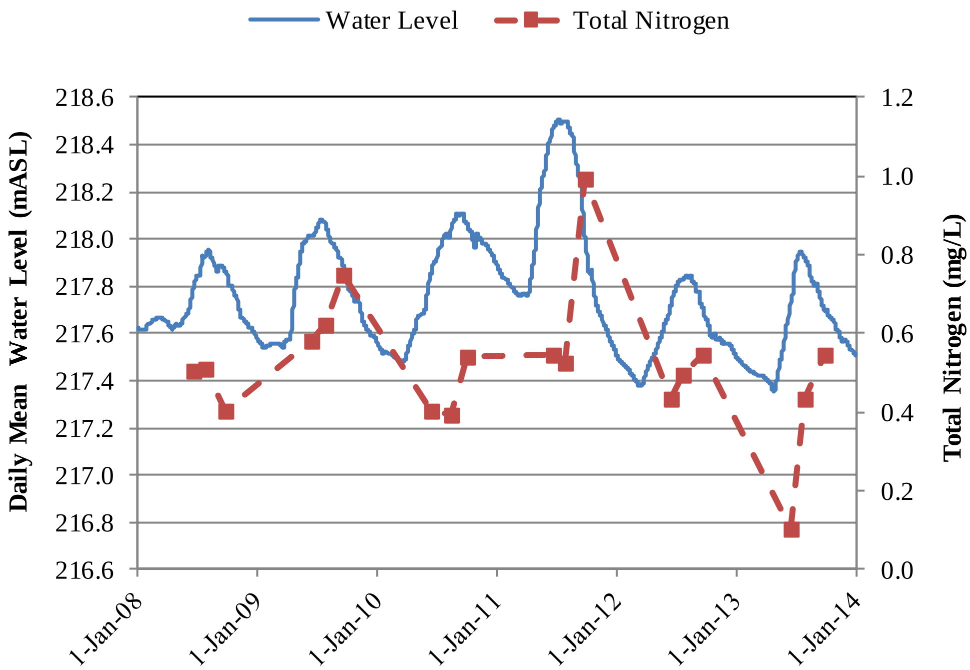


Figure 3-21. Open-water season hardness (mean±SE) at the annual on-system (Lake Winnipeg – Grand Rapids) and off-system (Lake Winnipegosis – Site 3) sites. No significant inter-annual differences were found.



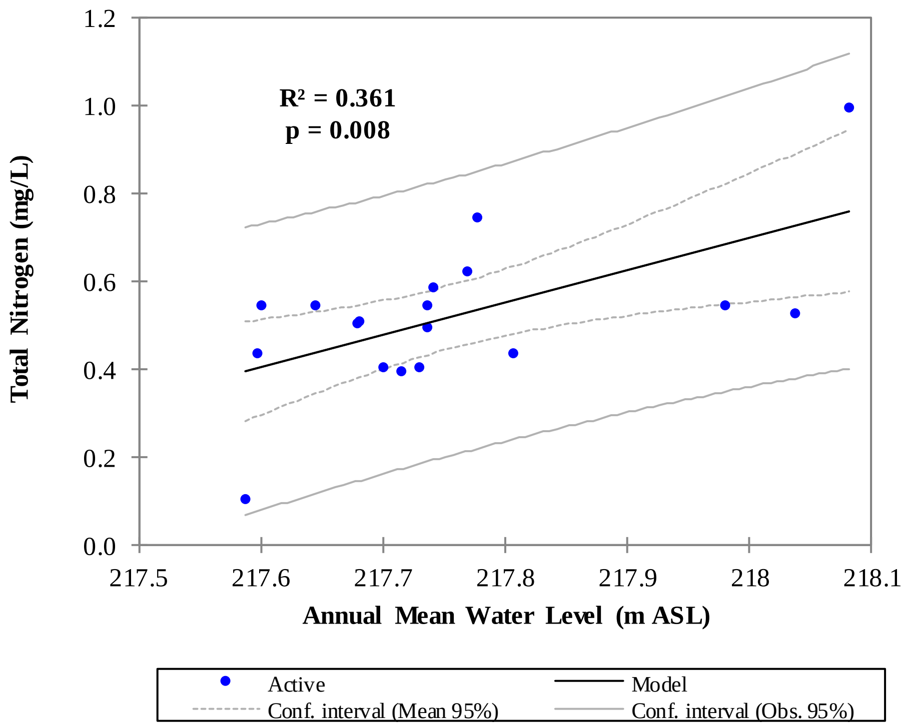


Figure 3-22. Open-water season total nitrogen concentrations versus water level in Lake Winnipeg: 2008-2013.

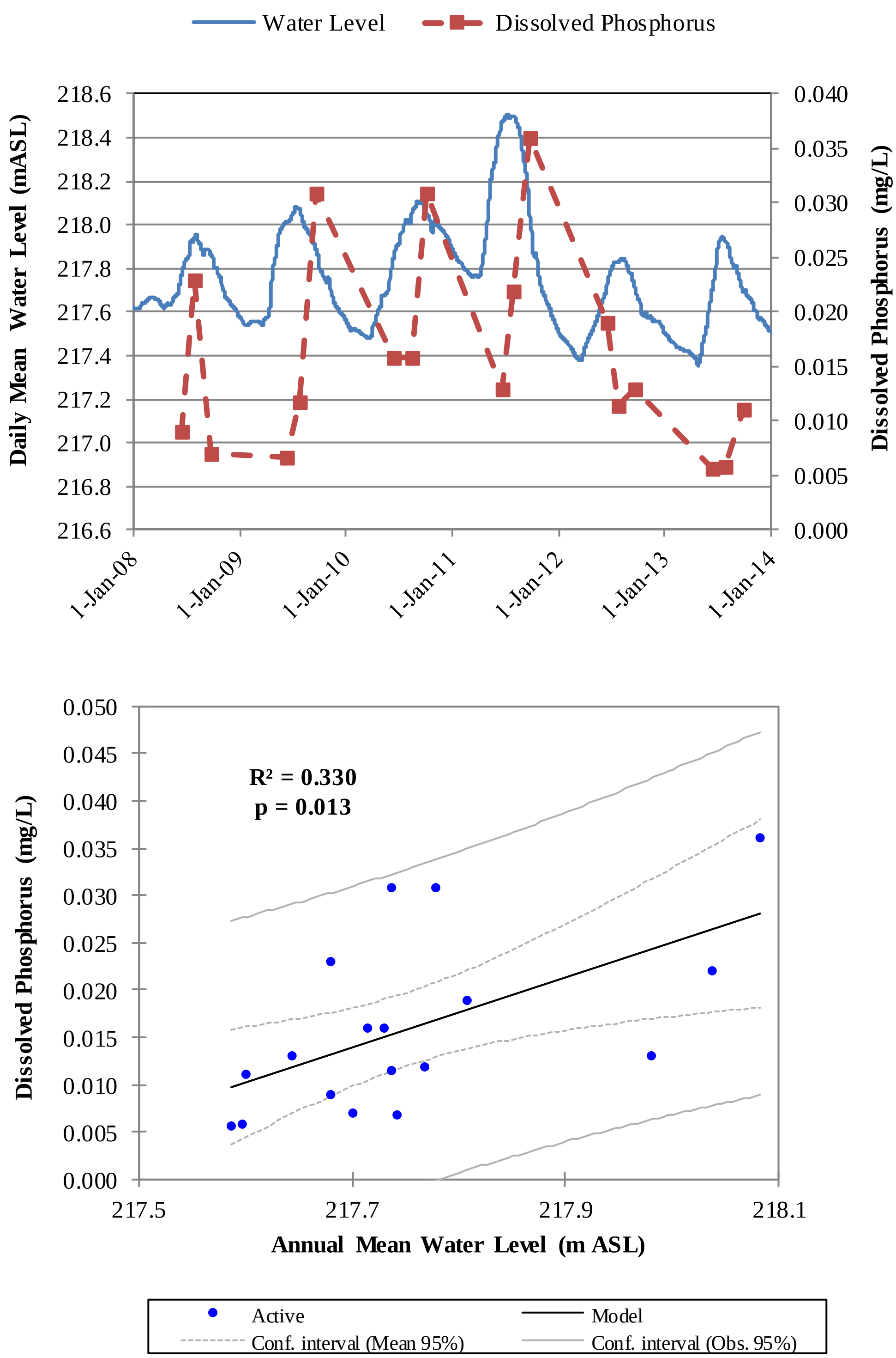
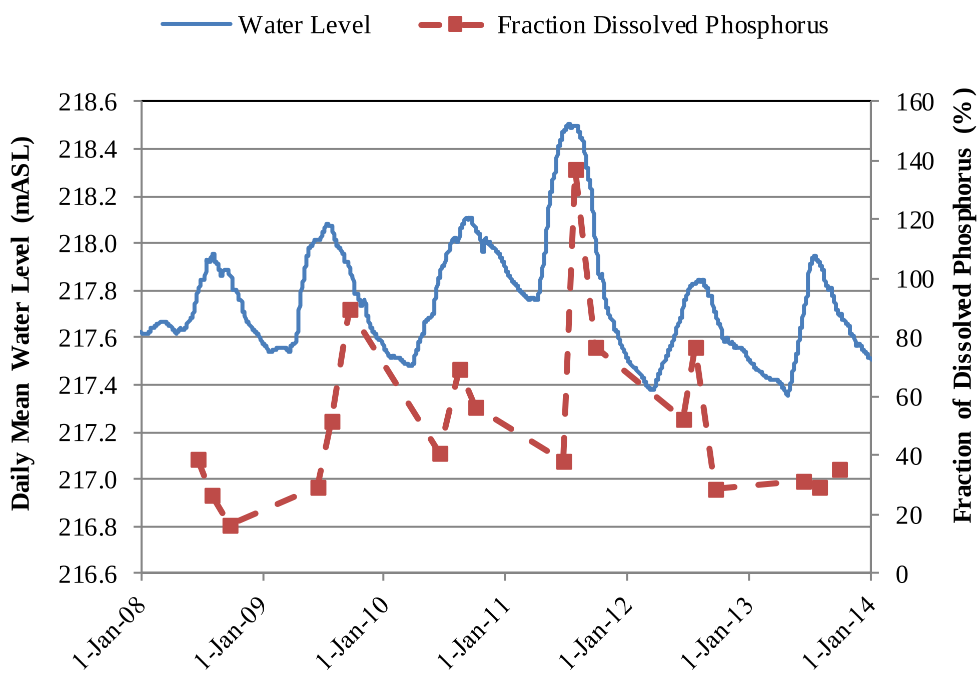


Figure 3-23. Open-water season dissolved phosphorus concentrations versus water level in Lake Winnipeg: 2008-2013.



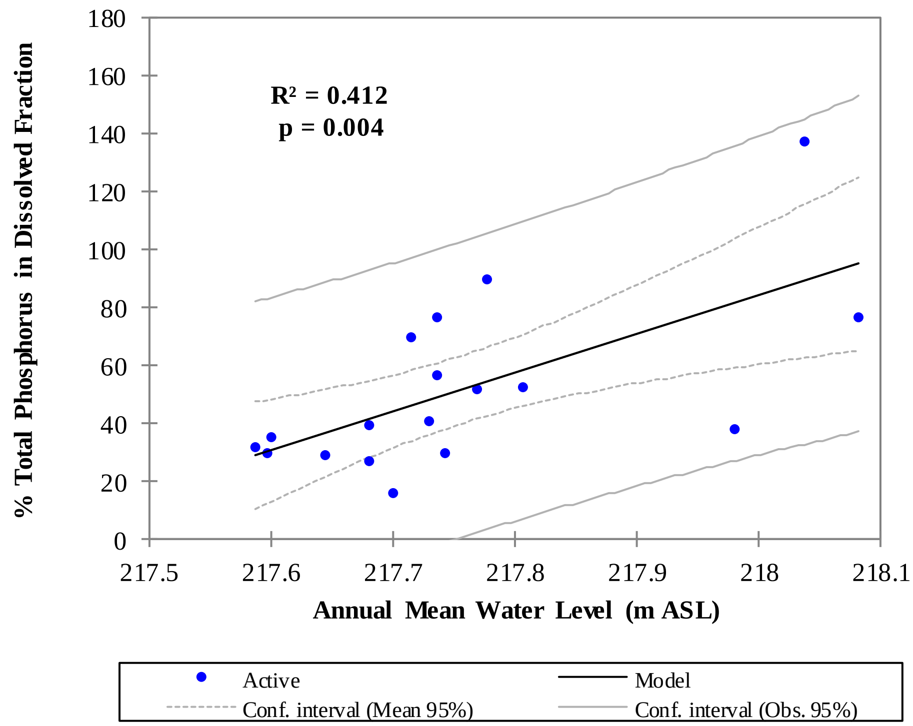
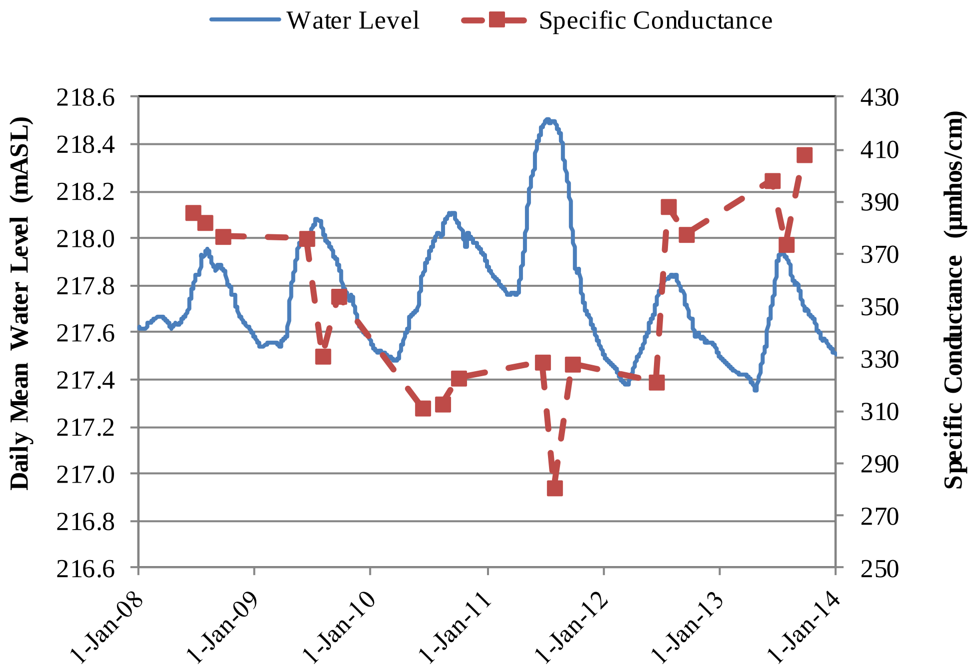


Figure 3-24. Open-water season percent phosphorus in dissolved form versus water level in Lake Winnipeg: 2008-2013.



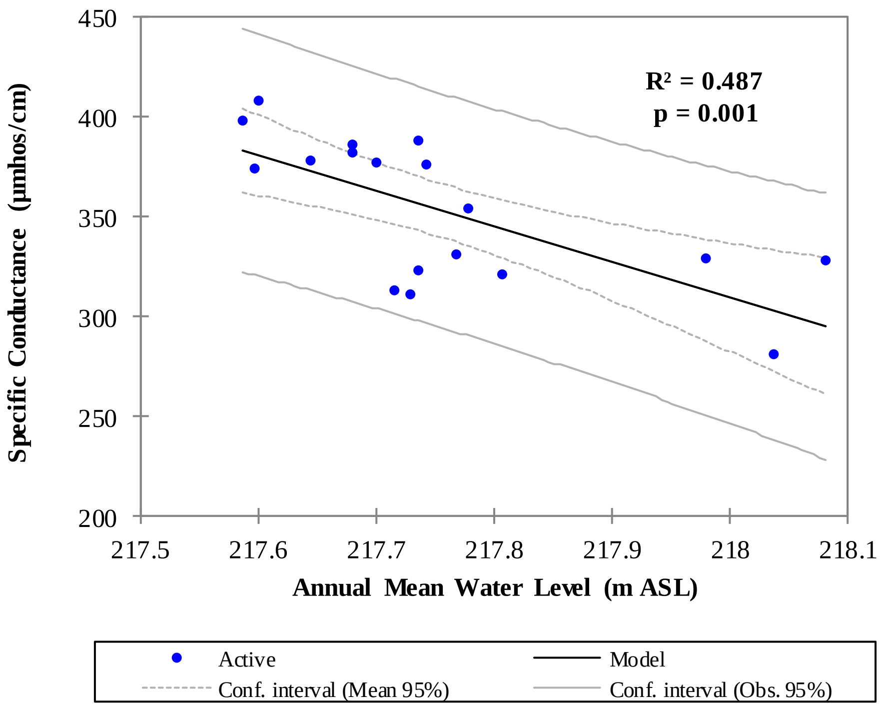
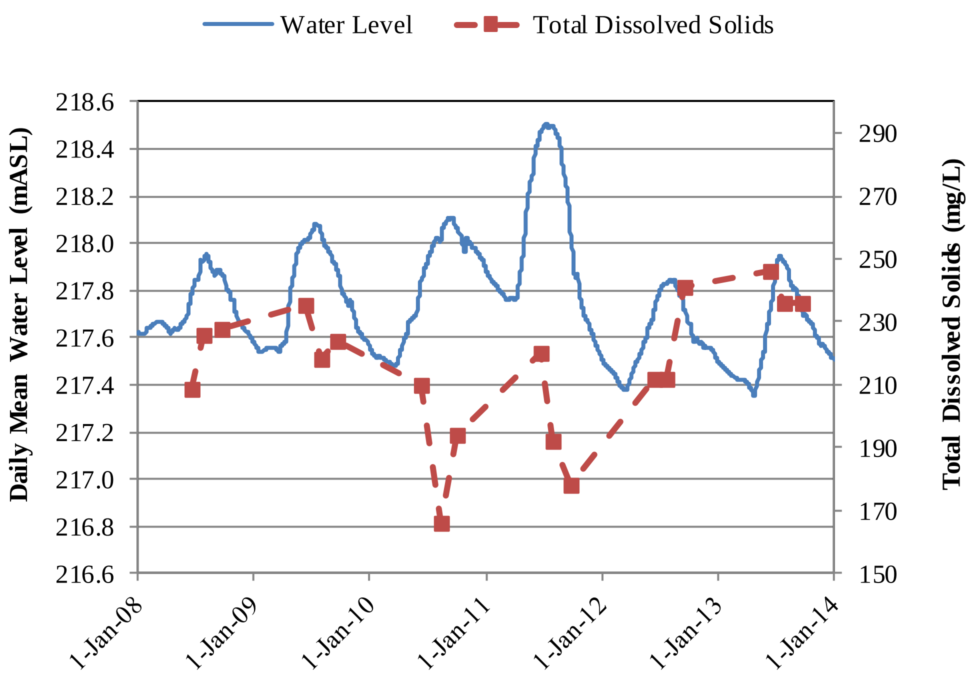


Figure 3-25. Open-water season specific conductance versus water level in Lake Winnipeg: 2008-2013.



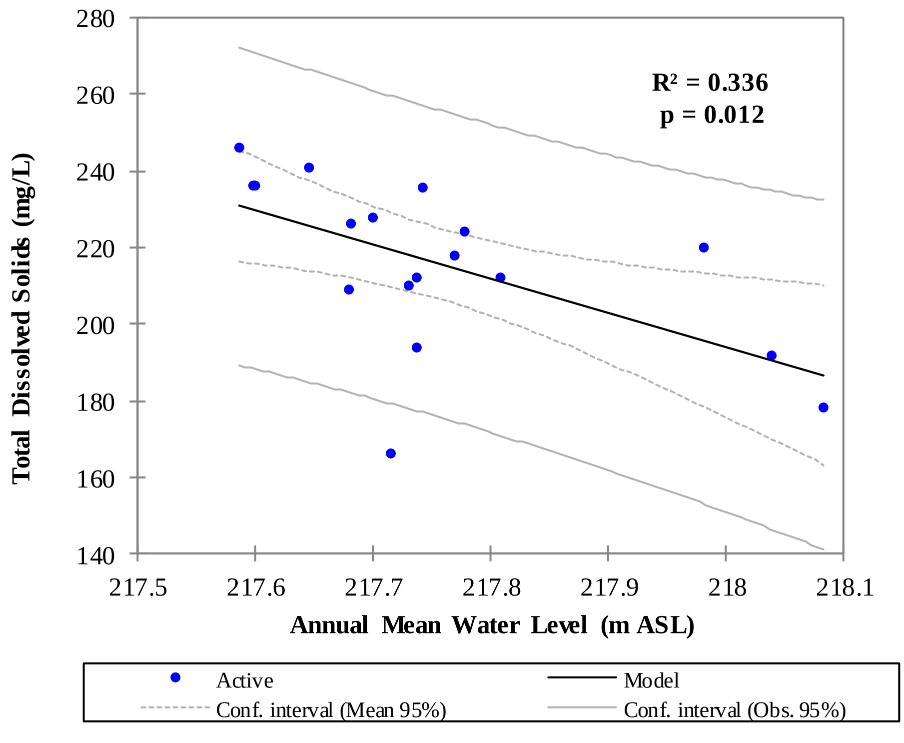


Figure 3-26. Open-water season total dissolved solids versus water level in Lake Winnipeg: 2008-2013.

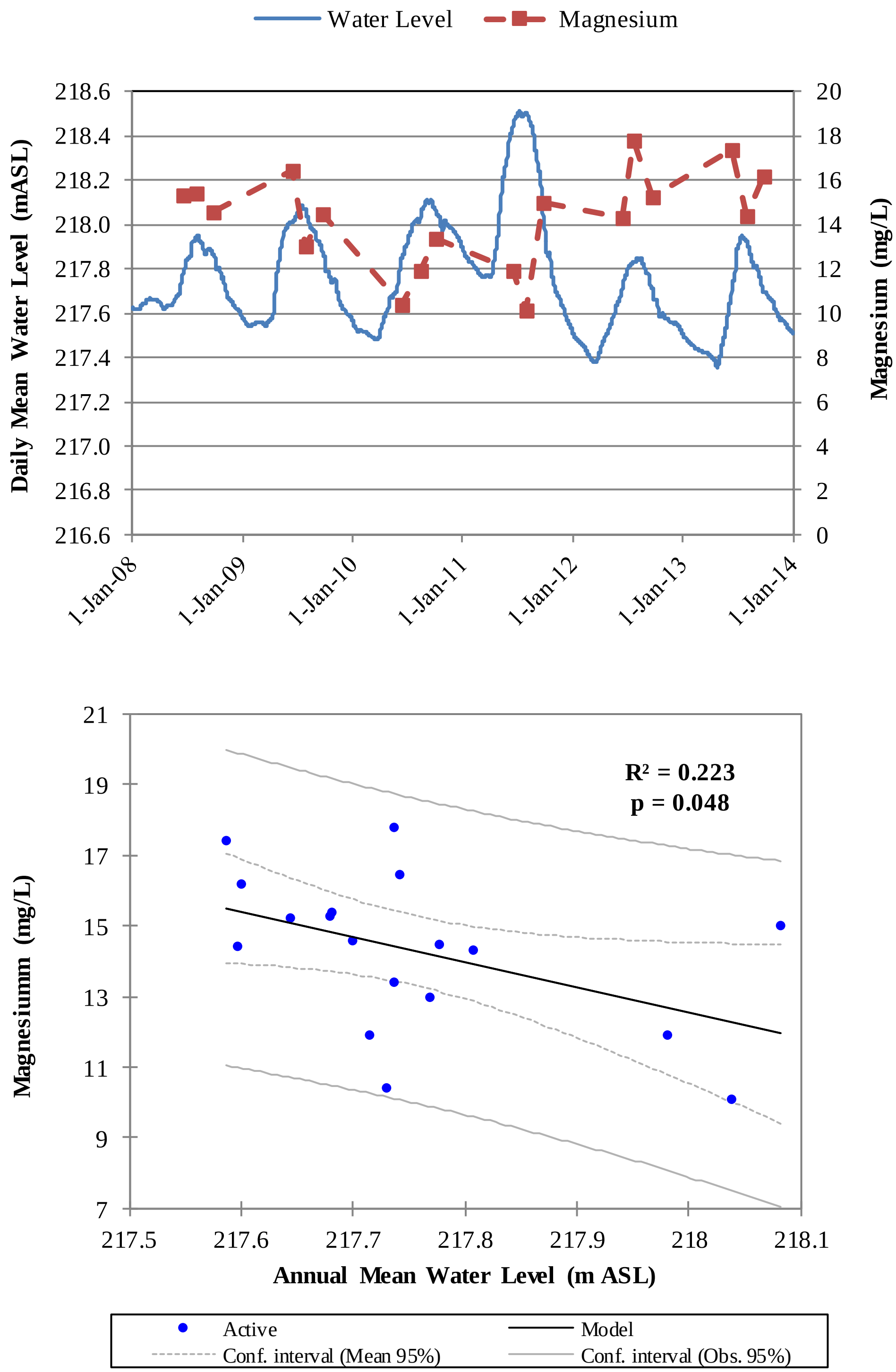


Figure 3-27. Open-water season total dissolved solids versus water level in Lake Winnipeg: 2008-2013.

4.0 SEDIMENT QUALITY

4.1 INTRODUCTION

The following provides an overview of sediment quality conditions measured under CAMP in the LKWPGR in the first six years of the program; 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 in the LKWPGR was measured in 2011 at the off-system waterbody – Lake Winnipegosis (Figure 4-1).

Sediment quality monitoring in Lake Winnipeg was undertaken by MSD as part of the broader overall Lake Winnipeg monitoring program. The methods employed by MSD differed from CAMP methods; MSD measured sediment quality in the upper 2 cm of sediment in 2011.

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 LAKE WINNIPEG

Lake Winnipeg sediments contained relatively high concentrations of total Kjeldahl nitrogen (TKN; Figure 4-2) and phosphorus (Figure 4-3) and both exceeded the Ontario LEL. All but one metal (chromium), including arsenic, cadmium, copper, lead, mercury, and zinc, were on average within the Manitoba SQGs at the Lake Winnipeg site (Table 4-1; Figures 4-4 to 4-10). Chromium exceeded the Manitoba SQG but not the PEL in Lake Winnipeg sediments (Figure 4-6). Iron (Figure 4-11), manganese (Figure 4-12), and nickel (Figure 4-13) exceeded the Ontario LEL but not the SEL, in Lake Winnipeg. Selenium concentrations in surficial sediments from Lake Winnipeg were marginally above the analytical detection limit (0.5 µg/g) but well below the BC SAC and the AB ISQG (2.0 µg/g; Figure 4-14). Results for other metals are presented in Table 4-2.

The concentrations of key metrics were higher in Lake Winnipeg compared to Lake Winnipegosis. The potential influence of supporting variables (i.e., particle size and total organic carbon [TOC]) on these differences are not known due to the absence of data for the Lake Winnipeg monitoring site.

4.3 OFF-SYSTEM WATERBODY: LAKE WINNIPEGOSIS

Particle size analysis indicated that the sediment samples from Lake Winnipegosis were predominantly sand (93%; Figure 4-15). TOC (Figure 4-16) and TP (Figure 4-3) levels were below the Ontario LELs, but TKN (Figure 4-2) concentrations exceeded the LEL. All metals were below sediment quality benchmarks in Lake Winnipegosis

4.4 SUMMARY

Most of the sediment quality parameters measured in Lake Winnipeg and Lake Winnipegosis sediments were within sediment quality benchmarks. Metrics that exceeded guidelines in this region were also commonly above these benchmarks, and concentrations were similar to those observed, in other lakes and rivers monitored under CAMP (Table 4-1). Although metals were generally higher in Lake Winnipeg sediments than the off-system site in Lake Winnipegosis, the lack of supporting data for the former increases the uncertainty associated with comparisons to other sites.

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 Lake Winnipeg region: 2008-2013.

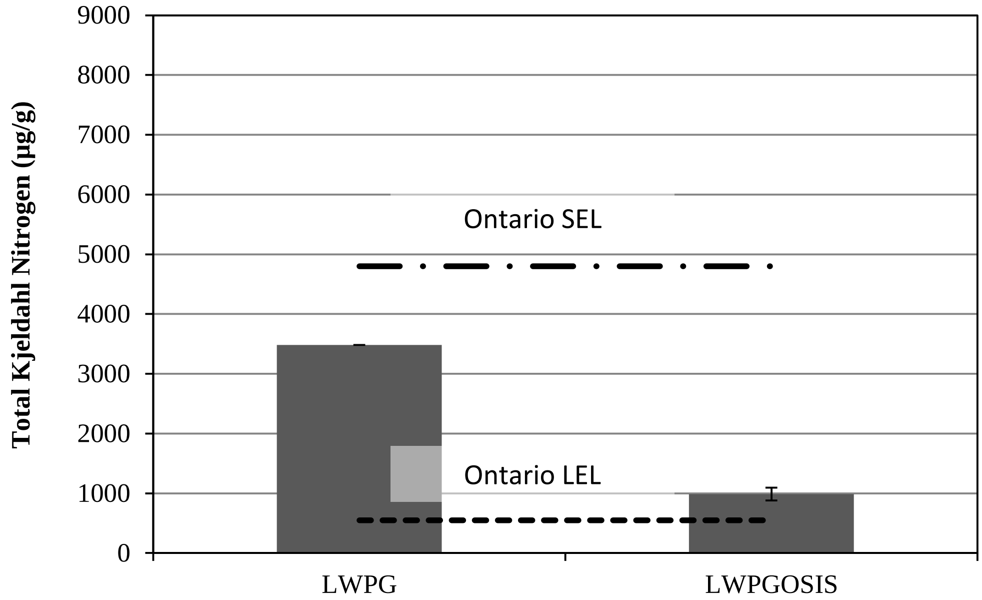


Figure 4-2. Mean (±SE) concentrations of total Kjeldahl nitrogen in surficial sediment from Lake Winnipeg (LWPG) and Lake Winnipegosis (LWPGOSIS) and comparison to Ontario sediment quality guidelines.

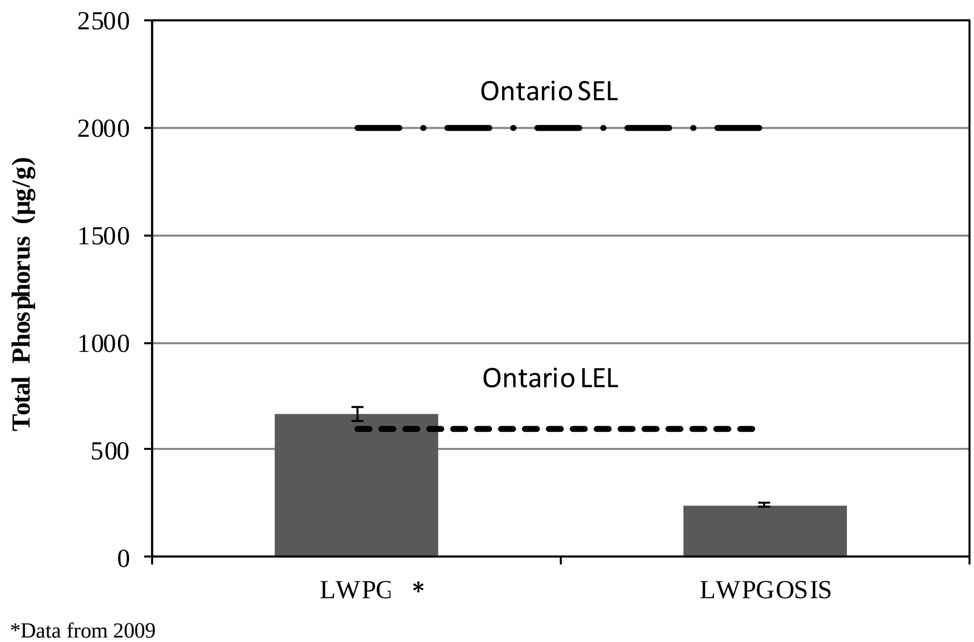


Figure 4-3. Mean (±SE) concentrations of total phosphorus in surficial sediment from Lake Winnipeg (LWPG) and Lake Winnipegosis (LWPGOSIS) and comparison to Ontario sediment quality guidelines.

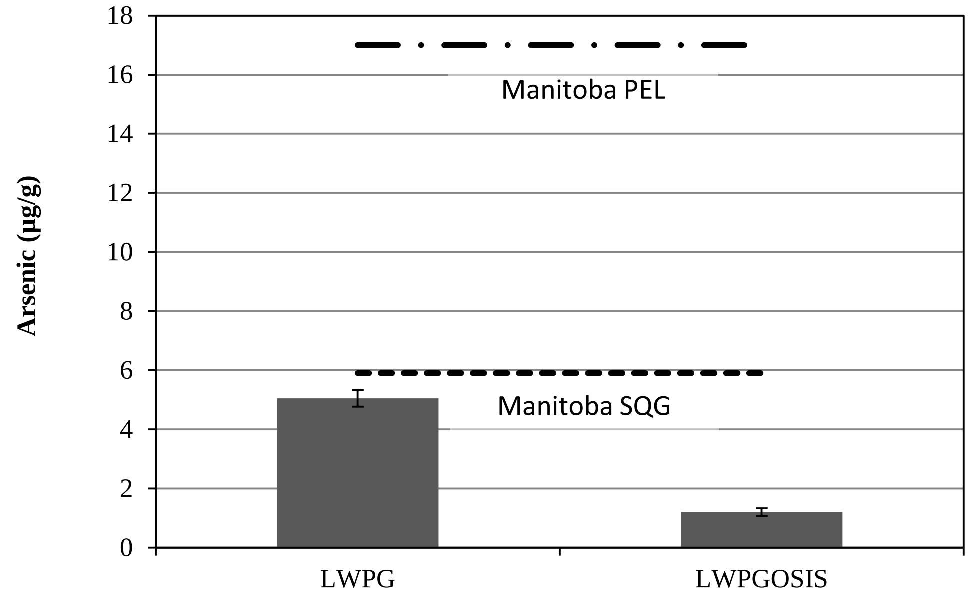


Figure 4-4. Mean (±SE) concentrations of arsenic in surficial sediment from Lake Winnipeg (LWPG) and Lake Winnipegosis (LWPGOSIS) and comparison to Manitoba sediment quality guidelines.

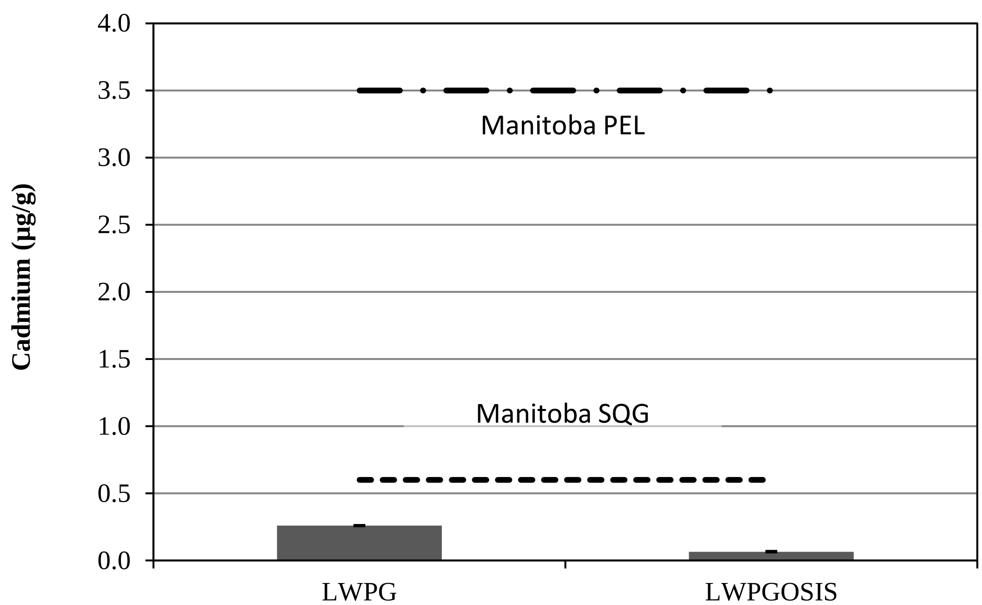


Figure 4-5. Mean (±SE) concentrations of cadmium in surficial sediment from Lake Winnipeg (LWPG) and Lake Winnipegosis (LWPGOSIS) and comparison to Manitoba sediment quality guidelines.

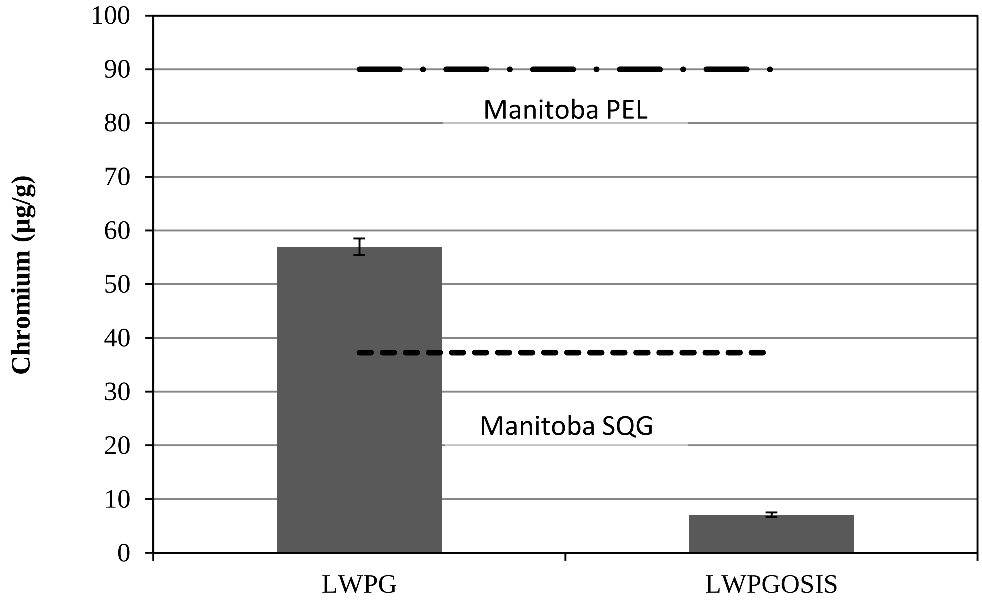


Figure 4-6. Mean (±SE) concentrations of chromium in surficial sediment from Lake Winnipeg (LWPG) and Lake Winnipegosis (LWPGOSIS) and comparison to Manitoba sediment quality guidelines.

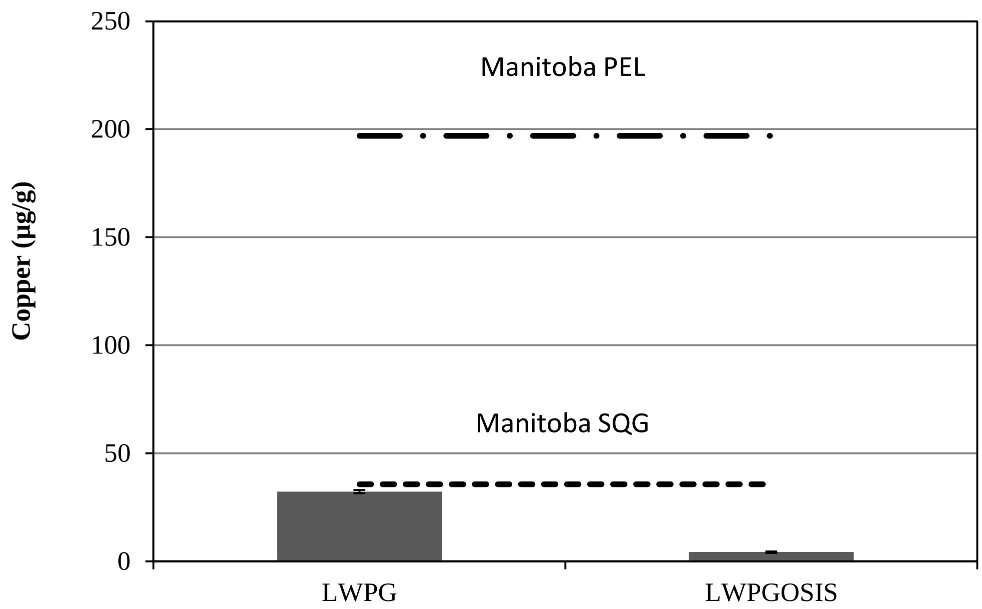


Figure 4-7. Mean (±SE) concentrations of copper in surficial sediment from Lake Winnipeg (LWPG) and Lake Winnipegosis (LWPGOSIS) and comparison to Manitoba sediment quality guidelines.

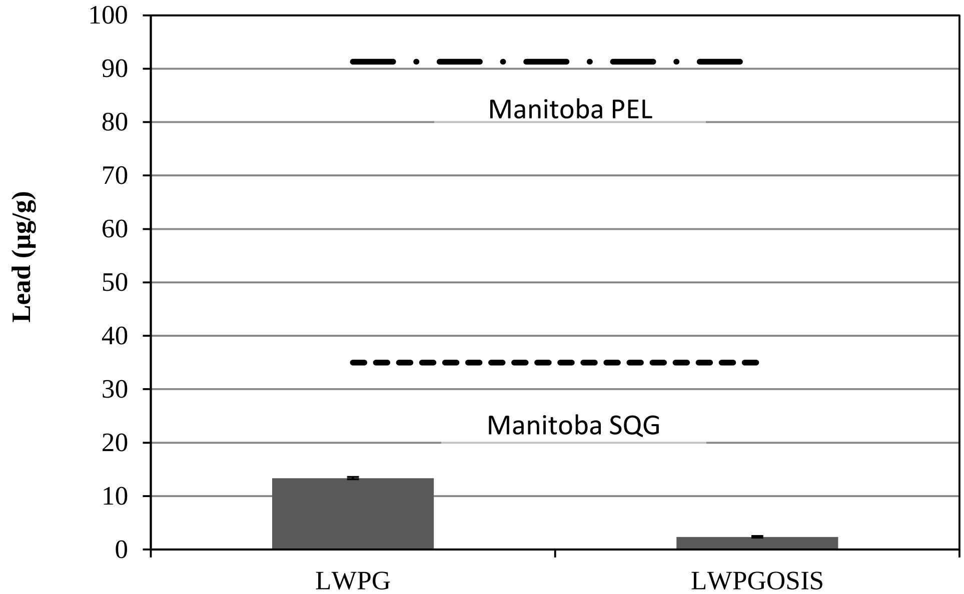


Figure 4-8. Mean (±SE) concentrations of lead in surficial sediment from Lake Winnipeg (LWPG) and Lake Winnipegosis (LWPGOSIS) and comparison to Manitoba sediment quality guidelines.

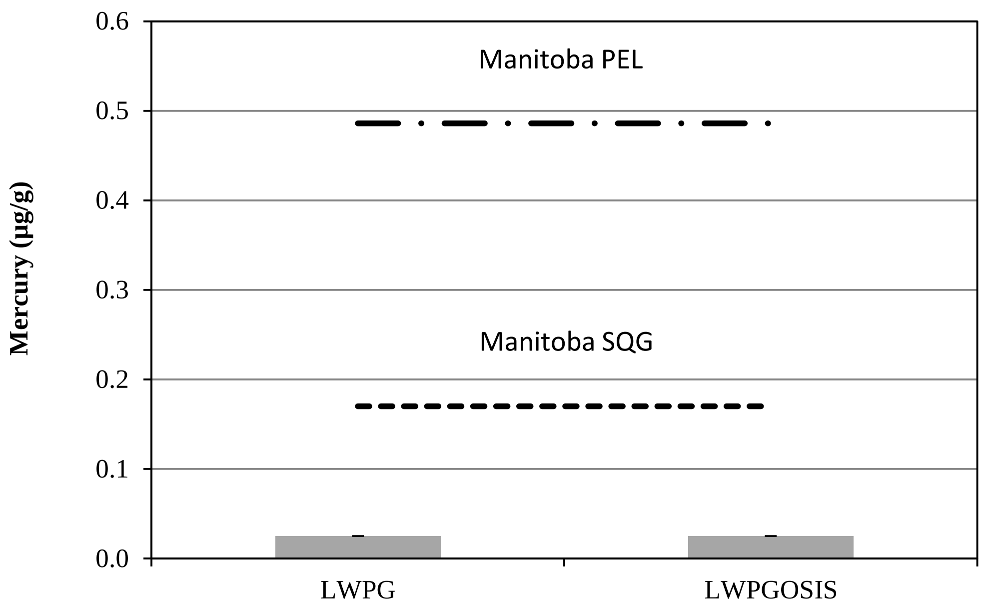


Figure 4-9. Mean (±SE) concentrations of mercury in surficial sediment from Lake Winnipeg (LWPG) and Lake Winnipegosis (LWPGOSIS) and comparison to Manitoba sediment quality guidelines. Means indicated in light grey were below the analytical detection limit.

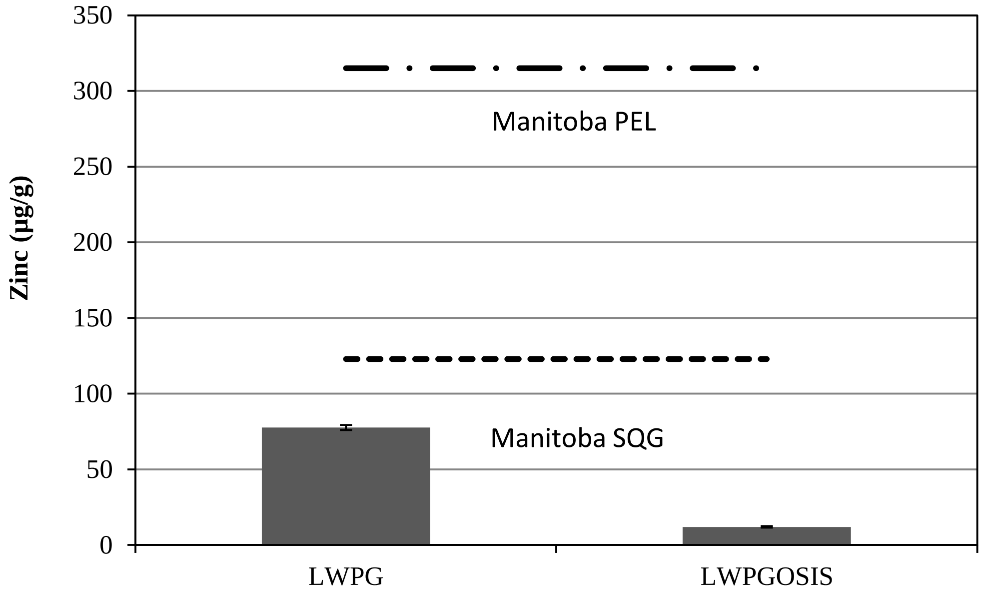


Figure 4-10. Mean (±SE) concentrations of zinc in surficial sediment from Lake Winnipeg (LWPG) and Lake Winnipegosis (LWPGOSIS) and comparison to Manitoba sediment quality guidelines.

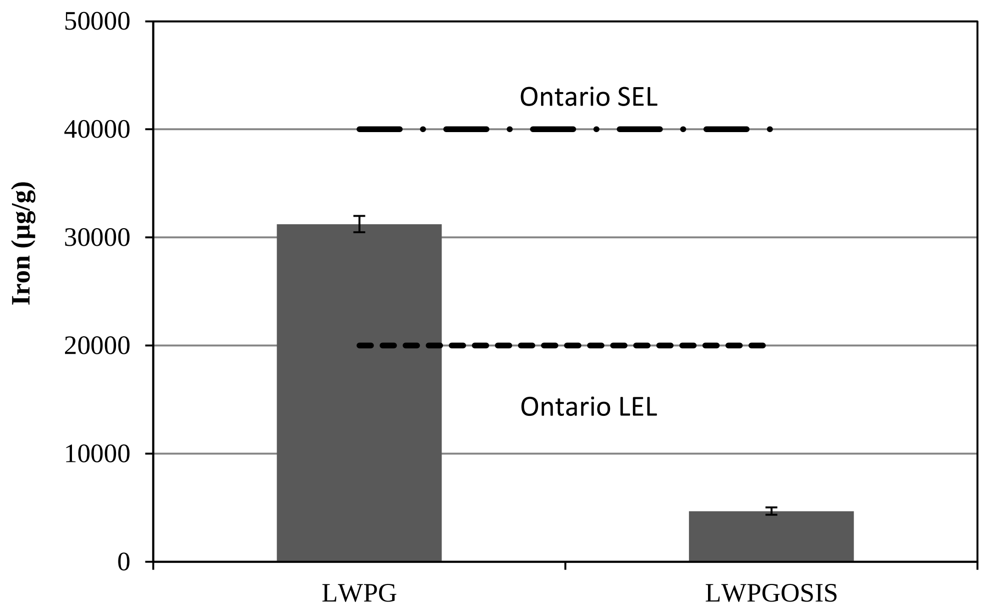


Figure 4-11. Mean (±SE) concentrations of iron in surficial sediment from Lake Winnipeg (LWPG) and Lake Winnipegosis (LWPGOSIS) and comparison to Ontario sediment quality guidelines.

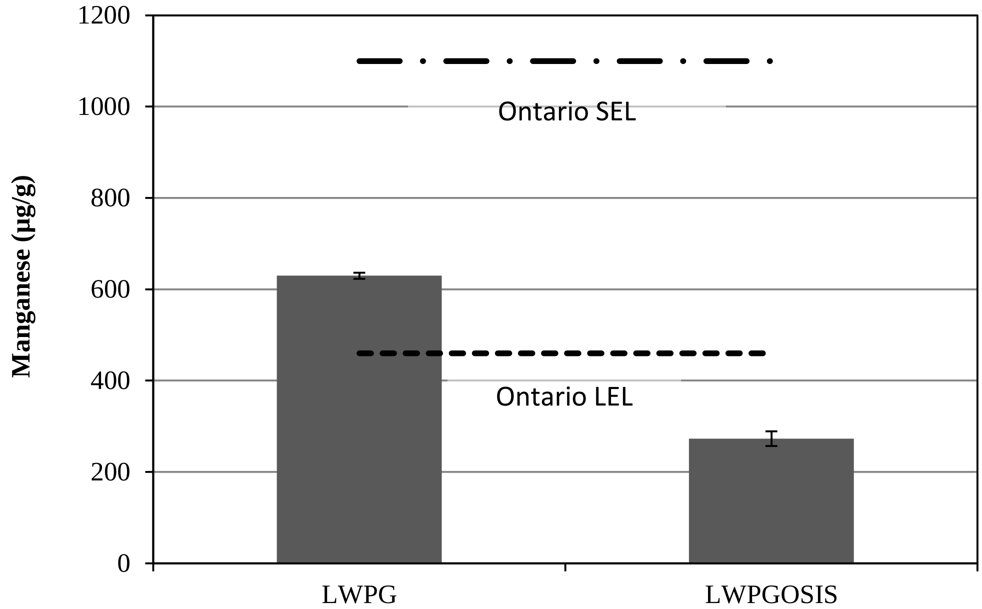


Figure 4-12. Mean (±SE) concentrations of manganese in surficial sediment from Lake Winnipeg (LWPG) and Lake Winnipegosis (LWPGOSIS) and comparison to Ontario sediment quality guidelines.

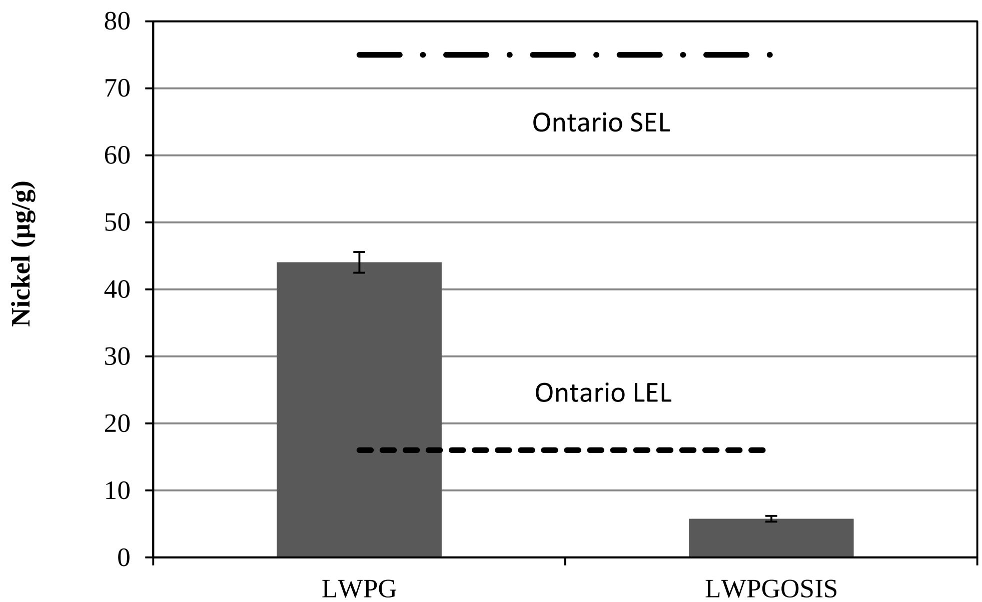


Figure 4-13. Mean (±SE) concentrations of nickel in surficial sediment from Lake Winnipeg (LWPG) and Lake Winnipegosis (LWPGOSIS) and comparison to Ontario sediment quality guidelines.

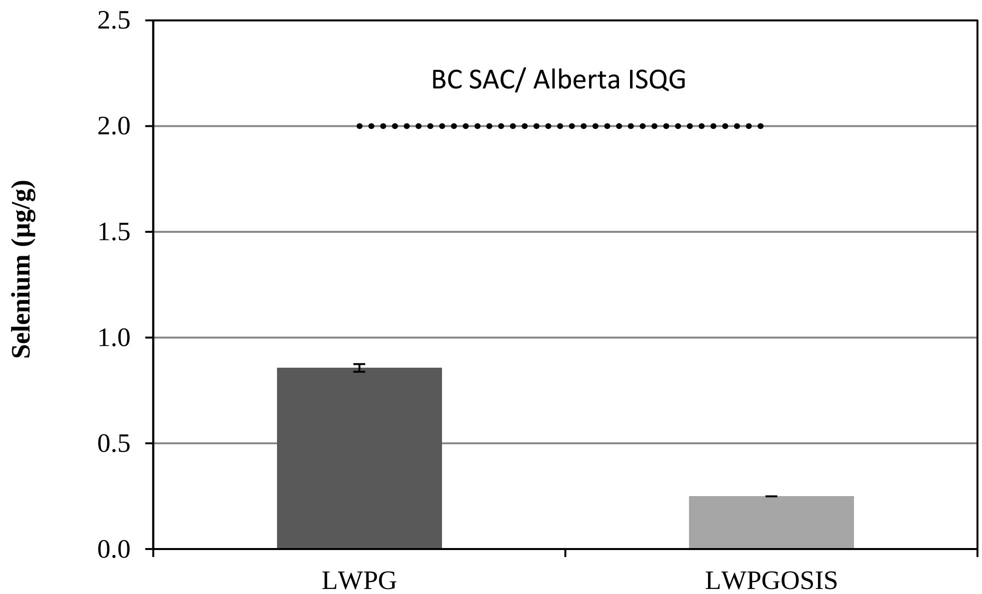


Figure 4-14. Mean (±SE) concentrations of selenium in surficial sediment from Lake Winnipeg (LWPG) and Lake Winnipegosis (LWPGOSIS) and comparison to the BC sediment alert concentration and the Alberta ISQG. Means indicated in light grey were below the analytical detection limit.

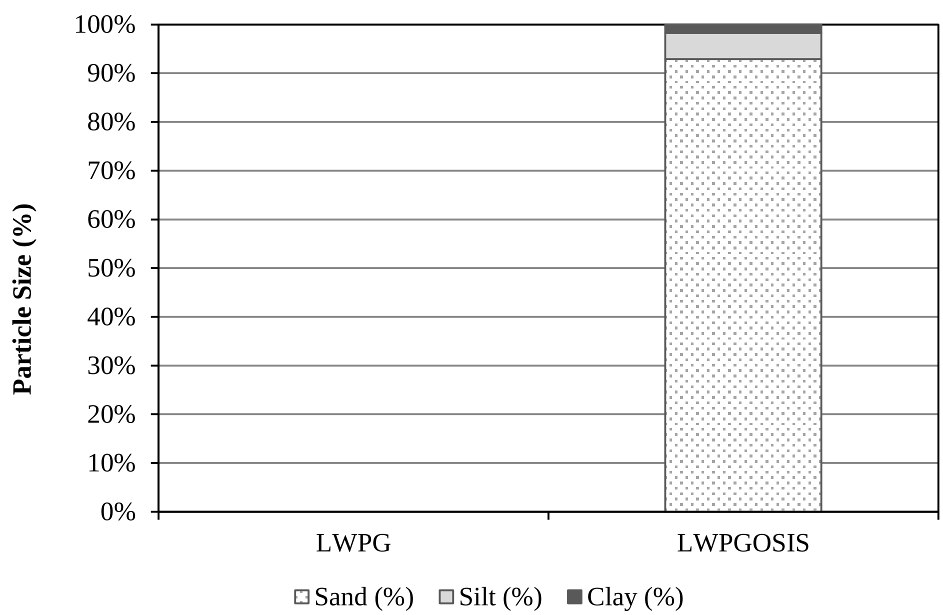


Figure 4-15. Particle size of surficial sediment from Lake Winnipeg (LWPG) and Lake Winnipegosis (LWPGOSIS).

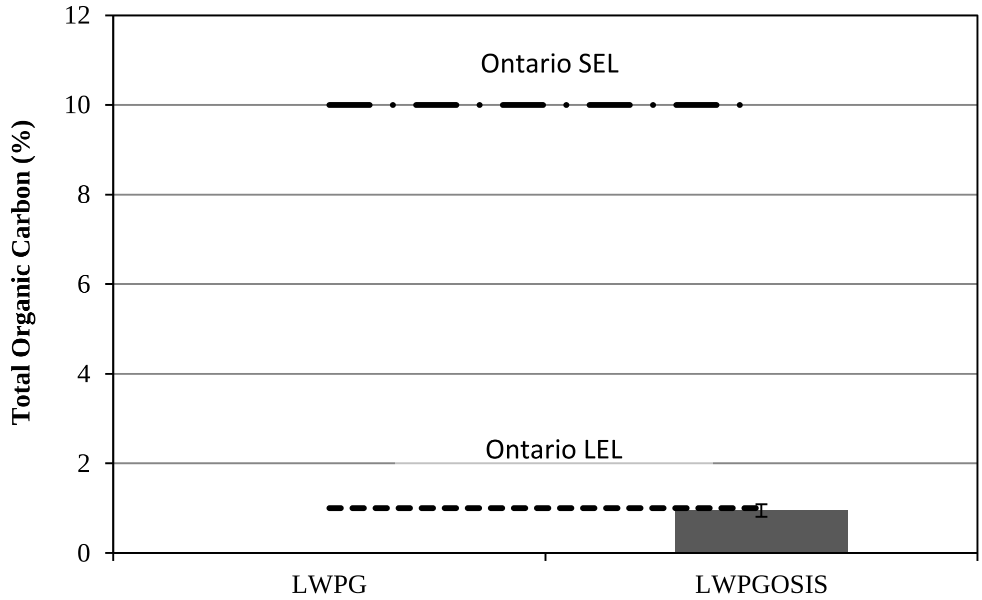


Figure 4-16. Percentage of total organic carbon in surficial sediment from Lake Winnipeg (LWPG) and Lake Winnipegosis (LWPGOSIS) and comparison to Ontario sediment quality guidelines.

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 LKWPGR. Data are restricted to this four-year time period as the sampling design was modified beginning in 2010 in an attempt to minimize the inherent variability within the BMI data (see Technical Document 1, Section 1.6.3). As noted in Section 1.0, waterbodies sampled annually included two on-system sites in Lake Winnipeg (Grand Rapids and Mossy Bay) and one off-system lake (Lake Winnipegosis; Figure 5-1). Although the two sites in Lake Winnipeg are both sampled annually for most CAMP components (e.g., fish, water quality), monitoring of BMIs was not initiated at these two sites until 2013. Due to the lack of data, temporal trends and inter-annual variability could not be assessed for Lake Winnipeg. As Lake Winnipegosis BMI sampling has been conducted since 2010, there was sufficient data to explore variability over time for this waterbody.

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) 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 (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 only one year of data was collected for the on-system waterbody and therefore no analysis of temporal variation could be conducted.

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.

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 presented 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) are also 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 may 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 from the benchmark along the shore to the water level at time of sampling 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 and discharges were provided by Manitoba Hydro for select locations in the LKWPGR, for varying periods of time (Section 2.0). Relationships between select BMI indicators 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 Lake Winnipeg

The nearshore habitat in the Lake Winnipeg – Grand Rapids area consisted mainly of coarse, hard substrate (cobble) and, as such, supporting sediment samples were not collected for laboratory analysis (Table 5-1). Sediments at the other on-system site at Lake Winnipeg – Mossy Bay consisted of sand (33%) and silt/clay (66% silt/clay; Figure 5-2). The TOC content of sediments sampled in the nearshore of Lake Winnipeg – Mossy Bay was low (< 1%; Table 5-2; Figure 5-3); however, benthic invertebrate samples contained a large amount of organic matter (e.g., small woody debris, plant fragments) that were not included in the sediment sample submitted for analysis.

The offshore habitat of the Lake Winnipeg – Grand Rapids area consisted mainly of silt/clay (96%; Figure 5-4). The Lake Winnipeg – Mossy Bay sediments were also predominantly silt/clay (78%), but had a greater proportion of sand (22%) in comparison to Grand Rapids (4%). The TOC content of sediments sampled in the Grand Rapids area was low (3%; Figure 5-5).

5.2.2 Off-system Waterbody: Lake Winnipegosis

The nearshore habitat of Lake Winnipegosis consisted of mainly coarse, hard substrate (cobble, gravel); as such sediment samples were only collected in 2010 for laboratory analysis (Table 5-1). These sediment samples were predominantly sand (73%; Figure 5-2); TOC content was low (approximately 2%; Figure 5-3).

The offshore habitat of Lake Winnipegosis consisted of a greater mean proportion of sand (85%) in comparison to the on-system Lake Winnipeg (Figure 5-4); TOC content was consistently low (approximately 0.8-1.2%; 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 Lake Winnipeg

The mean total abundance of BMIs in nearshore habitat varied considerably between Lake Winnipeg sites, ranging from an average high of ~34,000 individuals/sample at the Lake Winnipeg – Grand Rapids site to a low of 5 individuals/sample at the Lake Winnipeg – Mossy Bay site (Figure 5-6). The nearshore site in the Grand Rapids area was predominantly cobble substrate (Section 5.2.1) and abundant filamentous green algae were noted at the time of sampling in 2013, providing productive habitat for BMIs. Approximately 70% of BMIs at the Grand Rapids site were amphipods, which may feed on attached algae and associated detritus, and ~10% each Chironomidae and Gastropoda, for which attached algae are also suitable habitat. Even the small percentage (1%) of Ephemeroptera at the site is still equivalent to a large number of individuals (~500/sample) compared to many other locations. The Ephemeroptera were largely Heptageniidae and Leptohyphidae, groups that are generally described as crawling, deposit feeders.

In contrast, the nearshore in Mossy Bay was predominantly silt-clay (site adjacent to slumping clay bank) and exposed to extensive wave action. Fine woody debris and plant material from eroding shorelines or brought in by wind and wave action had formed a mat in the nearshore. It is not known the extent to which the substrate is disturbed by wave action, but the extremely low BMI abundance (Figure 5-6), consisting of a few Chironomidae and Trichoptera, suggests that it does not provide a stable environment. The Trichoptera present were in the family Hydropsychidae, net spinning caddisflies that live along wave-washed shorelines of lakes.

Similar to the nearshore habitat, the mean density of BMIs in offshore habitat varied considerably between the two Lake Winnipeg sites: densities at the Grand Rapids site were high (~8,500 individuals/m^2) and densities in Mossy Bay were very low (~100 individuals/m^2; Figure 5-7). Amphipods still predominated at the Grand Rapids site (~50%), with ~20% each of

Chironomidae and Bivalvia. As was noted for the nearshore habitat, the 6% of the total catch comprised by Ephemeroptera corresponds to a sizeable number of organisms (an average of 480/m^2). In Mossy Bay, the offshore fauna is predominantly Chironomidae (70%) with Gastropoda comprising most of the remainder.

The high abundance in the Grand Rapids offshore area is likely linked to the generally productive environment and is similar to the offshore of Cedar Lake (Saskatchewan River Region [SRR]; Technical Document 3, Section 5). The extremely low productivity in Mossy Bay is not linked to substrate composition or organic content, both of which are comparable to other locations sampled in CAMP. However, the substrate was extremely compact, making it a challenge to sample, and possibly less suitable for BMIs as well.

5.3.1.2 Off-system Waterbody: Lake Winnipegosis

The mean abundance of BMIs in the nearshore habitat of Lake Winnipegosis was considerably higher than Lake Winnipeg at Mossy Bay and lower than the Grand Rapids area, but within the range observed at nearby Cedar Lake (SRR; Technical Document 3, Section 5). Typically more than 70% of the BMI were non-insects, with Amphipoda comprising greater than 50% of the catch, in all years except 2013, when Amphipoda comprised ~40% and Oligochaeta ~20% of the total. Ephemeroptera typically comprised the majority of the Insecta, except in 2013 when Chironomidae were more abundant.

As with the nearshore habitat, the mean density of BMIs in the offshore habitat of Lake Winnipegosis was considerably less than at the Grand Rapids site and considerably greater than at Mossy Bay (Figure 5-7). Numbers were more comparable to South Moose Lake, in the SRR. Insecta were predominant in 2010 and 2013, comprising 70-80% of the samples, while in 2011 and 2012, non-insects were relatively more abundant, comprising 60-80% of the catch. Oligochaeta and Chironomidae were the predominant taxa.

5.3.1.3 Temporal Comparisons and Trends

Although there was no indication of trends in Lake Winnipegosis, there was notable inter-annual variability. Total invertebrate abundance in nearshore habitat was particularly high in 2010 and 2012, which was about two times higher than in 2011 and about four times higher than in 2013 (Figure 5-6). In the offshore Lake Winnipegosis habitat, the lowest abundance also occurred in 2013 (Figure 5-7).

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 habitat.

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 Lake Winnipeg

The ratio of EPT:C for the Lake Winnipeg – Grand Rapids area in both the nearshore and offshore was much less than one, indicating an insect community dominated by Chironomidae when compared to EPT (Figures 5-8 and 5-9). However, as previously noted, Ephemeroptera were still abundant in the nearshore, despite being relatively much less abundant than Chironomidae. Too few invertebrates were collected at Mossy Bay to allow meaningful interpretation of the EPT:C ratio.

5.3.2.2 Off-system Waterbody: Lake Winnipegosis

The nearshore habitat of Lake Winnipegosis had a higher mean EPT:C ratio (6.5) than Lake Winnipeg (Figure 5-8). The ephemeropteran families Leptophlebiidae, Caenidae (*Caenis* sp.), and Heptageniidae (*Stenacron* sp.) largely contributed to the higher EPT:C ratio.

The mean ratio of EPT:C in offshore habitat was similar to the on-system Grand Rapids site, indicating a benthic community heavily dominated by chironomids in comparison to EPT (Figure 5-9).

5.3.2.3 Temporal Comparisons and Trends

The EPT:C ratio in the nearshore at Lake Winnipegosis was greater than one in all years but 2013, indicating that EPT were more abundant than Chironomidae in most years. In 2013 there were notably fewer ephemeropterans, including *Caenis* spp., *Stenacron* spp., and particularly Leptophlebiidae.

The mean EPT:C ratio in offshore habitat of Lake Winnipegosis was less than 0.2 in all four years sampled indicating a predominance of chironomids when compared to EPT, though significant inter-annual variability was observed (Figure 5-9).

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 Lake Winnipeg

Total richness at the predominantly cobble nearshore Grand Rapids site varied between nine and 16 families with an average of 14 (Figure 5-10). The mean total richness of BMIs in the offshore habitat at Grand Rapids was eight families, just over half that of the nearshore environment (Figure 5-11). Too few invertebrates were collected at Mossy Bay to allow meaningful analysis of richness.

5.3.3.2 Off-system Waterbody: Lake Winnipegosis

The mean total richness of BMIs in the nearshore habitat of the off-system Lake Winnipegosis was marginally higher (16 families) than at Grand Rapids (Figure 5-10), while in the offshore habitat it was marginally lower (five families; Figure 5-11).

5.3.3.3 Temporal Comparisons and Trends

Total richness of BMIs in both the nearshore and offshore habitats in Lake Winnipegosis varied slightly among years, but there were no statistically significant differences and no indications of trends (Figures 5-10 and 5-11).

5.3.4 Ephemeroptera, Plecoptera, and Trichoptera Richness

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

5.3.4.1 Lake Winnipeg

Mean EPT richness at Grand Rapids was six families in the nearshore and one in the offshore (Figures 5-10 and 5-11). Too few invertebrates were collected at Mossy Bay to allow meaningful analysis of richness.

5.3.4.2 Off-system Waterbody: Lake Winnipegosis

EPT taxa richness at the off-system site was comparable to that observed in the Grand Rapids area of Lake Winnipeg, with an average of seven families in the nearshore and one family in the offshore (Figures 5-10 and 5-11).

5.3.4.3 Temporal Comparisons and Trends

Mean EPT richness in the nearshore habitat of Lake Winnipegosis varied between seven and eight families between 2010 and 2012, but was significantly lower (four families) in 2013 (Figure 5-10). Mean EPT richness in the offshore varied by no more than two families among years (Figure 5-11).

5.3.5 Simpson's Diversity Index

Simpson's Diversity Index may provide more information about BMI community structure than abundance or richness alone. The 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. Yearly results for the offshore environment are provided in Figure 5-13.

5.3.5.1 Lake Winnipeg

Simpson's Diversity Index for the nearshore BMI community for the Grand Rapids area was moderately low (0.43; Figure 5-12). The lower diversity, despite the number of taxa present, was due to a greater abundance of only a few taxa (i.e., lower evenness). In the offshore, the mean index (0.66) was greater than the nearshore despite fewer taxa present because of a more equal distribution among taxa (i.e., greater evenness).

Too few invertebrates were collected at Mossy Bay to allow meaningful analysis of diversity.

5.3.5.2 Off-system Waterbody: Lake Winnipegosis

Simpson's Diversity Index was much higher in the nearshore at the off-system Lake Winnipegosis site (0.71) than at the on-system Grand Rapids site (Figure 5-12). However, in the offshore habitat, diversity was lower (0.53) than the nearshore of Lake Winnipegosis and slightly lower than the offshore at Grand Rapids Figure 5-13).

5.3.5.3 Temporal Comparisons and Trends

Simpson's Diversity Index in the nearshore and offshore habitat at the Lake Winnipegosis site was higher in 2013 than the other years. However, the only significant difference was noted between 2013 and 2011 in nearshore habitat. There were no noticeable temporal trends in either habitat.

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 Lake Winnipeg

Two to four Ephemeroptera genera were found in the nearshore habitat with a maximum of one genus at the Grand Rapids offshore site (Figures 5-14 and 5-15). Too few invertebrates were collected at Mossy Bay to allow meaningful analysis of the number of Ephemeroptera genera.

5.4.1.2 Off-system Waterbody: Lake Winnipegosis

Slightly more Ephemeroptera genera were present in the nearshore of Lake Winnipegosis (3-6) then at the Grand Rapids site (Figures 5-14 and 5-15). The maximum number of genera in the offshore was two.

5.4.1.3 Temporal Comparisons and Trends

No significant changes in Ephemeroptera richness were observed in the nearshore or offshore environments of Lake Winnipegosis, with no consistent temporal trends. Meaningful changes are unlikely given the small number of taxa.

5.5 RELATIONSHIPS WITH HYDROLOGICAL METRICS

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

Water levels on both Lake Winnipeg and Lake Winnipegosis were above average and generally above the upper quartile for the majority of the study period. Sampling at both Lake Winnipeg sites in 2013 was conducted as water levels declined from a mid-summer peak such that, if water level at the time of sampling was not affected by wind, the area sampled would have been totally wetted for at least two months.

Sampling on Lake Winnipegosis was also done at high water levels. The sampling site is subject to wind effects on water level so there is not good correspondence between the relative water level recorded on the shore during BMI sampling and water elevation data provided by Manitoba Hydro. Based on the shore records, sampling in 2012 and 2013 was conducted at a lower elevation than 2010 and 2011 but the duration of wetting cannot be determined.

No analysis of the potential relationship between average water level during the growing season and BMI metrics was conducted for Lake Winnipegosis due to uncertainty with respect to water elevation during the sampling period.

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

The nearshore habitat sampled on Lake Winnipeg near Grand Rapids and in Mossy Bay is thought to have been wetted for much of the growing season in 2013. However, the large differences among the two sites and the off-system location on Lake Winnipegosis are not likely related to the water regime, but, as discussed above, probably a combination of substrate, productivity, and exposure to wave action. However, if sampling at the Grand Rapids site had occurred immediately after a rapid rise in lake levels, then invertebrate numbers would have been much lower, as the high densities appear to be in response to algal growth on rocks in the nearshore.

As noted above, the degree to which the sampling site on Lake Winnipegosis was wetted during the growing season cannot be determined due to the effect of wind on water level during sample collection. Abundance in the nearshore was significantly lower in 2013 than in other years. However, in 2013 neither water elevation nor position on the shore as measured at the site were outside of the range of other sampling periods. In addition, water elevation was at a consistent level since late June, suggesting that the nearshore may have been wetted for at least two months. Therefore, the significantly lower abundance in 2013 does not seem to be directly attributable to hydrology.

5.6 SUMMARY

The BMI communities at the two sampling locations on Lake Winnipeg were dramatically different, likely due to the combined effects of habitat variation, wave exposure, and productivity. Nearshore abundance in the Grand Rapids area was extremely high, and dominated by invertebrates that could consume the abundant attached algae and associated detritus on the cobble substrate, in particular Amphipoda and, to a lesser extent, Chironomidae and Gastropoda. Although Ephemeroptera comprised only a small proportion of the total catch (1%), they were still present in large numbers. The offshore environment was also productive; Amphipoda comprised half the catch while Chironomidae and Bivalvia were also predominant. In contrast, exceptionally few invertebrates were found in the nearshore of Mossy Bay, possibly due to disturbance by wave action and/or a mat of organic debris. The offshore environment at Mossy Bay also had a low total abundance of BMI, with Chironomidae dominant. The cause for the low abundance offshore is not known, but may be linked to the hard packed substrate.

The mean abundance of BMIs in the nearshore habitat of Lake Winnipegosis was considerably less than at the Grand Rapids site but within the range observed at nearby Cedar Lake (SRR). Amphipoda were typically the most abundant overall taxon, with Ephemeroptera generally being the predominant insect. Oligochaeta and Chironomidae were present in substantial numbers in at least one of the sample years. In the offshore, Oligochaeta and Chironomidae were the predominant organisms. Inter-annul differences in total abundance and community composition could not be examined in relation to the potential effect of water level changes, as the water level at the time of sampling could not be reliably linked to seasonal changes in elevation.

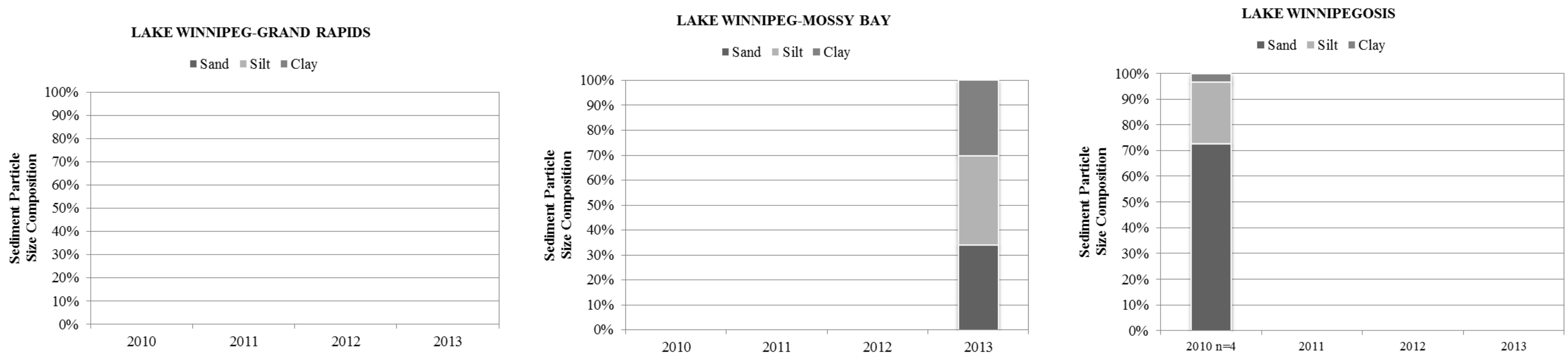
Overall, analysis of the four years of CAMP BMI monitoring data collected in Lake Winnipegosis indicated that none of the key metrics (including the additional metric Ephemeroptera richness) have undergone a consistent increasing or decreasing trend over this time period in Lake Winnipegosis; data were insufficient to examine trends or inter-annual variability for Lake Winnipeg. However, some statistically significant inter-annual variability was observed (e.g., total invertebrate abundance in the nearshore between 2013 and both 2010 and 2012; EPT:C ratio in the offshore habitat between 2011 and both 2010 and 2012; EPT richness in the nearshore between 2013 and all other years; and Simpsons Diversity Index in the nearshore between 2011 and 2013).

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

Waterbody	Date	Nearshore				Offshore				Relative Water Level[3]		Gauged Water Level (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)
WPGOSIS	25-Sep-10	0.6	standing	cobble, gravel, boulder, sand (flooded terrestrial)	loamy sand	7.1	standing	clay (shells, sand)	loamy sand	0.87	0.50	253.88	--
WPGOSIS	25-Aug-11	0.9	standing	cobble, gravel, boulder	--	7.4	standing	sand, organic matter (shells), clay	sand	0.85	0.68	254.30	--
WPGOSIS	27-Aug-12	0.7	standing	cobble, gravel	--	6.9	standing	sand, shells	loamy sand (sand)	1.30	n.r.	253.88	--
LW-GR	16-Aug-13	0.9	standing	cobble	--	6.2	standing	clay	silt loam	2.30	1.60	217.84	--
LW-MB	22-Aug-13	0.7	standing	clay	silty clay; clay loam (sand)	5.5	standing	clay (gravel)	silty clay (sandy loam)	0.86	0.55	217.82	--
WPGOSIS	18-Aug-13	0.5	standing	cobble, gravel	--	7.1	standing	silt	loamy sand	1.20	0.50	254.09	--

[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.

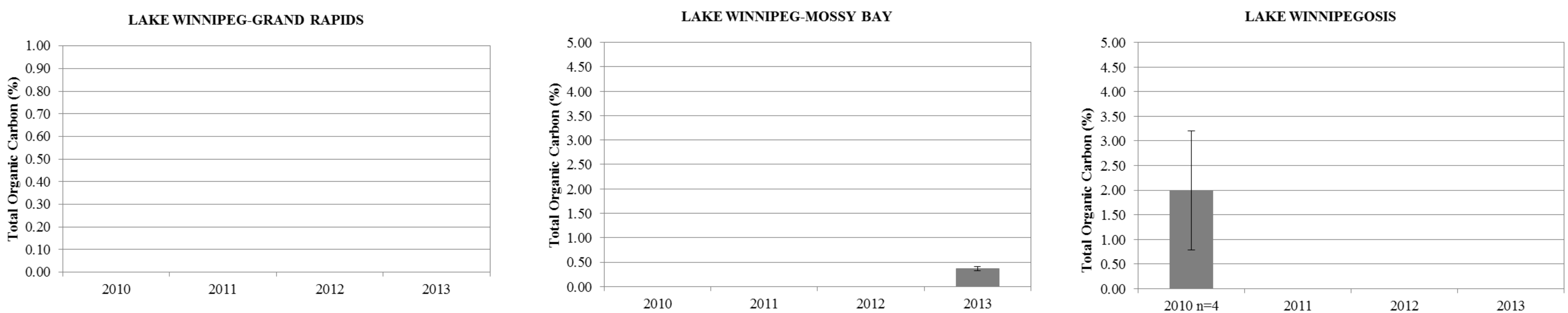
Figure 5-1. Benthic macroinvertebrate sampling sites in the Lake Winnipeg Region: 2010 – 2013.



No sediment samples collected at:

- Lake Winnipegosis (2011 – 2013) and Lake Winnipeg Grand Rapids (2013) due to predominantly hard substrate.

Figure 5-2. Sediment particle size composition (mean % of sand, silt, clay) in the nearshore habitat of the Lake Winnipeg Region, by year: 2010 – 2013. Lake Winnipeg sites sampled in 2013 only.



No sediment samples collected at:

- Lake Winnipegosis (2011 – 2013) and Lake Winnipeg Grand Rapids (2013) due to predominantly hard substrate.

Figure 5-3. Total organic carbon (mean % ± SE) in the nearshore habitat of the Lake Winnipeg Region, by year: 2010 – 2013. Lake Winnipeg sites sampled in 2013 only.

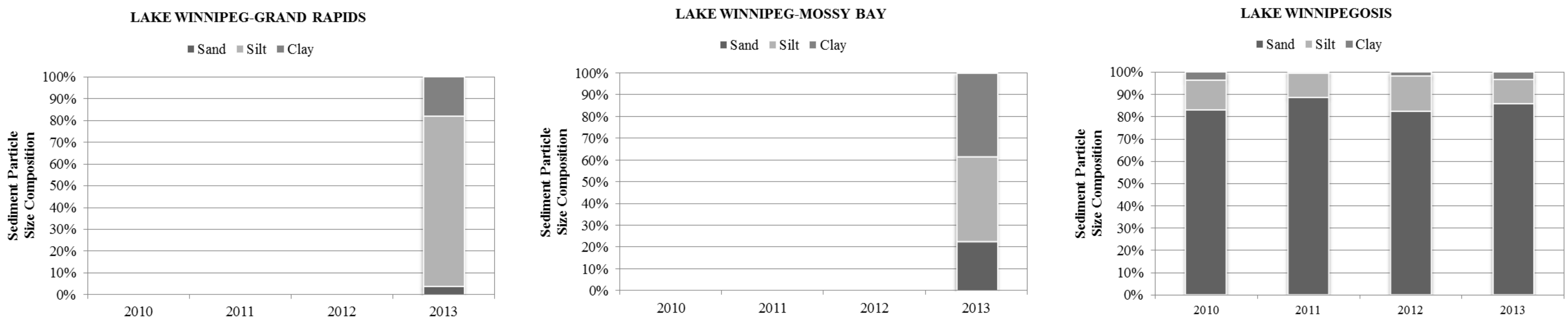


Figure 5-4. Sediment particle size composition (mean % of sand, silt, clay) in the offshore habitat of the Lake Winnipeg Region, by year: 2010 – 2013.

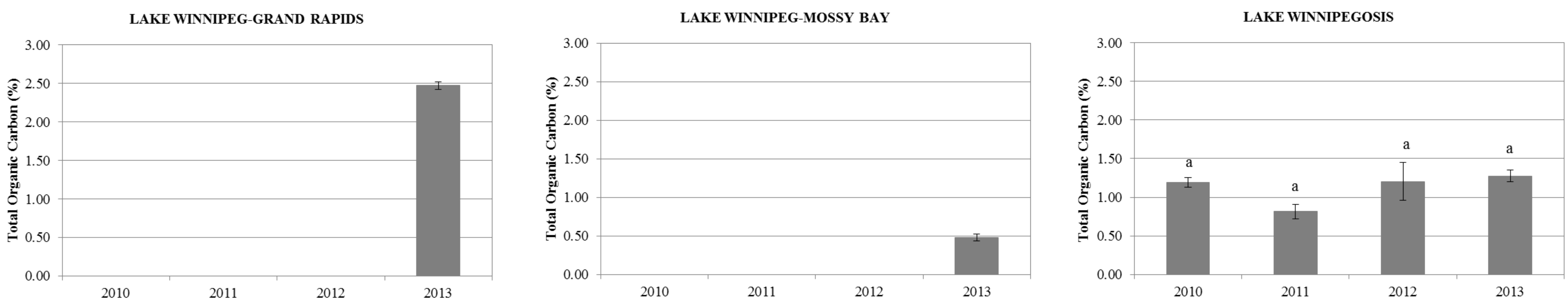


Figure 5-5. Total organic carbon (mean % ± SE) in the offshore habitat of the Lake Winnipeg Region, by year: 2010 – 2013. No statistically significant inter-annual differences were observed in the annual monitoring site (Lake Winnipegosis).

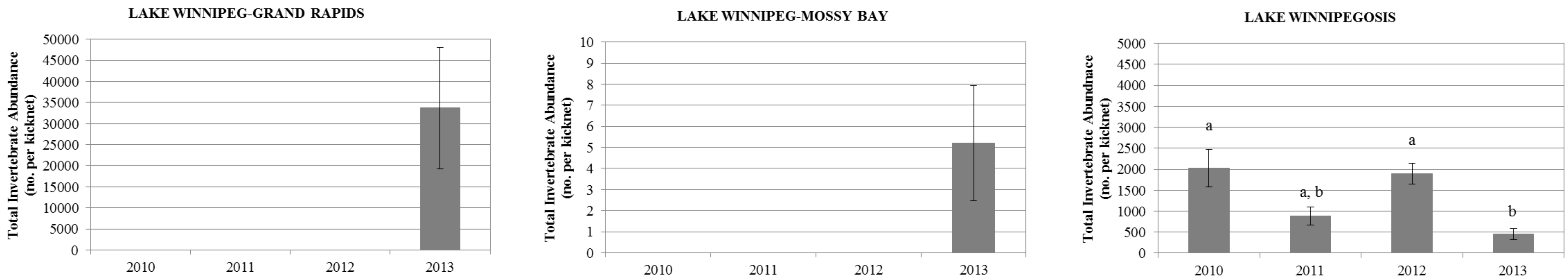


Figure 5-6. Total invertebrate abundance (mean ± SE) in the nearshore habitat of the Lake Winnipeg Region, by year: 2010 – 2013. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant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

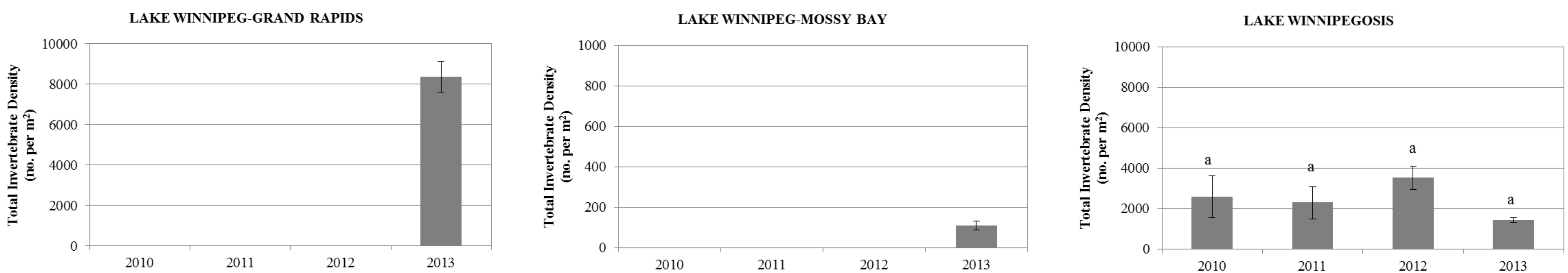


Figure 5-7. Total invertebrate density (mean ± SE) in the offshore of the Lake Winnipeg Region, by year: 2010 – 2013. Note the difference in scales for each of the figures. No statistically significant inter-annual differences were observed in the annual monitoring site (Lake Winnipegosis).

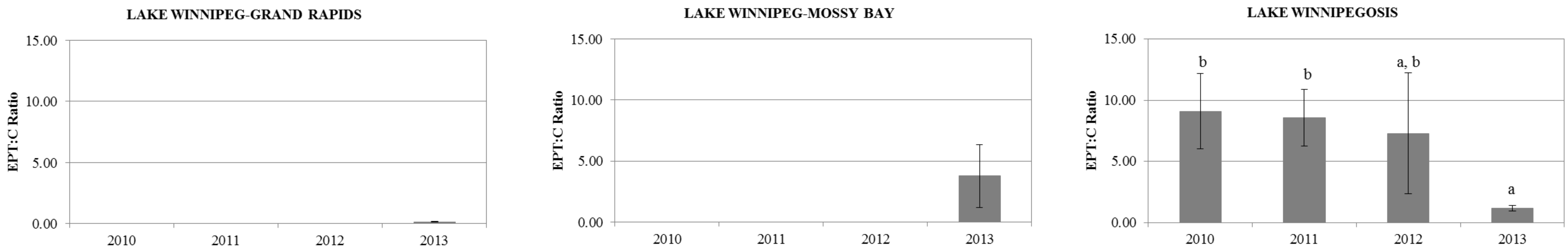


Figure 5-8. EPT:C ratio (mean ± SE) in the nearshore habitat of the Lake Winnipeg Region, by year: 2010 – 2013. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

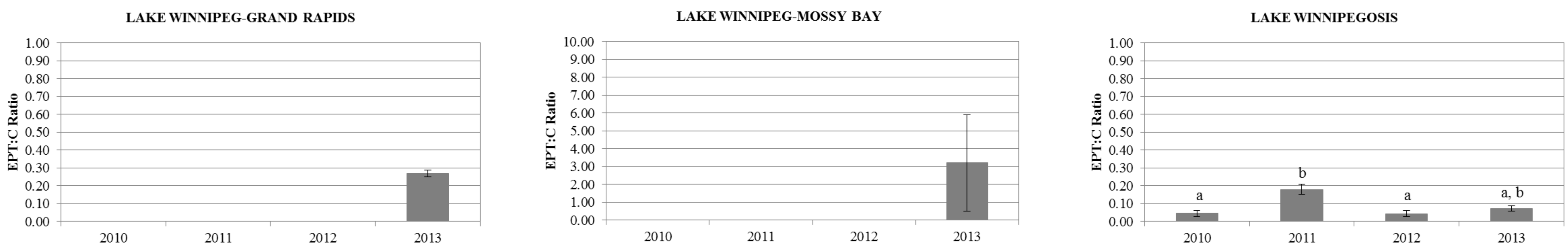


Figure 5-9. EPT:C ratio (mean ± SE) in the offshore habitat of the Lake Winnipeg Region, by year: 2010 – 2013. Note the difference in scales for each of the figures. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant difference.

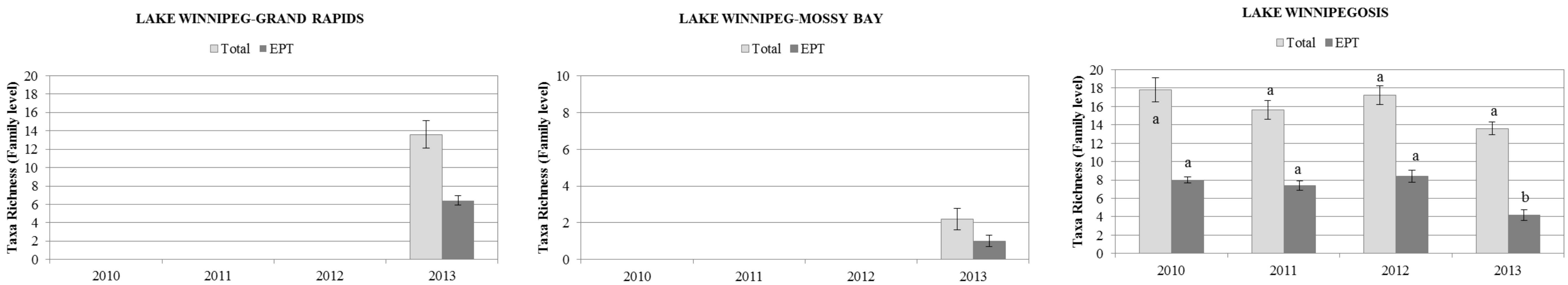


Figure 5-10. Taxonomic richness (total and EPT to family level; mean ± SE) in the nearshore habitat of the Lake Winnipeg Region, by year: 2010 – 2013. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no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

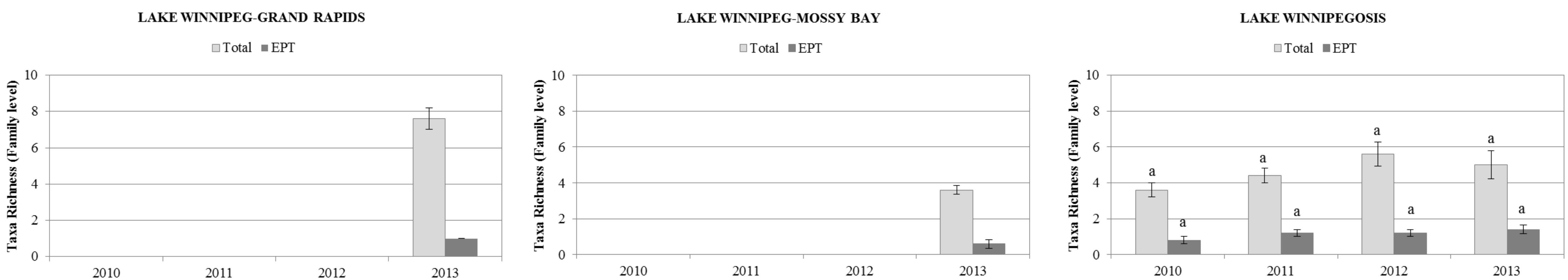


Figure 5-11. Taxonomic richness (total and EPT to family level; mean ± SE) in the offshore habitat of the Lake Winnipeg Region, by year: 2010 – 2013. No statistically significant inter-annual differences were observed in the annual monitoring site (Lake Winnipegosis).

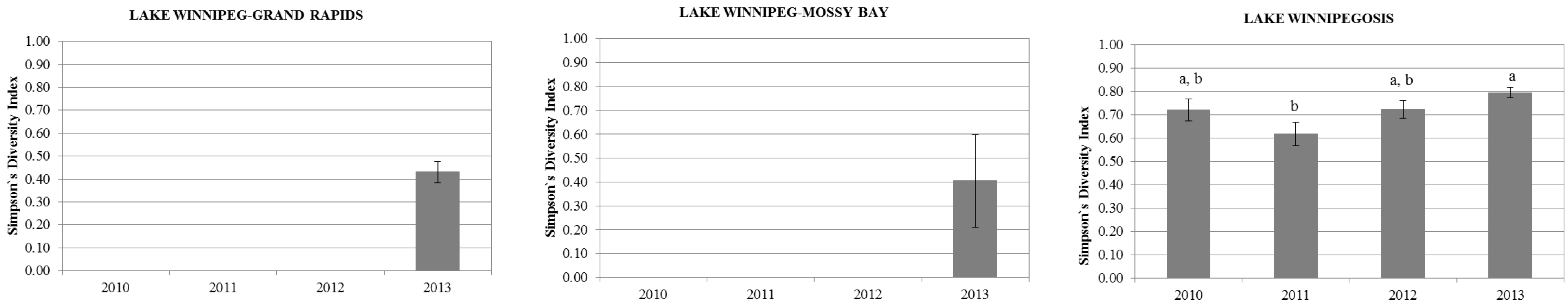


Figure 5-12. Simpson’s Diversity Index (mean ± SE) in the nearshore habitat of the Lake Winnipeg Region, by year: 2010 – 2013. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts denote no statistically significant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

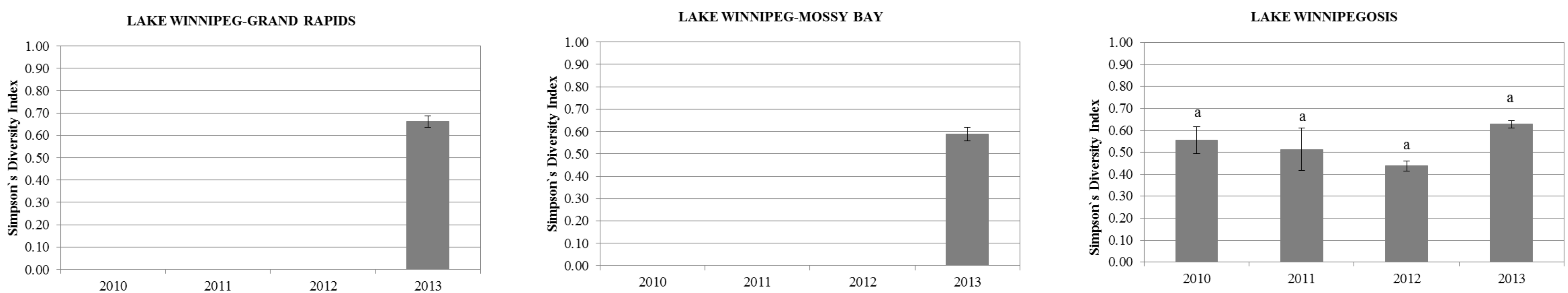


Figure 5-13. Simpson’s Diversity Index (mean ± SE) in the offshore habitat of the Lake Winnipeg Region, by year: 2010 – 2013. No statistically significant inter-annual differences were observed in the annual monitoring site (Lake Winnipegosis).

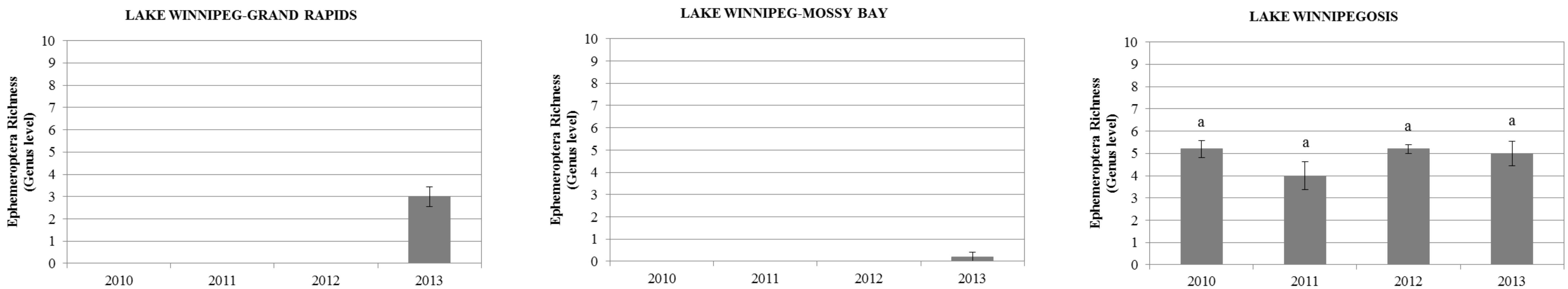


Figure 5-14. Ephemeroptera richness (genus level; mean ± SE) in the nearshore habitat of the Lake Winnipeg Region, by year: 2010 – 2013. No statistically significant inter-annual differences were observed in the annual monitoring site (Lake Winnipegosis).

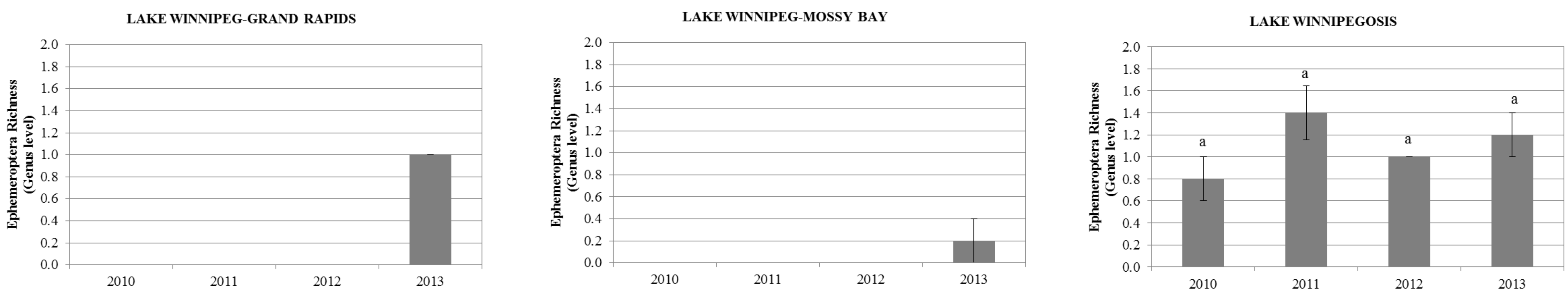


Figure 5-15. Ephemeroptera richness (genus level; mean ± SE) in the offshore habitat of the Lake Winnipeg Region, by year: 2010 – 2013. No statistically significant inter-annual differences were observed in the annual monitoring site (Lake Winnipegosis).

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 LKWPGR. As noted in Section 1.0, waterbodies sampled annually included three on-system sites within the north basin of Lake Winnipeg (Sturgeon Bay, Grand Rapids, and Mossy Bay) and one off-system site (Lake Winnipegosis; Table 6-1; Figure 6-1). Descriptions of the region and waterbodies monitored under CAMP are provided in Technical Document 1, Section 2.3 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 sampling periods as intended with the exception of Sturgeon Bay in 2011 due to lack of access associated with flood conditions in the Dauphin River.

All analyses presented below have been conducted on the results of annual or rotational index gillnetting studies. A detailed description of the sampling methodology 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 the Lake Winnipeg Region waterbodies 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) 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 gill nets; 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 5.6.1 of Technical Document 1.

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 Lake Winnipeg

The mean Hill's index ranged from a low of 4.8 in Lake Winnipeg – Sturgeon Bay to a high of 6.4 in Lake Winnipeg – Mossy Bay (Table 6-3). The mean Hill's number for the Lake Winnipeg Region sites increased from south to north within the lake with Lake Winnipeg – Sturgeon Bay having the lowest value (4.8), followed by Lake Winnipeg – Grand Rapids (5.5) and then Lake Winnipeg – Mossy Bay (6.4), the most northern site in the region (Figure 6-2). The highest Hill's value was primarily due to a more even distribution of the species present as six species accounted for 82% of the catch in Lake Winnipeg – Mossy Bay, with Yellow Perch (*Perca flavescens*), Trout-perch (*Percopsis omiscomaycus*) and Walleye (*Sander vitreus*) contributing 17% to 22% while White Sucker (*Catostomus commersonii*), Rainbow Smelt (*Osmerus mordax*) and Sauger (*Sander canadensis*) all contributed 9%. In Lake Winnipeg – Grand Rapids five species accounted for 90% of the catch, with Walleye contributing the most (27%), followed by Trout-perch (20%) and Rainbow Smelt (19%). Lake Winnipeg – Sturgeon Bay, which had the lowest Hill's number, had the most uneven species assemblage with Yellow Perch dominating the catch at 41% followed by Walleye at 14%, while White Sucker and Spottail Shiner (*Notropis hudsonius*) accounted for 9% and 8% of the catch, respectively. All other species present in Lake Winnipeg – Sturgeon Bay accounted for less than 5% of the catch.

6.2.1.2 Off-system Waterbody: Lake Winnipegosis

The mean Hill's number was 6.6 in Lake Winnipegosis (Table 6-3). The Hill's index for Lake Winnipegosis was similar to that in Lake Winnipeg – Mossy Bay which had the highest value of all the Lake Winnipeg sites (Figure 6-2). Nearly 90% of the catch from Lake Winnipegosis was accounted for by seven species with Yellow Perch accounting for 35% of the catch, followed by White Sucker at 18% and Walleye at 11%. Four other species accounted for between 4% and 9% of the catch each.

6.2.1.3 Temporal Comparisons and Trends

The Hill's value for Lake Winnipeg – Sturgeon Bay fluctuated between a low of 3.6 in 2009 and 6.4 in 2010 (Figure 6-2). Lake Winnipeg – Grand Rapids had the most consistent values ranging from 5.1 in 2009 to 6.1 in 2012. Lake Winnipeg – Mossy Bay was found to range from a low of 5.2 in 2011 to a high of 7.8 in 2012 (Figure 6-2).

No trends for this metric were apparent for Lake Winnipeg – Sturgeon Bay and Lake Winnipeg – Grand Rapids. Results from Lake Winnipeg – Mossy Bay showed an alternating pattern of high and low Hill's values, with no indication of an overall increasing or decreasing trend.

This alternating pattern was even more apparent in the off-system waterbody, Lake Winnipegosis. The Hill's number ranged widely between years (i.e., 2.8 in 2011 to 8.0 in 2008). The particularly low value observed in 2011 was the result of notably high catches of Yellow Perch that year (74% of the catch in 2011 versus 28 to 44% in all other years).

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 Lake Winnipeg

Fish Community

In standard gangs, the mean CPUE ranged from a high of 128 fish/100 m/24 h in Lake Winnipeg – Grand Rapids to a low of 60 fish/100 m/24 h in Lake Winnipeg – Sturgeon Bay (Table 6-3). At all three locations, the most abundant large-bodied species were Walleye, Yellow Perch, and White Sucker, while Sauger was abundant in Lake Winnipeg – Grand Rapids and Lake Winnipeg – Mossy Bay (Figure 6-3). The abundance of large-bodied fish in Lake Winnipeg – Grand Rapids was considerably higher than the other two locations of Lake Winnipeg with Lake Winnipeg – Mossy Bay having a slightly higher mean total CPUE than Lake Winnipeg – Sturgeon Bay (Figure 6-4).

The species composition in the standard gangs was generally similar among the Lake Winnipeg locations; however, some notable differences were apparent. Two percid species, Walleye and Yellow Perch, were the dominant species in all three locations, but there were differences in the CPUE of each species among waterbodies. The two species had similar CPUEs in Lake Winnipeg – Sturgeon Bay, Walleye had a higher CPUE in Lake Winnipeg – Grand Rapids, and Yellow Perch had a higher CPUE in Lake Winnipeg – Mossy Bay (Figure 6-3). A third percid species, Sauger, was also abundant in Lake Winnipeg – Mossy Bay and to a lesser extent in Lake Winnipeg – Grand Rapids, while very few Sauger were captured in Lake Winnipeg – Sturgeon Bay. Cisco (*Coregonus artedi*), Lake Whitefish (*Coregonus clupeaformis*), and Rainbow Smelt were more common in Lake Winnipeg – Grand Rapids and Lake Winnipeg – Mossy Bay compared to Lake Winnipeg – Sturgeon Bay. In Lake Winnipeg – Sturgeon Bay, species such as Northern Pike (*Esox lucius*) and Shorthead Redhorse (*Moxostoma macrolepidotum*) were more abundant than in the other two locations (Figure 6-3).

In small mesh gangs, the mean CPUE ranged from a high of 589 fish/30 m/24 h in Lake Winnipeg – Grand Rapids to a low of 157 fish/30 m/24 h in Lake Winnipeg – Mossy Bay (Table 6-3). Small mesh gillnet catches were much more variable than standard gang catches as evidenced by the large standard error (SE) values shown in Table 6-3. The most dominant species in catches in Lake Winnipeg – Sturgeon Bay was Yellow Perch while the Lake Winnipeg – Grand Rapids and Lake Winnipeg – Mossy Bay small mesh catches were dominated by two species, Rainbow Smelt and Trout-perch (Figure 6-3).

Within the small mesh catches, Lake Winnipeg – Grand Rapids and Lake Winnipeg – Mossy Bay had more similar species assemblages to each other than to Lake Winnipeg – Sturgeon Bay, which was dominated by Yellow Perch, a species that was present at both other locations but did not make up a large component of the catch (Figure 6-3). Rainbow Smelt and Trout-perch dominated the catches from Lake Winnipeg – Grand Rapids and Lake Winnipeg – Mossy Bay followed by Walleye and Sauger.

Lake Whitefish

Lake Whitefish mean CPUE values were low for all locations in Lake Winnipeg ranging from <1 fish/100 m/24 h in Lake Winnipeg – Sturgeon Bay to 3 fish/100 m/24 h in Lake Winnipeg – Grand Rapids (Table 6-3; Figure 6-5). Catches of Lake Whitefish in Lake Winnipeg –Mossy Bay were intermediate between the other two locations with a mean of 2 fish/100 m/24 h. All locations differed from one another as evidenced by the lack of overlap in interquartile ranges (Figure 6-5).

Northern Pike

Northern Pike mean CPUE ranged from a high of 5 fish/100 m/24 h in Lake Winnipeg – Sturgeon Bay to a low of <1 fish/100 m/24 h in Lake Winnipeg – Mossy Bay and in Lake Winnipeg – Grand Rapids (Table 6-3; Figure 6-6).

Sauger

Sauger were most abundant in Lake Winnipeg – Grand Rapids and in Lake Winnipeg – Mossy Bay with mean CPUE values of 11 fish/100 m/24 h (Table 6-3; Figure 6-7). In comparison, Sauger abundance in Lake Winnipeg – Sturgeon Bay was extremely low with a value of <1 fish/100 m/24 h (Table 6-3).

Walleye

Walleye mean CPUE ranged from a high of 56 fish/100 m/24 h in Lake Winnipeg – Grand Rapids to a low of 17 fish/100 m/24 h in Lake Winnipeg – Mossy Bay (Table 6-3 and Figure 6-8). Lake Winnipeg – Sturgeon Bay (21 fish/100 m/24 h) had a slightly higher mean CPUE value than in Lake Winnipeg – Mossy Bay with a similar range in values (Figure 6-8).

Walleye CPUE in Lake Winnipeg – Grand Rapids was considerably higher than in both the other Lake Winnipeg locations with no overlap between the interquartile ranges (Figure 6-8).

White Sucker

Lake Winnipeg – Grand Rapids had the highest White Sucker catches with a mean CPUE of 21 fish/100 m/24 h, while both Lake Winnipeg – Sturgeon Bay and Lake Winnipeg – Mossy Bay had values of 9 fish/100 m/24 h (Table 6-3). The Lake Winnipeg – Grand Rapids White Sucker CPUE was much higher than the other two locations of the lake with no overlap in interquartile ranges present (Figure 6-9).

6.2.2.2 Off-system Waterbody: Lake Winnipegosis

Fish Community

In standard gangs, the mean CPUE was 63 fish/100 m/24 h (Table 6-3). The large-bodied fish community in Lake Winnipegosis was dominated by White Sucker and Walleye, and to a lesser extent, Yellow Perch, Cisco, Northern Pike and Common Carp (*Cyprinus carpio*; Figure 6-3).

In small mesh gangs, the mean CPUE was 361 fish/30 m/24 h in Lake Winnipegosis (Table 6-3). The small-bodied fish community in Lake Winnipegosis was dominated by Yellow Perch with some Spottail Shiner and Logperch (*Percina caprodes*) present along with very small numbers of various forage fish and juvenile large-bodied fish (Figure 6-3).

Total CPUE at the off-system Lake Winnipegosis was similar to those of Lake Winnipeg – Sturgeon Bay and Lake Winnipeg – Mossy Bay and much lower than that of Lake Winnipeg – Grand Rapids, the site in the Lake Winnipeg Region with the highest total CPUE (Figure 6-4). With the exception of Common Carp being present and Sauger being absent, the catches from Lake Winnipegosis were similar to the on-system locations of Lake Winnipeg (Figure 6-3).

Lake Whitefish

The mean CPUE of Lake Whitefish in Lake Winnipegosis standard gangs was 2 fish/100 m/24 h, a value similar to Lake Winnipeg – Mossy Bay but lower than Lake Winnipeg – Grand Rapids, and higher than Lake Winnipeg – Sturgeon Bay (Table 6-3; Figure 6-5).

Northern Pike

Northern Pike mean CPUE in standard gangs was 6.0 fish/100 m/24 h in Lake Winnipegosis (Table 6-3). Northern Pike CPUE in Lake Winnipegosis was similar to that of Lake Winnipeg –

Sturgeon Bay and considerably higher than those of Lake Winnipeg – Grand Rapids and Lake Winnipeg – Mossy Bay (Figure 6-6).

Sauger

Sauger were not captured in Lake Winnipegosis (Table 6-3; Figure 6-7).

Walleye

Walleye mean CPUE in standard gangs was 12 fish/100 m/24 h in Lake Winnipegosis (Table 6-3). Walleye CPUE in Lake Winnipegosis was similar to both Lake Winnipeg – Mossy Bay and Lake Winnipeg – Sturgeon Bay and considerably lower than in Lake Winnipeg – Grand Rapids (Figure 6-8).

White Sucker

The mean CPUE of White Sucker in standard gangs was 22 fish/100 m/24 h, similar to the mean CPUE for Lake Winnipeg – Grand Rapids, the on-system location with the highest catch rates for White Sucker (Table 6-3; Figure 6-9). The mean CPUE for White Sucker in Lake Winnipegosis was higher than those for Lake Winnipeg – Sturgeon Bay and Lake Winnipeg – Mossy Bay (Figure 6-9).

6.2.2.3 Temporal Comparisons and Trends

Fish Community

The annual total CPUE values for Lake Winnipeg locations showed some variability among sampling years with statistically significant differences between years at some locations. The mean CPUE ranged from 46 fish/100 m/24 h in 2009 to 100 fish/100 m/24 h in 2012 in Lake Winnipeg – Sturgeon Bay, from 89 fish/100 m/24 h in 2008 to 182 fish/100 m/24 h in 2013 in Lake Winnipeg – Grand Rapids, and from 50 fish/100 m/24 h in 2011 to 102 fish/100 m/24 h in 2013 in Lake Winnipeg – Mossy Bay (Figure 6-4). In Lake Winnipeg – Sturgeon Bay the high mean CPUE recorded in 2012 was found to be significantly different from all other years (Figure 6-10). In Lake Winnipeg – Grand Rapids the highest annual total CPUE that was recorded in 2013 was significantly higher than the lowest recorded in 2008. In Lake Winnipeg – Mossy Bay the three years with the lowest total CPUE values (2008, 2011, and 2012) were significantly lower than in 2013 (Figure 6-10). An increasing trend in mean CPUE was apparent in Lake Winnipeg – Grand Rapids.

The off-system Lake Winnipegosis showed some variation in total CPUE over time ranging from 40 to 80 fish/100 m/24 h (Figure 6-4) but no statistically significant differences between years were detected and no increasing or decreasing trends in mean CPUE were apparent (Figure 6-10).

Lake Whitefish

Intra- and inter-annual variability in Lake Whitefish CPUE was relatively low for Lake Winnipeg – Mossy Bay and Lake Winnipeg – Sturgeon Bay although some significant differences between years were noted. In Lake Winnipeg – Sturgeon Bay, CPUE values were extremely low in most years with the highest catch occurring in 2008 (2 fish/100 m/24 h), which was statistically different from 2012 and 2013 (Figure 6-11). Lake Winnipeg – Mossy Bay Lake Whitefish CPUE values were consistently low ranging from <1 fish/100 m/24 h in 2012 to 3 fish/100 m/24 h in 2013 (Figure 6-5). A statistical difference in CPUE occurred only between values recorded in 2012 and 2013 (Figure 6-11).

The CPUE of Lake Whitefish was notably higher for Lake Winnipeg – Grand Rapids compared to the other sites and exhibited higher intra- and inter-annual variability; as a result, no significant differences between years were observed (Figure 6-11). Lake Whitefish mean annual CPUE in Lake Winnipeg – Grand Rapids ranged from a low of <1 fish/100 m/24 h in 2008 to a high of 8 fish/100 m/24 h in 2012 (Figure 6-5).

No trends were apparent for Lake Whitefish CPUE from any of the Lake Winnipeg locations.

Lake Whitefish catch rates in Lake Winnipegosis varied little over time ranging from nearly zero in 2012 to 3 fish/100 m/24 h in 2010 with no statistically significant differences between years and no indication of a trend (Figure 6-11).

Northern Pike

Among the on-system locations, the CPUE of Northern Pike was highest in Lake Winnipeg – Sturgeon Bay ranging from 3 fish/100 m/24 h in 2008 to 7 fish/100 m/24 h in 2010, while the Lake Winnipeg – Grand Rapids and Lake Winnipeg – Mossy Bay locations had values of <1 fish/100 m/24 h, with the exception of 2008 in Lake Winnipeg – Grand Rapids (Figure 6-6). No significant differences were found between years for any of the Lake Winnipeg locations and no trends were apparent (Figure 6-12).

Catch rates in Lake Winnipegosis ranged widely between years, from <1 fish/100 m/24 h in 2011 to 11 fish/100 m/24 h in 2012 (Figure 6-6). While no significant inter-annual differences were found and no trend was observed, CPUE was notably low in 2011 (Figure 6-12).

Sauger

The CPUE of Sauger showed an increasing trend over time for all on-system locations (Figure 6-7). Values in Lake Winnipeg – Grand Rapids increased from a low of <1 fish/100 m/24 h in 2009 to a high of 23 fish/100 m/24 h in 2013 while in Lake Winnipeg – Mossy Bay the lowest value was 2 fish/100 m/24 h in 2008 and 2009 and the highest value was 40 fish/100 m/24 h in 2013. Mean CPUE in 2013 was significantly higher than 2008 and 2009 at all three locations (Figure 6-13). In Lake Winnipeg – Mossy Bay, the mean CPUE in 2013 was significantly higher than all other years (Figure 6-13). Although low compared to other locations, the abundance of Sauger in Lake Winnipeg – Sturgeon Bay also showed an increased from 0 fish/100 m/24 h in 2008 and 2009 to 1 fish/100 m/24 h in 2013.

No Sauger were captured from the off-system Lake Winnipegosis during the study period.

Walleye

There were no increasing or decreasing trends apparent and few significant inter-annual differences in Walleye CPUE at on-system locations (Figures 6-8 and 6-14). Further, the years that were statistically highest varied between each of the three locations in Lake Winnipeg. In Lake Winnipeg – Sturgeon Bay, the mean annual Walleye CPUE ranged from 1 fish/100 m/24 h in 2008 to 38 fish/100 m/24 h in 2012, and the difference between 2008 and 2012 was significant (Figure 6-14). In Lake Winnipeg – Grand Rapids the mean annual Walleye CPUE ranged from 40 to 60 fish/100 m/24 h in all years except 2010, when the mean CPUE was much higher at 106 fish/100 m/24 h. Due to high variability within the 2010 catch, the CPUE for this year was only statistically higher than that from 2008 (Figure 6-14). The mean annual Walleye CPUE in Lake Winnipeg – Mossy Bay ranged from 6 fish/100 m/24 h in 2011 to 36 fish/100 m/24 h in 2009. The value in 2009 was significantly higher than those of all other years with the exception of 2013 (Figure 6-14).

The CPUE of Walleye in the off-system Lake Winnipegosis ranged from 7 fish/100 m/24 h in 2009 to 22 fish/100 m/24 h in 2013 (Figure 6-8). Statistical differences were found between 2009 and 2010 (the two years with the lowest Walleye catches) and 2013 which had the highest CPUE (Figure 6-14). Unlike the Lake Winnipeg locations, there did appear to be an increasing trend in Walleye CPUE in Lake Winnipegosis.

White Sucker

There was a high degree of inter-annual variability for White Sucker CPUE in the Lake Winnipeg – Sturgeon Bay and Lake Winnipeg – Grand Rapids locations and no indication of trends. However, significant differences between years were observed in Lake Winnipeg –

Sturgeon Bay, where the mean annual CPUE for White Sucker ranged from 1 fish/100 m/24 h in 2009 to 21 fish/100 m/24 h in 2012; the two years with the highest mean CPUE (2008 and 2012) were significantly different than the two years with the lowest mean CPUE (2009 and 2013; Figure 6-15). In Lake Winnipeg – Grand Rapids White Sucker CPUE ranged from 7 fish/100 m/24 h in 2010 to 29 fish/100 m/24 h in 2008 but no statistical differences were found among the years.

At Lake Winnipeg-Mossy Bay the data indicate an increase over time (Figures 6-9 and 6-15). The abundance of White Sucker in Lake Winnipeg – Mossy Bay increased from 3 fish/100 m/24 h in 2008 to 18 fish/100 m/24 h in 2013, with CPUE in 2013 being significantly higher than in 2008, 2009, and 2011 (Figure 6-15).

There were no significant inter-annual differences in the CPUE of White Sucker in Lake Winnipegosis (Figure 6-15), where mean values ranged from 15 fish/100 m/24 h in 2008 to 27 fish/100 m/24 h in 2011 (Figure 6-9). The CPUE increased from 2008 to 2011, but decreased after 2011.

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, 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 Lake Winnipeg

Lake Whitefish

Few Lake Whitefish were captured in the region so a sufficient number of fish with which to analyze K_F were only captured in a few years. In those years, the mean Fulton's condition factor for Lake Whitefish between 300 and 499 mm in fork length ranged from 1.47 in Lake Winnipeg – Grand Rapids to 1.52 in Lake Winnipeg – Sturgeon Bay (Figure 6-16). The condition of Lake Whitefish was generally consistent between the on-system locations; however, the data sets were limited due to a lack of individuals that fell within the target fork length range (Figure 6-16).

Northern Pike

The ability to analyze mean Fulton's condition factor for Northern Pike for the target size range (i.e., 400-699 mm in fork length) from Lake Winnipeg locations was limited to Lake Winnipeg – Sturgeon Bay as it was the only location with sufficient catches of this species. The mean condition factor for Northern Pike in Lake Winnipeg – Sturgeon Bay was 0.77 (Figure 6-17).

Sauger

The number of Sauger sampled for condition from the Lake Winnipeg locations was insufficient for analysis, as Sauger were not considered a key species from this region and weights were not typically recorded from individuals.

Walleye

Mean Fulton's condition factor for Walleye between 300 and 499 mm in fork length from on-system locations ranged from a high of 1.32 in Lake Winnipeg – Mossy Bay to a low of 1.19 in Lake Winnipeg – Sturgeon Bay (Table 6-3). The condition of Walleye varied among on-system locations increasing in a south to north direction with no overlap between interquartile ranges occurring between any of the locations (Figure 6-18).

White Sucker

The mean Fulton's condition factor for White Sucker between 300 and 499 mm in fork length was 1.54 in Lake Winnipeg – Sturgeon Bay and 1.69 in Lake Winnipeg – Mossy Bay (Table 6-3; Figure 6-19). There were insufficient data for the Lake Winnipeg – Grand Rapids location for analysis of this metric.

6.2.3.2 Off-system Waterbody: Lake Winnipegosis

Lake Whitefish

Mean Fulton's condition factor for Lake Whitefish between 300 and 499 mm in fork length from Lake Winnipegosis was 1.44 (Figure 6-16). The condition of Lake Whitefish from Lake Winnipegosis was within the range of values observed at the locations in Lake Winnipeg (Figure 6-16).

Northern Pike

Mean Fulton's condition factor for Northern Pike between 400 and 699 mm in fork length from Lake Winnipegosis was 0.76 (Figure 6-17). Mean condition factor of Northern Pike in Lake Winnipegosis was comparable to that in Lake Winnipeg – Sturgeon Bay (Figure 6-17).

Sauger

Sauger were not captured in Lake Winnipegosis.

Walleye

Mean Fulton's condition factor for target size Walleye in Lake Winnipegosis was 1.10 (Table 6-3) and was lower than the mean condition factors observed at all of the on-system locations within Lake Winnipeg, as indicated by the lack of overlap of the interquartile ranges of the CPUE boxplots (Figure 6-18).

White Sucker

Mean Fulton's condition factor for target size White Sucker from Lake Winnipegosis was 1.40 (Table 6-3) and was lower than fish from the on-system locations (Figure 6-19).

6.2.3.3 Temporal Comparisons and Trends

Lake Whitefish

There were insufficient numbers of Lake Whitefish captured within the selected fork length range to examine temporal trends for either on- or off-system locations.

Northern Pike

Insufficient numbers of Northern Pike within the selected fork length range were captured at the on-system locations to examine temporal trends. At the off-system Lake Winnipegosis, the annual mean condition of Northern Pike ranged from 0.73 in 2008 to 0.79 in 2012 (Figure 6-17), but no overall temporal trend in Northern Pike condition was apparent at this location.

Sauger

There were insufficient numbers of Sauger captured within the selected fork length range annually to examine temporal trends for either on- and off-system locations.

Walleye

The condition of Walleye at all three Lake Winnipeg locations showed a gradual increase initially to 2010 or 2011, followed by a decrease to 2013 (Figure 6-18). A number of significant inter-annual differences were observed in each location and 2013 was significantly lower than all other years at each location (Figure 6-20). This pattern of declining Walleye condition in the three locations of Lake Winnipeg has continued to at least 2015 (CAMP unpublished data).

A possible explanation for the decline in Walleye condition in the north basin of Lake Winnipeg is discussed in Section 6.3.

The trend observed in Lake Winnipeg was not mirrored in the off-system Lake Winnipegosis. However, significant inter-annual variation was observed; the condition of Walleye was highest in 2010 and lowest in 2008 (Figures 6-18 and 6-20).

White Sucker

Based on the available data, no trends in White Sucker condition were apparent over the period of 2010 to 2013 in Lake Winnipeg – Mossy Bay, although statistical inter-annual differences were observed (Figure 6-21). There were insufficient data for detailed analysis for the other two Lake Winnipeg locations.

Condition data for White Sucker from Lake Winnipegosis was limited to only three years (2011-2013). There were no significant differences in White Sucker condition among the years and no trends were apparent (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 year-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 Lake Winnipeg

Lake Whitefish

Lake Whitefish captured in Lake Winnipeg ranged from 1 to 25 years of age, with most of the fish captured over the 6-year sampling period aged between 2 and 5 years in Lake Winnipeg – Grand Rapids and Lake Winnipeg – Mossy Bay (Figure 6-22). Very few Lake Whitefish were captured in Lake Winnipeg – Sturgeon Bay. In both Lake Winnipeg – Grand Rapids and Lake Winnipeg – Mossy Bay, the mean length increased until age 8 from about 175 mm at age 1 to about 460 mm at age 8. The length of fish older than 8 years fluctuated between 425 mm and 500 mm. The Lake Winnipeg – Grand Rapids location had a larger representation of large, adult Lake Whitefish than Lake Winnipeg – Mossy Bay, with 44 individuals greater than 10 years of age, while Lake Winnipeg – Mossy Bay only had 17.

Although the number of 4- and 5-year-old Lake Whitefish captured in the on-system locations was low, available data indicate differences between the three locations in the north basin of Lake Winnipeg. Lake Winnipeg – Mossy Bay had the highest mean length-at-age 4 for Lake Whitefish (371 mm), followed by Lake Winnipeg – Sturgeon Bay (357 mm), and Lake Winnipeg – Grand Rapids (349 mm; Table 6-3; Figure 6-23).

Lake Whitefish length-at-age 5 was about the same in both Lake Winnipeg – Grand Rapids (384 mm) and Lake Winnipeg – Mossy Bay (377 mm; Figure 6-24). Insufficient numbers of 5-year-old Lake Whitefish were captured in Lake Winnipeg – Sturgeon Bay for analysis.

Northern Pike

There were insufficient numbers of 4-year-old Northern Pike from the on-system Lake Winnipeg locations for analysis (Figure 6-25).

Sauger

The mean length-at-age 3 for Sauger in Lake Winnipeg – Grand Rapids, for the five years where data were sufficient for analysis, was 230 mm (Figure 6-26). There were insufficient numbers of 3-year-old Sauger at the other two on-system locations for analysis.

Walleye

Walleye captured from the Lake Winnipeg locations ranged from 1 to 16 years, with most of the catch between 2 and 7 years of age (Figure 6-27). The fork length of Walleye increased incrementally for each age class up to age 9 (Figure 6-27). The overall pattern of growth and maximum fork length achieved for all locations (575 to 600 mm) were similar (Figure 6-27).

The mean length-at-age 3 ranged from a low of 276 mm in Lake Winnipeg – Mossy Bay to a high of 309 mm in Lake Winnipeg – Sturgeon Bay; Walleye from Lake Winnipeg – Grand Rapids had a mean value of 286 mm (Table 6-3; Figure 6-28).

6.2.4.2 Off-system Waterbody: Lake Winnipegosis

Lake Whitefish

Lake Whitefish captured from Lake Winnipegosis ranged from 1 to 10 years of age, with most of the fish captured over the 6-year sampling period aged between 1 and 5 years (Figure 6-22). The mean length increased for every age up to age 10, from 189 mm at age 1 to 458 mm at age 10.

Lake Whitefish from Lake Winnipegosis had a mean fork length-at-age 4 and 5 of 342 mm and 341 mm, respectively (Figures 6-23 and 6-24). The length-at-age 4 and 5 for Lake Whitefish from Lake Winnipegosis was smaller than the values observed for the Lake Winnipeg locations (Figures 6-23 and 6-24).

Northern Pike

Four-year-old Northern Pike from Lake Winnipegosis averaged 597 mm in length (Figure 6-25). There were insufficient numbers of Northern Pike captured from the on-system locations for comparison.

Sauger

Sauger were not captured in Lake Winnipegosis.

Walleye

Walleye ranged from 1 to 9 years of age, with most of the fish captured over the 6-year sampling period aged between 2 and 4 years of age (Figure 6-27). The mean length increased for every age up to age 9, from 243 mm at age 1 to 558 mm at age 9.

The length-at-age 3 of Walleye from Lake Winnipegosis (mean of 382 mm) was considerably higher than that observed at all Lake Winnipeg locations (Figure 6-28).

6.2.4.3 Temporal Comparisons and Trends

Lake Whitefish

The annual mean length-at-age 4 for Lake Whitefish showed little variation for the limited data available (Figure 6-23), and no statistical differences between years were observed (Figure 6-29).

Data for 5-year-old Lake Whitefish were more limited and sufficient data for analysis were only available for Lake Winnipeg – Mossy Bay (Figure 6-24). No statistical difference between years and temporal trends were observed (Figure 6-30).

Northern Pike

The fork length-at-age 4 of Northern Pike could only be assessed for Lake Winnipegosis as the Lake Winnipeg locations lacked sufficient numbers to calculate annual mean values. The values for the off-system waterbody were similar between years ranging from 584 mm in 2009 to 615 mm in 2013 and no trends were evident over the monitoring period (Figure 6-25).

Sauger

Sufficient data for evaluation of the fork length-at-age 3 of Sauger was limited to Lake Winnipeg – Grand Rapids (Figure 6-26). No statistical differences were found between years and no increasing or decreasing trends in length-at-age 3 were apparent (Figure 6-31).

Walleye

The length-at age 3 of Walleye in Lake Winnipeg – Grand Rapids showed statistically significant decreases from 2008 to 2010 and then remained fairly constant from 2010 to 2013 (Figure 6-32). The more limited data for this metric for Lake Winnipeg – Sturgeon Bay (i.e., data limited to 2009, 2010, 2012, and 2013) suggests a similar pattern may have occurred in this location. Both Lake Winnipeg – Mossy Bay and Lake Winnipegosis showed declines in the mean length-at age 3 to about 2011 and some significant differences between years (Figure 6-32).

6.3 ADDITIONAL METRICS AND OBSERVATIONS OF NOTE

Two additional fish community metrics measured under CAMP were evaluated for the Lake Winnipeg Region: relative abundance; and the CPUE of Rainbow Smelt. 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). The abundance of Rainbow Smelt was evaluated as this species is known to be the primary food source for Walleye and, to a lesser extent, Sauger in the north basin of Lake Winnipeg (based on samples collected in 2010 and 2011 by Sheppard et al. 2015) and trends in the condition and growth metrics for Walleye were observed in this region.

Catches were dominated by Walleye, Yellow Perch and White Sucker in all three locations in Lake Winnipeg. There were some regional differences in the abundance of some species. For example, Sauger, Lake Whitefish, Cisco and Longnose Sucker (*Catostomus catostomus*) were more abundant in Lake Winnipeg – Grand Rapids and Lake Winnipeg – Mossy Bay, while Northern Pike and Shorthead Redhorse were more common in Lake Winnipeg – Sturgeon Bay. A few rarer species were only observed in one location: Mooneye (*Hiodon tergisus*), White Bass (*Morone chrysops*) and Brown Bullhead (*Ameiurus nebulosus*) in Lake Winnipeg – Sturgeon Bay; Goldeye (*Hiodon alosoides*) in Lake Winnipeg – Mossy Bay; and Quillback

(*Carpiodes cyprinus*) in Lake Winnipeg – Grand Rapids. Lake Winnipegosis had a similar species assemblage as all three locations in Lake Winnipeg with the same three species dominating the catch; however, unlike Lake Winnipeg, White Sucker was more abundant than the percid species. Sauger, a species common in Lake Winnipeg was notably absent from Lake Winnipegosis catches. There were several species captured in Lake Winnipegosis that were not observed in Lake Winnipeg catches including Common Carp, Common Shiner (*Luxilus cornutus*), Fathead Minnow (*Pimephales promelas*), and Bigmouth Buffalo (*Ictiobus cyprinellus*; Table 6-2).

Rainbow Smelt were first captured in Lake Winnipeg in 1990 (Campbell et al. 1991), and quickly became established as an important component of the small-bodied fish community of Lake Winnipeg. Pelagic trawling conducted between 2002 and 2008 throughout Lake Winnipeg found that Rainbow Smelt comprised the majority of the biomass in the north basin, but were much less abundant in the narrows and south basin areas of Lake Winnipeg (Lumb et al. 2012). Considering Lake Winnipeg as a whole, Rainbow Smelt biomass in pelagic trawls increased annually between 2002 and 2008 (Lumb et al. 2012).

Studies conducted after 2008 indicated recent changes to Rainbow Smelt populations have occurred in Lake Winnipeg. The Lake Winnipeg trawling program has shown that Rainbow Smelt biomass in the north basin of Lake Winnipeg peaked in approximately 2011 and declined markedly from 2011 to 2015 (C. Lumb, MSD, pers. comm.).

Similarly, CAMP small mesh gillnet catches from 2008 to 2013 indicate that Rainbow Smelt CPUE in Lake Winnipeg – Mossy Bay doubled from 2008 (approximately 60 fish/30 m/24 h) to 2009 and 2010 (approximately 110 to 120 fish/30 m/24 h) and then decreased to less than 15 fish/30 m/24 h from 2011 to 2013 (Figure 6-34). Although a decrease was not observed for Lake Winnipeg – Grand Rapids or Lake Winnipeg – Sturgeon Bay based on the 2008 to 2013 data (Figure 6-35), analysis of data collected under CAMP in 2014 and 2015 indicate a substantive decline in Rainbow Smelt CPUE values by 2015 in all three locations of Lake Winnipeg (i.e., CPUE less than 5 fish/30 m/24 h; CAMP unpublished data).

Taken collectively, available data suggest that the recent decrease in the availability of Rainbow Smelt, a key prey item, may be a contributing factor to the observed decreasing trend in Walleye condition and growth (as measured by the length-at-age 3; Figures 6-20 and 6-32).

Reasons for the decline in Rainbow Smelt abundance in Lake Winnipeg are not known. However, Lake Winnipeg is not the only large lake to experience recent changes in the abundance of Rainbow Smelt. Recent rapid declines in Rainbow Smelt abundance and changes in population dynamics have been documented for several of the Laurentian Great Lakes including Lake Superior (Gorman 2007), and Lake Michigan and Lake Huron (Feiner et al. 2015). Potential explanations for declines in the abundance of Rainbow Smelt in Lake Winnipeg, based on knowledge gained in other waterbodies, include the increasing abundance of predatory species (e.g., Sauger; see Section 6.2.2.3) and the recent invasion of Lake Winnipeg by the invasive zebra mussel (*Dreissena polymorpha*), which was first confirmed in Lake Winnipeg in 2013 (Lake Winnipeg Foundation 2017), and the spiny water flea (*Bythotrephes longimanus*), first confirmed in Manitoba in the Winnipeg River (a tributary to Lake Winnipeg) in 2009 (Gill 2011).

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 hydrologic conditions and fish community metrics for the three Lake Winnipeg locations and Lake Winnipegosis generated using water level data from gauges on Lake Winnipeg and Lake Winnipegosis provided by Manitoba Hydro and fish community metrics indicated very few statistically significant relationships (Table 6-4).

The only statistically significant relationships were a negative relationship between White Sucker CPUE and water level during the sampling period in Lake Winnipeg – Sturgeon Bay and a positive relationship between CPUE for the total catch and water level during the sampling period for Lake Winnipegosis. The former relationship is illustrated in Figure 6-36.

6.5 SUMMARY

A few of the key findings of the six years of CAMP monitoring in the Lake Winnipeg Region include:

- The most common large-bodied species captured from the north basin of Lake Winnipeg were consistent among the three locations, and included Walleye, Yellow Perch, and White Sucker.

- The diversity of the fish community, as indicated by the mean Hill's index, increased within Lake Winnipeg from south to north.
- Lake Winnipeg – Grand Rapids had the highest total catch (i.e., CPUE) of the three monitoring locations in the north basin of Lake Winnipeg. There were also differences in the abundance of the species between the three Lake Winnipeg locations:
    - Lake Whitefish and Northern Pike were generally not abundant in Lake Winnipeg; however, of the three locations these species were most abundant in Lake Winnipeg – Grand Rapids and Lake Winnipeg – Sturgeon Bay, respectively;
    - Sauger were most abundant in Lake Winnipeg – Grand Rapids and Lake Winnipeg – Mossy Bay; and
    - Walleye and White Sucker were most abundant in Lake Winnipeg – Grand Rapids.
- The condition of Walleye and White Sucker was considerably higher in Lake Winnipeg – Mossy Bay compared to the other locations in Lake Winnipeg.
- Three-year-old Walleye from Lake Winnipeg – Sturgeon Bay were longer than those from the other two Lake Winnipeg locations.
- Some key metrics for target fish species showed pronounced trends over the period of 2008-2013 including:
    - The abundance of Sauger at all three locations in Lake Winnipeg increased over the six-year monitoring period.
    - The condition of Walleye at all three Lake Winnipeg locations, but most notably in Lake Winnipeg – Mossy Bay, decreased over the monitoring period, particularly from 2011 to 2013. Recent data collected under CAMP suggests that this trend has continued, at least to 2015. This decrease may be attributable, at least in part, to recently observed declines in the abundance of Rainbow Smelt, the primary prey species of Walleye in the north basin of Lake Winnipeg.
    - There was a general decreasing trend in the size of Walleye (as measured for length-at-age 3 fish) in Lake Winnipeg – Grand Rapids. Data from Lake Winnipeg – Mossy Bay shows a less clear pattern but also suggest a potential decreasing trend.
- A quantitative consideration of hydrological conditions and fish community metrics found the following statistically significant relationships: a negative relationship between Lake Winnipeg – Sturgeon Bay White Sucker CPUE and Lake Winnipeg water level and a positive relationship between CPUE for the total catch and water level for Lake Winnipegosis.

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

Location	Site Abbreviation	On-system	Off-system	Annual	Rotational	Sampling Years					
						2008	2009	2010	2011	2012	2013
Lake Winnipeg – Sturgeon Bay	LW-ST	X		X		X	X	X		X	X
Lake Winnipeg – Grand Rapids	LW-GR	X		X		X	X	X	X	X	X
Lake Winnipeg – Mossy Bay	LW-MB	X		X		X	X	X	X	X	X
Lake Winnipegosis	WPGOSIS		X	X		X	X	X	X	X	X

Table 6-2. Fish species captured in standard gang index and small mesh index gill nets set in Lake Winnipeg Region waterbodies: 2008-2013.

Species	**LK-ST** n_Y=5	**LW-GR** n_Y=6	**LW-MB** n_Y=6	**WPGOSIS** n_Y=6
Goldeye			X*	
Mooneye	X*			
Common Carp				X
Common Shiner				X*
Emerald Shiner	X*	X*		X*
Spottail Shiner	X	X	X*	X
Fathead Minnow				X*
Quillback		X*		
Longnose Sucker		X	X	X
White Sucker	X	X	X	X
Bigmouth Buffalo				X*
Shorthead Redhorse	X		X*	X
Brown Bullhead	X*			X
Northern Pike	X	X	X	X
Rainbow Smelt	X	X	X	
Cisco	X*	X	X	X
Lake Whitefish	X*	X	X	X
Trout-perch	X	X	X	X
Burbot		X*	X*	X
Mottled Sculpin			X*	
Slimy Sculpin			X*	
White Bass	X			
Logperch	X	X*	X	X
Yellow Perch	X	X	X	X
Sauger	X*	X	X	
Walleye	X	X	X	X
Freshwater Drum	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 indicators, including Hills number, catch-per-unit-effort (CPUE), Fulton's condition factor (K_F), and fork length-at-age (FL; mm) calculated for Lake Winnipeg Region waterbodies: 2008-2013.

Component	Waterbody	Hill's Index			CPUE[1]			K_F [2]			$Fl_{at\text{-}age}$ [3]		
		n_Y	Mean	SE	n_F	Mean	SE	n_F	Mean	SE	n_F	Mean	SE
Diversity	LW-ST	5	4.8	0.4	-	-	-	-	-	-	-	-	-
	LW-GR	6	5.5	0.2	-	-	-	-	-	-	-	-	-
	LW-MB	6	6.4	0.4	-	-	-	-	-	-	-	-	-
	WPGOSIS	6	6.6	0.8	-	-	-	-	-	-	-	-	-
Standard gang	LW-ST	-	-	-	2584	59.9	10.1	-	-	-	-	-	-
	LW-GR	-	-	-	4594	128.1	12.8	-	-	-	-	-	-
	LW-MB	-	-	-	5859	69.0	7.9	-	-	-	-	-	-
	WPGOSIS	-	-	-	3799	63.0	6.6	-	-	-	-	-	-
Small mesh	LW-ST	-	-	-	3539	470.8	106.8	-	-	-	-	-	-
	LW-GR	-	-	-	6061	588.6	151.8	-	-	-	-	-	-
	LW-MB	-	-	-	3225	156.8	29.4	-	-	-	-	-	-
	WPGOSIS	-	-	-	4533	360.5	159.4	-	-	-	-	-	-
Lake	LW-ST	-	-	-	24	0.4	0.4	25	1.52	0.018	3	357	-
Whitefish											-	-	-
	LW-GR	-	-	-	129	3.4	1.1	86	1.47	0.021	16	349	4.2
											8	384	-
	LW-MB	-	-	-	143	1.6	0.4	81	1.51	0.022	17	371	4.4
											14	377	8.5
	WPGOSIS	-	-	-	106	1.6	0.4	40	1.44	0.026	10	342	2.7
											14	341	-
Northern Pike	LW-ST	-	-	-	207	4.8	0.7	35	0.77	0.011	1	280	-
	LW-GR	-	-	-	24	0.6	0.2	2	0.97	0.061	-	-	-
	LW-MB	-	-	-	33	0.4	0.1	9	0.81	0.024	1	604	-
	WPGOSIS	-	-	-	366	6.0	1.6	326	0.76	0.006	61	597	6.5
Sauger	LW-ST	-	-	-	21	0.5	0.2	12	1.04	0.046	3	245	12.5
	LW-GR	-	-	-	372	10.6	3.8	347	1.03	0.007	77	230	4.7
	LW-MB	-	-	-	927	10.8	6.1	-	-	-	-	-	-
	WPGOSIS	-	-	-	-	-	-	-	-	-	-	-	-

Table 6-3. continued.

Component	Waterbody	Hill's 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
Walleye	LW-ST	-	-	-	854	20.7	6.0	736	1.19	0.004	229	309	6.3
	LW-GR	-	-	-	1876	56.2	10.4	1217	1.23	0.003	525	286	10.3
	LW-MB	-	-	-	1329	16.8	4.6	1006	1.32	0.004	314	276	9.0
	WPGOSIS	-	-	-	722	11.6	2.2	574	1.10	0.005	233	382	8.7
White Sucker	LW-ST	-	-	-	418	9.4	3.5	148	1.54	0.014	-	-	-
	LW-GR	-	-	-	792	20.6	3.0	18	1.49	0.032	-	-	-
	LW-MB	-	-	-	824	9.2	2.4	685	1.69	0.005	-	-	-
	WPGOSIS	-	-	-	1313	21.6	1.9	434	1.40	0.007	-	-	-

[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 Sauger and 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 of linear regressions of fish community metrics (catch-per-unit-effort [CPUE] and Fulton's condition factor [K_F]) against hydrological metrics[1] for Lake Winnipeg Region waterbodies sampled annually between 2008 and 2013.

Metric	Species	Waterbody	Hydrology Metric	df	F	p	R^2	Direction
CPUE	White Sucker	LW-ST	WL (GN)	3	66.55	< 0.01	0.96	-
	Total	WPGOSIS	WL (GN)	4	9.05	0.04	0.69	+

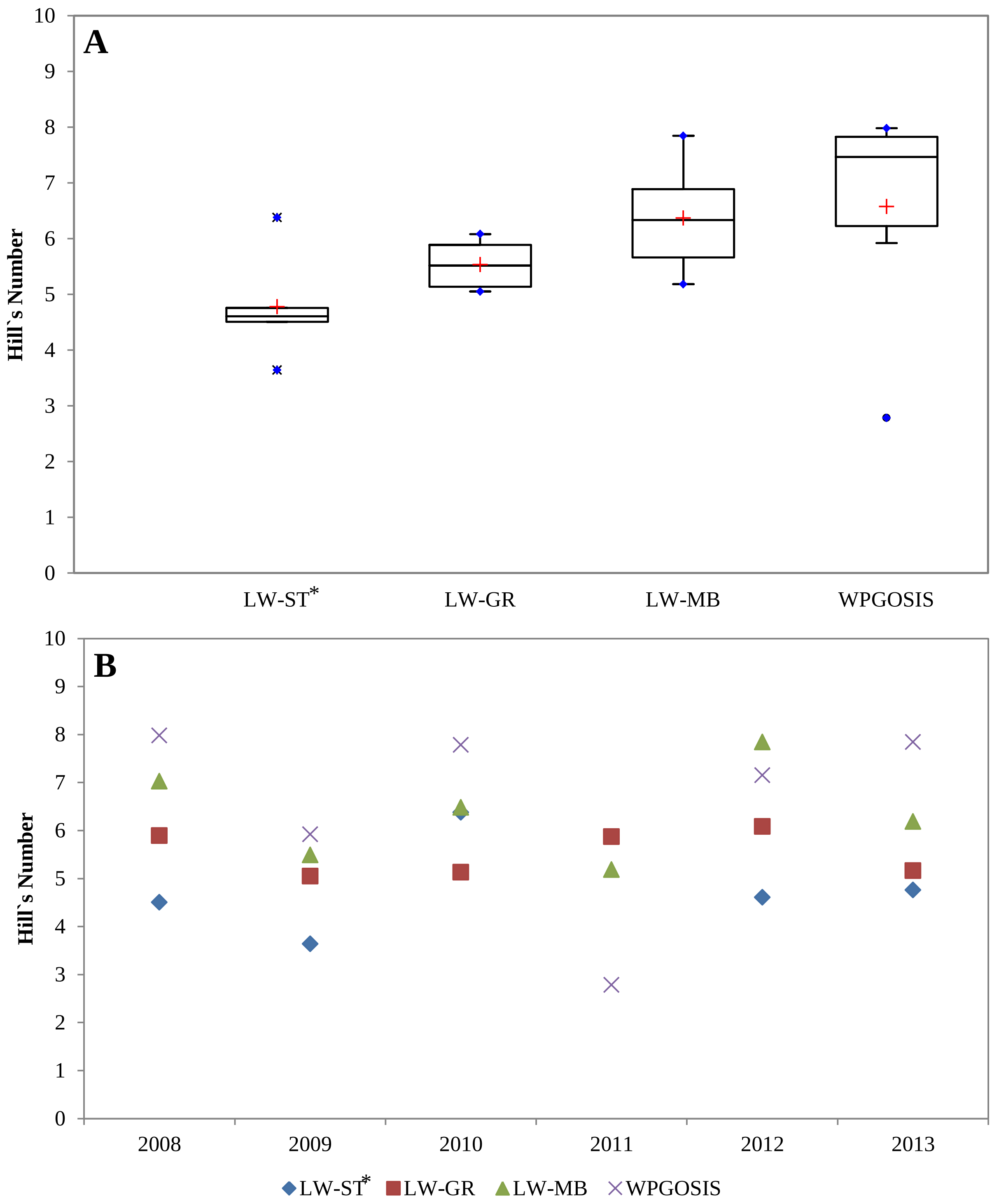
[1] Q (OW) = average discharge (cms) during the open water period (approximate average annual date of ice-free conditions in each waterbody to end of sampling period)

Q (GN) = average discharge (cms) during the gillnetting program

WL (OW) = average water level (m ASL) during the open water period (approximate average annual date of ice-free conditions in each waterbody to end of sampling period)

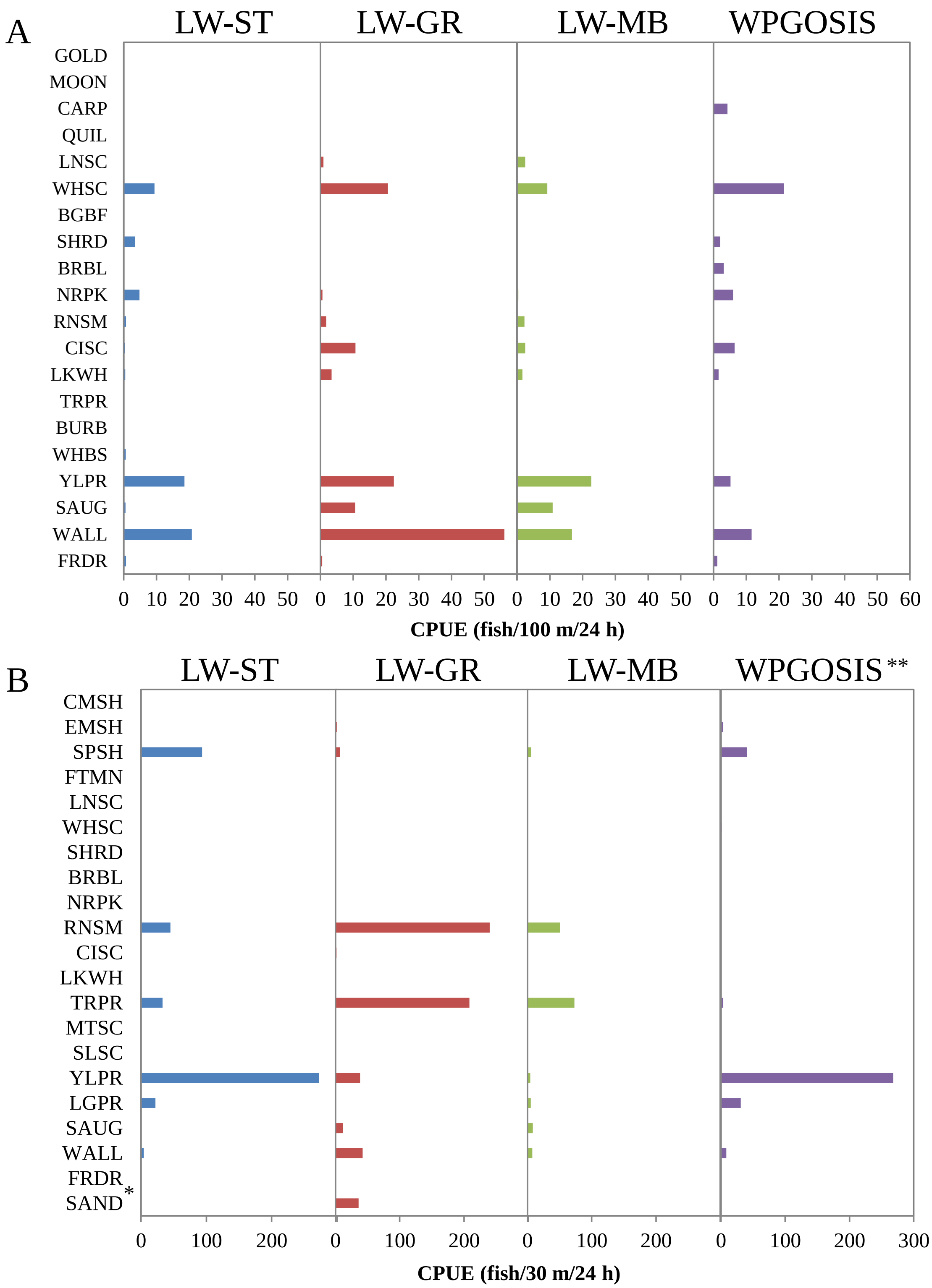
WL (GN) = average water level (m ASL) during the gillnetting program

Figure 6-1. Locations sampled in the Lake Winnipeg Region: 2008-2013.



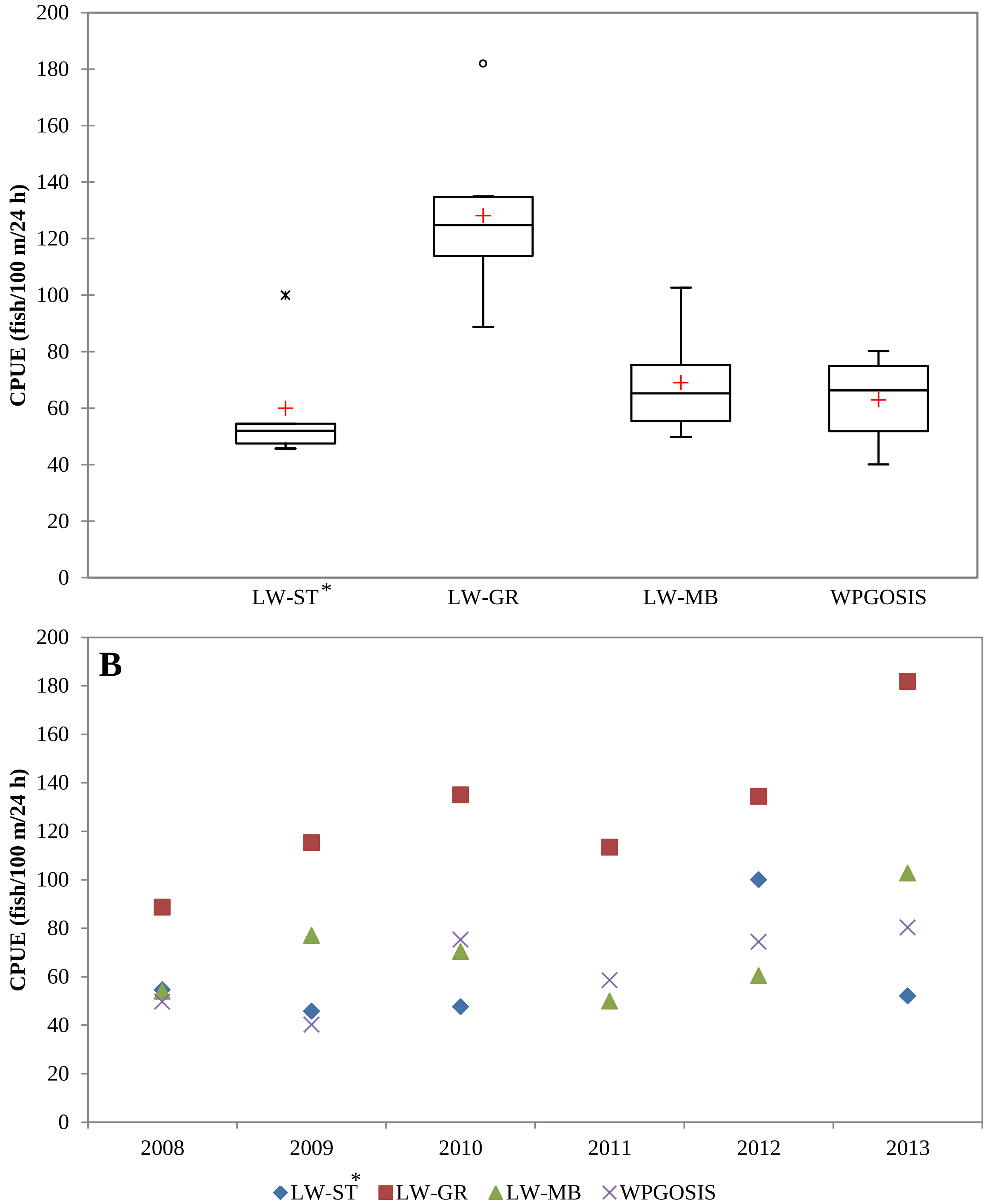
*LW-ST not sampled in 2011.

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



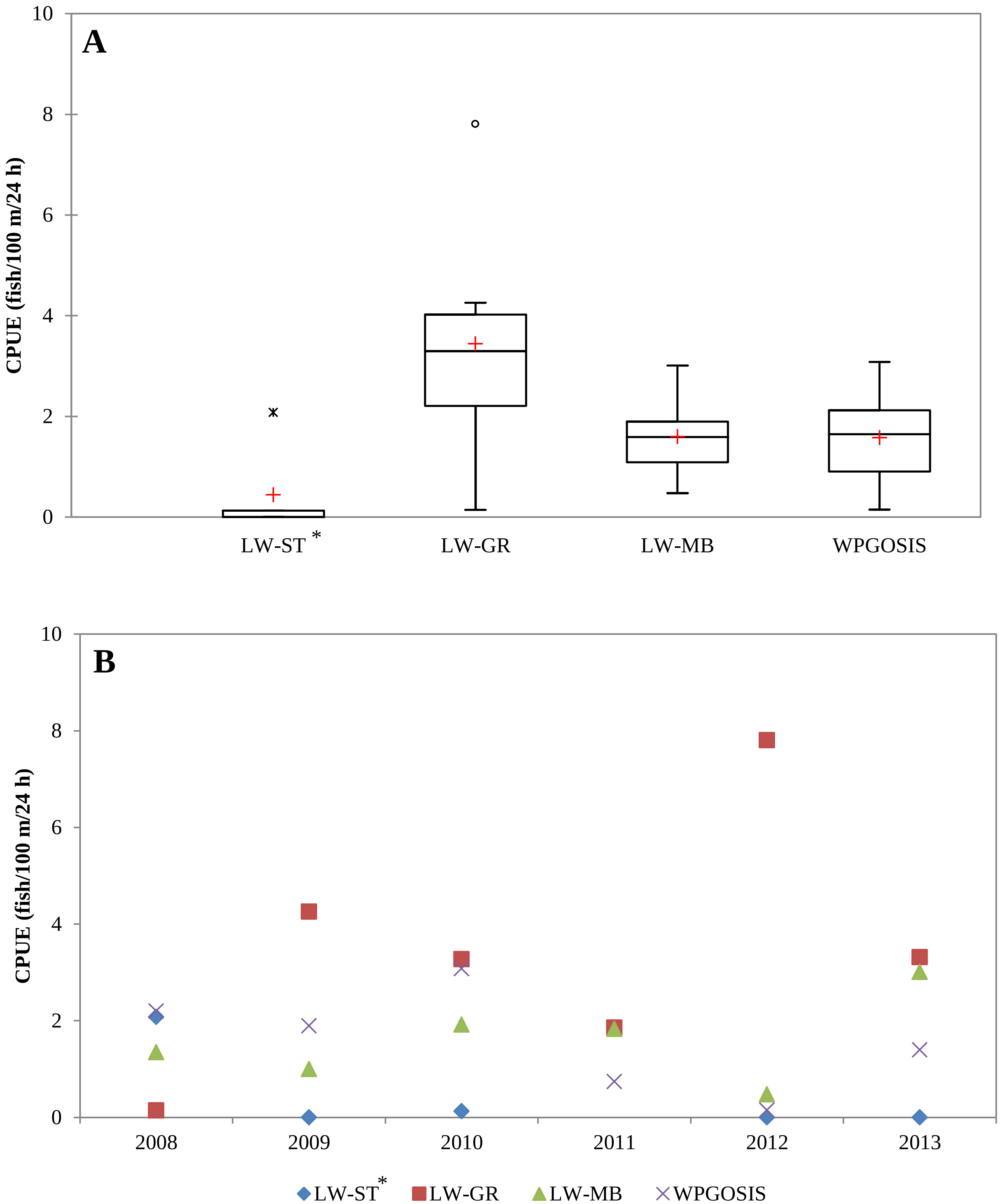
.*Represents unidentified *Sander sp*. **Scale varies from other locations

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 Lake Winnipeg Region waterbodies, 2008-2013.



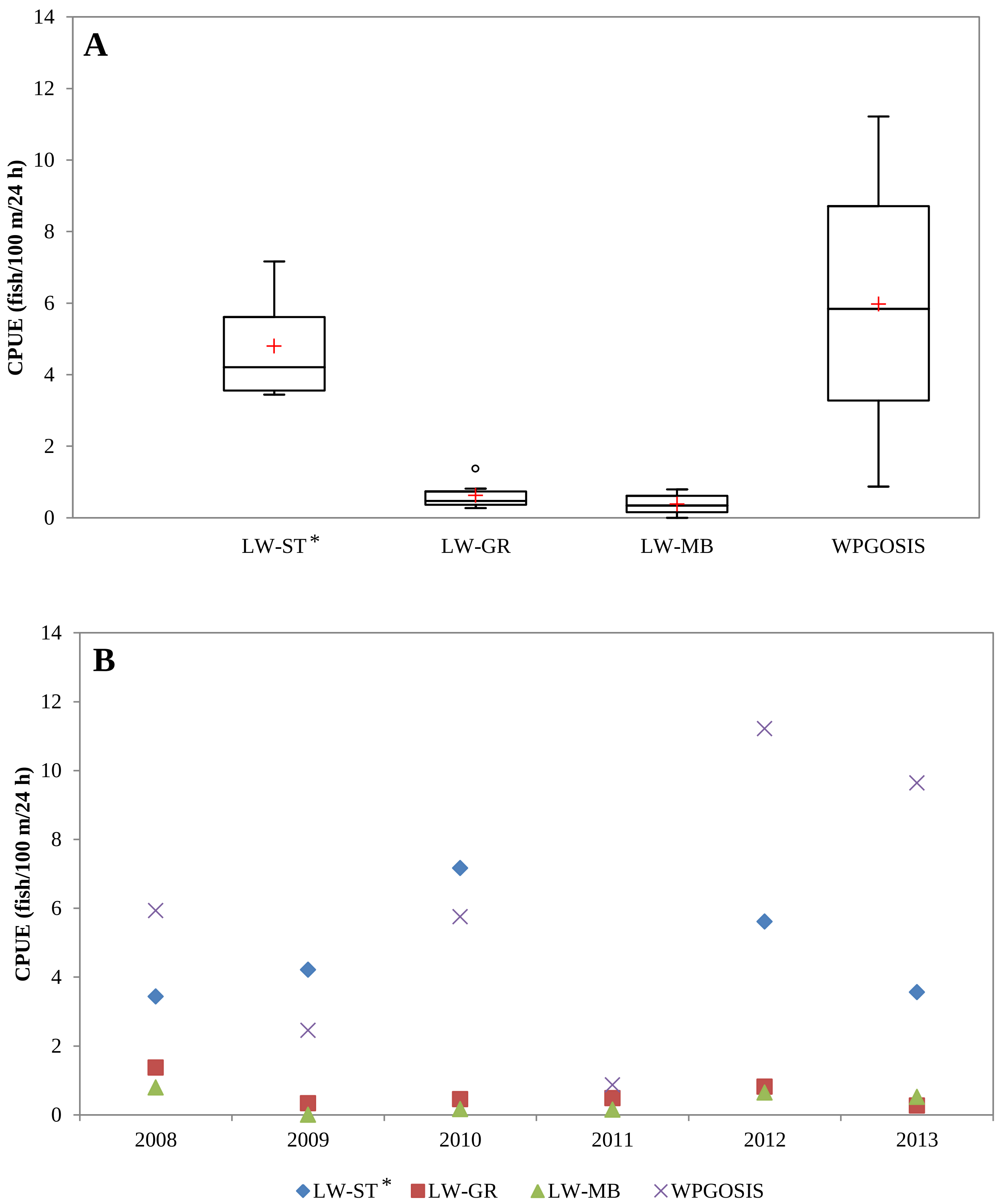
*LW-ST not sampled in 2011.

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



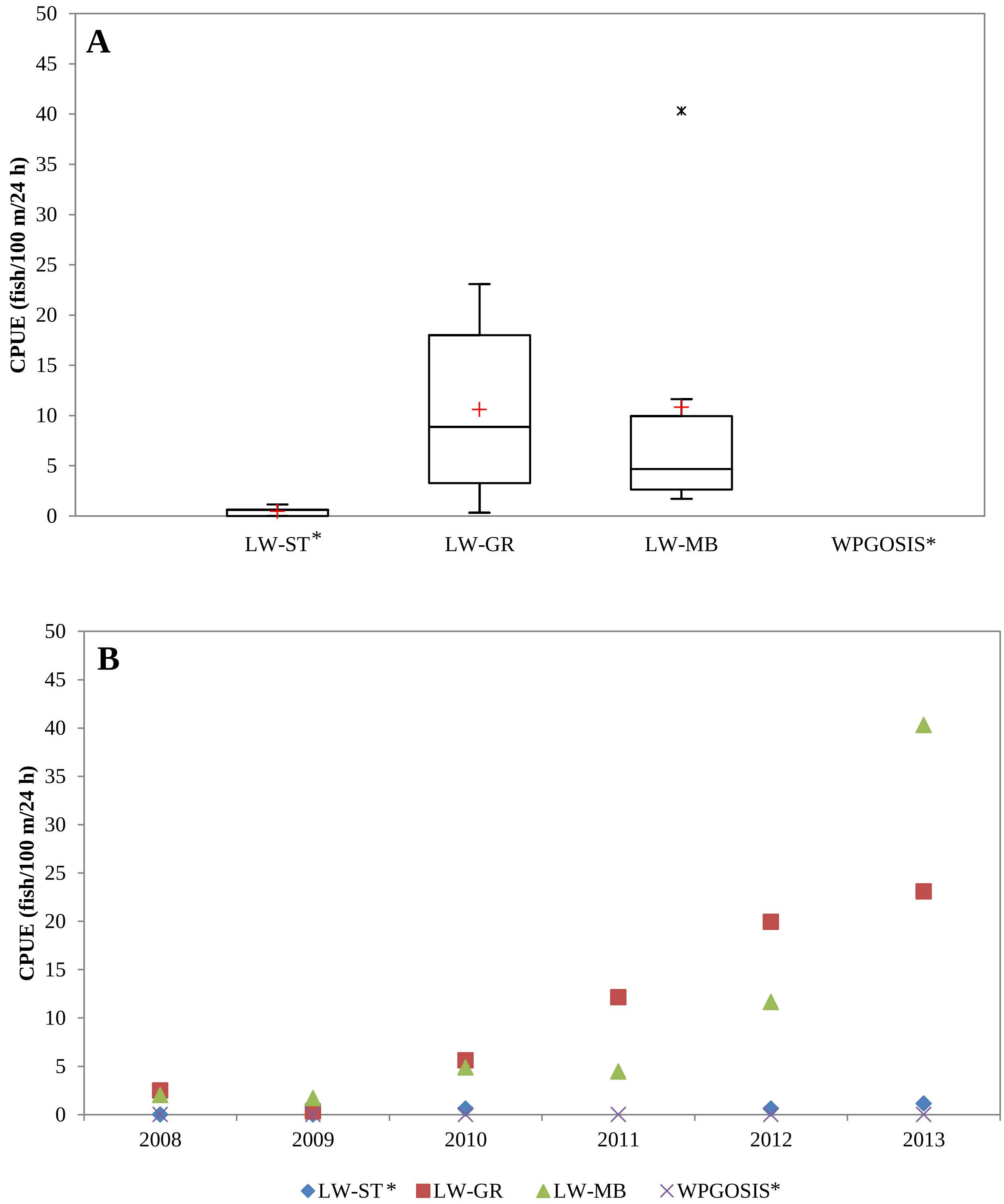
*LW-ST not sampled in 2011.

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



*LW-ST not sampled in 2011.

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



*LW-ST was not sampled in 2011; and Sauger were not captured from WPGOSIS

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

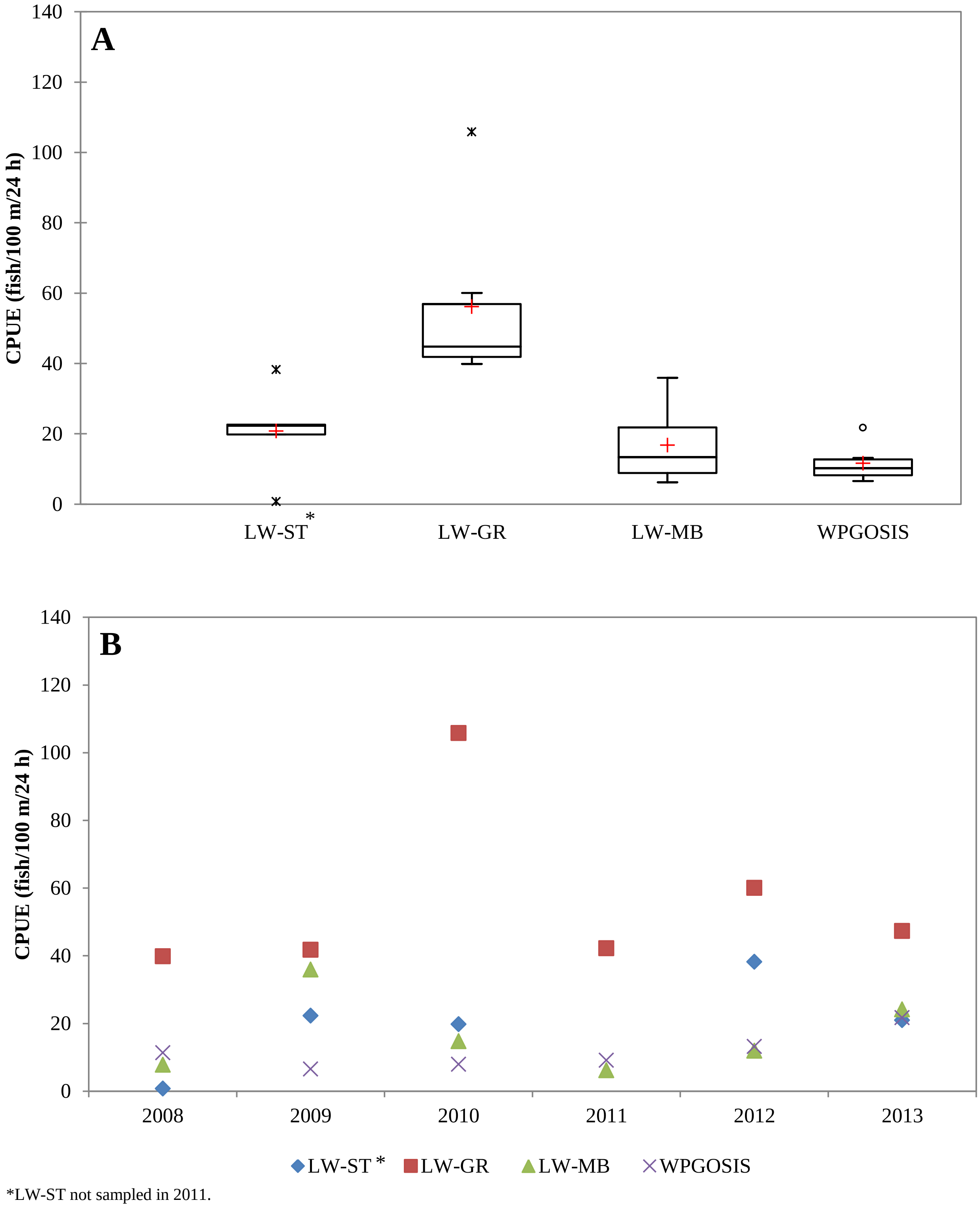
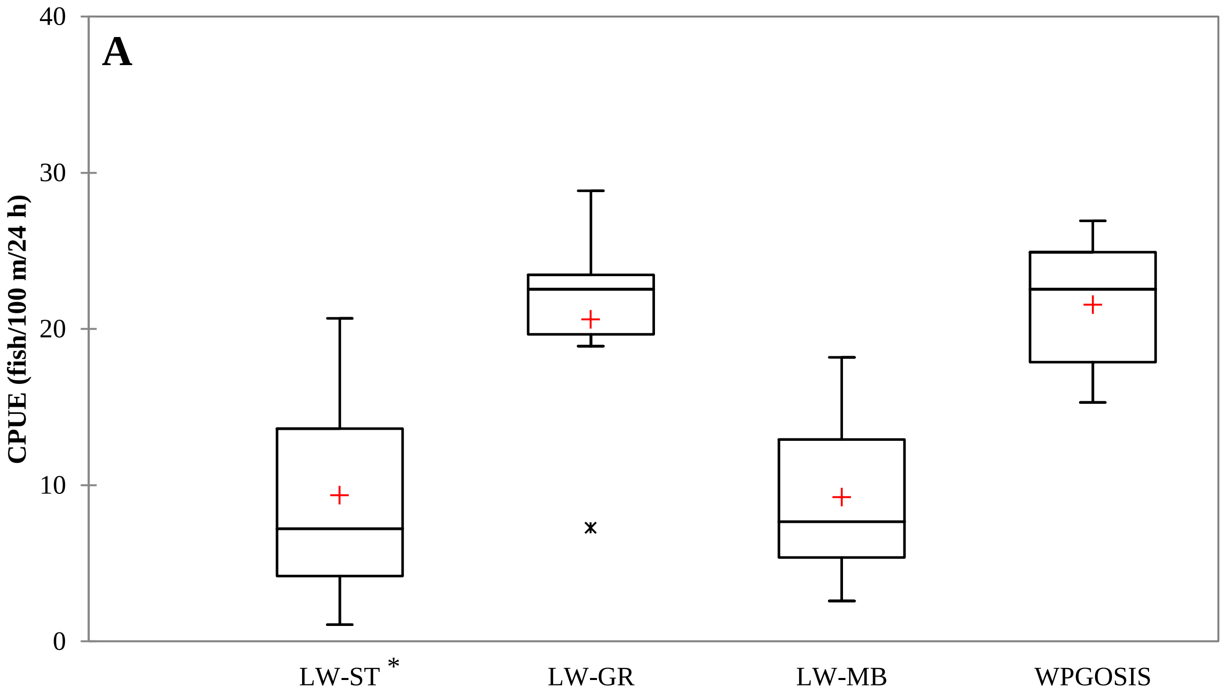
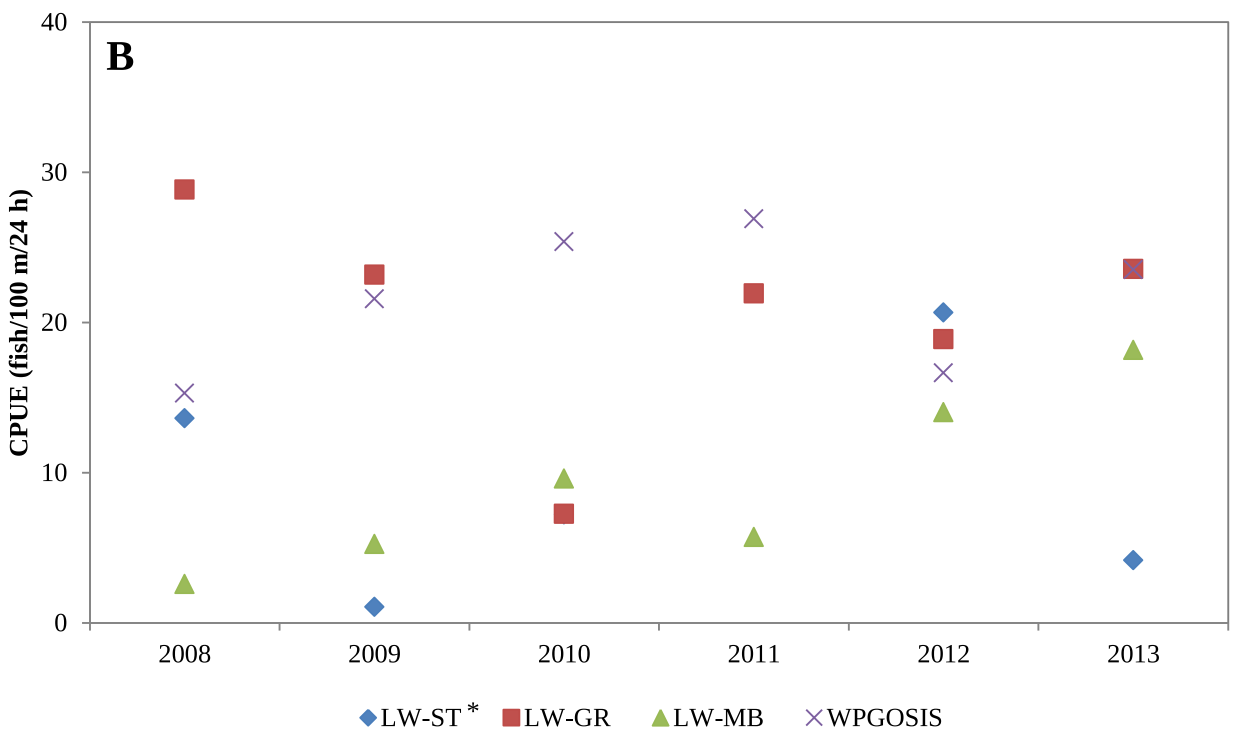


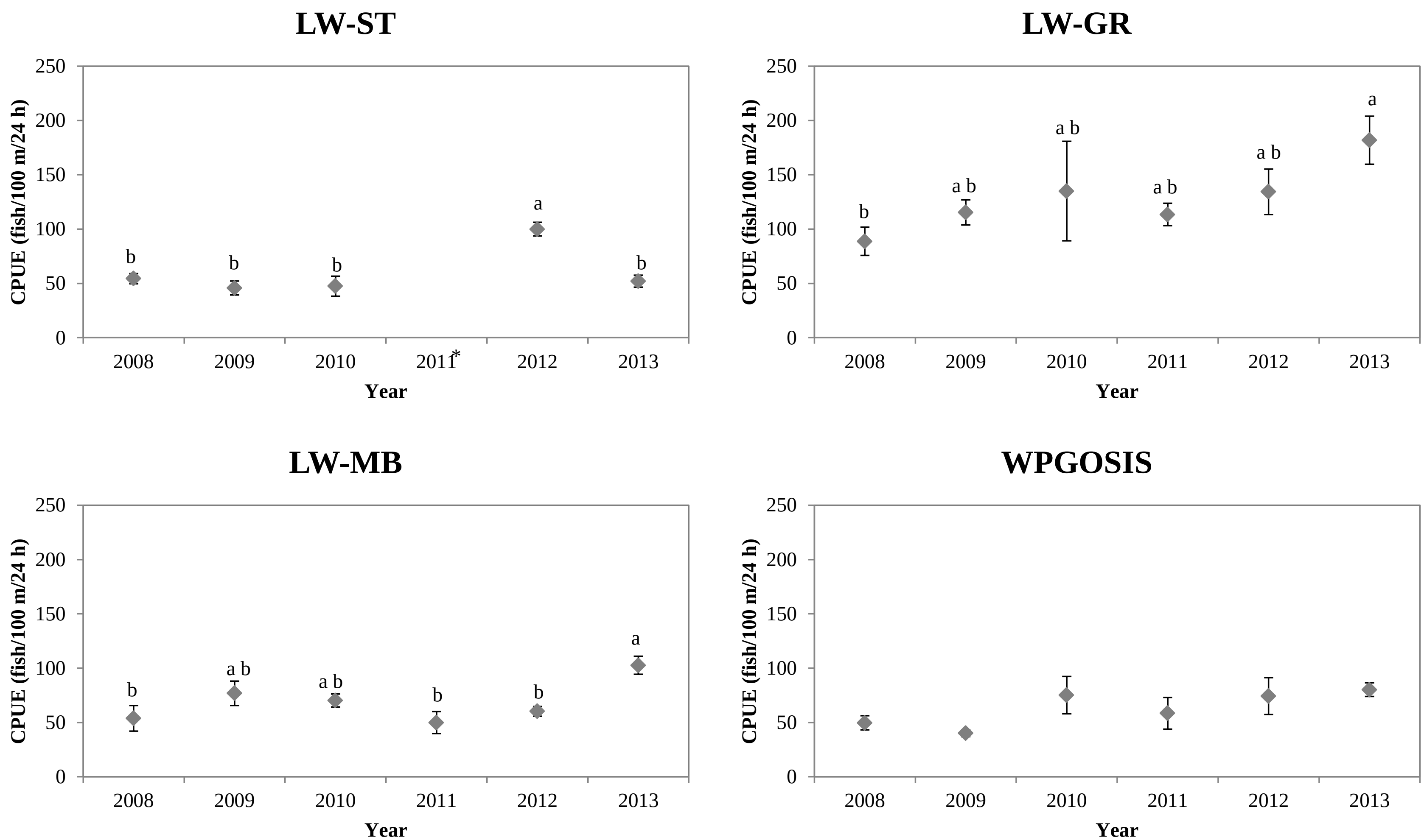
Figure 6-8. Annual mean catch-per-unit-effort (CPUE) calculated for Walleye captured in standard gang index gill nets set in Lake Winnipeg Region waterbodies, 2008-2013 by waterbody (A) and by year (B).





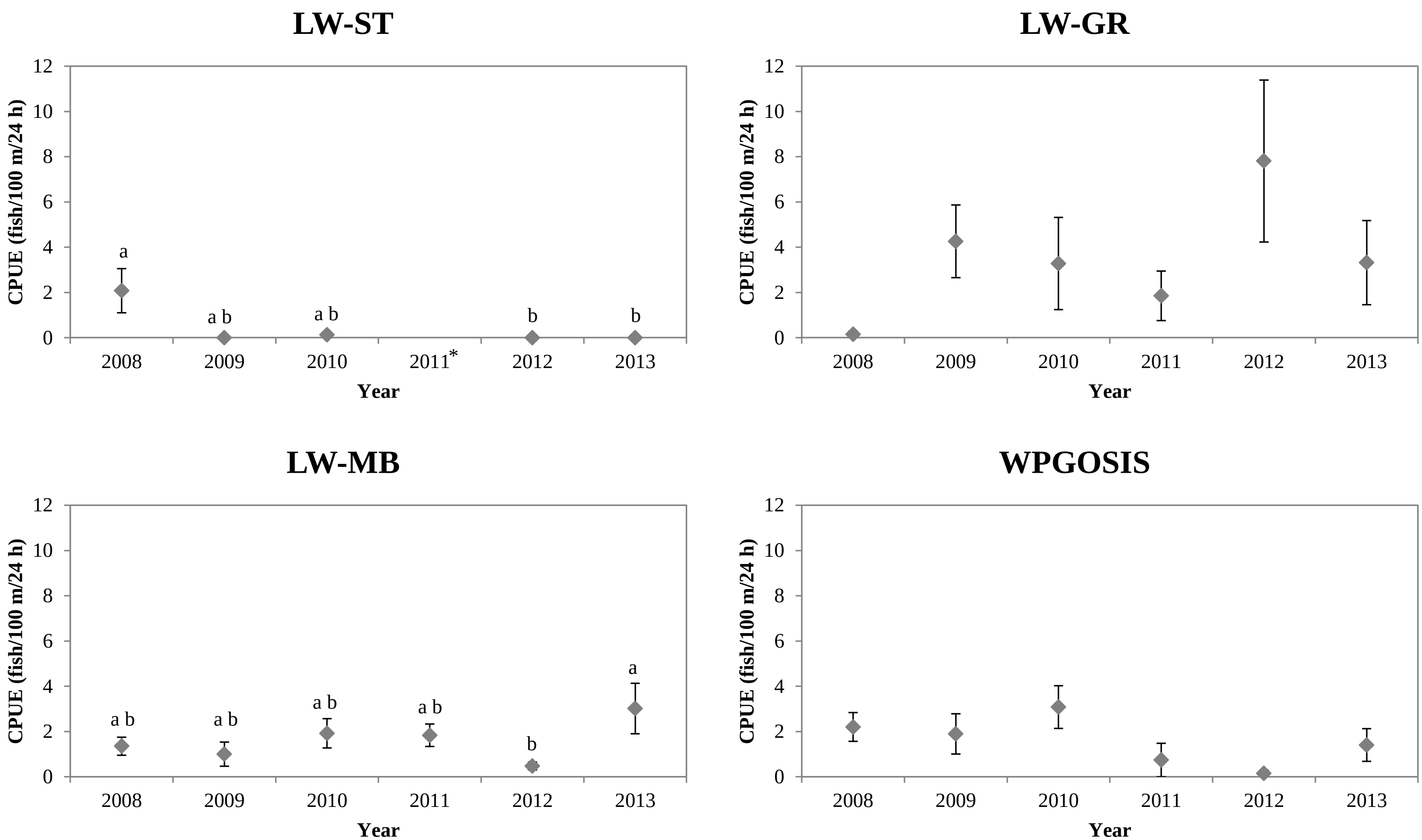
*LW-ST not sampled in 2011.

Figure 6-9. Annual mean catch-per-unit-effort (CPUE) calculated for White Sucker captured in standard gang index gill nets set in Lake Winnipeg Region waterbodies, 2008-2013 by waterbody (A) and by year (B).



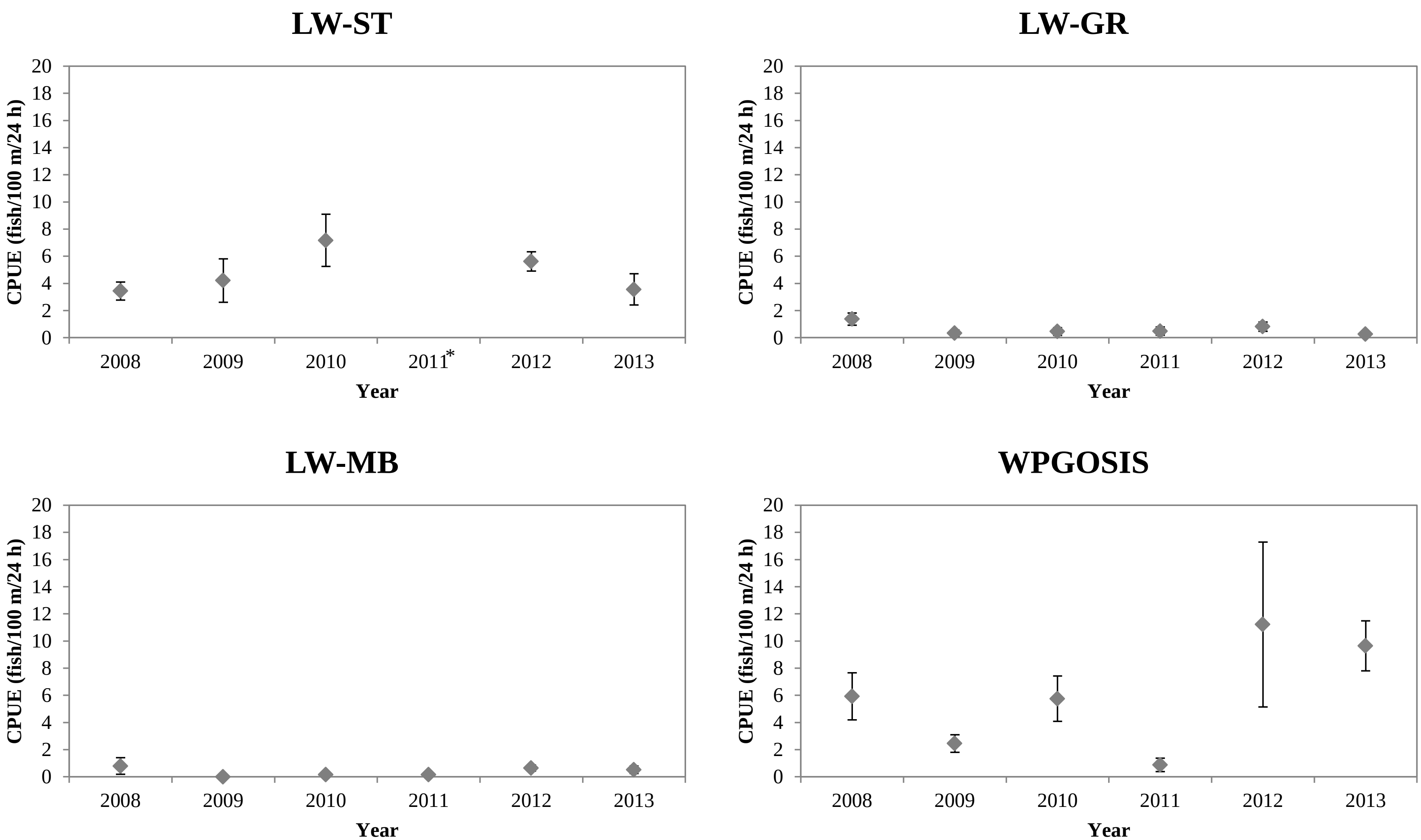
*LW-ST was not sampled in 2011.

Figure 6-10. Total catch-per-unit-effort (CPUE; mean ± SE) in standard gang index gill nets set 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.



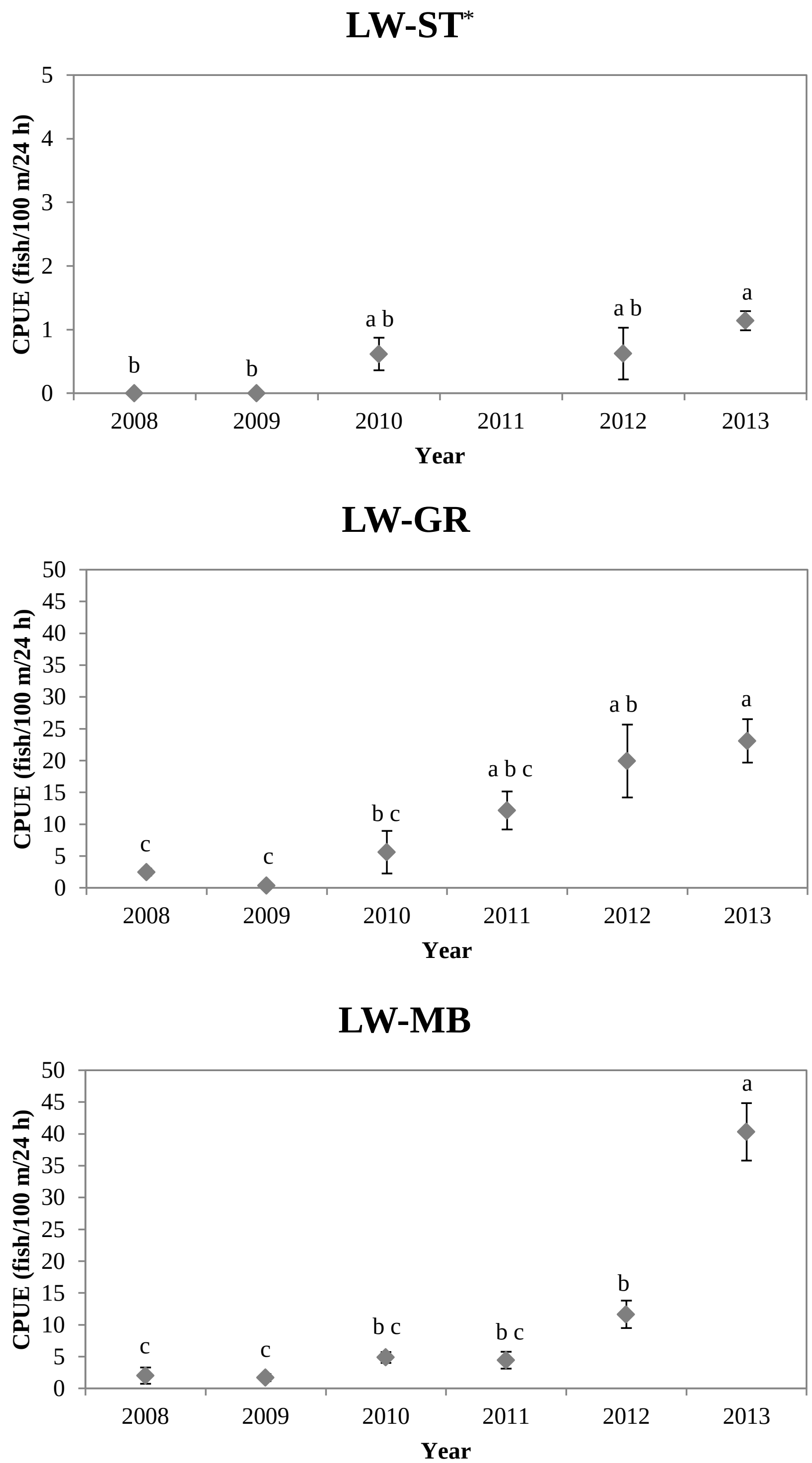
*LW-ST was not sampled in 2011.

Figure 6-11. Lake Whitefish catch-per-unit-effort (CPUE; mean ± SE) in standard gang index gill nets set 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.



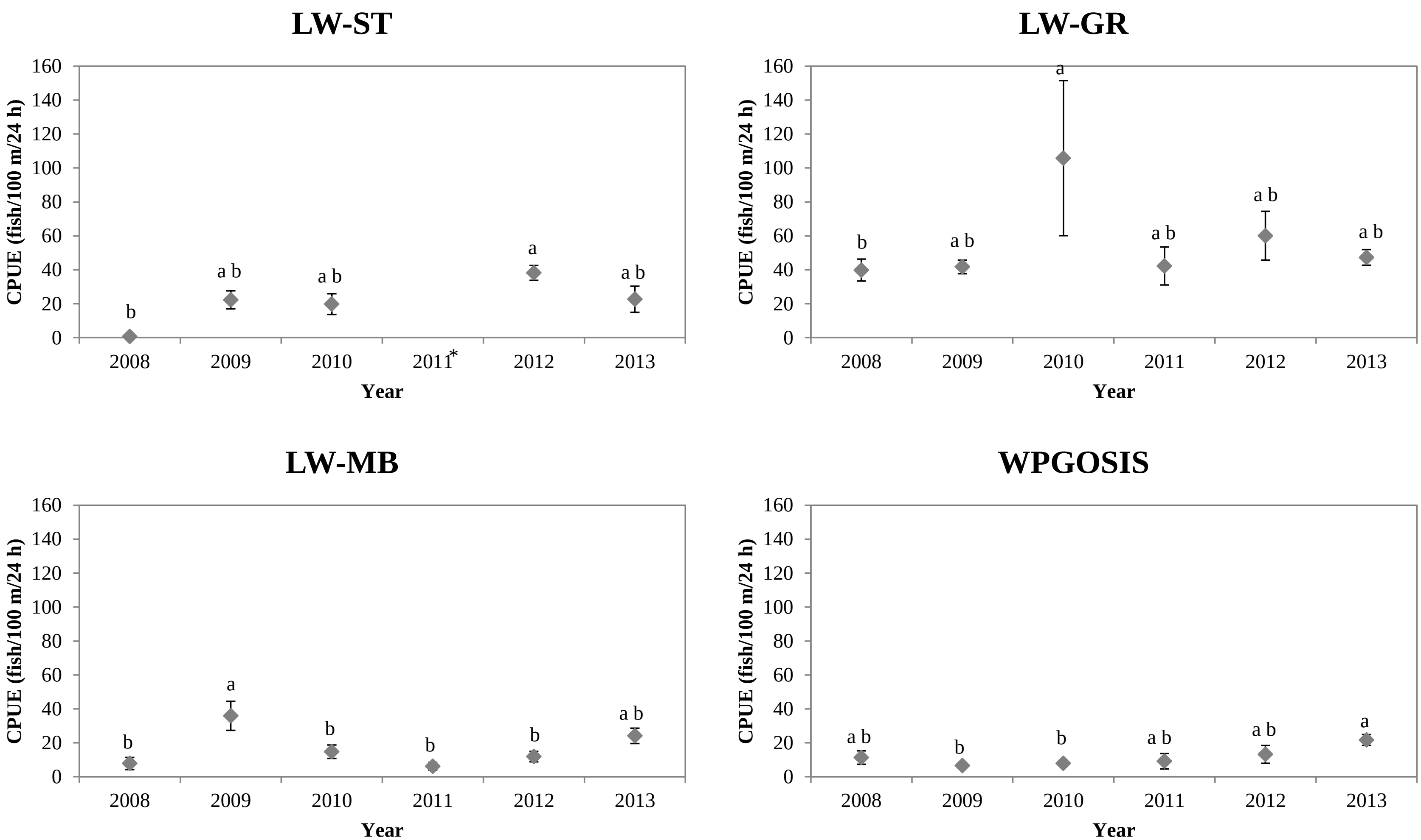
*LW-ST was not sampled in 2011.

Figure 6-12. Northern Pike catch-per-unit-effort (CPUE; mean ± SE) in standard gang index gill nets set 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.



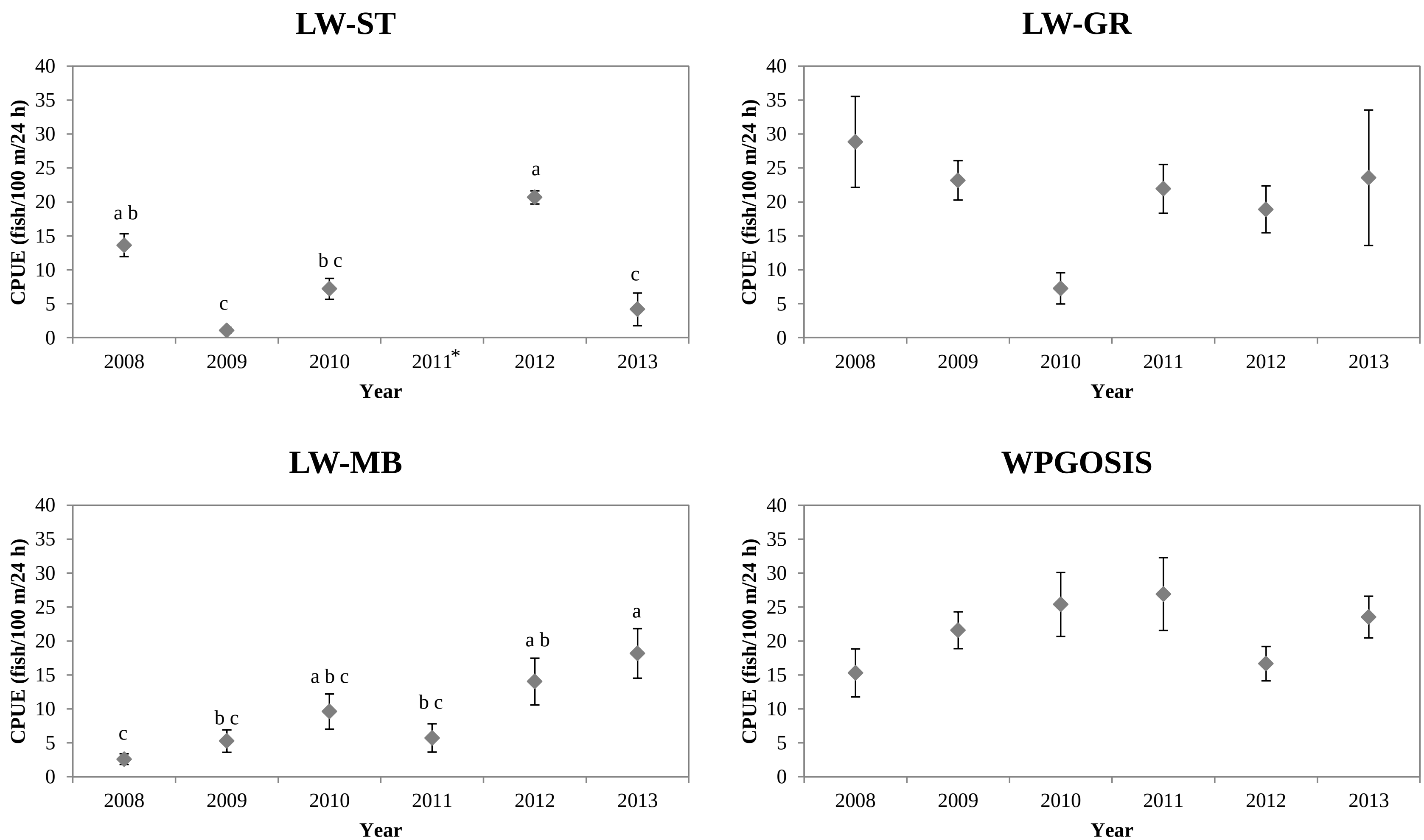
* LW-ST was not sampled in 2011 and axis scale varies from other locations.

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



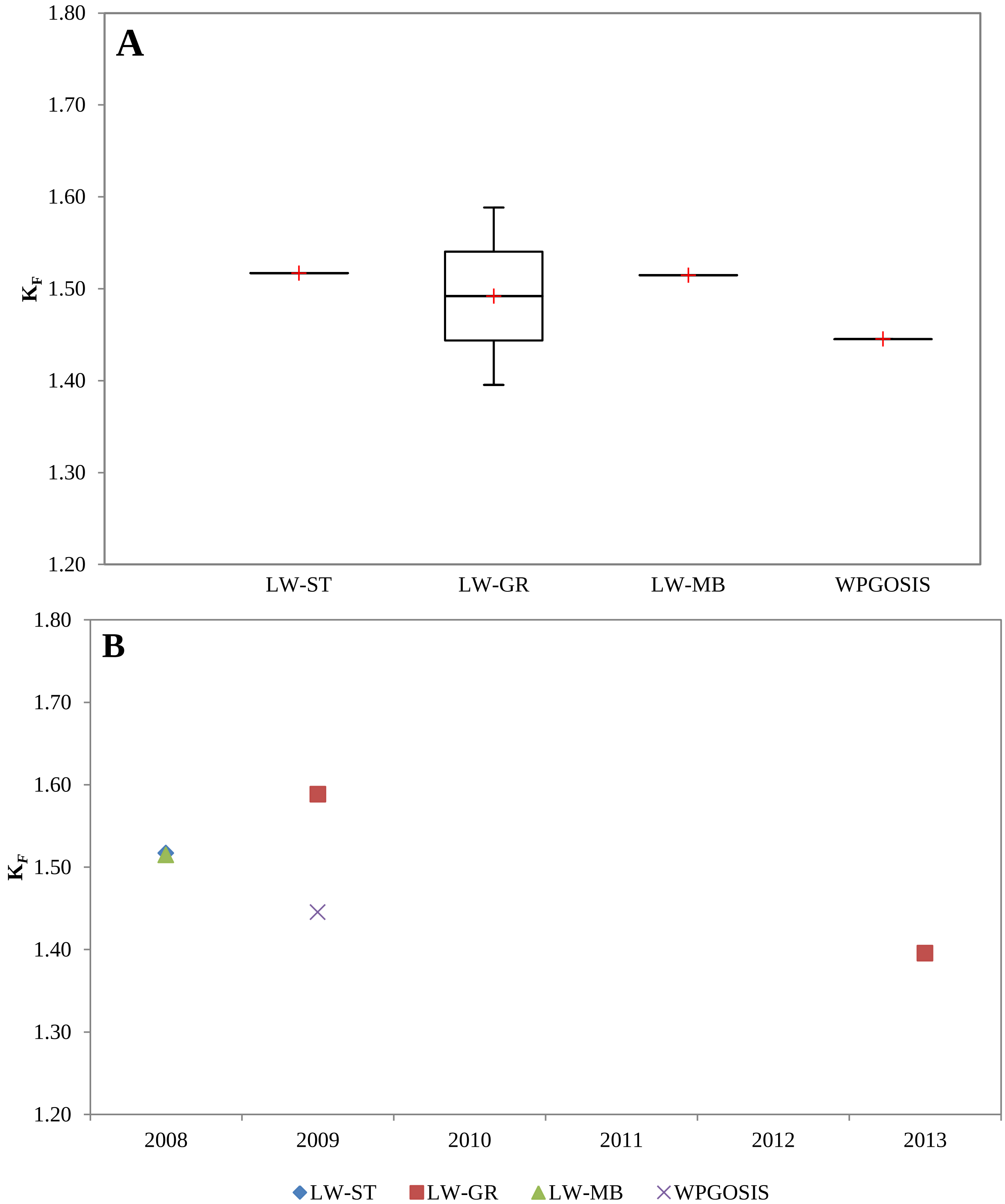
* LW-ST was not sampled in 2011

Figure 6-14. Walleye catch-per-unit-effort (CPUE; mean ± SE) in standard gang index gill nets set 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.



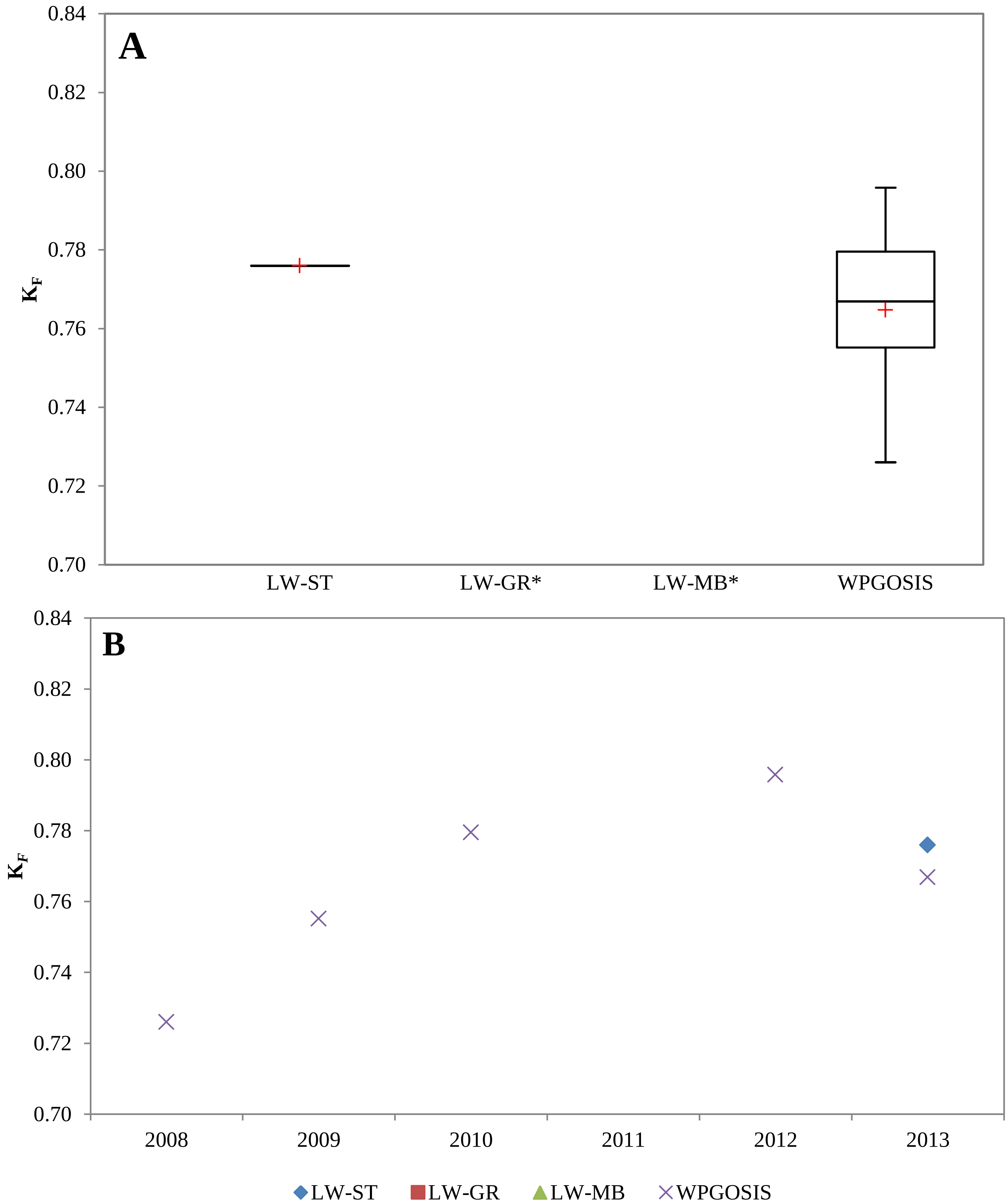
* LW-ST was not sampled in 2011

Figure 6-15. White Sucker catch-per-unit-effort (CPUE; mean ± SE) in standard gang index gill nets set 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.



* Too few fish were captured in some years.

Figure 6-16. Annual mean Fulton's condition factor (K_F) calculated for Lake Whitefish captured in standard gang index gill nets set in Lake Winnipeg Region waterbodies, 2008-2013 by waterbody (A) and by year (B).



* Too few fish were captured in some years.

Figure 6-17. Annual mean Fulton's condition factor (K_F) calculated for Northern Pike captured in standard gang index gill nets set in Lake Winnipeg Region waterbodies, 2008-2013 by waterbody (A) and by year (B).

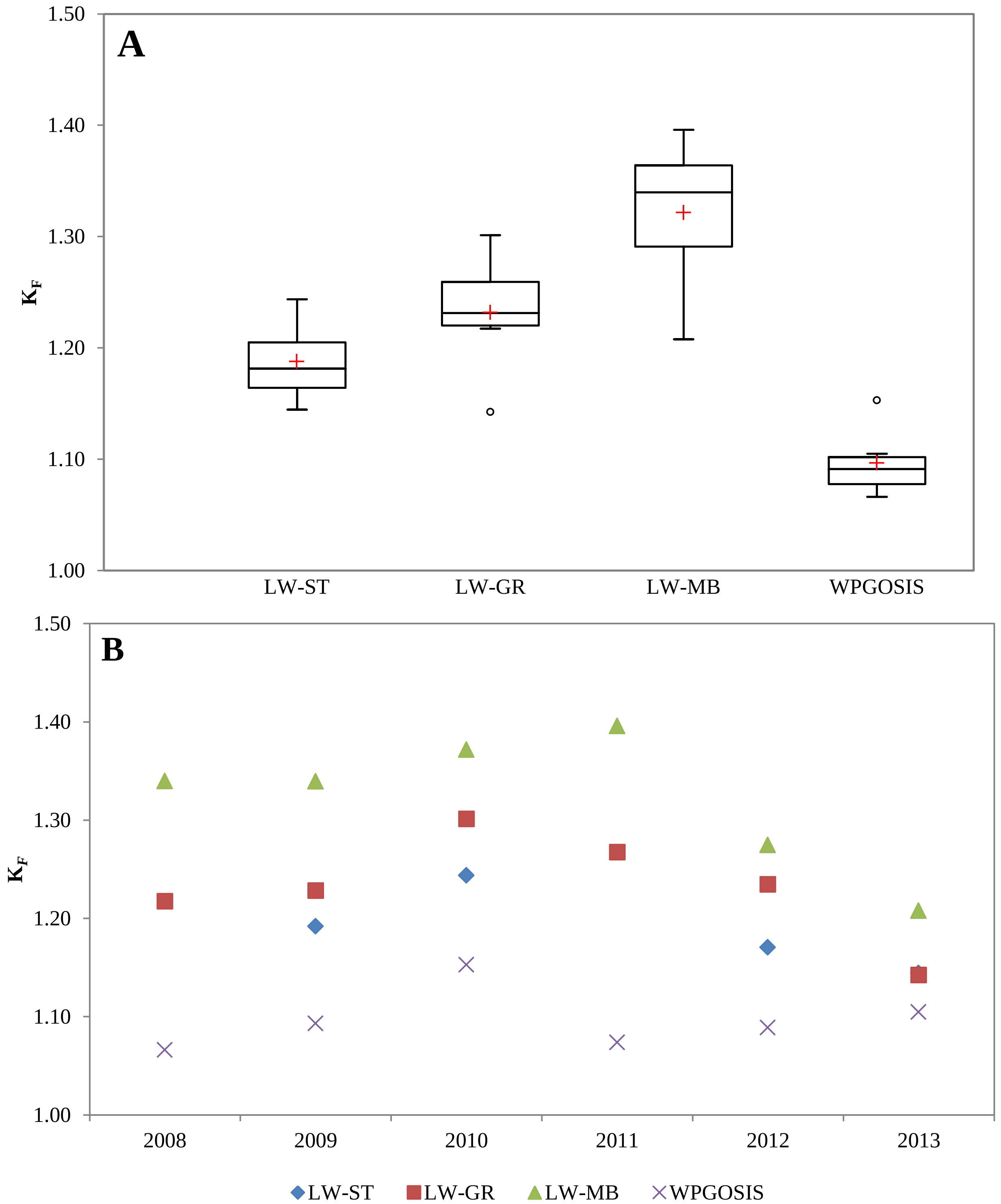
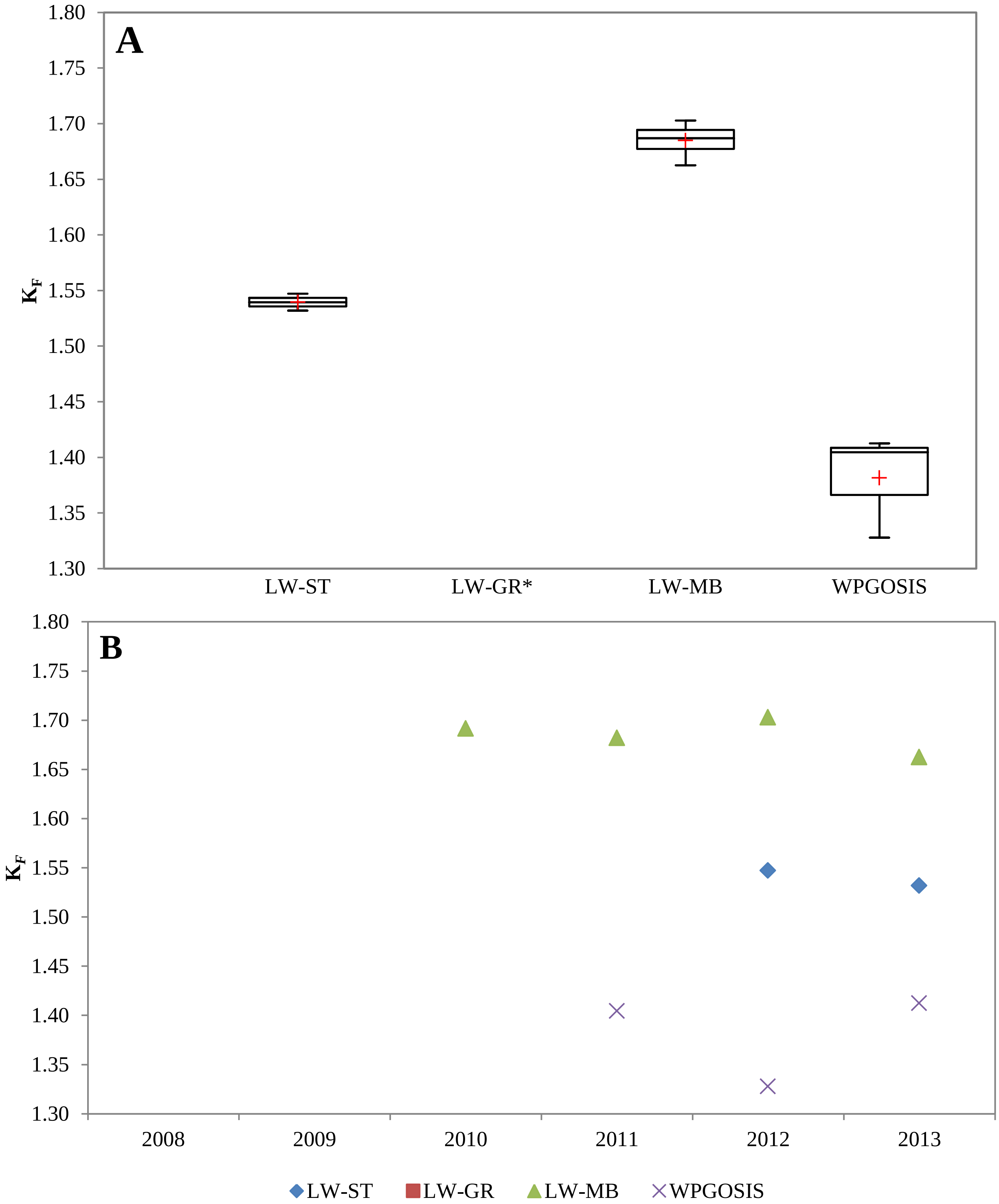


Figure 6-18. Annual mean Fulton's condition factor (K_F) calculated for Walleye captured in standard gang index gill nets set in Lake Winnipeg Region waterbodies, 2008-2013 by waterbody (A) and by year (B).



* Insufficient numbers of white sucker were sampled for biometric data in some years.

Figure 6-19. Fulton's condition factor (K_F) calculated for White Sucker captured in standard gang index gill nets set in Lake Winnipeg Region waterbodies, 2008-2013 by waterbody (A) and by year (B).

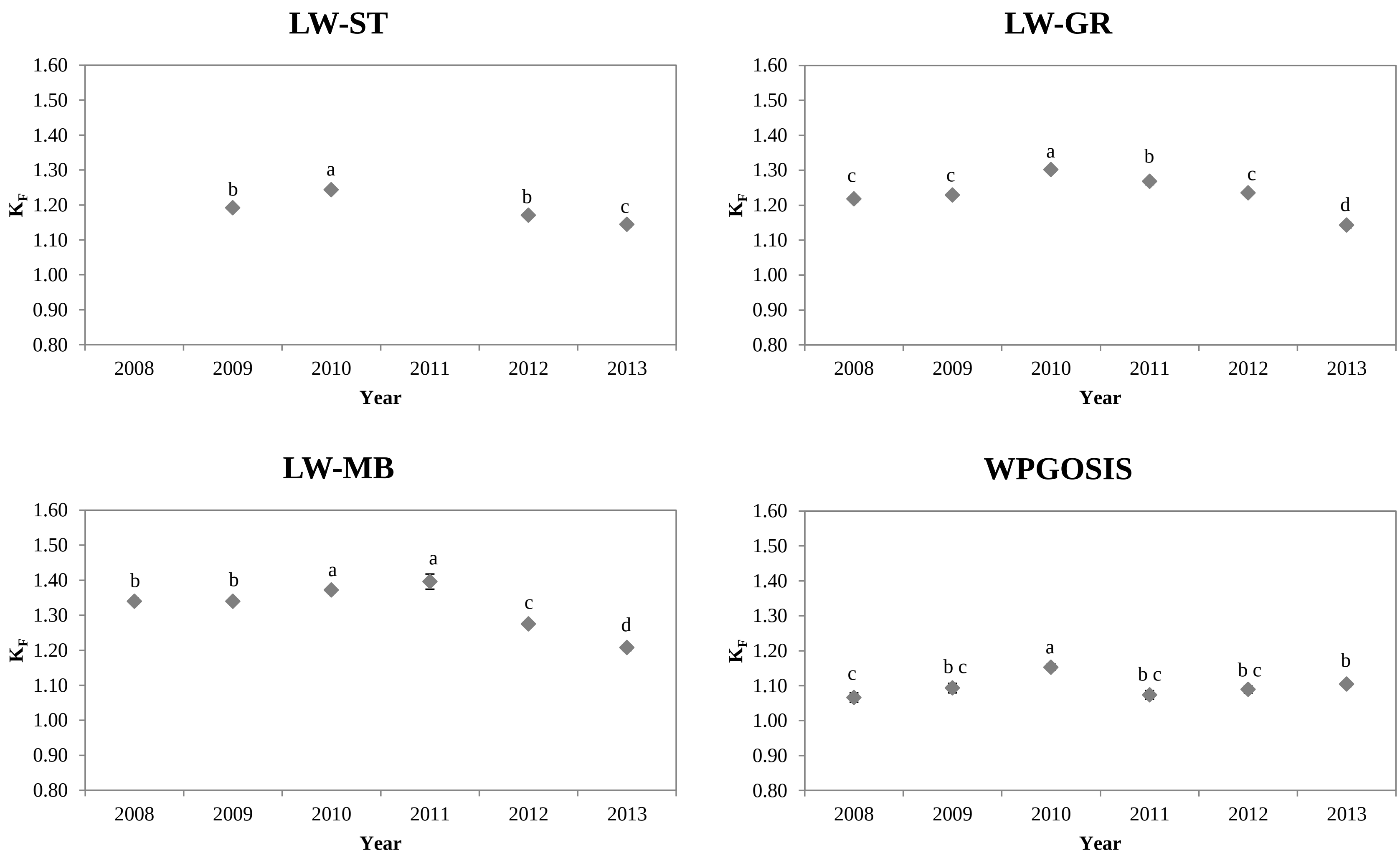


Figure 6-20. Fulton's condition factor (K_F; mean ± SE) of Walleye captured at annual on- and off-system locations. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts, or lack of superscripts, denote no statistically significant difference.

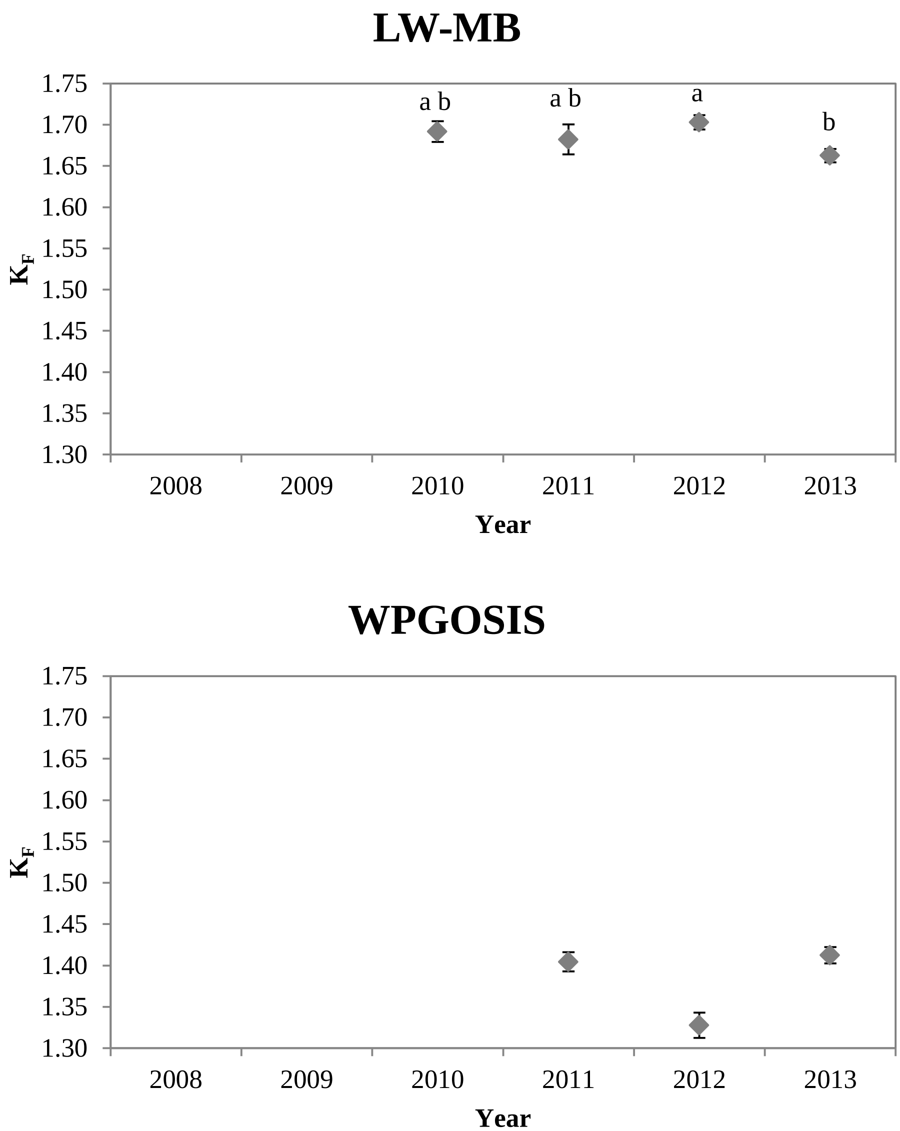


Figure 6-21. Fulton's condition factor (K_F; mean ± SE) of White Sucker captured at annual on- and off-system locations. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts, or lack of superscripts, denote no statistically significant difference.

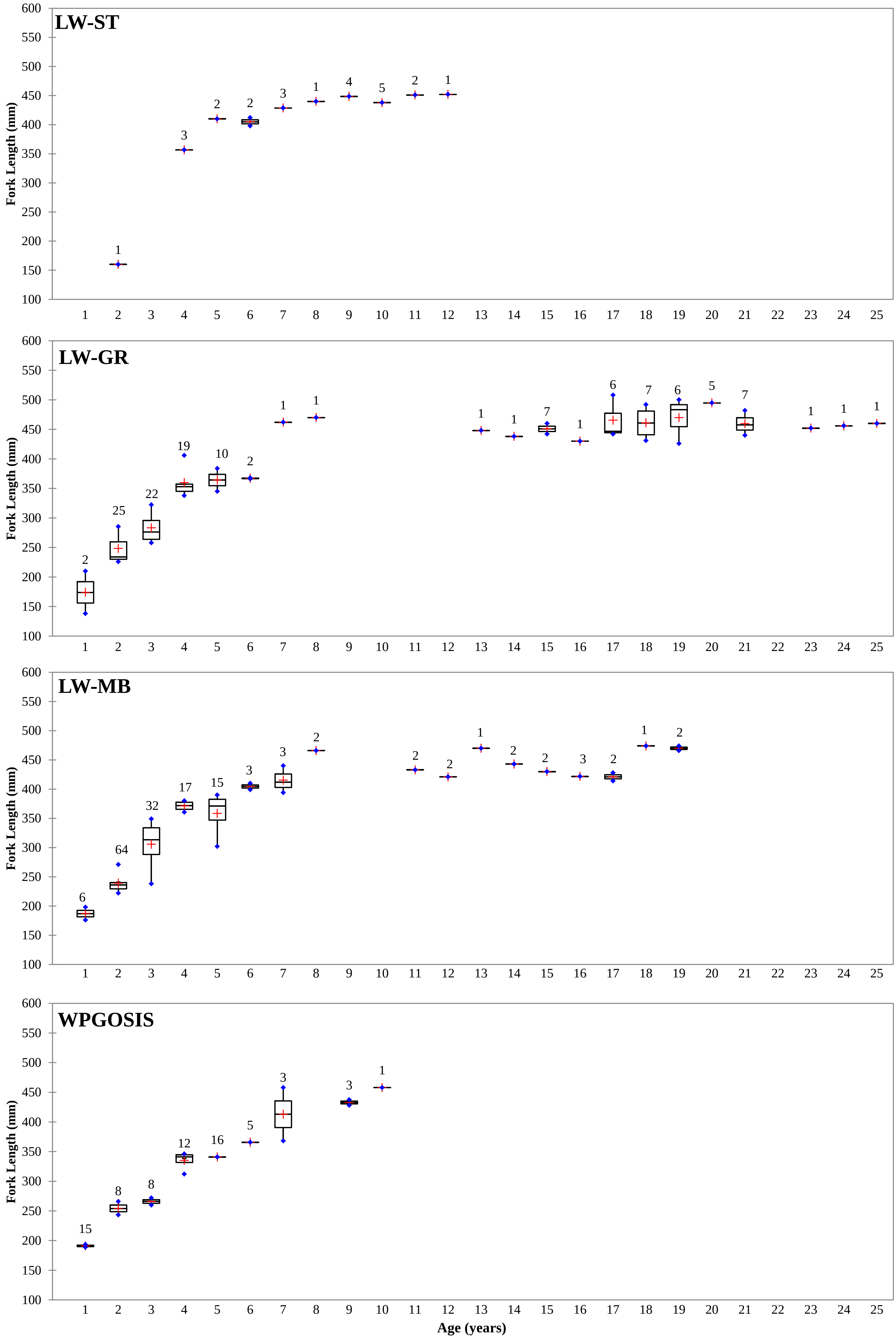


Figure 6-22. Annual mean length-at-age (mm) of Lake Whitefish captured in standard gang and small mesh index gill nets set at annual sampling locations in the Lake Winnipeg Region: 2008-2013. The number of fish captured over the 6-year sampling period is shown above the box for each age.

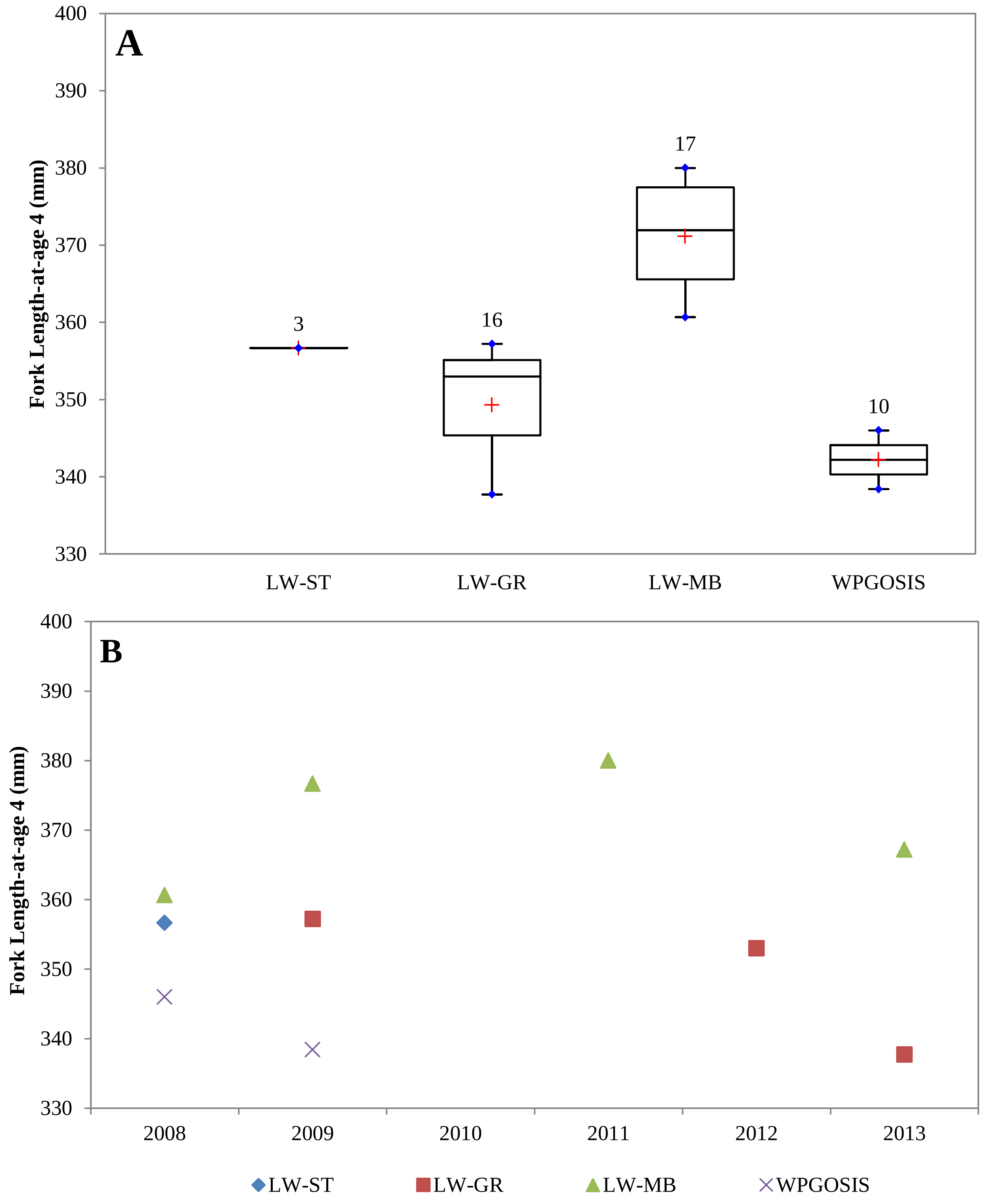
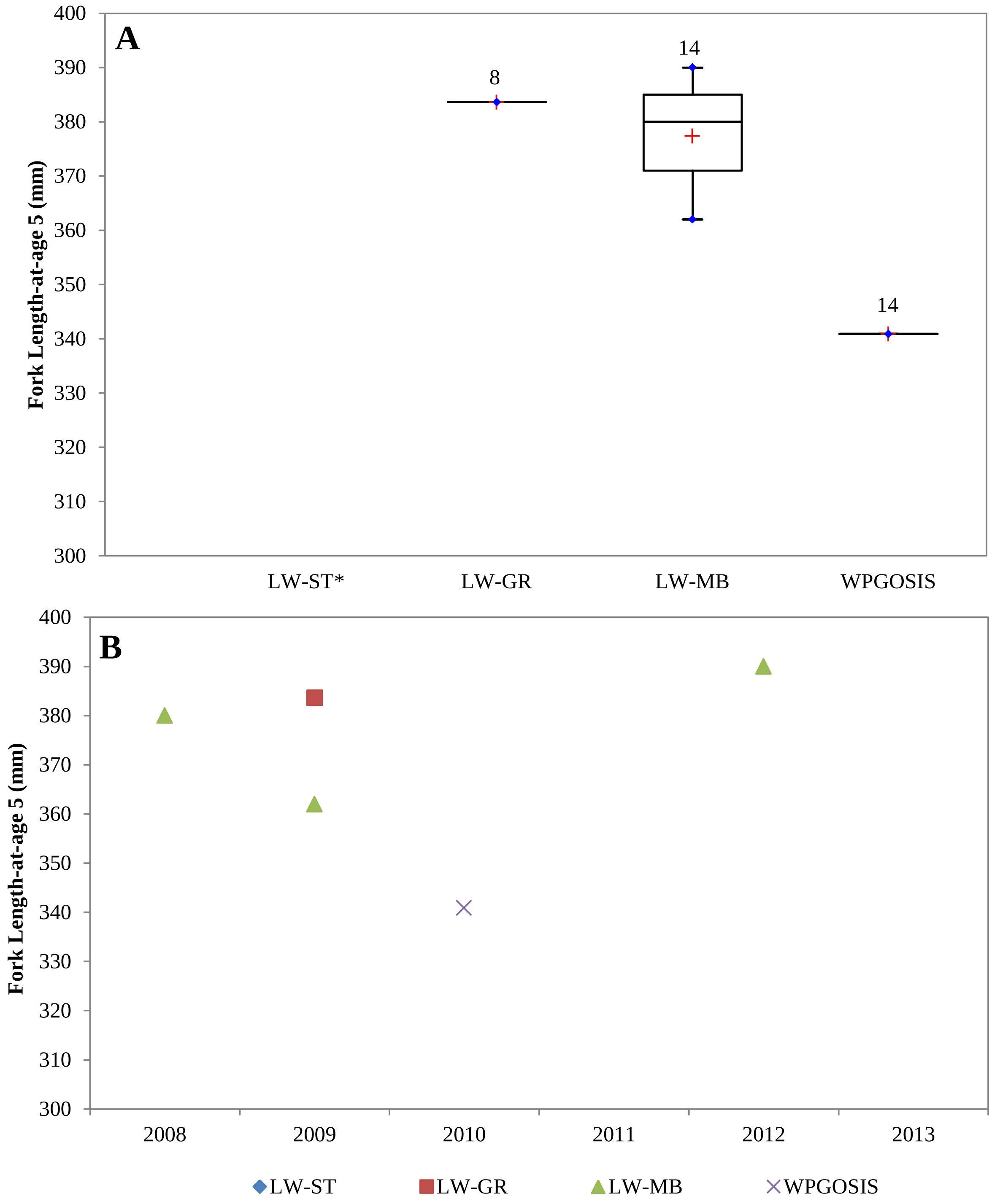
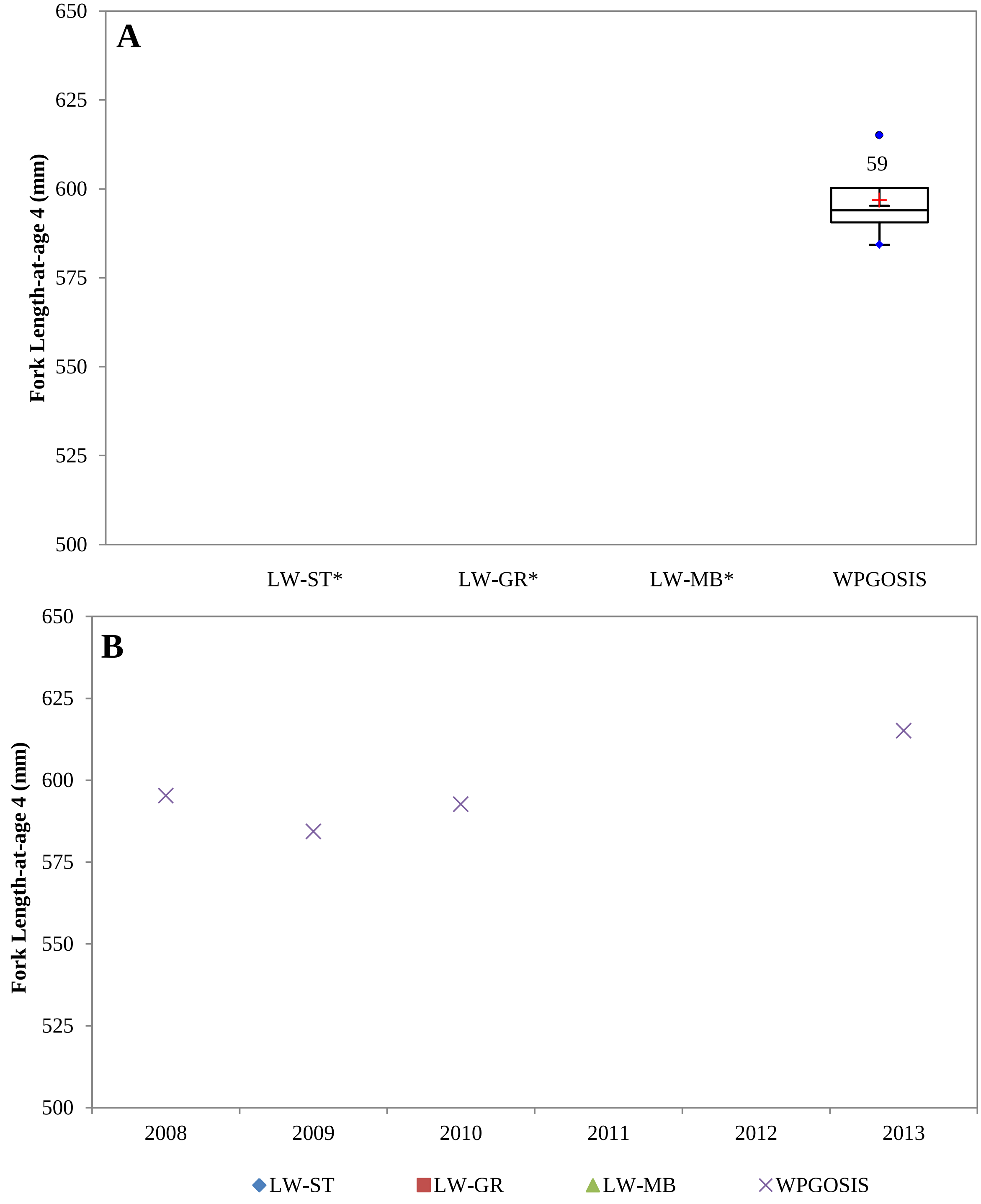


Figure 6-23. Annual mean length-at-age 4 of Lake Whitefish captured in standard gang and small mesh index gill nets set in Lake Winnipeg Region waterbodies: 2008-2013 by waterbody (A) and by year (B). The number of 4-year-old fish captured over the 6-year sampling period is shown above the box for each waterbody.



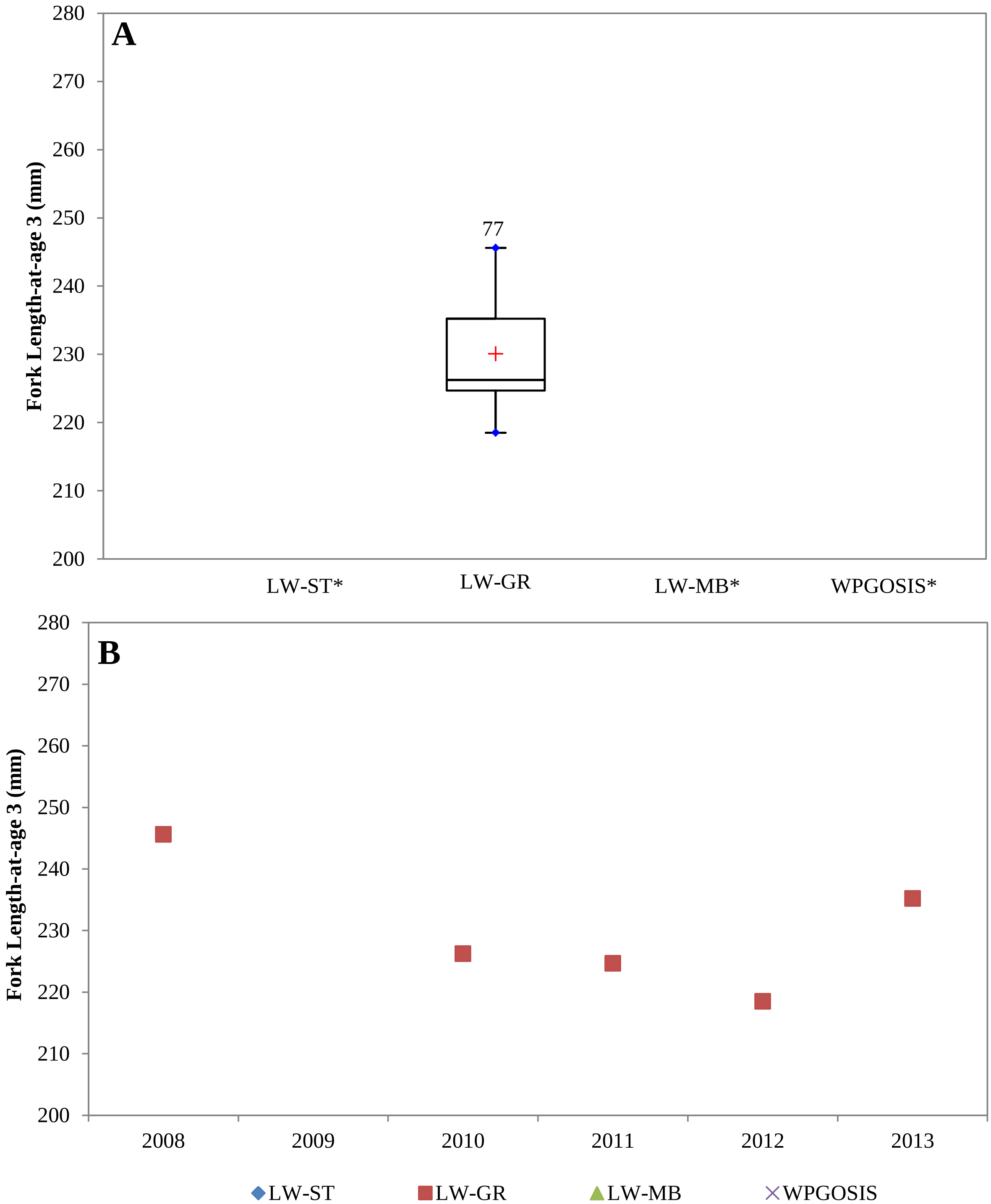
* Years in which 1 or 2 fish were captured were excluded from the analysis.

Figure 6-24. Annual mean length-at-age 5 (mm) of Lake Whitefish captured in standard gang and small mesh index gill nets set in Lake Winnipeg Region waterbodies, 2008-2013 by waterbody (A) and by year (B). The number of 5-year-old fish captured over the 6-year sampling period is shown above the box for each waterbody.



* Years in which 1 or 2 fish were captured were excluded from the analysis.

Figure 6-25. Annual mean length-at-age 4 (mm) of Northern Pike captured in standard gang and small mesh index gill nets set in Lake Winnipeg Region waterbodies, 2008-2013 by waterbody (A) and by year (B). The number of 4-year-old fish captured over the 6-year sampling period is shown above the box for each waterbody.



* Years in which 1 or 2 fish were captured were excluded from the analysis.

Figure 6-26. Annual mean length-at-age 3 (mm) of Sauger captured in standard gang and small mesh index gill nets set in Lake Winnipeg Region waterbodies, 2008-2013 by waterbody (A) and by year (B). The number of 3-year-old fish captured over the 6-year sampling period is shown above the box for each waterbody.

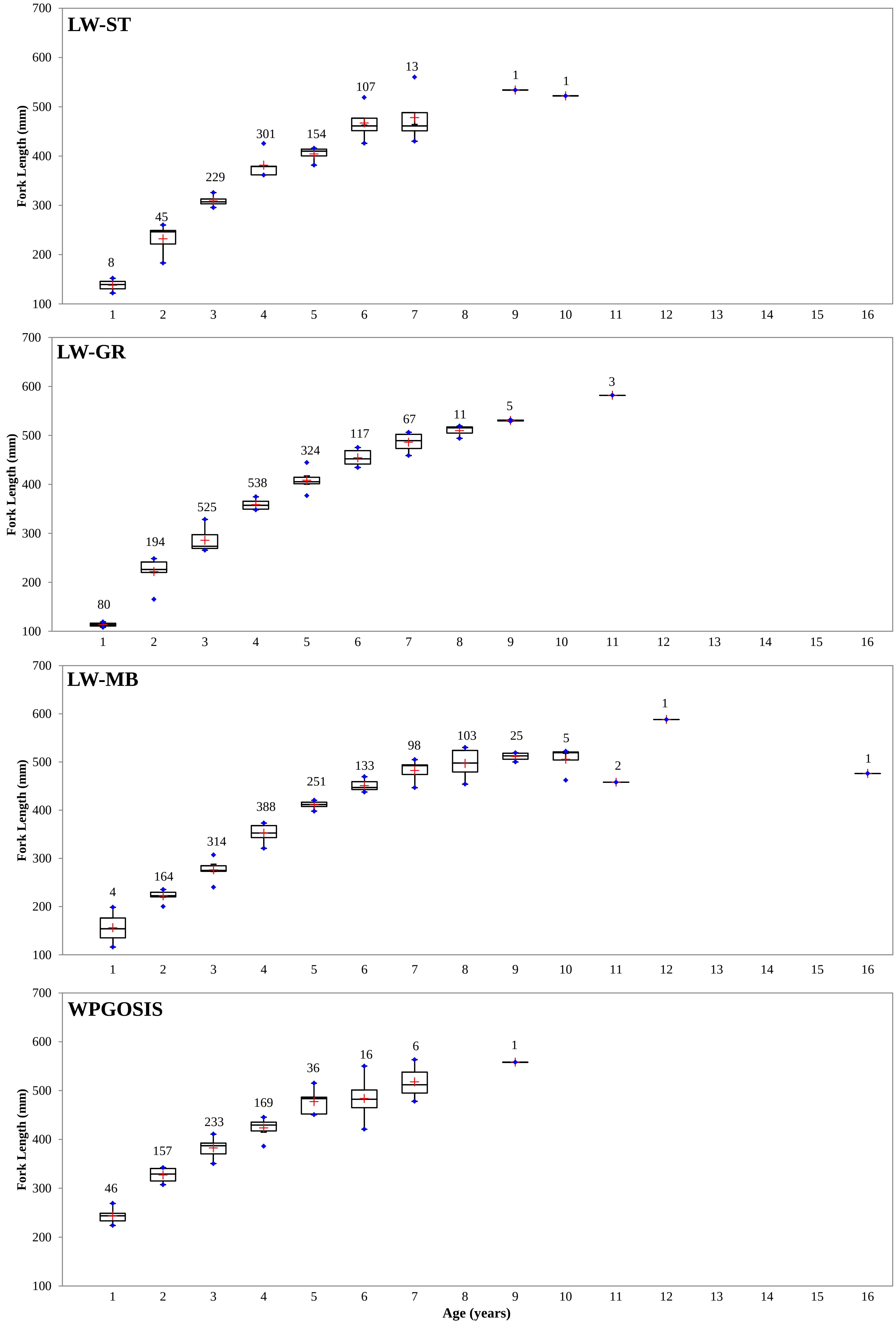


Figure 6-27. Annual mean length-at-age (mm) of Walleye captured in standard gang and small mesh index gill nets set at annual sampling locations in the Lake Winnipeg Region, 2008-2013. The number of fish captured over the 6-year sampling period is shown above the box for each age.

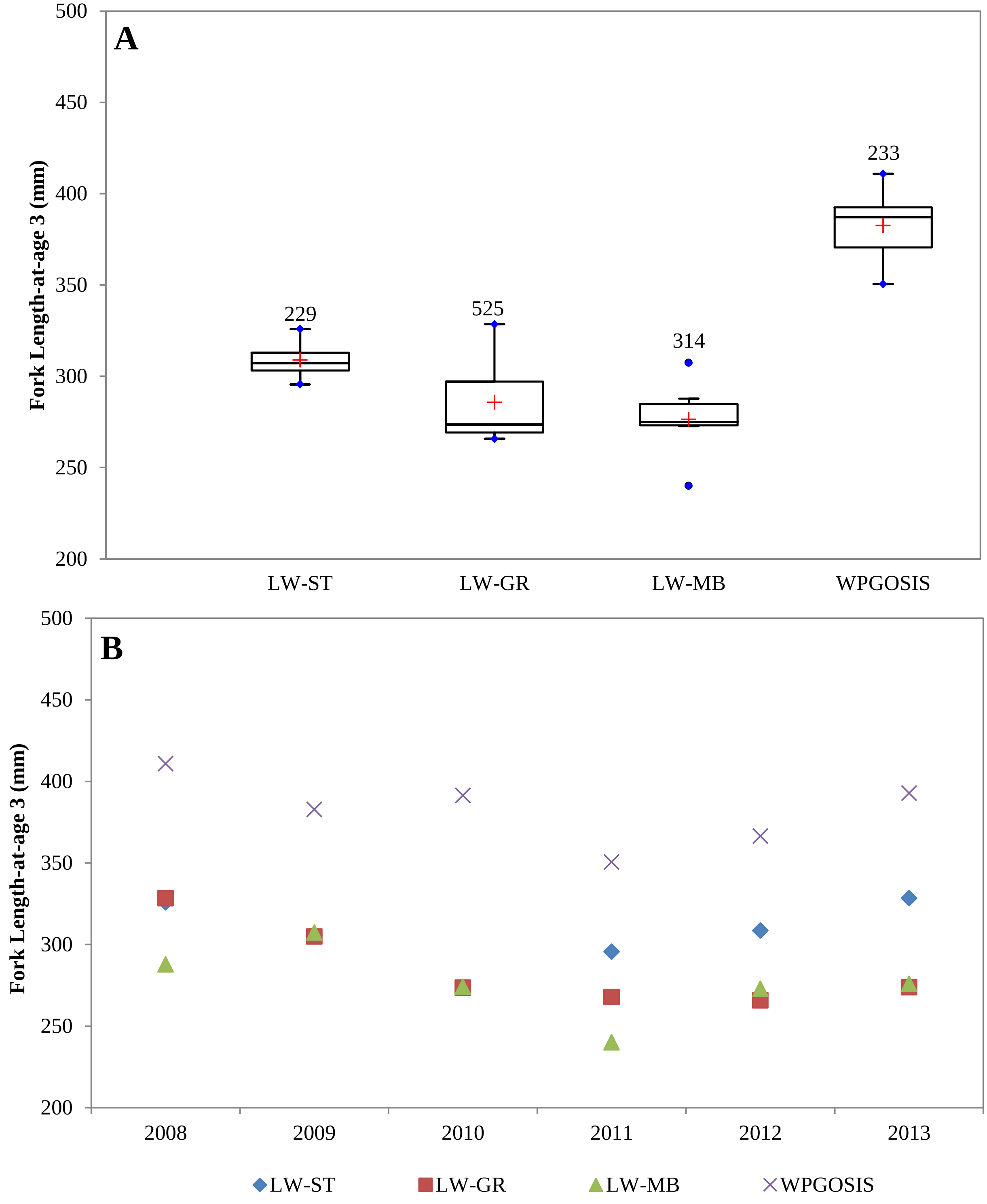


Figure 6-28. Annual mean length-at-age 3 (mm) of Walleye captured in standard gang and small mesh index gill nets set in Lake Winnipeg Region waterbodies, 2008-2013 by waterbody (A) and by year (B). The number of 3-year-old fish captured over the 6-year sampling period is shown above the box for each waterbody.

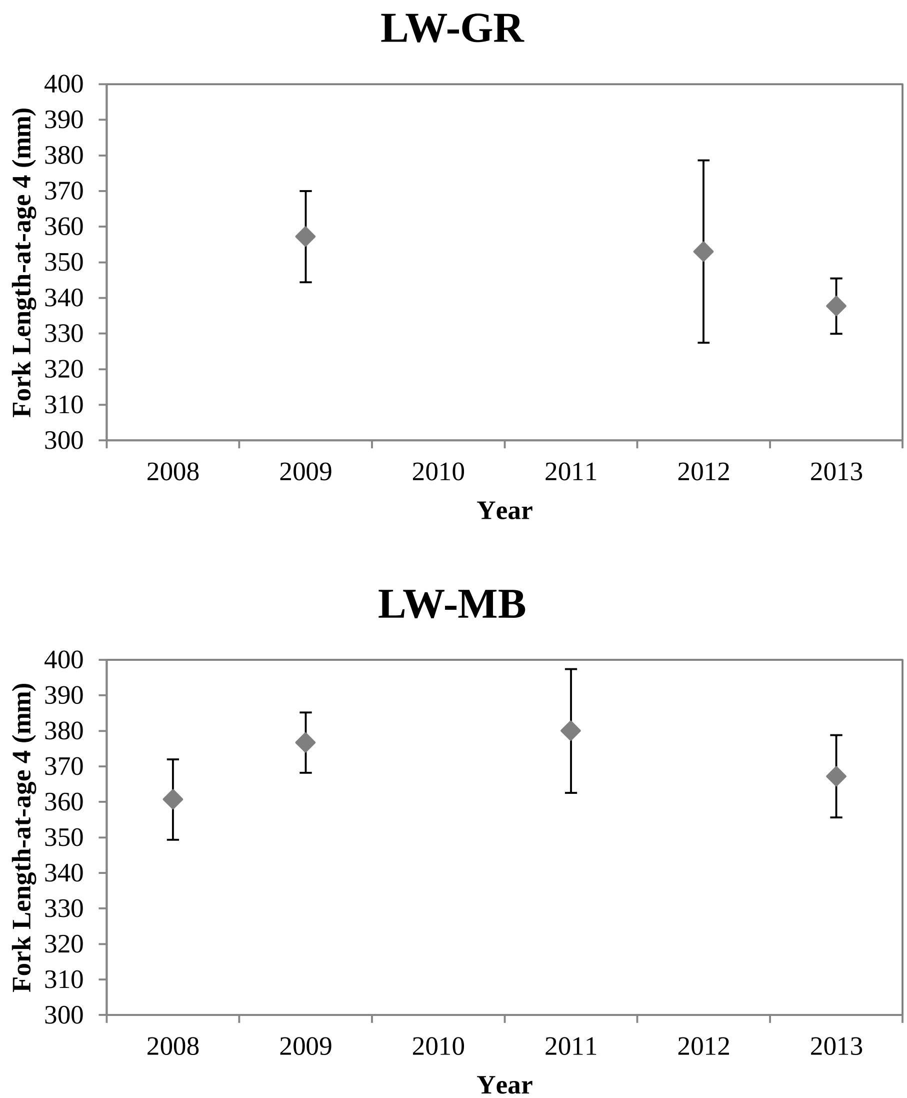


Figure 6-29. Fork length-at-age 4 (mean ± SE) for Lake Whitefish captured in the north basin of Lake Winnipeg. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts, or lack of superscripts, denote no statistically significant difference. There were insufficient data from Sturgeon Bay and Lake Winnipegosis for detailed analysis of this metric.

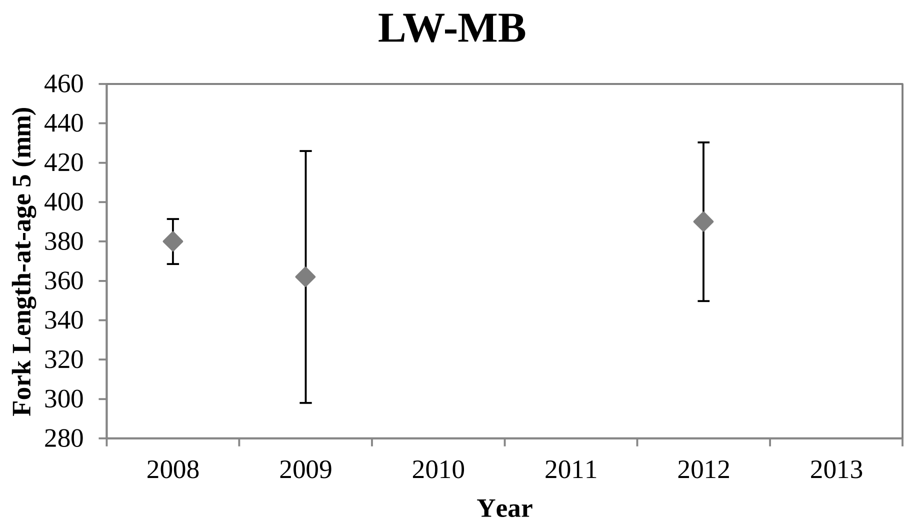


Figure 6-30. Fork length-at-age 5 (mean ± SE) calculated for Lake Whitefish captured in Mossy Bay. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts, or lack of superscripts, denote no statistically significant difference. There were insufficient data from Sturgeon Bay, Grand Rapids, and Lake Winnipegosis for detailed analysis of this metric.

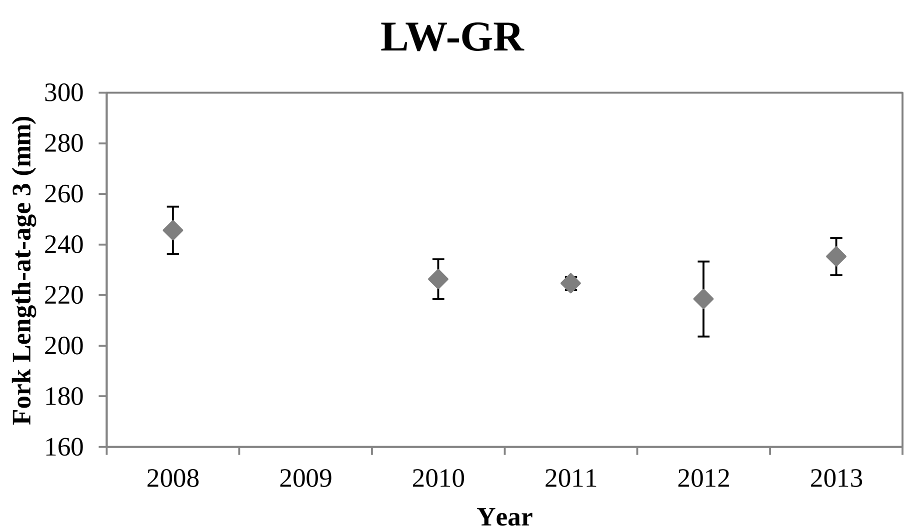


Figure 6-31. Fork length-at-age 3 (mean ± SE) calculated for Sauger captured at annual on- and off-system locations. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts, or lack of superscripts, denote no statistically significant difference. There were insufficient data from Sturgeon Bay, Mossy Bay, and Lake Winnipegosis for detailed analysis of this metric.

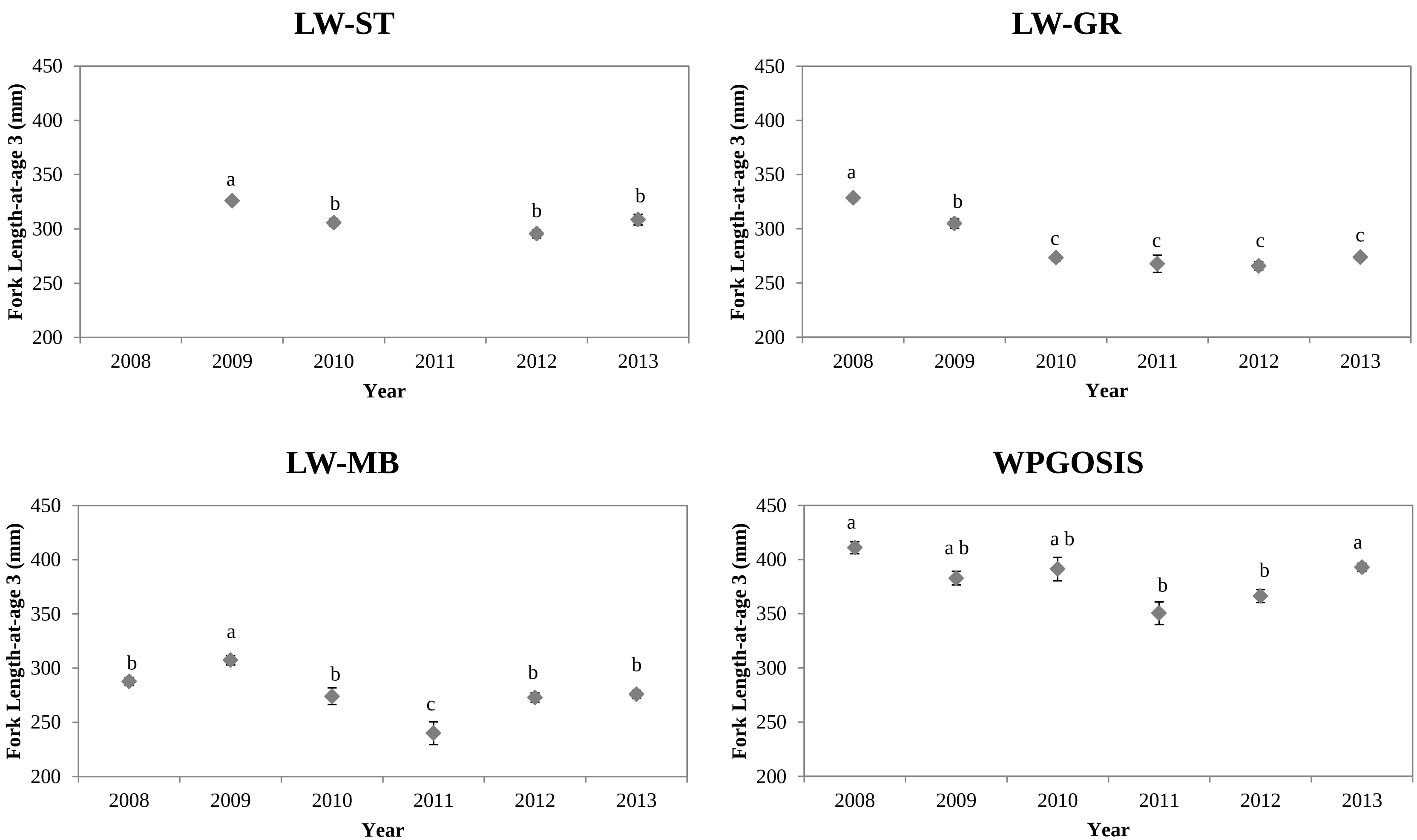


Figure 6-32. Fork length-at-age 3 (mean ± SE) calculated for Walleye captured at annual on- and off-system locations. Different superscripts denote statistically significant differences between groups not sharing the same superscript. Identical superscripts, or lack of superscripts, denote no statistically significant difference.

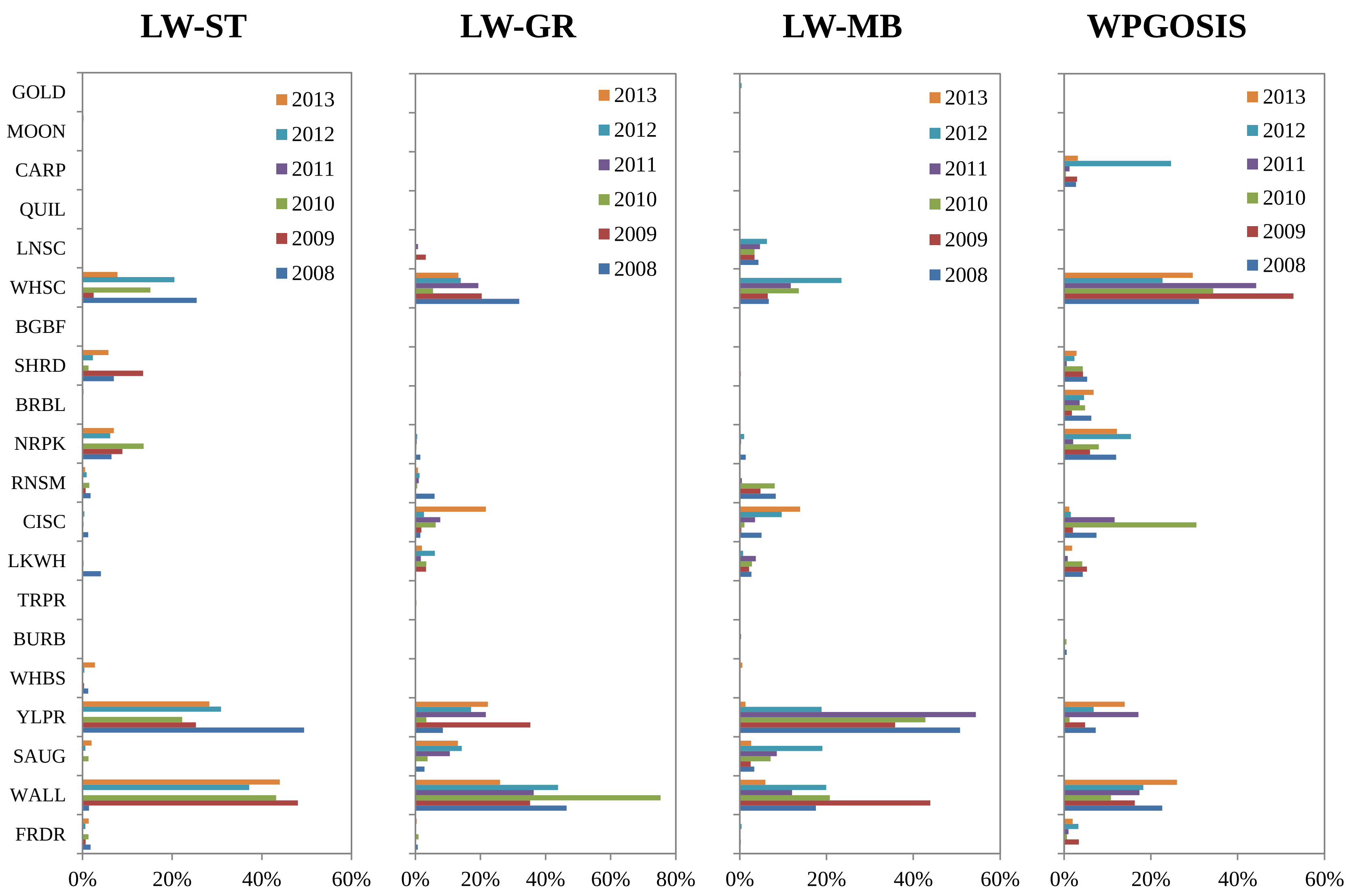


Figure 6-33. Relative abundance of fish species captured in standard gang index gill nets in on-system Lake Winnipeg Region sites and off-system Lake Winnipegosis, 2008-2013. LW-GR axis scale varies from other location.

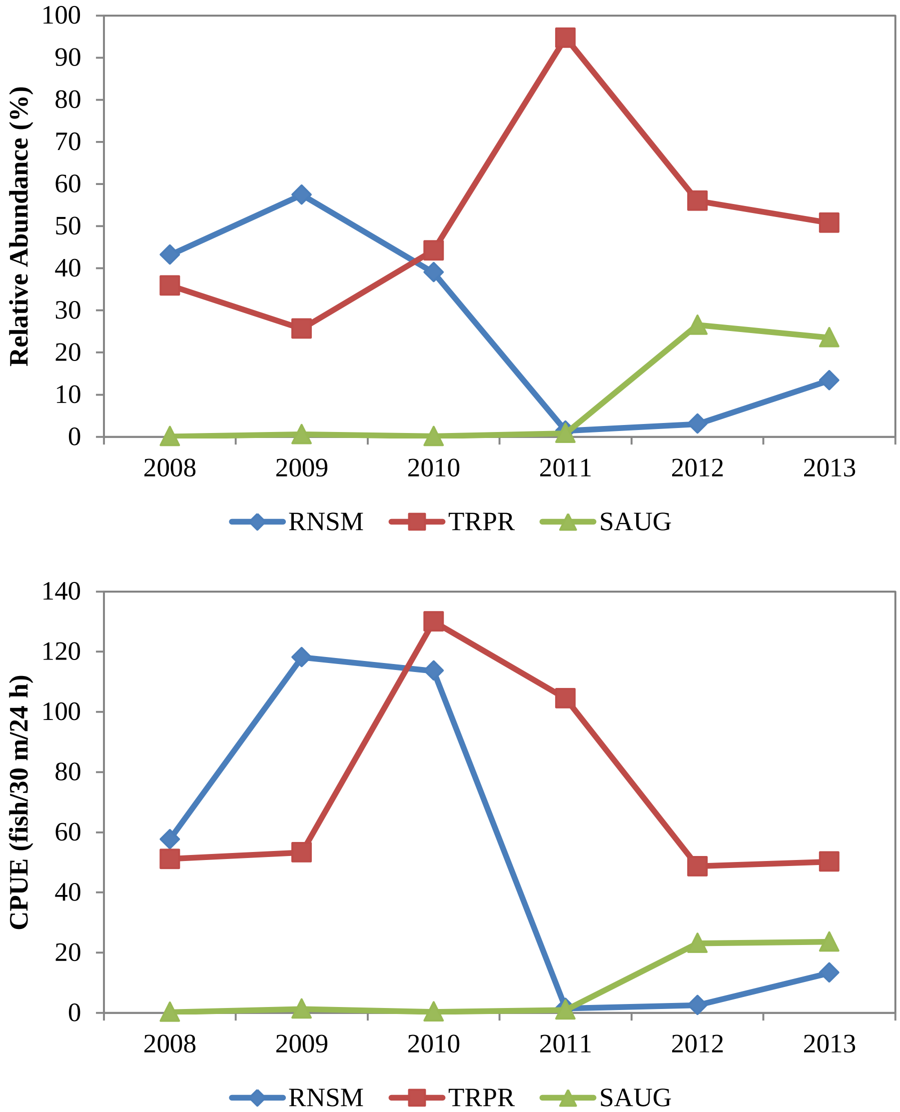


Figure 6-34. Relative abundance and catch-per-unit-effort (CPUE) calculated for Rainbow Smelt, Trout-perch and Sauger from small mesh index gill nets set in Mossy Bay: 2008-2013.

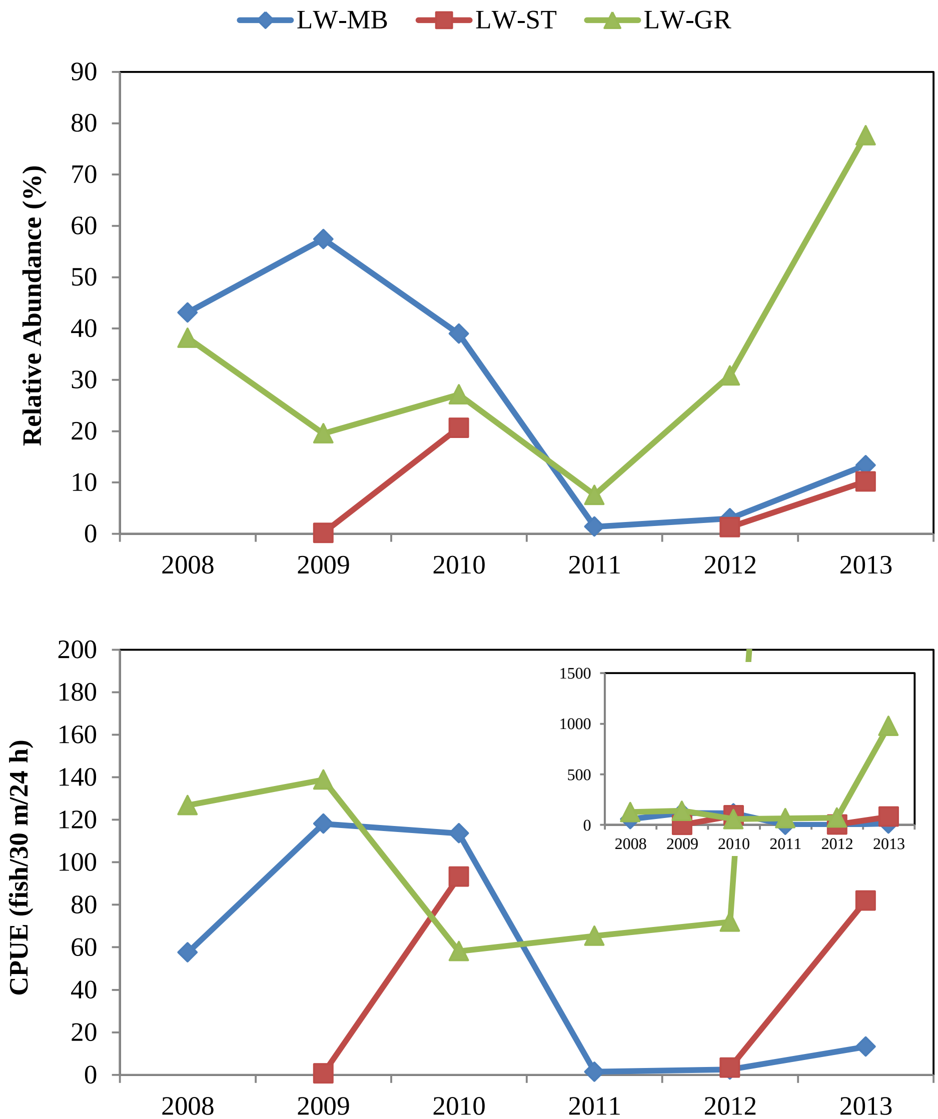


Figure 6-35. Relative abundance and catch-per-unit-effort (CPUE) calculated for Rainbow Smelt from small mesh index gill nets set in the north basin of Lake Winnipeg, 2008-2013.

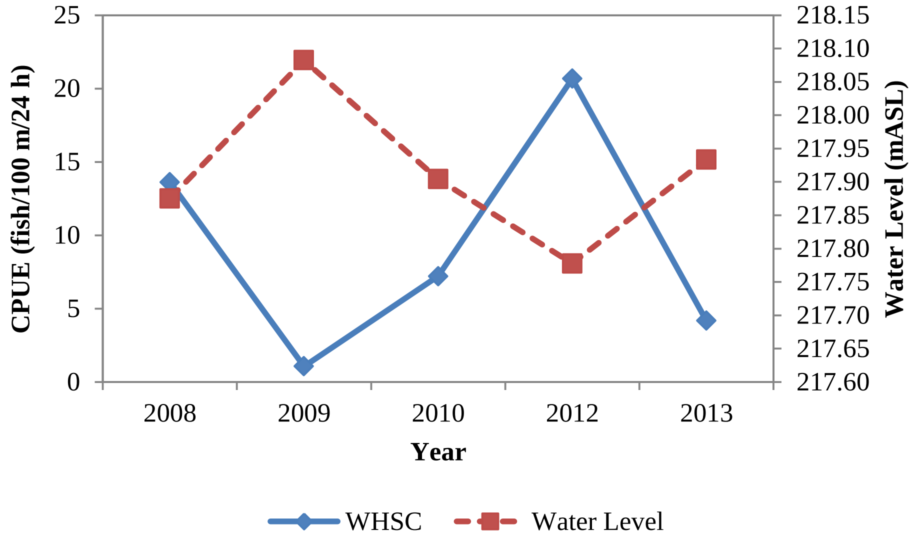


Figure 6-36. Abundance of White Sucker catch in gill nets set in Lake Winnipeg – Sturgeon Bay as measured by CPUE in relation to the average water level in Lake Winnipeg during the gillnetting period: 2008-2013.

7.0 FISH MERCURY

7.1 INTRODUCTION

The following provides an overview of the results of fish mercury monitoring conducted in the LKWPGR under CAMP in the first six years of the program. Fish mercury sampling was conducted on a three-year rotation (2010 and 2013) at Mossy Bay in Lake Winnipeg, the only waterbody sampled in this region.

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 pike, 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 Lake Winnipeg

A total of 213 fish were analyzed for mercury from Mossy Bay in Lake Winnipeg from 2010 to 2013 (Table 7-1). Sample sizes of Walleye and Lake Whitefish were generally at or near the sample size target of 36 fish in 2010 and 2013. In contrast, numbers of Northern Pike and Yellow Perch sampled were low throughout the program, except in 2013 when 17 pike were captured (Table 7-1).

Mean length-standardized mercury concentrations for Lake Whitefish (all years), Walleye (all years), and Northern Pike (2013) were below the 0.5 parts per million (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; Table 7-1). The sample size for Northern Pike (n = 2) was insufficient to derive length-standardized mercury concentration in 2010 and 2011. However, no fish sampled from Mossy Bay from 2010 to 2013 had a mercury concentration greater than 0.5 ppm (Figure 7-1).

7.2.2 Off-system Waterbodies

Mercury in fish was not analysed in an off-system waterbody in the LKWPGR.

7.2.3 Temporal Comparisons

Walleye and Lake Whitefish were the only species for which sample sizes were adequate to facilitate inter-annual comparisons. Length-standardized mercury concentrations in Walleye were highly consistent between years. Conversely, length-standardized mercury concentrations were significantly higher in Lake Whitefish in 2013 (Table 7-1; Figure 7-2). This difference may reflect the higher mean size and age of fish in 2013 than previous years (Table 7-2).

7.3 SUMMARY

Mean length-standardized concentrations for the target species were below the 0.5 ppm Health Canada standard for commercial marketing of fish in Canada and the Manitoba aquatic life tissue residue guideline for human consumers. Further, no fish sampled from Mossy Bay from 2010 to 2013 had a mercury concentration greater than 0.5 ppm. Although the length-standardized mean concentration of mercury in Lake Whitefish muscle was higher in 2013 than 2010 or 2011, concentrations remained well below the 0.5 ppm standard.

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 captured in the Lake Winnipeg Region: 2010-2013.

Waterbody	Year	Species	n	Mercury Concentration (ppm)			
				Arithmetic Mean	SE	Standard Mean	95% CL
Lake Winnipeg – Mossy Bay	2010	Pike	2	0.223	0.039	NS	-
		Walleye	36	0.117	0.010	0.112	0.100 - 0.125
		Whitefish	32	0.011	0.001	0.012	0.011 - 0.014
	2011	Pike	2	0.240	0.014	NS	-
		Walleye	30	0.092	0.010	0.108	0.089 - 0.132
		Whitefish	20	0.016	0.002	0.018	0.013 - 0.025
	2013	Pike	17	0.252	0.048	0.173	0.124 - 0.240
		Walleye	36	0.085	0.009	0.109	0.096 - 0.124
		Whitefish	36	0.028	0.013	0.028	0.021 - 0.037
		Perch	2	0.009	0.002	-	-

NS = Not significant

Table 7-2. Mean (± standard error, SE) fork length, round weight, condition (K_F), and age of Lake Whitefish, Northern Pike, Walleye, and Yellow Perch sampled for mercury from the Lake Winnipeg Region: 2010-2013.

Waterbody	Year	Species	n	Length (mm)	Weight (g)	K_F	Age (years)
Lake Winnipeg – Mossy Bay	2010	Pike	2	757.0 ± 31.0	3785.0 ± 535.0	0.87 ± 0.02	9.5 ± 1.5
		Walleye	36 [1]	393.1 ± 16.5	971.9 ± 92.8	1.33 ± 0.03	5.1 ± 0.3
		Whitefish	32 [2]	271.6 ± 11.1	312.2 ± 38.6	1.39 ± 0.04	2.4 ± 0.1
	2011	Pike	2	709.0 ± 9.0	2920.0 ± 180.0	0.82 ± 0.02	8.5 ± 0.5
		Walleye	30	313.7 ± 19.9	522.4 ± 89.7	1.17 ± 0.03	4.1 ± 0.4
		Whitefish	20	267.5 ± 15.6	306.8 ± 70.4	1.23 ± 0.05	2.7 ± 0.3
	2013	Pike	17 [3]	688.8 ± 26.2	2829.4 ± 294.9	0.83 ± 0.02	8.6 ± 0.8
		Walleye	36	308.4 ± 16.5	490.7 ± 91.4	1.21 ± 0.02	3.5 ± 0.3
		Whitefish	36 [4]	295.1 ± 13.0	444.3 ± 70.5	1.40 ± 0.02	3.6 ± 0.7
		Perch	2	80.0 ± 8.0	7.2 ± 2.3	1.58 ± 0.15	1.0 ± 0.0

[1] n=33 for age; [2] n=30 for age; [3] n=7 for age; [4] n=35 for weight and K_F and n=33 for age.

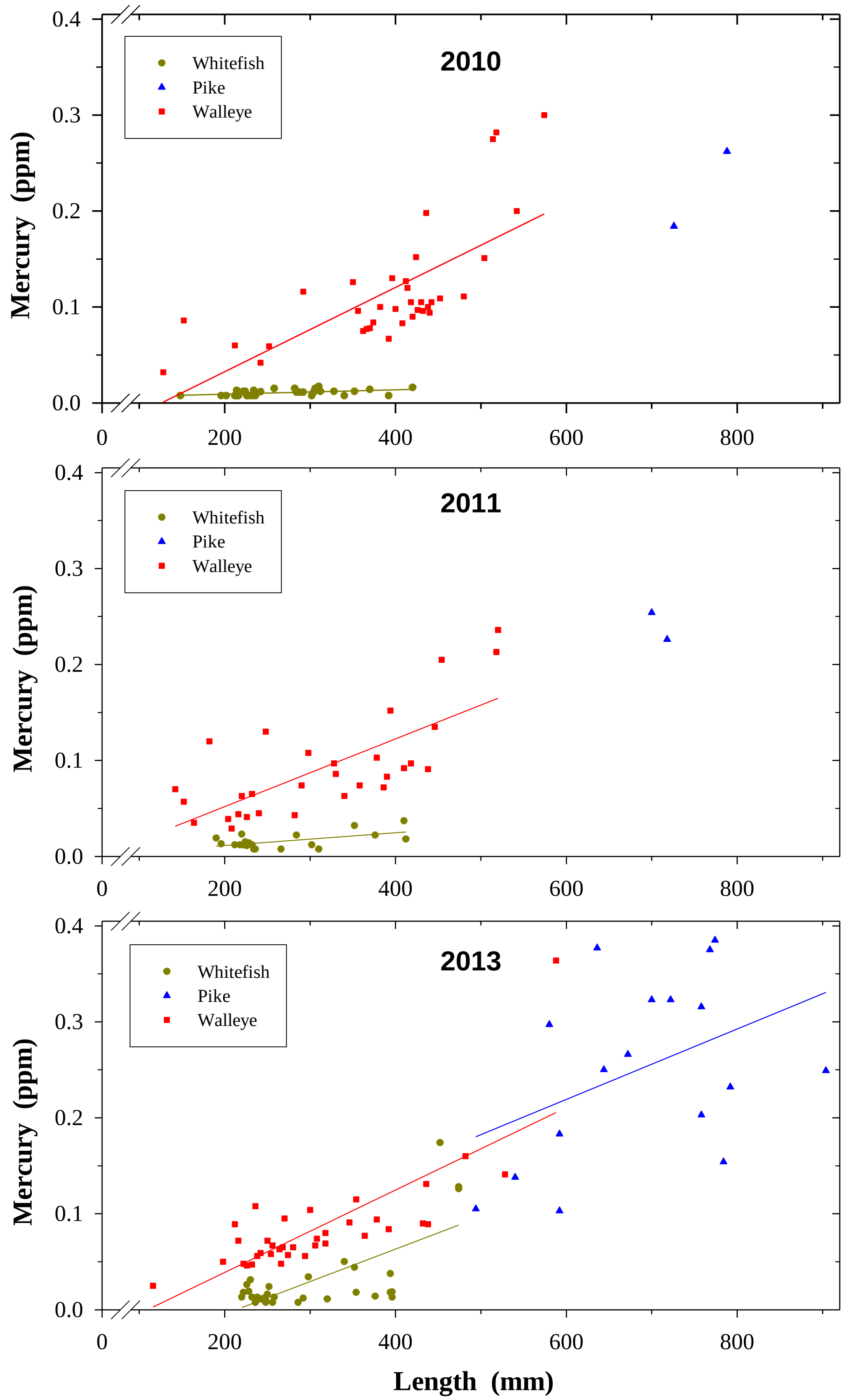
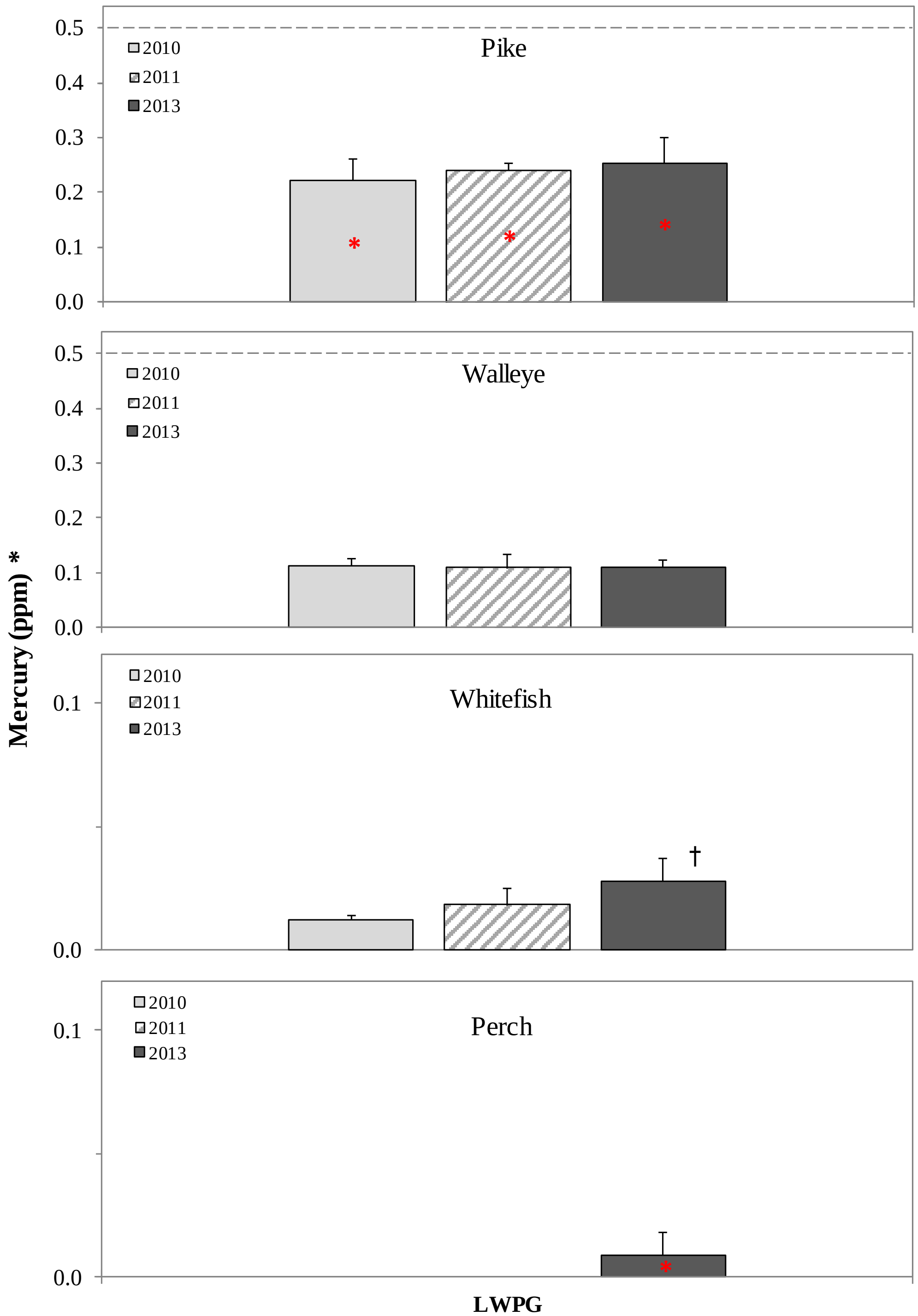


Figure 7-1. Relationship between mercury concentration and fork length for Lake Whitefish, Northern Pike, and Walleye from the Lake Winnipeg – Mossy Bay: 2010-2013. Significant linear regression lines are shown.



* Note differences in scale of the y-axis among species.

Figure 7-2. Standard or arithmetic (asterisk) mean (error bars indicate upper 95% CL) mercury concentrations of Northern Pike, Walleye, Lake Whitefish, and Yellow Perch from the Lake Winnipeg – Mossy Bay: 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.

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