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Sections 6-7: Summary of CAMPP Results; References

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SECTION 6: SUMMARY OF CAMPP RESULTS

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Coordinated Aquatic Monitoring Program (CAMP). 2014. Three Year Summary Report (2008-2010). Report prepared for the Manitoba/Manitoba Hydro MOU Working Group by North/South Consultants Inc., Winnipeg, MB.

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6.0 SUMMARY OF CAMPP RESULTS

The following discussion provides an overview of key results of CAMPP for each of the monitoring components. This discussion is focussed on a subset of metrics (i.e., parameters) within each of the monitoring components, but includes discussion of results for all the CAMPP waterbodies sampled in Years 1-3 of the pilot program. This overview is intended to provide a broad description of key metrics across the study regions (excluding the Lake Winnipeg Region) and to explore general patterns on a larger geographic scale. This analysis was also undertaken to inform the overall design of CAMP and facilitate discussion of potential modifications to the program in the future. As such, this discussion is not intended to be comprehensive and the reader is referred to discussions presented in Section 5 of this report for a detailed description of results of CAMPP.

For the purposes of exploring larger geographical patterns, sites located along the main river systems were grouped and considered separately from off-system sites. Although Granville and Eaglenest lakes are located upstream of Manitoba Hydro's hydraulic system and are designated as off-system waterbodies, they have been included in the on-system waterbody discussions presented below, because they are physically located on the main flow of the upper Churchill and Winnipeg rivers, respectively. These groups were identified to facilitate exploration of trends or relationships in conditions between waterbodies located on the major rivers relative to those uninfluenced by the major rivers.

6.1 HYDROLOGY

The following discussion provides a broad overview of the hydrological conditions that occurred during CAMPP monitoring between 2008 and 2010. The discussion focuses on on-system waterbodies and is intended to summarize the hydrologic conditions within each river system and any effects of Manitoba Hydro's hydroelectric system operations. This analysis was undertaken to assist in drawing relationships between hydrological conditions and observed water quality metrics and biological parameters.

Above average summer precipitation in the Winnipeg River drainage basin in 2008 led to record high Winnipeg River flows in late summer. With near average conditions on the Saskatchewan River also contributing to Lake Winnipeg inflows, the Jenpeg Generating Station (GS) was operated to maximize discharge out of Lake Winnipeg as required by licence. As a result, upper and lower Nelson River flows were well above average in late summer through fall 2008.

In 2008, upper Churchill River flows also peaked well above average in late summer. With the Nelson River already in flood because of a flood on the Winnipeg River, Churchill River

Diversion (CRD) flows were reduced to below average and excess water was spilled at Missi Falls throughout most of August to prevent Southern Indian Lake from exceeding its upper licence limit. As a result, lower Churchill River flows, which were generally slightly below average in 2008, also peaked to well above average in late summer.

An above average snowpack in the Winnipeg River basin in the winter of 2008/2009, combined with wet conditions from the previous summer, led to Winnipeg River flows being well above average to near record highs for much of 2009. Despite below average flows from the Saskatchewan River, Lake Winnipeg water levels rose to the point that the Jenpeg GS had to be operated to maximize discharge out of Lake Winnipeg as required by licence. This led to near record flows on the Nelson River for much of 2009. Similar to conditions in 2008, an above average snowpack led to upper Churchill River flows also peaking in later summer through fall to near record highs. This led to near record high Missi Falls outflows and flows on the lower Churchill River in the second half of 2009 as CRD was again operated at well below average discharges for the summer to avoid accentuating flood conditions on the Nelson River.

A below average snowpack in the winter of 2009/2010 led to below average flows on both the Winnipeg and Saskatchewan Rivers in the spring of 2010. However, persistent rainfall throughout the summer pushed flows to well above average by August on the Winnipeg River and by late September on the Saskatchewan River. These late summer inflow increases raised the level of Lake Winnipeg above the licensed upper regulation limit requiring the Jenpeg GS to maximize discharge out of the lake. Accordingly, the Nelson River followed a similar pattern with below average discharge in the spring followed by a steady rise to well above average by fall and reaching record highs flows entering the winter of 2010/2011.

On the upper Churchill River, a below average snow-pack followed by average levels of precipitation kept flows slightly below average for most of 2010. However, because of high flows in the winter of 2009/2010, which occurred as a result of conditions in 2009, Southern Indian Lake remained near its upper licence limit throughout the winter and as a result there was excess water to be released from the lake during the summer of 2010 despite below average 2010 inflows. For the third year in a row, CRD flows were reduced to below average for part of the summer to alleviate flood conditions on the Nelson River. These events also led to above average discharge from Missi Falls from late summer to early fall resulting in a period of above average flow along lower Churchill River which otherwise experienced below average flow conditions from spring to mid-summer.

6.2 WATER QUALITY

The following discussion provides an overview of water quality results based on a subset of water quality metrics (i.e., parameters) for all the CAMPP waterbodies sampled in Years 1-3 of the pilot program. This overview is intended to provide a broad description of key metrics across the study regions (excluding the Lake Winnipeg Region) and to explore general patterns respecting water quality on a larger geographic scale. This analysis was also undertaken to inform the overall design of the CAMP water quality monitoring program and facilitate discussion of potential modifications to the program in the future. As such, this discussion is not intended to be comprehensive and the reader is referred to discussions presented in Section 5 of this report for a detailed description of results of the CAMPP water quality program.

Summaries of water quality results for each of the regions are presented in Tables 6.2-1 to 6.2-7 and Figures 6.2-1 to 6.2-29. The discussion focuses upon results for on-system waterbodies, which are defined here as waterbodies located along the flow of the major river in each region, and off-system waterbodies, which include Manigotagan, Leftrook, Gauer, Setting, Assean, Walker, and Cormorant lakes and the Hayes River. Although Granville and Eaglenest lakes are designated as off-system waterbodies, they have been included in the on-system waterbody discussion presented below because they are physically located on the main flow of the upper Churchill and Winnipeg rivers, respectively. These groups were identified to facilitate exploration of trends or relationships in water quality conditions between waterbodies located on the major rivers relative to those uninfluenced or less influenced by the major rivers. Walker Lake, an off-system lake monitored under CAMPP, is also considered within the discussion of on-system waterbodies because it is affected by a backwater effect from Cross Lake under certain water levels.

6.2.1 On-System Waterbodies

6.2.1.1 Limnology

Most of the on-system lakes and reservoirs did not stratify or only periodically stratified in the open-water or ice-cover seasons of 2008/2009 to 2010/2011 (Tables 6.2-1 to 6.2-7). On-system waterbodies that exhibited thermal stratification during at least one sampling period included Eaglenest Lake (spring 2010), Cedar Lake (spring 2010), South Moose Lake (winter 2010), Granville Lake (spring 2008), Southern Indian Lake Area 6 (spring 2010), Southern Indian Lake Area 4 (spring and summer 2008/2009), Northern Indian Lake (spring 2008), Notigi Lake-West (spring and summer 2009), Notigi Lake-East (spring 2009), Footprint Lake (spring 2010), and Walker Lake (spring 2010). Where thermal stratification occurred at on-system waterbodies, it was most common in spring, was generally shallow (i.e., close to the water surface), and had typically broken down by the summer sampling period. The exceptions occurred in Notigi, Southern Indian, and Walker lakes, where the depth of the thermocline was high when stratification occurred and/or stratification occasionally persisted into summer.

Most of the on-system waterbodies were well-oxygenated across seasons and dissolved oxygen (DO) concentrations were generally above Manitoba Water Quality Standards, Objectives, and Guidelines (MWQSOGs) for the protection of aquatic life (PAL) throughout the sampling periods. However, several waterbodies developed lower DO concentrations at depth in the ice-cover season. Although DO depletion is generally more pronounced in aquatic systems that are thermally stratified, decreases in DO across depth are not uncommon in north temperate systems that experience long periods of ice cover, even in the absence of thermal stratification, and reflects the lack of atmospheric reaeration due to the physical presence of ice. On-system waterbodies where DO concentrations were below one or more of the MWQSOG PALs during one or more winter sampling periods in 2008/2009 – 2010/2011 included South Moose Lake, Cedar Lake, Footprint Lake, Cross Lake, and Walker Lake[1] (Tables 6.2-1 to 6.2-7). On-system waterbodies maintained DO concentrations above MWQSOG PALs in the open-water seasons across depth even when thermally stratified.

Water clarity, as estimated from Secchi disk depth, of most waterbodies was very low to low based on the Swedish Environmental Protection Agency (Swedish EPA 2000) categorization scheme for lakes (Figure 6.2-1). *In situ* turbidity, specific conductance, and pH were generally similar across depth at the on-system waterbodies over the monitoring period.

6.2.1.2 Routine Parameters

Key routine water quality variables for the seven CAMPP regions (Lake Winnipeg Region is excluded as noted above) are presented in Figures 6.2-2 to 6.2-12 and include total suspended solids (TSS), turbidity, pH, conductivity, true colour, dissolved organic carbon (DOC), hardness, and nitrogen and phosphorus. With the exception of the Saskatchewan River, all waterbodies sampled under CAMPP contained less than 20 mg/L of TSS on average, and most waterbodies had average TSS concentrations less than 10 mg/L (Figure 6.2-2). Patterns for turbidity were similar to those observed for TSS (Figure 6.2-3). Turbidity is typically correlated to TSS, though the specific relationship between these parameters can vary regionally or even among waterbodies. Linear regression analysis between TSS and laboratory turbidity for all on-system waterbodies indicated a significant correlation in general (Figure 6.2-4); however, it is noted that

[1] *One anomalous measurement of DO (4.1 mg/L) collected in Split Lake in summer 2009 was also below MWQSOGs for the protection of aquatic life. This value is considered to be a potential measurement error.*

relationships likely vary amongst the regions and correlations should be explored on a regional basis upon acquisition of additional data.

True colour was highest in the Winnipeg River Region; lakes on the Canadian Shield typically are more coloured than lakes in other regions (Mitchell and Prepas 1990; Figure 6.2-5). Similarly, DOC (i.e., a variable that contributes to water colour) was on average slightly higher in the Winnipeg River Region than other CAMPP regions (Figure 6.2-6).

Waterbodies ranged from soft (Winnipeg River system, lakes on the upper Rat/Burntwood River system, and lakes on the upper Churchill River system) to very hard (Saskatchewan River and South Moose Lake; Figure 6.2-7). Waterbodies sampled under CAMPP were slightly alkaline, with an average pH near 8 (Figure 6.2-8) and pH, was on average, within the MWQSOG PAL (range of 6.5-9.0) at all sites. Laboratory conductivity was higher in waterbodies located along the main flow of the upper and lower Nelson River and along the Saskatchewan River than the other regions (Figure 6.2-9). Conductivity measured along the Nelson River was similar to or lower than the mean level measured in the north basin of Lake Winnipeg (313 mg/L) over the period of 1999-2007 (Environment Canada [EC] and Manitoba Water Stewardship [MWS] 2011).

The highest total phosphorus (TP) concentrations occurred in the Saskatchewan River, the Lake Winnipeg outlet lakes (Playgreen, Little Playgreen, and Cross lakes), the Burntwood River (at the inlet to Split Lake), and sites located along the main flow of the lower Nelson River (Figure 6.2-10). The average phosphorus concentrations exceeded the Manitoba narrative guideline for lakes, ponds, and reservoirs and streams near to the point of entry to these waterbodies (0.025 mg/L) at the on-system sites along the Winnipeg River, the upper and lower Nelson River, and the Burntwood River from Threepoint Lake to Split Lake. The Saskatchewan River was also phosphorus-rich but concentrations of TP decreased downstream in Cedar Lake. Spatial patterns were less clear for total nitrogen (TN), though the lowest average concentrations occurred along the upper and lower Churchill River and along the upper stretches of the Rat/Burntwood River system (Figure 6.2-11). Molar total nitrogen:total phosphorus (TN:TP) ratios indicate all on-system waterbodies were, on average, phosphorus limited (Figure 6.2-12).

Other routine water quality variables for which there are MWQSOGs for PAL, including nitrate/nitrite and ammonia, were consistently within the objectives or guidelines across the CAMPP regions in 2008/2009 through 2010/2011.

Water quality of waterbodies that are more removed from the main flow of the major rivers (i.e., South Moose, Footprint, and Walker lakes and the north basin of Stephens Lake) differed from waterbodies located along the main river flow paths for some parameters. South Moose and

Walker lakes and the north basin of Stephens Lake were characterized by lower concentrations of TSS (Figure 6.2-2), turbidity (Figure 6.2-3), and TP (Figure 6.2-10) and had higher TN:TP ratios (Figure 6.2-12) and Secchi disk depths (Figure 6.2-1) than sites located directly on the main flow of the major rivers. Footprint Lake was harder (Figure 6.2-7), had a higher conductivity (Figure 6.2-9) and TN:TP ratio (Figure 6.2-12) than sites located along the main flow of the Rat/Burntwood River system. For some parameters, water quality of these waterbodies was more similar to off-system waterbodies than those located along the main flow of the major rivers. Overall, these off-current waterbodies have greater water clarity and lower concentrations of substances present in total or in a particulate form.

6.2.1.3 Trophic Status

There are numerous trophic categorization schemes that have been developed for lakes, including those presented in Canadian Council of Ministers of the Environment (CCME 1999; updated to 2013), Organization for Economic Cooperation and Development (OECD 1982), Nürnberg (1996), and Carlson (1977). Trophic categorization schemes vary in terms of the thresholds applied as well as the water quality parameters included in the categorization; parameters that are frequently included are TP, TN, chlorophyll *a*, and Secchi disk depth. Lakes and reservoirs sampled under CAMPP were compared to the trophic categorization schemes indicated in Table 6.2-8.

Trophic status of on-system waterbodies, based on mean open-water season TP concentrations, ranged from mesotrophic to eutrophic (Figures 6.2-13 and 6.2-14). Trophic status of on-system lakes based on chlorophyll *a* as the indicator ranged from oligotrophic to eutrophic (Figures 6.2-15 and 6.2-16). The ranking of trophic status for on-system lakes was somewhat lower using chlorophyll *a* instead of TP as the indicator (Table 6.2-9). Several lakes/reservoirs (Southern Indian Lake – areas 6 and 4, and Partridge Breast, Rat, Notigi East, Threepoint, Playgreen, Little Playgreen, Split and Stephens Lakes and the Limestone Forebay) were ranked with a higher trophic category on the basis of TP than using chlorophyll *a*. Conversely, Cross Lake ranked as eutrophic on the basis of chlorophyll *a* but was categorized as meso-eutrophic on the basis of TP concentration. The latter observation may relate to a particularly high concentration of chlorophyll *a* measured in Cross Lake in September 2008. Collectively, this information suggests that phytoplankton may be more limited or co-limited by factors other than TP (e.g., light, temperature). Regression analysis indicates TP is more closely related to TSS concentrations than to chlorophyll *a* when considering all on-system lakes collectively (Figure 6.2-17).

Trophic categorization of lakes and reservoirs based on TN indicates most on-system lakes rank as mesotrophic, though some lakes fall into the oligotrophic category (i.e., those in the northwestern portion of the province) and one lake (Little Playgreen Lake) ranked as eutrophic (Figures 6.2-18 and 6.2-19). Similar to chlorophyll *a*, trophic categorization based on TN was similar to or lower than the ranking when using TP as the indicator (Table 6.2-9). Lakes/reservoirs located on the upper and lower Churchill River and on the Rat/upper Burntwood River ranked as oligotrophic based on TN, but were ranked as mesotrophic or meso-eutrophic based on TP. Similarly, Playgreen, Split and Stephens (south) Lakes and the Limestone Forebay ranked as eutrophic on the basis of TP but only mesotrophic based on TN. The latter sites also ranked lower using chlorophyll *a* as the indicator. Like TP, TN was only weakly correlated to chlorophyll *a* in on-system lakes and reservoirs (Figure 6.2-20).

There are numerous trophic categorization schemes for lakes which employ Secchi disk depth as a metric (e.g., OECD 1982, Nurnberg 1996, Carlson 1977). These classic trophic categorization schemes are based on the conventional lake paradigm where water clarity is inversely related to trophic status and are founded on the principle that water clarity in lakes is largely a reflection of organic materials, such as phytoplankton, rather than inorganic turbidity. However, relationships between water clarity and productivity or trophic status of riverine lakes and reservoirs typically differ from natural lakes with longer residence times and these conventional categorization schemes do not necessarily apply.

As expected, the use of Secchi disk depth as an indicator of trophic status of on-system lakes and reservoirs was deemed to be inappropriate due to the lack of a relationship between Secchi disk depth and chlorophyll *a* (Figure 6.2-21). Secchi disk depth trophic categorization generally resulted in a higher ranking than generated based on TP, TN, or chlorophyll *a* (Table 6.2-9). On system lakes/reservoirs have relatively low water clarity which is largely a result of inorganic turbidity rather than phytoplankton (Figure 6.2-21) and the application of Secchi disk depth as an indicator of trophic status is inappropriate for these waterbodies.

There are fewer trophic categorization schemes for rivers and streams, though the CCME (1999, updated to 2013) TP trophic categorization scheme is intended to be applied to all freshwater ecosystems, including rivers and streams. Comparison of TP, TN, and chlorophyll *a* concentrations (open-water season means) measured at CAMPP river sites to the trophic categorization schemes presented in Table 6.20-10, indicates that all sites ranked as oligotrophic on the basis of TN and chlorophyll *a* (Table 6.2-11). Conversely, river sites ranked from mesotrophic (lower Churchill River) to eutrophic (Burntwood and Saskatchewan rivers) on the basis of TP (Table 6.2-11).

6.2.1.4 *Escherichia coli*

E. coli was detected at least once in most on-system waterbodies; exceptions occurred in Cedar, South Moose, Walker, and Rat lakes where no detections occurred. When detected, concentrations were generally low and below the Manitoba water quality objective for primary recreation (200 colony forming units [CFU]/100 mL). High concentrations of *E. coli* (i.e., reported as "overgrown") were detected in March 2010 from two sites located along the Burntwood River (Apussigamasi Lake and the Burntwood River at the inlet to Split Lake). As these samples were measured in winter, the Manitoba recreational guideline is not applicable.

6.2.1.5 Metals and Major Ions

The dominant major cation in all CAMPP waterbodies was calcium (Figure 6.2-22). The second most abundant major cation varied between the regions; magnesium was the next most abundant major cation in the Winnipeg River Region, the Upper and Lower Churchill River regions, and the Churchill River Diversion Region. With the exceptions of South Moose and Walker lakes, where magnesium was the second most abundant cation, sodium was the second most abundant major cation at on-system waterbodies located on the Saskatchewan River and upper and lower Nelson River. In addition, the latter waterbodies contained higher concentrations of the four major cations (calcium, magnesium, potassium, and sodium).

Chloride and sulphate varied across the CAMPP sampling regions. Chloride was highest in waterbodies located on the main flow of the Saskatchewan River (i.e., Saskatchewan River and Cedar Lake sites) and the main flow of the upper and lower Nelson River (Figure 6.2-23). Concentrations of chloride measured along the Nelson River system are similar to the mean concentration measured in the north basin of Lake Winnipeg from 1999-2007 (19 mg/L; EC and MWS 2011), indicating the source is primarily the outflow of Lake Winnipeg. Mean concentrations for all other regions were less than 5 mg/L of chloride. All concentrations of chloride were well below the CCME (1999, updated to 2013) long-term PAL water quality guideline (120 mg/L) in waterbodies of these seven regions (there is no Manitoba PAL guideline for chloride). Chloride is a naturally occurring substance but may be anthropogenically increased in aquatic environments through activities such as logging, de-icing of roadways and infrastructure, and from wastewaters. The CCME (1999; updated to 2013) reported that chloride concentrations are typically < 5 mg/L in northern lakes of the Canadian prairie provinces but high levels occur in some southern areas of these provinces.

Sulphate was also highest in the Saskatchewan River and Upper and Lower Nelson River regions (Figure 6.2-24). However, unlike chloride, sulphate was also higher in lakes located off the main flow of the Saskatchewan and lower Nelson rivers (i.e., South Moose Lake and Stephens Lake-

North) than in waterbodies from other CAMPP regions. Like chloride, sulphate concentrations measured along the Nelson River are similar to those measured recently in the north basin of Lake Winnipeg (28 mg/L; EC and MWS 2011), indicating the lake outflow rather than local inputs is the primary source of this compound. Although there is currently no Manitoba or CCME PAL guideline for sulphate, all measurements of sulphate were below the British Columbia Ministry of Environment (BCMOE) guidelines which range from 128 to 429 mg/L for waters ranging from soft to very hard (Meays and Nordin 2013).

Up to 38 metals were analysed in water samples collected under CAMPP over the three year pilot program. Metals that were never detected at any of the on-system CAMPP waterbodies were beryllium, bismuth, and tellurium. Most metals for which there are MWQSOGs for PAL, including arsenic, boron, cadmium, chromium, copper, molybdenum, nickel, thallium, uranium, and zinc, were within the objectives or guidelines at all on-system sites during all sampling periods.

Two metals, aluminum and iron, were above the MWQSOGs for PAL in most on-system waterbodies during at least one sampling period; the exceptions were South Moose and Walker lakes, where there were no exceedances of MWQSOGs for PAL for any metal (Tables 6.2-1 to 6.2-7). The mean concentration of aluminum measured in most on-system waterbodies was more than twice the MWQSOG for PAL (0.1 mg/L) and, in some waterbodies (Apussigamasi Lake and the Burntwood River at Split Lake), mean concentrations were an order of magnitude or more above the PAL guideline (Figure 6.2-25). The mean concentrations of iron exceeded the PAL guideline (0.3 mg/L) in the Saskatchewan River, Southern Indian Lake (areas 1 and 6), several sites along the Churchill River Diversion (Rat, Threepoint, Footprint, and Apussigamasi lakes), and all sites sampled in the Lower Nelson River Region (Figure 6.2-26). Both aluminum and iron are relatively abundant elements (iron and aluminum are the third and fourth most abundant elements in the earth's crust, respectively) and elevated concentrations have been reported in 'pristine' environments, including waterbodies in Manitoba (e.g., Ramsey 1991).

Other metals for which there are MWQSOGs for PAL, including lead, mercury, selenium, and silver exceeded the PAL objectives or guidelines in at least one waterbody and one sampling period. Lead slightly exceeded the chronic PAL objective in Southern Indian Lake (area 1) in spring and summer 2009, though was consistently within PAL objectives in the other two sampling areas of the lake (areas 4 and 6). Selenium and silver were occasionally at or slightly higher than the PAL guidelines in several on-system waterbodies. Specifically, selenium was at or higher than the guideline (0.001 mg/L) in Lac du Bonnet (8% of samples), the lower Churchill River (9% of samples), Northern Indian Lake (8% of samples), the lower Nelson River (8% of samples), Granville Lake (25% of samples), Partridge Breast Lake (25% of samples), and

Southern Indian Lake Area 4 (17% of samples). Similarly, silver was at or slightly above the PAL guideline (0.0001 mg/L) in the Burntwood River (13% of samples), Lac du Bonnet (25% of samples), and Notigi Lake East and West (25% of samples at each site). However, the analytical DLs for silver and selenium are equivalent to the PAL guidelines. As noted in Section 5, measurements that are at or near analytical detection limits (DLs) are associated with relatively high uncertainty and there is low confidence that an actual exceedance of a PAL guideline has occurred when the measurement is at or near the DL.

Mercury was above the current MWQSOG for PAL (0.000026 mg/L) in a single sample collected in the Burntwood River. However, as previously discussed (see Section 5), the Manitoba water quality guideline for mercury was revised in 2011 and most samples collected under CAMPP in 2008/2009 through 2010/2011 were analysed using an analytical DL that was higher than the new PAL guideline. Therefore, most of the results could not be compared to the current PAL guideline.

Concentrations of metals were generally lower in South Moose and Walker lakes, and the north basin of Stephens Lake, than in waterbodies located along the main flow of the rivers. These waterbodies/areas are more removed from the main flow of the Saskatchewan, upper Nelson, and lower Nelson rivers, respectively, and contained lower concentrations of TSS; in general, waterbodies with higher concentrations of TSS contain higher concentrations of metals that are bound to or contained in suspended materials.

6.2.2 Off-system Waterbodies

Off-system waterbodies monitored under CAMPP are inherently different from on-system waterbodies due to differences in lake morphometry, drainage basin size, hydrology, etc. Thus, differences in the water quality and limnology of off-system and on-system waterbodies were anticipated.

6.2.2.1 Limnology

With the exception of Assean Lake, all off-system lakes developed thermal stratification and exhibited DO concentrations below one or more of the MWQSOGs for PAL during at least one sampling period. These lower DO events generally occurred under ice-cover conditions, though DO concentrations occasionally dropped below MWQSOGs for PAL in some open-water periods when thermal stratification occurred.

6.2.2.2 Routine Parameters

Off-system waterbodies were clearer (as demonstrated by lower TSS and turbidity and higher Secchi disk depths; Figures 6.2-1 to 6.2-3) than on-system waterbodies located along the main river flow. Similar to on-system waterbodies, TSS and turbidity were significantly correlated for all off-system waterbodies considered collectively (Figure 6.2-4).

Some off-system waterbodies were less phosphorus-rich than neighbouring on-system waterbodies; these included Manigotagan, Cormorant, Setting, and Assean lakes and the Hayes River (Figure 6.2-10). Concentrations of TP were similar in Gauer and Leftrook lakes to the neighbouring on-system waterbodies. Conversely, with the exception of Cormorant Lake, TN concentrations were either similar to or higher in off-system waterbodies relative to neighbouring on-system sites (Figure 6.2-11). Molar TN:TP ratios indicate that, on average, all waterbodies (on- and off-system) were phosphorus limited (Figure 6.2-12); however, TN:TP ratios were generally higher in off-system waterbodies relative to neighbouring on-system waterbodies, indicating stronger phosphorus limitation.

TP and TN were significantly correlated to chlorophyll *a* for off-system lakes, though the correlations were weak (Figure 6.2-28 and 6.2-29). Unlike on-system lakes and reservoirs, TP was not significantly correlated to TSS in the off-system waterbodies (Figure 6.2-28). Also unlike the on-system lakes and reservoirs, off-system lakes exhibited a significant, though weak, negative correlation between Secchi disk depth and chlorophyll *a* (Figure 6.2-27). Collectively this information suggests that the conventional lake paradigms respecting trophic status and trophic variables may be more applicable to off-system waterbodies.

6.2.2.3 Trophic Status

Trophic status, based on TP as the indicator, of most of the off-system lakes was similar to the trophic status of neighbouring on-system lakes and reservoirs despite the generally lower TP concentrations (Table 6.2-9 and Figure 6.2-13). The notable exception was the Lower Nelson River Region, where the trophic status of the off-system lake (Assean Lake; mesotrophic/meso-eutrophic) was notably lower than on-system lakes and reservoirs (eutrophic).

Conversely, trophic status of off-system lakes based on chlorophyll *a* varied in relation to neighbouring on-system waterbodies. Some waterbodies yielded the same trophic ranking (e.g., Manigotagan Lake), some a lower trophic ranking (e.g., Cormorant Lake), and others a higher trophic ranking than at least some of the adjacent on-system waterbodies (e.g., Leftrook Lake; Table 6.2-9). Trophic rankings based on TN were relatively similar between on- and off-system waterbodies (Tables 6.2-9 and 6.2-11), though Gauer Lake was ranked higher (mesotrophic) than on-system waterbodies of the Upper or Lower Churchill River regions.

The trophic status of the single off-system river included in CAMPP (Hayes River) was consistent with the neighbouring lower Nelson River based on TP, TN, and chlorophyll *a* (Table 6.2-11).

6.2.2.4 Escherichia coli

E. coli was detected at a low frequency in Assean, Setting, and Gauer lakes (≤ 25% of samples) but was detected more frequently in the Hayes River (63% of samples). *E. coli* was not detected in the remaining off-system waterbodies. When detected, concentrations were less than 10 CFU/100 mL and, therefore, well below the Manitoba water quality objective for primary recreation (200 CFU/100 mL).

6.2.2.5 Metals and Major Ions

Of the major cations, calcium was the most abundant, followed by magnesium, in all off-system waterbodies (Figure 6.2-22). Dissolved chloride (Figure 6.2-23) and sulphate (Figure 6.2-24) were notably lower in off-system waterbodies relative the neighbouring on-system waterbodies in the Saskatchewan River, Upper Nelson, and Lower Nelson River regions. Conversely, chloride and sulphate were similar between on- and off-system waterbodies in the Winnipeg River, Churchill River Diversion, Upper Churchill, and Lower Churchill River regions. Like the on-system waterbodies, all concentrations of chloride were well below the CCME (1999, updated to 2013) long-term PAL water quality guideline (120 mg/L) and the BCMOE guidelines which range from 128 to 429 mg/L for waters ranging from soft to very hard (Meays and Nordin 2013) at off-system sites.

Of the 38 metals analysed in surface water samples collected under CAMPP over the three year pilot program, six (beryllium, bismuth, cesium, mercury, tellurium, and thallium) were never detected at any of the off-system waterbodies. Most metals for which there are MWQSOGs for PAL, including arsenic, boron, cadmium, chromium, lead, mercury, molybdenum, nickel, thallium, uranium, and zinc, were within the objectives or guidelines at all off-system sites during all sampling periods. However, exceedances of at least one PAL objective or guideline for metals occurred in at least one sample in all off-system waterbodies except Gauer and Leftrook lakes.

In general, off-system waterbodies contained lower concentrations of metals, lower detection frequencies for metals, and lower frequencies of exceedances of PAL objectives or guidelines for metals than on-system waterbodies. However, aluminum and iron were above guidelines in some off-system waterbodies, as typically observed at on-system sites. Aluminum exceeded the PAL guideline (0.1 mg/L) in some samples from the Hayes River (55%), Setting Lake (83%), Assean Lake (88%), and Manigotagan Lake (42%) and the mean concentrations in Setting and Assean lakes and the Hayes River were above the PAL guideline (Figure 6.2-25). Iron only exceeded the PAL guideline in the Hayes River (36%) and Assean Lake (50%), and mean concentrations were below the PAL guideline in all off-system waterbodies (Figure 6.2-26).

Other metals for which there are MWQSOGs for PAL, including copper, selenium, and silver, exceeded the PAL objectives or guidelines in at least one waterbody and one sampling period. Copper exceeded the PAL chronic objective in one sample collected from the Hayes River in fall 2010 and selenium and silver were occasionally at or slightly higher than the PAL guidelines in several off-system waterbodies. Specifically, selenium was higher than the guideline (0.001 mg/L) in Manigotagan Lake (8% of samples) and the Hayes River (9% of samples), and silver was at the guideline (0.0001 mg/L) in one sample from Setting Lake (8% of samples) and was approximately four times the guideline in one sample from the Hayes River (9% of samples). As noted in Section 6.2.1.5, the analytical DLs for these metals are equivalent to the PAL guidelines and these exceedances may reflect analytical limitations.

Table 6.2-1. Water quality summary: Winnipeg River Region.

Metric		Waterbody			
		Eaglenest Lake	Pointe du Bois Forebay	Lac du Bonnet	Manigotagan Lake
Thermal Stratification	(Y/N)	Yes (spring 2010)	No	No	Yes (spring, summer, fall 2008, 2010; summer and fall 2009)
TP - Whole year	(mg/L)	0.026	0.025	0.028	0.023
TP - Open-water season	(mg/L)	0.025	0.024	0.027	0.020
TP Trophic Status - Whole year	-	Meso-eutrophic	Meso-eutrophic	Meso-eutrophic	Mesotrophic/Meso-eutrophic
TP Trophic Status - Open-water season	-	Meso-eutrophic	Meso-eutrophic	Meso-eutrophic	Meso-eutrophic
TN - Whole year	(mg/L)	0.41	0.43	0.48	0.54
TN - Open-water season	(mg/L)	0.36	0.41	0.45	0.50
TN Trophic Status - Whole year	-	Mesotrophic	Mesotrophic	Mesotrophic	Mesotrophic
TN Trophic Status - Open-water season	-	Mesotrophic	Mesotrophic	Mesotrophic	Mesotrophic
Secchi Disk Depth	(m)	1.59	1.46	1.07	1.63
DO Lower than MWQSOGs for PAL	(Y/N)	No	No	No	Yes (fall and winter each year)
Conductivity	(µmhos/cm)	90.6	93.0	97.2	72.6
TSS	(mg/L)	2.3	3.2	3.9	<2
DOC	(mg/L)	11.0	10.2	10.5	13.7
Hardness	(mg/L)	42.5	43.5	46.3	36.7
pH	-	7.86	7.86	7.89	7.84
Metals > MWQSOGs for PAL	-	Al, Fe	Al, Fe	Al, Fe, Se, Ag	Al, Se
Chlorophyll *a* - Whole year	(µg/L)	3.24	4.29	4.26	4.04
Chlorophyll *a* - Open-water season	(µg/L)	4.22	5.15	5.42	5.03
Chlorophyll *a* Trophic Status - Whole year	-	Mesotrophic	Mesotrophic	Mesotrophic	Mesotrophic
Chlorophyll *a* Trophic Status - Open-water season	-	Mesotrophic	Mesotrophic	Mesotrophic	Mesotrophic

Table 6.2-2. Water quality summary: Saskatchewan River Region.

Metric		Waterbody			
		Saskatchewan River	South Moose Lake	Cedar Lake -Southeast	Cormorant Lake
Thermal Stratification	(Y/N)	No	Yes (winter 2010)	Yes (spring 2010)	Yes (spring 2008; spring and summer 2010)
TP - Whole year	(mg/L)	0.042	0.017	0.019	0.011
TP - Open-water season	(mg/L)	0.050	0.018	0.019	0.012
TP Trophic Status - Whole year	-	Eutrophic	Mesotrophic	Mesotrophic	Mesotrophic
TP Trophic Status - Open-water season	-	Eutrophic	Mesotrophic	Mesotrophic	Mesotrophic
TN - Whole year	(mg/L)	0.57	0.50	0.42	0.37
TN - Open-water season	(mg/L)	0.57	0.49	0.36	0.38
TN Trophic Status - Whole year	-	Oligotrophic	Mesotrophic	Mesotrophic	Mesotrophic
TN Trophic Status - Open-water season	-	Oligotrophic	Mesotrophic	Mesotrophic	Mesotrophic
Secchi Disk Depth	(m)	0.4	2.2	2.1	3.9
DO Lower than MWQSOGs for PAL	(Y/N)	No	Yes (at depth; winter 2009/10)	Yes (at depth; winter 2010/11)	Yes (at depth; winter 2009/10 and 2010/11; summer 2010)
Conductivity	(µmhos/cm)	435	360	397	300
TSS	(mg/L)	58.2	2.2	<2	<2
DOC	(mg/L)	8.9	7.2	6.0	6.9
Hardness	(mg/L)	187	186	171	163
pH	-	8.22	8.42	8.40	8.46
Metals > MWQSOGs for PAL	-	Al, Fe	-	Al	Al, Ag[1]
Chlorophyll *a* - Whole year	(µg/L)	2.91	3.68	5.97	1.56
Chlorophyll *a* - Open-water season	(µg/L)	3.63	4.57	7.61	1.68
Chlorophyll *a* Trophic Status - Whole year	-	Oligotrophic	Mesotrophic	Mesotrophic	Oligotrophic
Chlorophyll *a* Trophic Status - Open-water season	-	Oligotrophic	Mesotrophic	Mesotrophic	Oligotrophic

[1] results was at or near the analytical detection limit

Table 6.2-3. Water quality summary: Upper Churchill River Region.

Metric		Waterbody				
		Granville Lake	Southern Indian Lake-Area 1	Southern Indian Lake-Area 6	Southern Indian Lake-Area 4	Gauer Lake
Thermal Stratification	(Y/N)	Yes (spring 2008)	No	Yes (spring 2010)	Yes (spring and summer 2008/2009)	Yes (spring 2008)
TP - Whole year	(mg/L)	0.018	0.021	0.024	0.016	0.019
TP - Open-water season	(mg/L)	0.019	0.023	0.026	0.015	0.020
TP Trophic Status - Whole year	-	Mesotrophic	Meso-eutrophic	Meso-eutrophic	Mesotrophic	Mesotrophic
TP Trophic Status - Open-water season	-	Mesotrophic	Meso-eutrophic	Meso-eutrophic	Mesotrophic	Mesotrophic/ Meso-eutrophic
TN - Whole year	(mg/L)	0.35	0.28	0.34	0.30	0.41
TN - Open-water season	(mg/L)	0.33	0.21	0.33	0.25	0.39
TN Trophic Status - Whole year	-	Oligotrophic	Oligotrophic	Oligotrophic	Oligotrophic	Mesotrophic
TN Trophic Status - Open-water season	-	Oligotrophic	Oligotrophic	Oligotrophic	Oligotrophic	Mesotrophic
Secchi Disk Depth	(m)	1.42	0.97	0.58	1.48	1.94
DO Lower than MWQSOGs for PAL	(Y/N)	No	No	No	No	Yes (at depth; winter 2008)
Conductivity	(µmhos/cm)	82	73	93	120	153
TSS	(mg/L)	3.93	3.85	5.45	2.53	2.57
DOC	(mg/L)	7.51	7.48	7.24	7.07	8.64
Hardness	(mg/L)	37	36	44	60	80
pH	-	7.78	7.80	7.92	8.09	8.14
Metals > MWQSOGs for PAL	-	Al, Se	Al, Fe, Pb	Al, Fe	Al, Se	-
Chlorophyll *a* - Whole year	(µg/L)	3.46	2.70	1.31	2.01	4.40
Chlorophyll *a* - Open-water season	(µg/L)	3.98	3.43	1.65	2.44	5.54
Chlorophyll *a* Trophic Status - Whole year	-	Mesotrophic	Mesotrophic	Oligotrophic	Oligotrophic	Mesotrophic
Chlorophyll *a* Trophic Status - Open-water season	-	Mesotrophic	Mesotrophic	Oligotrophic	Oligotrophic	Mesotrophic

Table 6.2-4. Water quality summary: Lower Churchill River Region.

Metric		Waterbody				
		Partridge Breast Lake	Northern Indian Lake	Billard Lake	Lower Churchill River	Hayes River
Thermal Stratification	(Y/N)	No	Yes (spring 2008)	No	No	No
TP - Whole year	(mg/L)	0.018	0.018	0.017	0.018	0.018
TP - Open-water season	(mg/L)	0.015	0.018	0.017	0.019	0.020
TP Trophic Status - Whole year	-	Mesotrophic	Mesotrophic	Mesotrophic	Mesotrophic	Mesotrophic
TP Trophic Status - Open-water season	-	Mesotrophic	Mesotrophic	Mesotrophic	Mesotrophic	Mesotrophic/ Meso-eutrophic
TN - Whole year	(mg/L)	0.33	0.34	0.33	0.42	0.49
TN - Open-water season	(mg/L)	0.29	0.31	0.30	0.42	0.50
TN Trophic Status - Whole year	-	Oligotrophic	Oligotrophic	Oligotrophic	Oligotrophic	Oligotrophic
TN Trophic Status - Open-water season	-	Oligotrophic	Oligotrophic	Oligotrophic	Oligotrophic	Oligotrophic
Secchi Disk Depth	(m)	1.14	1.78	1.25	1.20[1]	1.56[1]
DO Lower than MWQSOGs for PAL	(Y/N)	No	No	No	No	No
Conductivity	(µmhos/cm)	121	132	131	134	152
TSS	(mg/L)	2.80	2.78	4.35	6.85	11.30
DOC	(mg/L)	6.68	7.78	8.14	7.78	10.25
Hardness	(mg/L)	61	67	64	69	86
pH	-	8.16	8.04	8.28	8.16	8.18
Metals > MWQSOGs for PAL	-	Al, Fe, Se	Al, Fe, Se	Al	Al, Fe, Se	Al, Fe
Chlorophyll *a* - Whole year	(µg/L)	1.50	2.39	2.88	2.93	1.83
Chlorophyll *a* - Open-water season	(µg/L)	1.90	3.02	3.74	3.50	2.20
Chlorophyll *a* Trophic Status - Whole year	-	Oligotrophic	Oligotrophic	Mesotrophic	Oligotrophic	Oligotrophic
Chlorophyll *a* Trophic Status - Open-water season	-	Oligotrophic	Mesotrophic	Mesotrophic	Oligotrophic	Oligotrophic

[1]n = 2

Table 6.2-5. Water quality summary: Churchill River Diversion Region.

Metric		Waterbody						
		Rat Lake	Notigi Lake -West	Notigi Lake -East	Threepoint Lake	Footprint Lake	Apussigamasi Lake	Leftrook Lake
Thermal Stratification	(Y/N)	No	Yes (spring and summer 2009)	Yes (spring 2009)	No	Yes (spring 2010)	No	Yes (spring and winter 2009/10)
TP - Whole year	(mg/L)	0.022	0.017	0.018	0.026	0.026	0.034	0.026
TP - Open-water season	(mg/L)	0.023	0.015	0.017	0.025	0.026	0.035	0.029
TP Trophic Status - Whole year	-	Meso-eutrophic	Mesotrophic	Mesotrophic	Meso-eutrophic	Meso-eutrophic	Meso-eutrophic	Meso-eutrophic
TP Trophic Status - Open-water season	-	Meso-eutrophic	Mesotrophic	Mesotrophic	Meso-eutrophic	Meso-eutrophic	Meso-eutrophic/ Eutrophic	Meso-eutrophic
TN - Whole year	(mg/L)	0.32	0.35	0.33	0.35	0.54	0.45	0.56
TN - Open-water season	(mg/L)	0.30	0.32	0.30	0.34	0.61	0.43	0.56
TN Trophic Status - Whole year	-	Oligotrophic	Oligotrophic	Oligotrophic	Oligotrophic	Mesotrophic	Mesotrophic	Mesotrophic
TN Trophic Status - Open-water season	-	Oligotrophic	Oligotrophic	Oligotrophic	Oligotrophic	Mesotrophic	Mesotrophic	Mesotrophic
Secchi Disk Depth	(m)	0.83	1.07	1.30	0.60	0.98	0.39	1.77
DO Lower than MWQSOGs for PAL	(Y/N)	No	No	No	No	Yes (at depth; winter 2010/11)	No	Yes (at depth; spring 2010, winters)
Conductivity	(µmhos/cm)	101	98	100	104	168	118	198
TSS	(mg/L)	2.27	1.90	2.40	5.33	5.45	10.10	1.80
DOC	(mg/L)	7.02	7.90	7.85	8.23	9.10	9.20	9.18
Hardness	(mg/L)	47	47	48	49	85	59	104
pH	-	8.12	7.83	7.90	7.99	8.26	8.08	8.26
Metals > MWQSOGs for PAL	-	Al, Fe	Al, Fe, Ag	Al, Ag	Al, Fe	Al, Fe	Al, Fe	-
Chlorophyll *a* - Whole year	(µg/L)	1.27	1.86	1.98	1.49	2.57	2.07	6.01
Chlorophyll *a* - Open-water season	(µg/L)	1.59	2.40	2.57	1.88	3.33	2.70	7.71
Chlorophyll *a* Trophic Status - Whole year	-	Oligotrophic	Oligotrophic	Oligotrophic	Oligotrophic	Mesotrophic	Oligotrophic	Mesotrophic
Chlorophyll *a* Trophic Status - Open-water season	-	Oligotrophic	Oligotrophic	Mesotrophic	Oligotrophic	Mesotrophic	Mesotrophic	Mesotrophic

Table 6.2-6. Water quality summary: Upper Nelson River Region.

Metric		Waterbody				
		Playgreen Lake	Little Playgreen Lake	Cross Lake	Walker Lake	Setting Lake
Thermal Stratification	(Y/N)	No	No	No	Yes (spring 2010)	Yes (spring, summer, fall 2008; and spring and summer 2009)
TP - Whole year	(mg/L)	0.041	0.042	0.040	0.025	0.027
TP - Open-water season	(mg/L)	0.041	0.041	0.033	0.029	0.022
TP Trophic Status - Whole year	-	Eutrophic	Eutrophic	Eutrophic	Meso-eutrophic	Meso-eutrophic
TP Trophic Status - Open-water season		Eutrophic	Eutrophic	Meso-eutrophic	Meso-eutrophic	Meso-eutrophic
TN - Whole year	(mg/L)	0.45	0.66	0.59	0.55	0.54
TN - Open-water season	(mg/L)	0.42	0.71	0.57	0.57	0.51
TN Trophic Status - Whole year		Mesotrophic	Eutrophic	Mesotrophic	Mesotrophic	Mesotrophic
TN Trophic Status - Open-water season		Mesotrophic	Eutrophic	Mesotrophic	Mesotrophic	Mesotrophic
Secchi Disk Depth	(m)	0.81	0.73	1.00	2.53	1.77
DO Lower than MWQSOGs for PAL	(Y/N)	No	No	Yes (at depth; some winters)	Yes (at depth; winter)	Yes (at depth; winter, some summers)
Conductivity	(µmhos/cm)	316.9	312.3	292	138.8	157
TSS	(mg/L)	11.2	9.4	7.8	1.5	2.7
DOC	(mg/L)	8.5	9.6	10.4	10.2	13.8
Hardness	(mg/L)	126.1	117.8	115	72.2	82
pH	-	8.22	8.3	8.16	8.13	8.07
Metals > MWQSOGs for PAL	-	Al, Fe	Al, Fe	Al, Fe	-	Al, Ag
Chlorophyll *a* - Whole year	(µg/L)	5.83	3.57	7.04	3.84	3.33
Chlorophyll *a* - Open-water season	(µg/L)	7.33	4.06	8.96	4.73	4.15
Chlorophyll *a* Trophic Status - Whole year	-	Mesotrophic	Mesotrophic	Mesotrophic	Mesotrophic	Mesotrophic
Chlorophyll *a* Trophic Status - Open-water season	-	Mesotrophic	Mesotrophic	Eutrophic	Mesotrophic	Mesotrophic

Table 6.2-7. Water quality summary: Lower Nelson River Region.

Metric		Waterbody							
		Burntwood River	Split Lake	Stephens Lake -South	Stephens Lake -North	Limestone Forebay	Lower Nelson River	Hayes River	Assean Lake
Thermal Stratification	(Y/N)	No	No	No	No	No	No	No	No
TP - Whole year	(mg/L)	0.037	0.038	0.041	0.023	0.045	0.018	0.018	0.020
TP - Open-water season	(mg/L)	0.038	0.041	0.038	0.015	0.044	0.020	0.020	0.020
TP Trophic Status - Whole year	-	Eutrophic	Eutrophic	Eutrophic	Meso-eutrophic	Eutrophic	Eutrophic	Mesotrophic	Mesotrophic/ Meso-eutrophic
TP Trophic Status - Open-water season	-	Eutrophic	Eutrophic	Eutrophic	Mesotrophic	Eutrophic	Mesotrophic/ Meso-eutrophic	Mesotrophic /Meso-eutrophic	Mesotrophic/ Meso-eutrophic
TN - Whole year	(mg/L)	0.46	0.49	0.53	0.44	0.44	0.55	0.49	0.45
TN - Open-water season	(mg/L)	0.48	0.47	0.50	0.36	0.40	0.56	0.50	0.43
TN Trophic Status - Whole year	-	Oligotrophic	Meso-trophic	Mesotrophic	Mesotrophic	Mesotrophic	Oligotrophic	Oligotrophi c	Mesotrophic
TN Trophic Status - Open-water season	-	Oligotrophic	Meso-trophic	Mesotrophic	Mesotrophic	Mesotrophic	Oligotrophic	Oligotrophi c	Mesotrophic
Secchi Disk Depth	(m)	0.35	0.44	0.43	1.09	0.43	n/a	1.6	0.84
DO Lower than MWQSOGs for	(Y/N)	No	Yes[1]	No	No	No	No	No	No
Conductivity	(µmhos/cm)	122	295	288	266	268	287	152	237
TSS	(mg/L)	18.7	11.2	13.0	5.1	9.7	15.0	11.3	6.8
DOC	(mg/L)	9.3	9.2	8.4	8.5	9.2	8.4	10.2	11.2
Hardness	(mg/L)	65	120	124	124	110	120	86	134
pH	-	8.10	8.27	8.17	8.20	8.19	8.26	8.18	8.34
Metals > MWQSOGs for PAL	-	Al, Fe, Ag[2], Hg[2]	Al, Fe	Al, Fe	Al, Fe	Al, Fe	Al, Fe, Se[2]	Al, Cu, Fe, Se, Ag[2]	Al, Fe
Chlorophyll *a* - Whole year	(µg/L)	1.42	3.47	3.30	1.07	1.79	3.57	1.83	1.63
Chlorophyll *a* - Open-water season	(µg/L)	1.90	4.44	4.20	1.37	2.29	4.72	2.20	1.82
Chlorophyll *a* Trophic Status - Whole year	-	Oligotrophic	Meso-trophic	Mesotrophic	Oligotrophic	Oligotrophic	Oligotrophic	Oligotrophi c	Oligotrophic
Chlorophyll *a* Trophic Status - Open-water season	-	Oligotrophic	Meso-trophic	Mesotrophic	Oligotrophic	Oligotrophic	Oligotrophic	Oligotrophi c	Oligotrophic

[1]summer 2010 across depth - suspected measurement error

[2]measurements were at or near analytical detection limits and are associated with relatively high uncertainty such that there is low confidence that an actual exceedance of a PAL guideline has occurred.

Table 6.2-8. Trophic categorization schemes applied for lakes and reservoirs.

		Ultra-oligotrophic	Oligotrophic	Mesotrophic	Meso-eutrophic	Eutrophic	Hyper-eutrophic	Reference
TP	(mg/L)	<0.004	0.004-0.010	0.010-0.020	0.020-0.035	0.035-0.100	> 0.100	CCME (1999; updated to 2013)
TN	(mg/L)	-	<0.350	0.350-0.650	-	0.651-1200	>1200	Nurnberg (1996)
Chlorophyll *a*	(µg/L)	-	<2.5	2.5-8	-	8-25	>25	OECD (1982)
Secchi Disk Depth	(m)	-	> 6	3-6	-	1.5-3	<1.5	OECD (1982)

Table 6.2-9. Trophic status of CAMPP lakes and reservoirs based on mean open-water season total phosphorus (TP), total nitrogen (TN), and chlorophyll *a* concentrations and Secchi disk depth.

	TP	TN	Chlorophyll *a*	Secchi Disk Depth
Winnipeg River Region				
Eaglenest Lake	Meso-eutrophic	Mesotrophic	Mesotrophic	Eutrophic
Pointe du Bois Forebay	Meso-eutrophic	Mesotrophic	Mesotrophic	Hypereutrophic
Lac du Bonnet	Meso-eutrophic	Mesotrophic	Mesotrophic	Hypereutrophic
Manigotagan Lake	Meso-eutrophic	Mesotrophic	Mesotrophic	Eutrophic
Saskatchewan River Region				
South Moose Lake	Mesotrophic	Mesotrophic	Mesotrophic	Eutrophic
Cedar Lake - Southeast	Mesotrophic	Mesotrophic	Mesotrophic	Eutrophic
Cormorant Lake	Mesotrophic	Mesotrophic	Oligotrophic	Mesotrophic
Upper Churchill River Region				
Granville Lake	Mesotrophic	Oligotrophic	Mesotrophic	Hypereutrophic
Southern Indian Lake - Area 1	Meso-eutrophic	Oligotrophic	Mesotrophic	Hypereutrophic
Southern Indian Lake - Area 6	Meso-eutrophic	Oligotrophic	Oligotrophic	Hypereutrophic
Southern Indian Lake - Area 4	Mesotrophic	Oligotrophic	Oligotrophic	Hypereutrophic
Gauer Lake	Mesotrophic/Meso-eutrophic	Mesotrophic	Mesotrophic	Eutrophic
Lower Churchill River Region				
Partridge Breast Lake	Mesotrophic	Oligotrophic	Oligotrophic	Hypereutrophic
Northern Indian Lake	Mesotrophic	Oligotrophic	Mesotrophic	Eutrophic
Billard Lake	Mesotrophic	Oligotrophic	Mesotrophic	Hypereutrophic
Churchill River Diversion Region				
Rat Lake	Meso-eutrophic	Oligotrophic	Oligotrophic	Hypereutrophic
Notigi Lake - West	Mesotrophic	Oligotrophic	Oligotrophic	Hypereutrophic
Notigi Lake - East	Mesotrophic	Oligotrophic	Mesotrophic	Hypereutrophic
Threepoint Lake	Meso-eutrophic	Oligotrophic	Oligotrophic	Hypereutrophic
Footprint Lake	Meso-eutrophic	Mesotrophic	Mesotrophic	Hypereutrophic
Apussigamasi Lake	Meso-eutrophic/Eutrophic	Mesotrophic	Mesotrophic	Hypereutrophic
Leftrook Lake	Meso-eutrophic	Mesotrophic	Mesotrophic	Eutrophic
Upper Nelson River Region				
Playgreen Lake	Eutrophic	Mesotrophic	Mesotrophic	Hypereutrophic
Little Playgreen Lake	Eutrophic	Eutrophic	Mesotrophic	Hypereutrophic
Cross Lake	Meso-eutrophic	Mesotrophic	Eutrophic	Hypereutrophic
Walker Lake	Meso-eutrophic	Mesotrophic	Mesotrophic	Eutrophic
Setting Lake	Meso-eutrophic	Mesotrophic	Mesotrophic	Eutrophic
Lower Nelson River Region				
Split Lake	Eutrophic	Mesotrophic	Mesotrophic	Hypereutrophic
Stephens Lake - South	Eutrophic	Mesotrophic	Mesotrophic	Hypereutrophic
Stephens Lake - North	Mesotrophic	Mesotrophic	Oligotrophic	Hypereutrophic
Limestone Forebay	Eutrophic	Mesotrophic	Oligotrophic	Hypereutrophic
Assean Lake	Mesotrophic/Meso-eutrophic	Mesotrophic	Oligotrophic	Hypereutrophic

Table 6.2-10. Trophic categorization schemes applied for CAMPP river sites.

Parameter/Metric		Trophic Categories						Reference
		Ultra-oligotrophic	Oligotrophic	Mesotrophic	Meso-eutrophic	Eutrophic	Hyper-eutrophic	
TP	(mg/L)	<0.004	0.004-0.010	0.010-0.020	0.020-0.035	0.035-0.100	> 0.100	CCME (1999; updated to 2013)
TN	(mg/L)	-	<0.7	0.7-1.5	-	>1.5	-	Dodds et al. (1998)
Chlorophyll *a*	(µg/L)	-	<10	10-30	-	>30	-	Dodds et al. (1998)

Table 6.2-11. Trophic status of CAMPP rivers based on mean open-water season total phosphorus (TP), total nitrogen (TN), and chlorophyll *a* concentrations.

	TP	TN	Chlorophyll *a*
Saskatchewan River	Eutrophic	Oligotrophic	Oligotrophic
Lower Churchill River	Mesotrophic	Oligotrophic	Oligotrophic
Burntwood River	Eutrophic	Oligotrophic	Oligotrophic
Lower Nelson River	Mesotrophic/Meso-eutrophic	Oligotrophic	Oligotrophic
Hayes River	Mesotrophic/Meso-eutrophic	Oligotrophic	Oligotrophic

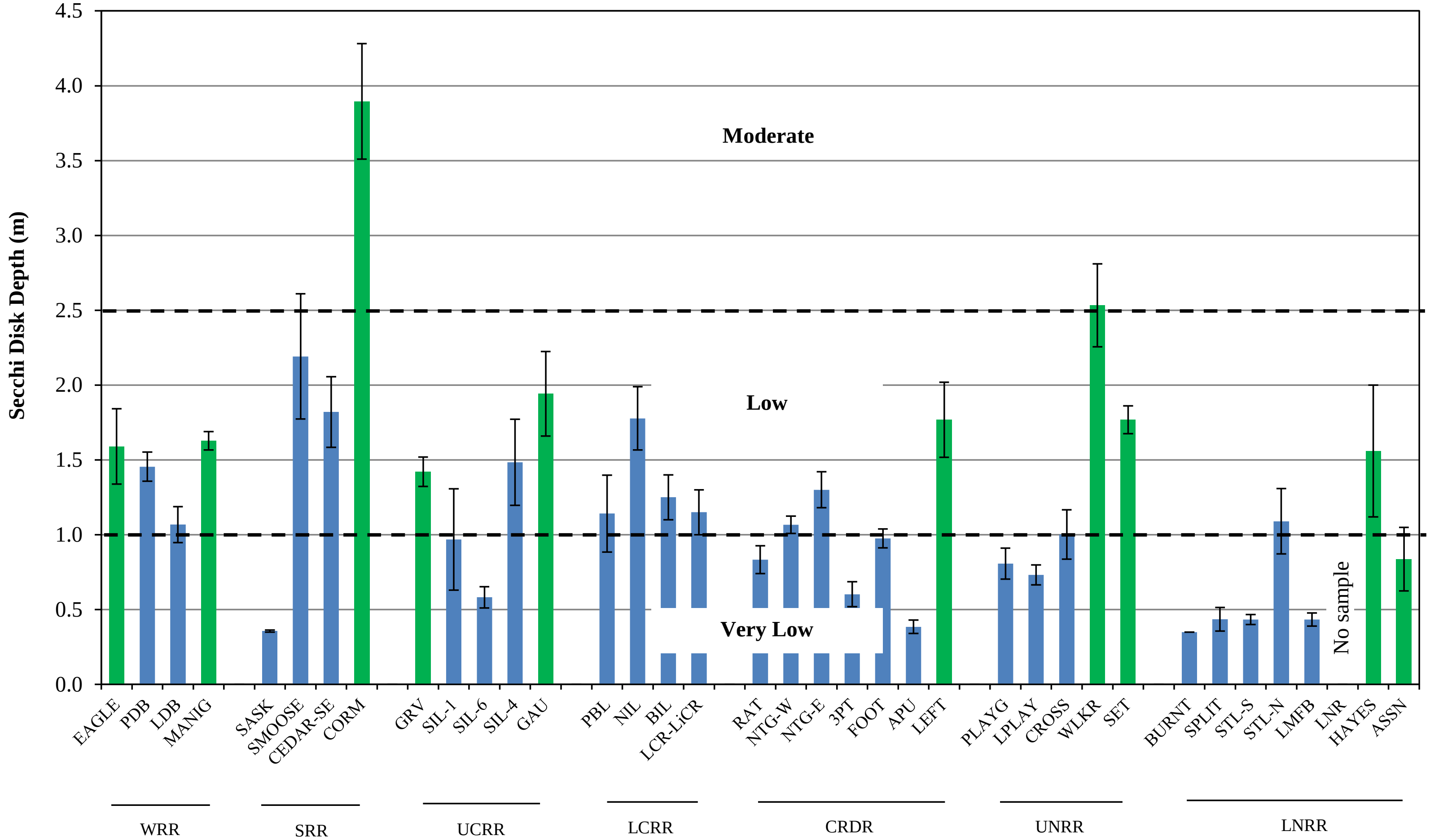


Figure 6.2-1. Mean (±SE) of Secchi disk depths measured across the seven sampling regions (Lake Winnipeg Region excluded) for the open-water season. Off-system waterbodies are indicated in green. WRR = Winnipeg River Region; SRR = Saskatchewan River Region; UCRR = Upper Churchill River Region; CRDR = Churchill River Diversion Region; UNRR = Upper Nelson River Region; and LNRR = Lower Nelson River Region. Water clarity classifications based on Swedish EPA (2000).

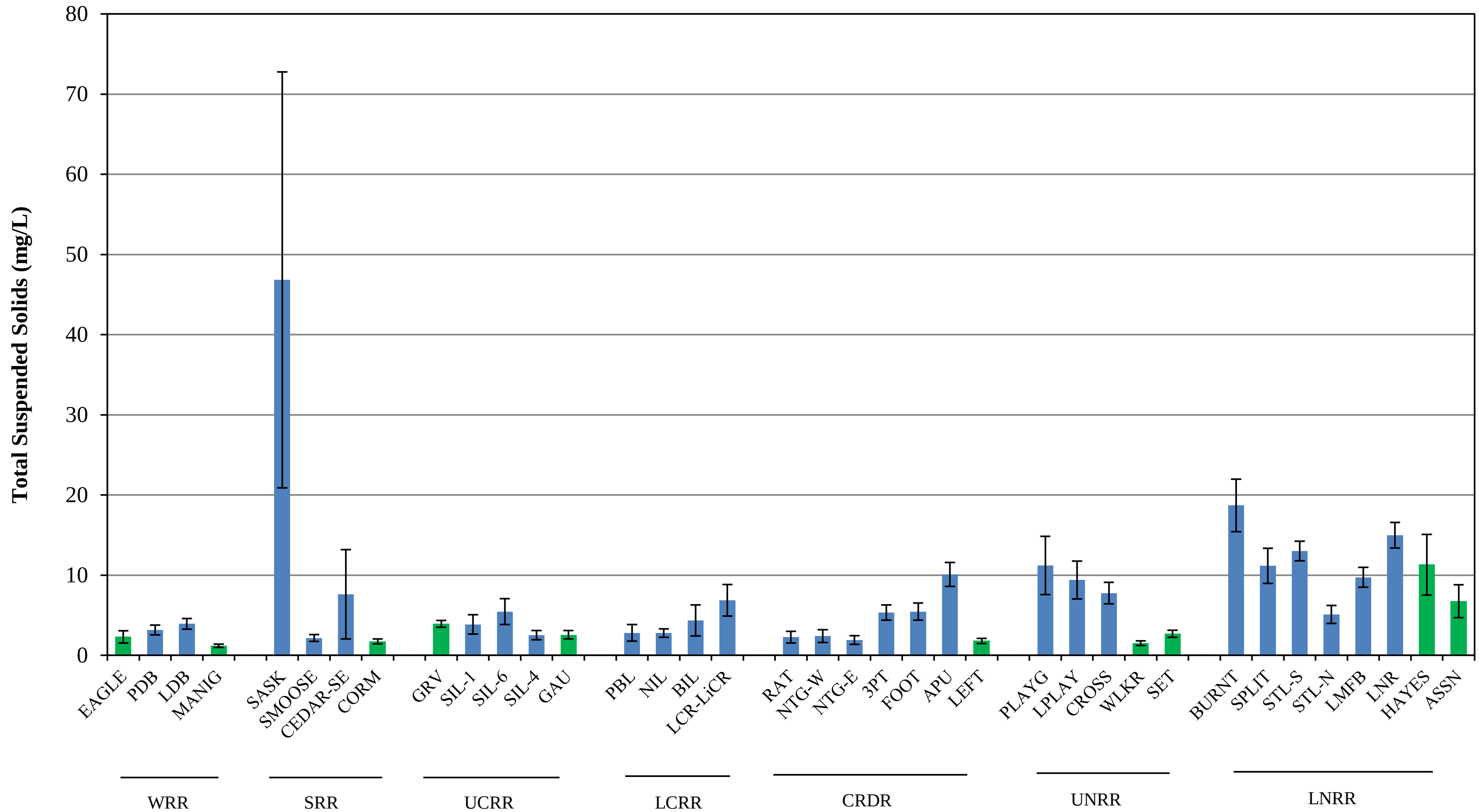


Figure 6.2-2. Mean (±SE) total suspended solids (TSS) concentrations measured in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). Off-system waterbodies are indicated in green.

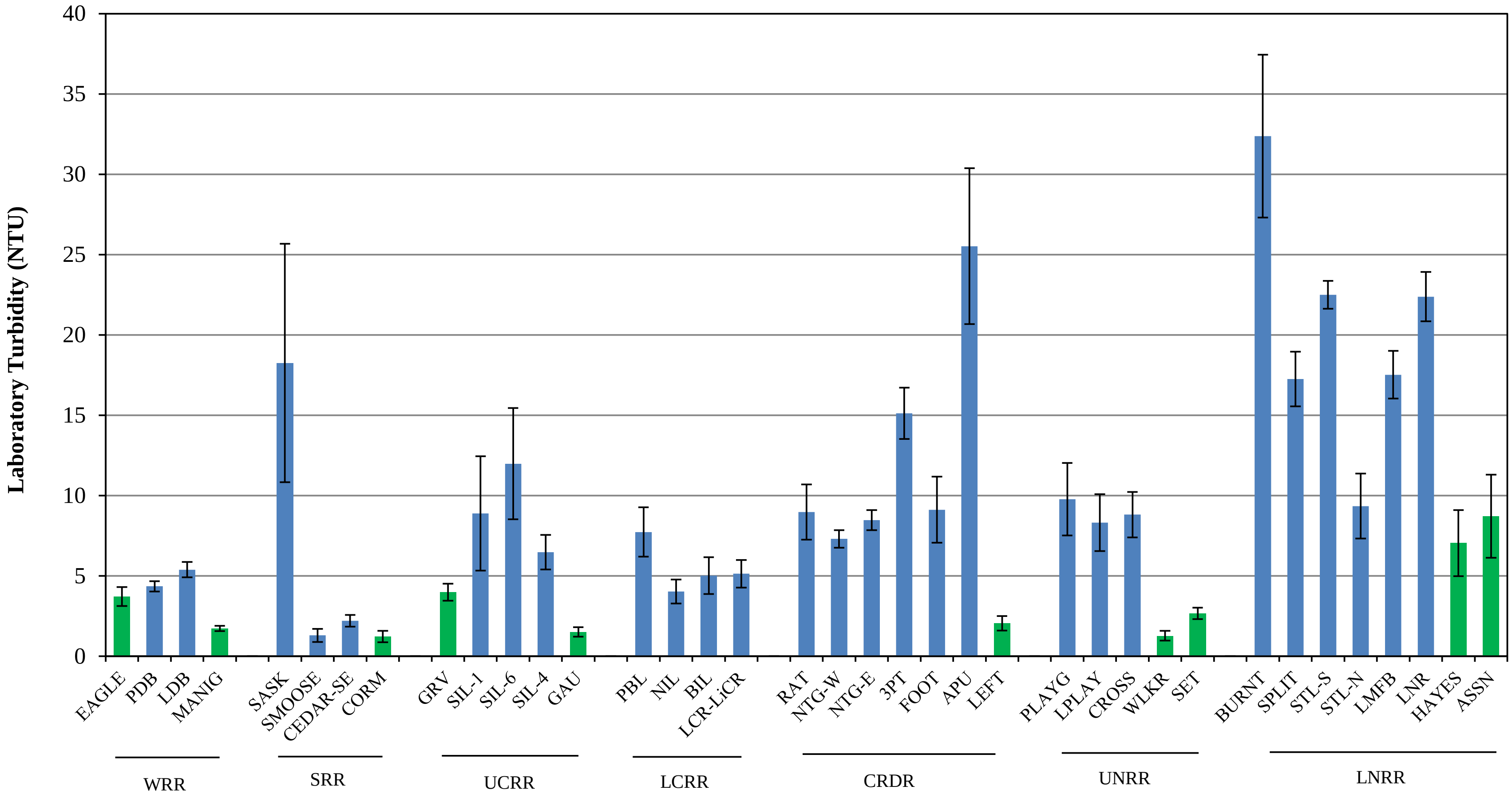
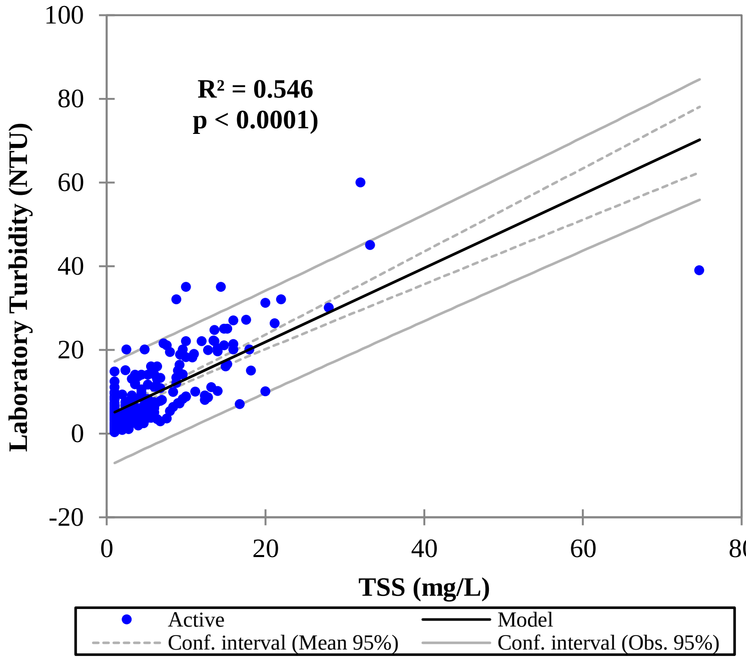


Figure 6.2-3. Mean (±SE) turbidity measured in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). Off-system waterbodies are indicated in green.

(A)



(B)

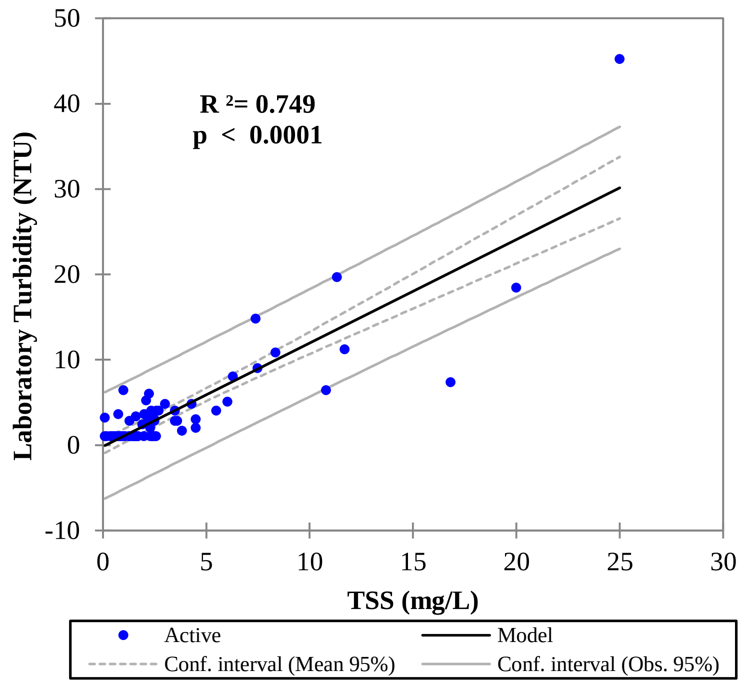


Figure 6.2-4. Linear regressions between total suspended solids (TSS) and laboratory turbidity in: (A) on-system lakes, reservoirs, and rivers across the seven sampling regions (Lake Winnipeg Region excluded), excluding two outliers; and (B) off-system lakes and rivers.

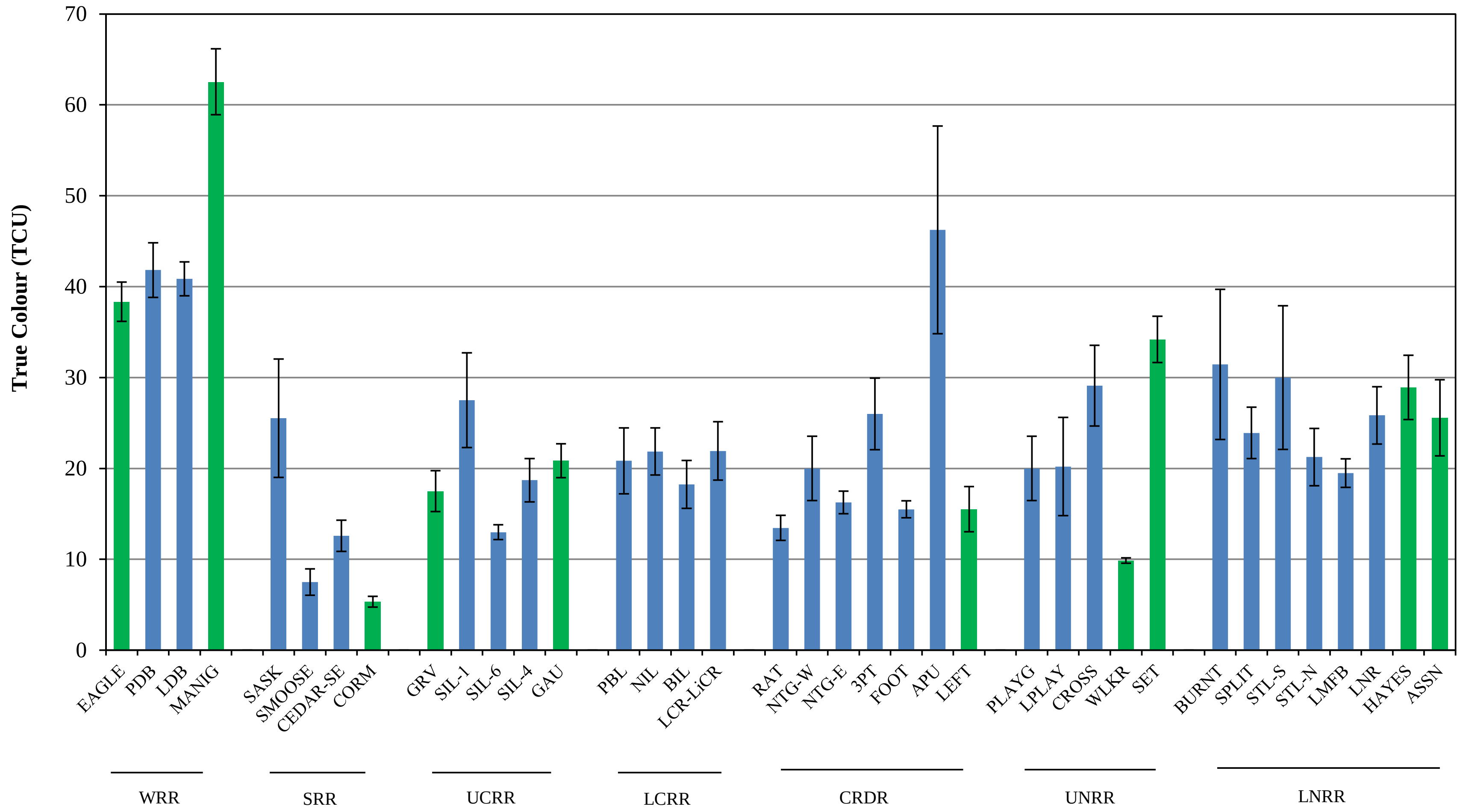


Figure 6.2-5. Mean (±SE) true colour levels measured in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). Off-system waterbodies are indicated in green.

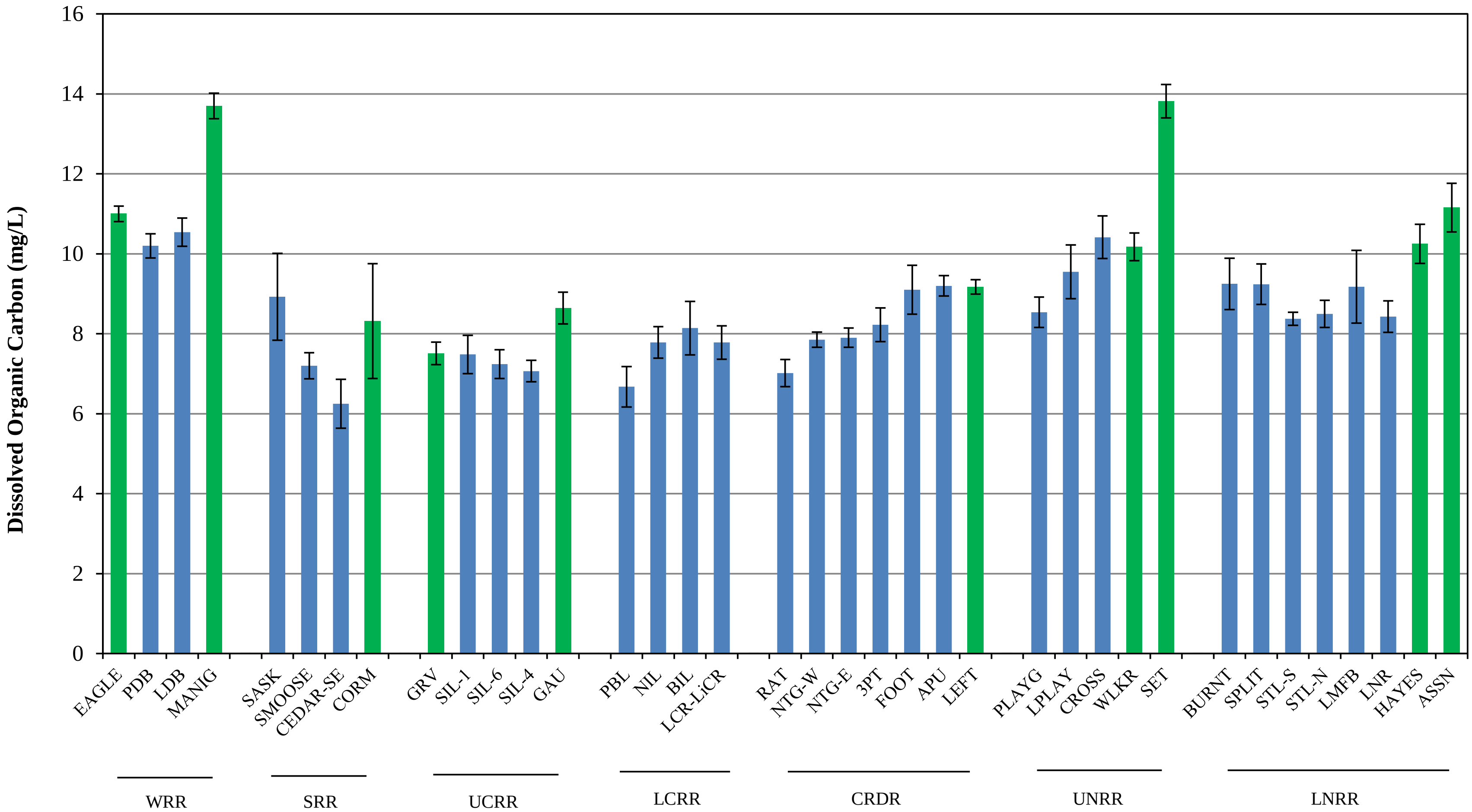


Figure 6.2-6. Mean (±SE) dissolved organic carbon concentrations measured in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). Off-system waterbodies are indicated in green.

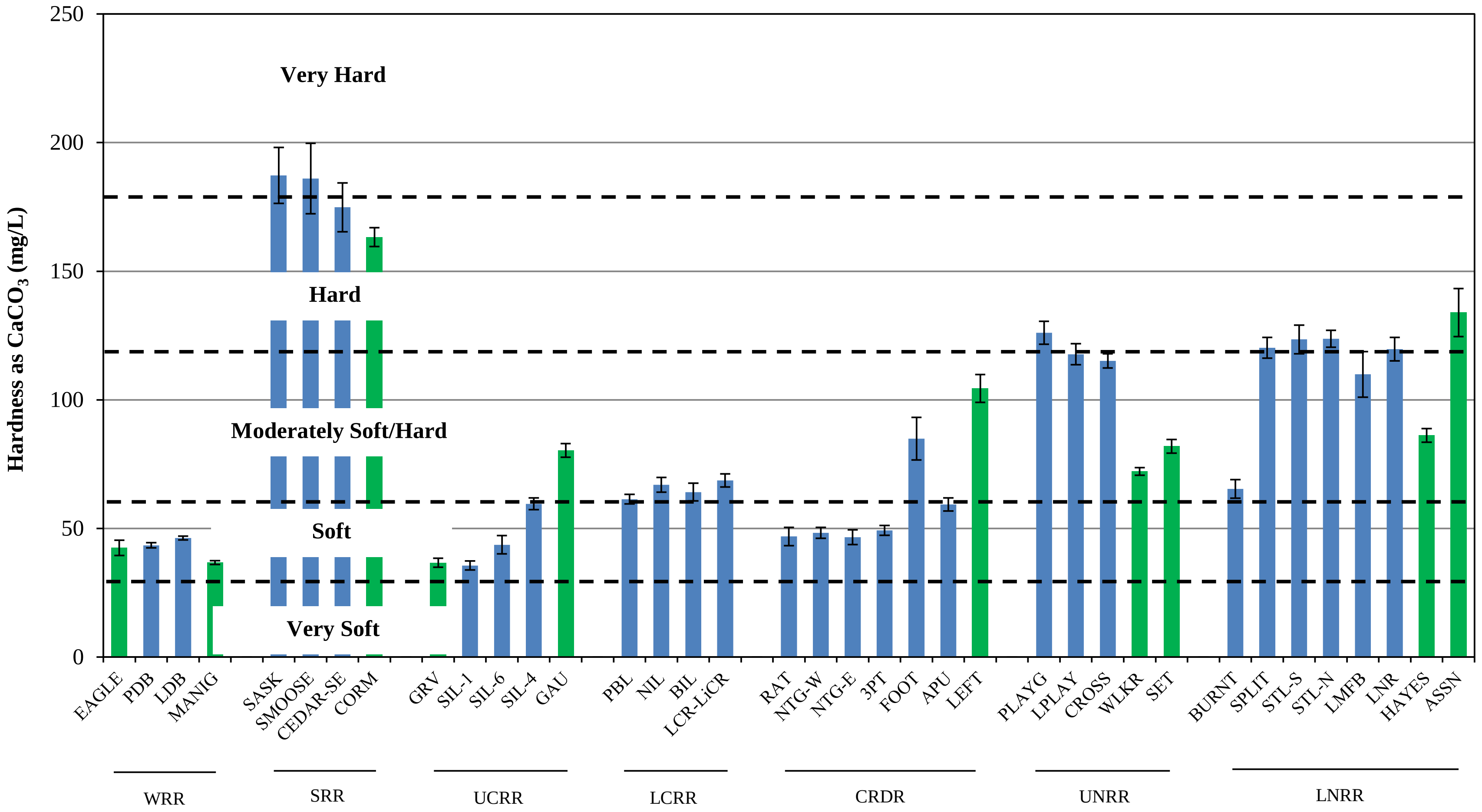


Figure 6.2-7. Mean (±SE) hardness measured in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). Off-system waterbodies are indicated in green.

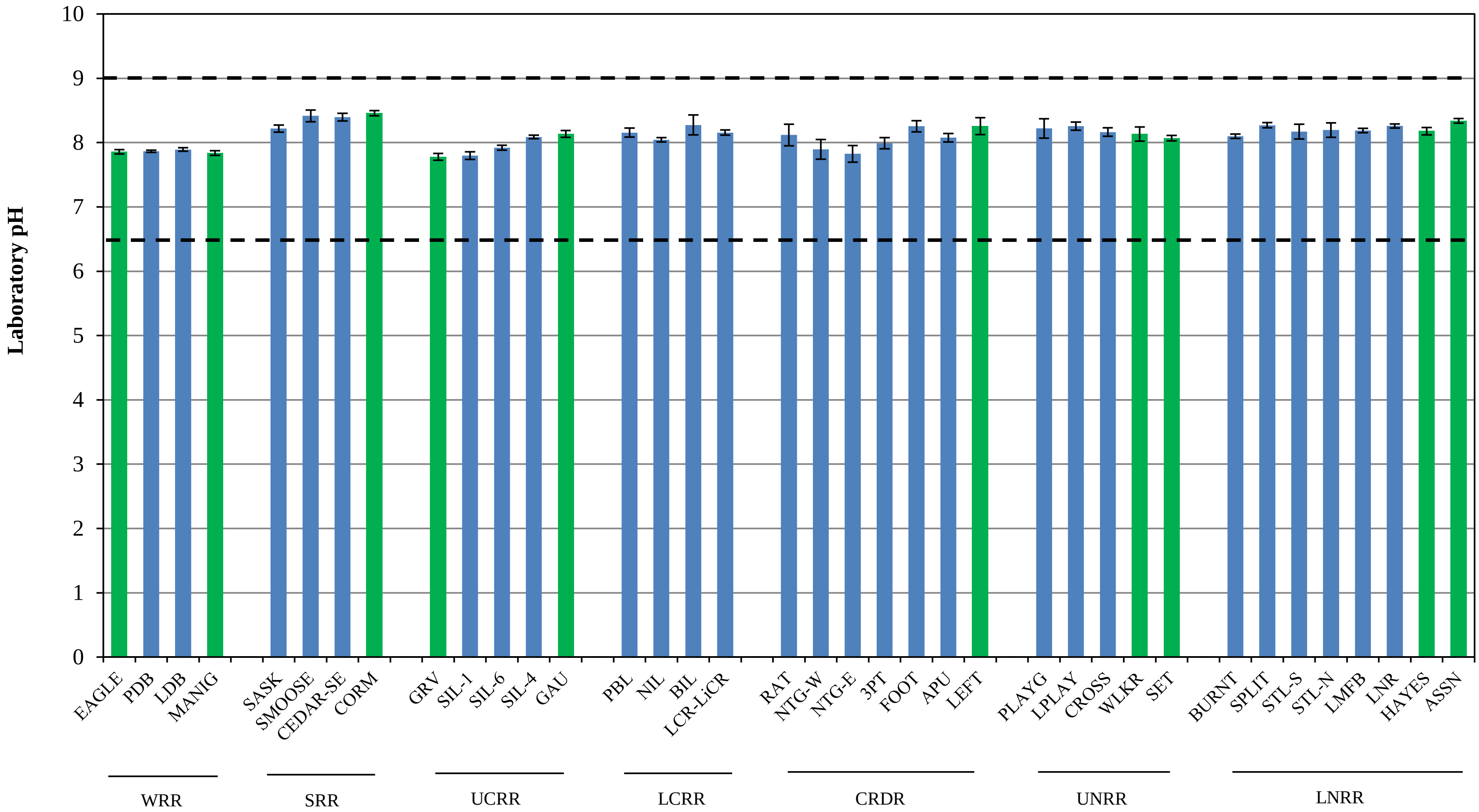


Figure 6.2-8. Mean (±SE) pH (laboratory) measured in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). The Manitoba water quality guideline is the range of pH between the dashed lines (6.5-9). Off-system waterbodies are indicated in green.

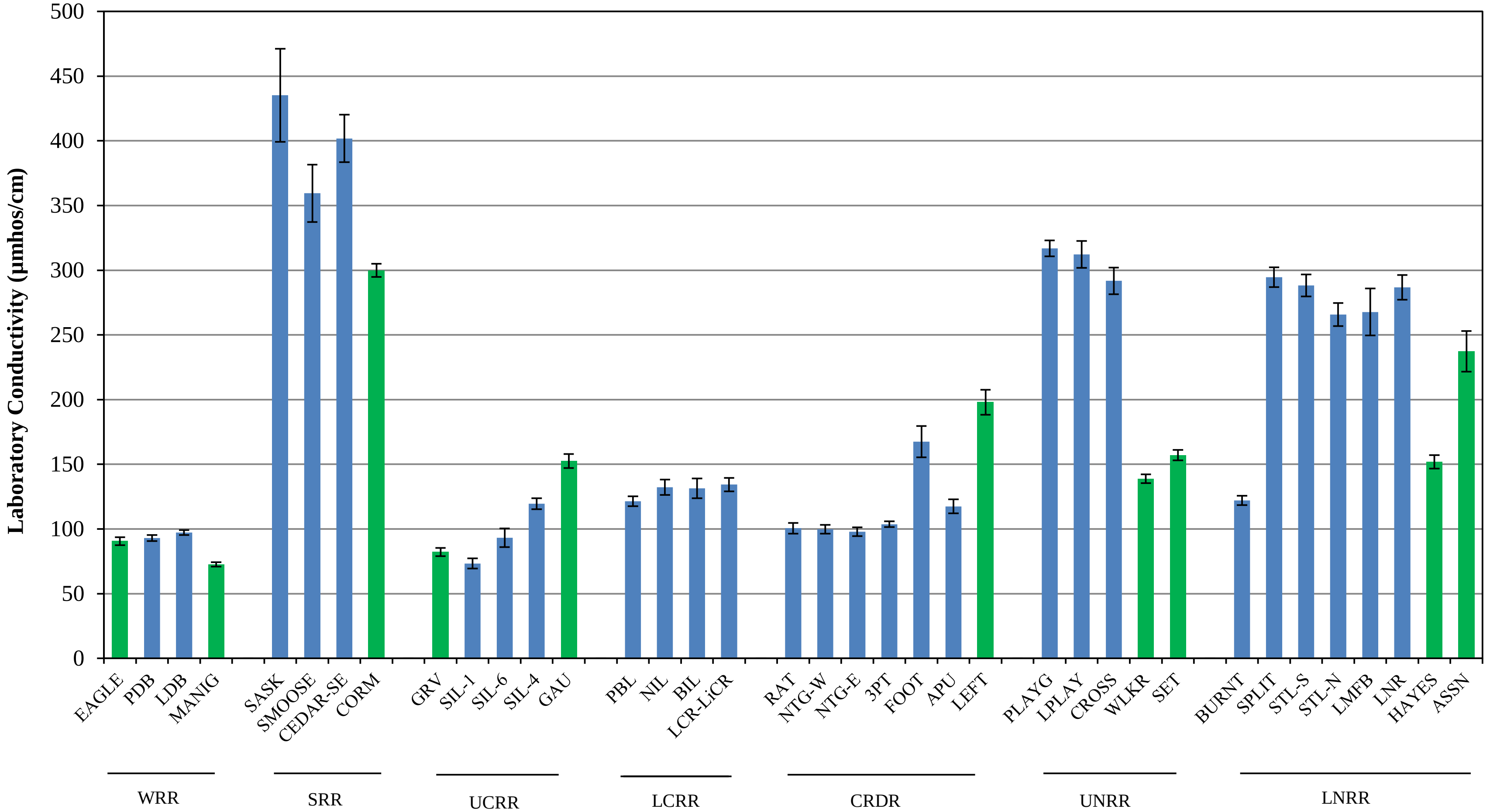


Figure 6.2-9. Mean (±SE) conductivity (laboratory) measured in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). Off-system waterbodies are indicated in green.

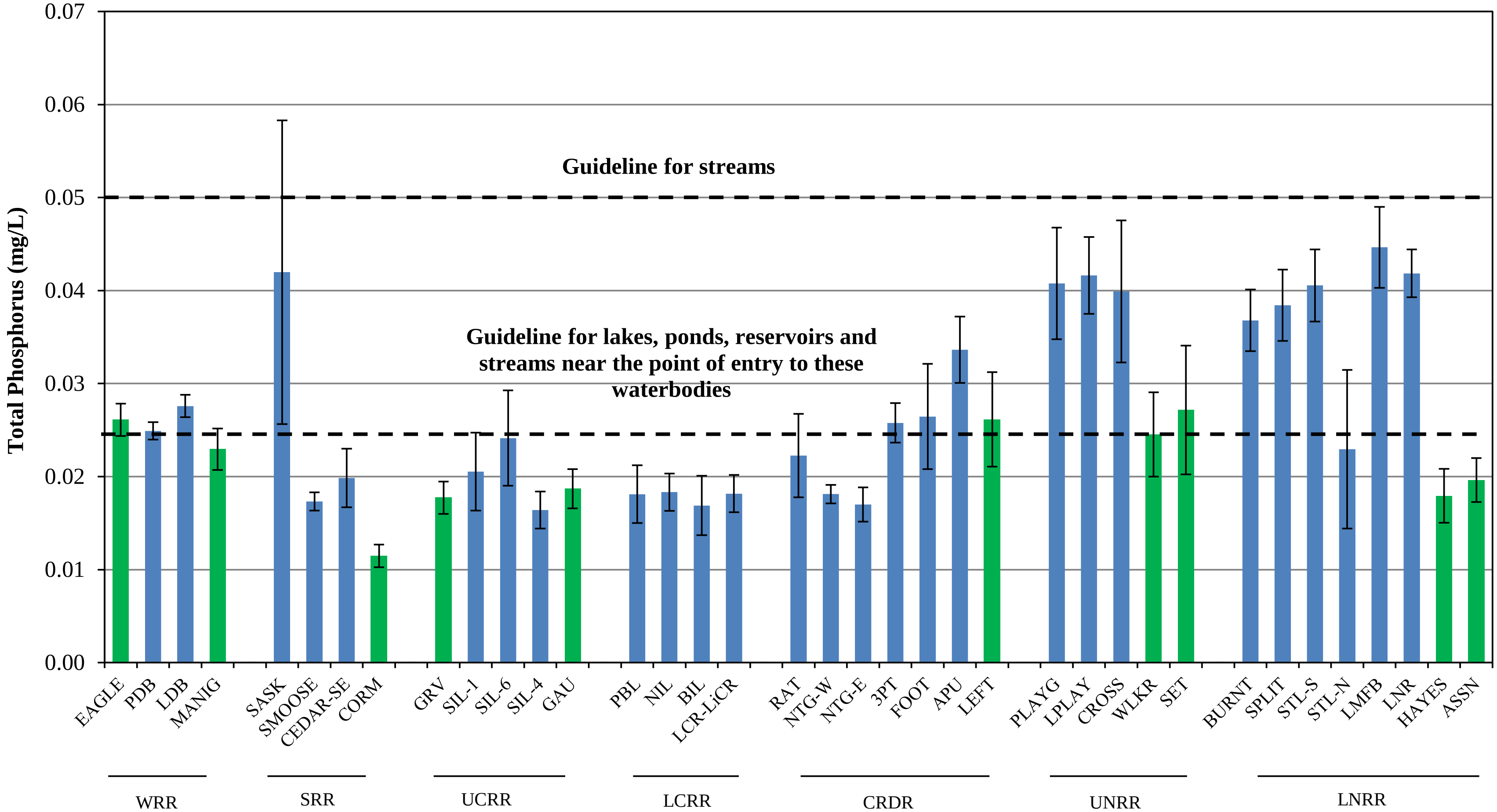


Figure 6.2-10. Mean (±SE) total phosphorus (all sampling periods) in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). Dashed lines indicate the Manitoba narrative guideline for TP. Off-system waterbodies are indicated in green.

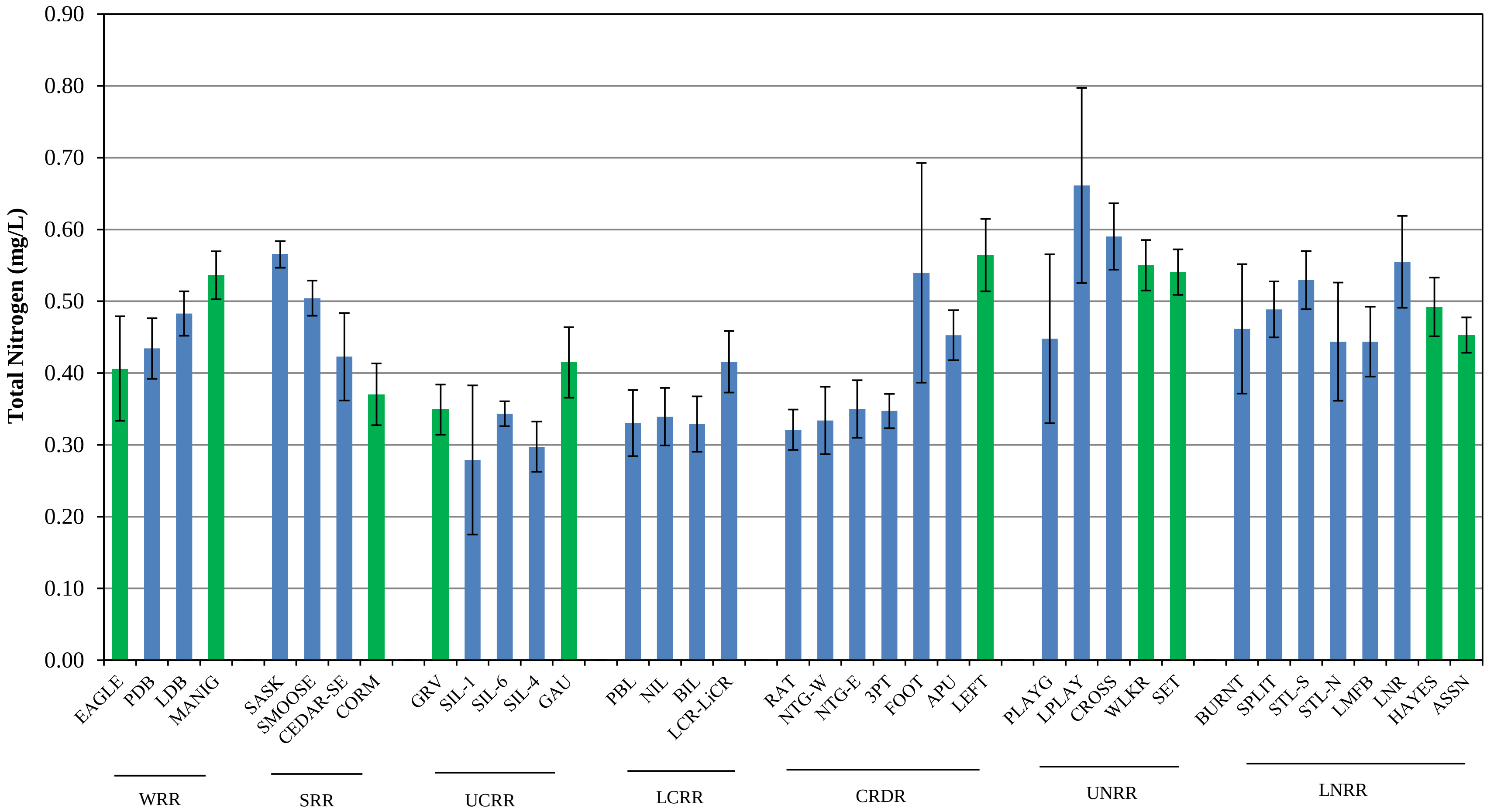


Figure 6.2-11. Mean (±SE) total nitrogen (all sampling periods) in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). Off-system waterbodies are indicated in green.

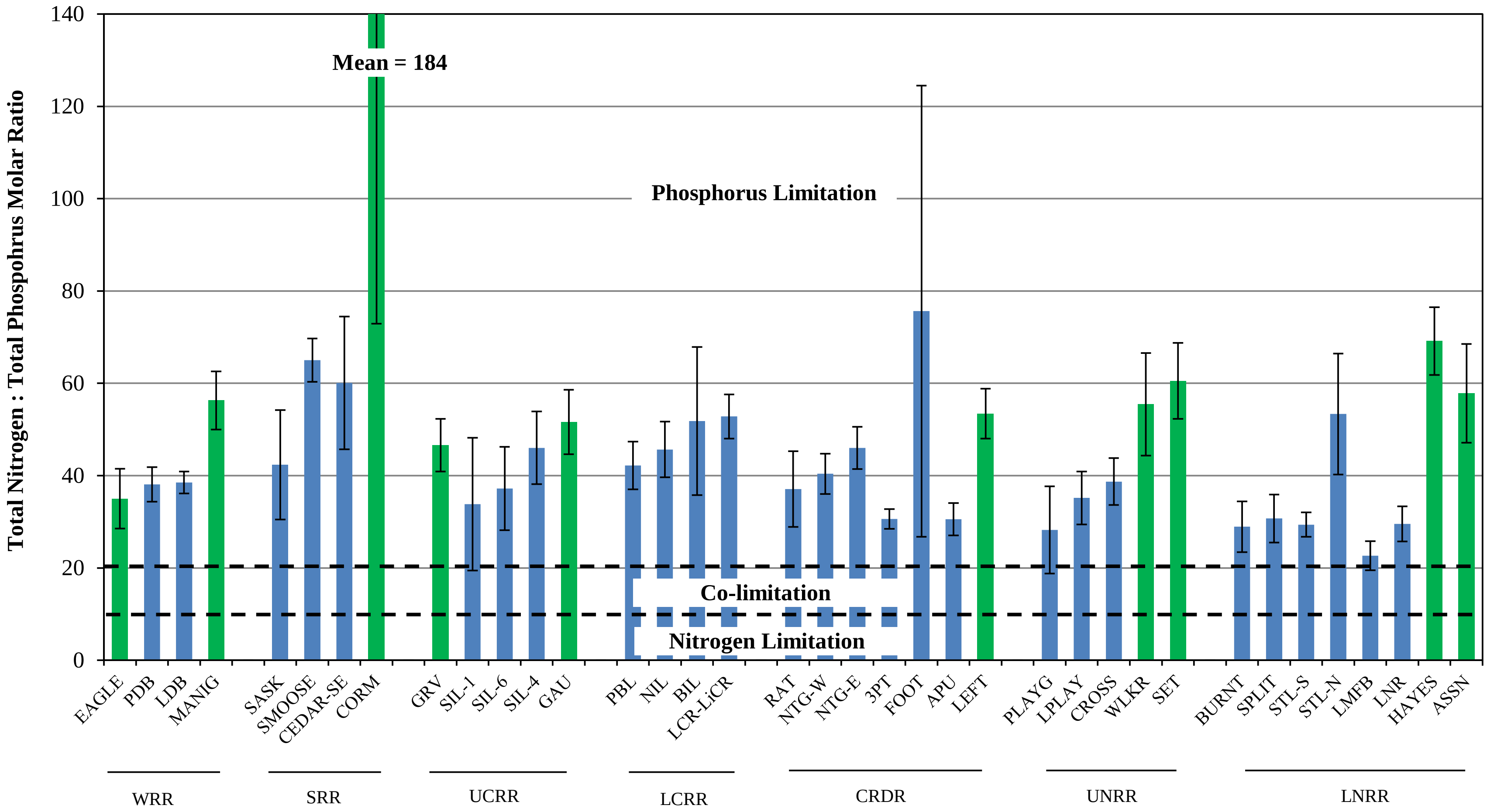


Figure 6.2-12. Mean (±SE) total nitrogen to total phosphorus molar ratios in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). Off-system waterbodies are indicated in green.

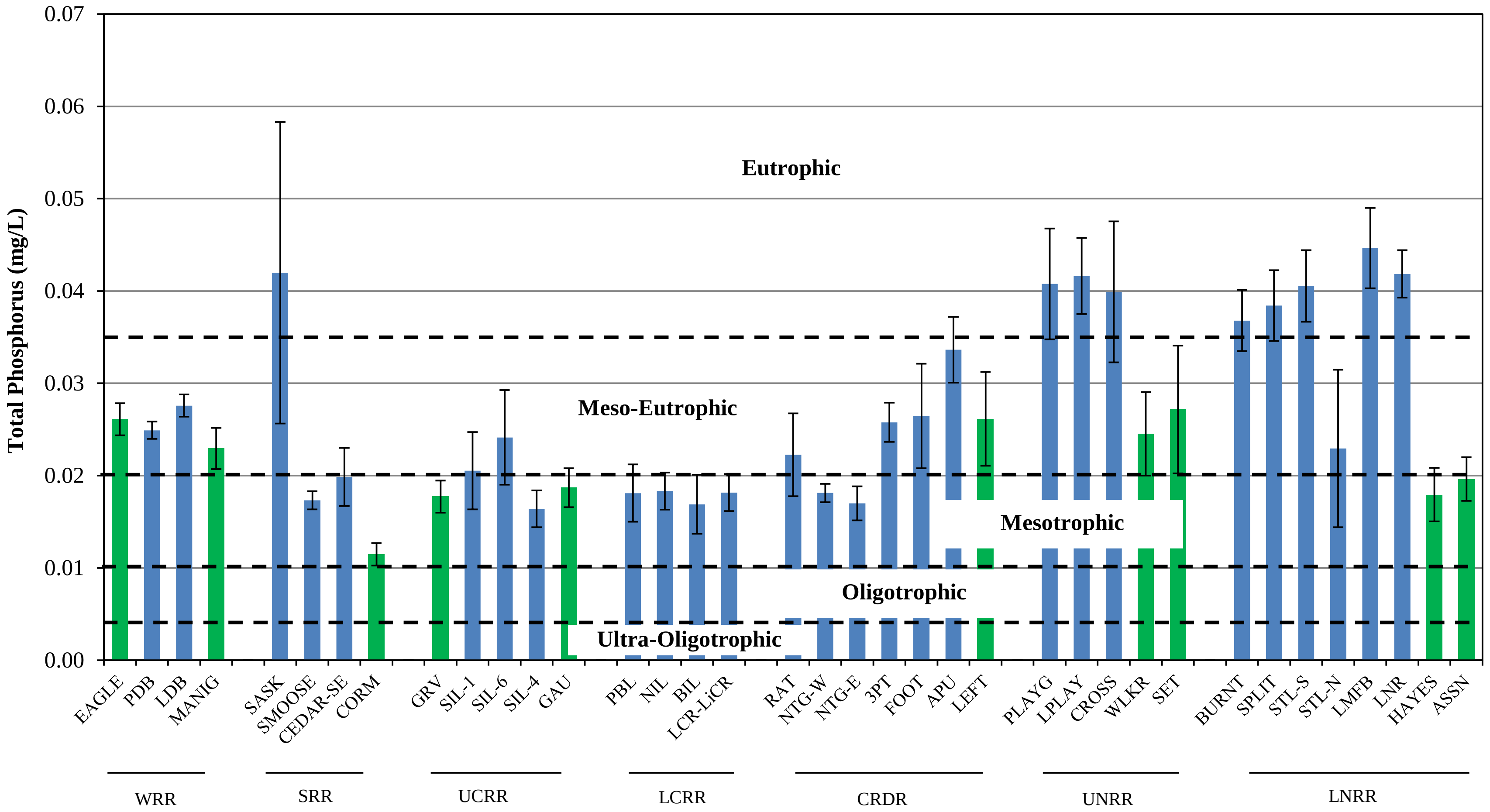


Figure 6.2-13. Mean (±SE) total phosphorus measured in the open-water seasons in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). Dashed lines indicate boundaries between CCME (1999; updated to 2013) trophic categories. Off-system waterbodies are indicated in green.

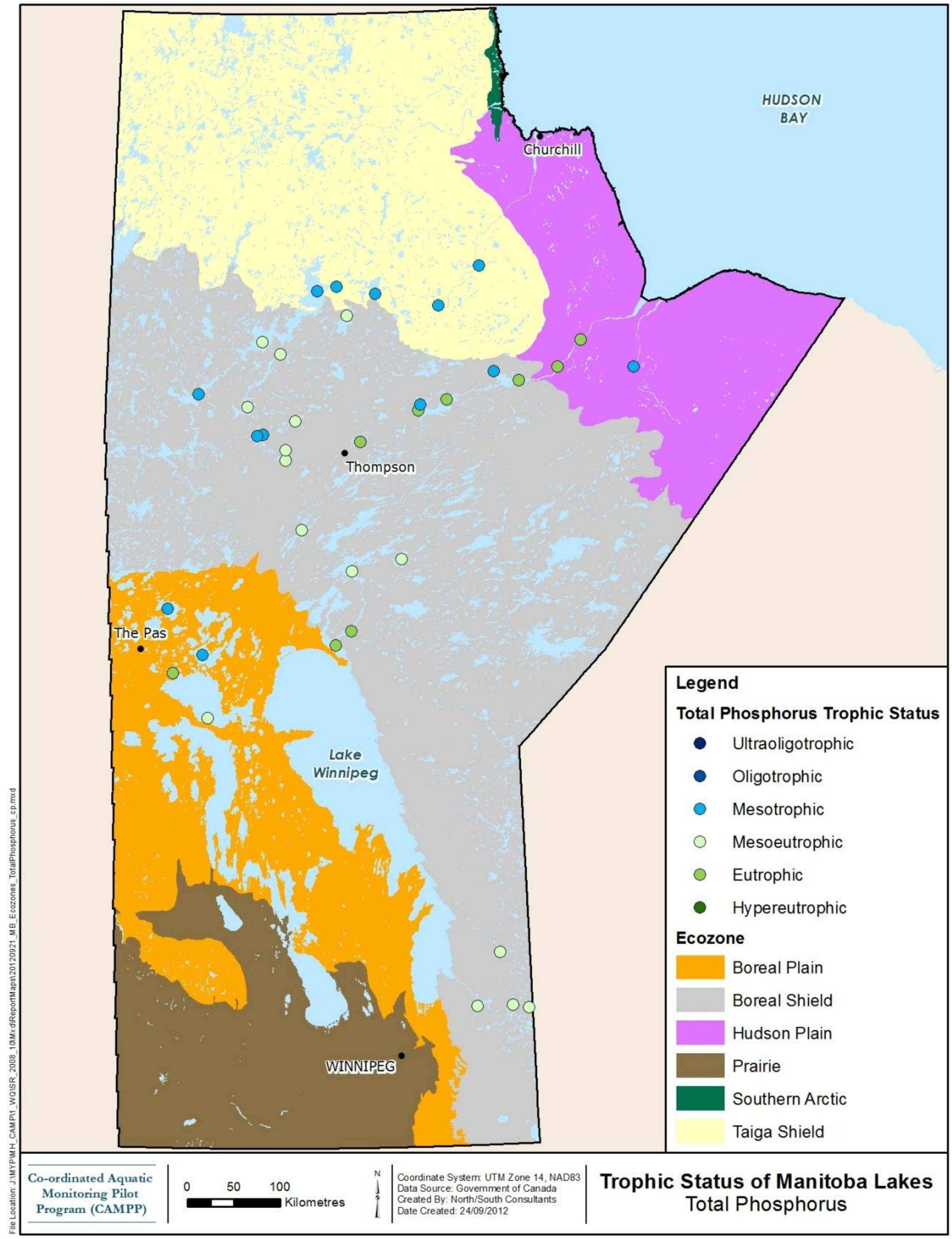


Figure 6.2-14. Trophic status of lakes and rivers based on mean total phosphorus concentrations (open-water seasons) from 2008/2009 through 2010/2011.

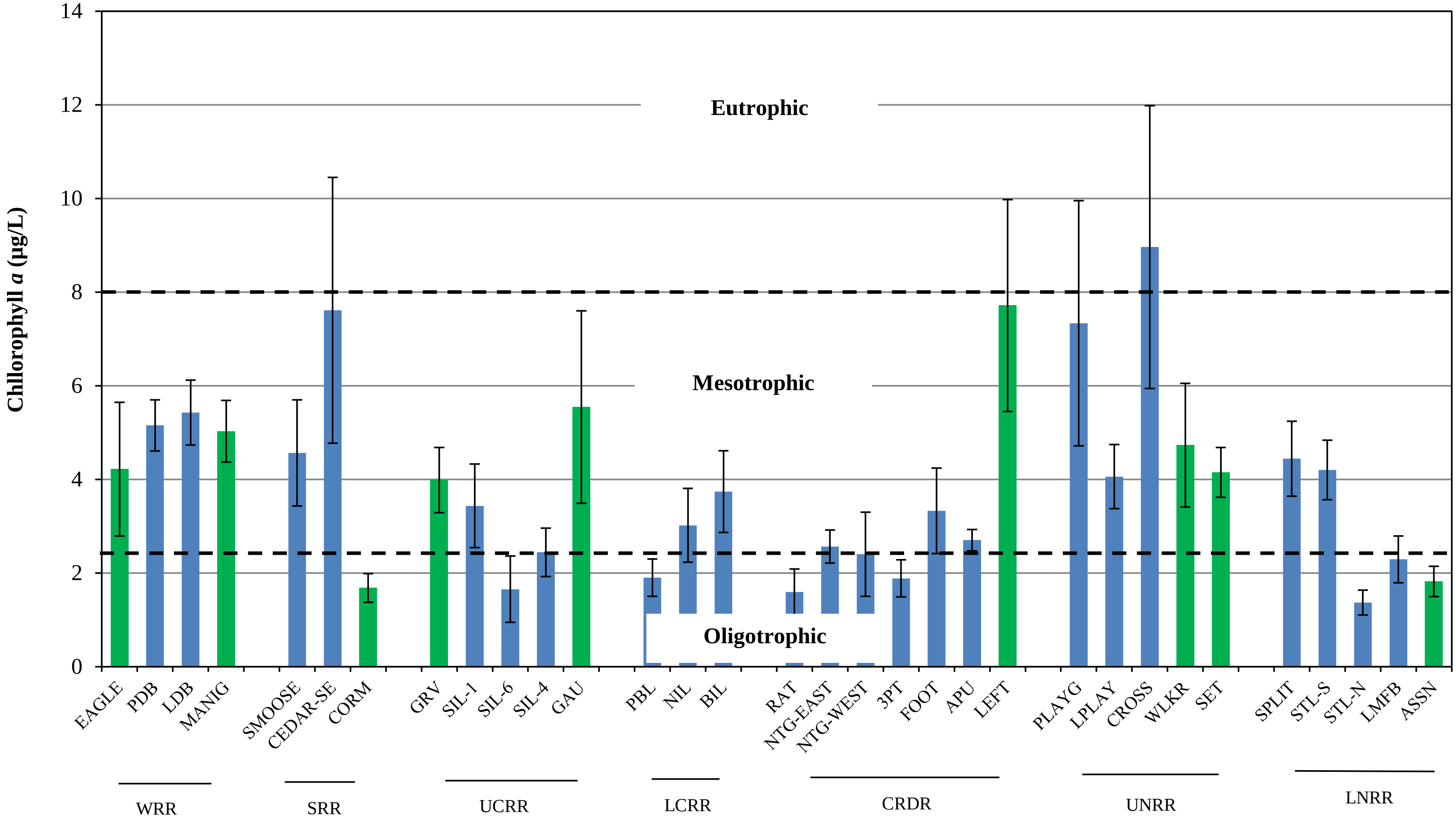


Figure 6.2-15. Mean (±SE) chlorophyll *a* measured in the open-water seasons in lakes and reservoirs in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). Trophic categories are from the OECD (1982). Off-system waterbodies are indicated in green.

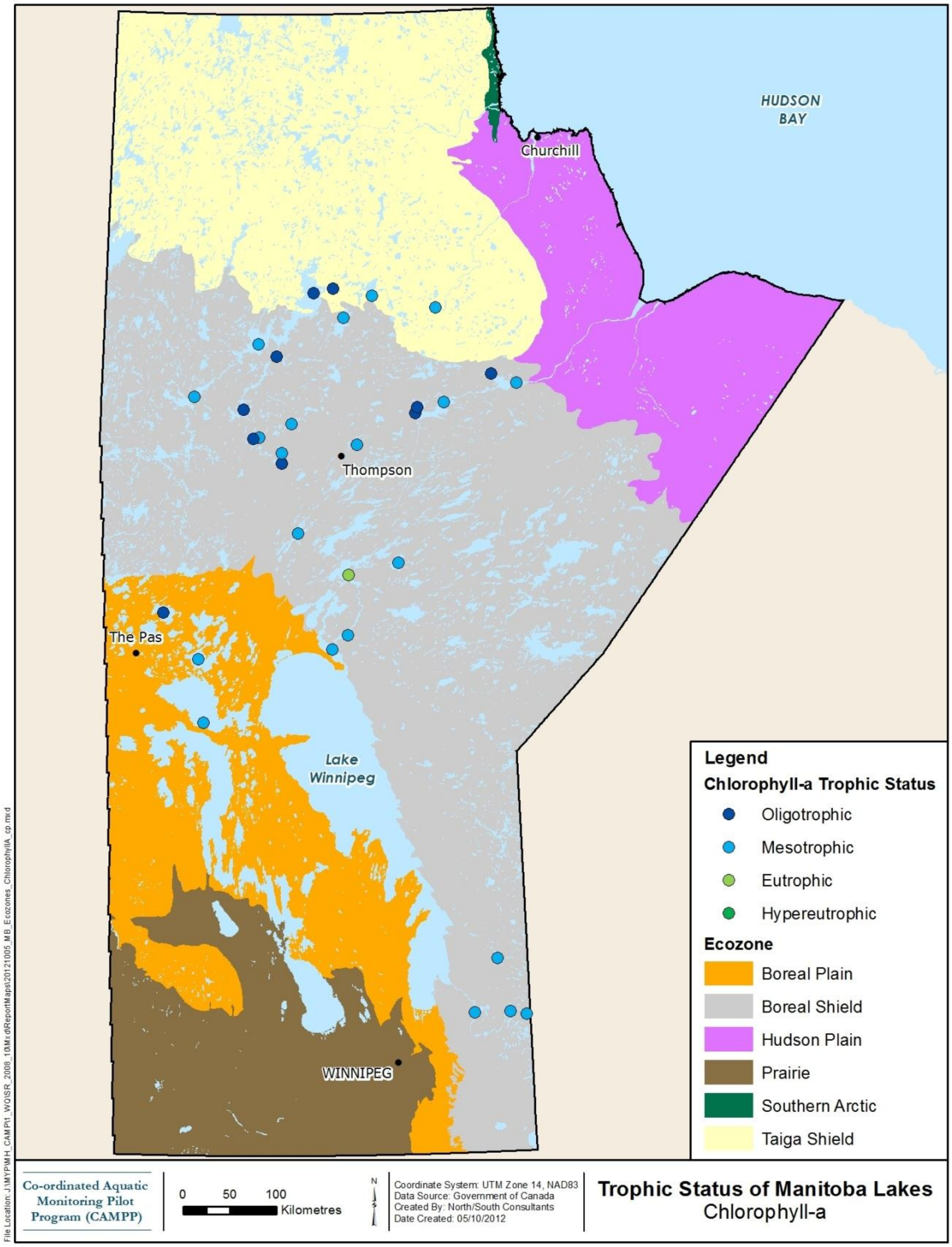
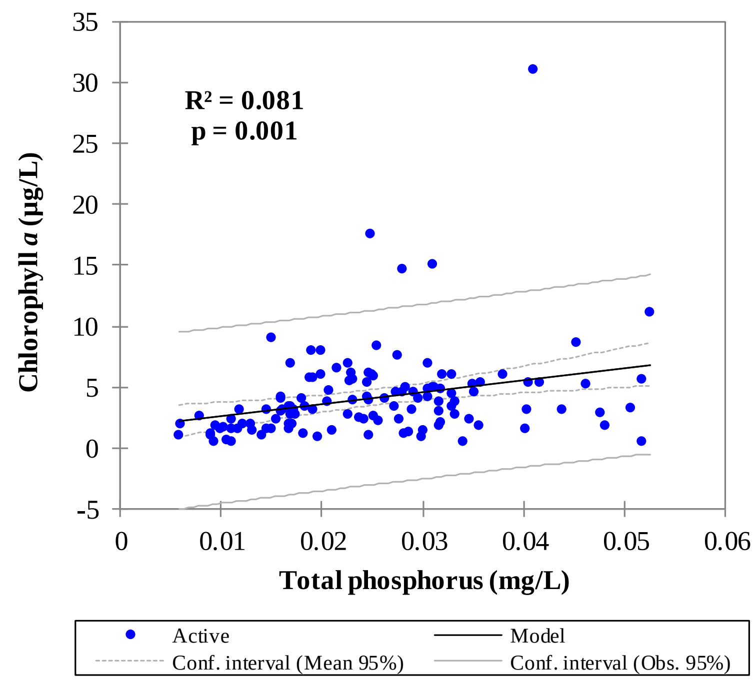


Figure 6.2-16. Trophic status of lakes based on mean chlorophyll *a* concentrations (open-water seasons) from 2008/2009 through 2010/2011.

(A)



(B)

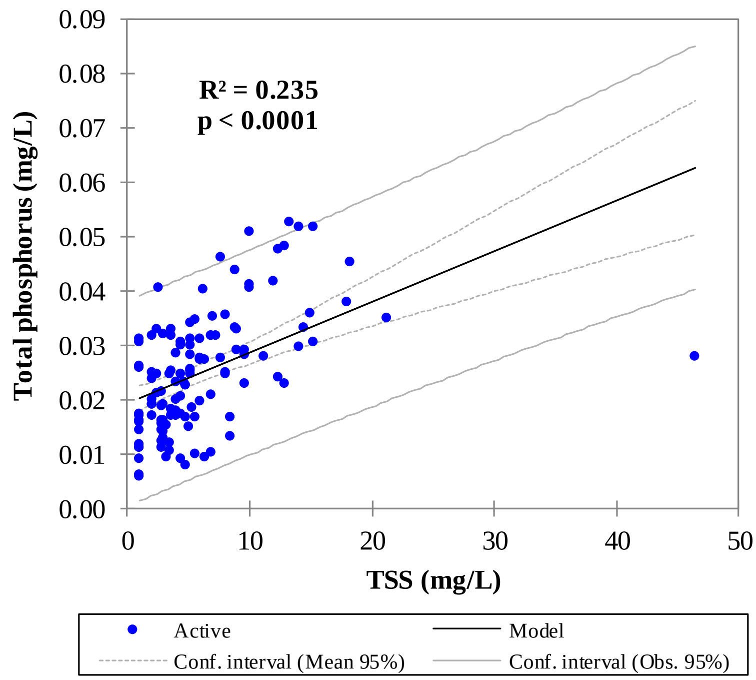


Figure 6.2-17. Linear regressions between (A) total phosphorus (TP) and chlorophyll *a*, and (B) total suspended solids (TSS) and TP for on-system lakes and reservoirs across the seven sampling regions (Lake Winnipeg Region excluded). Data represent the open-water seasons only.

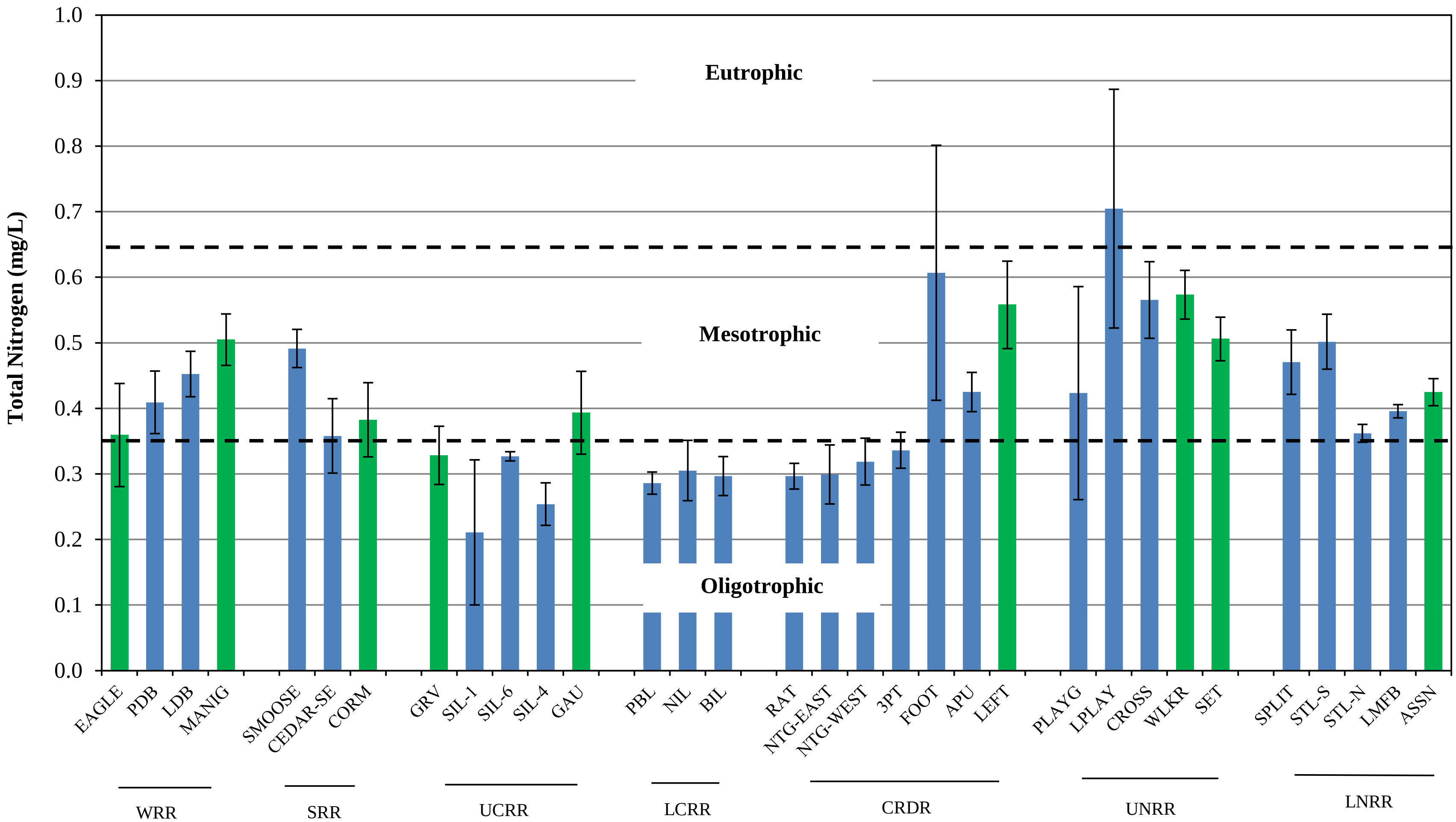


Figure 6.2-18. Mean (±SE) total nitrogen measured in the open-water seasons in lakes and reservoirs in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). Off-system waterbodies are indicated in green. Trophic categories are from Nürnberg (1996).

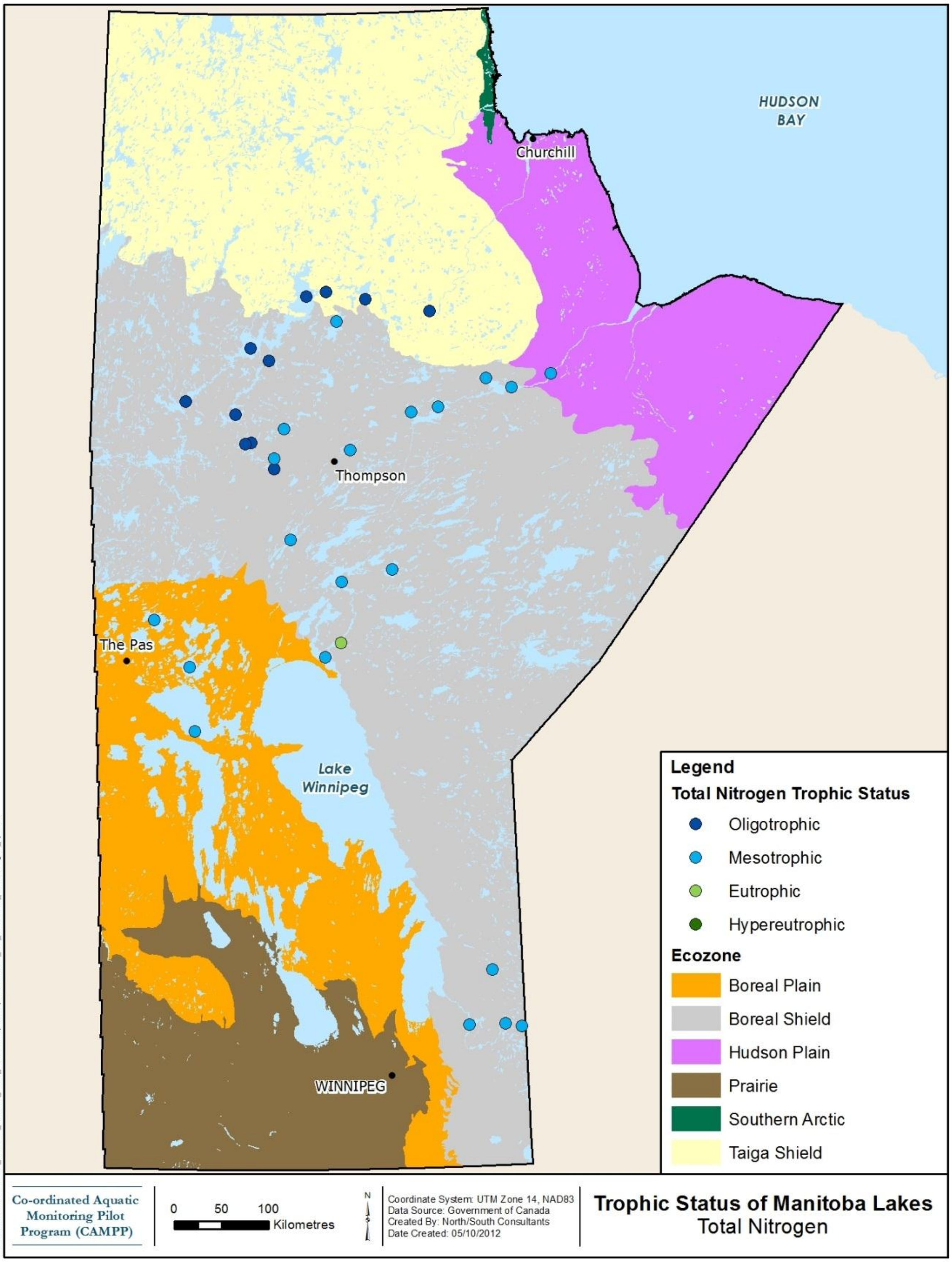


Figure 6.2-19. Trophic status of lakes based on mean total nitrogen concentrations (open-water seasons) from 2008/2009 through 2010/2011.

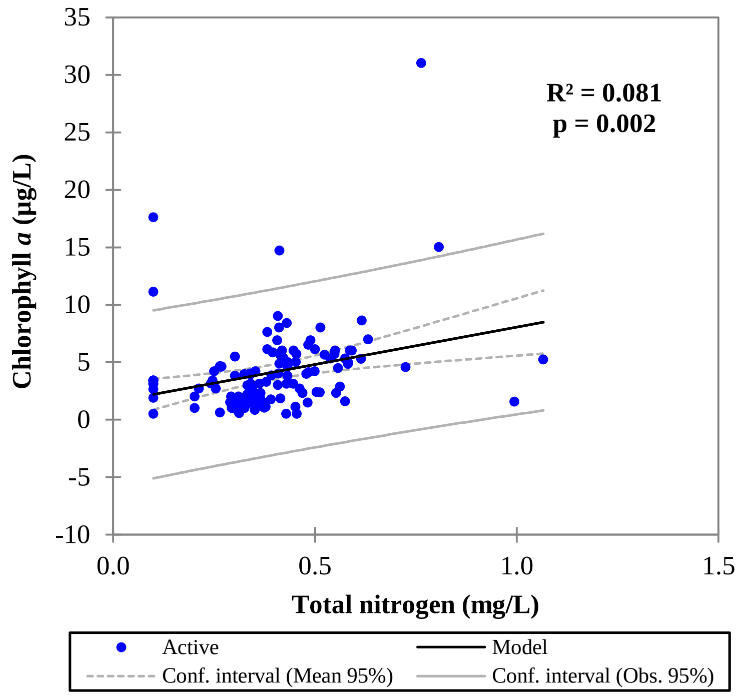


Figure 6.2-20. Linear regression between open-water season total nitrogen and chlorophyll *a* from on-system lakes and reservoirs across the seven sampling regions (Lake Winnipeg Region excluded).

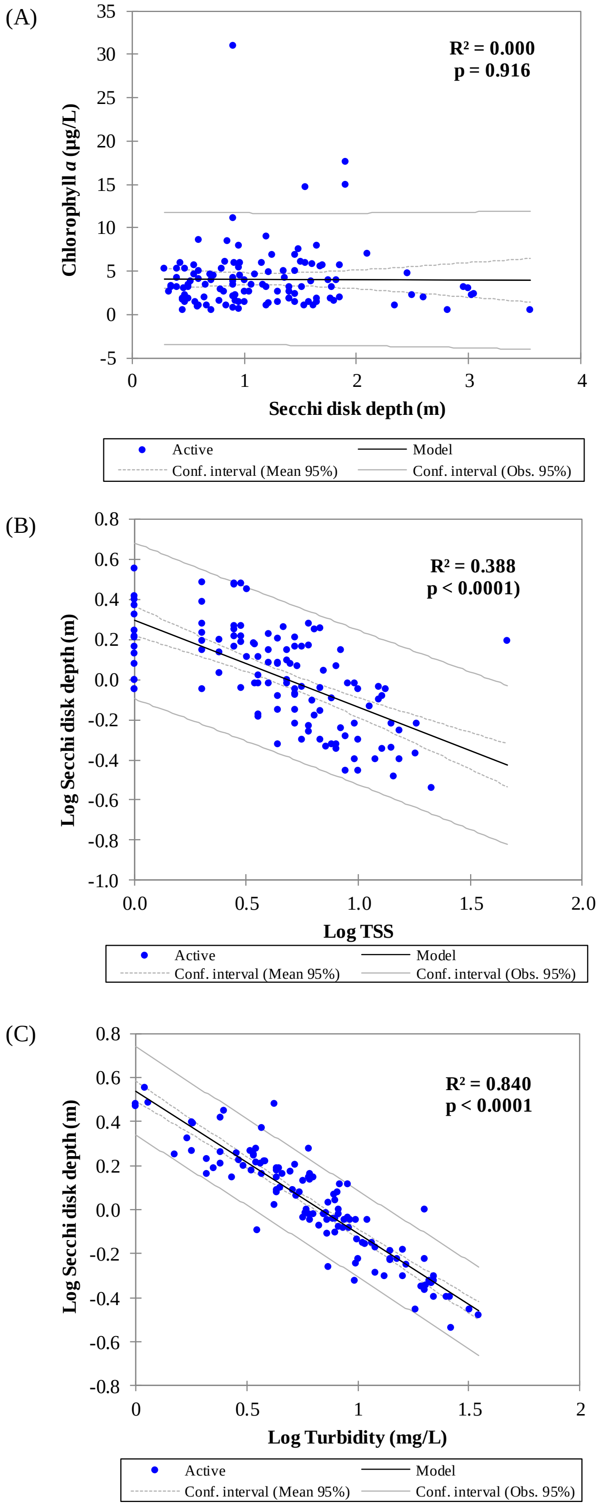


Figure 6.2-21. Linear regressions between (A) Secchi disk depth and chlorophyll *a*, (B) total suspended solids and Secchi disk depth, and (C) turbidity and Secchi disk depth. Data included in the analyses are on-system lakes and reservoirs across the seven sampling regions (Lake Winnipeg Region excluded).

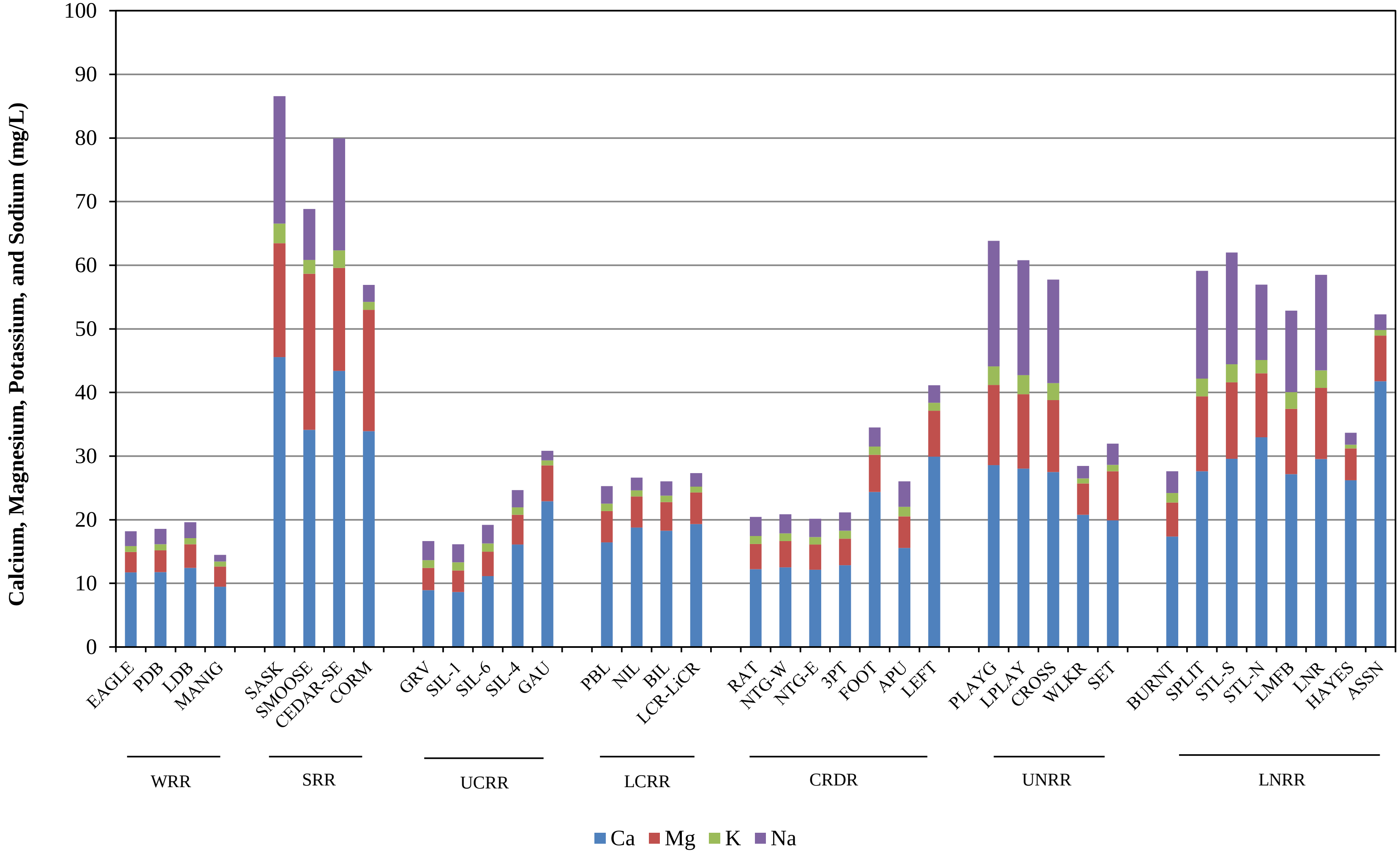


Figure 6.2-22. Mean (±SE) concentrations of calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR).

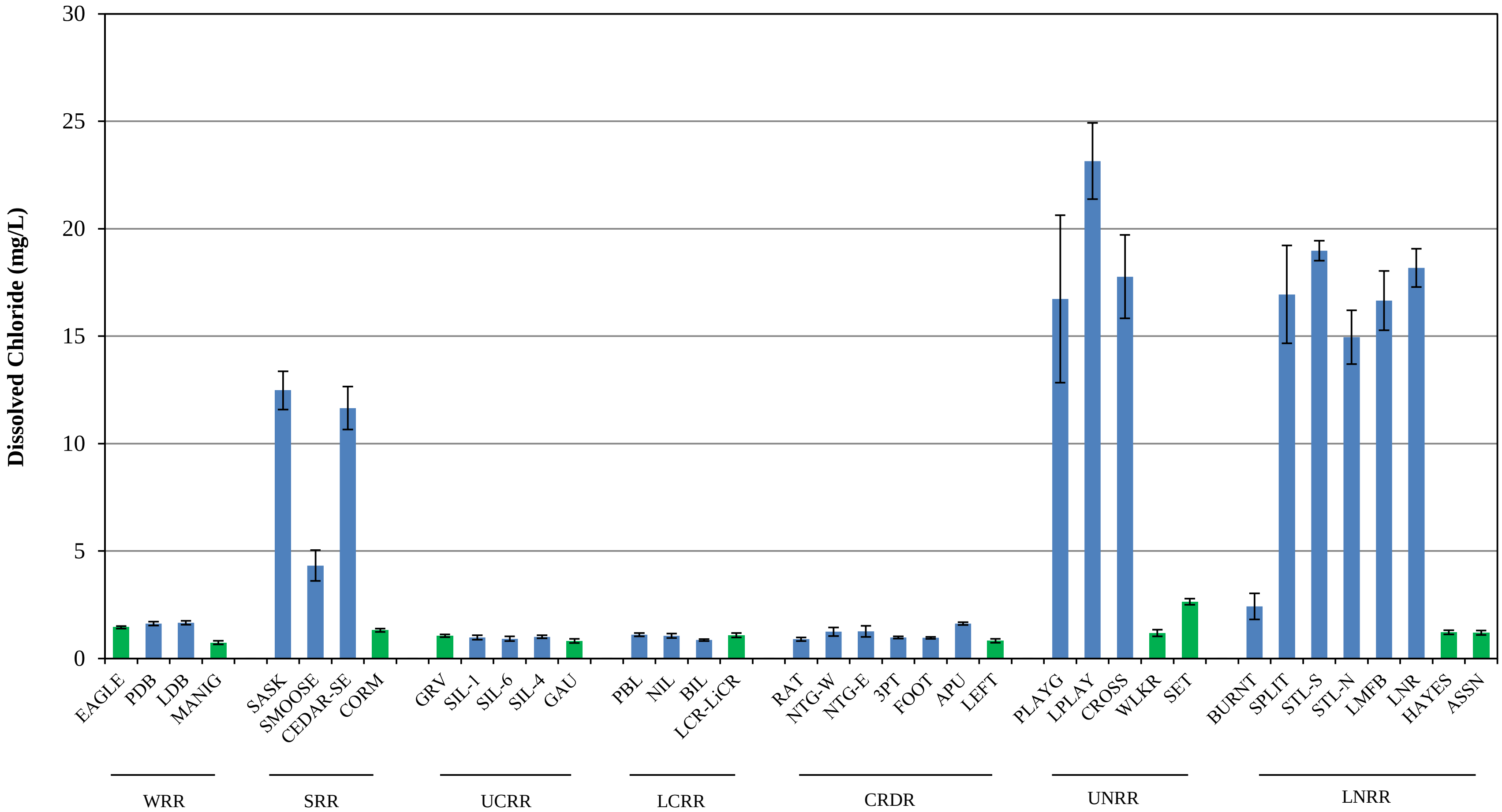


Figure 6.2-23. Mean (±SE) chloride concentrations in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). Off-system waterbodies are indicated in green.

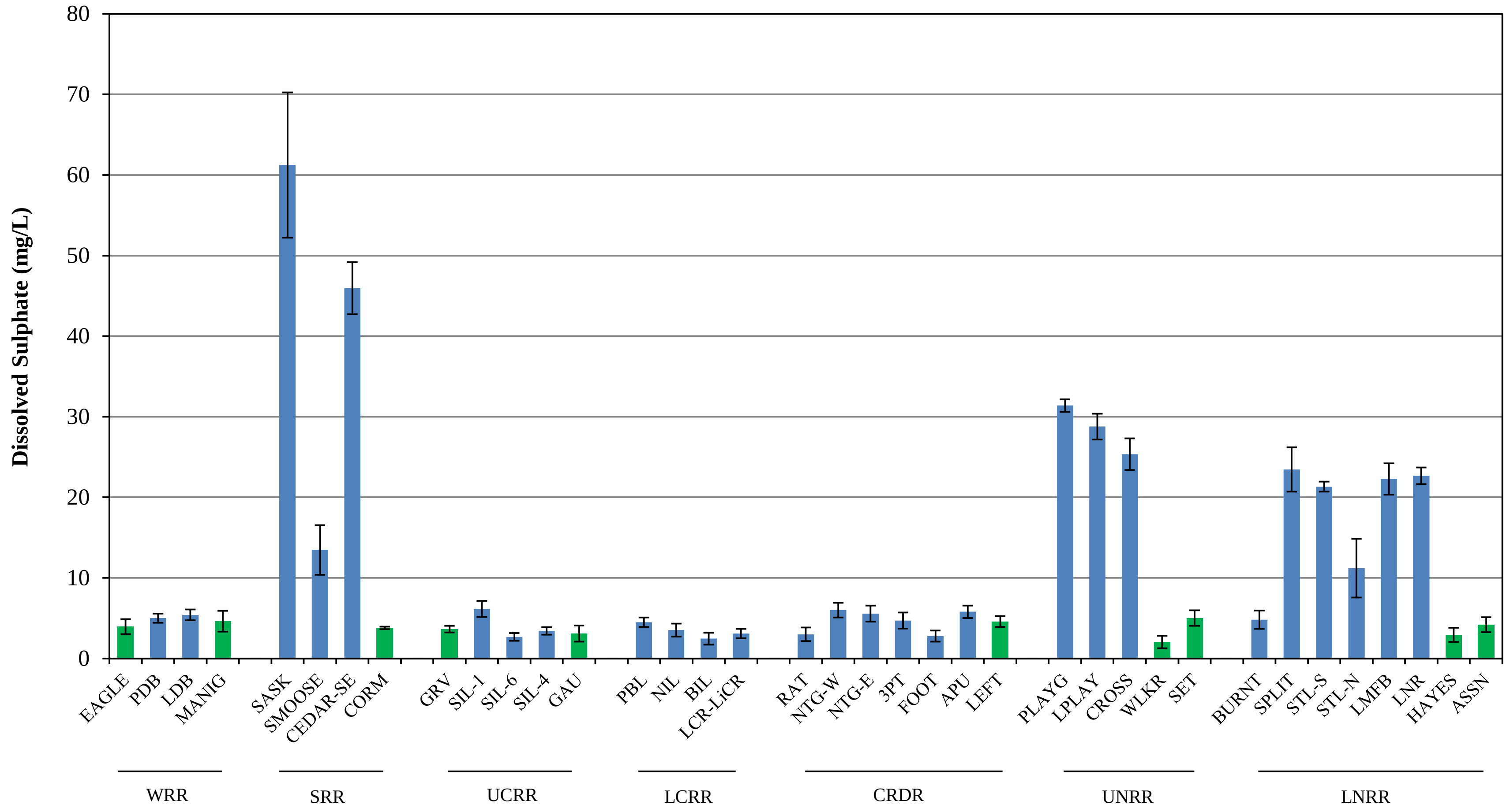


Figure 6.2-24. Mean (±SE) sulphate concentrations in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). Off-system waterbodies are indicated in green.

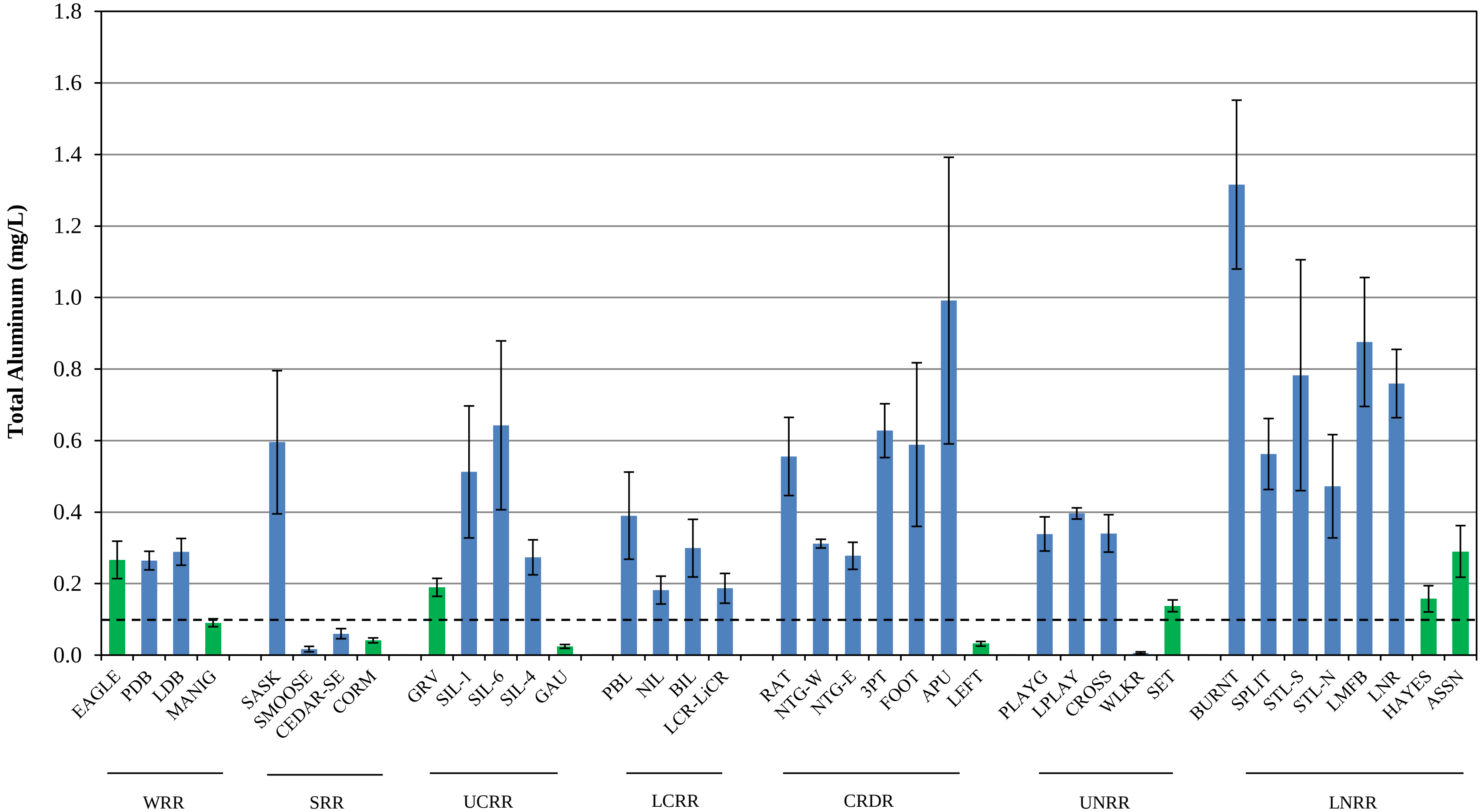


Figure 6.2-25. Mean (±SE) aluminum concentrations measured in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). Off-system waterbodies are indicated in green. The dashed line indicates the MWQSOG for PAL.

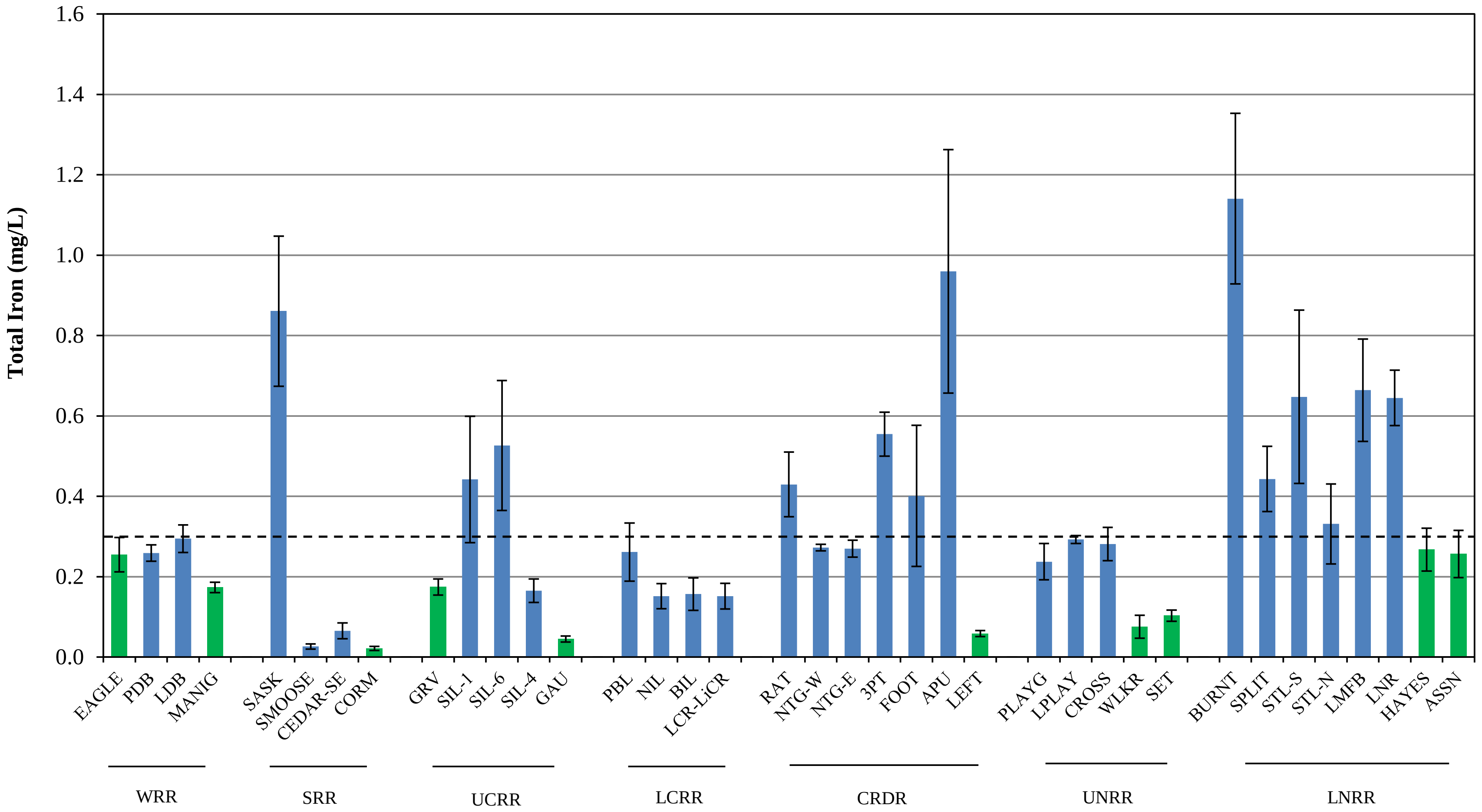


Figure 6.2-26. Mean (±SE) iron concentrations measured in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). Off-system waterbodies are indicated in green. The dashed line indicates the MWQSOG for PAL.

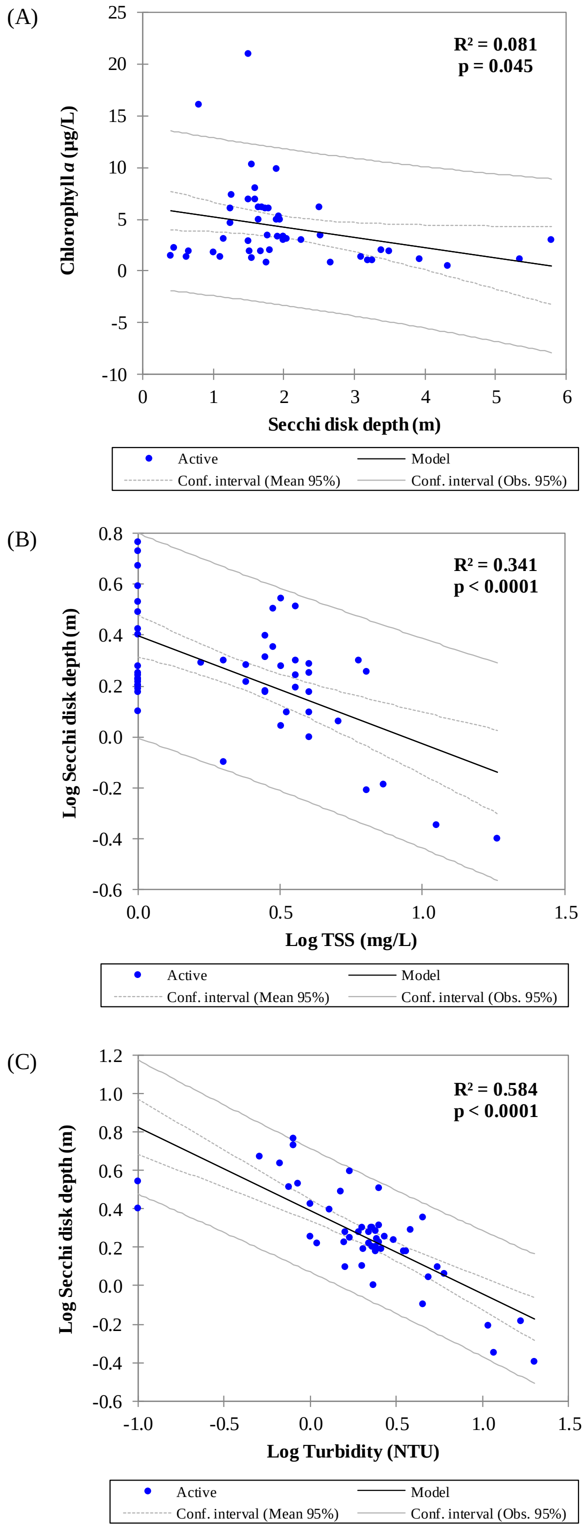


Figure 6.2-27. Linear regressions between (A) Secchi disk depth and chlorophyll *a*, (B) TSS and Secchi disk depth, and (C) turbidity and Secchi disk depth for off-system lakes across the seven sampling regions (Lake Winnipeg Region excluded).

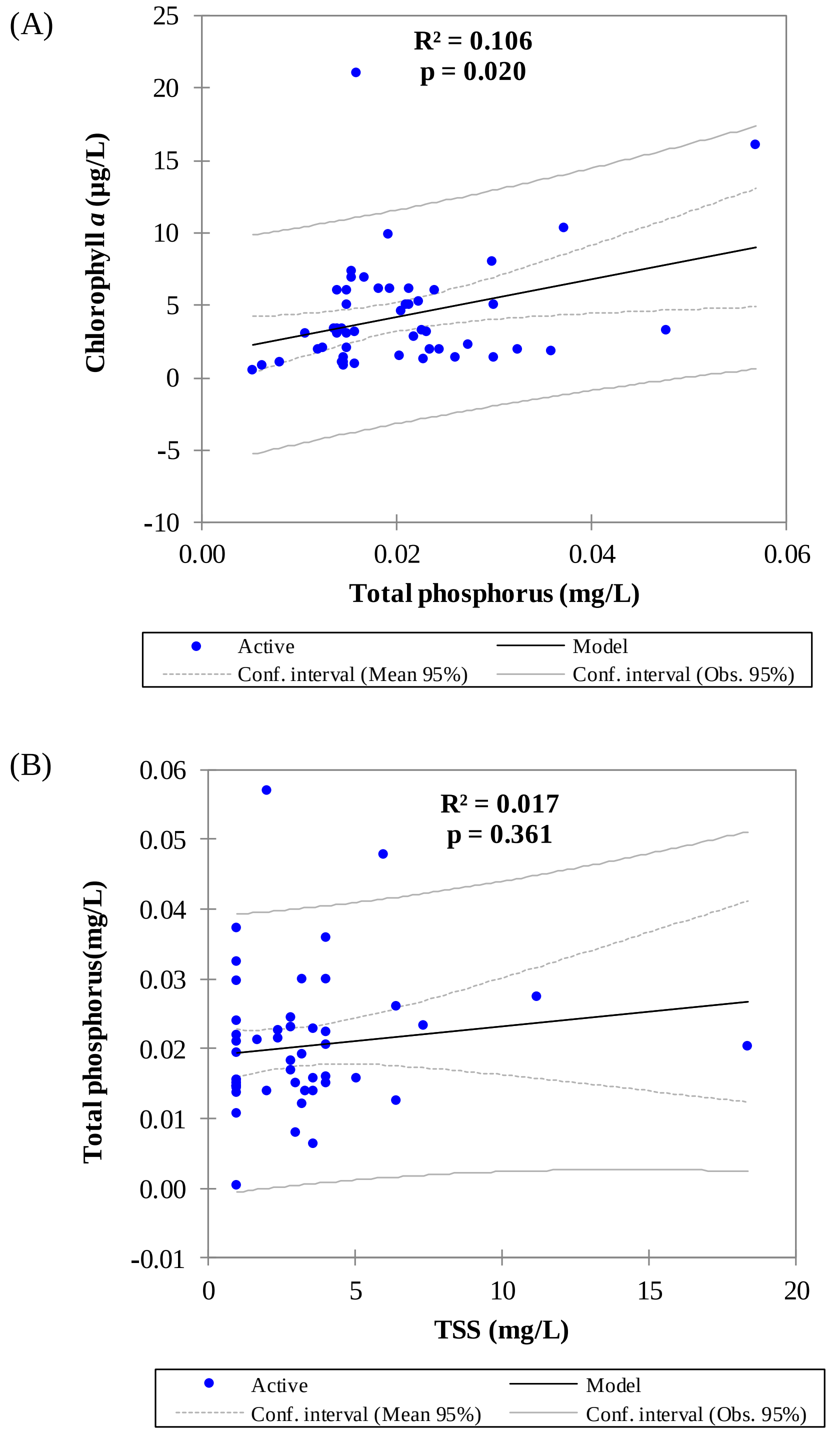


Figure 6.2-28. Linear regressions between (A) total phosphorus (TP) and chlorophyll *a*, and (B) total suspended solids (TSS) and TP for off-system lakes across the seven sampling regions (Lake Winnipeg Region excluded). Data represent the open-water seasons only.

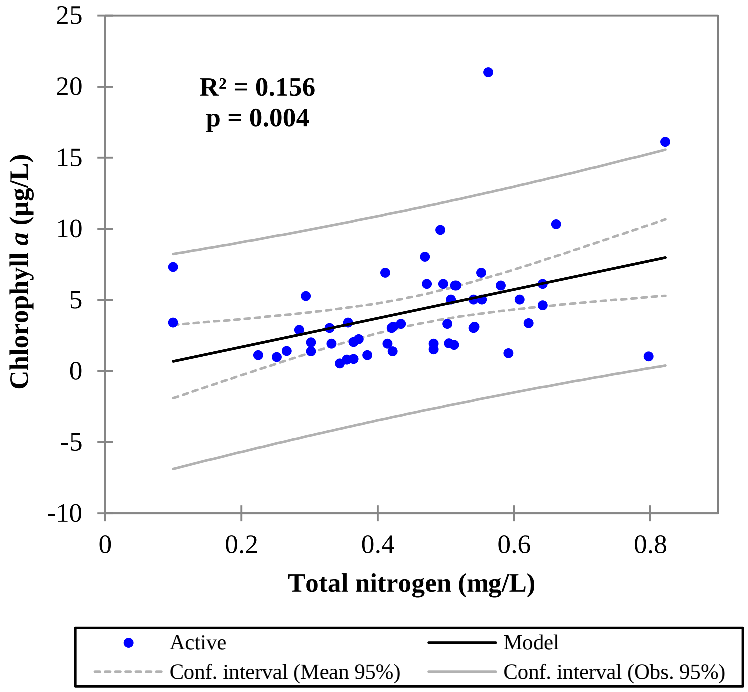


Figure 6.2-29. Linear regression between open-water season total nitrogen and chlorophyll *a* from off-system lakes across the seven sampling regions (Lake Winnipeg Region excluded).

6.3 PHYTOPLANKTON

The following discussion provides an overview of key phytoplankton results for all the CAMPP waterbodies sampled in Years 1-3 of the Pilot Program. This overview is intended to provide a broad description of key metrics across the study regions (excluding the Lake Winnipeg Region) and to explore general patterns respecting phytoplankton on a larger geographic scale. This analysis was also undertaken to inform the overall design of the CAMPP phytoplankton monitoring program and facilitate discussion of potential modifications to the program in the future. As such, this discussion is not intended to be comprehensive and the reader is referred to discussions presented in Section 5 of this report for a detailed description of results of the CAMPP phytoplankton program.

Results of key phytoplankton metrics measured in each region are presented in Tables 6.3-1 to 6.3-7 and Figures 6.3-1 to 6.3-7. As described for water quality (see Section 6.2 for a detailed discussion), Granville, Eaglenest and Walker lakes have been grouped with the on-system waterbodies in the discussion presented below. Although these waterbodies are designated as off-system under CAMP, this grouping was made in order to facilitate exploration of trends or relationships in phytoplankton between waterbodies located on or influenced by (i.e., Walker Lake via Cross Lake) the major rivers relative to those uninfluenced by the major rivers or waterbodies associated with them.

6.3.1 Chlorophyll *a*

Mean chlorophyll *a* concentrations measured in CAMPP waterbodies during the three year Pilot Program ranged from 1.1 µg/L (Stephens Lake-North) to 7.0 µg/L (Cross Lake; Figure 6.3-1 and Tables 6.3-1 to 6.3-7). On average, chlorophyll *a* was highest in the Lake Winnipeg outlet lakes (particularly Playgreen and Cross lakes) and lowest in Partridge Breast Lake, the on-system waterbodies of the Churchill River Diversion Region, the Burntwood River, and Stephens Lake-North. Off-system waterbodies generally had mean chlorophyll *a* concentrations similar to or higher than concentrations measured in neighbouring on-system waterbodies; the exception was Cormorant Lake, where chlorophyll *a* was notably lower than in on-system waterbodies in the Saskatchewan River Region.

As discussed in Section 6.2, chlorophyll *a* was weakly correlated with total phosphorus (TP; Figures 6.2-17 and 6.2-28) and total nitrogen (TN; Figures 6.2-20 and 6.2-29) in both the on- and off-system water bodies but the relationships were stronger in off-system waterbodies than in on-system ones. Secchi disk depth was also correlated with chlorophyll *a* concentrations in off-system lakes and rivers but not in on-system waterbodies. Additionally, TP in on-system waterbodies was more strongly correlated with TSS than chlorophyll *a* (Figure 6.2-17).

Collectively, these results indicate that productivity in off-system lakes is limited by nutrient concentrations but other factors, such as light and temperature, limit or co-limit phytoplankton productivity in on-system lakes and reservoirs.

Linear regression analysis also indicated that chlorophyll *a* was generally a good indicator of phytoplankton biomass, but that its usefulness as a predictor was stronger for the off-system sites (Figure 6.3-2). Specifically, although the relationship between chlorophyll *a* concentrations and phytoplankton biomass was significant for both the on-system and off-system waterbodies, the relationship is weaker in the on-system waterbodies. It is noted that relationships likely vary amongst the regions and correlations should be explored on a regional basis after acquisition of additional data.

6.3.2 Taxonomic Composition and Biomass

Mean phytoplankton biomass measured in CAMPP waterbodies typically ranged from 294 mg/m^3 (Notigi Lake-East) to 5,601 mg/m^3 (Cedar Lake; Figure 6.3-3 and Tables 6.3-1 to 6.3-7); however, the mean biomass at Walker Lake was unusually high at 15,503 mg/m^3. Biomass was generally low in waterbodies influenced by the major river in most regions, although higher biomass was measured in Eaglenest Lake, the Saskatchewan River, Cedar Lake, Footprint Lake, waterbodies of the Upper Nelson River Region, and Split Lake. Similar to chlorophyll *a*, mean phytoplankton biomass was generally higher in Leftrook and Gauer lakes, and lower at Cormorant and Assean lakes and the Hayes River, when compared to neighbouring on-system waterbodies. As with a number of water quality parameters, phytoplankton biomass measured in South Moose and Footprint lakes was also more similar to that measured in the neighbouring off-system waterbody than to the sites located on the main flow of the Saskatchewan and Rat/Burntwood rivers, respectively.

Although phytoplankton biomass was not measured during winter, the low chlorophyll *a* concentrations during this period suggest that phytoplankton biomass was also typically lower in the ice-cover season than the open-water season.

Although there was considerable variation both seasonally and spatially, the phytoplankton communities of CAMPP waterbodies were, on average, typically dominated by diatoms with either blue-green algae and/or cryptophytes as the second most abundant group(s) (Figure 6.3-4 and Tables 6.3-1 to 6.3-7). Green algae, chrysophytes, dinoflagelates and euglenoids generally comprised a relatively small proportion of each phytoplankton community. The exceptions to these patterns were as follows: diatoms and blue-green algae were on average co-dominant at Billard and Walker lakes; blue-green algae dominated on average at South Moose Lake; cryptophytes dominated the phytoplankton assemblage at Southern Indian Lake-Area 6, Rat

Lake and the Burntwood River; and, at Notigi Lake-East and the two off-system waterbodies in the Lower Nelson River Region (i.e., Hayes River and Assean Lake) the phytoplankton biomass was fairly evenly distributed amongst several groups.

Phytoplankton community complexity varied between waterbodies, seasons, and metrics considered, with no obvious regional patterns (Figures 6.3-5 and 6.3-6). The average Simpson's Diversity Index ranged from 0.40 to 0.88 across CAMPP waterbodies, and the average Hill's effective richness ranged from 3 to 13 (Tables 6.3-1 to 6.3-7). South Moose Lake had the highest mean diversity and effective richness of all CAMPP waterbodies whereas Rat Lake had the lowest. Off-system waterbodies consistently showed high effective richness and diversity.

6.3.3 Phytoplankton Blooms

Phytoplankton blooms (i.e., operationally defined as periods when chlorophyll *a* concentrations exceeded 10 µg/L) were periodically observed at Cedar, Gauer, Leftrook, Playgreen and Cross lakes, and all blooms occurred during either the summer or fall sampling periods. During the blooms, phytoplankton biomass ranged between 1,762 mg/m^3 and 15,238 mg/m^3. Blue-green algae typically dominated each phytoplankton community at these times (Figure 6.3-7); however, diatoms and blue-green algae were co-dominant at Cedar Lake in summer 2010, and diatoms were dominant at Cedar, Leftrook, and Playgreen lakes in fall 2009.

6.3.4 Microcystin

Some forms of blue-green algae are capable of producing microcystins (liver toxins), including species of *Anabaena*, *Aphanizomenon*, *Microcystis*¸ *Nostoc* and *Planktothrix* (a.k.a. *Oscillatoria*; Zurawell et al. 2005). Although not completely understood, several factors such as species, bacterial strain, and environmental conditions appear to influence production of microcystins.

Phytoplankton species capable of producing microcystin were identified in all CAMPP waterbodies. *Anabaena* and *Aphanizomenon* were ubiquitous in samples collected from the CAMPP waterbodies. *Planktothrix*/*Oscillatoria* was also found at most waterbodies; exceptions were Footprint, Rat, Split, Little Playgreen, Walker and Eaglenest lakes, the Saskatchewan River, and Southern Indian Lake-Area 6. *Microcystis* was only found in Leftrook and Walker lakes and *Nostoc* was not identified in any samples.

During the three-year Pilot Program, microcystin-LR was analysed in eight samples collected from four waterbodies (Cedar, South Moose, Leftrook and Cross lakes), when chlorophyll a exceeded the trigger of 10 µg/L. Despite the presence of algae capable of producing microcystins, microcystin-LR but was not detected (<0.2 µg/L) in any of these samples.

6.3.5 Trophic Status

Several trophic categorization schemes have been developed for lakes and reservoirs, as well as rivers, on the basis of TP, TN, and chlorophyll *a* concentrations. Waterbodies sampled under CAMPP are compared to several of these schemes in Section 6.2; the discussion here focuses on trophic categorization schemes based on chlorophyll *a*.

Trophic status of CAMPP lakes and reservoirs, using mean open-water season chlorophyll *a* as the indicator, ranged from oligotrophic to eutrophic (Table 6.2-9 and Figures 6.2-15 and 6.2-16). Specifically, on-system waterbodies within the Upper and Lower Churchill River, Churchill River Diversion, and Lower Nelson River regions ranged from oligotrophic to mesotrophic, on-system waterbodies within the Winnipeg River and Saskatchewan River regions were classified as mesotrophic, and on-system lakes within the Upper Nelson River Region ranged from mesotrophic to eutrophic. The off-system lakes were typically of similar trophic status as some or all of the neighbouring on-system waterbodies; the two exceptions were that Cormorant Lake ranked lower (oligotrophic) and Leftrook Lake higher (mesotrophic) compared to the neighbouring on-system waterbodies.

Trophic status of all CAMPP rivers based on mean chlorophyll *a* was oligotrophic (Table 6.2-11 and Figure 6.2-16).

Table 6.3-1. Phytoplankton summary: Winnipeg River Region.

Mean Metric		Waterbody			
		Eaglenest Lake	Pointe du Bois Forebay	Lac du Bonnet	Manigotagan Lake
Chlorophyll *a* - whole year	(µg/L)	3.24	4.29	4.26	4.04
Chlorophyll *a* - open-water season	(µg/L)	4.22	5.15	5.42	5.03
Bloom Detected (Chlorophyll *a* >10 µg/L)	(Yes/No)	No	No	No	No
Total Biomass	(mg/m^3)	2,936	1,358	1,075	1,094
Simpson's Diversity Index	-	0.68	0.56	0.80	0.83
Effective Richness	-	5	4	7	7
Major Taxa	-	Diatoms	Diatoms	Diatoms	Diatoms
Chlorophyll *a* Trophic Status - whole year	-	Mesotrophic	Mesotrophic	Mesotrophic	Mesotrophic
Chlorophyll *a* Trophic Status - open-water season	-	Mesotrophic	Mesotrophic	Mesotrophic	Mesotrophic

Table 6.3-2. Phytoplankton summary: Saskatchewan River Region.

Mean Metric		Waterbody			
		Saskatchewan River	South Moose Lake	Cedar Lake -Southeast	Cormorant Lake
Chlorophyll *a* - whole year	(µg/L)	2.91	3.68	5.97	1.56
Chlorophyll *a* - open-water season	(µg/L)	3.63	4.57	7.61	1.68
Bloom Detected (Chlorophyll *a* >10 µg/L)	(Yes/No)	No	No	Yes	No
Bloom Period(s)	-	-	-	Fall 2009, Summer 2010	-
Total Biomass[1]	(mg/m^3)	3,927	1,213	5,601	580
Simpson's Diversity Index[1]	-	0.62	0.88	0.81	0.82
Effective Richness[1]	-	6	13	8	8
Major Taxa[1]	-	Diatoms	Blue-green algae	Diatoms	Diatoms
Chlorophyll *a* Trophic Status - whole year	-	Oligotrophic	Mesotrophic	Mesotrophic	Oligotrophic
Chlorophyll *a* Trophic Status - open-water season	-	Oligotrophic	Mesotrophic	Mesotrophic	Oligotrophic

[1]Does not include extra samples analysed under the Bloom Monitoring Program.

Table 6.3-3. Phytoplankton summary: Upper Churchill River Region.

Mean Metric		Waterbody				
		Granville Lake	Southern Indian Lake-Area 1	Southern Indian Lake-Area 6	Southern Indian Lake-Area 4	Gauer Lake
Chlorophyll *a* - whole year	(µg/L)	3.46	2.70	1.31	2.01	4.40
Chlorophyll *a* - open-water season	(µg/L)	3.98	3.43	1.65	2.44	5.54
Bloom Detected (Chlorophyll *a* >10 µg/L)	(Yes/No)	No	No	No	No	Yes
Bloom Period(s)	-	-	-	-	-	Summer 2008
Total Biomass[1]	(mg/m^3)	1,183	1,161	440	483	3,834
Simpson's Diversity Index[1]	-	0.81	0.49	0.64	0.68	0.82
Effective Richness[1]	-	7	4	5	5	9
Major Taxa[1]	-	Diatoms	Diatoms	Cryptophytes	Diatoms	Diatoms
Chlorophyll *a* Trophic Status - whole year	-	Mesotrophic	Mesotrophic	Oligotrophic	Oligotrophic	Mesotrophic
Chlorophyll *a* Trophic Status - open-water season	-	Mesotrophic	Mesotrophic	Oligotrophic	Oligotrophic	Mesotrophic

[1]Does not include extra samples analysed under the Bloom Monitoring Program.

Table 6.3-4. Phytoplankton summary: Lower Churchill River Region.

Mean Metric		Waterbody					
		Partridge Breast Lake	Northern Indian Lake	Billard Lake	Lower Churchill River	Hayes River	Gauer Lake
Chlorophyll *a* - whole year	(µg/L)	1.50	2.39	2.88	2.93	1.83	4.40
Chlorophyll *a* - open-water season	(µg/L)	1.90	3.02	3.74	3.50	2.20	5.54
Bloom Detected (Chlorophyll *a* >10 µg/L)	(Yes/No)	No	No	No	No	No	Yes
Bloom Period(s)	-	-	-	-	-	-	Summer 2008
Total Biomass[1]	(mg/m^3)	546	972	1,245	1,043	508	3,834
Simpson's Diversity Index[1]	-	0.65	0.63	0.80	0.59	0.85	0.82
Effective Richness[1]	-	4	4	9	7	11	9
Major Taxa[1]	-	Diatoms	Diatoms	Diatoms/ Blue-green algae	Diatoms	Mixed	Diatoms
Chlorophyll *a* Trophic Status - whole year	-	Oligotrophic	Oligotrophic	Mesotrophic	Oligotrophic	Oligotrophic	Mesotrophic
Chlorophyll *a* Trophic Status - open-water season	-	Oligotrophic	Mesotrophic	Mesotrophic	Oligotrophic	Oligotrophic	Mesotrophic

[1]Does not include extra samples analysed under the Bloom Monitoring Program.

Table 6.3-5. Phytoplankton summary: Churchill River Diversion Region.

Mean Metric		Waterbody						
		Rat Lake	Notigi Lake -West	Notigi Lake -East	Threepoint Lake	Footprint Lake	Apussigamasi Lake	Leftrook Lake
Chlorophyll *a* - whole year	(µg/L)	1.27	1.86	1.98	1.49	2.57	2.07	6.01
Chlorophyll *a* - open-water season	(µg/L)	1.59	2.40	2.57	1.88	3.33	2.70	7.71
Bloom Detected (Chlorophyll *a* >10 µg/L)	(Yes/No)	No	No	No	No	No	No	Yes
Bloom Period(s)	-	-	-	-	-	-	-	Fall and Summer 2009, Fall 2010
Total Biomass[1]	(mg/m^3)	968	616	294	540	4,612	617	3,769
Simpson's Diversity Index[1]	-	0.40	0.83	0.76	0.82	0.74	0.75	0.67
Effective Richness[1]	-	3	9	6	9	8	6	9
Major Taxa[1]	-	Cryptophytes	Diatoms	Mixed	Diatoms	Diatoms	Diatoms	Diatoms
Chlorophyll *a* Trophic Status - whole year	-	Oligotrophic	Oligotrophic	Oligotrophic	Oligotrophic	Mesotrophic	Oligotrophic	Mesotrophic
Chlorophyll *a* Trophic Status - open-water season	-	Oligotrophic	Oligotrophic	Mesotrophic	Oligotrophic	Mesotrophic	Mesotrophic	Mesotrophic

[1]Does not include extra samples analysed under the Bloom Monitoring Program.

Table 6.3-6. Phytoplankton summary: Upper Nelson River Region.

Mean Metric		Waterbody				
		Playgreen Lake	Little Playgreen Lake	Cross Lake	Walker Lake	Setting Lake
Chlorophyll *a* - whole year	(µg/L)	5.83	3.57	7.04	3.84	3.33
Chlorophyll *a* - open-water season	(µg/L)	7.33	4.06	8.96	4.73	4.15
Bloom Detected (Chlorophyll *a* >10 µg/L)	(Yes/No)	Yes	No	Yes	No	No
Bloom Period(s)	-	Fall 2009	-	Summer and Fall 2008	-	-
Total Biomass[1]	(mg/m^3)	2,594	2,170	1,264	15,503	2,199
Simpson's Diversity Index[1]	-	0.78	0.71	0.73	0.71	0.81
Effective Richness[1]	-	6	6	9	8	10
Major Taxa[1]	-	Diatoms	Diatoms	Diatoms	Diatoms/Blue-green algae	Diatoms
Chlorophyll *a* Trophic Status - whole year	-	Mesotrophic	Mesotrophic	Mesotrophic	Mesotrophic	Mesotrophic
Chlorophyll *a* Trophic Status - open-water season	-	Mesotrophic	Mesotrophic	Eutrophic	Mesotrophic	Mesotrophic

[1]Does not include extra samples analysed under the Bloom Monitoring Program.

Table 6.3-7. Phytoplankton summary: Lower Nelson River Region.

Mean Metric		Waterbody							
		Burntwood River	Split Lake	Stephens Lake -South	Stephens Lake -North	Limestone Forebay	Lower Nelson River	Hayes River	Assean Lake
Chlorophyll *a* - whole year	(µg/L)	1.42	3.47	3.30	1.07	1.79	3.57	1.83	1.63
Chlorophyll *a* - open-water season	(µg/L)	1.90	4.44	4.20	1.37	2.29	4.72	2.20	1.82
Bloom Detected (Chlorophyll *a* >10 µg/L)	(Yes/No)	No	No	No	No	No	No	No	No
Total Biomass	(mg/m^3)	762	2,514	-	-	970	-	508	429
Simpson's Diversity Index	-	0.56	0.64	-	-	0.75	-	0.85	0.84
Effective Richness	-	6	4	-	-	7	-	11	9
Major Taxa	-	Cryptophytes	Diatoms	-	-	Diatoms	-	Mixed	Mixed
Chlorophyll *a* Trophic Status - whole year	-	Oligotrophic	Mesotrophic	Mesotrophic	Oligotrophic	Oligotrophic	Oligotrophic	Oligotrophic	Oligotrophic
Chlorophyll *a* Trophic Status - open-water season	-	Oligotrophic	Mesotrophic	Mesotrophic	Oligotrophic	Oligotrophic	Oligotrophic	Oligotrophic	Oligotrophic

-

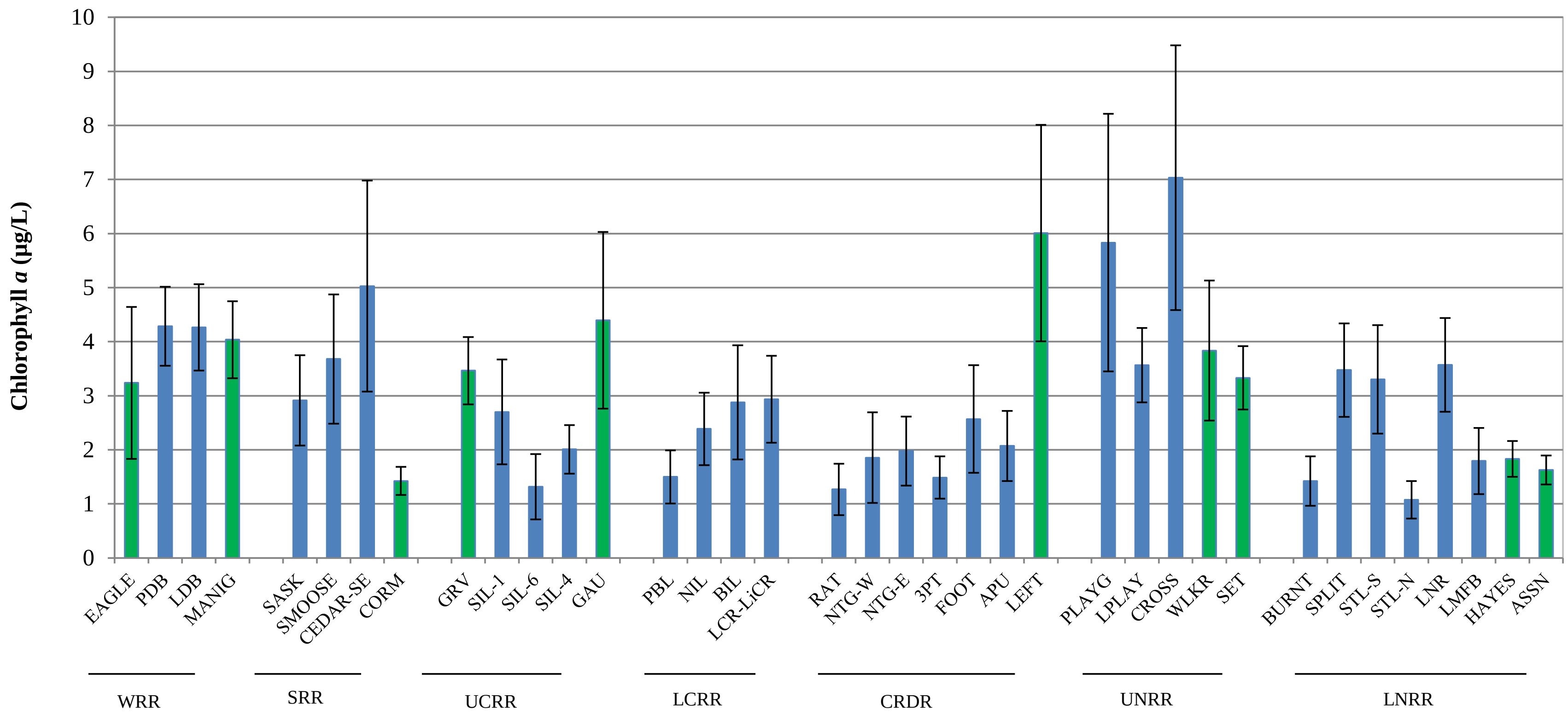


Figure 6.3-1. Mean (±SE) chlorophyll *a* (annual) measured in waterbodies in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). Off-system waterbodies are indicated in green.

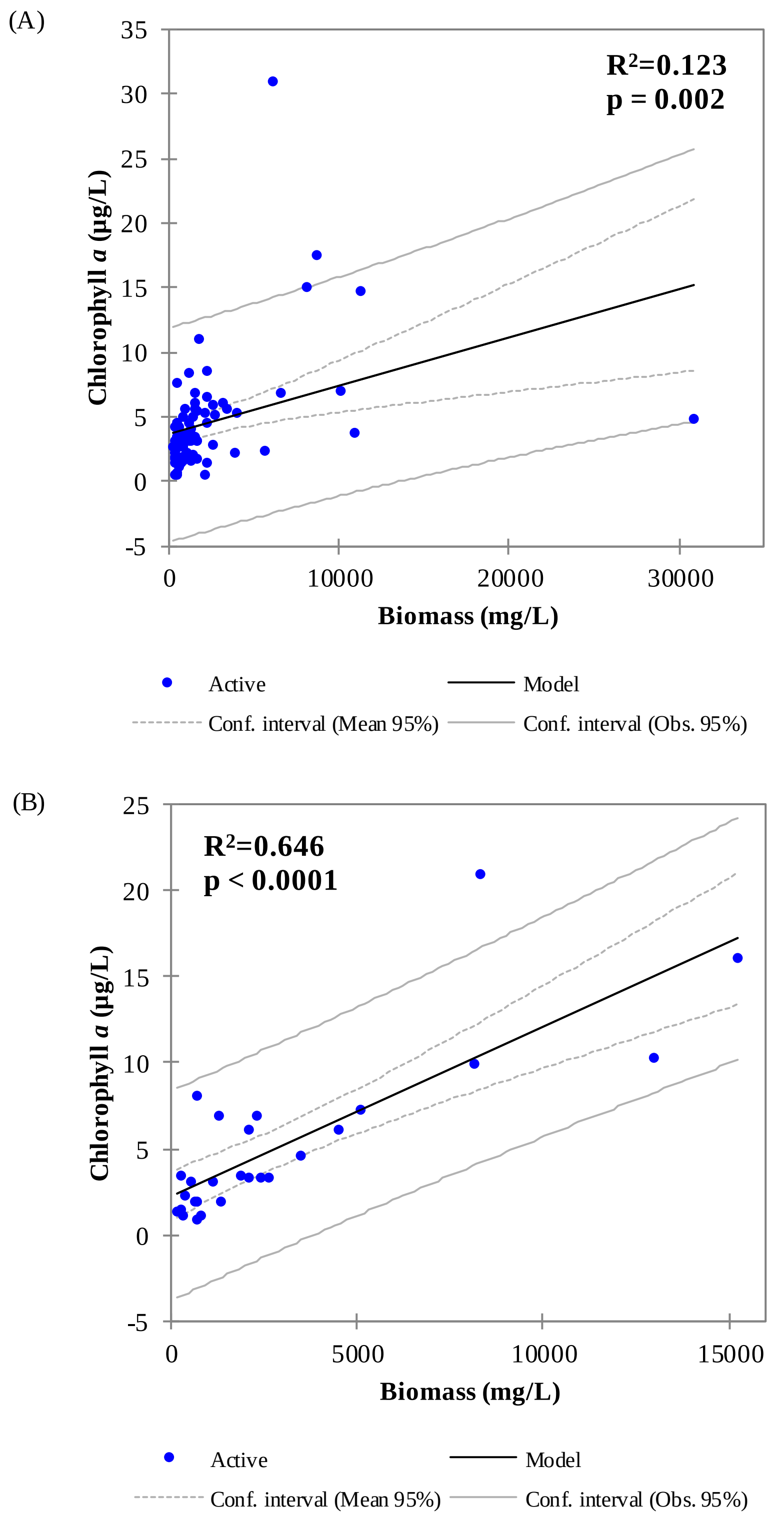


Figure 6.3-2. Linear regressions between chlorophyll *a* and phytoplankton biomass in: (A) on-system lakes and reservoirs across the seven sampling regions (Lake Winnipeg Region excluded); and, (B) off-system lakes.

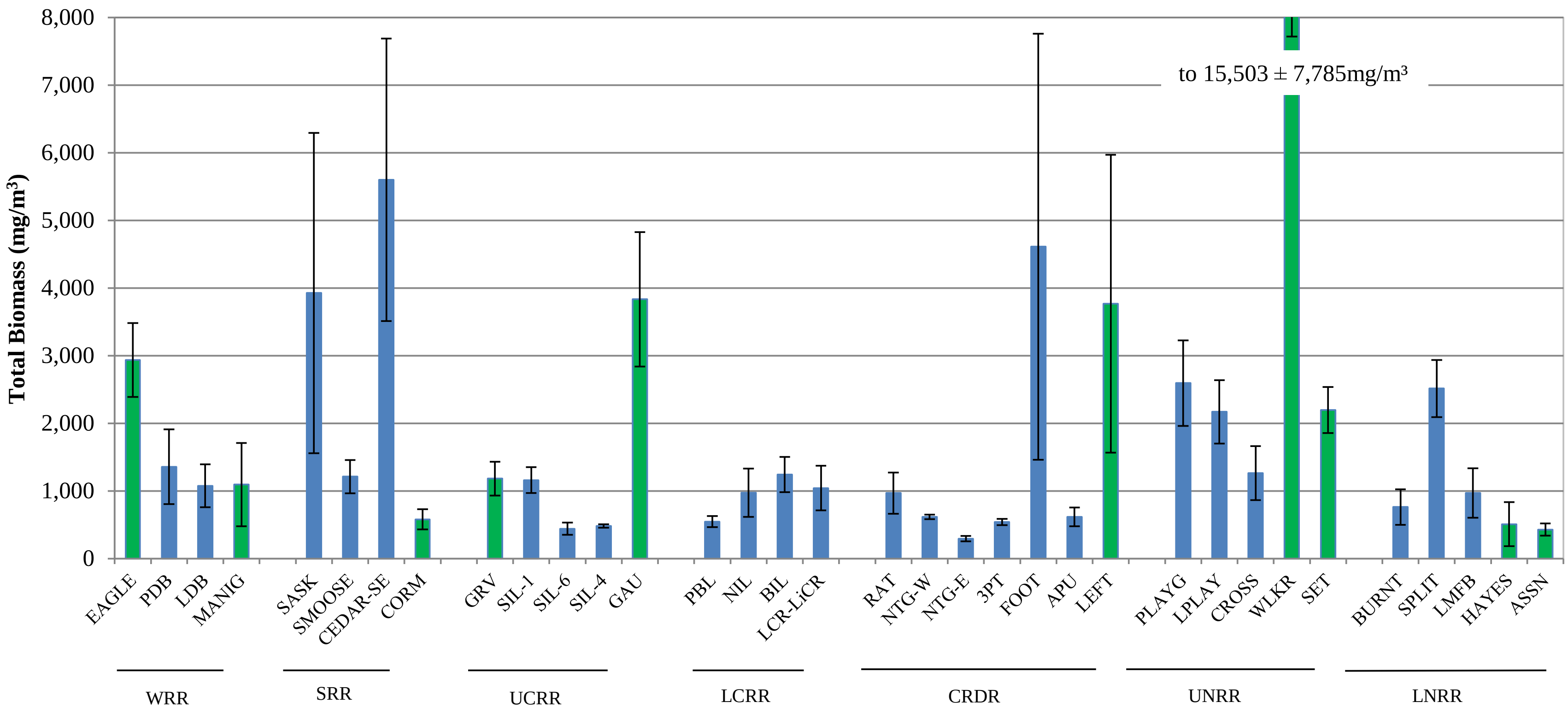


Figure 6.3-3. Mean (±SE) phytoplankton biomass (open-water season) measured in waterbodies in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). Off-system waterbodies are indicated in green.

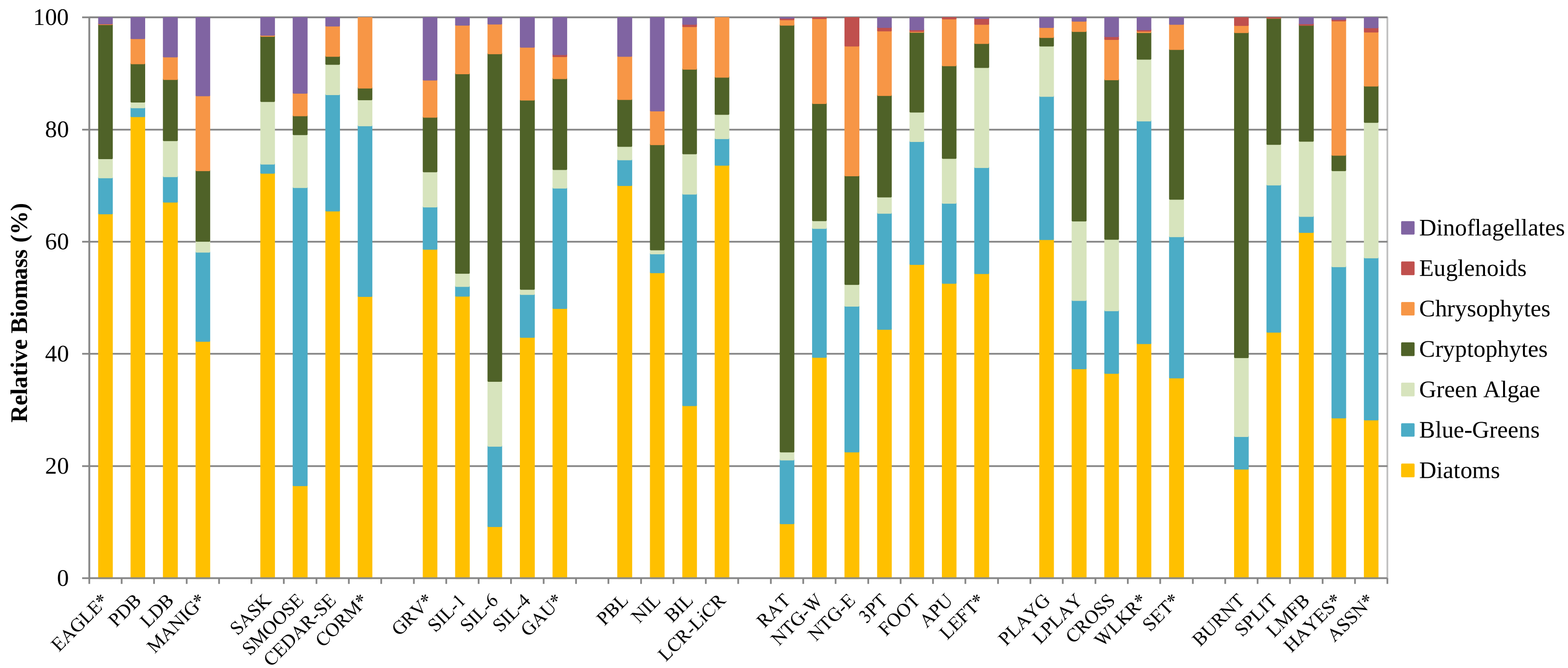


Figure 6.3-4. Mean relative biomass (open-water season) of phytoplankton groups measured in waterbodies in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). Off-system waterbodies are indicated with an asterisk.

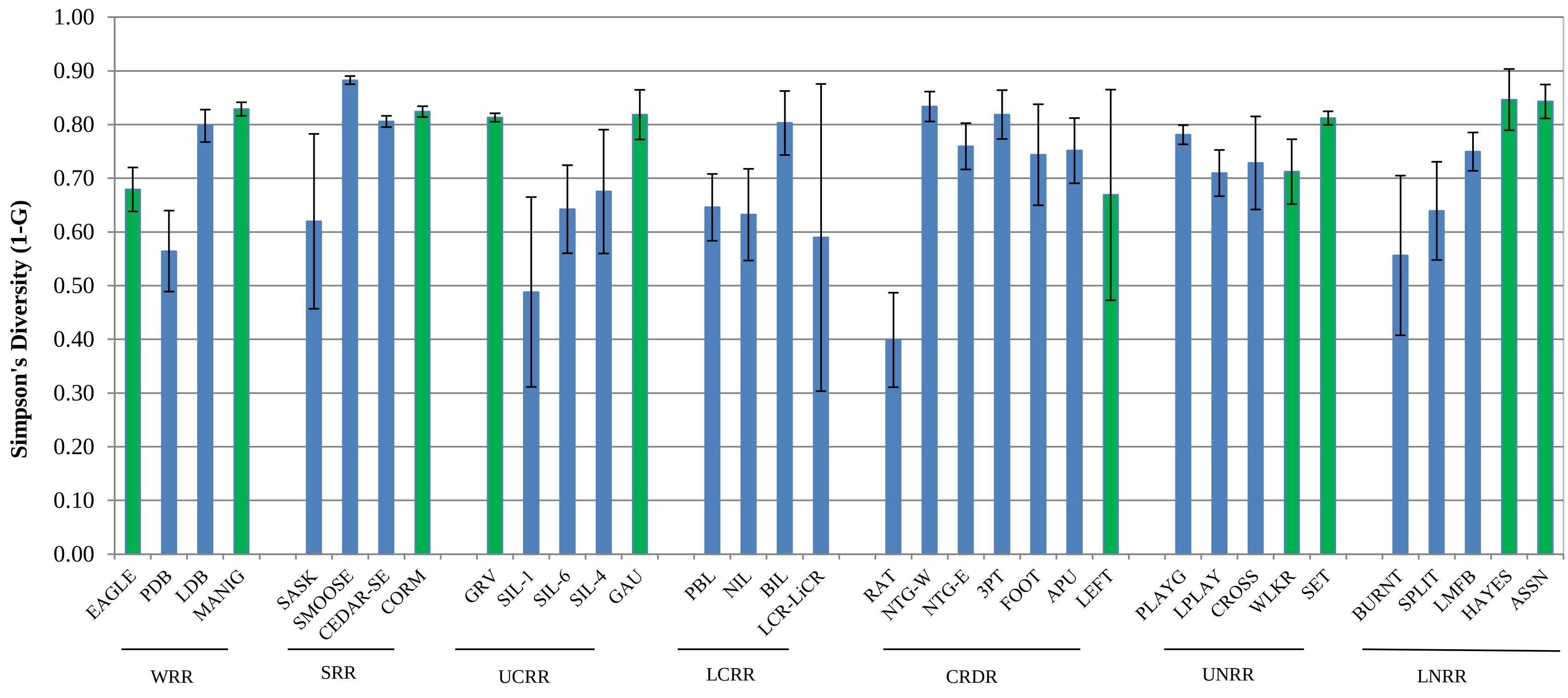


Figure 6.3-5. Mean diversity of phytoplankton communities in waterbodies in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). Off-system waterbodies are indicated in green.

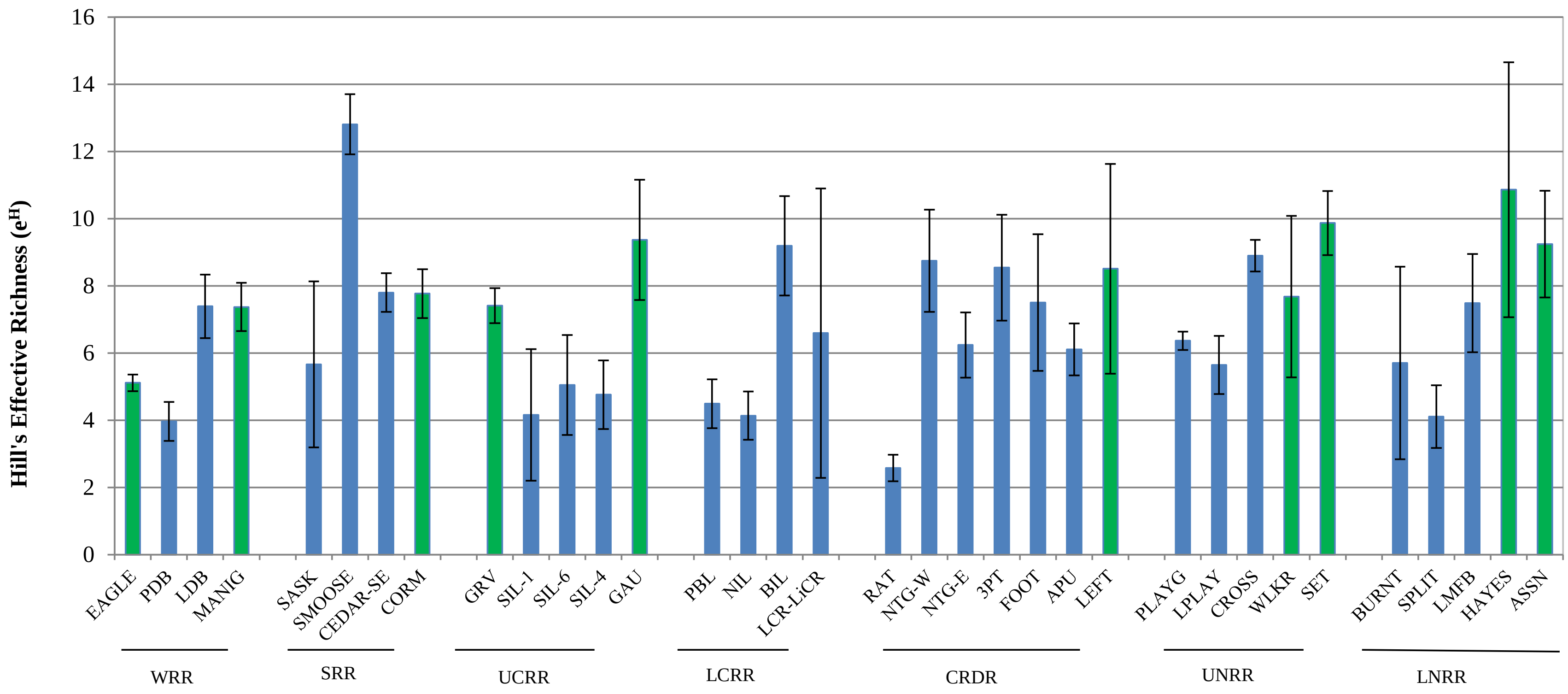


Figure 6.3-6. Mean effective richness of phytoplankton communities in waterbodies in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR). Off-system waterbodies are indicated in green.

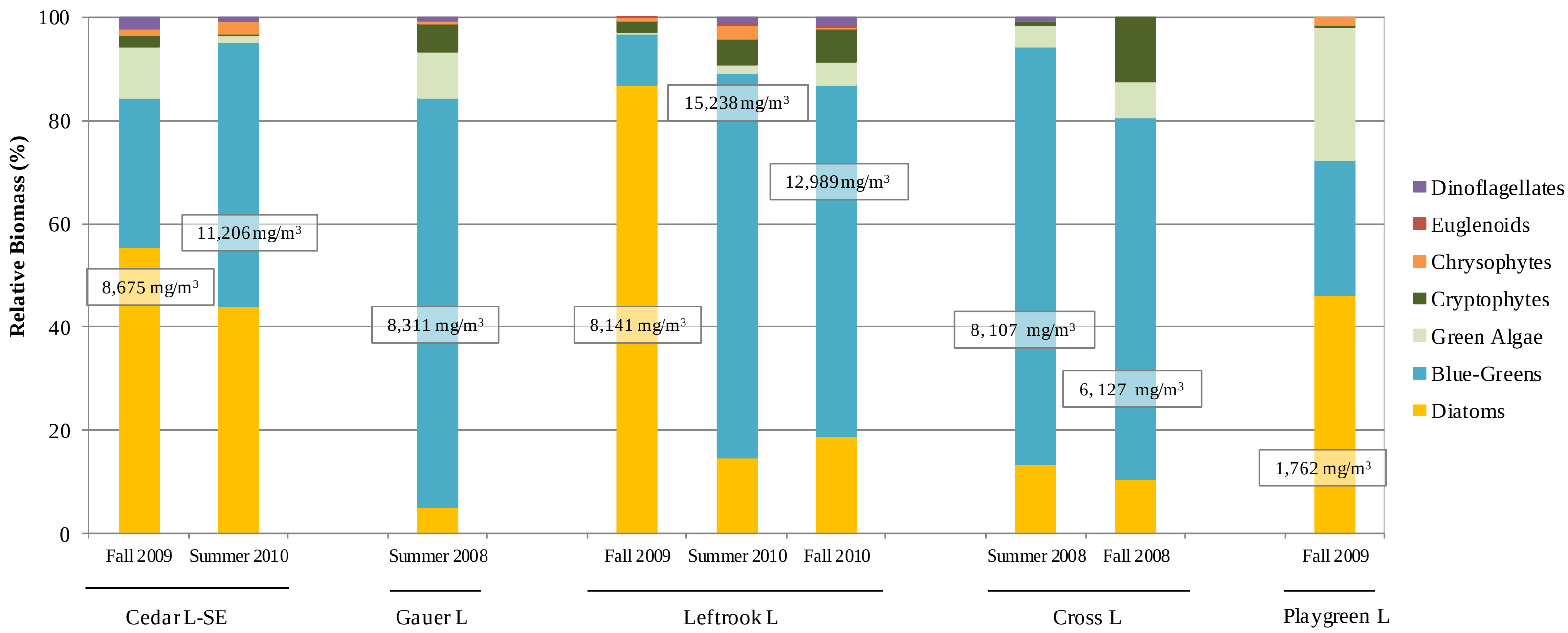


Figure 6.3-7. Relative biomass (%) and total biomass (mg/m^3) of phytoplankton groups measured during bloom conditions (i.e., when chlorophyll *a* > 10 µg/L) in CAMPP waterbodies.

6.4 BENTHIC MACROINVERTEBRATES

The following discussion provides an overview of key benthic macroinvertebrate (BMI) community results based on selected BMI community metrics (community descriptors or parameters) for all the CAMPP waterbodies sampled in Years 1-3 of the pilot program. This overview is intended to provide a broad description of key results for nearshore and offshore habitats sampled across the study regions (excluding the Lake Winnipeg Region), and to comment on general differences and similarities in the BMI communities between on- and off-system waterbodies. Additionally, this review was undertaken to help assess the overall design of the CAMPP BMI community monitoring program and facilitate discussion of potential modifications to the program in the future. As such, the following sections are not intended to provide a comprehensive discussion and the reader is referred to Section 5 of this report for a detailed description of results of the CAMPP BMI community program.

For the purposes of exploring larger geographical patterns, sites located along the main river systems were grouped (on-system) and considered separately from off-system sites. Although Granville lake is located upstream of Manitoba Hydro's hydraulic system, it has been included in the on-system waterbody discussions presented below as it is physically located on the main flow of the upper Churchill River. These two major groups of waterbodies were identified to facilitate exploration of patterns or relationships in BMI community metrics among waterbodies located along the major rivers in comparison to those uninfluenced by the major rivers.

Summaries of key BMI community results for each of the regions are presented in Tables 6.4-1 to 6.4-7 and Figures 6.4-1 to 6.4-18. In Years 1 and 2, nearshore aquatic habitat at water depths between 3 and 5 m (i.e., predominantly wetted) was sampled with a grab device. However, in Year 3, nearshore habitat at water depths less than or equal to 1 m (i.e., intermittently wetted and wadeable) was sampled with a kicknet. Due to this change in sampling methodology, Year 3 nearshore results are not directly comparable to Years 1 and 2 and are discussed separately.

6.4.1 On-System Waterbodies

6.4.1.1 Intermittently Wetted Nearshore Aquatic Habitat

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 mean total BMI abundance measured in a waterbody is a reflection of numerous aquatic habitat variables that have been integrated by the community over time. The mean total BMI abundance measured in intermittently wetted nearshore habitat varied among on-system waterbodies and ranged widely between 35 individuals/kicknet (Footprint Lake – Churchill River Diversion Region) and 7,816 individuals/kicknet (Little Playgreen Lake – Upper Nelson River Region) (Tables 6.4-1 to 6.4-7; Figure 6.4-1). Variability within and among waterbodies may be elevated as only one year of data were available for this aquatic habitat type. The highest mean total abundances occurred within the Winnipeg River, Lower Churchill River, and Upper Nelson River regions, while the lowest occurred within the Saskatchewan River, Churchill River Diversion and Lower Nelson River regions. Within a given region, on-system waterbodies tended to have notably different mean total BMI abundances. Differences were less pronounced among waterbodies within the Upper Churchill River, Churchill River Diversion, and Lower Nelson River regions, where abundances ranged from 35 individuals/kicknet to 323 individuals/kicknet (Tables 6.4-3, 6.4-5, and 6.4-7).

The mean total abundance of Ephemeroptera, Plecoptera, and Trichoptera (EPT) among waterbodies within a region tended to follow a pattern similar to the one observed for mean total BMI abundance (Figures 6.4-1 and 6.4-2), with the exception of waterbodies within the Saskatchewan River, Upper Churchill River and Lower Churchill River regions where order of EPT abundance between lakes was reversed in comparison to total abundance. The highest mean total abundance of EPT occurred within Little Playgreen Lake (552 individuals/kicknet: Upper Nelson River Region), followed by Lac du Bonnet (42 individuals/kicknet: Winnipeg River Region) (Figure 6.4-2). The lowest abundance of EPT occurred in Northern Indian Lake (Lower Churchill River Region) and Limestone Forebay (lower Nelson River) (less than 1 and 1 individual/kicknet, respectively: Tables 6.4-4 and 6.4-7; Figure 6.4-2). EPT comprised between less than 0.1% (Northern Indian Lake) and 59% (Saskatchewan River) of the macroinvertebrate community sampled in intermittently wetted nearshore habitat (see Section 5).

Genus analysis of the Ephemeroptera indicated that the following eight species were dominant or co-dominant in this type of habitat across the regions: *Caenis* sp. (Caenidae), *Ephemera* sp. (Ephemeridae), *Hexagenia* sp. (Ephemeridae), *Procoleon* sp. (Baetidae), *Stenonema* sp. (Heptageniidae), *Callibaetis* sp. (Baetidae), and *Parameletus* (Siphlonuridae). The Ephemeroptera community in waterbodies of the Winnipeg River Region was dominated by *Caenis* sp. or *Ephemera* sp., both of which are similar in their general aquatic habitat preferences in that they prefer fine bottom sediments (silt-clay, silt-sand); however, they may also be representative of heterogeneous bottom sediments (e.g., silt-clay, boulder-cobble mixture) (Table 6.4-1). In the Saskatchewan River Region, *Caenis* sp. and *Hexagenia* sp. were dominant (Table 6.4-2). In Southern Indian Lake within the Upper Churchill River Region, *Caenis* sp. continued to be a dominant genera in Area 4, however, *Procoleon* sp. was dominant in Area 6; *Procoleon* sp. also has the same general aquatic habitat preferences as *Caenis* sp. (Table 6.4-3). *Caenis* sp. was again the dominant genera identified in waterbodies of the Lower Churchill River Region, with the exception of the lower Churchill River at Little Churchill River where *Parameletus* sp. was dominant (Table 6.4-4). *Parameletus* sp. differs in its general aquatic habitat preferences in that they tend to prefer rooted vascular plants; they are swimmers and climbers that associate with plants as collector-gatherers. In the Churchill River Diversion Region, *Hexagenia* sp. was dominant in the intermittently wetted nearshore of Threepoint and Footprint lakes, whereas *Callibaetis* sp. was dominant in Rat Lake (Table 6.4-5). *Hexagenia* sp. has the same general aquatic habitat preferences as *Caenis* sp. Similar to *Parameletus* sp., *Callibaetis* sp. generally prefers rooted vascular plants. The Ephemeroptera community in waterbodies of the Upper Nelson River Region was dominated by *Caenis* sp. (Table 6.4-6). Waterbodies within the Lower Nelson River region were somewhat more variable in terms of the dominant Ephemeroptera genera in comparison to other regions, particularly the Limestone Forebay. In Split Lake, *Caenis* sp. was dominant, while *Procloeon* sp. was dominant in the lower Nelson River; however, in the Limestone Forebay, *Caenis* sp., *Procloeon* sp., and *Stenonema* sp. were co-dominant (Table 6.4-7). *Stenonema* sp. differs in it general aquatic habitat preferences from *Caenis* sp. and *Procloeon* sp. in that they tend to prefer coarse bottom sediments, such as boulder-cobble, and are typically found in waters with some flow (Merritt and Cummins 1996). Overall, the greater variety of dominant genera observed in the intermittently wetted nearshore habitat across the regions and within a region in comparison to the predominantly wetted nearshore likely reflects the increased variability of this intermittently wetted habitat; this type of habitat is more strongly affected by water level fluctuations and wave energy, increased substrate heterogeneity, and potentially by anthropogenic factors (e.g., water level regulation; shoreline development, etc.).

EPT are generally considered to be more sensitive and Chironomidae less sensitive to environmental stress (e.g., nutrient enrichment, low dissolved oxygen concentrations). A community considered to be in good biotic condition may display an even distribution among these groups, while communities with disproportionately high numbers of chironomids may indicate environmental stress, either natural or anthropogenic. Although chironomids 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. The mean ratio of EPT:C was less than 1 for 9 of the 18 on-system waterbodies sampled across the regions, indicative of an insect community typically dominated by Chironomidae in intermittently wetted nearshore habitat (Figure 6.4-3). Waterbodies with an EPT:C ratio greater than 1 included Pointe du Bois Forebay and Lac du Bonnet in the Winnipeg River Region (1.48 and 1.42, respectively: Table 6.4-1), Saskatchewan River and Cedar Lake-Southeast in the Saskatchewan River Region (10.73 and 2.04, respectively: Table 6.4-2), Southern Indian Lake-Area 6 in the Upper Churchill River Region (8.73: Table 6.4-3), Billard Lake and lower Churchill River at Little Churchill River in the Lower Churchill River Region (1.36 and 5.75, respectively: Table 6.4-4), Rat Lake in the Churchill River Diversion Region (1.04: Table 6.4-5), and Split Lake in the Lower Nelson

River Region (1.37: Table 6.4-7). On-system waterbodies within the Upper Nelson River Region all had an insect community dominated by Chironomidae, whereas other regions had both Chironomidae and Ephemeroptera dominated communities in this type of aquatic habitat.

The number of unique taxa (total taxonomic richness) provides information about the "health" or 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]) at a site, with more taxa often suggesting a more "pristine" or less perturbed site. The mean taxonomic richness (at the family level) among waterbodies within a region tended to reflect the pattern observed for mean total macroinvertebrate abundance, with the exception of waterbodies within the Winnipeg River Region, Upper Churchill River Region, and Lower Churchill River Region, where order of richness between lakes was reversed in comparison to abundance (Figures 6.4-1 and 6.4-4). The highest mean taxonomic richness occurred within Cedar Lake-Southeast (Saskatchewan River Region) (20 families; Table 6.4-2); the lowest occurred in the Saskatchewan River (Saskatchewan River Region) and Limestone Forebay (Lower Nelson River Region) (6 families: Tables 6.4-2 and 6.4-7, respectively). Within a given region, on-system waterbodies tended to have notably different mean taxonomic richness in this aquatic habitat type. The exceptions to this were the waterbodies sampled along the Winnipeg River and the upper Churchill River, where richness was relatively comparable among a region's waterbodies (Tables 6.4-1 and 6.4-3, respectively; Figure 6.4-4).

Simpson's Diversity index provides an estimate of the probability that two individuals in a sample belong to the same species. The higher the index (0 to 1), the less likely it is that two individuals belong to the same species, i.e., likely the higher the diversity (Magurran 2004). However, it is important to keep in mind that this index is not itself a diversity and it is highly nonlinear. Diversity indices attempt to summarize the relative abundance of various taxa. An index may provide more succinct information about BMI communities than abundance or richness alone. 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). Simpson's Diversity index and taxonomic richness demonstrated the same pattern among waterbodies within the Winnipeg River, Saskatchewan River, Upper Churchill River, Upper Nelson River, and Lower Nelson River regions (Figures 6.4-4 and 6.4-5). The order of the index of diversity between lakes was reversed in comparison to richness for the Lower Churchill River and Churchill River Diversion regions. An opposing pattern where a lower index of diversity corresponds to a higher richness value may indicate that the higher richness value is due to the presence of rare taxa in samples. The highest index of diversity occurred within Rat Lake (Churchill River Diversion Region), and Split Lake (Lower Nelson River Region) (0.80 and 0.82, respectively: Tables 6.4-5 and 6.4-7; Figure 6.4-5); the lowest index of diversity occurred in Lac du Bonnet (Winnipeg River Region) and Granville Lake (Upper Churchill River Region) (0.40 and 0.38, respectively: Tables 6.4-1 and 6.4-3; Figure 6.4-5). Within a given region, on-system waterbodies tended to have notably different indices of diversity (Table 6.5-5).

Mean Hill's effective richness among waterbodies within a region generally followed the same pattern as was observed for the index of diversity (Figures 6.4-5 and 6.4-6). Effective richness provides an estimate of the number of taxa that contribute to the majority of the community represented in the sample collected (i.e., the number of taxa identified in a sample that are considered 'dominant'). As for the highest index of diversity, the highest effective richness occurred within Rat Lake and Split Lake (8 families: Tables 6.4-5 and 6.4-7). In a pattern similar to the index of diversity, the lowest effective richness occurred within Lac du Bonnet and Granville lake (3 families: Tables 6.4-1 and 6.4-3); however, other waterbodies with an effective richness of 3 families included the Saskatchewan River, lower Churchill River at Little Churchill River and the Limestone Forebay (Figure 6.4-6).

6.4.1.2 Predominantly Wetted Nearshore Aquatic Habitat

The mean total BMI abundance measured in predominantly wetted nearshore habitat varied among on-system waterbodies and ranged from 375 individuals/m^2 (Split Lake – Lower Nelson River Region) to 7,811 individuals/m^2 (South Moose Lake – Saskatchewan River Region) (Tables 6.4-1 to 6.4-7; Figure 6.4-7). The highest mean total abundances occurred within the Saskatchewan River and Upper Nelson River regions, while the lowest occurred within the Upper Churchill River, Churchill River Diversion, and Lower Nelson River regions. Within a given region, on-system waterbodies tended to have notably different mean total BMI abundances. The exception to this was the waterbodies sampled along the Churchill River Diversion route, where abundances were comparable and relatively low (less than 1,000 individuals/m^2) (Table 6.4-5).

The mean total abundance of the major insect groups Ephemeroptera, Plecoptera, and Trichoptera taken together (i.e., EPT) among waterbodies within a region followed a pattern similar to the one observed for mean total macroinvertebrate abundance (Figures 6.4-8 and 6.4-8), with the exception of waterbodies within the Upper Churchill River, Lower Churchill River, and Upper Nelson River regions where order of EPT abundance between lakes was reversed in comparison to total abundance. The highest mean total abundance of EPT occurred within Stephens Lake-South (1,368 individuals/m^2: Lower Nelson River Region), followed by Cross Lake, Pointe du Bois Forebay, and Northern Indian Lake; the lowest abundance occurred in Partridge Breast Lake (3 individuals/m^2: Lower Churchill River Region) (Figure 6.4-8). EPT comprised between less than 0.5% (Partridge Breast Lake) and 83% (Stephens Lake-South) of the macroinvertebrate community sampled in predominantly wetted nearshore habitat (see Section 5).

Genus analysis of the Ephemeroptera indicated that *Hexagenia* sp. (Ephemeridae) was the dominant Ephemeroptera taxon in this type of aquatic habitat across the regions, with the exception of Southern Indian Lake-Area 4 (Upper Churchill River Region), where *Hexagenia* sp. was co-dominant with *Caenis* sp. (Caenidae), and Partridge Breast Lake, where *Caenis* sp. was dominant (Tables 6.4-1 to 6.4-7). These two genera are similar in their general aquatic habitat preferences in that they prefer fine bottom sediments, such as silt-clay and/or silt-sand, and their predominance likely reflects the sediment characteristics of the areas sampled (see Section 5). Both are collector-gatherers, however, *Hexagenia* sp. are referred to as burrowers and *Caenis* sp. as sprawlers and climbers (Merritt and Cummins 1996).

The mean ratio of EPT to Chironomidae (EPT:C) was less than 1 for the majority of waterbodies sampled across the regions, indicative of an insect community dominated by Chironomidae in predominantly wetted nearshore habitat (Figure 6.4-9). Exceptions to this included Pointe du Bois Forebay and Lac du Bonnet in the Winnipeg River Region (1.54 and 1.13, respectively: Table 6.4-1), Southern Indian Lake-Area 1 in the Upper Churchill River Region (1.30: Table 6.4-3), Threepoint Lake in the Churchill River Diversion Region (1.38: Table 6.4-5), Cross Lake in the Upper Nelson River Region (5.17: Table 6.4-6), and Stephens Lake-South in the Lower Nelson River Region (9.32: Table 6.4-7), where Ephemeroptera were more abundant than Chironomidae.

The mean taxonomic richness (at the family level) among waterbodies within a region reflected the pattern observed for mean total BMI abundance, with the exception of waterbodies within the Lower Churchill River, the Churchill River Diversion, and Lower Nelson River regions, where order of richness between lakes was reversed in comparison to abundance (Figures 6.4-7 and 6.4-10). Agreement in the pattern between total taxonomic richness and total BMI abundance indicates that BMI communities with higher measured abundances are typically comprised of a greater number of families. The highest mean taxonomic richness occurred within Playgreen Lake (9 families: Upper Nelson River Region), followed closely by South Moose Lake and Pointe du Bois Forebay; the lowest taxonomic richness occurred in Partridge Breast Lake (3 families: Lower Churchill River Region), followed closely by Southern Indian Lake-Area 1 and Notigi Lake (Figure 6.4-10).Within a given region, on-system waterbodies tended to have notably different mean taxonomic richness. The exception to this was the waterbodies sampled along the Churchill River Diversion route, where richness was comparable and relatively low (4 families or less) (Table 6.4-5).

Simpson's Diversity index and taxonomic richness demonstrated the same pattern among waterbodies within the Winnipeg River, Upper Churchill River, Lower Churchill River, and Upper Nelson River regions (Figures 6.4-10 and 6.4-11). The order of the index of diversity between lakes was reversed in comparison to richness for the Saskatchewan River, Churchill River Diversion, and Lower Nelson River regions. An opposing pattern where a lower index of diversity corresponds to a higher richness value may indicate that the higher richness value is due to the presence of rare taxa in samples. The highest index of diversity occurred within Pointe du Bois Forebay (Winnipeg River Region), Southern Indian Lake-Area 4 (Upper Churchill River Region), and Stephens Lake-North (Lower Nelson River Region) (0.72, 0.73, and 0.73, respectively: Tables 6.4-1, 6.4-3, and 6.4-7; Figure 6.4-11); the lowest index of diversity occurred in Partridge Breast Lake (0.13: Lower Churchill River Region) (Table 6.4-4; Figure 6.4-11). Within a given region, on-system waterbodies tended to have notably different indices of diversity. The exception to this was the waterbodies sampled along the Churchill River Diversion route, where indices of diversity were somewhat more comparable (range of 0.50 to 0.59: Table 6.4-5).

Mean Hill's effective richness among waterbodies within a region generally followed the same pattern as was observed for the index of diversity (Figures 6.4-11 and 6.4-12). The highest effective richness occurred within the Pointe du Bois Forebay (6 families: Table 6.4-1) and the lowest in Partridge Breast Lake (1 family: Table 6.4-4).

6.4.1.3 Offshore Aquatic Habitat

The mean total BMI abundance measured in offshore aquatic habitat varied among on-system waterbodies and ranged widely from 124 individuals/m^2 (Rat Lake – Churchill River Diversion Region) to 7,794 individuals/m^2 (Stephens Lake-South – Lower Nelson River Region) (Tables 6.4-5 and 6.4-7; Figure 6.4-13). The highest mean total abundances occurred within the Upper Nelson River and Lower Nelson River regions, while the lowest occurred within the Saskatchewan River, Upper Churchill River, and Churchill River Diversion regions (waterbodies with less than 1,000 individuals/m^2). Within a given region, on-system waterbodies tended to have notably different mean total BMI abundances. The exception to this was the waterbodies sampled along the Churchill River Diversion, particularly Rat, Notigi, Threepoint, and Footprint lakes, where abundances were comparable and relatively low in comparison to other regions (Figure 6.4-13).

The pattern in mean total EPT abundance among waterbodies within a region was dissimilar from the one observed for total macroinvertebrate abundance, with the exception of the Saskatchewan River and Lower Nelson River regions (Figures 6.4-13 and 6.4-14). This was likely due in part to the very low EPT abundances that obscured the development of clear patterns of abundances among waterbodies in offshore aquatic habitat. Additionally, it is also likely indicative of a BMI community that is comprised of taxa that are proportionately more abundant in comparison to EPT. The highest mean total abundance of EPT in offshore habitat occurred in Stephens Lake-South, followed by Split Lake (1,818 and 1,392 individuals/m^2, respectively: Lower Nelson River Region) (Figure 6.4-14). Numerous waterbodies across the regions had comparatively low abundances of EPT (less than 150 individuals/m^2); South Moose Lake and Cedar Lake-Southeast in the Saskatchewan River Region (6 and 30 individuals/m^2, respectively: Table 6.4-2), Granville Lake, Southern Indian Lake-Area 1, Southern Indian Lake-Area 6, Southern Indian Lake-Area 4 in the Upper Churchill River Region (120, 32, 61, and 0 individuals/m^2, respectively: Table 6.4-3), Partridge Breast Lake, Billard Lake, and lower Churchill River at Little Churchill River in the Lower Churchill River Region (20, 12, and 133 individuals/m^2, respectively: Table 6.4-4), Rat, Notigi, Threepoint, Footprint, and Apussigamasi lakes in the Churchill River Diversion Region (38, 0, 60, 32, and 63 individuals/m^2: Table 6.4-5), and Stephens Lake-North in the Lower Nelson River Region (23 individuals/m^2: Table 6.4-7). EPT comprised between 0% (Southern Indian Lake-Area 4 and Notigi Lake) and 52% (Pointe du Bois Forebay and Cross Lake) of the BMI community sampled in offshore habitat (see Section 5).

Genus analysis of the Ephemeroptera indicated that *Hexagenia* sp. (Ephemeridae: burrowing Ephemeroptera that prefer fine bottom sediments such as silt-clay and/or silt-sand) was the dominant Ephemeroptera taxon in this type of aquatic habitat across the regions (Tables 6.4-1 to 6.4-7). The three exceptions to this were Southern Indian Lake-Area 4 and Notigi Lake, where no EPT were captured, and the lower Nelson River, where no Ephemeroptera were captured. The EPT community sampled in the lower Nelson River consisted exclusively of Trichoptera with Hydropsychidae being the dominant family encountered. Hydrospsychidae generally prefer coarse bottom sediments, such as boulder-cobble, and are found in waters with some flow (Merritt and Cummins 1996).

The mean ratio of EPT:C was less than 1 for the majority of waterbodies sampled across regions, indicating an insect community that was dominated by Chironomidae in offshore habitat (Figure 6.4-15). Notable exceptions to this included Pointe du Bois Forebay in the Winnipeg River Region (4.34: Table 6.4-1), Cross Lake in the Upper Nelson River Region (3.69: Table 6.4-6), and Split Lake in the Lower Nelson River Region (10.52: Table 6.4-7), where Ephemeroptera were considerably more abundant than Chironomidae.

The pattern in mean taxonomic richness (at the family level) among waterbodies within a region was generally dissimilar from the one observed for total BMI abundance, with the exception of the Winnipeg River and Saskatchewan River regions (Figures 6.4-13 and 6.4-16). Disagreement in the pattern between total taxonomic richness and total macroinvertebrate abundance indicates that BMI communities with higher measured abundances are typically comprised of a fewer number of families. However, Playgreen Lake did exhibit one of the higher mean total macroinvertebrate abundances and one of the highest mean taxonomic richness values, and Rat Lake the lowest total abundance and one of the lowest richness values, which indicates that abundance and richness may reflect the same pattern in offshore habitat for a sub-set of waterbodies. The highest taxonomic richness occurred within the Limestone Forebay (Lower Nelson River Region) (10 families: Table 6.4-7), followed by Little Playgreen Lake (Upper Nelson River Region) (9 families: Table 6.4-6); the lowest occurred in Rat and Notigi lakes within the Churchill River Diversion Region (2 families: Table 6.4-5). Within a given region, on-system waterbodies tended to have notably different taxonomic richness values in offshore habitat (Figure 6.4-16).

Simpson's Diversity index and taxonomic richness demonstrated a very similar pattern among waterbodies within the majority of regions sampled (Figures 6.4-16 and 6.4-17). The highest index of diversity for on-system waterbodies occurred in the Limestone Forebay (0.82: Table 6.4-7), the waterbody with the correspondingly highest taxonomic richness value of 10 families. The on-system water body with the lowest index diversity was Partridge Breast Lake (0.26: Table 6.4-4); however, Partridge Breast Lake did not have the lowest taxonomic richness value, which suggests that its comparatively higher richness value was due to the presence of rare taxa in samples. Within a given region, offshore aquatic habitat sampled in on-system waterbodies tended to have notably different indices of diversity, with the exception of waterbodies sampled along the Winnipeg River where indices of diversity were both 0.58 (Table 6.4-1).

Mean Hill's effective richness among waterbodies within a region typically followed the same pattern as was observed for the index of diversity (Figures 6.4-17 and 6.4-18). As for the highest index of diversity, the highest effective richness occurred in the Limestone Forebay (7 families: Table 6.4-7). In a pattern similar to the index of diversity, the lowest effective richness occurred in Partridge Breast Lake (2 families: Table 6.4-4). However, other waterbodies with comparably higher indices of diversity also had effective richness values of 2 families; these included, Southern Indian Lake-Area 1 (0.31 index of diversity: Table 6.4-3), Southern Indian Lake-Area 4 (0.41: Table 6.4-3), Rat Lake (0.33: Table 6.4-5), Notigi Lake (0.31: Table 6.4-5), and Stephens Lake-North (0.40: Table 6.4-7) (Figure 6.4-18).

6.4.2 Off-system Waterbodies

Off-system waterbodies monitored under CAMPP are inherently different from on-system waterbodies due to differences in lake morphometry, drainage basin size (particularly in proportion to waterbody size), hydrology, etc. (see Section 3). Thus, differences in the BMI community of on-system and off-system waterbodies were anticipated.

In intermittently wetted nearshore and offshore aquatic habitat, off-system waterbodies often fell within the range of or were higher than total BMI abundances observed for neighbouring on-system waterbodies (Figures 6.4-1 and 6.4-13). For the predominantly wetted nearshore aquatic habitat type, total abundance measured in off-system waterbodies was often notably higher than the range of abundances observed for corresponding on-system waterbodies (Figure 6.4-7). Intermittently wetted nearshore habitat in Manigotagan Lake, and offshore habitat in Eaglenest Lake and Assean Lake were notable exceptions to the above, as each had the lowest total abundance in their respective regions.

The mean total abundance of EPT in off-system waterbodies often fell within the range observed for on-system waterbodies within the same region, particularly for predominantly wetted nearshore and offshore aquatic habitat types (Figures 6.4-8 and 6.4-14). In intermittently wetted nearshore habitat, off-system waterbody Manigotagan Lake had an EPT abundance that was lower in comparison to its on-system counterparts, while Eaglenest, Cormorant, and Assean lakes had notably higher abundances of EPT (Figure 6.4-2). As for on-system waterbodies, *Hexagenia* sp. was the dominant type of Ephemeroptera taxon in off-system waterbodies for both predominantly wetted nearshore and offshore habitat (Tables 6.4-1 to 6.4-7). Similar to the intermittently wetted nearshore habitat sampled in on-system waterbodies, there was a greater variety of dominant genera observed in the off-system waterbodies that likely reflected the increased variability or heterogeneity of this habitat type. Genera encountered in this type of habitat in off-system waterbodies were also captured on-system, with the exception of *Baetisca* sp. (Baetiscidae) that was only observed in the off-system Hayes River. *Baetisca* sp. prefers sandy bottom sediments, often with detritus, and are typically found in depositional areas of flowing waters (Merritt and Cummins 1996).

The EPT:C ratio in off-system waterbodies were typically within the range of ratios observed for predominantly wetted nearshore and offshore habitat types in adjacent on-system waterbodies (Figures 6.4-9 and 6.4-15), but comparatively less so for intermittently wetted nearshore habitat (Figure 6.4-3). Intermittently wetted nearshore habitat in Manigotagan and Cormorant lakes had EPT:C ratios that were lower than the range exhibited for on-system waterbodies in the same region, whereas Leftrook, Setting, and Assean lakes, and the Hayes River had ratios that were higher.

Mean taxonomic richness values of off-system waterbodies were somewhat less likely to be encompassed by the range of values for neighbouring on-system waterbodies in intermittently wetted nearshore habitat in comparison to predominantly wetted nearshore and offshore habitats (Figures 6.4-4, 6.4-10, and 6.4-16). Intermittently wetted nearshore habitat in Manigotagan Lake had richness values that were lower than the range exhibited for adjacent on-system waterbodies, whereas Walker, Setting, and Assean lakes had richness values that were higher.

Similar to other BMI community metrics, diversity index values in off-system waterbodies were less likely to be encompassed by the range of values for adjacent on-system waterbodies in intermittently wetted nearshore habitat in comparison to predominantly wetted nearshore and offshore habitat (Figures 6.4-5, 6.4-11, and 6.4-17). Intermittently wetted nearshore habitat in Gauer Lake and the Hayes River had diversity index values that were lower than the range of on-system waterbodies in the same region; Eaglenest, Cormorant, and Setting lakes had diversity index values that were higher. Hill's effective richness in off-system waterbodies reflected a pattern similar to Simpson's Diversity index (Figures 6.4-6, 6.4-12, and 6.4-18).

Table 6.4-1. Benthic macroinvertebrate summary: Winnipeg River Region.

Invertebrate Community Measure	units	Eaglenest Lake		Pointe du Bois Forebay		Lac du Bonnet		Manigotagan Lake	
		Nearshore (2008-2009)	Offshore (2010)	Nearshore (2008-2009)	Offshore (2008-2010)	Nearshore (2008-2009)	Offshore (2008-2010)	Nearshore (2008-2009)	Offshore (2008-2010)
Total Invertebrates (density/abundance)	mean no./m^2	--	721	3373	1196	1063	4097	3669	1869
EPT Index (abundance)	mean no./m^2	--	248	452	626	95	379	316	5
Genus analysis of Ephemeroptera	dominant	--	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*
EPT:Chironomidae	ratio	--	1.87	1.54	4.34	1.13	1.04	0.20	0.04
Taxonomic Richness	family-level	--	6	8	4	5	7	7	5
Simpson's Diversity (D)	index	--	0.61	0.72	0.58	0.52	0.58	0.64	0.73
Hill's Effective Richness ($E_{H'}$)	family-level	--	4	6	3	3	4	4	5
		Nearshore (2010)	--	Nearshore (2010)	--	Nearshore (2010)	--	Nearshore (2010)	--
Total Invertebrates (density/abundance)	mean no./kicknet	401	--	174	--	556	--	107	--
EPT Index (abundance)	mean no./kicknet	93	--	14	--	42	--	10	--
Genus analysis of Ephemeroptera	dominant	Caenidae: *Caenis*	--	Caenidae: *Caenis*	--	Ephemeridae: *Ephemera*	--	Leptophlebiidae: unidentified + Baetidae: *Procloeon*	--
EPT:Chironomidae	ratio	0.88	--	1.48	--	1.42	--	0.43	--
Taxonomic Richness	family-level	17	--	18	--	16	--	11	--
Simpson's Diversity (D)	index	0.85	--	0.71	--	0.40	--	0.69	--
Hill's Effective Richness ($E_{H'}$)	family-level	10	--	7	--	3	--	6	--

Table 6.4-2. Benthic macroinvertebrate summary: Saskatchewan River Region.

Invertebrate Community Measure	units	Saskatchewan River		South Moose Lake		Cedar Lake-Southeast		Cormorant Lake	
		--	Offshore (2010)	Nearshore (2009)	Offshore (2009)	Nearshore (2009)	Offshore (2009-2010)	Nearshore (2009)	Offshore (2009-2010)
Total Invertebrates (density/abundance)	mean no./m^2	--	915	7811	762	1434	2701	3406	1033
EPT Index (abundance)	mean no./m^2	--	352	340	6	23	30	59	70
Genus analysis of Ephemeroptera	dominant	--	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	--	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*
EPT:Chironomidae	ratio	--	2.60	0.14	0.07	0.05	0.04	0.11	0.25
Taxonomic Richness	family-level	--	6	9	4	5	5	7	5
Simpson's Diversity (D)	index	--	0.55	0.59	0.61	0.68	0.68	0.72	0.65
Hill's Effective Richness ($E_{H'}$)	family-level	--	3	4	3	4	4	5	4
		Nearshore (2010)	--	--	--	Nearshore (2010)	--	Nearshore (2010)	--
Total Invertebrates (density/abundance)	mean no./kicknet	61	--	--	--	356	--	215	--
EPT Index (abundance)	mean no./kicknet	36	--	--	--	32	--	53	--
Genus analysis of Ephemeroptera	dominant	Ephemeridae: *Hexagenia*	--	--	--	Caenidae: *Caenis*	--	Caenidae: *Caenis*	--
EPT:Chironomidae	ratio	10.73	--	--	--	2.04	--	0.56	--
Taxonomic Richness	family-level	6	--	--	--	20	--	20	--
Simpson's Diversity (D)	index	0.60	--	--	--	0.69	--	0.77	--
Hill's Effective Richness ($E_{H'}$)	family-level	3	--	--	--	6	--	8	--

Table 6.4-3. Benthic macroinvertebrate summary: Upper Churchill River Region.

Invertebrate Community Measure	units	Granville Lake		Southern Indian Lake-Area 1		Southern Indian Lake-Area 6		Southern Indian Lake-Area 4		Gauer Lake	
		Nearshore (2008-2009)	Offshore (2008-2010)	Nearshore (2009)	Offshore (2009)	--	Offshore (2010)	Nearshore (2008-2009)	Offshore (2008-2010)	Nearshore (2008-2009)	Offshore (2008-2010)
Total Invertebrates (density/abundance)	mean no./m^2	733	1824	459	1094	--	643	3512	2132	5375	3758
EPT Index (abundance)	mean no./m^2	84	120	139	32	--	61	17	0	114	21
Genus analysis of Ephemeroptera	dominant	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	--	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia* + *Caenis*	--	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*
EPT:Chironomidae	ratio	0.70	0.73	1.30	0.50	--	0.73	0.01	0.00	0.13	0.02
Taxonomic Richness	family-level	4	5	3	3	--	6	5	4	6	5
Simpson's Diversity (D)	index	0.51	0.48	0.52	0.31	--	0.67	0.73	0.41	0.61	0.65
Hill's Effective Richness (E_H)	family-level	3	3	3	2	--	4	5	2	3	4
		Nearshore (2010)	--	--	--	Nearshore (2010)	--	Nearshore (2010)	--	Nearshore (2010)	--
Total Invertebrates (density/abundance)	mean no./kicknet	323	--	--	--	100	--	110	--	180	--
EPT Index (abundance)	mean no./kicknet	4	--	--	--	6	--	4	--	4	--
Genus analysis of Ephemeroptera	dominant	Baetidae: *Procloeon*	--	--	--	Baetidae: *Procloeon*	--	Caenidae: *Caenis*	--	Heptageniidae: *Stenonema*	--
EPT:Chironomidae	ratio	0.26	--	--	--	8.73	--	0.15	--	2.89	--
Taxonomic Richness	family-level	11	--	--	--	12	--	14	--	13	--
Simpson's Diversity (D)	index	0.38	--	--	--	0.59	--	0.69	--	0.29	--
Hill's Effective Richness (E_H)	family-level	3	--	--	--	4	--	6	--	3	--

Table 6.4-4. Benthic macroinvertebrate summary: Lower Churchill River Region.

Invertebrate Community Measure	units	Partridge Breast Lake		Northern Indian Lake		Billard Lake		Lower Churchill River at Little Churchill River	
		Nearshore (2009)	Offshore (2009)	Nearshore (2008-2009)	Offshore (2008-2010)	--	Offshore (2010)	--	Offshore (2010)
Total Invertebrates (density/abundance)	mean no./m^2	4250	2005	3207	3413	--	2438	--	1737
EPT Index (abundance)	mean no./m^2	3	20	408	528	--	12	--	133
Genus analysis of Ephemeroptera	dominant	Caenide: *Caenis*	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	--	Ephemeridae: *Hexagenia*	--	Ephemeridae: *Hexagenia*
EPT:Chironomidae	ratio	0.03	0.11	0.32	0.39	--	0.02	--	0.12
Taxonomic Richness	family-level	3	3	6	6	--	6	--	6
Simpson's Diversity (D)	index	0.13	0.26	0.63	0.62	--	0.48	--	0.49
Hill's Effective Richness ($E_{H'}$)	family-level	1	2	4	4	--	3	--	3
		--	--	Nearshore (2010)	--	Nearshore (2010)	--	Nearshore (2010)	--
Total Invertebrates (density/abundance)	mean no./kicknet	--	--	120	--	241	--	666	--
EPT Index (abundance)	mean no./kicknet	--	--	0	--	35	--	29	--
Genus analysis of Ephemeroptera	dominant	--	--	Caenidae: *Caenis*	--	Caenidae: *Caenis*	--	Siphlonuridae: *Parameletus*	--
EPT:Chironomidae	ratio	--	--	0.10	--	1.36	--	5.75	--
Taxonomic Richness	family-level	--	--	13	--	18	--	13	--
Simpson's Diversity (D)	index	--	--	0.71	--	0.70	--	0.52	--
Hill's Effective Richness ($E_{H'}$)	family-level	--	--	6	--	7	--	3	--

Table 6.4-5. Benthic macroinvertebrate summary: Churchill River Diversion Region.

Invertebrate Community Measure	units	Rat Lake		Notigi Lake		Threepoint Lake		Footprint Lake		Apussigamasi Lake		Leftrook Lake	
		--	Offshore (2010)	Nearshore (2009)	Offshore (2009)	Nearshore (2009)	Offshore (2008-2009)	--	Offshore (2010)	Nearshore (2009)	Offshore (2009)	Nearshore (2009)	Offshore (2008-2009)
Total Invertebrates (density/abundance)	mean no./m^2	--	124	684	517	886	493	--	678	594	1728	3431	3173
EPT Index (abundance)	mean no./m^2	--	38	58	0	150	60	--	32	130	63	211	12
Genus analysis of Ephemeroptera	dominant	--	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	--	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	--	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*
EPT:Chironomidae	ratio	--	0.13	0.34	0.00	1.38	0.53	--	0.41	0.74	0.41	0.17	0.01
Taxonomic Richness	family-level	--	2	3	2	4	4	--	6	4	4	4	4
Simpson's Diversity (D)	index	--	0.33	0.51	0.31	0.50	0.50	--	0.65	0.59	0.46	0.63	0.58
Hill's Effective Richness ($E_{H'}$)	family-level	--	2	3	2	3	3	--	4	3	3	3	3
		Nearshore (2010)	--	--	--	Nearshore (2010)	--	Nearshore (2010)	--	--	--	Nearshore (2010)	--
Total Invertebrates (density/abundance)	mean no./kicknet	243	--	--	--	46	--	35	--	--	--	151	--
EPT Index (abundance)	mean no./kicknet	17	--	--	--	3	--	2	--	--	--	17	--
Genus analysis of Ephemeroptera	dominant	Baetidae: unidentified + *Callibaetis*	--	--	--	Ephemeridae: *Hexagenia*	--	Ephemeridae: *Hexagenia*	--	--	--	Heptageniidae: *Stenomena*	--
EPT:Chironomidae	ratio	1.04	--	--	--	0.58	--	0.42	--	--	--	2.79	--
Taxonomic Richness	family-level	18	--	--	--	12	--	9	--	--	--	17	--
Simpson's Diversity (D)	index	0.80	--	--	--	0.66	--	0.68	--	--	--	0.71	--
Hill's Effective Richness ($E_{H'}$)	family-level	8	--	--	--	6	--	4	--	--	--	7	--

Table 6.4-6. Benthic macroinvertebrate summary: Upper Nelson River Region.

Invertebrate Community Measure	units	Playgreen Lake		Little Playgreen Lake		Cross Lake		Walker Lake		Setting Lake	
		Nearshore (2009)	Offshore (2009)	--	Offshore (2010)	Nearshore (2008-2009)	Offshore (2008-2010)	--	Offshore (2010)	Nearshore (2008-2009)	Offshore (2008-2010)
Total Invertebrates (density/abundance)	mean no./m^2	6686	6267	--	3916	2405	1262	--	1226	2583	2764
EPT Index (abundance)	mean no./m^2	124	742	--	208	561	657	--	26	101	35
Genus analysis of Ephemeroptera	dominant	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	--	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	--	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*
EPT:Chironomidae	ratio	0.05	1.18	--	0.32	5.17	3.69	--	0.03	0.40	0.05
Taxonomic Richness	family-level	9	8	--	9	5	4	--	6	6	4
Simpson's Diversity (D)	index	0.68	0.72	--	0.55	0.48	0.57	--	0.71	0.53	0.51
Hill's Effective Richness ($E_{H'}$)	family-level	5	5	--	4	3	3	--	4	4	3
		--	--	Nearshore (2010)	--	Nearshore (2010)	--	Nearshore (2010)	--	Nearshore (2010)	--
Total Invertebrates (density/abundance)	mean no./kicknet	--	--	7816	--	248	--	339	--	331	--
EPT Index (abundance)	mean no./kicknet	--	--	552	--	37	--	43	--	87	--
Genus analysis of Ephemeroptera	dominant	--	--	Caenidae: *Caenis*	--	Caenidae: *Caenis*	--	Caenidae: *Caenis* + Leptophlebiidae: unidentified	--	Caenidae: *Caenis*	--
EPT:Chironomidae	ratio	--	--	0.44	--	0.62	--	0.66	--	1.10	--
Taxonomic Richness	family-level	--	--	15	--	11	--	20	--	22	--
Simpson's Diversity (D)	index	--	--	0.78	--	0.49	--	0.77	--	0.89	--
Hill's Effective Richness ($E_{H'}$)	family-level	--	--	7	--	4	--	7	--	12	--

Table 6.4-7. Benthic macroinvertebrate summary: Lower Nelson River Region.

Invertebrate Community Measure	units	Split Lake		Stephens Lake-South		Stephens Lake-North		Limestone Forebay		Lower Nelson River		Hayes River		Assean Lake	
		Nearshore (2009)	Offshore (2009-2010)	Nearshore (2009)	Offshore (2009)	Nearshore (2009)	Offshore (2009)	--	Offshore (2010)	--	Offshore (2010)	--	--	Nearshore (2009)	Offshore (2009-2010)
Total Invertebrates (density/abundance)	mean no./m^2	375	4952	1653	7794	765	1570	--	1838	--	2204	--	--	3310	624
EPT Index (abundance)	mean no./m^2	133	1392	1368	1818	156	23	--	343	--	602	--	--	78	136
Genus analysis of Ephemeroptera	dominant	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	Ephemeridae: *Hexagenia*	--	Ephemeridae: *Hexagenia*	--	--	--	--	Ephemeridae: *Ephemera + Hexagenia*	
EPT:Chironomidae	ratio	0.36	10.52	9.32	2.08	0.96	0.02	--	1.22	--	0.54	--	--	0.06	0.80
Taxonomic Richness	family-level	3	7	4	5	5	3	--	10	--	5	--	--	8	4
Simpson's Diversity (D)	index	0.51	0.65	0.36	0.55	0.73	0.40	--	0.82	--	0.60	--	--	0.62	0.64
Hill's Effective Richness ($E_{H'}$)	family-level	3	4	2	3	5	2	--	7	--	3	--	--	5	3
		Nearshore (2010)	--	--	--	--	--	Nearshore (2010)	--	Nearshore (2010)	--	Nearshore (2010)	--	Nearshore (2010)	--
Total Invertebrates (density/abundance)	mean no./kicknet	95	--	--	--	--	--	36	--	57	--	440	--	708	--
EPT Index (abundance)	mean no./kicknet	22	--	--	--	--	--	1	--	7	--	10	--	309	--
Genus analysis of Ephemeroptera	dominant	Caenidae: *Caenis*	--	--	--	--	--	Caenidae: *Caenis* Baetidae: *Procloeon* Heptageniidae: *Stenonema*	--	Baetidae: *Procloeon*	--	Baetiscidae: *Baetisca*	--	Caenidae: *Caenis*	--
EPT:Chironomidae	ratio	1.37	--	--	--	--	--	0.02	--	0.60	--	1.83	--	15.68	--
Taxonomic Richness	family-level	13	--	--	--	--	--	6	--	9	--	8	--	19	--
Simpson's Diversity (D)	index	0.82	--	--	--	--	--	0.59	--	0.69	--	0.20	--	0.71	--
Hill's Effective Richness ($E_{H'}$)	family-level	8	--	--	--	--	--	3	--	5	--	2	--	5	--

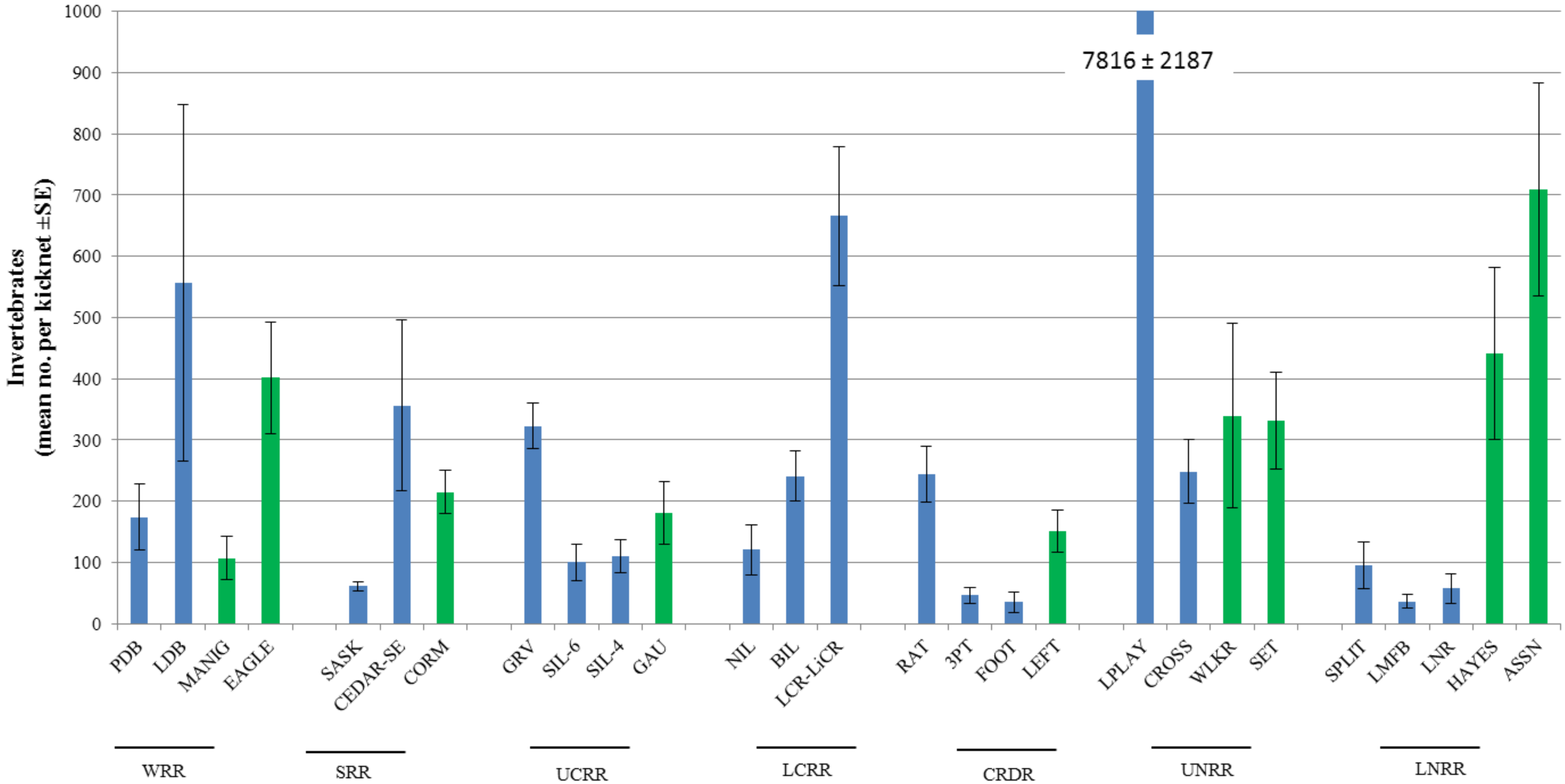


Figure 6.4-1. Mean (±SE) total number of macroinvertebrates from nearshore kicknet samples collected across the seven sampling regions (Lake Winnipeg excluded). Off-system waterbodies are indicated in green. WRR = Winnipeg River Region; SRR = Saskatchewan River Region; UCRR = Upper Churchill River Region; CRDR = Churchill River Diversion Region; UNRR = Upper Nelson River Region; and LNRR = Lower Nelson River Region.

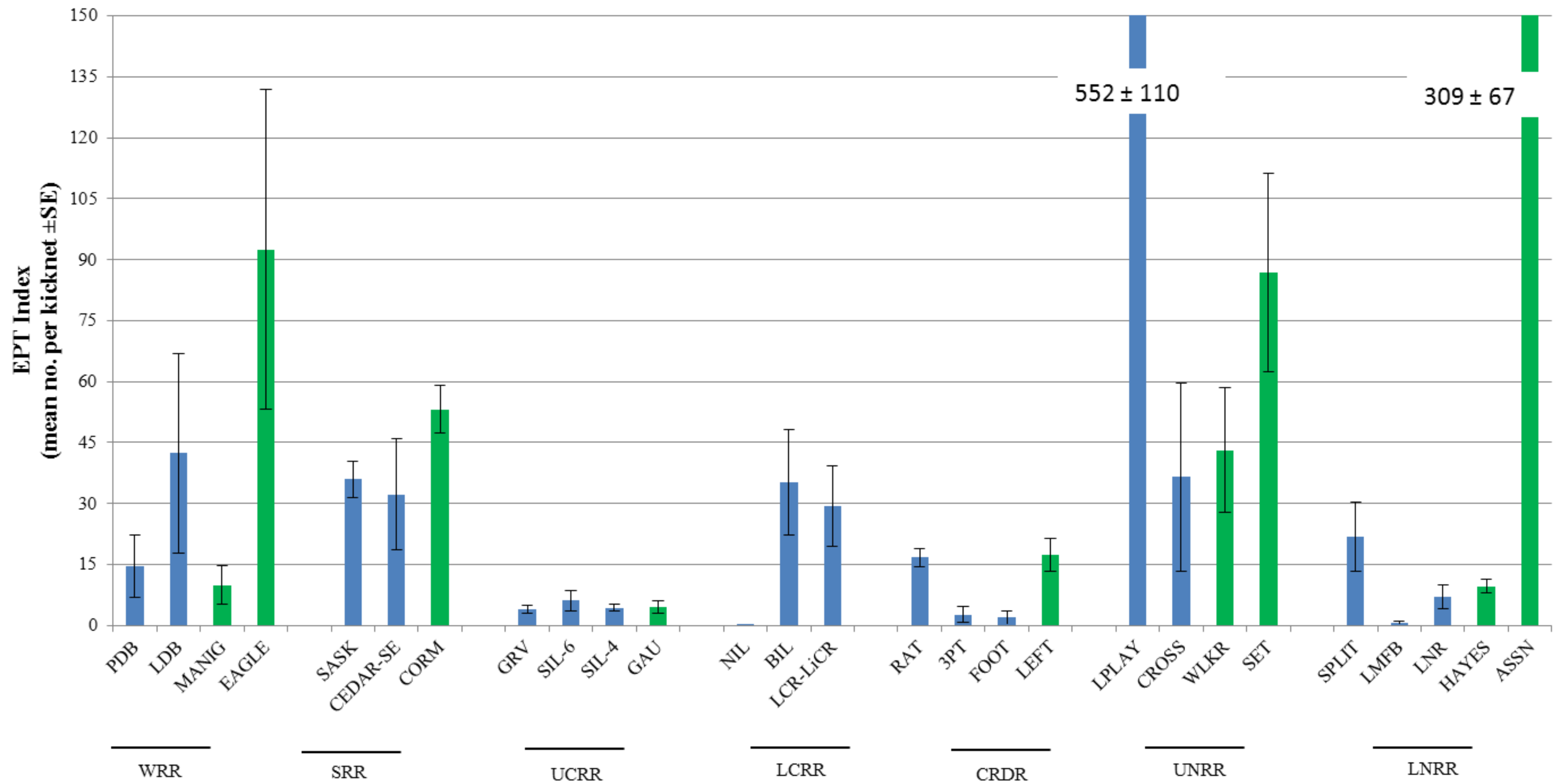


Figure 6.4-2. Mean (±SE) total number of EPT (Ephemeroptera, Trichoptera, and Plecoptera) from nearshore kicknet samples collected across the seven sampling regions (Lake Winnipeg excluded). Off-system waterbodies are indicated in green. WRR = Winnipeg River Region; SRR = Saskatchewan River Region; UCRR = Upper Churchill River Region; CRDR = Churchill River Diversion Region; UNRR = Upper Nelson River Region; and LNRR = Lower Nelson River Region.

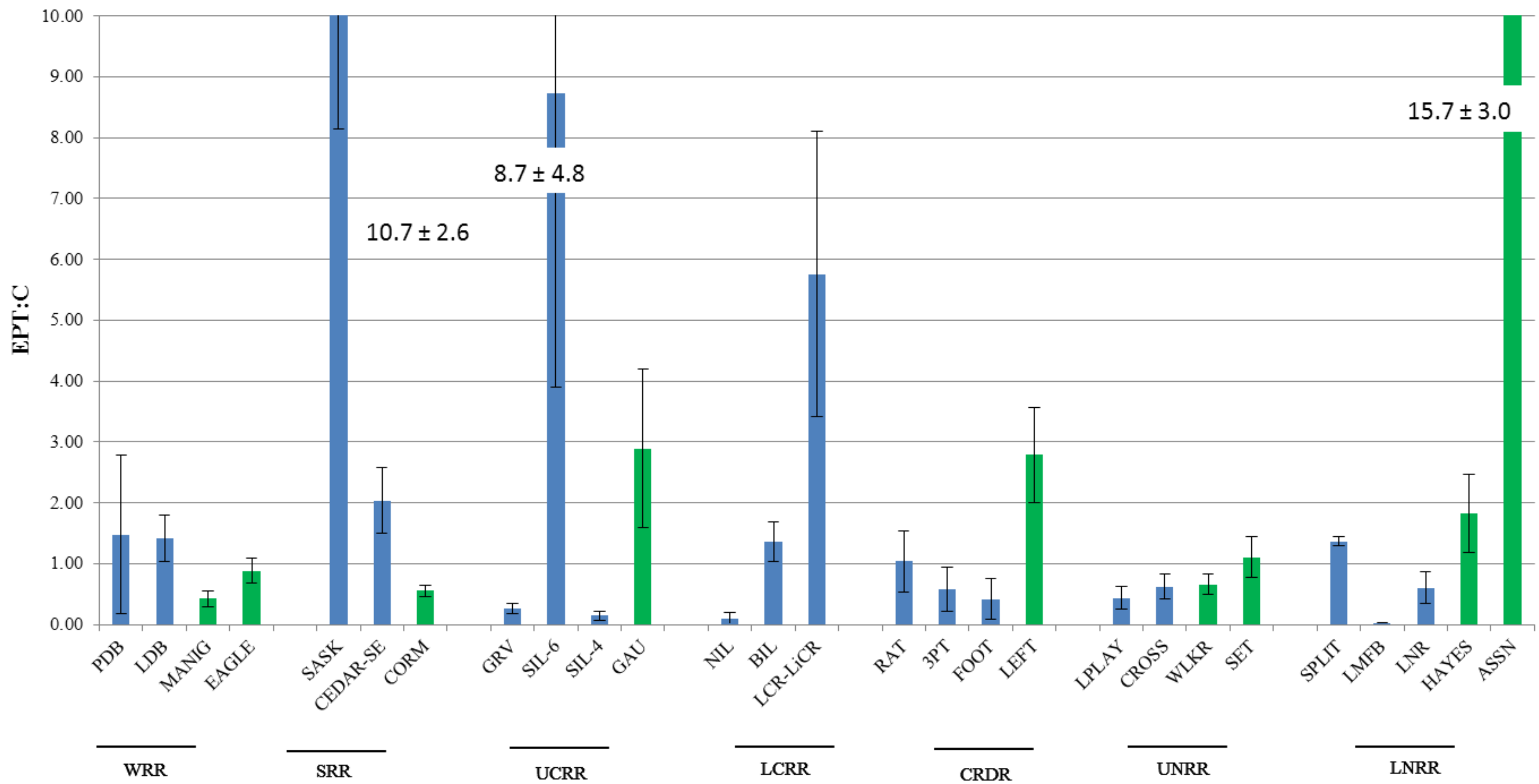


Figure 6.4-3. Mean (±SE) EPT:C (ratio of Ephemeroptera, Trichoptera, and Plecoptera to Chironomidae) from nearshore kicknet samples collected across the seven sampling regions (Lake Winnipeg excluded). Off-system waterbodies are indicated in green. WRR = Winnipeg River Region; SRR = Saskatchewan River Region; UCRR = Upper Churchill River Region; CRDR = Churchill River Diversion Region; UNRR = Upper Nelson River Region; and LNRR = Lower Nelson River Region.

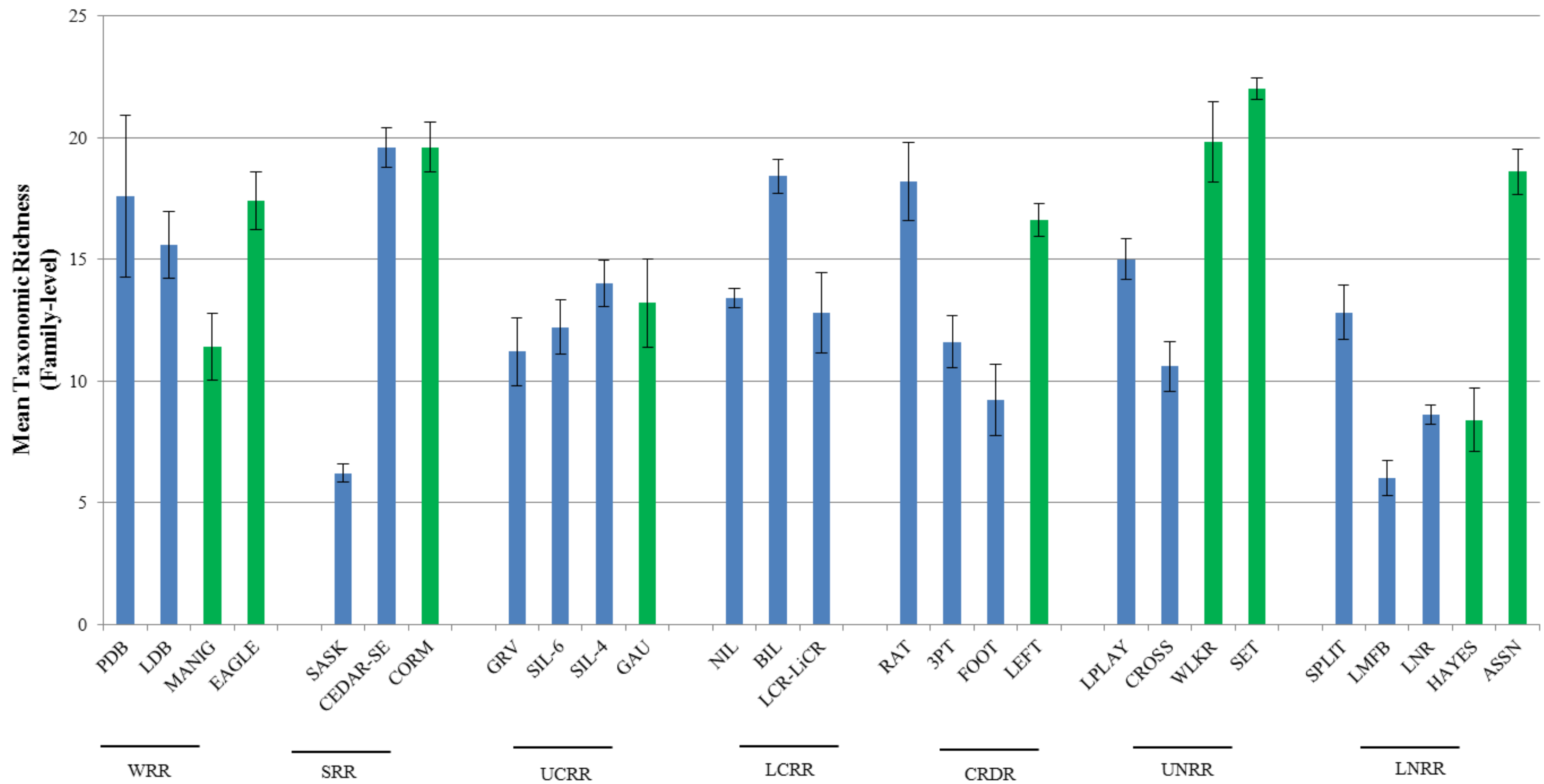


Figure 6.4-4. Mean (±SE) taxonomic richness (number of families) from nearshore kicknet samples collected across the seven sampling regions (Lake Winnipeg excluded). Off-system waterbodies are indicated in green. WRR = Winnipeg River Region; SRR = Saskatchewan River Region; UCRR = Upper Churchill River Region; CRDR = Churchill River Diversion Region; UNRR = Upper Nelson River Region; and LNRR = Lower Nelson River Region.

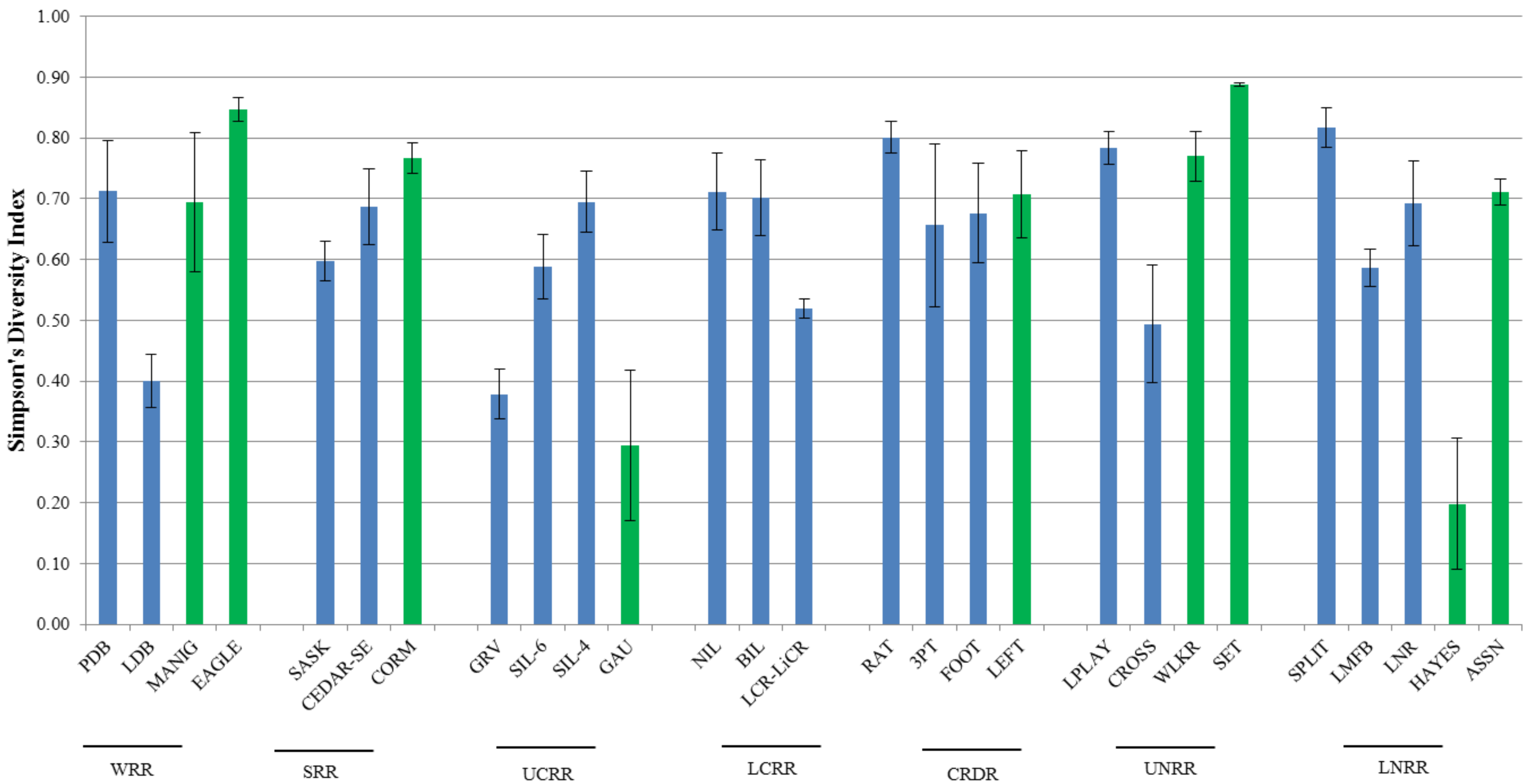


Figure 6.4-5. Mean (±SE) Simpson's diversity index from nearshore kicknet samples collected across the seven sampling regions (Lake Winnipeg excluded). Off-system waterbodies are indicated in green. WRR = Winnipeg River Region; SRR = Saskatchewan River Region; UCRR = Upper Churchill River Region; CRDR = Churchill River Diversion Region; UNRR = Upper Nelson River Region; and LNRR = Lower Nelson River Region.

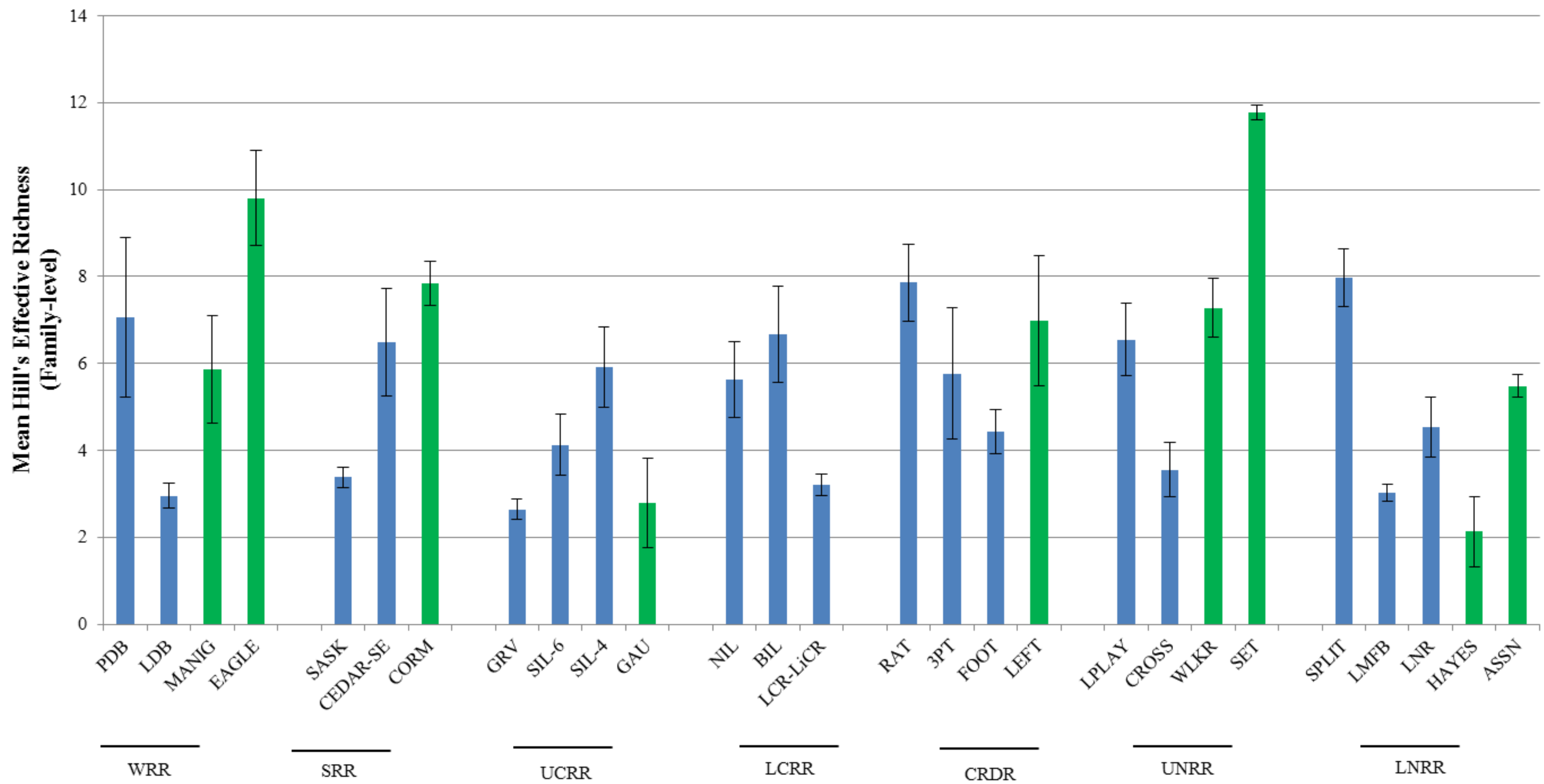


Figure 6.4-6. Mean (±SE) Hill's effective richness from nearshore kicknet samples collected across the seven sampling regions (Lake Winnipeg excluded). Off-system waterbodies are indicated in green. WRR = Winnipeg River Region; SRR = Saskatchewan River Region; UCRR = Upper Churchill River Region; CRDR = Churchill River Diversion Region; UNRR = Upper Nelson River Region; and LNRR = Lower Nelson River Region

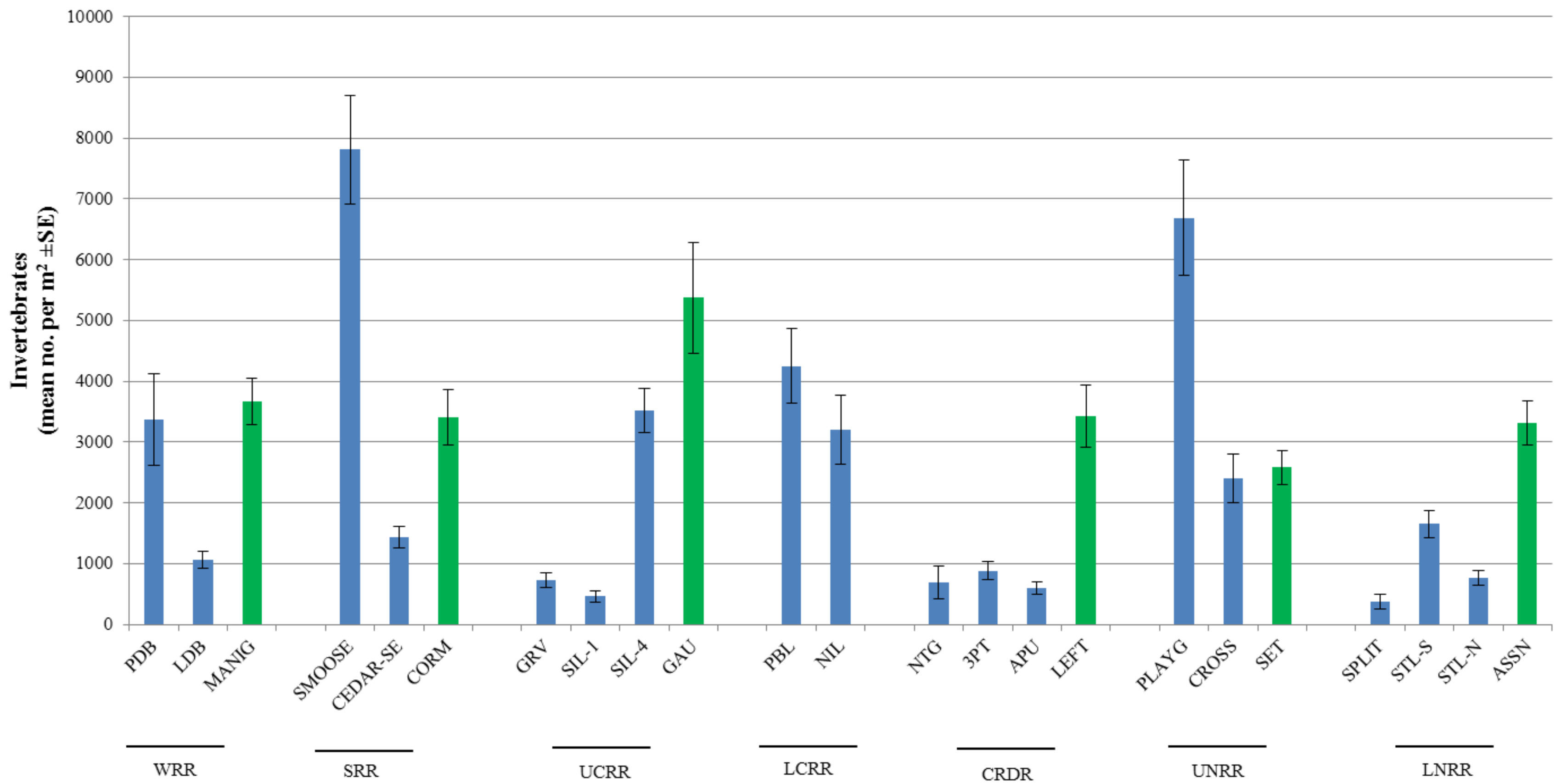


Figure 6.4-7. Mean (±SE) total number of macroinvertebrates from nearshore grab samples collected across the seven sampling regions (Lake Winnipeg excluded). Off-system waterbodies are indicated in green. WRR = Winnipeg River Region; SRR = Saskatchewan River Region; UCRR = Upper Churchill River Region; CRDR = Churchill River Diversion Region; UNRR = Upper Nelson River Region; and LNRR = Lower Nelson River Region.

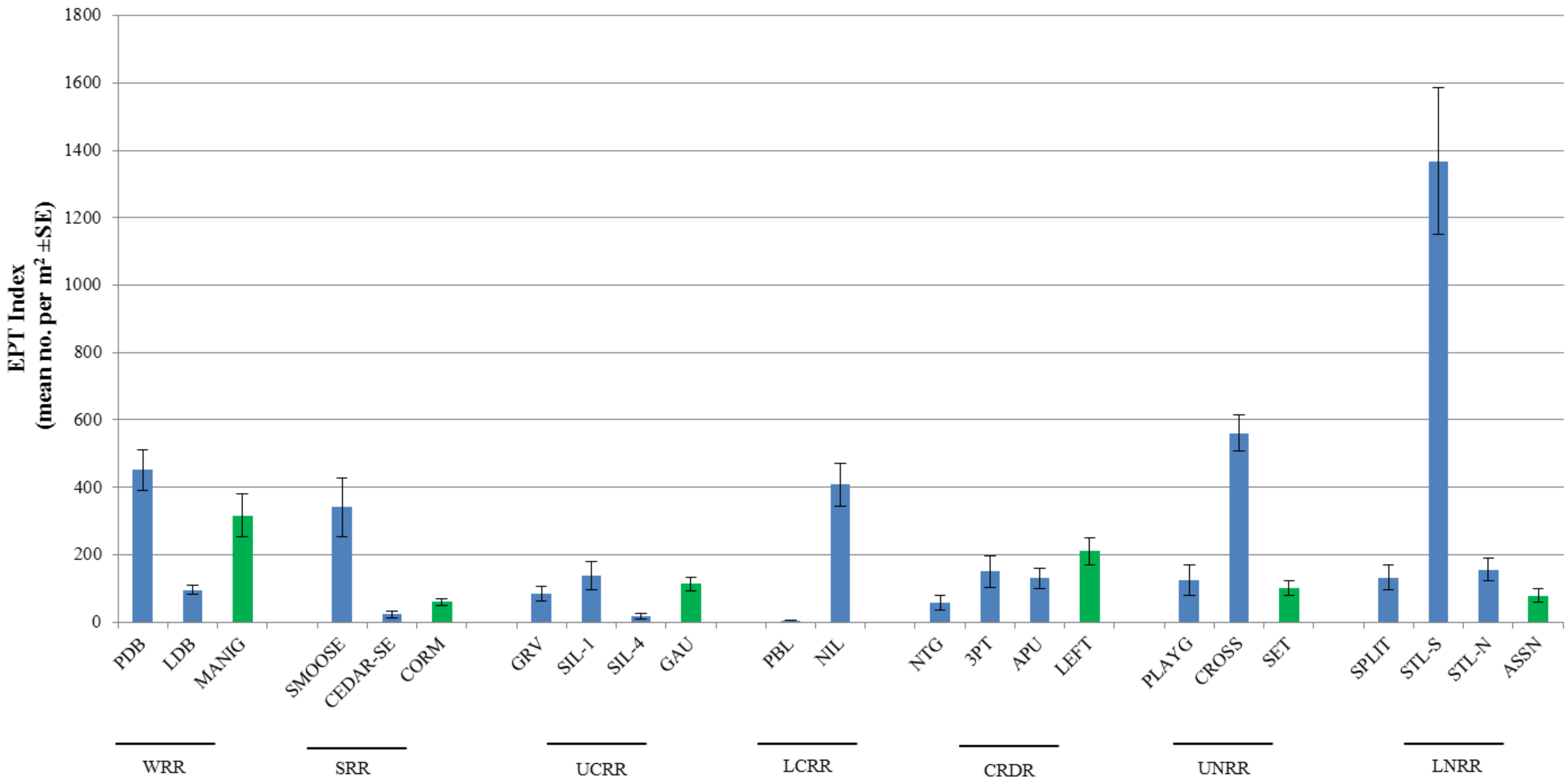


Figure 6.4-8. Mean (±SE) total number of EPT (Ephemeroptera, Trichoptera, and Plecoptera) from nearshore grab samples collected across the seven sampling regions (Lake Winnipeg excluded). Off-system waterbodies are indicated in green. WRR = Winnipeg River Region; SRR = Saskatchewan River Region; UCRR = Upper Churchill River Region; CRDR = Churchill River Diversion Region; UNRR = Upper Nelson River Region; and LNRR = Lower Nelson River Region.

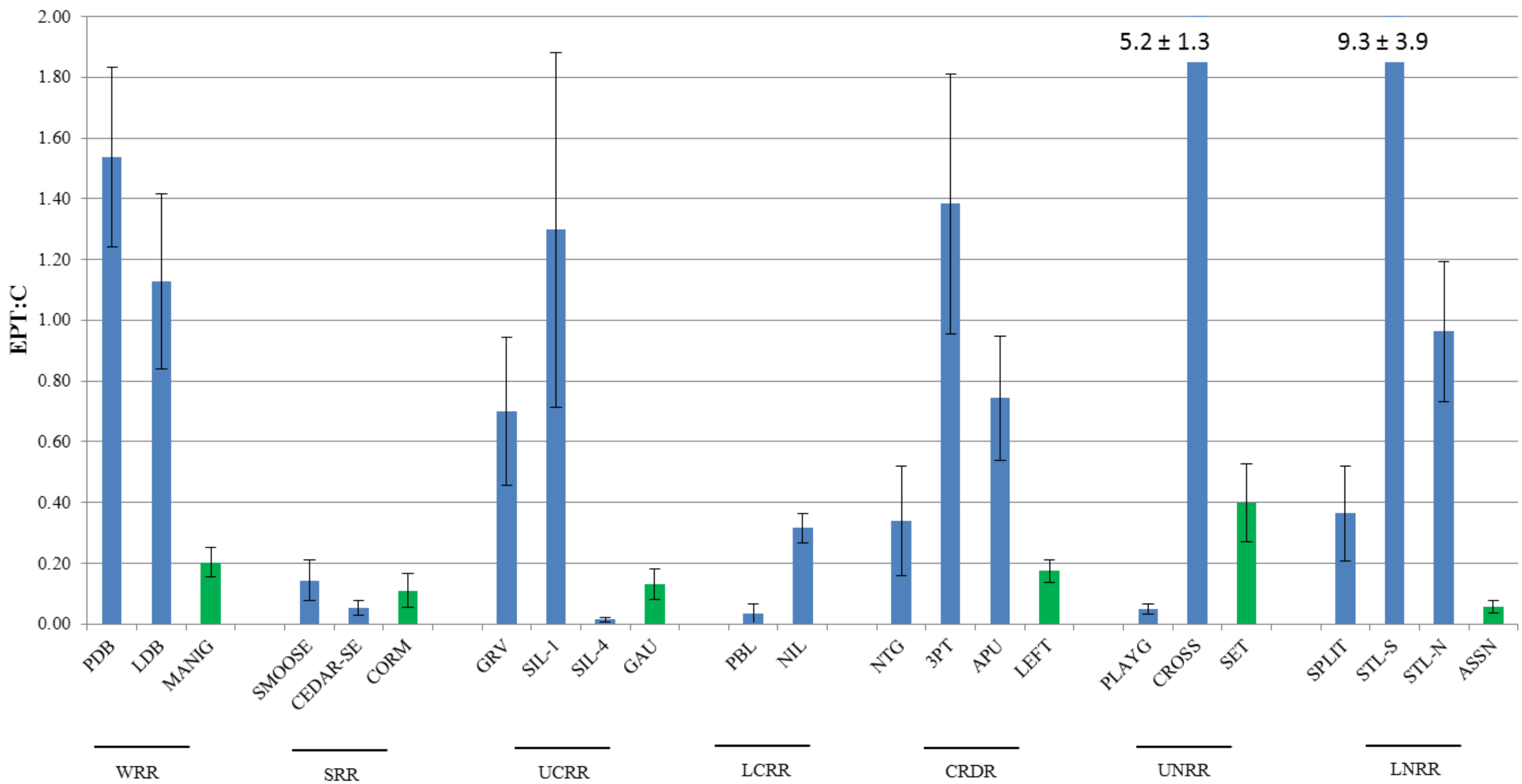


Figure 6.4-9. Mean (±SE) EPT:C (ratio of Ephemeroptera, Trichoptera, and Plecoptera to Chironomidae) from nearshore grab samples collected across the seven sampling regions (Lake Winnipeg excluded). Off-system waterbodies are indicated in green. WRR = Winnipeg River Region; SRR = Saskatchewan River Region; UCRR = Upper Churchill River Region; CRDR = Churchill River Diversion Region; UNRR = Upper Nelson River Region; and LNRR = Lower Nelson River Region.

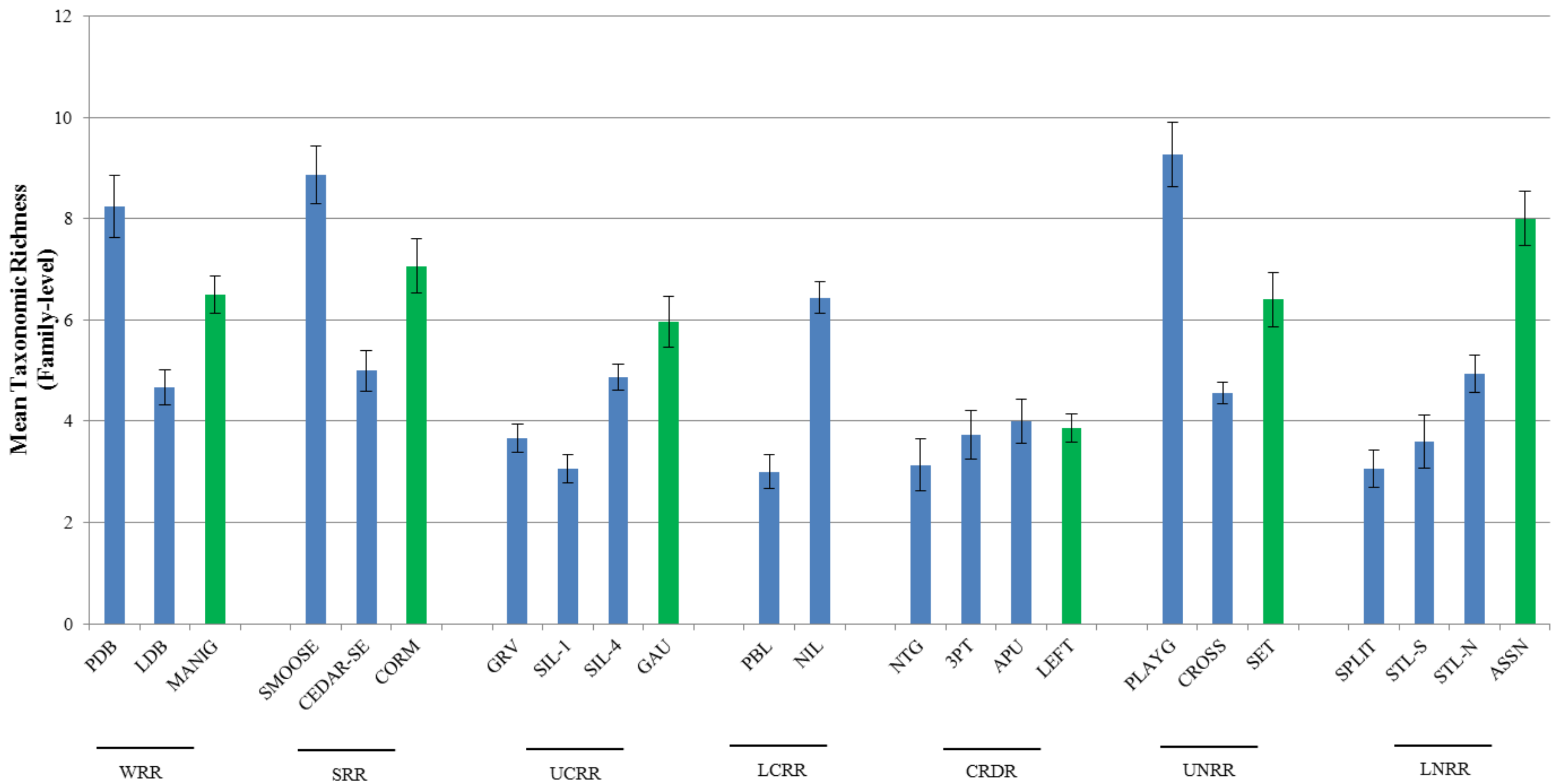


Figure 6.4-10. Mean (±SE) taxonomic richness (number of families) from nearshore grab samples collected across the seven sampling regions (Lake Winnipeg excluded). Off-system waterbodies are indicated in green. WRR = Winnipeg River Region; SRR = Saskatchewan River Region; UCRR = Upper Churchill River Region; CRDR = Churchill River Diversion Region; UNRR = Upper Nelson River Region; and LNRR = Lower Nelson River Region.

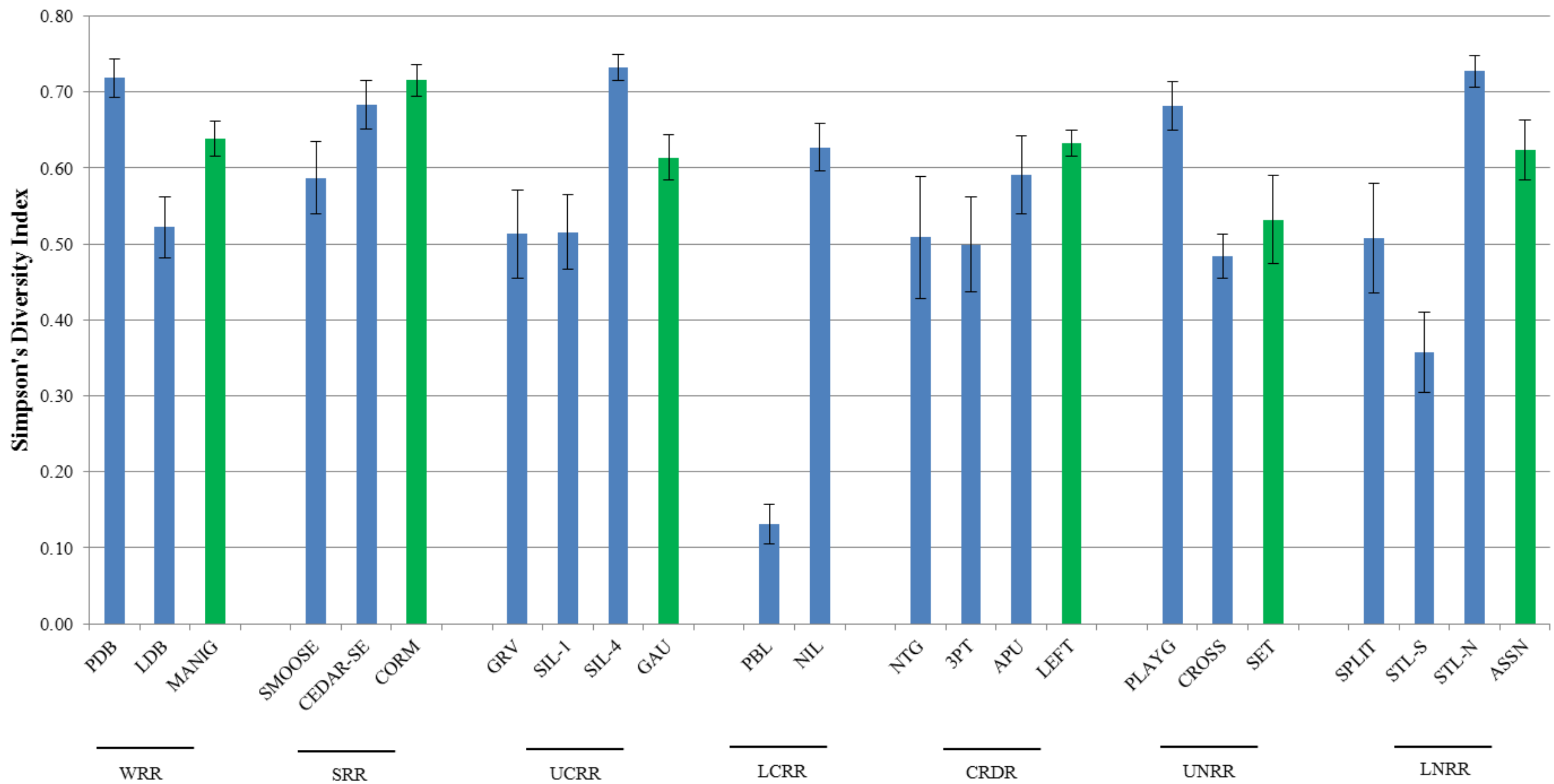


Figure 6.4-11. Mean (±SE) Simpson's diversity index from nearshore grab samples collected across the seven sampling regions (Lake Winnipeg excluded). Off-system waterbodies are indicated in green. WRR = Winnipeg River Region; SRR = Saskatchewan River Region; UCRR = Upper Churchill River Region; CRDR = Churchill River Diversion Region; UNRR = Upper Nelson River Region; and LNRR = Lower Nelson River Region.

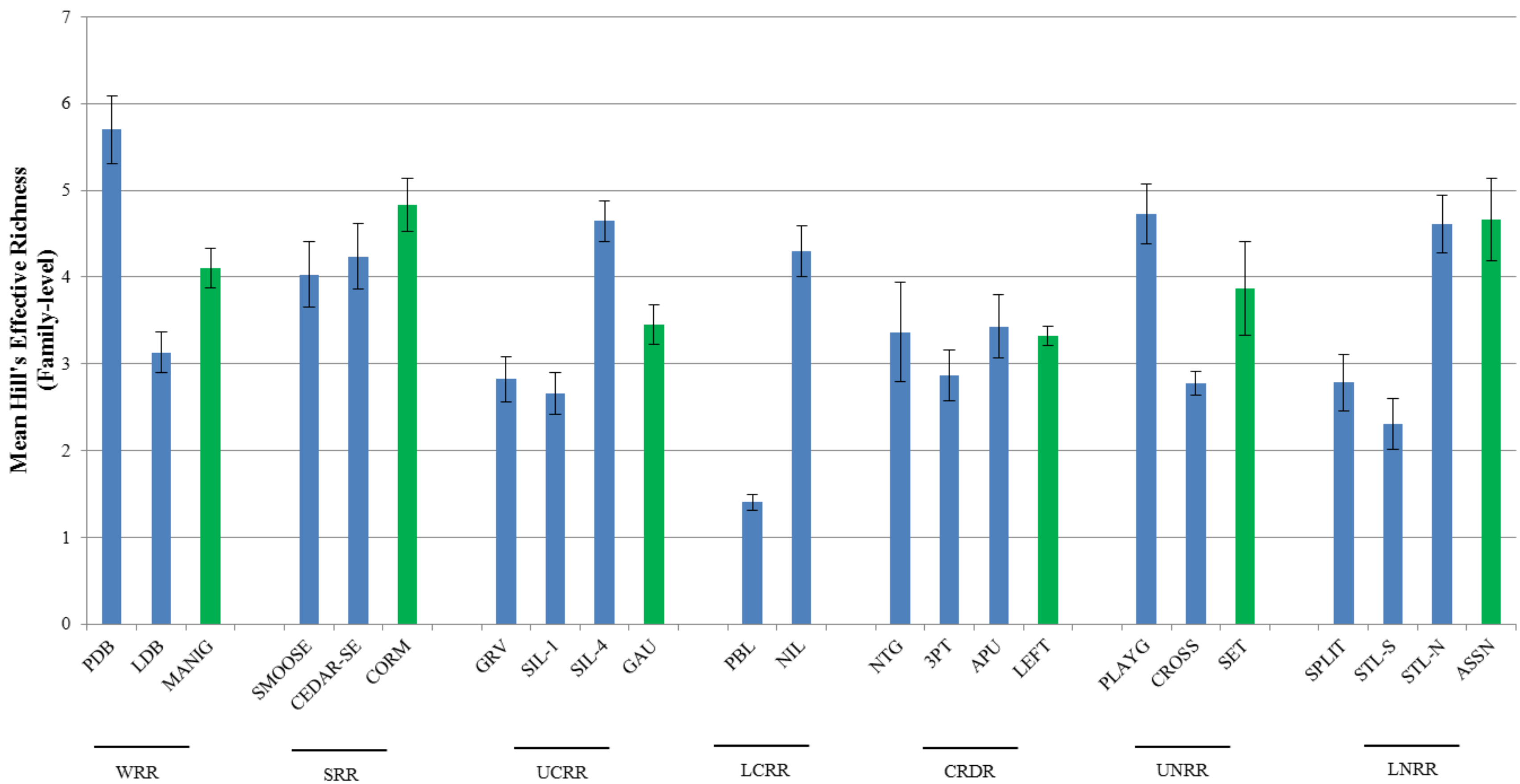


Figure 6.4-12. Mean (±SE) Hill's effective richness from nearshore grab samples collected across the seven sampling regions (Lake Winnipeg excluded). Off-system waterbodies are indicated in green. WRR = Winnipeg River Region; SRR = Saskatchewan River Region; UCRR = Upper Churchill River Region; CRDR = Churchill River Diversion Region; UNRR = Upper Nelson River Region; and LNRR = Lower Nelson River Region.

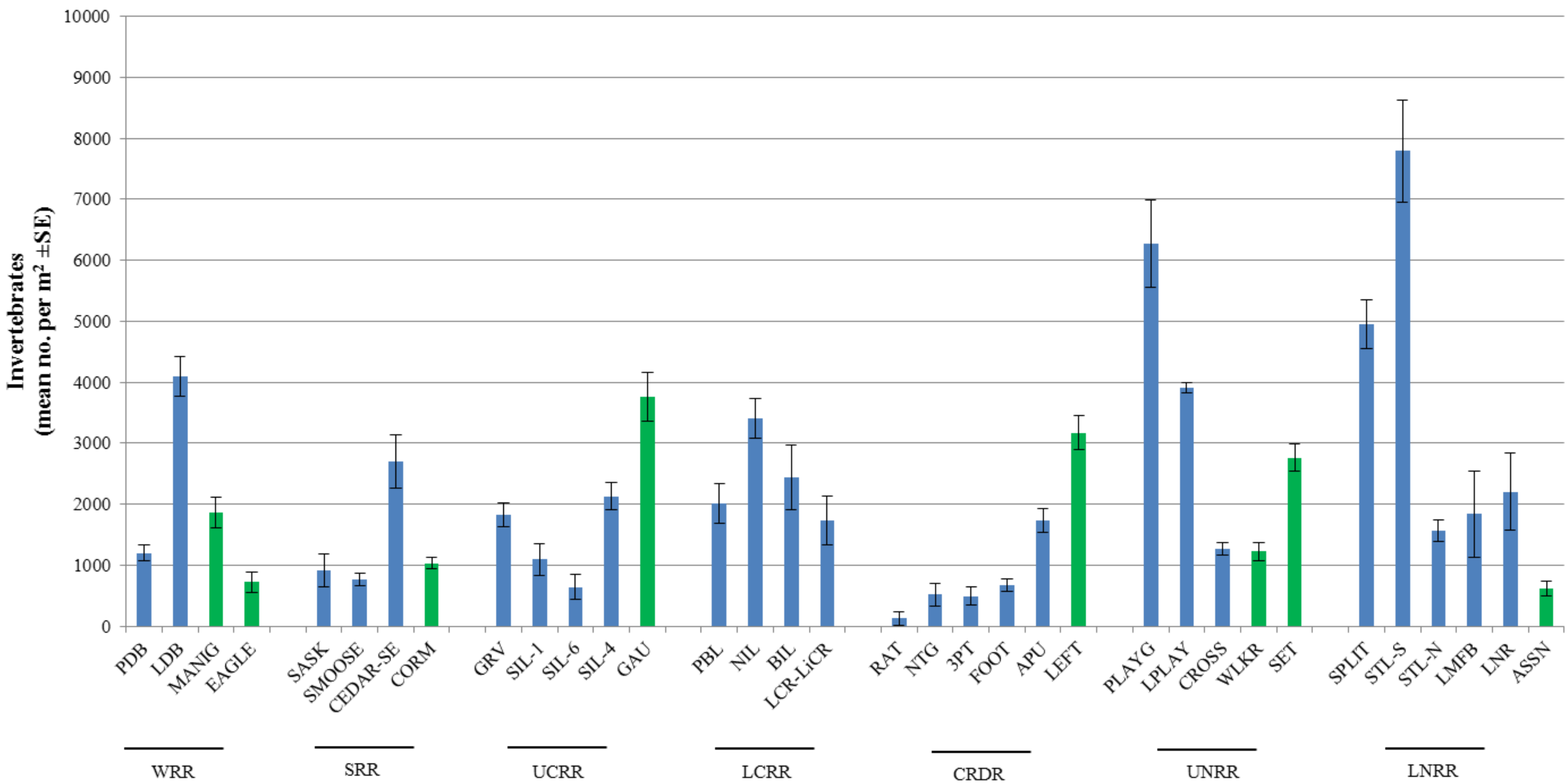


Figure 6.4-13. Mean (±SE) total number of macroinvertebrates from offshore grab samples collected across the seven sampling regions (Lake Winnipeg excluded). Off-system waterbodies are indicated in green. WRR = Winnipeg River Region; SRR = Saskatchewan River Region; UCRR = Upper Churchill River Region; CRDR = Churchill River Diversion Region; UNRR = Upper Nelson River Region; and LNRR = Lower Nelson River Region.

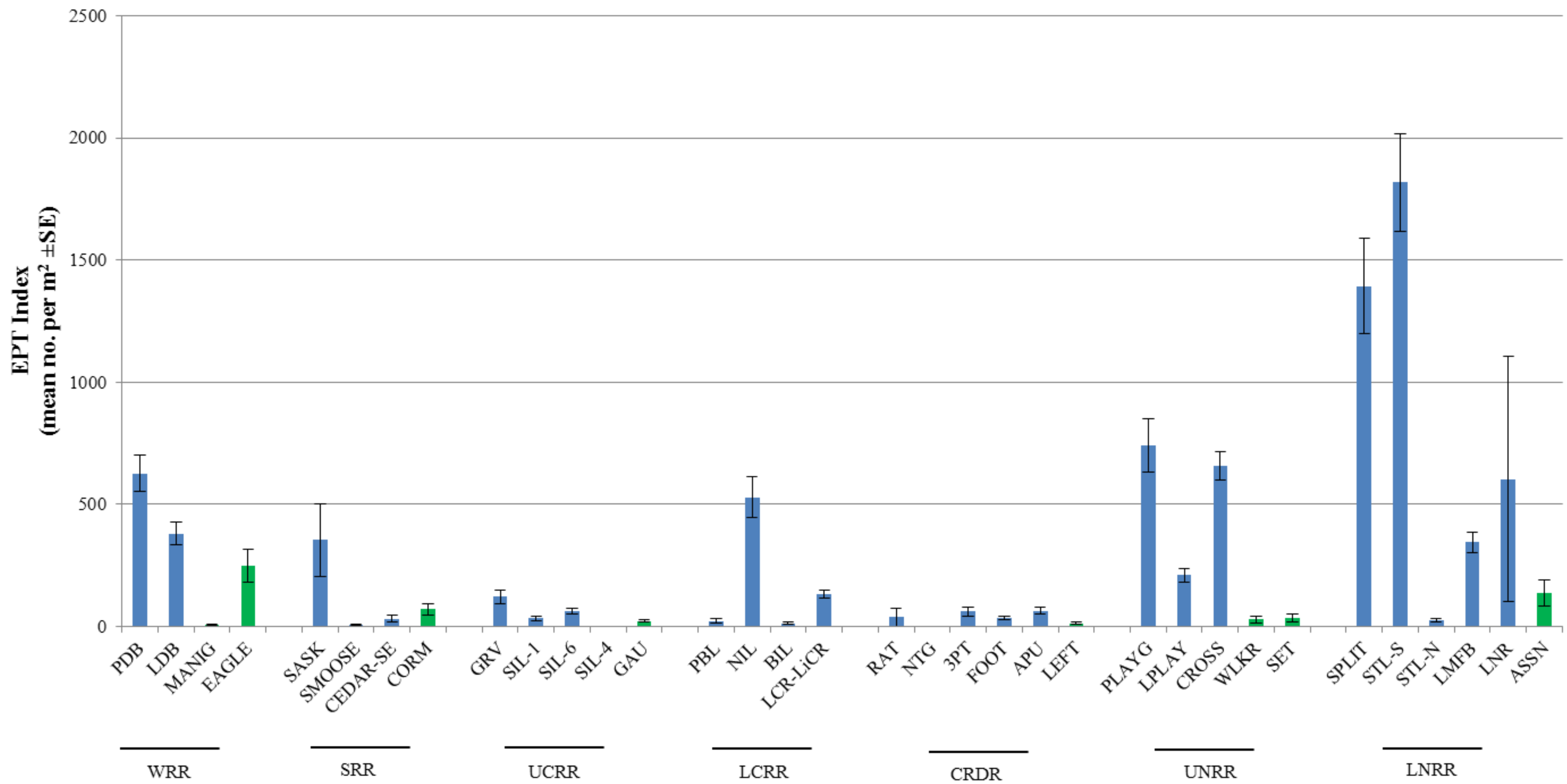


Figure 6.4-14. Mean (±SE) total number of EPT (Ephemeroptera, Trichoptera, and Plecoptera) from offshore grab samples collected across the seven sampling regions (Lake Winnipeg excluded). Off-system waterbodies are indicated in green. WRR = Winnipeg River Region; SRR = Saskatchewan River Region; UCRR = Upper Churchill River Region; CRDR = Churchill River Diversion Region; UNRR = Upper Nelson River Region; and LNRR = Lower Nelson River Region.

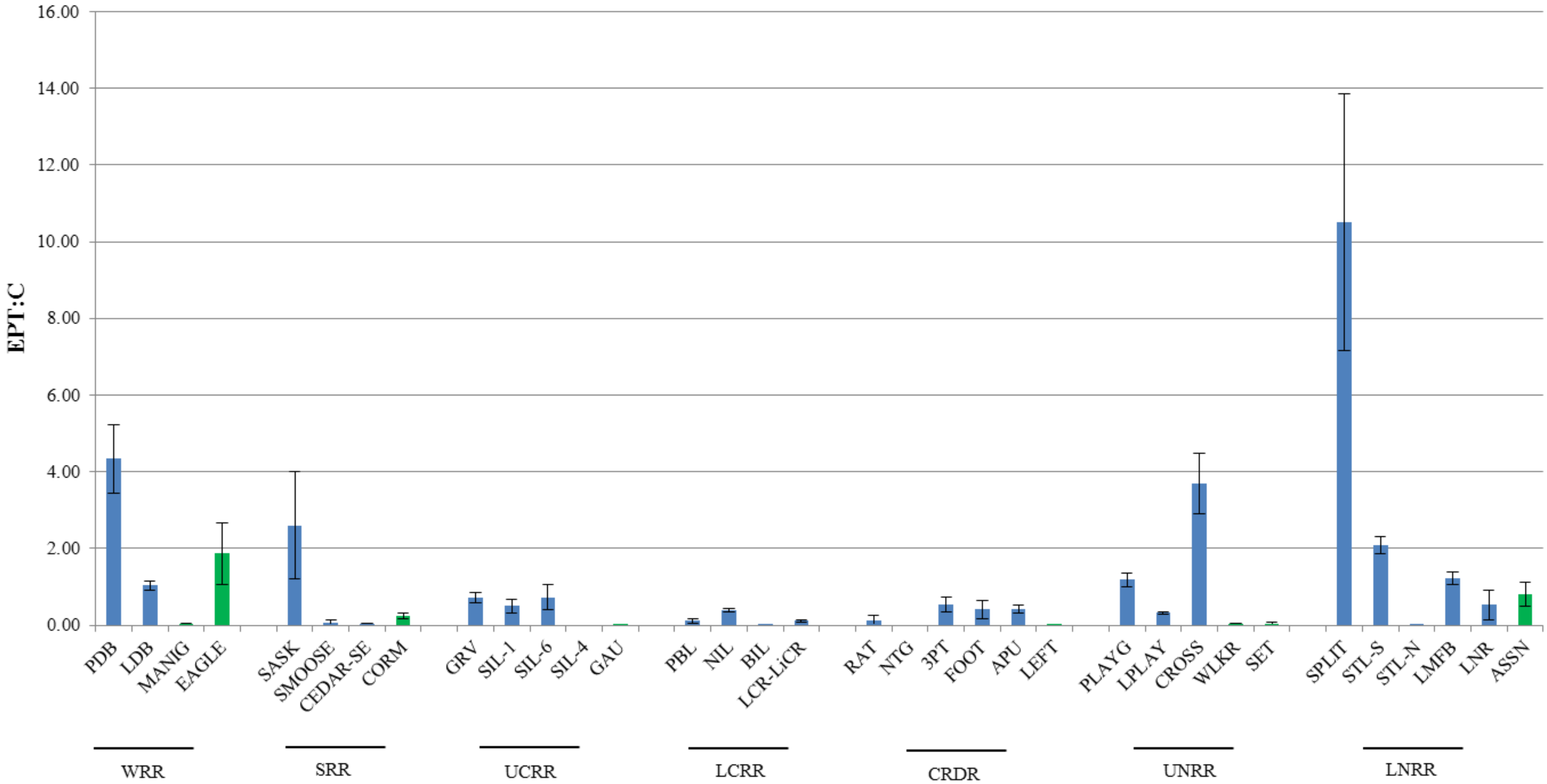


Figure 6.4-15. Mean (±SE) EPT:C (ratio of Ephemeroptera, Trichoptera, and Plecoptera to Chironomidae) from offshore grab samples collected across the seven sampling regions (Lake Winnipeg excluded). Off-system waterbodies are indicated in green. WRR = Winnipeg River Region; SRR = Saskatchewan River Region; UCRR = Upper Churchill River Region; CRDR = Churchill River Diversion Region; UNRR = Upper Nelson River Region; and LNRR = Lower Nelson River Region.

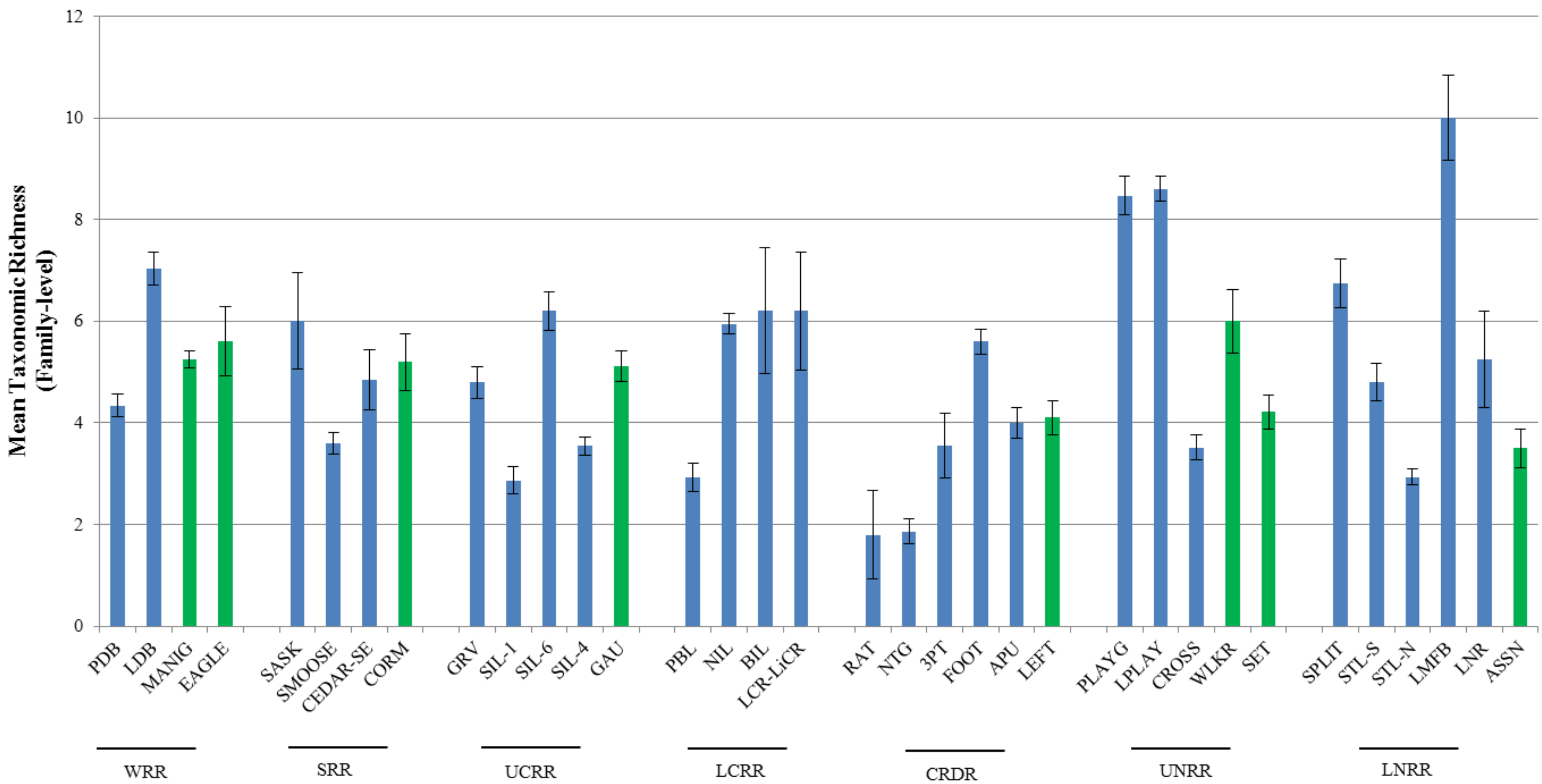


Figure 6.4-16. Mean (±SE) taxonomic richness (number of families) from offshore grab samples collected across the seven sampling regions (Lake Winnipeg excluded). Off-system waterbodies are indicated in green. WRR = Winnipeg River Region; SRR = Saskatchewan River Region; UCRR = Upper Churchill River Region; CRDR = Churchill River Diversion Region; UNRR = Upper Nelson River Region; and LNRR = Lower Nelson River Region.

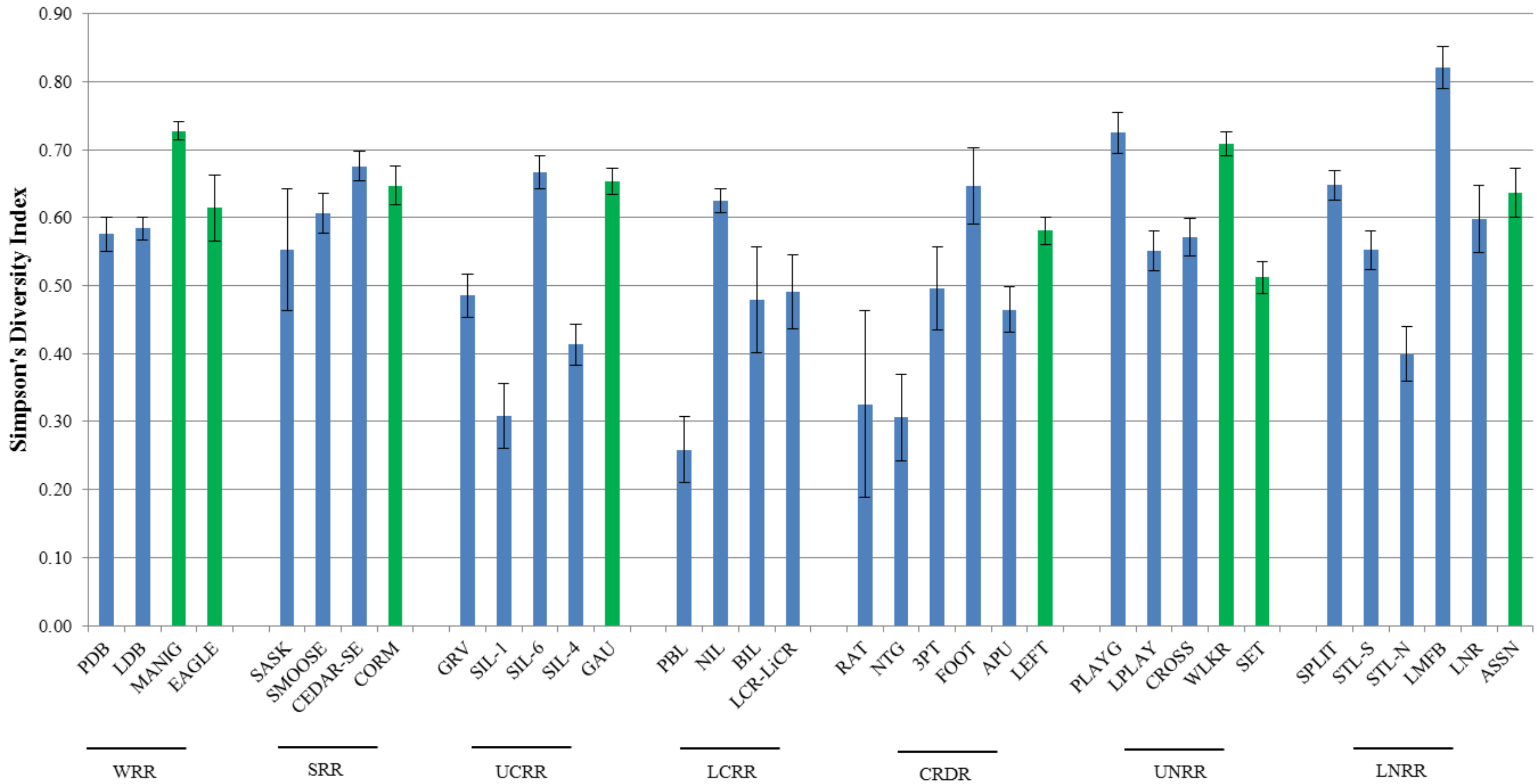


Figure 6.4-17. Mean (±SE) Simpson's diversity index from offshore grab samples collected across the seven sampling regions (Lake Winnipeg excluded). Off-system waterbodies are indicated in green. WRR = Winnipeg River Region; SRR = Saskatchewan River Region; UCRR = Upper Churchill River Region; CRDR = Churchill River Diversion Region; UNRR = Upper Nelson River Region; and LNRR = Lower Nelson River Region.

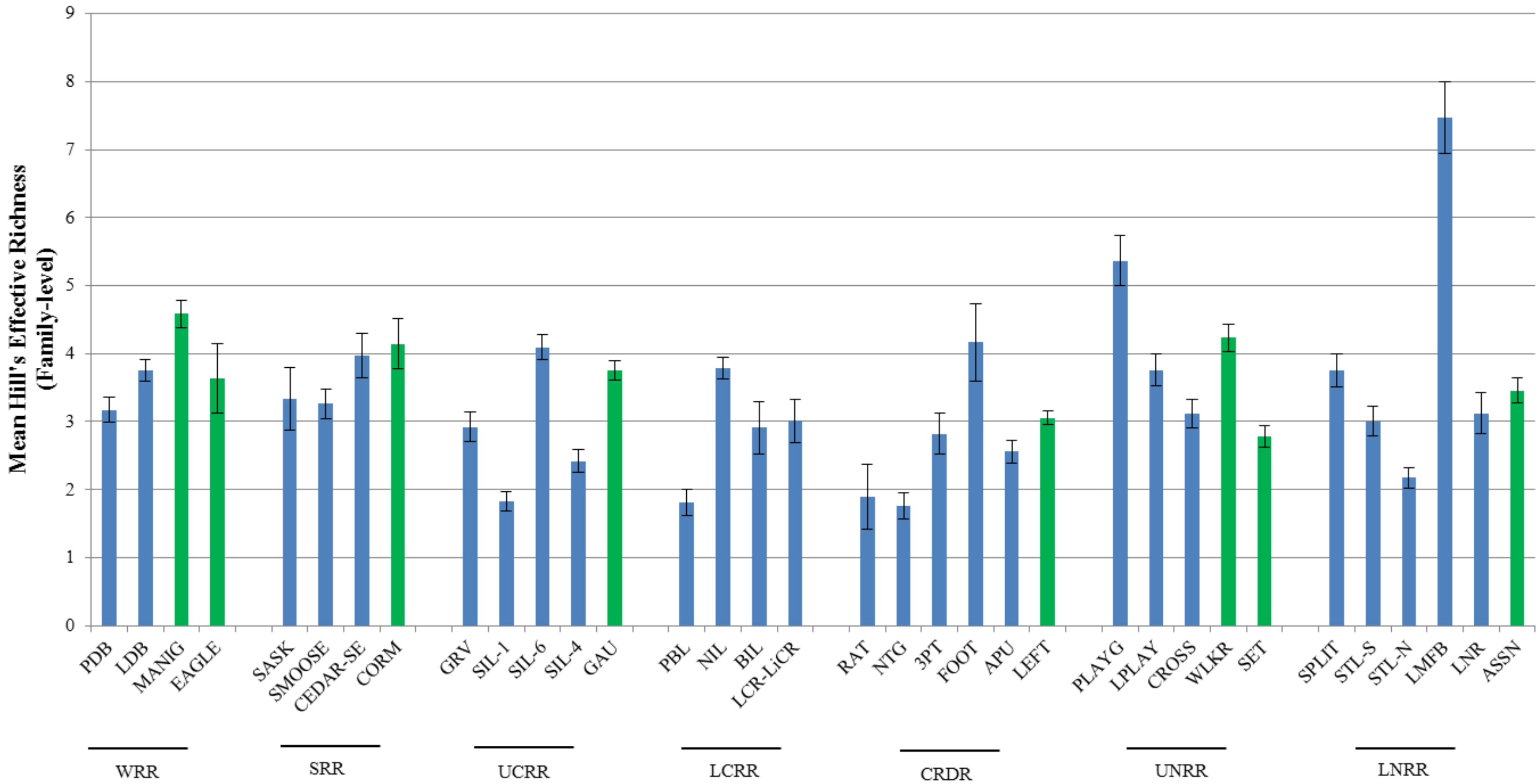


Figure 6.4-18. Mean (±SE) Hill's effective richness from offshore grab samples collected across the seven sampling regions (Lake Winnipeg excluded). Off-system waterbodies are indicated in green. WRR = Winnipeg River Region; SRR = Saskatchewan River Region; UCRR = Upper Churchill River Region; CRDR = Churchill River Diversion Region; UNRR = Upper Nelson River Region; and LNRR = Lower Nelson River Region.

6.5 FISH COMMUNITIES

The following discussion provides an overview of key fish community results based on selected fish community metrics (parameters) for the CAMPP waterbodies sampled in Years 1-3 of the pilot program. This overview is intended to provide a broad description of key results across the study regions (excluding the Lake Winnipeg Region). This analysis was also undertaken to assess the overall design of the CAMPP fish community monitoring program and facilitate discussion of potential modifications to the program in the future. As such, the summary provided in this section is not intended to be comprehensive and the reader is referred to information presented in Section 5 of this report for a detailed description of results of the CAMPP fish community program. It should also be noted that the total number of species presented in this data set in no way suggests that this represents the extent of species present in any CAMPP waterbody. These numbers are merely the total number of species captured by the specific methods outlined for the program (standard and small mesh index nets). However, because similar methodology and effort was utilized to obtain these results within each waterbody it was considered reasonable to compare the total number of species captured.

6.5.1 Species Composition

For the overview section species composition was examined by looking at the total number of species captured in each waterbody (Figure 6.5-1) and the relative abundance of the four species of interest selected for the program, Northern Pike (*Esox lucius*), Lake Whitefish (*Coregonus clupeaformis*), Sauger (*Sander canadensis*) and Walleye (*Sander vitreus*) (Figure 6.5-2).

In terms of the total number of species captured in on-system waterbodies within the CAMPP regions, the Winnipeg River Region had the most species (Pointe du Bois n=21) while the fewest number of species were captured in the Lower Churchill River Region (Billard Lake n = 9). Most regions tended to have 10 to 15 species present within each of the waterbodies that were sampled within the region; however, several had 18 or more species (e.g., Playgreen and Cross lakes in the Upper Nelson River Region, Split Lake and the lower Nelson River downstream of Limestone GS in the Lower Nelson River Region). The off-system waterbodies for each region tended to have a similar total number of species present with the notable exception of Manigotagan Lake in the Winnipeg River Region which only had nine species while the on-system waterbodies within the region had 19 to 21species and the other off-system waterbody, Eaglenest Lake, had 18 species. It should be noted that some waterbodies were sampled on an annual basis (3 years of data) while others were only sampled for one or two years which would affect the total number of species captured as it would be more likely to increase over time as more sampling is conducted.

The proportion of Northern Pike in the total catch of a given region ranged from a low of approximately 6% in the Winnipeg River Region to a high of approximately 25% of the total catch from the Lower Nelson River Region (Figure 6.5-2). Relative abundance of Northern Pike within most other regions ranged from 8 to 20% of the catch. Waterbodies where Northern Pike relative abundances exceeded 25% included Partridge Breast Lake in the Lower Churchill River Region (28.8%), Cross Lake in the Upper Nelson River Region (25.9%), Stephens Lake-North (38.9%) and the Limestone Forebay (29.1%) both in the Lower Nelson River Region.

Lake Whitefish were present in all the CAMPP regions but overall relative abundance differed among regions, with the Lower Churchill River Region having approximately 25% of the standard index gill net catch made up of Lake Whitefish (nearly 50% for Billard Lake) (Figure 6.5-2). The Upper Churchill River Region had around 15% of the catch made up by Lake Whitefish. In the Upper Nelson River Region Lake Whitefish made up less than 2% of the catch for Playgreen Lake and less than 1% for the remaining waterbodies in the region. Lake Whitefish were found to account for less than 10% of the catch for all other regions.

Relative abundance of Sauger was highest in the Winnipeg River Region where it accounted for nearly 20% of the catch for on-system waterbodies (Figure 6.5-2). The lowest abundance was found for the Lower Churchill River Region where no Sauger were reported. The remaining regions had relative abundances for Sauger ranging from less than 5% to approximately 14% of the catch.

Walleye were abundant throughout all of the CAMPP regions usually being the most abundant of the four species of interest (Figure 6.5-2). The Lower Nelson River, Saskatchewan River, Lower Churchill River, and Upper Churchill River regions had the highest Walleye abundances with regional on-system waterbody averages above 25%. The highest Walleye relative abundance was recorded in Stephens Lake-South (54%) followed by the Saskatchewan River (51%), and Stephens Lake-North (49%). The lowest recorded relative abundance was for Southern Indian Lake where Walleye relative abundance for all three areas (1, 4, and 6) was under 4% of the total catch. The Winnipeg River and Upper Nelson River regions had similar regional Walleye relative abundances (16 – 17%); however, Cross Lake in the Upper Nelson River Region had a comparatively high Walleye abundance (31.4%).

6.5.2 Catch Per Unit Effort

Mean total catch per unit effort using standard gang index gillnets was examined for all fish species as well as for the four species of interest. Playgreen and Little Playgreen lakes, two on-system waterbodies in the Upper Nelson River Region, were found to have the highest CPUEs for all on-system waterbodies (approximately 70 and 80 fish/100 m/24 hr, respectively) (Figure

6.5-3). The mean total CPUE for on-system waterbodies the Upper Nelson River Region was higher than that of the Lower Churchill River Region (62.8 and 53.9 fish, respectively). The Upper Churchill River Region had a total CPUE of 41.9 fish due to low values for Southern Indian Lake areas 1 and 6. The Lower Nelson River Region had the lowest total CPUE for on-system waterbodies at 24 fish while the remaining four regions ranged from approximately 34 to 45 fish. The most consistent CPUE values among waterbodies within a single region were found for the Winnipeg River Region where the two on-system waterbodies and Eaglenest Lake, an off-system Winnipeg River mainstem waterbody, ranged from 33.3 to 34.2 fish. Within a given region, the highest CPUE was typically found within an off-system waterbody, although some off-system waterbodies had the lowest total CPUE within a given region (i.e., Eaglenest Lake in the Winnipeg River Region and Hayes River within the Lower Nelson River and Lower Churchill River regions; Figure 6.5-3).

For Northern Pike the mean total CPUE values for on-system waterbodies within all regions ranged from 2.0 fish (Winnipeg River Region) to 10.8 fish (Upper Nelson River Region) (Figure 6.5-4). The Upper Nelson River Region had high CPUE values for all three on-system waterbodies (Playgreen Lake [8.9 fish], Little Playgreen Lake [13.6 fish], and Cross Lake [9.8 fish]). Partridge Breast Lake had the highest overall CPUE for Northern Pike for all waterbodies at 16.7 fish.

The Lower Churchill River Region had the highest mean total CPUE for Lake Whitefish captured within on-system waterbodies (13.5 fish) followed by the Upper Churchill River Region (8.4 fish) (Figure 6.5-5). A major contributor to the high CPUE value for the Lower Churchill River Region was the CPUE for Lake Whitefish from Billard Lake which had the highest of all CAMPP waterbodies at approximately 26 fish. The remaining five regions had extremely low CPUE values ranging from 0.2 to 1.1 fish.

Sauger were completely absent from the Lower Churchill River Region and from half of the waterbodies examined in the Lower Nelson River Region (Figure 6.5-6). Sauger had low CPUE values for most on-system CAMPP waterbodies. Some notable exceptions were South Indian Lake – Area 6 (12.8 fish), Lac Du Bonnet (8.9 fish) and Apussigamasi Lake (7.6 fish).

The Lower Churchill River Region had the highest mean total CPUE for Walleye captured within on-system waterbodies (14.4 fish) followed closely by the Upper Nelson River Region (11.0 fish) and the Saskatchewan River Region (11.5) (Figure 6.5-7). The Churchill River Diversion and Lower Nelson River regions had very similar Walleye CPUE values ranging from 8.5 to 8.9 fish. The Upper Churchill River Region had the lowest overall mean Walleye CPUE at only 0.6 fish while the Winnipeg River Region was second lowest at 4.7 fish. It should be noted that for many regions the off-system waterbodies had higher Walleye CPUE values, with the exceptions of Cormorant Lake in the Saskatchewan River Region, Walker Lake in the Upper Nelson River Region, and the Hayes River in the Lower Nelson River and Lower Churchill River regions.

6.5.3 Fork Length Variation

Mean fork lengths were examined for Northern Pike, Lake Whitefish, and Walleye within each region in Section 5. In this section the focus is an examination of regional differences in mean fork length of the three species looking only at on-system and off-system waterbodies.

The highest mean Northern Pike fork lengths for on-system waterbodies were recorded for the Winnipeg River (616 mm) and Lower Churchill River (606 mm) regions (Figure 6.5-8). Apussigamasi Lake in the Churchill River Diversion Region had the highest mean fork length for all CAMPP waterbodies (684 mm) while the other waterbodies in the same region had values less than 450 mm giving the region the lowest overall mean fork length for Northern Pike. The mean fork length for Northern Pike from the remaining regions ranged from 541 mm (Upper Churchill River Region) to 577 mm (Lower Nelson River Region). Within each region the off-system mean fork lengths for Northern Pike were within the range of or slightly higher than those for the on-system waterbodies.

For Lake Whitefish, mean fork length for on-system waterbodies ranged from 341 mm in the Upper Churchill River Region to 459 mm in the Lower Nelson River Region for on-system waterbodies (Figure 6.5-9). The Lower Churchill River Region had the second lowest mean fork length (373 mm) while the Winnipeg River, Churchill River Diversion, and Upper Nelson River regions had similar mean fork lengths. Fork lengths for off-system waterbodies were found to have similar mean total fork lengths to the on-system waterbodies.

Two regions, the Lower Churchill River and Lower Nelson River regions, had the same and overall highest mean fork lengths for Walleye captured in on-system waterbodies at 433 mm followed closely by the Upper Nelson River Region at 421 mm (Figure 6.5-10). The lowest mean fork length was recorded for the Upper Churchill River Region (343 mm), only slightly lower than the values recorded for the Winnipeg River (354 mm) and Churchill River Diversion (356 mm) regions. In general, the fork lengths measured for Walleye tended to vary less among waterbodies in a given region than those measured for either Lake Whitefish or Northern Pike. Off-system mean fork lengths for walleye were similar to those for the on-system waterbodies.

6.5.4 Growth

Age composition and growth have previously been discussed in Section 5 for each region. In this section the focus is on the examination of the Von Bertalanffy growth curves that were fit for each waterbody for Northern Pike, Lake Whitefish, and Walleye. Several things must be noted. First, the growth curves presented in Figures 6.5-11, 6.5-12, and 6.5-13 are extrapolated outside of the data range for most waterbodies. Second, the Brody growth coefficient (K) was used to compare growth rates between waterbodies and/or regions. Although the Brody growth coefficient is not a growth rate per se (its units are yr^{-1}) (Ricker 1975 *In* Ogle 2013), it does measure the exponential rate of approach to the asymptotic average length (L_∞) (Schnute and Fournier 1980 *In* Ogle 2013). L_∞ is somewhat sensitive to the number and composition of large/old individuals in the population, and is generally negatively correlated with K (i.e., the lower L_∞, the higher the value of K and vice versa). Only more data from a greater range of ages, and/or exploring other versions of the Von Bertalanffy growth model (i.e., that proposed by Gallucci and Quinn 1979) can increase model interpretability and improve comparisons between waterbodies and regions.

Growth for Northern Pike, as measured by the Brody growth coefficient (K), varied both within and among the regions (Figure 6.5-11). Within the Winnipeg River Region, the off-system waterbody, Eaglenest Lake, had the highest growth coefficient followed closely by Lac du Bonnet, then Pointe du Bois. Although Pointe du Bois Northern Pike appeared to be the fastest growing in the region, a linear trajectory caused by a lack of individuals older than 11 years-of-age in the Pointe du Bois data set resulted in an extremely high asymptotic average length (L_∞) and as a result, a low growth coefficient (K). In the Saskatchewan River Region two waterbodies had similar growth rates, South Moose and Cedar Lake, while Cormorant Lake and Saskatchewan River, had extremely high asymptotic average lengths (L_∞) and as a result, low growth coefficients (K). In the Upper Churchill River Region Granville Lake, one of the off-system waterbodies, had the highest Northern Pike growth coefficient. The growth coefficient for Gauer Lake, the other off-system waterbody, was similar to both Southern Indian Lake areas. The Lower Churchill River Region had no difference between the growth coefficients estimated for Partridge Breast Lake, Northern Indian Lake and the lower Churchill River. The Churchill River Diversion Region showed little variation in growth for all waterbodies; however, the Brody growth coefficients and the asymptotic average lengths varied considerably for Notigi and Footprint lakes, primarily due to a lack of larger bodied individuals. Leftrook Lake had, on average, the smallest asymptotic average length (≈585 mm) in the region. Within the Upper Nelson River Region, three waterbodies (Playgreen Lake, Little Playgreen Lake and Walker Lake [off-system]), had similar growth curves while Cross Lake and Setting Lake (off-system) differed from these three lakes. The lower Nelson River waterbodies were all very similar in terms of Northern Pike growth, with only one waterbody, Hayes River, having a low sample size, making inference difficult. Due to the variability present within each region it is difficult to make comparisons between regions using Northern Pike growth rate curves.

Within each region, both the on- and off-system waterbodies had fairly similar growth curves for Lake Whitefish (Figure 6.5-12). Only two waterbodies were represented in the Winnipeg River Region, Lac Du Bonnet and Manigotagan Lake, and they had relatively similar rates of growth. However, Lac Du Bonnet Lake Whitefish obtained an overall larger size than those from Manigotagan Lake and at an earlier age. The greatest difference in the Upper Churchill River Region was noted for areas 1 and 4 in Southern Indian Lake where Area 1 Lake Whitefish obtained an overall larger size and Area 4 Lake Whitefish had a slower growth rate than Lake Whitefish for all other waterbodies in the region. The remaining regions did not show much difference in the growth rate of Lake Whitefish among waterbodies. Across all regions the growth curves for Lake Whitefish also varied very little with similar rates of growth and overall maximum sizes.

The growth rates for Walleye were found to be similar both within and between regions (Figure 6.5-13). Of all the regions, Walleye within the Lower Churchill River Region appeared to have the slowest growth followed by those in the Winnipeg River Region. The remaining regions exhibited similar growth patterns. The Winnipeg River Region appeared to have walleye that obtained the highest asymptotic average length at around 700 to 800 mm, with the exception of Eaglenest Lake where average asymptotic length was approximately 500 mm. The remaining regions ranged from 400 to 600 mm with the exception of Cross Lake in the Upper Nelson River Region which was closer to 700 mm).

6.5.5 Deformities, Erosion, Lesions, and Tumours (DELTs)

The frequency of deformities, erosion, lesions and tumours (DELTs) was considered to be low for all regions. One of the metrics used in calculating the Index of Biotic Integrity (IBI) scores for each region in the section below was based on the frequency of DELTs. Table 6.5-1 shows the average scores for on- and off-system waterbodies for all metrics including DELTs. Unlike the other metrics used in calculating the overall IBI scores, DELTs were scored between five and zero, with five indicating no reported DELTs and 0 indicating all individuals had DELTs present. Both on- and off-system waterbodies within the Saskatchewan River Region had no reported DELTs while the Winnipeg River, Upper Churchill River, Churchill River Diversion, and Upper Nelson River regions all had calculated scores above four. The Lower Nelson River Region had the greatest frequency of DELTs with scores of 3.7 for both the on- and off-system waterbodies. As previously noted in Section 4, the value given to the DELTs metric in the overall calculation of IBI scores was less than that of the other metrics due to differences in how agencies and individuals identified DELTs in the field early on in the program. A more clearly defined protocol for determining DELTs was established and incorporated into the field collection manual to address the issue.

6.5.6 Index of Biotic Integrity

For the overview section mean IBI scores were calculated for both on- and off-system waterbodies within each region as well as IBI scores for individual waterbodies with all years combined (Table 6.5-1 and Figure 6.5-14). The highest regional IBI score for on-system waterbodies was calculated for the Winnipeg River Region (65.8) followed closely by the Lower Churchill River Region (62.4). The remaining regions had very similar overall mean IBI scores ranging from 52.2 (Churchill River Diversion Region) to 56.1 (Upper Nelson River Region). In terms of individual on-system waterbodies, the highest IBI scores were calculated for Lac Du Bonnet (72.9), Apussigamasi Lake (67.9), and the Churchill River at Little Churchill River (67.9). The on-system waterbodies with the lowest IBI scores were the Limestone Forebay in the Lower Nelson River Region (36.9), Notigi Lake in the Churchill River Diversion Region (42.4), and South Moose Lake in the Saskatchewan River Region (43.5). Off-system waterbodies also showed considerable variability in IBI scores, with a high of 65.8 for Eaglenest Lake in the Winnipeg River Region and a low of 41.8 for Walker Lake in the Upper Nelson River Region.

An examination of the average metric scores for each region and system presented in Table 6.5-1 provides information about how individual metrics contributed to the total IBI scores. For the Winnipeg River Region on-system, which had the highest total IBI score, the metrics that contributed most were the total number of species present, the number of sensitive species present, the number of insectivore species present, and evenness. The proportion of tolerant individuals metric also scored high meaning that they made up a small proportion of the overall fish community present. The Winnipeg River Region off-system consisting of Eaglenest and Manigotogan lakes had a slightly lower IBI score. Although the total number of species, number of sensitive species, and number of insectivore species scored low, several other metrics had high values (proportion of lithophilic spawners, proportion of tolerant individuals, and omnivore biomass) contributing to the total IBI score. Within the Saskatchewan River Region the on- and off-system IBI scores were very similar (53.5 for on-system and 50.5 for off-system) as were the metrics contributing to them. No particular metric scored highly, however several extremely low scores were calculated for the proportion of insectivore biomass, total number of sensitive species, and proportion of omnivore biomass. Within the Upper Churchill River Region, most metrics scored slightly higher for off-system than on-system with neither scoring very high for any metric with the exception of the proportion of lithophilic spawners, which scored 8.9 for on-system and only 6.9 for off-system. The Lower Churchill River Region on-system had the third highest total IBI score of any group. Despite having relatively low scores for the total number of species, sensitive species, and CPUE, it had high scores for proportion of tolerant individuals and for proportion of omnivore biomass indicating that both of the waterbodies in the region tended to have low proportions of both. Within the Churchill River Diversion Region the on- and off-system waterbodies had similar total IBI scores and also similar individual metric scores. Most metric scores were relatively low with the exception of CPUE, which scored much higher for the off-system than the on-system, and the proportion of lithophilic spawners which was high for both. The Upper Nelson River Region on-system had a slightly higher IBI score than the off-system waterbodies due mostly to a higher number of total species and piscivore biomass. Both on- and off-system had relatively high metric scores for total number of species, proportion of tolerant individuals, and the number of insectivore species present. The Lower Nelson River Region on- and off-system total IBI scores were similar with the off-system having higher scores for the proportion of tolerant individuals, proportion of omnivore biomass, and the proportion of lithophilic spawners while the on-system had higher scores for total number of species, number of insectivore species, and evenness.

6.5.7 Off-system Waterbodies

Off-system waterbodies monitored under CAMPP are inherently different from on-system waterbodies due to differences in lake morphometry, drainage basin size, hydrology etc. Thus, differences in the fish community of off-system and on-system waterbodies were anticipated. Despite those anticipated differences some aspects of the off-system waterbodies were similar to those of the on-system waterbodies. The total number of species was not considerably different within each region for on- versus off-system waterbodies with the exception of the previously noted variation between Manigotagan Lake and the other Winnipeg River Region waterbodies. Relative abundance of the four species of interest was also similar within each region again with the notable exception of Manigotagan Lake where Sauger was absent. One of the key metrics that was found to be different between on- and off-system waterbodies was CPUE, particularly for mean total CPUE for all species as well as for Northern Pike and Walleye, where the off-system waterbodies were often considerably higher than the on-system ones. Mean fork lengths for Lake Whitefish, Northern Pike, and Walleye were similar between on- and off-system waterbodies. The overall IBI scores were very similar between on- and off-system waterbodies within each region.

Table 6.5-1. Average metric scores and total IBI scores for CAMPP waterbodies grouped by region and system status (on- versus off-system waterbodies). Years (2008 – 2010) and waterbodies were combined for each score calculated.

	IBI Scores												
Metric ID	WRR-ON	WRR-OFF	SRR-ON	SRR-OFF	UCRR-ON	UCRR-OFF	LCRR-ON	CRDR-ON	CRDR-OFF	UNRR-ON	UNRR-OFF	LNRR-ON	LNRR-OFF
NUMSPP	9.0	5.4	6.0	6.8	5.0	6.3	5.8	6.5	4.8	7.3	6.4	6.6	4.7
NUMSS	8.2	6.0	3.3	2.8	2.4	2.8	2.4	3.6	2.4	3.8	2.4	3.0	2.9
PROPTS	6.6	8.7	7.5	5.2	5.9	4.0	7.9	5.9	5.9	7.0	6.3	4.5	7.3
NUMIS	7.6	3.8	6.0	7.0	4.1	6.4	5.9	6.0	4.5	6.9	6.0	5.8	4.2
EVENNESS	7.6	5.1	4.7	5.2	4.9	6.0	5.9	6.2	6.1	5.3	6.2	6.6	5.3
INSBIO	3.6	4.3	1.7	1.7	5.5	2.3	6.0	2.5	5.0	1.6	2.7	2.6	4.9
OMNBIO	4.4	7.6	3.8	1.8	4.7	2.1	7.7	2.9	3.9	5.4	3.0	7.0	8.0
PISBIO	4.3	6.0	4.9	3.6	3.4	3.0	5.2	3.8	3.1	6.0	3.9	6.5	5.9
PROPLS	6.7	8.1	5.7	5.1	8.9	6.9	6.5	7.0	6.4	3.0	7.7	5.2	8.1
CPUE	3.4	5.5	4.9	6.3	4.8	7.3	5.2	3.3	8.1	5.6	6.5	2.6	2.8
DELTS	4.4	4.4	5.0	5.0	4.9	4.7	3.9	4.5	4.2	4.2	4.6	3.7	3.7
Total IBI	65.8	64.9	53.5	50.5	54.5	51.8	62.4	52.2	54.5	56.1	55.7	54.2	57.8

WRR = Winnipeg River Region, SRR = Saskatchewan River Region, UCRR = Upper Churchill River Region, LCRR = Lower Churchill River Region, CRDR = Churchill River Diversion Region, UNRR = Upper Nelson River Region.

NUMSPP = Number of species, NUMSS = Number of sensitive species, PROPTS = Proportion of tolerant individuals, NUMIS = Number of insectivore species, EVENNESS = Hill's Species Richness Index, INSBIO = Insectivore biomass, OMNBIO = Omnivore biomass, PISBIO = Piscivore biomass, PROPLS = Proportion of simple lithophilic spawners, CPUE = Catch per unit effort, DELTS = Percent individuals with DELTS.

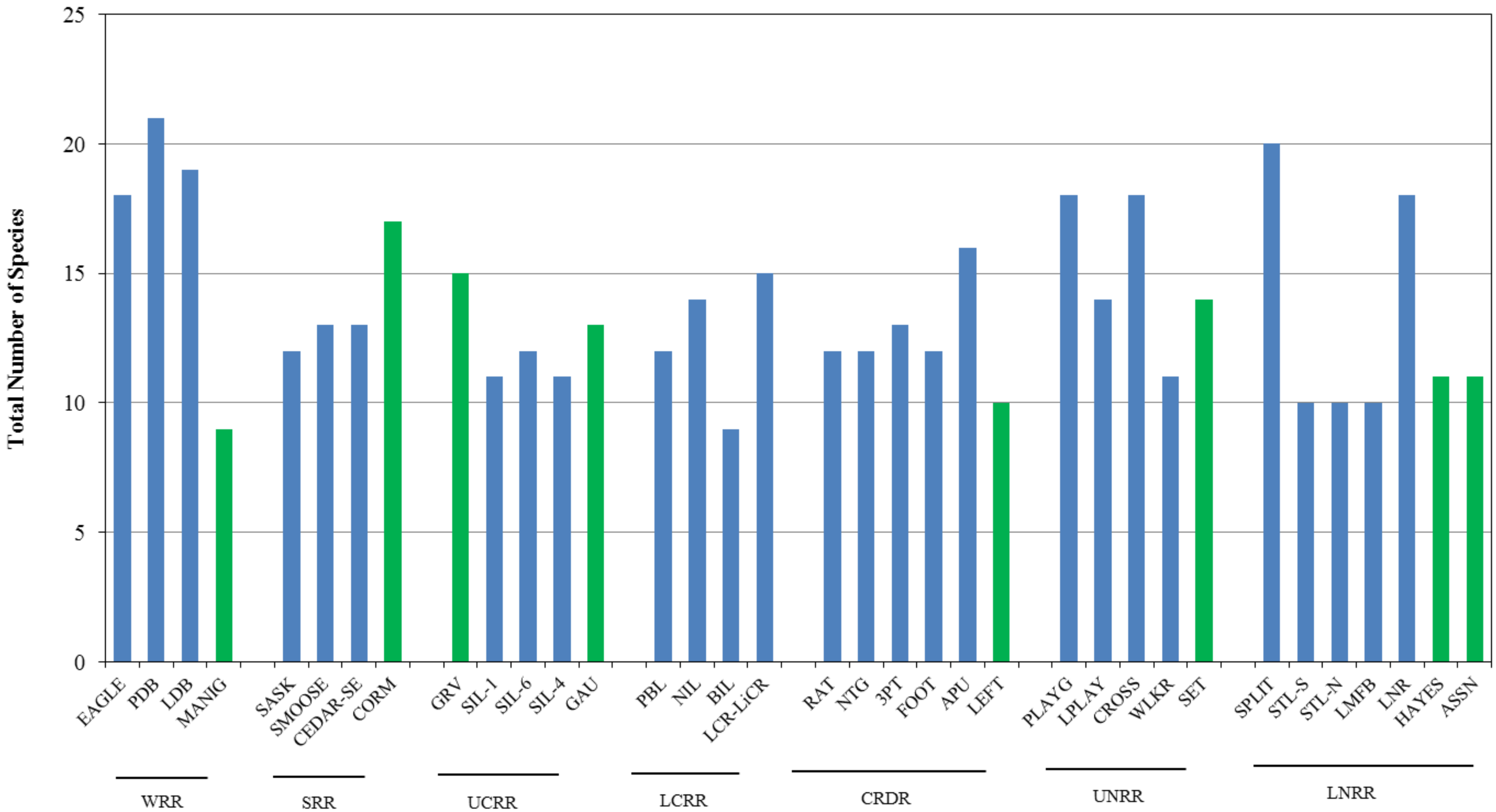


Figure 6.5-1. Total number of fish species captured by standard index and small mesh gang gillnet from CAMP waterbodies, 2008 – 2010. Off-system waterbodies are indicated in green.

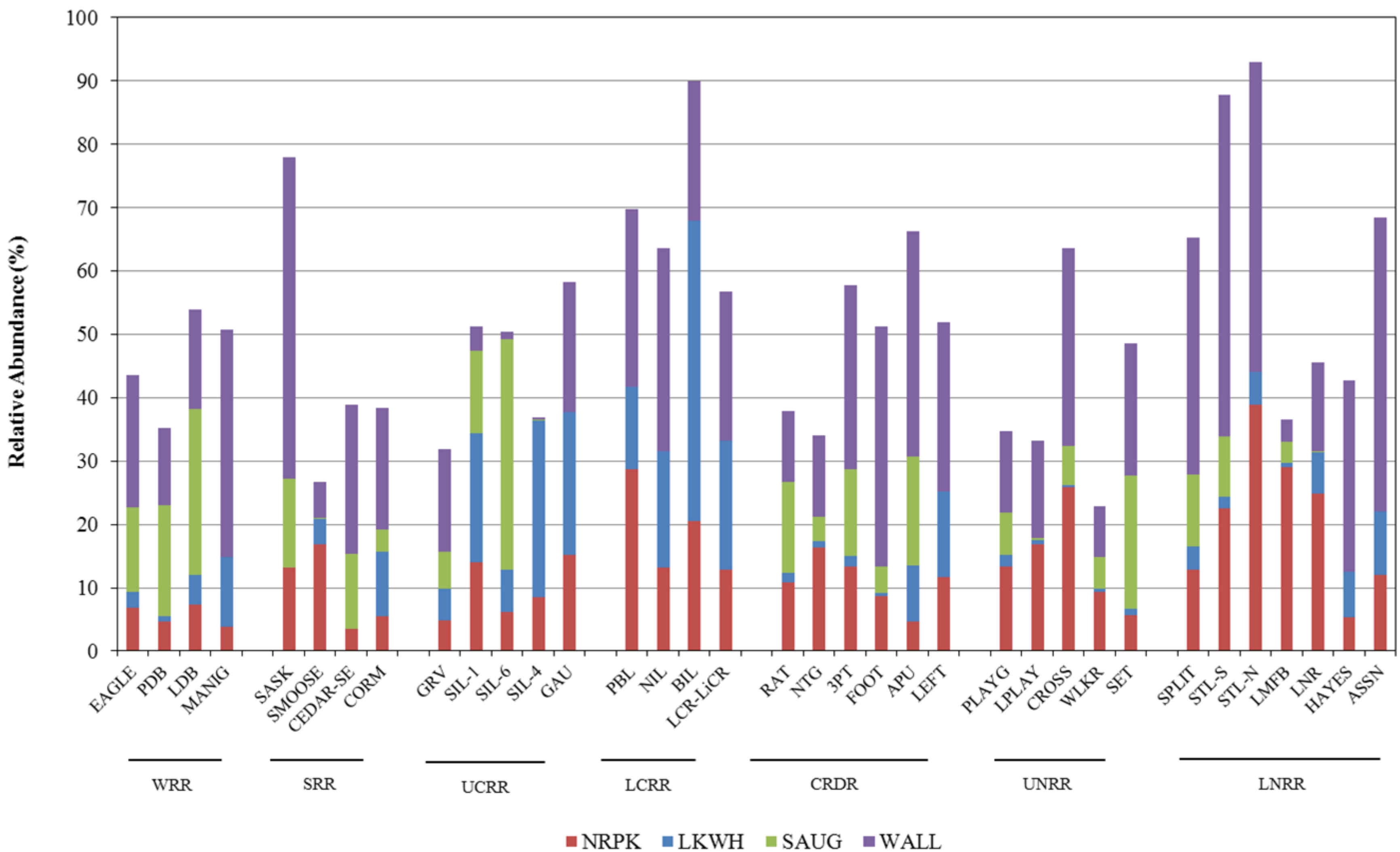


Figure 6.5-2. Relative abundance of Northern Pike (NRPK), Lake Whitefish (LKWH), Sauger (SAUG) and Walleye (WALL) captured by standard gang index gillnets from the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR), 2008 - 2010.

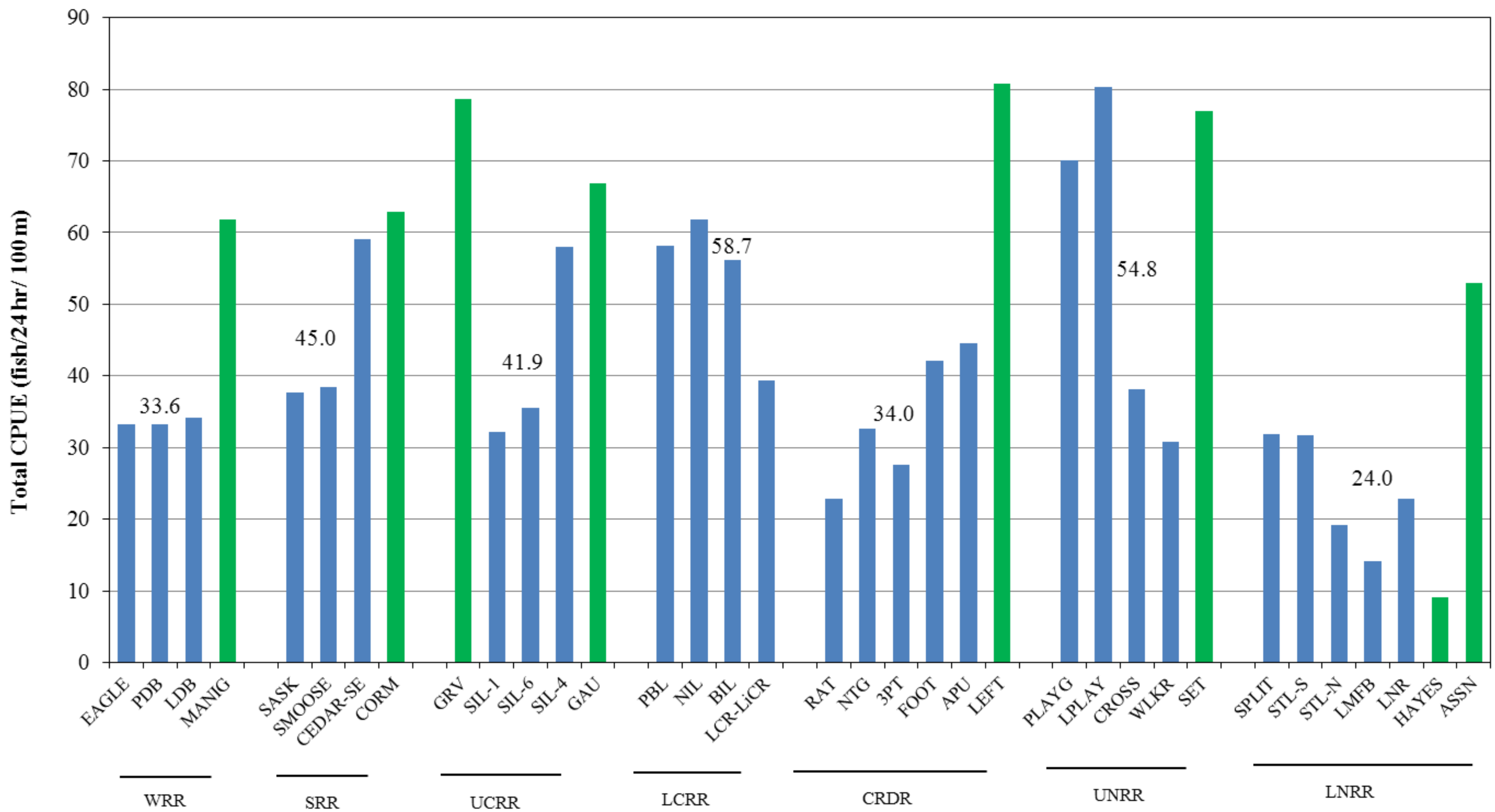


Figure 6.5-3. Mean total CPUE for all fish captured by standard index gillnets in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR), 2008 - 2010. Off-system waterbodies are indicated in green and On-system average CPUE values are indicated for each region.

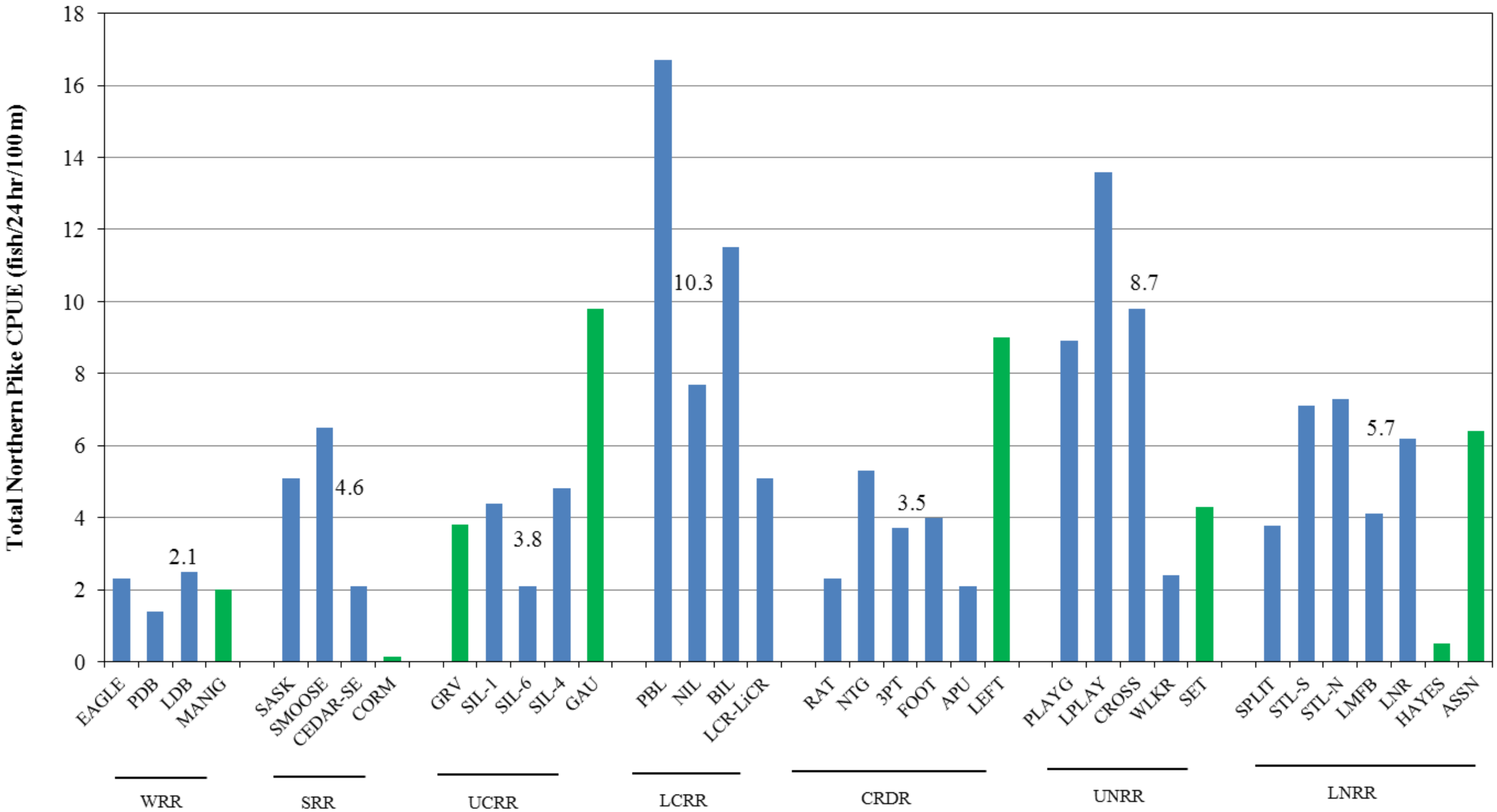


Figure 6.5-4. Mean total CPUE for Northern Pike captured by standard index gillnets in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR), 2008 - 2010. Off-system waterbodies are indicated in green and On-system average CPUE values are indicated for each region.

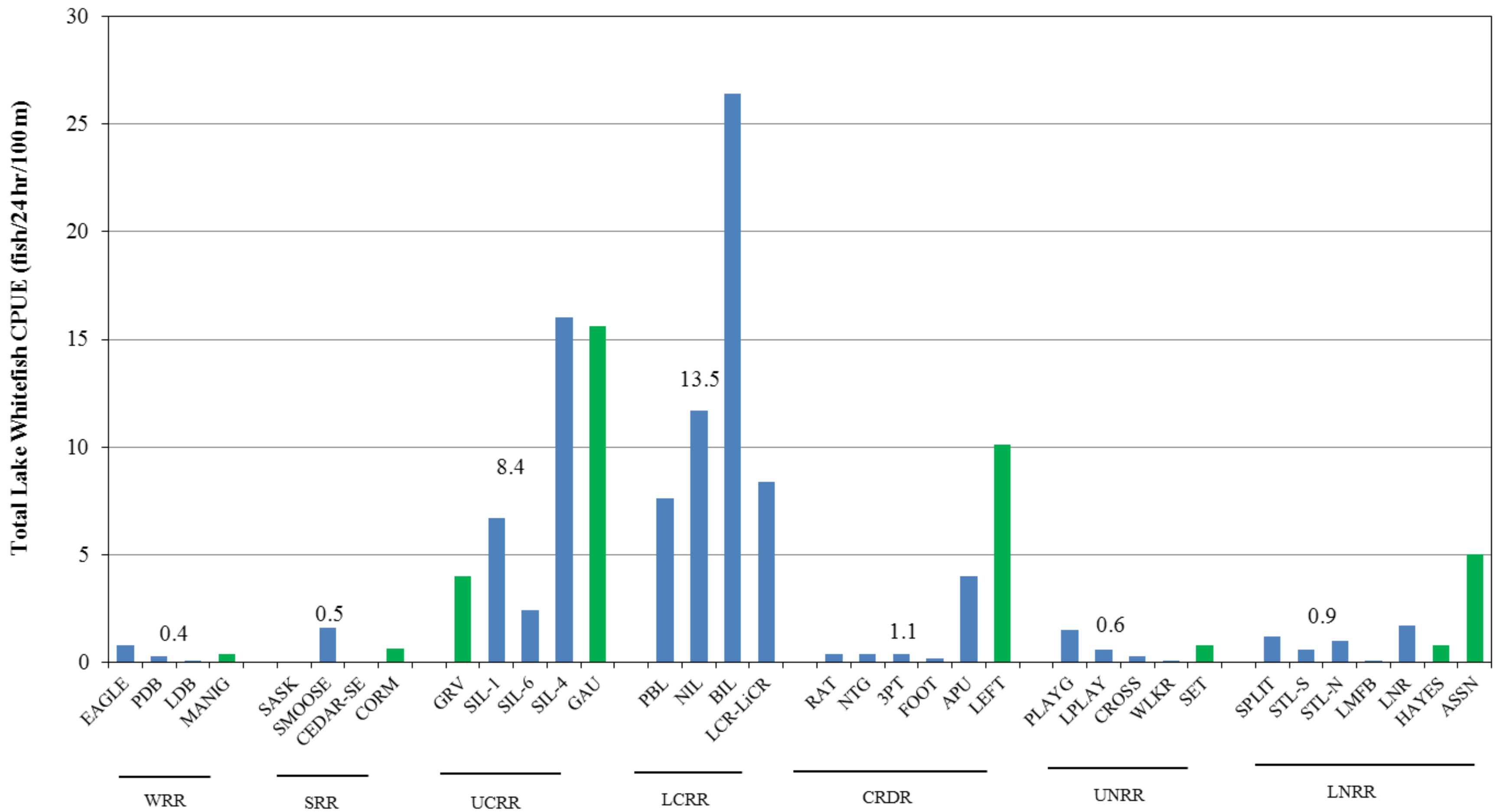


Figure 6.5-5. Mean total CPUE for Lake Whitefish captured by standard gang index gillnets in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR), 2008 - 2010. Off-system waterbodies are indicated in green and On-system average CPUE values are indicated for each region.

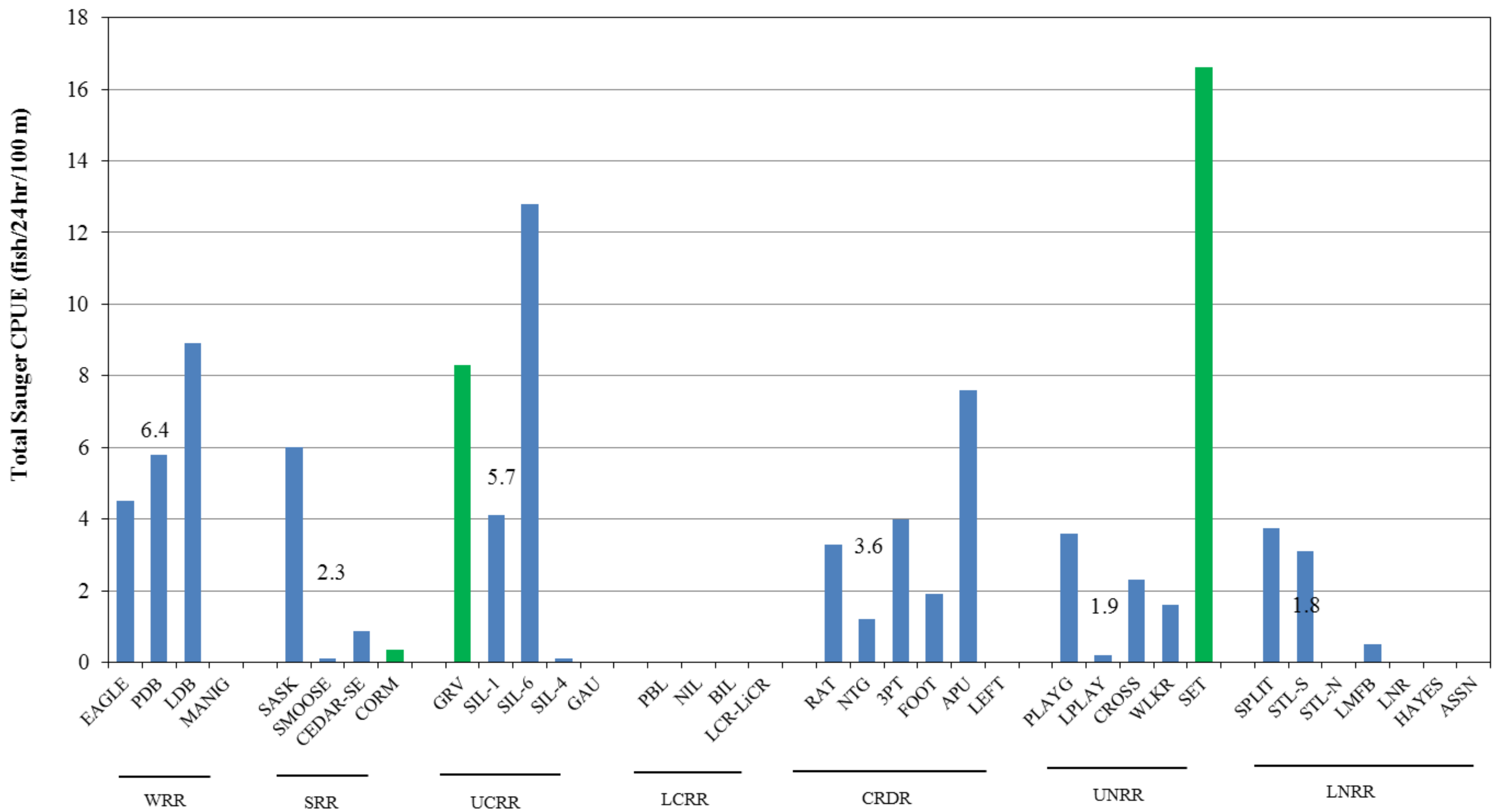


Figure 6.5-6. Mean total CPUE for Sauger captured by standard index gillnets in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR), 2008 - 2010. Off-system waterbodies are indicated in green and On-system average CPUE values are indicated for each region.

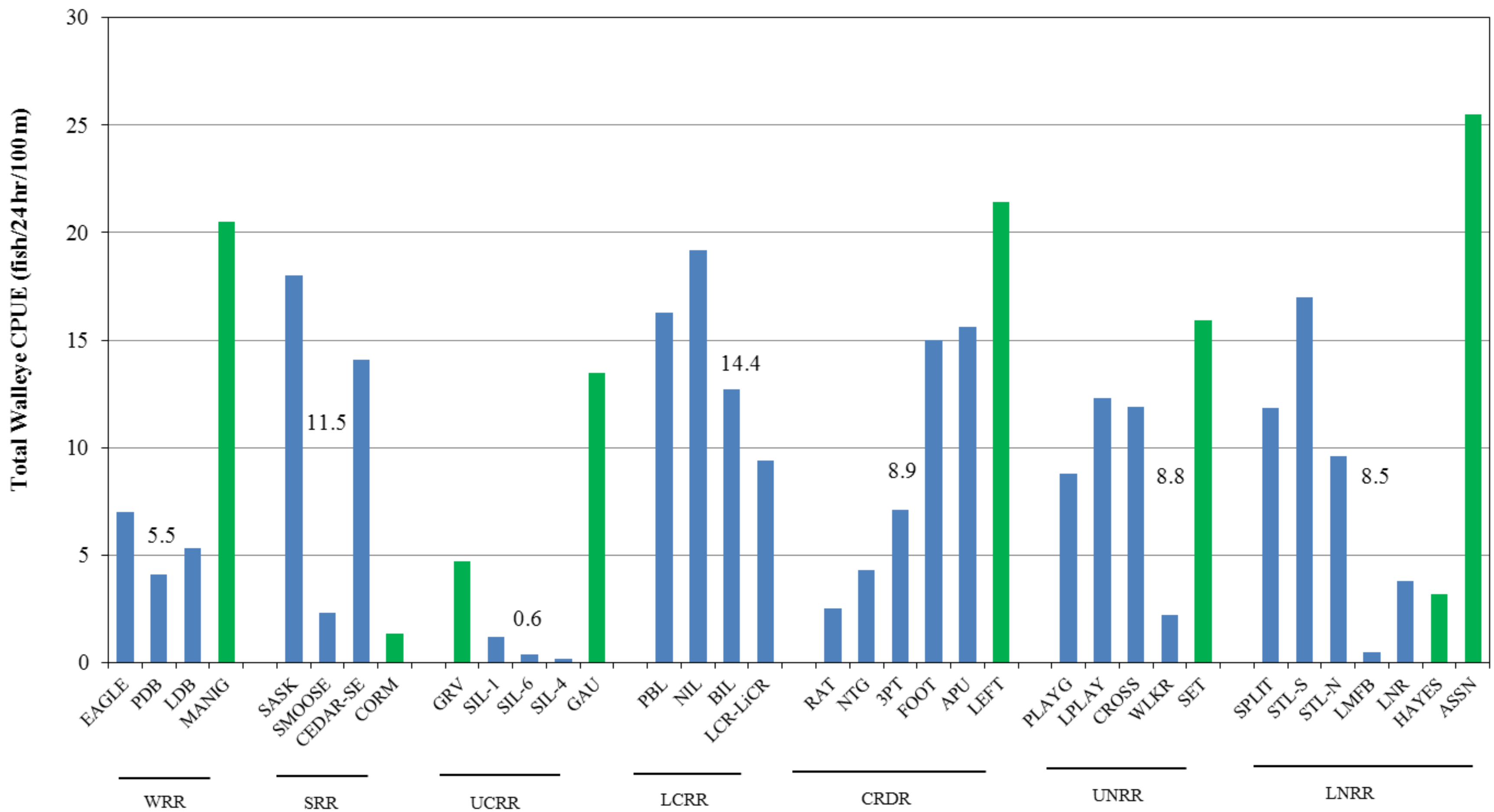


Figure 6.5-7. Mean total CPUE for Walleye captured by standard index gillnets in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR), 2008 - 2010. Off-system waterbodies are indicated in green and On-system average CPUE values are indicated for each region.

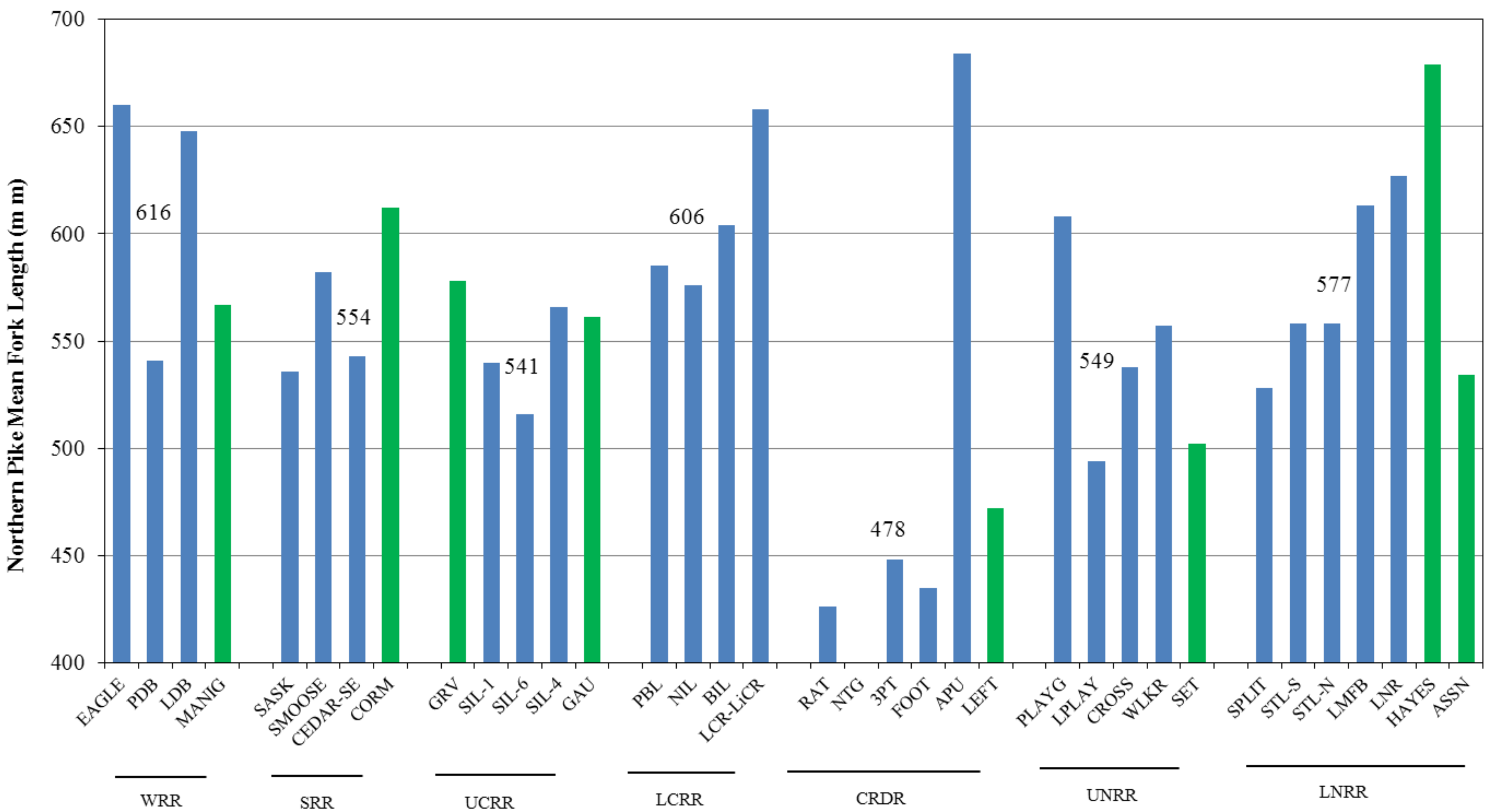


Figure 6.5-8. Mean fork length for Northern Pike captured by standard index gillnets in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR), 2008 - 2010. Off-system waterbodies are indicated in green and On-system average fork length values are indicated for each region.

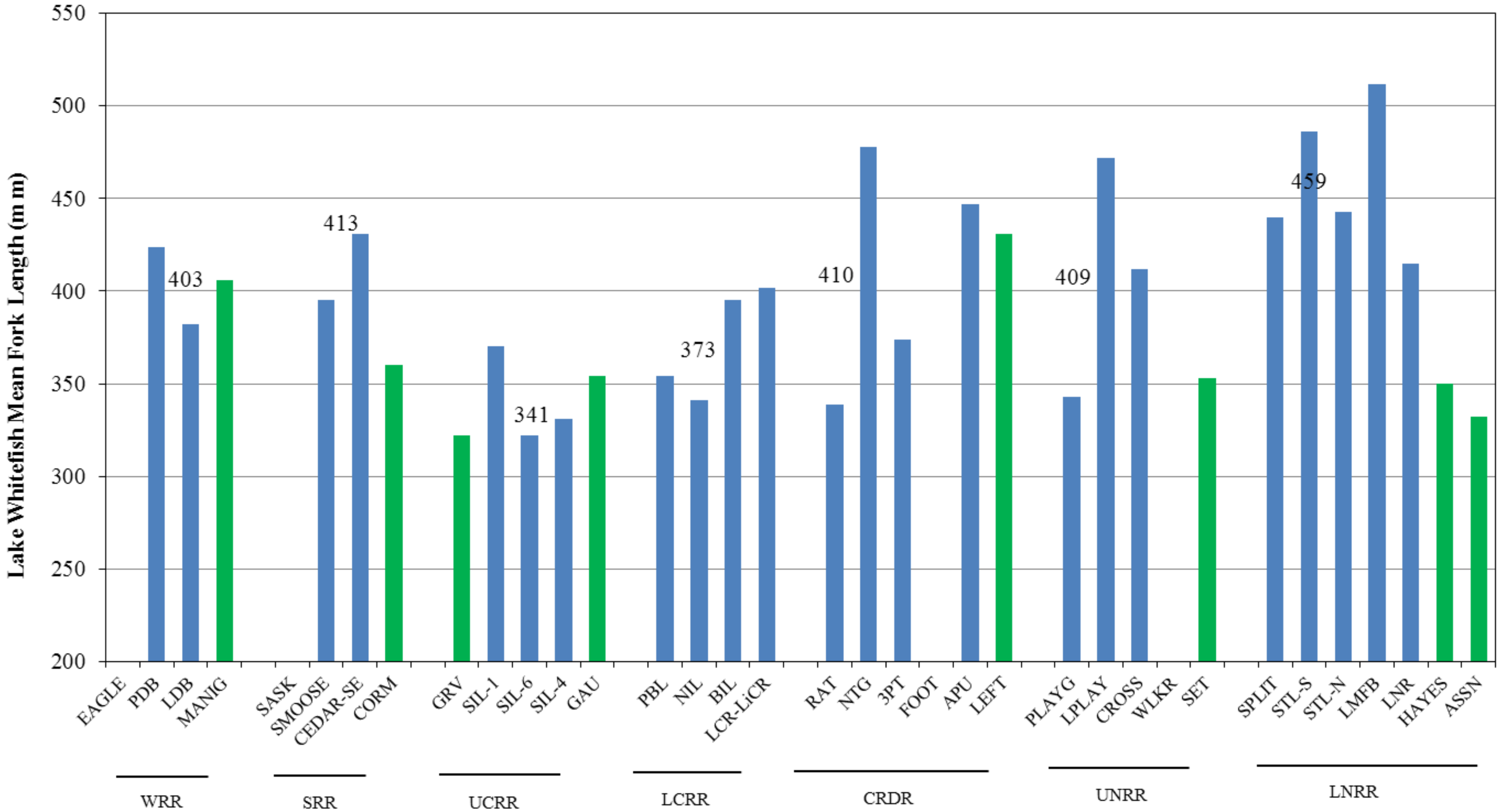


Figure 6.5-9. Mean fork length for Lake Whitefish captured by standard index gillnets in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR), 2008 - 2010. Off-system waterbodies are indicated in green and On-system average fork length values are indicated for each region.

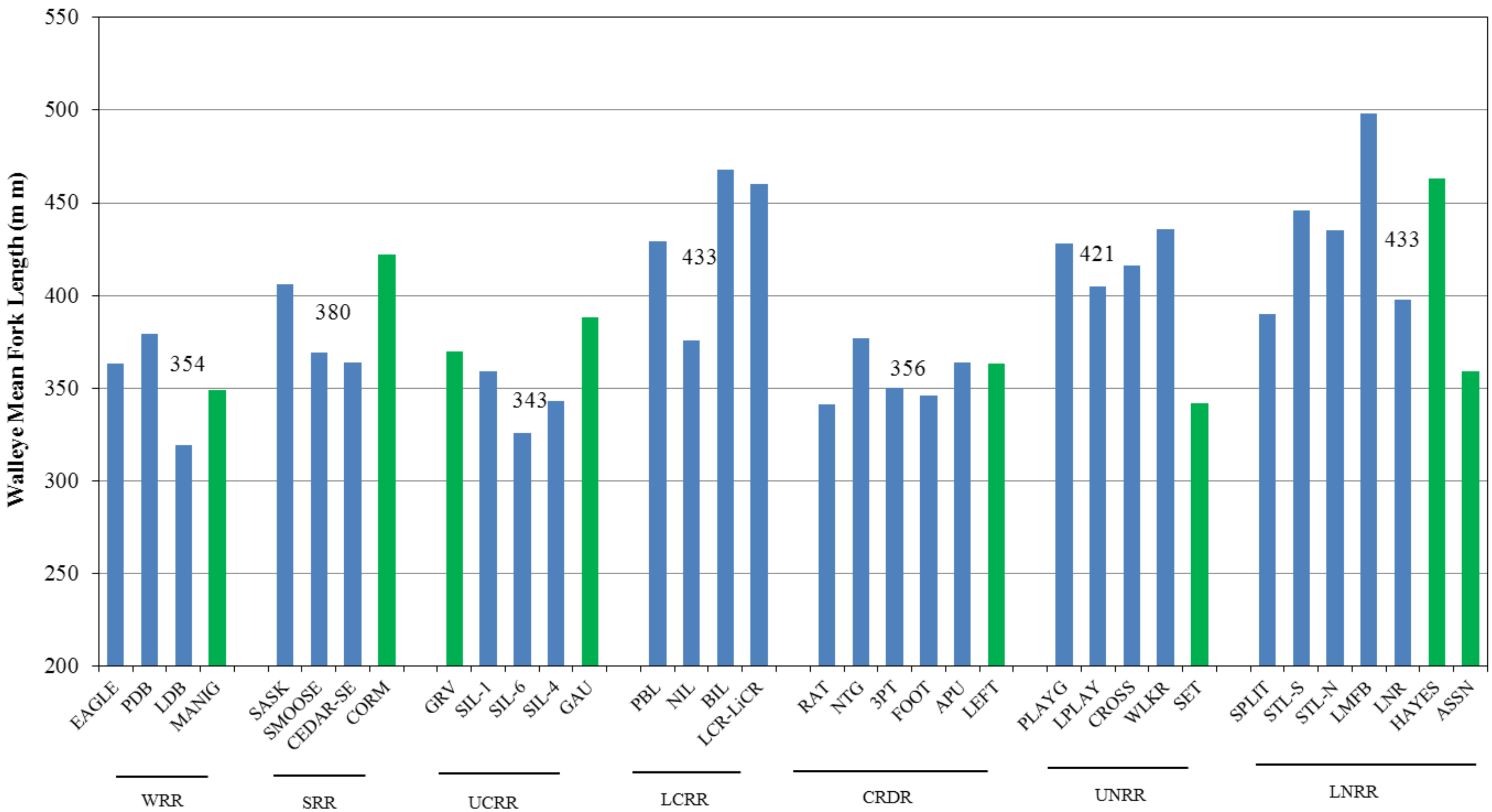


Figure 6.5-10. Mean fork length for Walleye captured by standard index gillnets in the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR), 2008 - 2010. Off-system waterbodies are indicated in green and On-system average fork length values are indicated for each region.

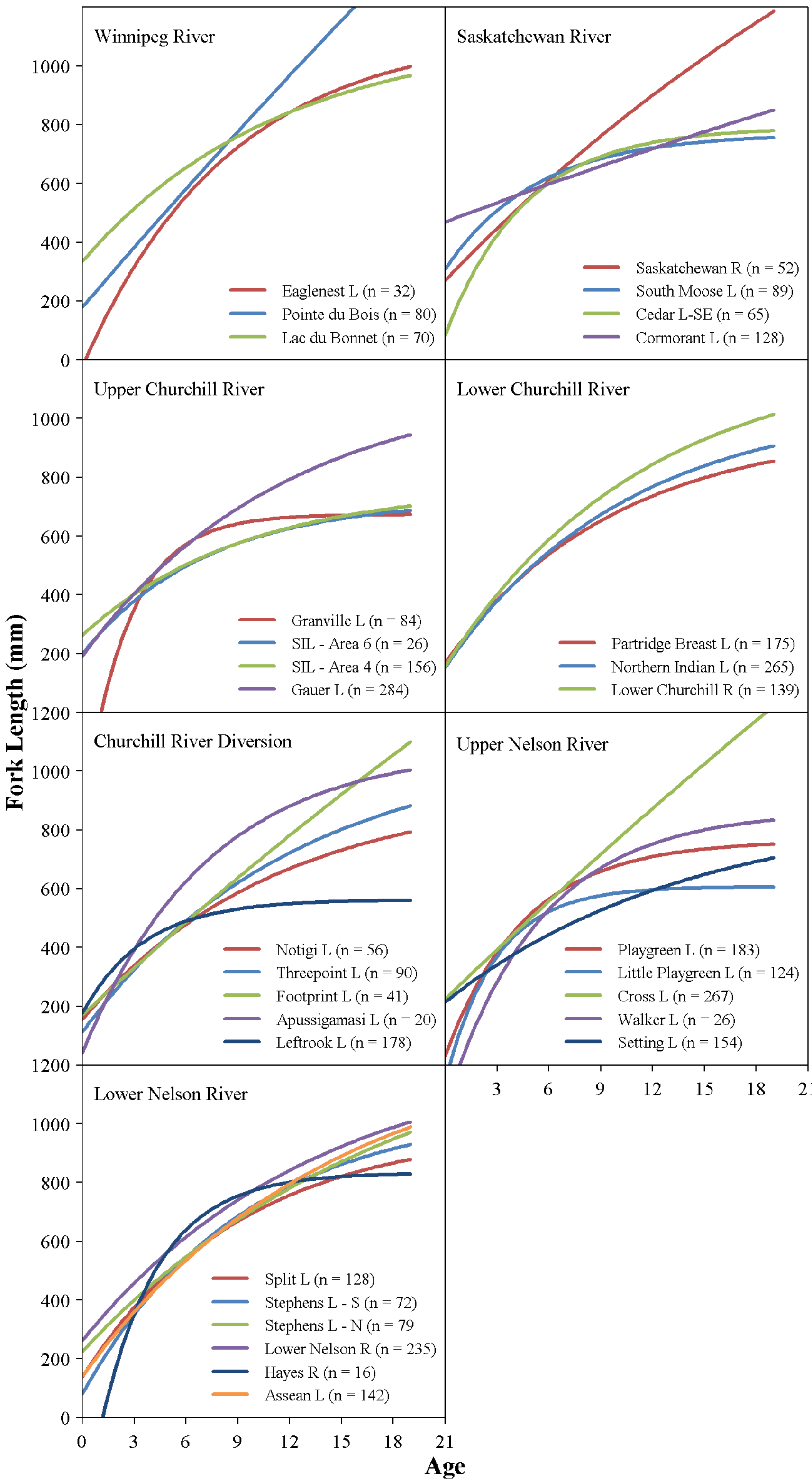


Figure 6.5-11. Von Bertalanffy growth models for all Northern Pike captured in standard gang index gill nets. Waterbodies are grouped by regions and n values are indicated in parenthesis.

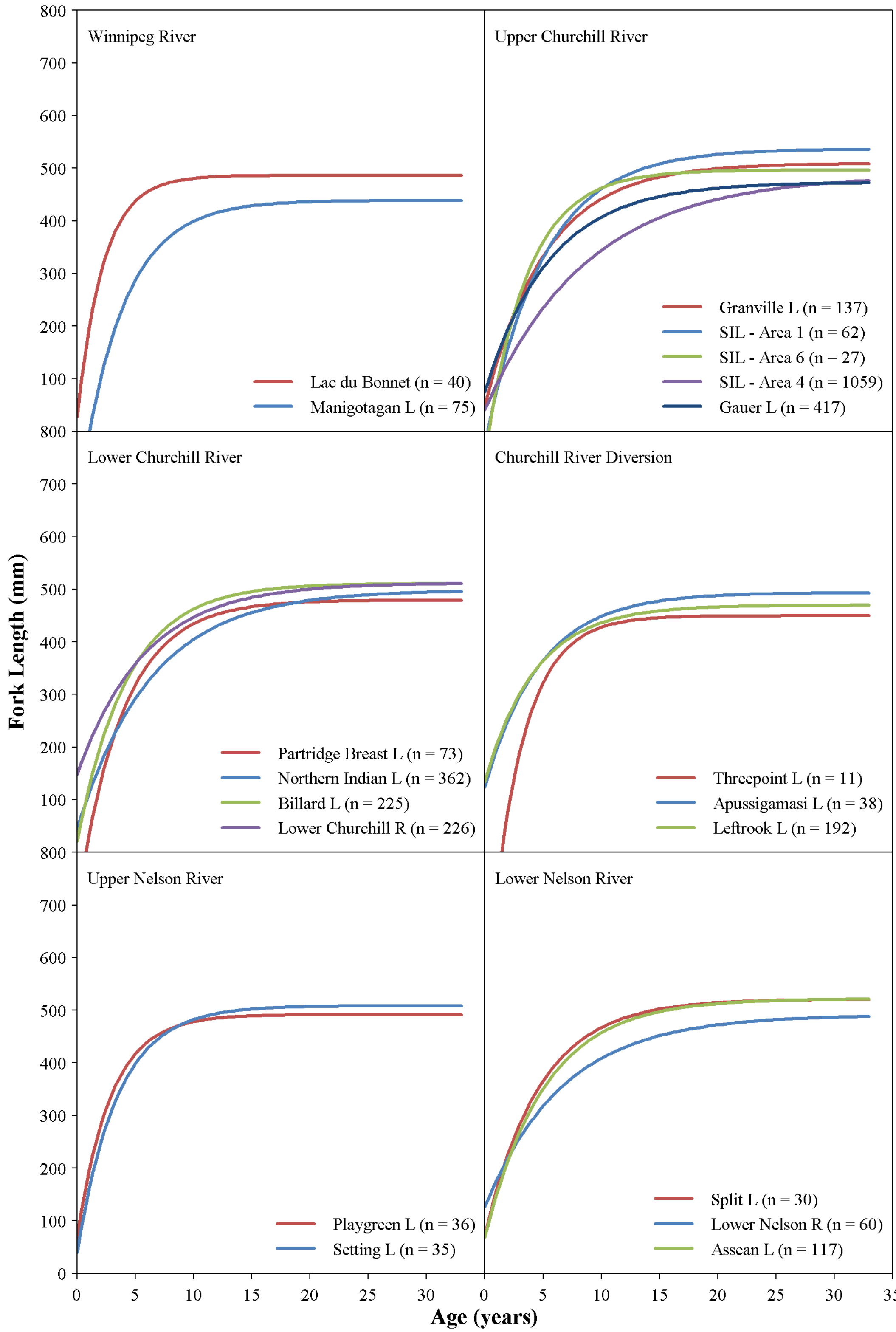


Figure 6.5-12. Von Bertalanffy growth models for all Lake Whitefish captured in standard gang index gill nets. Waterbodies are grouped by regions and n values are indicated in parenthesis.

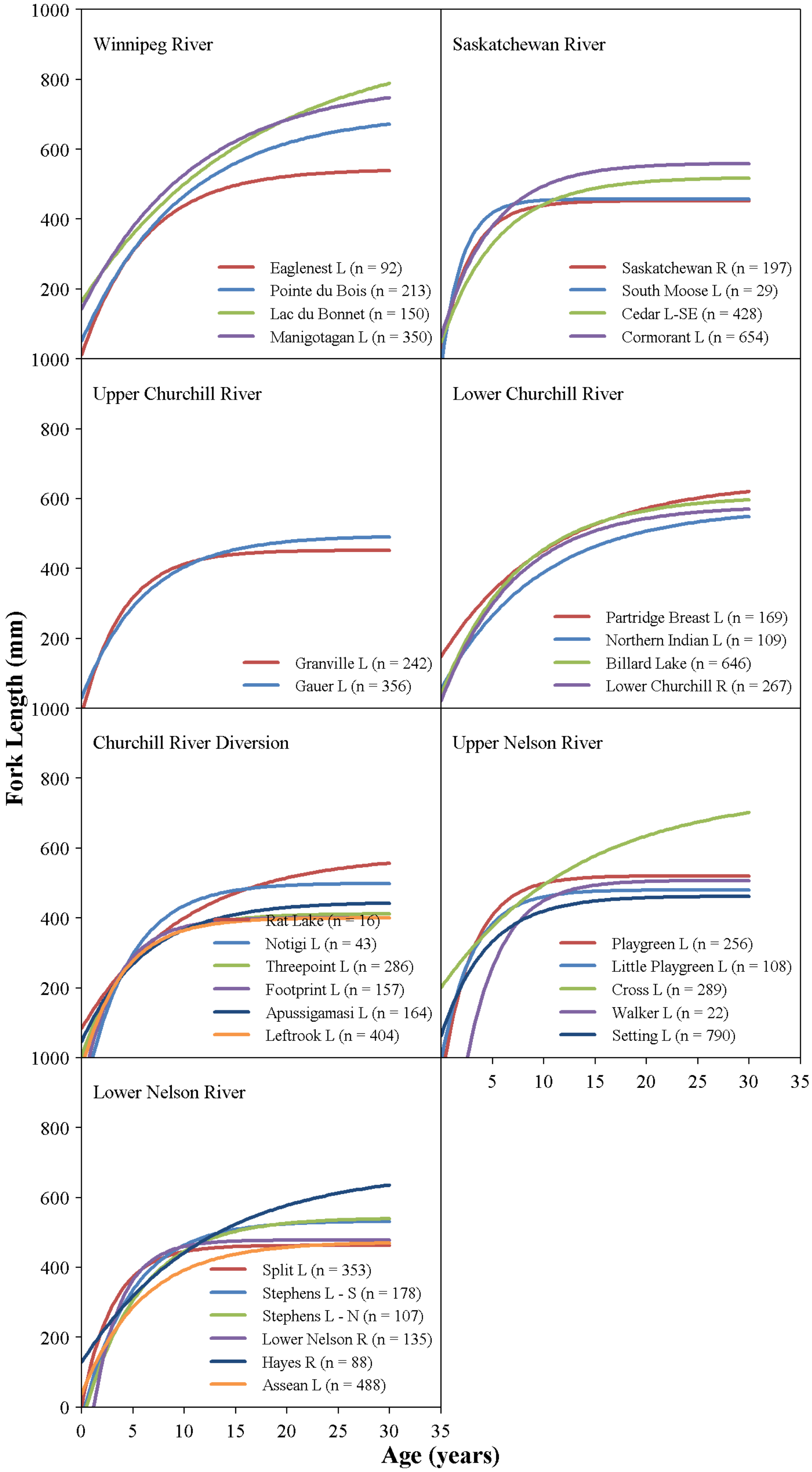


Figure 6.5-13. Von Bertalanffy growth models for all Walleye captured in standard gang index gill nets. Waterbodies are grouped by regions and n values are indicated in parenthesis.

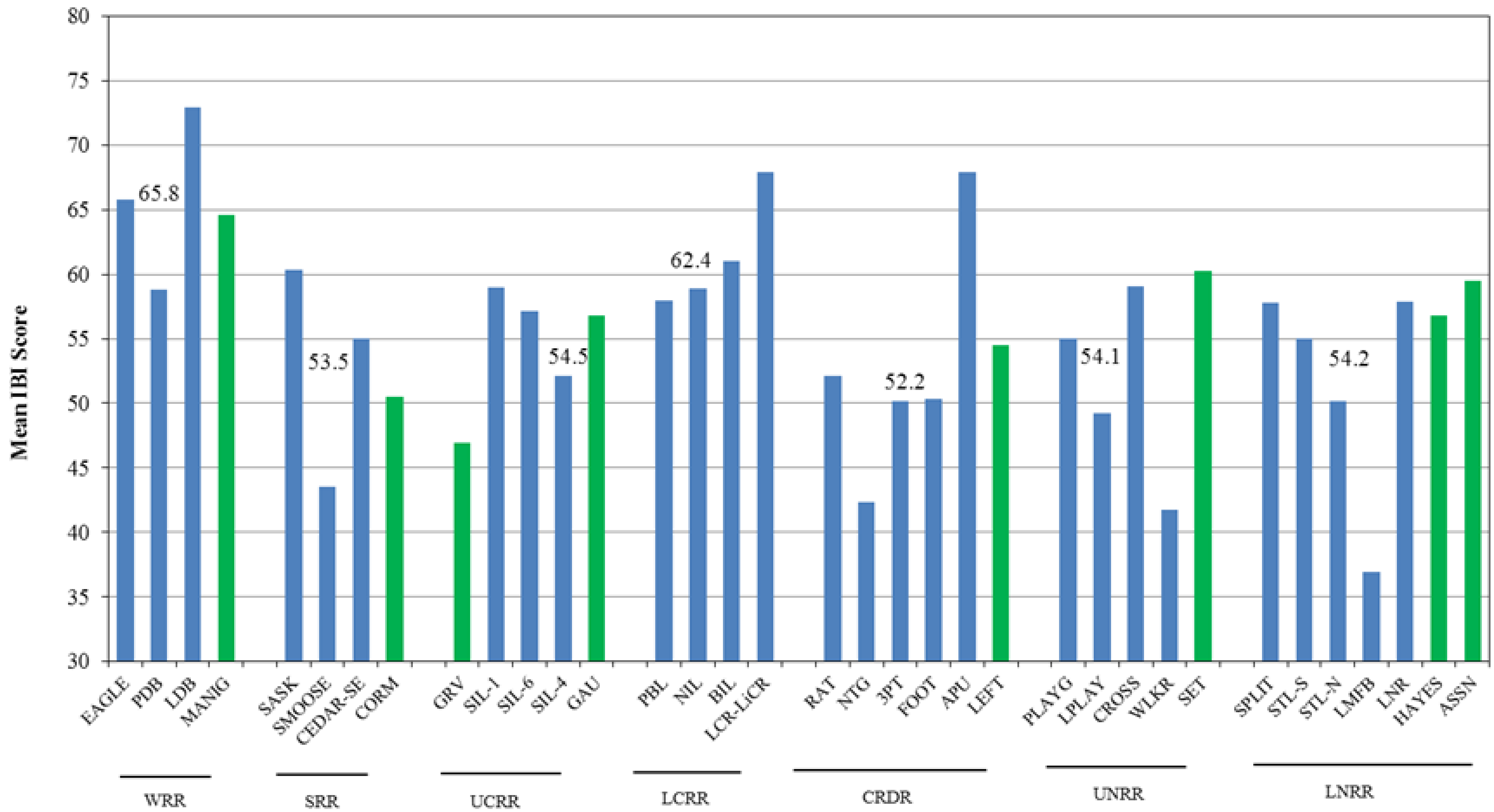


Figure 6.5-14. Mean Index of Biotic Integrity (IBI) scores based on 11 fish community metrics calculated from the Winnipeg River (WRR), Saskatchewan River (SRR), Upper Churchill River (UCRR), Lower Churchill River (LCRR), Churchill River Diversion (CRDR), Upper Nelson River (UNRR), and Lower Nelson River regions (LNRR), 2008 - 2010. Off-system waterbodies are indicated in green and On-system IBI scores are indicated for each region.

6.6 FISH MERCURY

As outlined in Section 4.8, fish mercury monitoring was conducted during one year under CAMPP (largely completed in 2010); most waterbodies continue to be monitored under the current CAMP on a three-year rotational basis, though annual monitoring was initiated in Year 4 of CAMP at two waterbodies. As only one year of data were collected under CAMPP, temporal comparisons of fish mercury concentrations could not be conducted. The following discussion focusses on spatial comparisons of mercury concentrations between waterbodies and regions, comparisons between species, relationships between mercury concentrations and fish length, and comparisons to mercury standards and guidelines. Because mercury data are available for relatively few populations of Yellow Perch, and because Yellow Perch size ranges sometimes differed substantially between waterbodies, spatial comparisons of mercury concentrations for this species could not be undertaken for this report, but will be incorporated into future reporting with acquisition of additional data.

6.6.1 Relationship between Mercury Concentration and Fish Size

The relationship between total mercury concentrations in muscle and fish fork length was consistently highly significant and positive for all three large-bodied species (Lake Whitefish, Northern Pike, and Walleye), when sample sizes corresponded to at least 70% or higher of the target size of 36 fish. Only the 12 Walleye from SIL - Area 4 and the 24 Lake Whitefish from Setting Lake showed no significant correlation between mercury concentration and fish size. The generally significant relationship between these two parameters indicated that length standardization of mercury concentrations was necessary for spatial (and future temporal) comparisons within species.

In contrast to the large-bodied species, the relationship between mercury concentration and fish size was not significant for five of the seven waterbodies where 1-year-old Yellow Perch were collected (Figure 6.6-1). The lack of a significant correlation between these parameters may be partially explained by the relatively small sample sizes obtained from Cedar, Setting, Leftrook, and Little Playgreen lakes. However, no significant relationship was found for this species where larger sample sizes were obtained (i.e., Cross, Cormorant, and Northern Indian lakes), suggesting for at least some waterbodies, that the typically positive correlation between mercury concentration and fish length may not apply for young Yellow Perch (see discussion below). Further, where significant correlations were found between mercury concentrations and Yellow Perch length, the relationship was negative (Cedar and Setting lakes; $p<0.01$; Figure 6.6-1). In addition, though not significant, the relationship between these parameters was negative for two other waterbodies (Northern Indian and Cross lakes).

Yellow Perch from Setting Lake represented the smallest fish caught from any of the CAMPP waterbodies (fork lengths of 60-70 mm), whereas their conspecifics from Cedar Lake spanned the largest size range of all Yellow Perch collected for mercury analysis (75-133 mm). Yellow Perch from Little Playgreen Lake were by far the largest analyzed for mercury in 2010 (Figure 6.6-1). Though these fish were not aged, their lengths (158-182 mm) indicated ages of greater than 1 year. An older age of these fish was also indicated by the fact that Little Playgreen Lake was sampled early in the season of 2010 (June 11-12) when water temperatures ranged from 11-14ºC. At this time growth of Yellow Perch may have just started.

The predominantly negative correlation between mercury concentration and Yellow Perch size is in contrast to the general paradigm in which mercury concentrations in fish are positively correlated to fish length/age (Green 1986; Evans et al. 2005), and which is supported by the results for the older, mainly mature Lake Whitefish, Northern Pike, and Walleye analyzed for mercury under CAMPP. This difference in the way mercury concentrations change with body size in the young, mainly immature Yellow Perch could be the result of growth dilution of mercury concentrations (Ward et al. 2010; Essington and Hauser 2003). The ratio of new to existing muscle mass increases rapidly during the growing-season of young Yellow Perch and these fish accumulate more biomass relative to mercury if food mercury concentrations are stable. This process is most pronounced for the fastest-growing and, consequently, largest individuals of a cohort, resulting in a negative correlation between mercury concentration and fish length. Emperical evidence for an age-related shift from a negative to a positive relationship between muscle mercury concentration and fish length has previously been reported by Braune (1987).

6.6.2 Comparisons of Mercury Concentrations between Waterbodies within Species

Mean length-standardized mercury concentrations in Lake Whitefish, Northern Pike, and Walleye ranged several fold between waterbodies sampled under CAMPP. Similar relative differences in arithmetic mean concentrations were found for Yellow Perch between waterbodies (comparison for this species could not be based on length-standardized means). The following provides an overview of differences observed between waterbodies for each of the fish species. Unless otherwise indicated, mean mercury concentrations refer to length-standardized concentrations.

6.6.2.1 Lake Whitefish

Mean mercury concentrations in Lake Whitefish varied approximately five fold, from 0.022 parts per million (ppm) for Playgreen Lake to 0.112 ppm for Northern Indian Lake (Figure 6.6-2).

Irrespective of CAMPP Region and excluding all samples with seven or less fish, three groups of waterbodies were found to have statistically significantly different mercury concentrations. Specifically, Lake Whitefish from Northern Indian Lake had higher concentrations than their conspecifics from all other waterbodies. Furthermore, Lake Whitefish from Playgreen Lake, Setting Lake, Southern Indian Lake-Area 6, and Leftrook Lake were distinct from all other waterbodies and, as a group, had the lowest mercury concentrations. All other waterbodies made up the third group. Although statistical differences in Lake Whitefish mercury concentrations existed between some waterbodies of this group (e.g., fish from Gauer Lake had lower concentrations compared to all other waterbodies except Assean Lake), no single waterbody was statistically distinct from all other waterbodies in terms of Lake Whitefish mercury concentrations. Within Southern Indian Lake, the only CAMPP waterbody where fish mercury data were collected from two distinctly separate areas, Lake Whitefish mercury concentrations were significantly different between the areas sampled (i.e., higher in Area 4 than in Area 6).

Considering lakes and rivers separately, Lake Whitefish mercury concentrations varied widely among lakes, whereas they were relatively uniform (i.e., not significantly different) and moderate to high across the four rivers (three on-system and one off-system) sampled under CAMPP (Figure 6.6-2). This pattern may reflect the more constant and uniform conditions in biogeochemical and broad ecological conditions in these rivers which were all sampled in similar (downstream) reaches within the river continuum (Vannote et al. 1980). In contrast the CAMPP lakes are quite heterogeneous, particularly in size, morphometry, and degree of riverine influence.

Based on individual fish, mercury concentrations of the 432 Lake Whitefish analyzed across regions ranged from 0.008 ppm (i.e., below detection limit) for several 1-year old fish from Playgreen Lake to 0.51 ppm measured in a 458 mm-long, 18 year old fish from the lower Nelson River. The arithmetic mean concentration of mercury measured in all Lake Whitefish was 0.067 ppm.

6.6.2.2 Northern Pike

Mean mercury concentrations in Northern Pike varied by almost an order of magnitude (0.105-1.012 ppm) between waterbodies (Figure 6.6-3). The two lakes representing with the minimum and maximum mean mercury concentrations were statistically distinct; Northern Pike from Cedar Lake-SE contained significantly lower concentrations, and Northern Pike from Manigotagan Lake contained significantly higher concentrations, than their conspecifics from all other waterbodies. Northern Pike from the remaining waterbodies showed a fairly even gradient of lower to higher mercury concentrations, and although statistical differences in mercury concentrations existed between waterbodies, these were largely related to regional differences or off-system versus on-system conditions (see Section 6.6.3 for a discussion). Similar to Lake Whitefish, mercury concentrations in Northern Pike collected from Areas 4 and 6 of Southern Indian Lake differed significantly; but unlike Lake Whitefish, Northern Pike contained higher concentrations in Area 6 (Figure 6.6-3).

Similar to Lake Whitefish, mercury concentrations of Northern Pike inhabiting rivers were generally more uniform than their conspecifics captured from lakes. However, unlike Lake Whitefish, significant differences in mercury concentrations of Northern Pike from different rivers were observed. Concentrations in Northern Pike from the Winnipeg River at Pointe du Bois were significantly higher compared to their conspecifics from all other rivers, and Northern Pike from the Churchill River at the Little Churchill River exceeded concentrations in fish from the remaining three rivers (Figure 6.6-3).

Based on individual fish, mercury concentrations of the 751 Northern Pike analyzed across regions ranged from 0.011 ppm measured in a 153 mm long, 1-year old fish from Assean Lake to 1.69 ppm (770 mm long, 10 year old fish from Manigotagan Lake). The arithmetic mean concentration of all Northern Pike was 0.37 ppm.

6.6.2.3 Walleye

Mean mercury concentrations in Walleye varied approximately six fold (from 0.107 ppm in Cedar Lake-SE to 0.648 ppm in the Winnipeg River at Pointe du Bois) across waterbodies (Figure 6.6-4). Concentrations in Walleye from Cedar Lake were significantly lower compared to their conspecifics from all other waterbodies. Spatial patterns regarding mercury concentrations in this species appear to be mainly related to regional and on-system/off-system differences (see Section 6.6.3 below). Similar to Northern Pike, concentrations of mercury were higher in Walleye from Area 6 than Area 4 of Southern Indian Lake. However, these arithmetic mean concentrations (the relationship between mercury concentration and fish length for Walleye from Area 4 was non-significant) did not differ statistically, possibly due to the small numbers of Walleye collected from both areas.

In contrast to Northern Pike, and particularly Lake Whitefish, mercury concentrations measured in Walleye from rivers were almost equally variable compared to their conspecifics from lakes. This was largely a result of the high concentrations in fish from the Winnipeg River, which represented the highest mean concentration for any Walleye population analyzed and was significantly different from those of all other river locations. Furthermore, Walleye from the Hayes River had a significantly higher mean concentration than their conspecifics from the Churchill, Nelson, and Saskatchewan rivers. Although mercury concentrations in Walleye from the Saskatchewan River were significantly lower than in Walleye from all other river locations, this is not relevant for a comparison of fish mercury in rivers because the sampling sites for the Saskatchewan River were all located in the west basin of Cedar Lake (see Section 5.2.8).

Based on individual fish, mercury concentrations of the 778 Walleye analyzed ranged from 0.024 ppm for a 98 mm long, un-aged fish (likely age 0+) from Playgreen Lake to 1.92 ppm for a 710 mm long, 27 year old fish from the Winnipeg River at Pointe du Bois. The mean concentration of all Walleye was 0.34 ppm.

6.6.2.4 Yellow Perch

Because the relationship between mercury concentration and fish length was not significant for the majority of Yellow Perch samples, arithmetic means were used for the comparison of mercury concentrations between populations. Mean concentrations in Yellow Perch varied almost five fold, from 0.016 ppm for Cedar Lake-SE to 0.075 ppm for Cross and Northern Indian lakes (Figure 6.6-5). Two groups of means were statistically different: Yellow Perch from Little Playgreen, Cross, Setting, and Northern Indian lakes had similar and significantly higher mercury concentrations than their conspecifics from Cedar, Cormorant, and Leftrook lakes.

Individual mercury concentrations of the 120 Yellow Perch analyzed ranged from 0.011 ppm for two 115 and 118 mm-long individuals from Cedar Lake that were aged as 2+ to 0.134 ppm for a 164 mm long, un-aged fish from Little Playgreen Lake. The third highest overall concentrations and the highest concentration for a confirmed 1-year-old fish was 0.102 ppm, which was measured in an 85-mm long Yellow Perch from Cross Lake. The arithmetic mean concentration of the 120 Yellow Perch analysed was 0.05 ppm.

6.6.2.5 Lake Sturgeon

Of the 34 Lake Sturgeon analyzed for mercury, 32 were captured from the Churchill River. The single Lake Sturgeon caught in each of the lower Nelson River and the Hayes River contained concentrations of 0.18 ppm (fork length 690 mm) and 0.19 ppm (fork length 664 mm), respectively. These values fitted well with the distributions of fish lengths and mercury concentrations obtained from the larger sample of Lake Sturgeon from the Churchill River. Mercury concentrations ranged from 0.03 ppm for a 221 mm long, un-aged fish to 0.65 ppm for a 1,207 mm long, un-aged fish (both collected from the Churchill River). The arithmetic mean concentration of all 34 Lake Sturgeon was 0.16 ppm.

6.6.3 Comparisons Between Regions and Between On-System and Off-System Waterbodies

Comparisons of fish mercury concentrations between CAMPP regions or between on- and off-system waterbodies indicated some general spatial patterns, even with the single year of data collected under CAMPP. The following provides an overview of spatial differences observed with the CAMPP fish mercury dataset.

6.6.3.1 Comparisons Between Regions

The seven CAMPP regions can be broadly grouped into four classes in terms of fish mercury concentrations. This classification is mainly based on data collected for Northern Pike and Walleye from on-system waterbodies. Regions with relatively low fish mercury concentrations in 2009-2010 were the Saskatchewan River and the lower and upper Nelson River. Higher mercury concentrations were found in fish from the Winnipeg River Region, the Lower and Upper Churchill River Regions, and the CRD Region. The inclusion of the Lower Churchill River Region in the latter group is primarily a function of data from one lake (Northern Indian Lake). Mercury concentrations in all species from Northern Indian Lake, including Lake Whitefish and Yellow Perch, consistently ranked among the highest of all waterbodies sampled under CAMPP (Figures 6.6-2 to 6.6-5).

The highest mercury concentrations for both Walleye and Northern Pike were observed in the Winnipeg River Region (Figures 6.6-3 and 6.6-4). The highest mean concentration measured for Northern Pike in any of the CAMPP waterbodies occurred in fish collected from the off-system Manigotagan Lake (see below). Another region in which relatively high mercury concentrations were observed in Northern Pike and Walleye was the CRD Region. Concentrations in these two piscivors from the two on-system waterbodies Rat and Threepoint lakes, consistently ranked second or third highest among all waterbodies (Figures 6.6-3 and 6.6-4).

Most Northern Pike and Walleye populations from on-system lakes of the Saskatchewan River and Upper Nelson River Regions contained significantly lower mercury concentrations compared to on-system lakes of the lower Nelson River (Figures 6.6-3 and 6.6-4). However, the relatively high mercury concentrations in the two piscivores from the off-system lakes of the former two Regions, Cormorant and Setting lakes (see below), balanced the overall mercury concentration in the comparison of the three Regions.

Mercury concentrations in Yellow Perch from two of the three waterbodies sampled in the Saskatchewan River Region and three of the four waterbodies sampled in the Upper Nelson

River Region, indicated that Yellow Perch from the latter Region had significantly higher concentrations (Figure 6.6-5).

Significant differences in mercury concentrations of large-bodied fish species also existed between the off-system waterbodies of the different regions. Mercury concentrations in Northern Pike from Manigotagan Lake were significantly higher than in Northern Pike from off-system lakes of all other regions (Figure 6.6-3). Walleye from Manigotagan and Granville lakes had similar mercury concentrations, which were significantly higher compared to those in their conspecifics from the remaining off-system lakes (Figure 6.6-4). All three large-bodied species from Gauer and Granville lakes, the two off-system lakes from the Lower and Upper Churchill River regions, respectively, had significantly different mercury concentrations, with concentrations in fish from Gauer Lake being lower (Figures 6.6-2 to 6.6-4).

6.6.3.2 Comparison Between On- and Off-System Waterbodies

Differences in mercury concentrations of fish between on-system and off-system waterbodies within regions were not consistent. Mean mercury concentrations in fish from the off-system lakes in the Lower Churchill River and Churchill River Diversion regions (Gauer and Leftrook lakes, respectively) were consistently (i.e., for all three large-bodied species) and significantly lower than concentrations measured in the same species from on-system lakes in their respective regions (Figures 6.6-2 to 6.6-4). In contrast, mean concentrations in Walleye, Northern Pike, and Yellow Perch from the off-system lake (Cormorant Lake) were significantly higher than their conspecifics from the on-system waterbody Cedar Lake-SE) in the Saskatchewan River Region (Figures 6.6-3 to 6.6-5). Similarly, mercury concentrations in Walleye and Northern Pike from the off-system lake in the Upper Nelson River Region (Setting Lake) were significantly higher than those in their conspecifics from all (Northern Pike) or most (Walleye) of the on-system lakes of the Region. Finally, Northern Pike from the off-system Manigotagan Lake had significantly higher mercury concentrations than Northern Pike from the Winnipeg River at Pointe du Bois, whereas the reverse relationship was observed in Walleye from the same two waterbodies.

Comparisons between fish mercury concentrations for on- and off-system river sites (i.e., the Hayes River compared to the lower Nelson and lower Churchill rivers) also yielded inconsistent differences, depending on the species. Specifically, concentrations in Northern Pike were lower (Figure 6.6-3), concentrations in Walleye were higher (Figure 6.6-4), and concentrations in Lake Whitefish (Figure 6.6-2) were similar in the Hayes River relative to either the lower Churchill or lower Nelson rivers.

In addition to the significant differences in fish mercury concentrations of some fish species between on-system and off-system waterbodies for some regions, concentrations in other species or for other regions were similar between the two types of waterbodies. Specifically, concentrations of mercury in all fish species collected from on-system lakes in the Lower Nelson River Region and the Upper Churchill River Region were not significantly different from the off-system waterbodies sampled in those regions. In addition, mercury concentrations in Yellow Perch from Setting Lake were intermediate and statistically similar to their conspecifics from the two on-system lakes in the same region (Little Playgreen and Cross lakes; Figure 6.6-5). Similarly, Lake Whitefish from Setting Lake had mercury concentrations not significantly different from Lake Whitefish in the two on-system lakes with available data (Playgreen and Little Playgreen lakes; Figure 6.6-2).

6.6.4 Comparison of Mercury Concentrations to Consumption Guidelines

Length-standardized and arithmetic mean mercury concentrations of all Lake Whitefish and Yellow Perch populations sampled under CAMPP in 2009 and 2010 were substantially below the 0.2 ppm, a level commonly accepted as a safe consumption limit for people eating large quantities of fish domestically (see section 4.8.2.3). In fact, with the exception of Lake Whitefish from Northern Indian Lake (length-standardized concentration of 0.11 ppm), mean mercury concentrations of both Lake Whitefish and Yellow Perch were less than 0.10 ppm in all waterbodies (Figures 6.6-2 and 6.6-5) . Moreover, mean mercury concentrations in Yellow Perch from Cedar and Leftrook lakes and Lake Whitefish from Area 6 of Southern Indian Lake, Playgreen Lake ,and Leftrook Lake were below the Canadian and Manitoba tissue residue guidelines of 0.033 ppm methylmercury for the protection of wildlife consumers of aquatic biota (Canadian Council of Ministers of the Environment [CCME] 1999; updated to 2013; MWS 2011). With just under 0.16 ppm, the arithmetic mean mercury concentration of all Lake Sturgeon analyzed for mercury in 2009/10 was also well below the 0.2 ppm guideline for human consumption.

In contrast to the above two species, length-standardized concentrations of the majority of the 24 Northern Pike and Walleye populations sampled under CAMPP exceeded the 0.2 ppm guideline; only Northern Pike and Walleye from Cedar-SE and Cross lakes, and Walleye from the Saskatchewan River (i.e., Cedar Lake West), and Playgreen and Split lakes contained concentrations below 0.2 ppm (Figures 6.6-3 and 6.6-4). All Northern Pike and Walleye populations contained mean mercury concentrations above the tissue residue guideline of 0.033 ppm methylmercury for the protection of wildlife consumers of aquatic biota (Canadian Council of Ministers of the Environment [CCME] 1999; updated to 2013; MWS 2011). While CAMPP monitors for total mercury rather than methylmercury in fish muscle, the vast majority of mercury in fish muscle is in the form of methylmercury (see section 4.8.2.3) and comparison to these guidelines is conservative.

Length-standardized mercury concentrations in Northern Pike and Walleye from several waterbodies exceeded 0.5 ppm, 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). All populations exceeding the 0.5 ppm standard were located in the Winnipeg River, Lower and Upper Churchill River and the Churchill River Diversion regions.

Based on individual fish, 22% of all Northern Pike and 18% of all Walleye had mercury concentrations that exceeded the 0.5 ppm Health Canada standard (Table 6.6-1). In contrast, none of the Yellow Perch, and only one Lake Whitefish and two Lake Sturgeon (i.e., 6%) contained mercury concentrations above the 0.5 ppm standard. Furthermore, no Yellow Perch and less than 5% of all Lake Whitefish had mercury concentrations exceeding the 0.2 ppm guideline for safe domestic consumption, whereas 18% of all Lake Sturgeon, 63% of all Walleye, and 73% of all Northern Pike exceeded this guideline. The vast majority of individuals from all four fish species had mercury concentrations higher than the 0.033 ppm methylmercury guideline for the protection of wildlife consumers of aquatic biota with only 1-3 individuals each of all Northern Pike, Walleye, and Lake Sturgeon remaining below this guideline, and approximately 35% of all Lake Whitefish and Yellow Perch (Table 6.6-1).

Table 6.6-1. Numbers (n) and percentages (%) of fish exceeding mercury concentration guideline values and standards regarding human consumption or the protection of wildlife consumers of aquatic biota. Numbers for each species represent sums across all waterbodies and Regions for 2009/2010.

Species	Total (n)	Exceeding (n)	Exceeding (%)
0.50 ppm - Standard for Commercial Marketing of Freshwater Fish [a]			
Northern Pike	751	164	21.8
Walleye	778	143	18.4
Lake Whitefish	432	1	0.2
Yellow Perch	120	0	0.0
Lake Sturgeon	34	2	5.9
0.20 ppm - Guideline for Frequent Consumers of Fish [b]			
Northern Pike	751	548	73.0
Walleye	778	511	65.7
Lake Whitefish	432	21	4.9
Yellow Perch	120	0	0.0
Lake Sturgeon	34	6	17.6
0.033 ppm - Guideline for the Protection of Wildlife Consumers of Aquatic Biota [c]			
Northern Pike	751	748	99.6
Walleye	778	777	99.9
Lake Whitefish	432	298	69.0
Yellow Perch	120	78	65.0
Lake Sturgeon	34	33	97.1

[a] see Health Canada (2007a,b);
[b] see section 4.8.2.3 and Wheatley (1979);
[c] see CCME 1999; updated to 2013 and MWS (2011); the guideline value is given as ppm methylmercury.

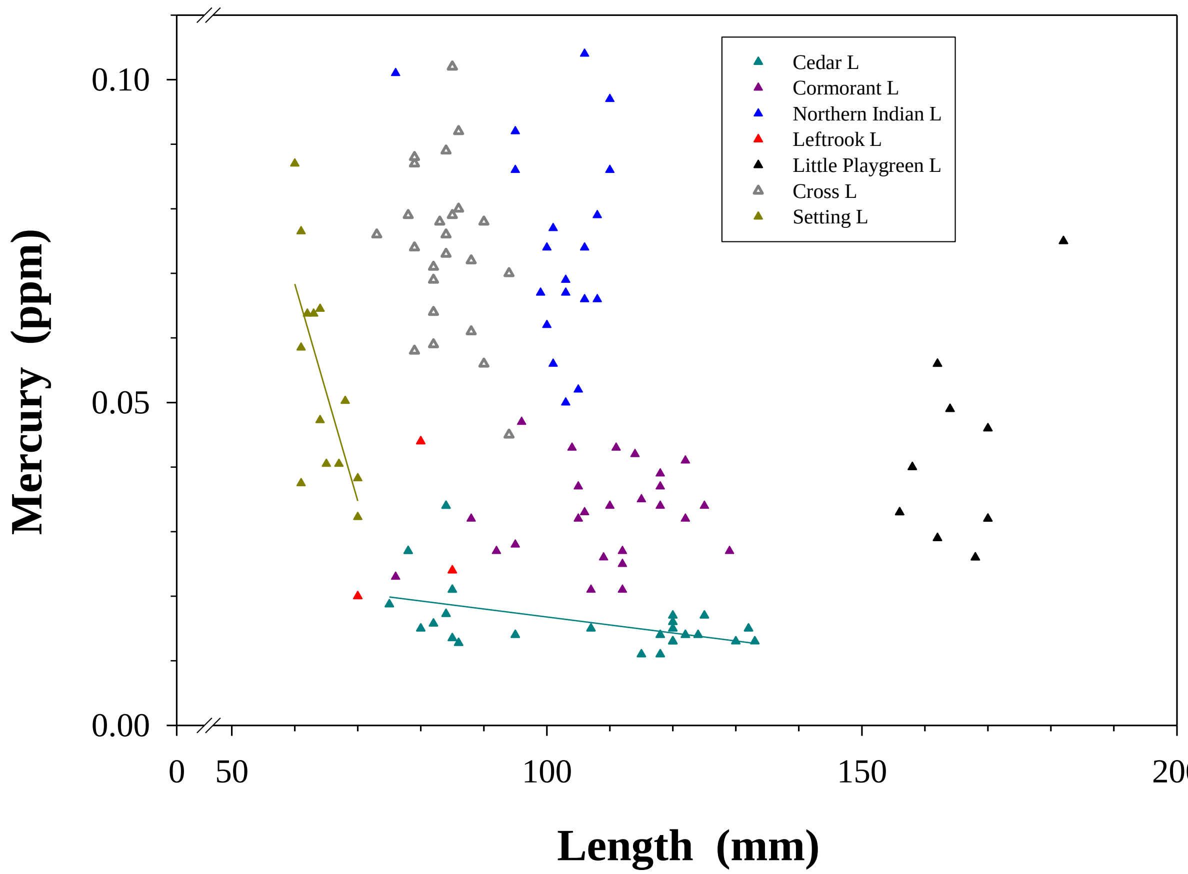


Figure 6.6-1. Relationship between mercury concentration and fork length for Yellow Perch from Cedar Lake-Southeast, Cross Lake-West, Cormorant, Northern Indian, Leftrook, Little Playgreen, and Setting lakes in 2010. Significant linear regression lines are shown.

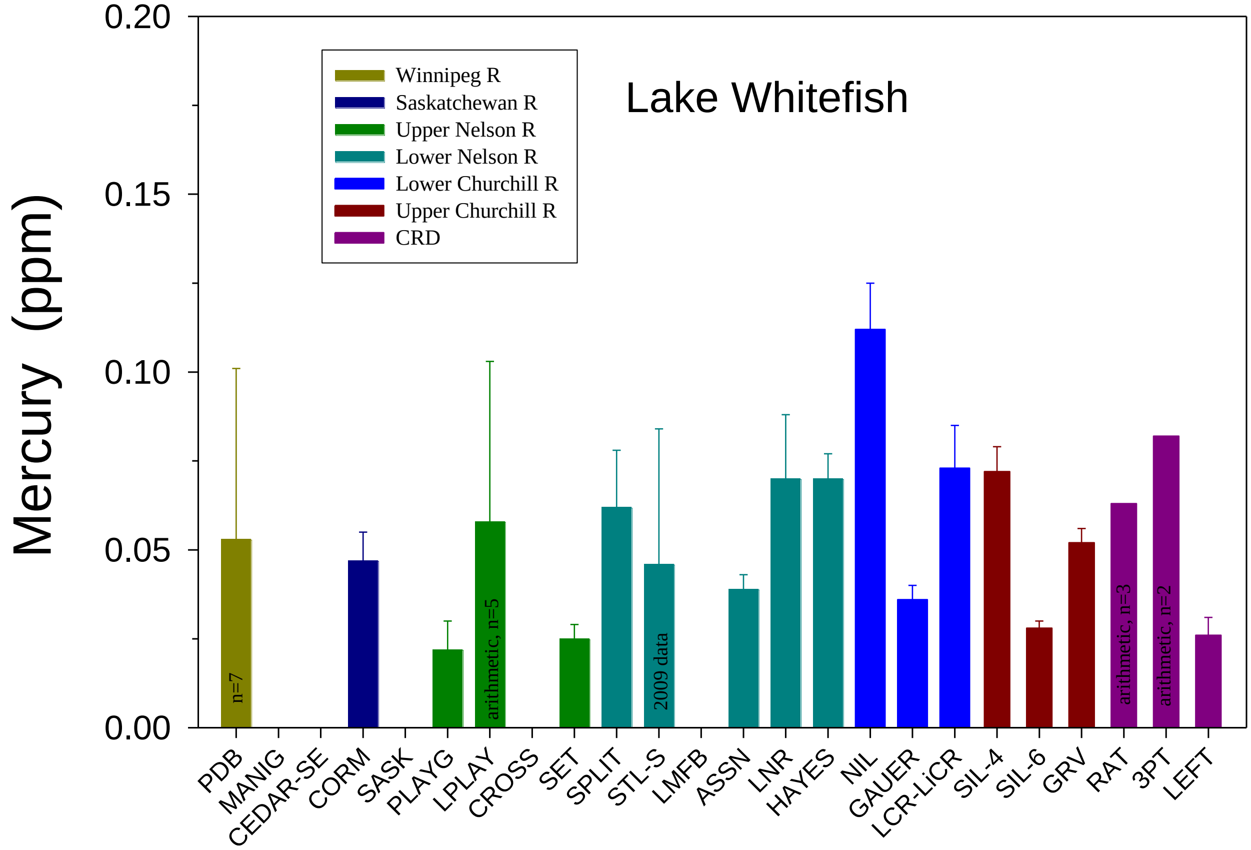


Figure 6.6-2. Length-standardized mean (+95% CL) mercury concentrations of Lake Whitefish from CAMPP waterbodies in 2009-2010. The upper range of the mercury concentration scale (0.2 ppm) represents the guideline for frequent human consumption. Means with small sample size (n<10) and that represent arithmetic means are indicated.

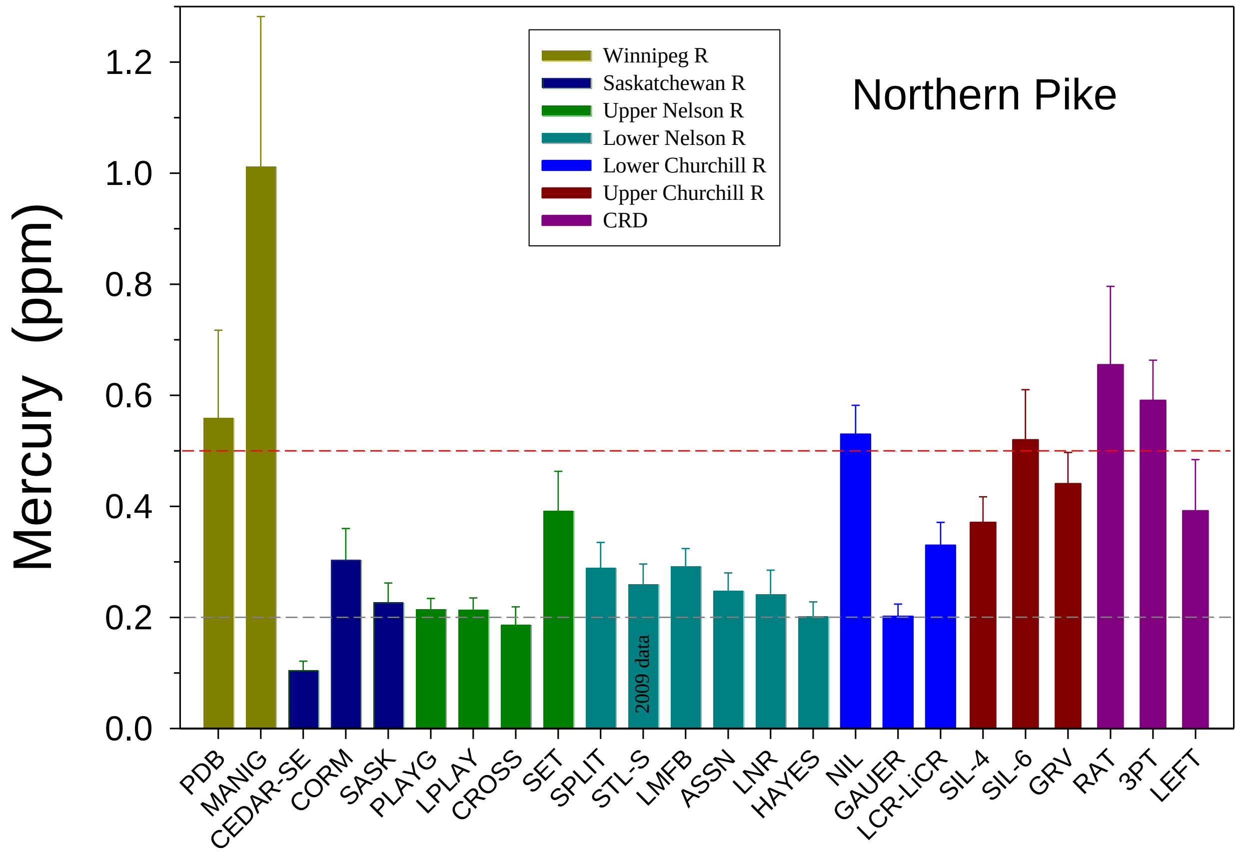


Figure 6.6-3. Length-standardized mean (+95% CL) mercury concentrations of Northern Pike from CAMPP waterbodies in 2009-2010. Stippled lines indicate the 0.5 ppm standard and the 0.2 ppm guideline for human consumption. Means with small sample size (n<10) and that represent arithmetic means are indicated.

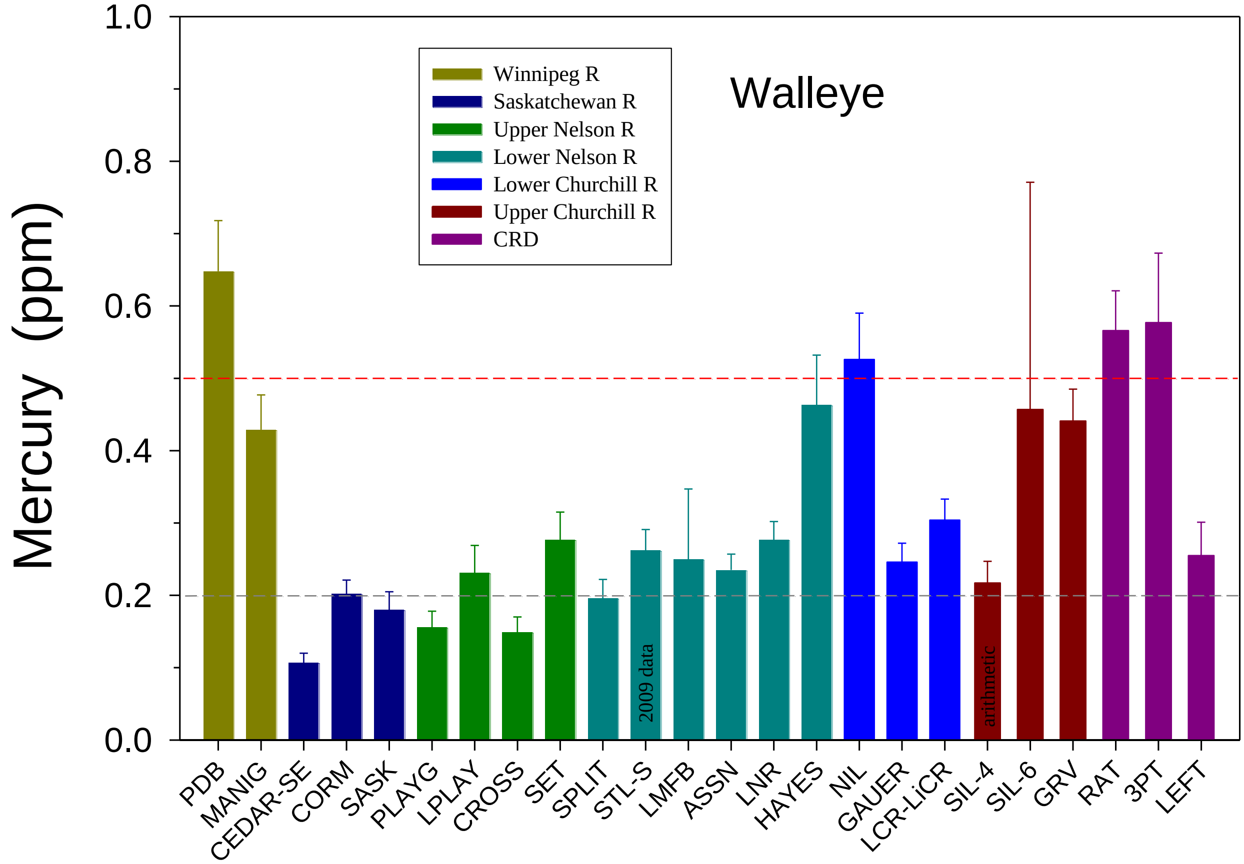


Figure 6.6-4. Length-standardized mean (+95% CL) mercury concentrations of Walleye from CAMPP waterbodies in 2009-2010. Stippled lines indicate the 0.5 ppm standard and the 0.2 ppm guideline for human consumption. The mean concentration for fish from SIL-area 4 is the arithmetic mean.

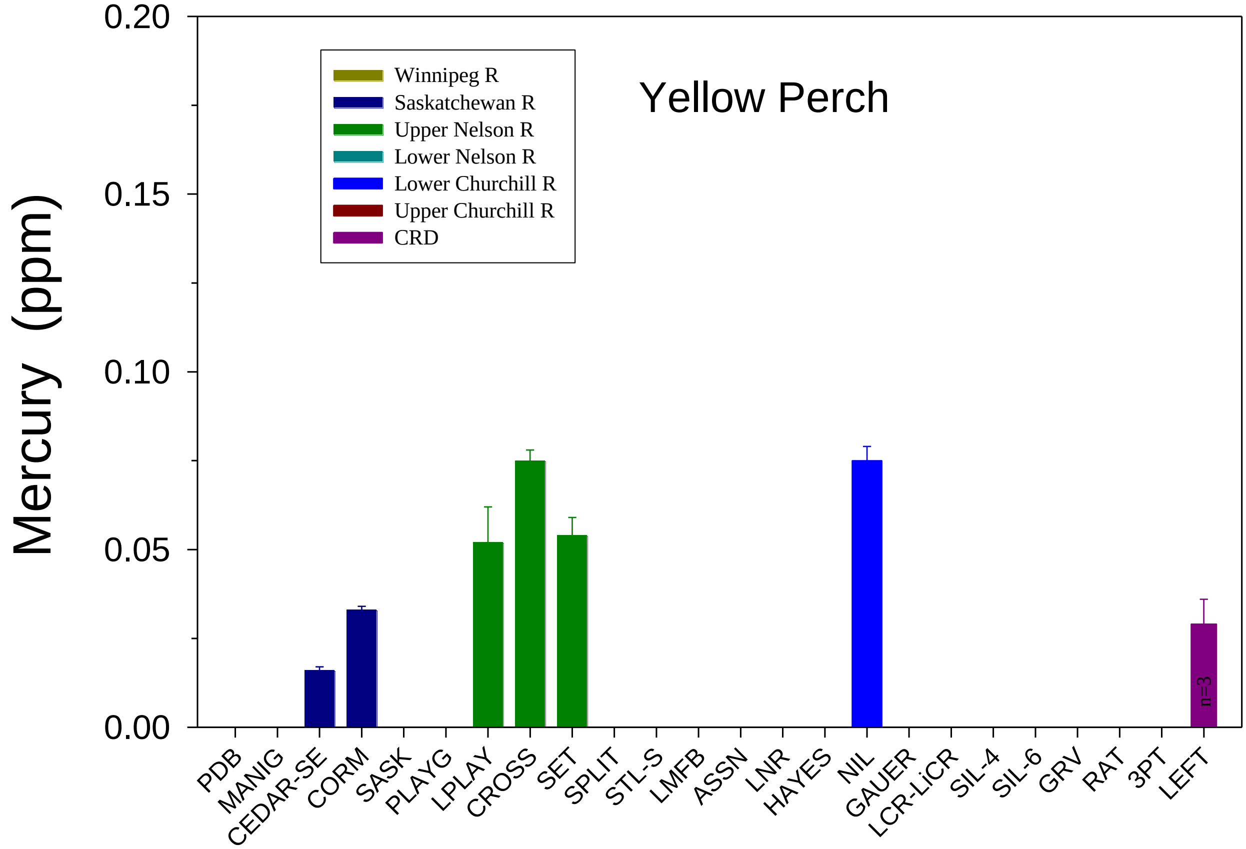


Figure 6.6-5. Mean (+SE) arithmetic mercury concentrations of Yellow Perch from CAMPP waterbodies in 2009-2010. The upper range of the mercury concentration scale (0.2 ppm) represents the guideline for frequent human consumption.

SECTION 7: REFERENCES

7.0 REFERENCES

Baird and Stantec. 2000. Lake Winnipeg shoreline erosion study. A report prepared by W.F. Baird & Associates Coastal Engineers Ltd. and Stantec Consulting Ltd. 2000. W.F. Baird & Associates Coastal Engineers Ltd., Oakville, ON.

Barbour, M.T., J.B. Stribling, and J.R. Karr. 1995. Multimetric approach for establishing biocriteria and measuring biological condition. In W.S. Davis and T.P. Simon (Eds.), Biolgical Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Lewis, Boca Raton, FL. 63-80.

Baty, F. and M.L. Delignette-Muller. 2011. nlstools: tools for nonlinear regression diagnostics. R package version 0.0-11.

Beck, A.E. 1977. An inventory and assessment of the resources of the Hayes River. Manitoba Rep. No. 77-3. Dept. of Mines, Resources and Environmental Management. 118 pp.

Beke, G.J., H. Veldhuis, and J. Thie. 1973. Bio-physical land inventory of the Churchill-Nelson rivers study area north-central Manitoba. The Lake Winnipeg, Churchill and Nelson Rivers Study Board technical report, Appendix 3, Section A. 167 pp.

Bodaly, R.A., N.E. Strange, R.E. Hecky, R.J.P. Fudge, and C. Anema. 1987. Mercury content of soil, lake sediment, net plankton, vegetation, and forage fish in the area of the Churchill River Diversion, Manitoba, 1981-82. Canadian Data Report of Fisheries and Aquatic Sciences 610, 30 pp.

Bodaly, R.A., W.A. Jansen, A.R. Majewski, R.J.P. Fudge, N.E. Strange, A.J. Derksen, and D.J. Green. 2007. Post-impoundment time course of elevated mercury concentrations in fish in hydroelectric reservoirs of northern Manitoba, Canada. Arch. Environ. Contam. Toxicol. 53: 379-389.

Bourne, A., N. Armstrong, and G. Jones. 2002. A preliminary estimate of total nitrogen and total phosphorus loading in streams in Manitoba, Canada. Manitoba Conservation Rep. # 2002-04. Manitoba Conservation, Winnipeg, MB.

Braune, B. M. 1987. Mercury accumulation in relation to size and age of Atlantic herring (*Clupea harengus harengus*) from the southwestern bay of Fundy, Canada. Arch. Environ. Contam. Toxicol. 16:311-320.

British Columbia Ministry of Environment, Lands, and Parks (BCMELP). 1998. Guidelines for interpreting water quality data, version 1. May 1998. Prepared for the Land Use Task Force Resource Inventory Committee.

Brunskill, G.J., S.E.M. Elliott, and P. Campbell. 1980. Morphometry, hydrology, and watershed data pertinent to the limnology of Lake Winnipeg. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 1556. 32 pp.

Canadian Council of Ministers of the Environment (CCME). 1999. Canadian environmental quality guidelines. Canadian Council of Ministers of the Environment, Winnipeg, MB. Updated to 2013.

Canadian Council of Resource and Environment Ministers (CCREM). 1987. Canadian water quality guidelines. Canadian Council of Resource and Environment Ministers, Winnipeg, MB.

Carlson, R. 1977. A trophic state index for lakes. Limnol. Oceanogr. 22: 361-362.

Centre for Topographic Information. 2010. National Topographic Database (NTDB) [computer file]. Government of Canada, Natural Resources Canada, Earth Sciences Sector (GeoGratis), Sherbrooke, QC. Available: http://geogratis.cgdi.gc.ca/geogratis/en/index.html. (November 2012).

Chammartin, T. 2008. Sagkeeng First Nation. Available: http://www.first-nations-art-store.com/sagkeeng-fort-alexander-first-nation.html. (November 2012).

Cherepak, B.C. 1990. The post-flood bathymetry of Split and Stephens Lakes, 1989. Manitoba Department of Natural Resources. Fisheries Branch MS Report No. 90-08. 78 pp.

Christoffersen, J.E. 2005. Geological report on the Assean Lake gold property, Manitoba, Canada. A report prepared for Canadian Gold Hunter Corp. 41 pp. Available: http://www.ngexresources.com/i/pdf/AsseanLakeTechnicalReport.pdf. (November 2012).

Clifford, H.F. 1991. Aquatic invertebrates of Alberta. The University of Alberta Press, Edmonton, AB. 538 pp.

Cooley, P. and J. Macdonald. 2008. Lake Sturgeon habitat on the Churchill River near Island Falls Hydroelectric Station. A report prepared for Saskatchewan Power Corporation by North/South Consultants Inc. 85 pp.

Depew, D.C., N.M. Burgess, and L. Campbell 2013. Modelling mercury concentrations in prey fish: derivation of a national-scale common indicator of dietary mercury exposure for piscivorous fish and wildlife. Env. Poll. 176: 234-243.

Dodds, W.K., J.R. Jones, and E.B. Welch. 1998. Suggested classification of stream trophic state: distributions of temperate stream types by chlorophyll, total nitrogen, and phosphorus. Wat. Res. 32: 1455-1462.

Environment Canada and Manitoba Water Stewardship (EC and MWS). 2011. State of Lake Winnipeg: 1999 to 2007. June, 2011. 209 pp.

Environment Canada (EC). 2010. Pulp and paper environmental effects monitoring (EEM) technical guidance document. Government of Canada. 490 pp.

Environment Canada (EC). 2012a. Metal mining technical guidance for environmental effects monitoring. Government of Canada. 550 pp.

Environment Canada (EC). 2012b. Canadian Aquatic Biomonitoring Network (CABIN): Wadeable streams field manual. Government of Canada. 52 pp.

Essington, T. E., and J. N. Houser. 2003. The effect of whole lake nutrient enrichment on mercury concentration in age-1 yellow perch. Transactions of the American Fisheries Society 132:57-68.

Fausch, K.D., J. Lyons, J.R. Karr, and P.L. Angermeier. 1990. Fish communities as indicators of environmental degradation. Pages 123-144 *in* S.M. Adams, editor. Biological indicators of stress in fish. American Fisheries Society Symposium 8, Bethesda, MD.

Findlay, D.L. and H.J. Kling. Undated. Protocols for measuring biodiversity: phytoplankton in fresh water. Department of Fisheries and Oceans. Winnipeg, MB.

Fisheries and Oceans Canada (DFO). 2008. Lake of the Woods. Canadian Hydrographic Service, digital charts. BSB V4. CEN12.

Fisheries and Oceans Canada (DFO). 2009. Lakes and Rivers in Manitoba and Saskatchewan. Canadian Hydrographic Service, digital charts. BSB V4. CEN13.

Fitzjohn, D. 1985. Caribou (Quesnel) – Manigotagan lakes creel census, 1984. Manitoba Department of Natural Resources, Fisheries Branch. 39 pp.

Ford, E. 1933. An account of the herring investigations conducted at Plymouth during the years from 1924-1933. Journal of the Marine Biology Association (U.K.) 19: 305-384.

Fore, L.S., J.R. Karr, and L.L. Conquest. 1994. Statistical properties of an index of biotic integrity used to evaluate water resources. Canadian Journal of Fisheries and Aquatic Sciences 51: 1077-1087.

Gallucci, V.F. and T. Quinn II. 1979. Reparameterizing, fitting, and testing a simple growth model. Transactions of the American Fisheries Society. 108: 14-25.

Green, D.J. 1986. Summary of fish mercury data collected from lakes on the Rat Burntwood and Nelson River systems, 1983-1985. Manitoba Natural Resources, Fisheries Branch MS Report No. 86 06. 359 pp.

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

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

Heilman-Ternier, J. and V.L. Harms. 1975. Plant ecology - taxonomy. Churchill River Study Final Report 5, Saskatoon, SK. 126 pp.

Holm, J., V.L. Richardson, and R.L. Bretecher. 2003. Results of index gillnetting studies conducted in Assean Lake, Manitoba, summer 2002. Report # 02-05. North/South Consultants Inc., Winnipeg, MB. 80 pp.

Hutchinson, G.E. 1957. A treatise on limnology v.1. Geography, Physics and Chemistry. Wiley. 1015 pp.

Integrated Taxonomic Information System (ITIS). 2013. Available: http://www.itis.gov. (September 2013).

Jackson, T.A. 1991. Biological and environmental control of mercury accumulation by fish in lakes and reservoirs of northern Manitoba, Canada. Can. J. Fish. Aquat. Sci. 48: 2449-2470.

Jansen, W. 2009. Fish Quality Baseline Monitoring: Fish Mercury Concentrations in the Wuskwatim GS Study Area, 2007. A report prepared for Wuskwatim Power Limited Partnership by North/South Consultants Inc., Report # 09-13, 33 pp.

Jansen, W. 2010a. Mercury in fish from six northern Manitoba lakes and reservoirs: results from 2007-2008 sampling and an update of time trends of monitoring data. Report prepared for Manitoba Hydro by North/South Consultants Inc. 46 pp.

Jansen, W. 2010b. Fish mercury concentrations in the Keeyask study area, 2009. A report prepared for Manitoba Hydro by North/South Consultants Inc., Report # 09-05, 32 pp.

Jansen, W. and N. Strange. 2007a. Mercury in fish from northern Manitoba reservoirs: results from 1999-2005 sampling and a summary of all monitoring data for 1970-2005. A report prepared for Manitoba Hydro by North/South Consultants Inc., 102 pp.

Jansen, W. and N. Strange. 2007b. Fish mercury concentrations from the Keeyask Project study area for 1999-2005. Report (# 05-04) prepared for Manitoba Hydro by North/South Consultants Inc., 152 pp.

Jansen, W. and N. Strange. 2009. Fish Quality Baseline Monitoring: Fish Mercury Concentrations in Nine Lakes Sampled During the Wuskwatim Generation Project Environmental Studies, 2001-2005. A draft report prepared for Wuskwatim Power Limited Partnership by North/South Consultants Inc., Report # 09-11, 61 pp.

Jones, G. and N. Armstrong. 2001. Long-term trends in total nitrogen and total phosphorus concentrations in Manitoba streams. Manitoba Conservation Rep. No. 2001-07. Manitoba Conservation, Winnipeg, MB.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. Fisheries. 6:21-27.

Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant, and I.J. Schlosser. 1986. Assessing biological integrity in running water: a method and its rationale. Illinois Natural History Survey Special Publication Number 5, Champaign, IL.

Lake Winnipeg Implementation Committee. 2005. Restoring the health of Lake Winnipeg: Canada's sixth great lake. Lake Winnipeg Implementation Committee, Winnipeg, MB. 56 pp.

Lake Winnipeg, Churchill and Nelson Rivers Study Board (LWCNRSB). 1975. Lake Winnipeg, Churchill and Nelson Rivers Study Board: technical report. Lake Winnipeg, Churchill and Nelson Rivers Study Board, Winnipeg, MB. 425 pp.

Larter, J.L., P.M. Cooley and T. Sutton. 2010. Depth, substratum, and aquatic macrophyte distributions: Lamprey Rapids to Slave Falls GS tailrace. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 51 pp. Report # 07-02.

MacKay, G.H. 1992. An evaluation of the impacts on water levels and flows within the Pukatawagan Resource Area caused by Manitoba Hydro actions. G.H. MacKay and Associates, Winnipeg, MB.

Magurran, A.E. 2004. Measuring biological diversity. Blackwell Science Ltd., Oxford, U.K. 215 pp.

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

Manitoba Conservation. 2003a. Threepoint Lake angling map.

Manitoba Conservation. 2003b. Split Lake angling map.

Manitoba Conservation. 2006. Cormorant Lake angling map.

Manitoba Conservation. 2007a. Manigotagan Lake angling map.

Manitoba Conservation. 2007b. Rat Lake angling map.

Manitoba Conservation. 2007c. Setting Lake angling map.

Manitoba Conservation and Water Stewardship (MCWS). 2012. The Coordinated Aquatic Monitoring Program website. Available: http://campmb.com. (November 2012).

Manitoba Hydro and Nisichawayasihk Cree Nation. 2003. Wuskwatim Generation Project: Environmental Impact Statement. Volumes 1-10. Manitoba Hydro, Winnipeg, MB.

Manitoba Hydro and the Town of Churchill. 1997. Lower Churchill River water level enhancement weir project. Manitoba Hydro, Winnipeg, MB, and the Town of Churchill, Churchill, MB.

Manitoba Innovation, Energy and Mines (MIEM). 2012. Manitoba mining through the centuries. Available: http://www.manitoba.ca/iem/mrd/min-ed/minfacts/mbhistory/aroundmb.html. (November 2012).

Manitoba Natural Resources. 1990. Gauer Lake angling map.

Manitoba Water Stewardship (MWS). 2011. Manitoba water quality standards, objectives, and guidelines. Water Science and Management Branch, MWS Report 2011-01, November 28, 2011. 67 pp.

McTavish, W.B. 1953. A biological survey of Manigotagan Lake. Manitoba Department of Mines and Natural Resources, Game and Fisheries Branch. 19 pp.

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

Merritt, R.W. and Cummins, K.W. 1996. An introduction to the aquatic insects of North America, 3rd Edition. Kendal/Hunt Publishing Co., Dubuque, IA. 862 pp.

MIEM and the Tantalum Mining Corporation of Canada Limited (TANCO). 2012. Commodity summaries: cesium, tantalum, and spodumene. Available: http://www.manitoba.ca/iem/mrd/busdev/industrial/cesium.html. (November 2012).

Ministry of Health. 2005. Draft guidelines for drinking-water quality management for New Zealand 2005, 2nd edition. Wellington: Ministry of Health.

Minns, C.K., V.W. Cairns, R.G. Randall, and J.E. Moore. 1994. An index of biotic integrity (IBI) for fish assemblages in the littoral zone of Great Lakes' areas of concern. Canadian Journal of Fisheries and Aquatic Sciences. 51: 1804-1822.

Mitchell, P. and E.E. Prepas. 1990. Atlas of Alberta Lakes. The University of Alberta Press, Edmonton, AB. 675 pp.

Murray, L. and M.A. Gillespie. 2011. Lake Sturgeon inventory and habitat assessment of the Winnipeg River from McArthur to Pine Falls, 2010. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, Manitoba. 52 pp. Report # 10-04.

Natural Resources Canada (NRC). 2011. Canvec Edition 8, 2011.04.18 (www.geogratis.ca)

Natural Resources Land Cover (NRLC). 2000. Circa 2000 Vector (www.geobase.ca)

Nielsen, E. 1998. Lake Winnipeg coastal submergence over the last three centuries. Journal of Paleolimnology 19(3): 335-342.

Niemela, S., E. Pearson, T.P. Simon, R.M. Goldstein, and P.A. Bailey. 1999. Development of an index of biotic integrity for the species-depauperate Lake Agassiz Plain Ecoregion, North Dakota and Minnesota. Pages 339-366 *in* T.P. Simon, editor. Assessing the sustainability and biological integrity of water resource quality using fish communities. CRC Press, Boca Raton, FL.

North/South Consultants Inc. (NSC). 2006. Literature review related to setting nutrient objectives for Lake Winnipeg. North/South Consultants Inc., Winnipeg, MB. 186 pp.

Nürnberg. 1996. Trophic state in clear and colored, soft- and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton and fish. Lake Reservoir Manage. 12: 432-447.

Ogle, D.H. 2012a. FSA: fisheries stock analysis. R package version 0.2-8.

Ogle, D.H. 2012b. NCStats: helper functions for statistics at Northland College. R package version 0.2-8.

Ogle, D.H. 2013. fishR vignette – Von Bertalanffy growth models. Available at: https://sites.google.com/site/fishrfiles/gnrl/VonBertalanffy.pdf?attredirects=0. (November 2013).

Organization for Economic Cooperation and Development (OECD). 1982. Eutrophication of waters: monitoring, assessment and control. Final Report. OECD cooperative programme on monitoring of inland waters (eutrophication control). Environment Directorate, OECD, Paris, France. 154 pp.

Peckarsky, B.L., P.R. Fraissinet, M.A. Penton, D.J. Conklin Jr. 1990. Freshwater macroinvertebrates of Northeastern North America. Cornell University Press, New York. 442 pp.

Prairie Farm Rehabilitation Administration (PFRA) Watershed Project. 2008. Version 8, 2008.03.31.

R Development Core Team. 2012. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Ramsey, D.J. 1991. Federal ecological monitoring program: final water quality report. Federal Ecological Monitoring Program, technical appendices, Volume 1. 320 pp.

Rawson, D.S. 1960. A limnological comparison of twelve large lakes in Northern Saskatchewan. Limnol. and Oceanog. 5:195-211.

Ricker, W. 1975. Computation and interpretation of biological statistics of fish populations. Technical Report Bulletin 191, Bulletin of the Fisheries Research Board of Canada. 382 pp.

Rodgers, D.W. and S.U. Quadri. 1982. Growth and mercury accumulation in yearling yellow perch, *Perca flavescens*, in the Ottawa River. Env. Biol. Fish. 7: 377-383.

Rosenberg, D.M., P.A. Chambers, J.M. Culp, W.G. Franzin, P.A. Nelson, A.G. Salki, M.P. Stainton, R.A. Bodaly, and R.W. Newbury. 2005. Nelson and Churchill River Basins. Pages 853-901 *in* A.C. Benke and C.E. Cushing, editors. Rivers of North America. Academic Press, San Diego, CA.

Royal Ontario Museum. 2005. Royal Ontario Museum website. Available: www.rom.on.ca. (November 2012).

Saffran, K.A. and D.O. Trew. 1996. Sensitivity of Alberta lakes to acidic deposition: an update of sensitivity maps with emphasis on 109 northern lakes. July 1996. Water Sciences Branch, Water Management Division, Alberta Environmental Protection.

SAS. 1999. SAS for Windows, version 8. SAS Institute Inc., Carry, NC.

Savard, T.G., S. Hnatiuk Stewart, and H.M. Cooley. 2010. Water Quality data for the Lower Nelson River system, 2009. Report # 5414.09-04. A report prepared for Manitoba Hydro by North/South Consultants Inc., Winnipeg, MB. 240 pp.

Schlick, R.O. 1968. A survey of Setting Lake in 1967. Manitoba Dep. Mines Nat. Res., Fish. Br. MS. Rep. No. 68-6. 17 pp.

Smith, D.G. 2001. Pennak's freshwater invertebrates of the United States: Porifera to Crustacea, 4th edition. John Wiley & Sons Inc., New York. 638 pp.

SPSS. 2003. SigmaStat 3.01. SPSS Inc., Chicago, IL.

Stewart, K.W. and B.P. Stark. 2002. Nymphs of North American stonefly genera (Plecoptera), 2nd edition. The Caddis Press, OH. 510 pp.

Strange, N.E. and R.A. Bodaly. 1999. Mercury in fish in northern Manitoba reservoirs and associated waterbodies: results from 1998 sampling. Prepared for the Program for Monitoring Mercury Concentrations in Fish in Northern Manitoba Reservoirs. 56 pp.

Swedish Environmental Protection Agency (EPA). 2000. Environmental quality criteria: lakes and watercourses. Report 5050, Stockholm, Sweden. 102+ pp.

United States Geological Survey (USGS). 2000. Source SRTM 90 m.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Can. J. Fish. Aquat. Sci. 37:130-137.

Walford, L.A. 1946. A new graphic method of describing the growth of animals. Biological Bulletin 90: 141-147.

Ward, D. M., K. H. Nislow, C. Y. Chen, and C. L. Folt. 2010. Rapid, efficient growth reduces mercury concentrations in stream dwelling Atlantic salmon. Transactions of the American Fisheries Society 139: 1-10.

Wentworth, C.K. 1922. A scale of grade and class terms for clastic sediments. The Journal of Geology 30: 377-392.

Wetzel, R.G. 1983. Limnology, 2nd edition. Saunders College Publishing, New York. 767 pp.

Wheatley, B. 1979. Methylmercury in Canada; exposure of Indian and Inuit residents to methylmercury in the Canadian Environment. Mercury Program Findings to December 31, 1978. Medical Services Branch, Health and Welfare Canada, Ottawa, ON, 200 pp.

Wiener, J.G., R. A. Bodaly, S.S. Brown, M. Lucotte, M.C. Newman, D.B. Porcella, R.J. Reash, and E.B. Swain. 2007. Monitoring and evaluating trends in methylmercury accumulation in aquatic biota. Pages 87-122 *in* R. Harris, D.P. Krabbenhoft, R. Mason, M.W. Murray, R. Reash, and T. Saltman, editors. Ecosystem responses to mercury contamination: indicators of change. CRC Press, New York.

Wiggins, G.B. 2004. Caddisflies the underwater architects. University of Toronto Press, Toronto. 292 pp.

Wilson 2013. Ross Wilson, Wilson Scientific Consulting, Vancouver, Canada, pers. comm., September 2013.

Zurawell, R.W., H. Chen, J.M. Burke, and E.E. Prepas. 2005. Hepatotoxic cyanobacteria: a review of the biological importance of microcystins in freshwater environments. J. Toxicol. Environ. Health 8: 1–37.