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Violet Camsell-Blondin, Chair – Wek'eezhii Land and Water Board
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Yellowknife, NT X1A 3S3
Canada

30 June 2016

Dear Ms. Camsell-Blondin:

Subject: 2011 to 2013 Aquatic Effects Re-evaluation Report Version 3.2

In a letter dated May 26, 2016, the Wek'èezhìi Land and Water Board (WLWB) directed Diavik Diamond Mines (2012) Inc. (DDMI) to re-submit the 2011 to 2013 Aquatic Effects Re-evaluation Report as Version 3.2 by June 30, 2016.

Version 3.2 of the 2011 to 2013 Aquatic Effects Re-evaluation Report is attached. In this version 3.2, revisions outlined in Directions 1B to 1G have been incorporated, and are as follows:

1B. Include all revisions outlined in Table 1.
1C. Include all revisions outlined in Table 2 and 3.
1D. Remove any reference to long-range transport of Asian or Eurasian dust.
1E. Remove the following sentence: "There are however, no regional background values with which to compare the observations."
1F. Not to include the substantially edited Section 3.3.4.1. Instead, the original version of this section submitted as part of Version 3.1, along with any edits outlined in Tables 1 to 3, if any, is to be included in Version 3.2 of the 2011 to 2013 Aquatic Effects Re-evaluation Report.
1G. Amend Section 2.6 of the Report to include information on the outlier method used for the dust analyses.

If you have any questions regarding the attached submission, please contact the undersigned at 867-669-6500 ext. 5536 or david.wells@riotinto.com.

Yours sincerely

David Wells
Superintendent - Environment

2011 to 2013 AQUATIC EFFECTS RE-EVALUATION REPORT
VERSION 3.2
FOR THE DIAVIK DIAMOND MINE, NORTHWEST TERRITORIES

Submitted to:

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June 2016
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Doc No. RPT-1523 Ver. 0
WP 460 Rev 1, PO No. D03176 line 1

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PLAIN LANGUAGE SUMMARY

This summary is intended for both technical and non-technical readers.

Section 1 – Introduction

This 2011 to 2013 Aquatic Effects Re-Evaluation Report provides a summary of all data collected under the Aquatic Effects Monitoring Program for the Diavik Diamond Mine. In this report the Aquatic Effects Monitoring Program is also called “the AEMP”, and the Diavik Diamond Mine is referred to as “the Mine”. The AEMP consists of monitoring the following components: dust; effluent; water quality; eutrophication indicators (for example, the nutrient phosphorus and the algal pigment chlorophyll *a*); plankton; sediment quality; benthic invertebrates; and fish. This report shows trends over time that may be occurring in these AEMP components. For example, data collected from 1995 to 2013 are shown in a graph. As well, this report compares the AEMP results each of these components back to the predictions of Mine effects made in the original 1998 Environmental Assessment (EA), to see if they were accurate.

Section 2 – Study Design

The AEMP is the main program described in the Water Licence for monitoring the aquatic environment of Lac de Gras. Mine water discharged into Lac de Gras is the main focus of the AEMP program.

Most components of the AEMP have been monitored every year during both the summer and winter. More recently, under the latest AEMP study design (Version 3.5) approved by the Wek’èezhìi Land and Water Board (also called “the WLWB” in this report) the nutrients and plankton are now sampled every year in only the areas where effluent is known to be present in Lac de Gras – this area is called the exposure area. The nutrients and plankton are then sampled every three years throughout the rest of the lake – this area is called the reference area. Water quality is measured monthly at the point where the effluent flows into the lake. Water is also sampled every year in the exposure areas and then every three years in the rest of the lake. Bottom sediments, benthic invertebrates (small animals that live in the sediments) and small-bodied fish are monitored once every three years.

Section 3 – Dust

The amount of dust coming off the Mine site is measured at several locations around the Mine and offsite. The amount of dust that is collected at these measurement locations has been going down in the last few years. Now that mining activities have gone underground, the amount of dust coming from the site should go down even more.

The amount of dust from the Mine was higher than the amount predicted in the EA. Starting in September 2012, all mining activities conducted at the Mine moved underground, which has led to a decrease in the amount of dust coming off the Mine.

Section 4 - Effluent

Treated water from the open pits, underground workings and mine infrastructure is called effluent. Effluent was evaluated to see if the amount of chemicals discharged from the Mine is increasing over time. The amount of chemicals entering the lake is called the “loading rate”. Water was also collected near the point where effluent enters Lac de Gras (also called the mixing zone boundary) to see if the amount of effluent chemicals in the lake is increasing.

Sampling of treated effluent is conducted approximately every six days. In addition to the chemical analysis conducted on these samples, the effluent is tested for toxicity (which means the effluent is tested in the lab to see if it harms laboratory-grown fish and plankton). In these tests, freshwater test organisms are exposed to whole effluent and/or effluent dilutions for a pre-determined time period to determine the effluent's effect on the organisms. Water quality sampling at the mixing zone boundary is conducted monthly at three stations, which are located along a semi-circle, 60 metres from the diffusers (pipe from which effluent is released into Lac de Gras).

The assessment of chemicals in the effluent was focused on the 24 chemicals that were identified as Substances of Interest (also called "SOIs" in this report). The focus was also on nutrients (nitrogen and phosphorus, Section 6), which are chemicals that promote the growth of algae in lakes.

The annual loading rate of total dissolved solids (a measure of the amount of dissolved salts in effluent) and several associated salts (calcium, chloride, fluoride, magnesium and sodium) increased from 2002 to approximately 2010. Since about 2010, the loading rate of these chemicals has decreased. Effluent loads and/or concentrations of some metals (molybdenum, silicon, strontium) have increased over time; however, most have either decreased (aluminum, barium, copper, manganese) or have remained at relatively similar levels over time (antimony, chromium, uranium). The annual loading rate and concentration of nitrogen peaked in the Mine effluent in 2006 and then declined until approximately 2010. The annual loading rate of phosphorus to Lac de Gras has generally increased over time. The concentrations of these SOIs and nutrients at the mixing zone boundary followed the same patterns described in the annual loads for these variables.

Effluent tested between 2002 and 2013 was generally non-toxic to aquatic test organisms as shown in over 500 toxicity tests conducted during this period. Mine effluent continues to meet the requirements for quality described in the Water Licence.

No predictions were made in the EA for effluent quality.

Section 5 - Water Quality

The goal of the water quality assessment was to provide a summary of changes and effects observed on the water chemistry of Lac de Gras over time. The importance of an effect was determined by comparing water chemistry concentrations in exposure areas to concentrations in reference areas, to lake background values or to benchmark values. Background values for Lac de Gras are those that fall within what is called the normal range. The normal range describes the natural variability within Lac de Gras. A concentration that is greater than the normal range is not considered normal for Lac de Gras, but it doesn't mean that it is harmful. Benchmark values are a better measure of when a chemical may be harmful to aquatic life.

A total of 25 different chemicals in samples analyzed from 2007 to 2013 had concentrations that were greater in exposure areas compared to the rest of the lake (that is, the reference areas). Fourteen of these chemicals also had exposure area concentrations that were greater than the normal range for Lac de Gras. No water quality variables had concentrations that were close to benchmark values.

Nine SOIs identified earlier in the “Effluent” section showed patterns of increasing concentration over time at most exposure areas. These SOIs included electrical conductivity, water hardness, total dissolved solids, several dissolved salts (sulphate, calcium, magnesium, sodium), and two metals (molybdenum and strontium). Statistical tests found these increases to be statistically significant, meaning that it was unlikely that these results would occur by chance. These nine SOIs were also found in each of the reference areas.

The EA predicted that water quality concentrations at the mixing zone would be below guidelines for the protection of aquatic life. With the exception of chromium in 2004 and 2006, all water quality concentrations were less than the guidelines.

Section 6 – Eutrophication Indicators

Eutrophication indicators consist of nutrients (phosphorus, nitrogen) chlorophyll *a* (the green pigment in algae, which are tiny plants) and zooplankton (tiny animals). Nutrients are a key component of the AEMP, because one of the predicted effects of the discharge of effluent was an increase in productivity in Lac de Gras. This can be seen by the growth of the algae, which is determined by measuring the chlorophyll *a.*

Concentrations of nutrients and chlorophyll *a,* as well as zooplankton biomass, in exposure areas have been greater than the normal range since 2007. The concentrations of nitrogen have been greater than the normal range in over 20% of the lake since 2008, and the concentrations of chlorophyll *a* were greater than the normal range in over 20% of the lake in 2009 and 2013.

Concentrations of phosphorus and nitrogen in the exposure areas have remained at similar levels during the open-water season since 2008. During the 2013 ice-cover season, total phosphorus concentrations in the exposure area increased outside of the normal range. The recent increase in 2013 may be related to effluent. Concentrations of nitrogen have been decreasing since 2009, again reflecting trends observed with effluent concentrations and loadings.

Concentrations of chlorophyll *a* in the exposure areas have been similar over the years. Zooplankton biomass in all exposure areas peaked in 2011 and has decreased since then. Zooplankton biomass values were still above the normal range in the exposure area and at some mid-field stations in 2013.

The EA predicted that phosphorus concentrations would not go over 5 micrograms per litre in more than 20 percent of the area of Lac de Gras. So far, this prediction has been exceeded twice when the lake has been covered with ice (2008 and 2013), but it has never been exceeded during the ice-free period.

Section 7 – Sediment Quality

A total of 15 metals analyzed from 2007 to 2013 had an average concentration in the exposure area that was statistically significantly greater than in the reference areas. However, none of the 15 metals had concentrations above guideline values. The guideline values are concentrations meant to protect the animals living in the sediments. The number of sediment SOIs showing an effect has not increased over time. The concentrations of the SOIs have not increased with time in recent years. However, the concentrations of three metals (bismuth, lead, and uranium) did increase in the exposure areas from 2001 or 2002 until approximately 2006 to 2008. The concentrations of these three SOIs have remained at similar levels since then. Results of the dike monitoring studies (separate studies to monitor the effect of the dikes) indicate that, in addition to Mine effluent, factors such as dike construction and possible leaching from the dikes may have contributed to the increases in concentrations of bismuth, lead and uranium.

No predictions were made in the EA for sediment quality.

Section 8 – Plankton

The plankton component of the AEMP evaluated whether there were any changes happening to the small plants (phytoplankton) and animals (zooplankton) in Lac de Gras. These small plants and animals together are referred to as plankton. Changes in plankton can affect fish in the lake, because plankton are part of the food chain upon which fish rely. Such changes can happen before fish are affected.

Differences in the plankton between exposure and reference areas have been seen every year from 2007 to 2013. The amount of phytoplankton (measured as “biomass”) in 2009 and 2011 was greater than the normal range in more than 20% of the lake.

The AEMP has shown that the Mine is not having a harmful effect (called a toxicological effect) on phytoplankton and zooplankton communities in Lac de Gras. The plankton communities in the exposure areas of Lac de Gras continue to be exhibiting a Mine-related nutrient enrichment effect. Although changes in the composition of the plankton communities are being seen from one year to another, similar changes are also being seen in the areas of the lake not exposed to effluent (for example, in the reference areas), indicating a natural change.

No predictions were made in the EA for plankton.

Section 9 – Benthic Invertebrates

The benthic invertebrate section of the AEMP evaluated whether the discharge of effluent into Lac de Gras has caused changes over time in the numbers and types of small animals that live on the bottom of Lac de Gras. These animals are referred to as benthic (bottom-dwelling) invertebrates (animals without backbones) and include snails, clams, worms and insects. These organisms provide food for fish. Changes in the numbers and types of bottom-dwelling invertebrates can cause changes in the numbers and types of fish in the lake.

The findings of the three-year re-evaluation were that the density of benthic invertebrates is greater in the exposure area compared to the reference area, and has been consistently greater since 2008. This effect was confirmed as being Mine-related, because the density of benthic invertebrates in Lac de Gras declines with distance away from the effluent.

Statistical analysis of community composition indicated a change in the types of benthic invertebrates observed over the years. The types of invertebrate animals varied, but the change with time was seen in both the exposure areas and the reference areas, suggesting that the community structure undergoes natural changes over time.

Consistent changes with time were not seen in the benthic invertebrates, although densities in the exposure area and mid-field areas have decreased and are now within the normal range for the lake.

No predictions were made in the EA for benthic invertebrates.

Section 10 – Fish Health and Fish Tissue

The goal of the fish chapter is to provide a summary of changes and effects observed to both the health and tissue chemistry of small fish (called Slimy Sculpin), and the mercury concentration in Lake Trout. These fish have been monitored every three years in Lac de Gras since 2007.

Overall, there were differences found in some Slimy Sculpin traits between the fish exposed to mine effluent, and the fish in reference areas, but there was no consistent trend in these differences among years. In 2007 there were few differences observed. In 2010, differences were found that indicated that the fish were responding to nutrient enrichment. For example, fish in the exposure areas were bigger and had bigger livers. In 2013, the effect seen was similar to what we see when fish are exposed to harmful chemicals (called a toxicological response). For example fish in the exposure areas were smaller in size and they had smaller reproductive organs (called gonads). This response is not the same as that seen in previous years, and no chemicals were measured in water or fish tissue that would indicate the fish are being harmed.

Concentrations of bismuth, lead, strontium and uranium have consistently been elevated in Slimy Sculpin in the exposure area, and concentrations of bismuth, strontium and uranium increased outside the normal range in recent years. The concentrations of these metals in water are consistently below guideline values.

Mercury in Lake Trout has increased over time in Lac de Gras; however, a similar increase has also been observed in Lake Trout captured in Lac du Sauvage.

There was one prediction made in the EA for fish tissue, and it was associated with the mercury concentration of the fish. The EA predicted that mercury concentration in sport fish and fish that are captured for food would remain below a mean of 0.2 µg/g ww. This prediction was exceeded in both Lac de Gras and Lac du Sauvage in 2008 and 2011.

Section 11 – Weight of Evidence

The weight of evidence (WOE) section of the AEMP combines the information and conclusions of the water quality, eutrophication indicators, sediment chemistry, plankton, benthic invertebrate community, fish health and fish tissue chemistry sections. A qualitative process was used to estimate the strength (or weight) of evidence for nutrient enrichment or toxicological impairment from 2011 to 2013. There was strong evidence for nutrient enrichment in Lac de Gras and weak evidence for toxicological impairment.

Section 12 – Traditional Ecological Knowledge

Traditional ecological knowledge (TEK) is intended to be an integral component of the AEMP for the Mine. During late 2010, DDMI proposed a new approach to working with each of the five Aboriginal Parties that were part of the Environmental Agreement. This was an effort to expand on the previous fish palatability component of the AEMP and incorporate more discussion and documentation of TEK relating to fish and water quality. Diavik proposed to fund the use of a third-party consultant, Thorpe Consulting Services (TCS), to engage with the Aboriginal working groups. Participants for these working groups were to be selected by the Aboriginal organizations. This process was supported by the Tlicho Government, Yellowknives Dene First Nation, Kitikmeot Inuit Association, Lutsel K'e Dene First Nation, and the North Slave Metis Alliance. Work to develop the program began in early 2011, with a goal of implementing the TEK program at the community-based monitoring camp on Lac de Gras during the summer of 2012.

Overall, camp participants noted that the status of the fish and water in Lac de Gras near the Diavik mine is good. Two fish were identified as being of poorer condition, noting that the fish were skinny and, in the case of one, had a larger head. Another fish was also observed as having some intestinal worms and being of poorer condition. Participants noted that this tends to occur in all fish populations and that the fish are not eaten. Those that were tasted as part of the palatability study resulted in scores of 1 (excellent for eating, looks better than fish usually caught) or 2 (good for eating, looks similar to fish usually caught) from all participants).

Camp participants noted the environmental indicators that they use to assess water quality, such as condition of the shoreline and clarity of the water. Additionally, a tea test was used to assess water quality, and participants noted that tea made from water of a poor quality results in film or scum on the surface of the cup. None of the water samples from Lac de Gras had this scum or film, and all the samples tasted acceptable to participants.

During the planning sessions, it was identified that TEK is best captured and shared through video rather than written reports. A small camera crew was hired to conduct a training session for youth from the communities to film and record the camp activities while learning from their Elders. A written report and documentary video were produced and approved by all participants; these capture the process undertaken and the results from the water quality and fish palatability studies. Recognizing the sensitivity of TEK and acknowledging that some information cannot be shared publicly, each Aboriginal organization will also receive a copy of the raw, unedited video footage of their members sharing their traditional stories and knowledge, for use by the community organization. DDMI is currently planning to conduct the AEMP TK program again in 2015.

The EA predicted that there would be no change to the taste or texture of the fish in Lac de Gras as a result of metals in the fish flesh. Based on the fish tasting program, this prediction is true, as there have been no changes in taste noted so far.

Section 13 – AEMP Summary of Effects

The type of effect being observed in Lac de Gras is consistent with that of nutrient enrichment over approximately 20% of Lac de Gras. This is what was predicted in the EA in 1998.

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Acronyms and Abbreviations

α	alpha
~	approximately
±	plus or minus
AEMP	Aquatic Effects Monitoring Program
AFDM	ash-free-dry-mass
ALS	ALS Laboratory Group
ANCOVA	analysis of covariance
ANOVA	analysis of variance
BIC	benthic invertebrate community
CCME	Canadian Council of Ministers of the Environment
DDMI	Diavik Diamond Mines (2012) Inc.
DFO	Fisheries and Oceans Canada
DIAND	Department of Indian Affairs and Northern Development, now Indigenous and Northern Affairs Canada (INAC)
DL	detection limit
dw	dry weight
e.g.	for example
EA	environmental assessment
EOI	Evidence of Impact
EQC	Effluent Quality Criteria
et al.	and others
ETL	Enviro-Test Laboratories
FF	far-field
Flett	Flett Research Ltd.
Golder	Golder Associates Ltd.
GSI	gonadosomatic index
Hg	mercury
i.e.	that is
IC	inhibitory concentration
ISQG	Interim Sediment Quality Guideline
K	condition factor
LC	lethal concentration
LDG	Lac de Gras
LDS	Lac du Sauvage
LEL	lowest effect level
LOE	Line of Evidence
LSI	liver somatic index

Acronyms and Abbreviations

Maxxam	Maxxam Analytics Inc.
MF	mid-field
Mine	Diavik Diamond Mine
mMDS	metric multidimensional scaling
n	number of samples
NF	near-field
NIWTP	North Inlet Water Treatment Plant
nMDS	nonmetric multidimensional scaling
OMOEE	Ontario Ministry of the Environment and Energy
P	statistical probability
PEL	probable effect level
pers comm.	personal communication
PR	percentile rank
PS	particle size
QAPP	Quality Assurance Project Plan
r	Pearson’s correlation coefficient
r^2	coefficient of determination
r_s	Spearman Rank correlation coefficient (*Rho*)
SD	standard deviation
SEL	severe effect level
SES	Special Effects Study
SNP	Surveillance Network Program
SOI	Substance of Interest
SOP	Standard Operating Procedure
sp.	species
SQG	sediment quality guideline
SRP	soluble reactive phosphorus
SS	snow sampling (station)
SYSTAT	SYSTAT Software Inc.
TDN	total dissolved nitrogen
TDS	total dissolved solids
TN	total nitrogen
TOC	total organic carbon
TOR	Terms of Reference
TP	total phosphorus
TSS	total suspended solids
UofA	University of Alberta

Acronyms and Abbreviations

VEC	valued ecosystem component
vs.	versus
WLWB	Wek’èezhìi Land and Water Board
WOE	Weight-of-Evidence
ww	wet weight
x	times
τ	Kendall’s tau

Units of Measure

%	percent
% dw	percent dry weight
<	less than
>	greater than
±	plus or minus
≥	greater than or equal to
µg/L	micrograms per litre
$\mu g/m^3$	micrograms per cubic metre
µm	micrometre
µS/cm	microSiemens per centimetre
cm	centimetre
g	gram
ha	hectare
kg	kilogram
kg/month	kilograms per month
kg/yr	kilograms per year
km	kilometre
km^2	square kilometre
L	litre
m	metre
mg	milligram
$mg/dm^2/d$	milligrams per square decimetre per day
$mg/dm^2/yr$	milligrams per square decimetre per year
mg/kg dw	milligrams per kilogram dry weight
mg/L	milligrams per litre
mg/m^3	milligrams per cubic metre

Units of Measure

mg-N/L	milligrams of nitrogen per litre
mg-P/L	milligrams of phosphorus per litre
mm	millimetre
no./m^2	number per square metre
no. of taxa	number of taxa
ww	wet weight

1 INTRODUCTION

1.1 Background

Up until November 1, 2007, Diavik Diamond Mines Inc. (now Diavik Diamond Mines (2012) Inc.; DDMI) had been operating under the terms and conditions of a Class A Water Licence issued to DDMI in August 2000 (N7L2-1645). The licence was amended in May 2004 and was valid until August 2007. In August 2005, DDMI submitted an application to renew the water licence, and hearings were subsequently held in November 2006. Before and during the hearings, various interveners (e.g., Aboriginal peoples; federal and territorial government regulators; consultants for the aforementioned parties) expressed concerns relating to fulfilment of conditions in the first Water Licence, particularly in relation to the Ammonia Management Plan, the abandonment and restoration plan, and the original Aquatic Effects Monitoring Program (AEMP) (DDMI 2001a) (herein referred to as Version 1.0). In addition to addressing concerns related to the Ammonia Management Plan and the abandonment and restoration plan, DDMI submitted a revised AEMP Design Document (herein referred to as AEMP Version 2.0) to the Wek’èezhìi Land and Water Board (WLWB) on February 16, 2007 (DDMI 2007a). With approval of the AEMP Design Document, DDMI secured their Class A Water Licence #W2007L2-0003) renewal for a period of eight years, effective November 1, 2007 (WLWB 2007). In 2015, the Water Licence was renewed for another period of eight years, effective October 19, 2015 (#W2015L2-0001, WLWB 2015a).

This current report is being prepared under Water Licence #W2007L2-0003, as per instructions provided by the WLWB (2015). For the last decade, DDMI has been conducting studies and monitoring programs relating to the aquatic ecosystem of Lac de Gras. In 2007, the monitoring programs were expanded as described in the AEMP Version 2.0, which was developed according to the final AEMP Terms of Reference (TOR) provided by the WLWB on January 22, 2007 (WLWB and Gartner Lee 2007). The AEMP Version 2.0 was approved by the WLWB on July 12, 2007. The objective of the AEMP Version 2.0 was to address Mine-related effects to the aquatic ecosystem of Lac de Gras in a scientifically defensible and cost-effective manner.

Following the initial three years of monitoring under the AEMP Version 2.0, DDMI was to submit a summary of findings from the monitoring programs undertaken to date. As stated in Part K (11) of the 2007 Water Licence #W2007L2-0003, DDMI is to submit to the WLWB “a summary of the significant results of the Aquatic Effects Monitoring Program from the Project inception, term effects [sic] of the Project, and of the actual effects of the Project to date, in comparison to the predicted impacts. This shall include an integration of all information related to assessing aquatic effects as described in the approved Aquatic Effects Monitoring Program Plan and the Aquatic Effects Monitoring Program Adaptive Management Plan.”

The initial three years of monitoring was intended to include the years 2007, 2008 and 2009; however, for a variety of reasons, which include delayed approval of the sampling program and difficult weather conditions, the open water sampling in 2007 was divided into two seasons instead of having three distinct open-water sampling periods. Consequently, the WLWB ruled that 2007 would not fulfil the first year of the initial three years of monitoring under the AEMP Version 2.0. A review of the information collected during the initial four years of the AEMP Version 2.0 (i.e., 2007 to 2010, inclusively) was submitted to the WLWB in July 2011 (Golder 2011a).

Part K (9) of Water Licence #W2007L2-0003 states that DDMI was to submit a modified AEMP for approval in 2011 and every three years thereafter. The intent of periodically updating the study design is to provide DDMI's AEMP the opportunity to make modifications according to the findings of the previous three years of monitoring. The AEMP Version 3.0 Study Design was submitted to the WLWB in October 2011 (Golder 2011b).

The sampling portion of the AEMP Design Document, Version 3.0, was approved by the WLWB on May 16, 2012 (WLWB 2012). At that time, the WLWB provided some recommendations for the program regarding further work to the Response Framework component of the study design. On December 5, 2012, the WLWB directed DDMI to resubmit a revised Response Framework and to commence work on ecologically-relevant benchmarks for eutrophication.

DDMI submitted a revised version (Version 3.1) of the Response Framework component (Sections 5.3 and 5.4) of the AEMP Design Document on May 31, 2013 (DDMI 2013a). In order to assist reviewers in their review of the revised Response Framework, an AEMP workshop was held June 25, 2013. Review comments on the document were due by July 15, 2013. Review comments were provided by Aboriginal Affairs and Northern Development Canada (AANDC), Environment Canada, the Environmental Monitoring Advisory Board (EMAB), Fisheries and Oceans Canada (DFO), Government of Northwest Territories – Environment and Natural Resources (GNWT-ENR), North Slave Métis Alliance (NSMA), and Yellowknife Dene First Nation (YKDFN). EcoMetrix Incorporated also provided an independent review for the Board. DDMI provided responses to all comments and recommendations by the proponent deadline of July 22, 2013.

On August 12, 2013, the WLWB approved Sections 5.3 and 5.4 of the AEMP Design Document as submitted by DDMI on May 31, 2013, conditional on the incorporation of the eight revisions listed in the Board's August 19, 2013, directive (WLWB 2013a,b). DDMI submitted an updated AEMP Design Plan, Version 3.2, on October 15, 2013. On December 19, 2013, the WLWB approved Version 3.2 of the AEMP Design Document, conditional on the incorporation of three additional revisions listed in the Board's December 19, 2013, directive (WLWB 2013c). Accordingly, DDMI submitted an updated AEMP Design Plan, as Version 3.3, in January 2014 that included the revisions recommended by the Board in its December 19, 2013, directive.

Following the preparation of the Version 3.3 Study Design, DDMI identified an inconsistency in the sampling regime between the water quality and indicators of eutrophication components. DDMI submitted an updated Study Design, Version 3.4 on January 31, 2014, that incorporated changes to the sampling schedule to align the water quality and indicators of eutrophication sampling programs. The sampling frequency for the indicators of eutrophication at reference areas (FF1, FFA and FFB) was changed from every year to every three years. On March 10, 2014, the WLWB approved Version 3.4 of AEMP Design Document.

The current version (Version 3.5) of the AEMP Study Design incorporated a similar update to the plankton sampling schedule to align the water quality, indicators of eutrophication and plankton sampling programs (Golder 2014a). The sampling frequency for plankton at reference areas (FF1, FFA and FFB) was changed from every year to every three years. Additionally, a clarification to the benthic invertebrate Methods section was made to indicate that sub-samples (i.e., individual grabs) would be composited. This addressed a recommendation made in the 2013 AEMP annual report (DDMI 2014).

1.2 Scope

Every three years, an integrated AEMP report is to be produced and submitted to the WLWB. The goal of this report, referred to as the Aquatic Effects Re-Evaluation Report (previously the Three Year Summary Report), is to meet the requirements of Water Licence #W2007L2-0003 (Part K Item 12 g), by providing:

> “a summary of the significant results of the AEM program from the Project inception, long-term effects of the Project, and of the actual effects of the Project to date, in comparison with the predicted impacts.”

The report also needs to present temporal trends. Such trends reflect cumulative effects, because the data collected at a given location in a given year represent the sum of all the effects on the aquatic environment (i.e., the cumulative effects) at each sampling station.

There is also a requirement that the AEMP design be able to confirm EA predictions: Is the AEMP collecting the right data in the right areas and at the appropriate frequency in Lac de Gras? The Aquatic Effects Re-Evaluation Report provides an opportunity to answer this question and presents the following information:

- major findings, trends over time, and comparisons to predicted effects; and
- use of weight of evidence to assess whether or not the AEMP has documented Mine-related effects on Lac de Gras.

1.3 Updates to the Previously Submitted 2011 to 2013 AEMP Summary Report Version 3.0

As described in the AEMP Study Design Version 3.5, DDMI was required to submit a three-year summary report in 2014. The 2011 to 2013 AEMP Summary Report Version 3.0 was submitted to the WLWB in October, 2014 (Golder 2014a) under Water Licence #W2007L2-0003. The WLWB did not approve the Version 3.0 Summary Report and requested that DDMI prepare an AEMP Reference Conditions Report prior to resubmitting the summary report with a number of required revisions. The intent of AEMP Reference Conditions Report was present re-calculated normal ranges for all AEMP variables, to be used in subsequent AEMP reports to evaluate potential effects of the Mine (WLWB 2015a). Following submission and approval of the AEMP Reference Conditions Report, the Board required that DDMI resubmit the AEMP Summary Report using a new title, the “2011 to 2013 Aquatic Effects Re-evaluation Report”, and as Version 3.1 (WLWB 2015a). As this Version 3.1 was to be a resubmission under Water Licence W2007L2-0003, DDMI was not required to satisfy the additional requirements of Water Licence #W2015L2-0001 for Aquatic Effects Re-evaluation Reports (WLWB 2015a).

Version 1.0 of the AEMP Reference Conditions Report was submitted to the WLWB on April 15, 2015. DDMI submitted a revised version (Version 1.1) of the report on September 15, 2015 (DDMI 2015). This version incorporated several required updates, such as revisions to the methods and time periods used to calculate normal ranges, handling of anomalous values and outliers, and treatment censored data (i.e., values reported as less than the detection limit [DL] in chemistry datasets). The WLWB approved the AEMP Reference Conditions Report Version 1.1 on November 27, 2015 (WLWB 2015a). This current Re-evaluation Report Version 3.1 includes a reassessment of all data against the approved reference conditions reported in the AEMP Reference Conditions Report Version 1.1. It presents updated trend plots that include the three years of data acquired since the 2007 to 2010 AEMP Summary Report (Golder 2011a), and provides a comparison of the effects observed over the 2011 to 2013 re-evaluation period with those reported in the 2007 to 2010 AEMP Summary Report Version 2.0.

A summary of the updates from the previous Version 3.0 and 3.1 Re-evaluation Reports are provided in Table 1-1. If applicable, reference(s) to sections of this report where the comments are addressed are provided in the final column of Table 1-1

Table 1-1 Revision History for AEMP Re-evaluation Report Version 3.1 and 3.2

Revision	Rationale for Revision	Location in Version 3.1 Report
Revised approach for identifying anomalous data	Requested as part of the AEMP Reference Conditions Report updates (WLWB 2015b)	Approach – Section 2.6 Application – Sections 4, 5, 6, 7 and 10
Detection Limit substitution	revised data substitution method requested for laboratory values below the detection limit	Sections 4, 5, 7, 10
Action Level revision	Update Action Level 2 following the approved revision to Action Level 2 so that Action Levels 1 and 2 are applied sequentially	Section 5.2.4.1.1
Updated normal ranges	Normal ranges from approved Reference Conditions Report Version 1.1 integrated	Sections 4, 5, 6, 7, 8, 9, 10
Updated trend assessment	Updates to trend assessments, using the revised normal ranges	Sections 4, 5, 6, 7, 8, 9, 10, 11
WLWB Directives from the 2011 to 2013 AEMP Summary Report Version 3.1	See Table 1-2	As described in Table 1-2
WLWB Directives on the 2011 to 2013 Aquatic Effects Re-evaluation Report Version 3.1, applied to Version 3.2	WLWB Directive Letter	As described in WLWB Directive Letter.

1.3.1 Conformity Table

A list of directives received from the WLWB that relate to the 2011 to 2013 Aquatic Effects Re-evaluation Report Version 3.1 is provided in Table 1-1 (WLWB 2015b). Additionally, several comments were acknowledged by DDMI in response to reviews of the AEMP Version 3.0 (2011 to 2013) Summary Report and are also provided in Table 1-2. Responses to these directives and comments, or references to sections of this report where the comments are addressed, are provided in the final column of Table 1-2.

Table 1-2 Conformity Table Indicating Where WLWB Required Revisions are Addressed and Comments Regarding Revisions

Component	Tracking Number	Recommendation	Response	Location in Version 3.0 Report	Location in Version 3.1 Report
General	-	Re-analysis of all parameters that were initially removed from temporal analysis due to lack of mine related effect if effluent was the only potential source considered	The first step of the Action Level evaluation involves a comparison of exposure data in Lac de Gras to reference values. This comparison is done for all variables analyzed for the AEMP (i.e., the full suite of parameters required under the AEMP Study Design Version 3.5), regardless of whether they are detected in Mine effluent or potentially in other mine-affected sources such as dust. As such, this first step of the Action Level evaluation considers the possible cumulative effects from other mine related inputs to Lac de Gras, because it begins with an analysis of trends in the receiving water environment. Although the AEMP sampling design is intended primarily to evaluate effects from Mine effluent, the spatial pattern in dust deposition is generally similar to that in effluent (i.e., there is a reduction in deposition rate with distance from the mine footprint; Section 3). Hence, constituent concentrations in the NF area would reflect inputs from dust deposition. The next step of the Action Level determination is to confirm whether the increase in concentration in the exposure area can be linked to the mine. This is done to confirm that the effect did not occur by chance or because of natural differences in water chemistry among sampling areas, or from one year to another. The presence of a constituent in the mine effluent was considered evidence that would establish the link to the mine that is required for an Action Level to be triggered. It is acknowledged, however, that the presence of these constituents in dust that may be deposited into Lac de Gras or in other sources would also provide evidence of the link to the mine. This has been clarified in the text in Section 5.3.1.1. Therefore, all constituents that could potentially be found in other mine affected sources, but not in effluent were included in the Action Level evaluation, provided that they are analyzed for the AEMP.	-	Section 5.3.1.1
General	-	A re-evaluation of all analyses and figures against the reference conditions detailed in the AEMP Reference Conditions Report, once the report has been approved by the Board.	Updates have been made throughout the Version 3.1 update to reflect the normal ranges in the Reference Conditions Report Version 3.1, as approved by the WLWB	-	All sections
General	-	revised text to indicate that effluent is not the only consideration for mine -related effect	This has been clarified in the text in Section 5.3.1.1	-	Section 5.3.1.1
General	-	Full explanation of outliers or reference to the explanations.	Data screening is the initial phase in assessing chemistry data sets. This initial step is undertaken prior to data analysis and interpretation to ensure that the data quality objectives established by the QAPP and in the study design have been met. The purpose of this step is to initially identify unusually high (or low) values in a data set, and make a decision whether to retain or exclude the anomalous data form further analysis. In previous DDMI AEMP reports, the judgment whether to retain an anomalous value in the analysis was made based on a visual inspection of the data using a scatter-plot, and logical consistency with results for other parameters. In this current version of the Re-evaluation report, a revised approach for identification of anomalous data was taken to address concerns identified by the WLWB and other reviewers regarding the handling of outliers in AEMP datasets. This revised data screening approach allows for using a numerical method to aid in the identification of outliers, thus removing the subjectivity of classifying values based on visual evaluation of data alone. An explanation of the objectives and specific methods taken to complete the initial data screening is provided in Section 2.6. Results of the screening for anomalous values for individual components are presented as an appendix to each section (chemistry data sets only). In cases where outliers were identified within the annual data sets, scatter-plots were generated to allow review of excluded data and provide transparency regarding the outcomes of this process. Overall the number of outliers identified by the data screening procedure was very low. For most components, data screening resulted in the removal of less than half of a percent of the total data points.	Outliers	Section 2.6
General	-	Reviewers did not believe that the AEMP adequately summarized or described the results. Future Annual reports and summary reports are to provide as much information as possible to explain the results.	A number of updates were made to this current version (Version 3.1) of the Re-evaluation Report which provides additional details that summarize and explain the results. Some examples of additions include appendix 5B, which provides detailed results of the Action Level Screening for water quality (Appendix 5B); Table 4-2, which provides an itemized summary of samples exceeding effluent quality criteria during the re-evaluation period; and Appendices 4A, 5A, 6A, 7A, which provide detailed summaries of the results of initial data screening and plots of anomalous values removed from further analysis.	Results Explanation	-
Eutrophication Indicators		Footnote (b) for Table 6-6 refers to Study Design 3.1 rather than 3.5	This footnote is no longer included; however, all footnote references have been reviewed for reference to Study Design Version 3.1 and updated where appropriate.	Table 6.6	-
Fish	-	correct table reference and clarify the text in footnote (a)	Acknowledged. The table reference has been corrected in the report and the text in the footnote has been clarified.	Table 10-1 and 10-3	Table 10-4
Fish	-	Review last section of the errata (in response to EMAB-51), because the new text is the exact same as in the summary report.	When available, additional literature on tissue chemistry effects is provided in the Annual AEMP reports. The next Annual AEMP fish report is scheduled for 2016, and fish tissue concentrations will be summarized in this report, if available.	Section: 10.4 Page: 10-81	-
General	EMAB-1	It would be useful to have each section bookmarked/labelled for more efficient navigation during review of the 580 page document.	Acknowledged. Bookmarks have been added to the report.	General	General
Effluent Assessment	EMAB-9	Consider keeping units consistent for each parameter throughout the report.	Acknowledged. Table 4-1 has been updated so that the units are consistent with the remainder of the report.	Table 4-1	Table 4-1
Sediment Quality	EMAB-15	The text should be reviewed and updated as appropriate.	This sentence has been removed from the report as a result of revisions made to the chapter.	Section: 7.3.1 Page: 7-7 Paragraph: 2	Section 7
Sediment Quality	EMAB-20	The figure should be reviewed and updated as appropriate.	This figure has been updated in the report as a result of revisions made to the sediment chapter.	Section: 7.3.2.2 Page 7-14	Section: 7.3.2.2

Table 1-2 Conformity Table Indicating Where WLWB Required Revisions are Addressed and Comments Regarding Revisions

Component	Tracking Number	Recommendation	Response	Location in Version 3.0 Report	Location in Version 3.1 Report
Plankton	EMAB-24	Footnote (b) is missing from the table. Recommendation The table should be updated as appropriate.	Acknowledged. Table 8-6 has been corrected in the report.	Table: 8-6 Page: 8-12	Section 8
Plankton	EMAB-25	Sentence 5 states "... the microflagellates had biomass peaks in the NF area in 2006 or 2007." However, the figures referenced in the text are for chlorophytes, diatoms, and dinoflagellates. Recommendation The text and figures should be reviewed and updated as appropriate.	Acknowledged. The text has been updated.	Section 8.3.2.2 Page: 8-14 Paragraph: 2	Section 8
Fish	EMAB-40	first sentence under the heading Action Levels indicates that "In 2007 age 1+ body size and male condition were significantly lower in the NF area relative to the reference area, but these effects were not confirmed in 2010". However, in Table 10-3 there is no symbol indicating such an effect in 2007 for age 1+ body size (i.e., there is a 0 indicating no change rather than a downward pointing arrow). Recommendation The text and table should be reviewed and updated as appropriate.	Acknowledged. Table 10-4 has been revised.	10.2.2.1 Page: 10-6	Table 10-4
Fish	EMAB-50	The second bullet concludes that enrichment effects were observed in both 2007 and 2010, which contradicts the discussion on Page: 10-5 that indicates there was no evidence for any effect in 2007. Recommendation The text should be reviewed and updated as appropriate.	Acknowledged. The text has been revised	Section: 10.4 Page: 10-81	Section 1.4

2 STUDY DESIGN

2.1 Objectives

DDMI conducts environmental monitoring programs under the terms and conditions of the Water Licence and the Fisheries Authorization issued by DFO. The AEMP is the primary program specified in the Water Licence for monitoring the aquatic environment of Lac de Gras. Mine water discharge represents the principal stressor of potential concern (SOPCs) to Lac de Gras (DDMI 2007a). Therefore, mine water discharge, and its potential impact on aquatic resources, is the principal focus of the AEMP. However, the AEMP considers all the major pathways leading to potential effects.

The principal goal of the AEMP is to monitor the Mine water discharge and other stressors from the Mine and assess potential ecological risks so that appropriate actions can be taken in the Mine operations to mitigate potential adverse effects. As defined in the Water Licence, the specific objectives of the AEMP are "to determine the short and long-term effects in the aquatic environment resulting from the project, test impact predictions, measure the performance of operations and evaluate the effectiveness of impact mitigation", particularly in relation to the primary Valued Ecosystem Components (VECs) of Lac de Gras. The VECs have been evaluated in previous site investigations, including the environmental assessment (EA) (DDMI 1998a), and consist of fish, fish habitat, water quality, sediment quality, lake productivity, planktonic and benthic invertebrate communities, and the use of fisheries resources in Lac de Gras.

2.2 Determining Effects

An "effect" is a change that follows an event or cause. An effect is not inherently negative or positive. A linkage must be established between a measured change and a cause (e.g., mining activity) for the change to be deemed an effect. The DDMI AEMP is designed to detect changes in Lac de Gras. Changes are not considered "effects" until a link to the Mine has been established.

Magnitudes of effects were determined by comparing measurement endpoints between exposure areas and reference areas, and to background values or benchmark values. Background values for Lac de Gras are those that fall within the range of natural variability, referred to as the *normal range*. The normal ranges used to assess effects of the Mine on individual components of the AEMP are described in the AEMP Reference Conditions Report, Version 1.1 (Golder 2015). Values that exceed the normal range are above what would be considered natural levels for Lac de Gras, but do not necessarily represent levels that are harmful.

During the Project EA, the ecological tolerance of changes in Lac de Gras were evaluated based on benchmark concentrations (termed ecological thresholds in the EA). These benchmarks were defined as concentrations at which a specific use could begin to be affected and were generally based on published guidelines, such as the Canadian Water Quality Guidelines (CWQGs) (CCME 1999a). The EA benchmarks have been carried through the AEMP process at Diavik and are herein referred to as *Effects Benchmarks*. This naming convention has been adopted because several of the CWQGs upon which EA benchmarks were based have changed over the years, and the Effects Benchmarks used in the AEMP are generally based on the revised CWQGs. In addition, some of the guidelines (e.g., aluminum and cadmium) have been adapted to the specific conditions of Lac de Gras (Golder 2014a). The Effects Benchmarks represent values that are protective of aquatic life and are intended to be conservative.

They represent a level which, if exceeded, could cause adverse effects, not a level which, if exceeded, would cause adverse effects.

The severity of possible effects to an assessment endpoint has been categorized according to Action Levels. The Action Level classifications were developed to meet the goals of the *Response Framework for Aquatic Effects Monitoring* (WLWB 2010; Racher et al. 2011), and are described for each component in the corresponding section in this report. The goal of the Response Framework is to ensure that significant adverse effects never occur. This is accomplished by requiring proponents to take actions at predefined Action Levels, which are triggered well before significant adverse effects could occur. A level of change that, if exceeded, would result in a significant adverse effect is termed a *Significance Threshold*. The Significance Threshold for the Mine was defined in the Comprehensive Study Report (Government of Canada 1999).

This AEMP addresses two broad impact hypotheses for Lac de Gras: a toxicological impairment hypothesis and a nutrient enrichment hypothesis. Toxicity to aquatic organisms is the hypothetical response to some substances released from the Mine (such as metals in the effluent). The process of eutrophication is the response to inputs of nutrients such as phosphorus and nitrogen.

The weight of evidence assessment is the process used to evaluate the strength of evidence for toxicological impairment and nutrient enrichment effects. The weight of evidence assessment is also used to establish a link between observed effects and the Mine. Both the evidence for the type of effect and for a link to the Mine must be strong for the effect to be deemed Mine-related. Hence, even if the Action Level conditions appear to have been met, the overall weight of evidence conclusions must indicate a linkage to the Mine *and* support the impact hypothesis prior to concluding that an Action Level has been met.

2.3 Locations of Sampling Stations

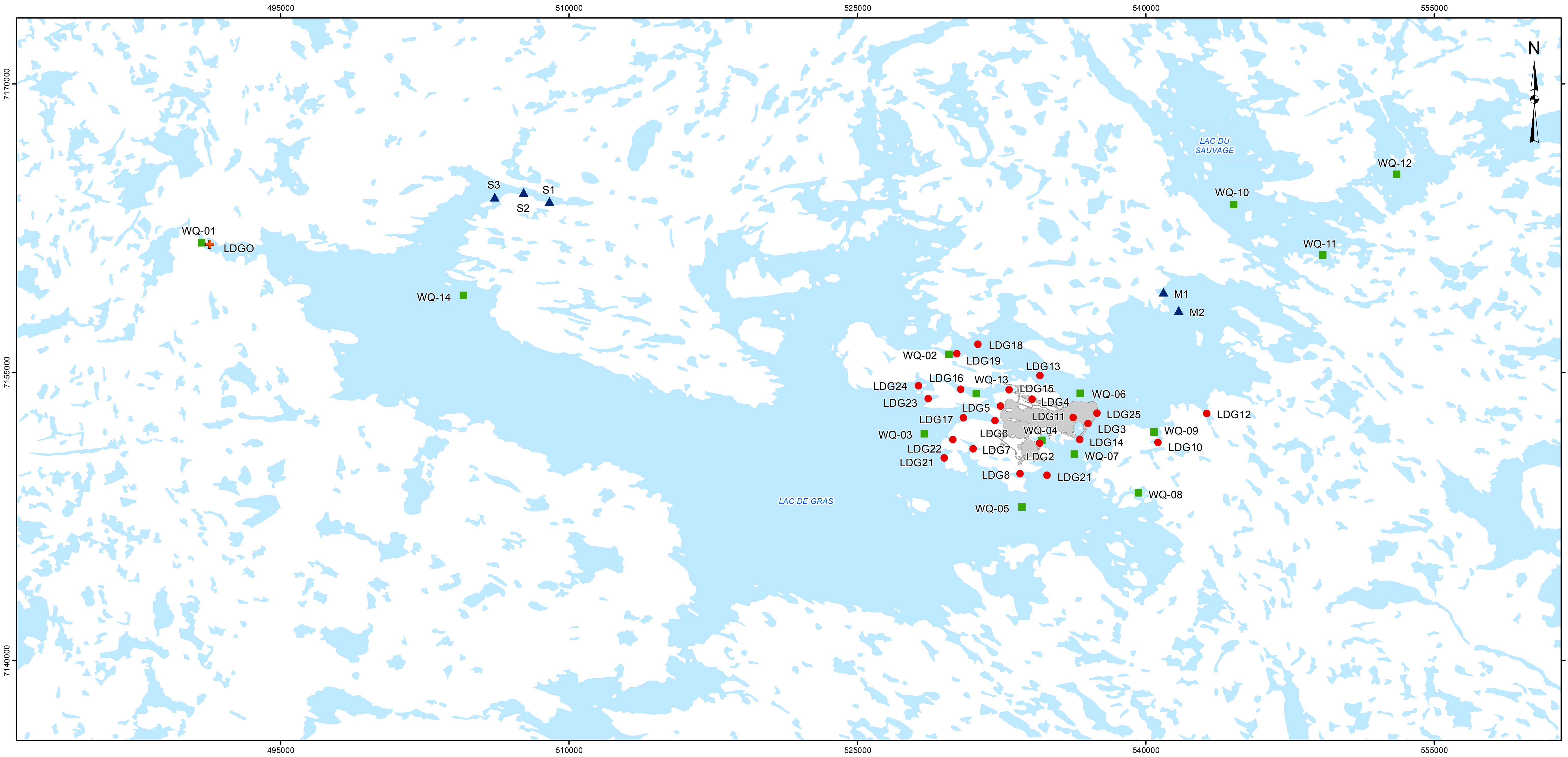
The locations and the naming of sampling stations has changed since the baseline period, and over the various versions of the AEMP (Figures 2-1 to 2-4). A significant expansion of the sampling program occurred during the AEMP Version 2.0. Sampling stations were initially located according to effluent concentrations, which were estimated by plume delineation studies (DDMI 2007a). Three broad groups of sampling areas were defined, according to their level of exposure to effluent. The Near-field stations are located in the area near the discharge where plume delineation studies estimated effluent concentration to be approximately 1% or greater during ice-covered conditions. Most Mid-field stations are located outside of the 1% zone, within a relatively wide range of exposure. Reference areas of the lake were located to represent the general variability that could be expected in such a large lake. These areas were as far removed from effluent exposure as possible, to document background conditions. Differences in sampling locations among the AEMP Versions are discussed in the next section.

The AEMP Versions 2.0 and 3.0 evaluated eight general areas of Lac de Gras, defined by distance from the diffuser. These areas consisted of the near-field exposure area (NF), the far-field exposure area (FF2), three reference areas (FF1, FFA and FFB), as well as three mid-field areas (MF1, MF2, and MF3), which are be located along three transects between the NF and FF study areas (Figures 2-3 and 2-4). The MF1-FF1 transect was sampled towards the FF1 reference area, northwest of the exposure area. The MF2-FF2 transect was sampled to the northeast, towards the FF2 area near the Lac du Sauvage inlet. The MF3-FFB-FFA transect was sampled south of the exposure area towards

FFB and FFA reference areas. Within each sampling area, clusters of replicate stations were sampled. The number of replicate stations differed depending on the study design version. Five stations were sampled in the NF exposure area and in each of the three FF reference areas under study designs Version 2.0 and 3.0. To better delineate the extent of effects and define gradients along each transect in AEMP Version 3.0, the number of stations within the MF3 transect were increased and the number of stations along the MF2 transect decreased.

Water quality, nutrients and chlorophyll *a* are sampled in the Coppermine River at the outlet from Lac de Gras (Station LDG 48) using the methods employed since 2000. Water quality, chlorophyll *a* and plankton are also sampled at three stations in Lac du Sauvage. Water from Lac du Sauvage enters the northeast portion of Lac de Gras. This “more productive” water (due to higher nutrient concentrations) has the potential to affect the FF2 area; therefore, it is important to determine if changes occurring in the FF2 area are due to exposure to Mine effluent, or the quality of water entering Lac de Gras.

I:\2010\10-1328\10-1328-0028\Mapping\MXD\2007_2011AEMP\Fig 2-1_Baseline_(1994-1999)_Sampling_Stations.mxd



5 0 5

SCALE 1:200,000 KILOMETRES

LEGEND

- ● 1994 - 1995 MONITORING STATION
- ■ 1996 - 1999 MONITORING STATION
- ▲ BHP AEMP MONITORING STATION
- ✚ DIAND WATER QUALITY STATION
- DIAVIK FOOTPRINT
- ▨ WATERBODY

REFERENCE

Projection: UTM Zone 12 Datum: NAD 83

PROJECT

DIAVIK DIAMOND MINES
NORTHWEST TERRITORIES

TITLE

BASELINE (1994-1999) SAMPLING STATIONS

DIAVIK DIAMOND MINES INC.

PROJECT No. 09-1328-0021			SCALE AS SHOWN	REV. 0
DESIGN	TD	07 Oct. 2014	**FIGURE: 2-1**	
GIS	SB	07 Oct. 2014		
CHECK	TD	07 Oct. 2014		
REVIEW	CF	07 Oct. 2014		

Legend

●	AEMP Lake Sediment Sampling Locations	▨	Diavik Footprint
▲	AEMP Water Quality Sampling Locations		

5 0 5

Scale 1: 250,000 Kilometers

REFERENCE

UTM Zone 12, NAD 83.

PROJECT

DIAVIK
DIAMOND MINES INC.

TITLE

AEMP VERSION 1.0 (2000-2006)
SAMPLING STATIONS

PROJECT:		06-1328-001	SCALE AS SHOWN	REV. 0
DESIGN	TD	08 Oct. 2014	FIGURE: 2-2	
GIS	SB	08 Oct. 2014		
CHECK	TD	08 Oct. 2014		
REVIEW	CF	08 Oct. 2014		

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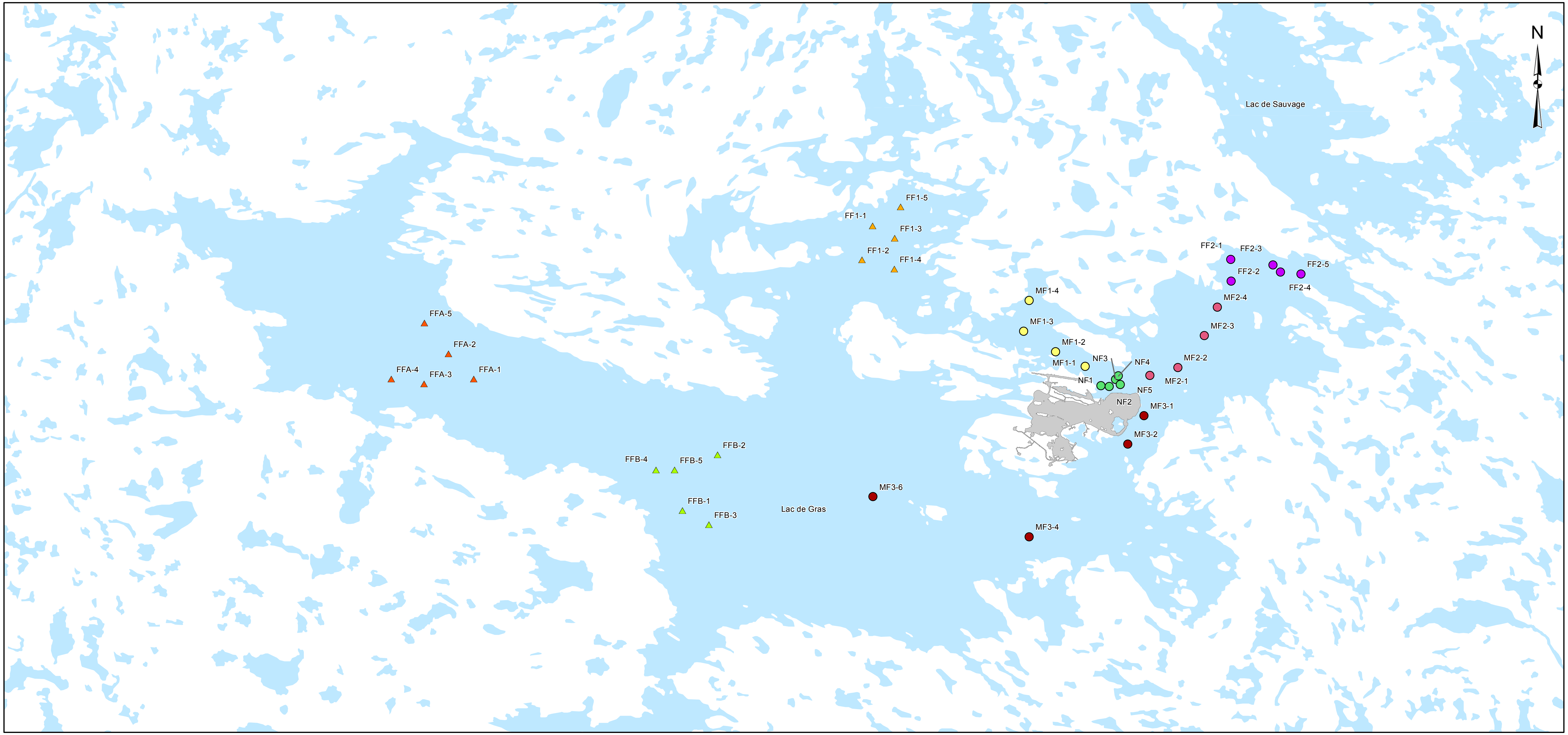
I:\2010\10-1328\10-1328-0028\Mapping\MXD\2011AEMP\Fig4.1-1AEMP_Version_2.0_Sampling_Stations_20111026.mxd



LEGEND

EXPOSURE

- ● FAR-FIELD 2
- ○ MID-FIELD 1
- ● MID-FIELD 2
- ● MID-FIELD 3
- ● NEAR-FIELD

REFERENCE

- △ FAR-FIELD 1
- ▲ FAR-FIELD A
- △ FAR-FIELD B

▨ DIAVIK FOOTPRINT

🟦 WATERBODY

REFERENCE

Data Produced by DMTI Spatial Inc., used under license.
Projection: UTM Zone 12 Datum: NAD 83

5 0 5
SCALE 1:175,000 KILOMETRES

PROJECT

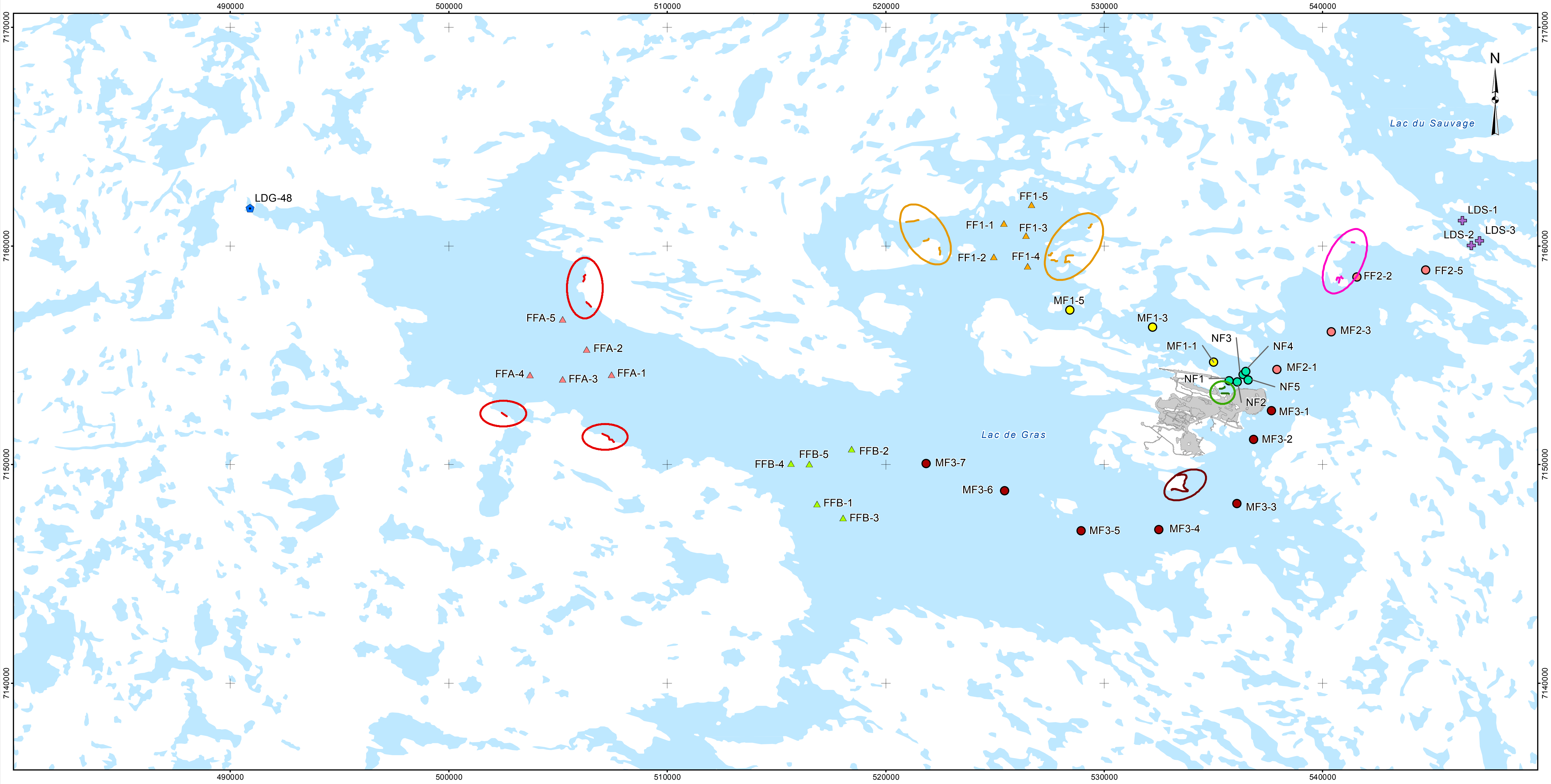
DIAVIK™
DIAMOND MINES INC.

TITLE

AEMP VERSION 2.0 (2007-2011) SAMPLING STATIONS

Golder Associates
Calgary, Alberta

PROJECT No. 10-1328-0028			SCALE AS SHOWN	REV. 0
DESIGN	TD	07 Oct. 2014	**FIGURE: 2-3**	
GIS	SB	07 Oct. 2014		
CHECK	TD	07 Oct. 2014		
REVIEW	CF	07 Oct. 2014		



LEGEND

EXPOSURE

- ● NEAR-FIELD
- ● MID-FIELD 3
- ● MID-FIELD 1
- ● FAR-FIELD 2; MID-FIELD 2

REFERENCE

- ▲ FAR-FIELD 1
- ▲ FAR-FIELD A
- ▲ FAR-FIELD B
- ✚ LAC DU SAUVAGE
- ⬟ LDG 48

SAMPLING SITES FOR SLIMY SCULPIN

- ○ FAR-FIELD 1
- ○ FAR-FIELD 2
- ○ FAR-FIELD A
- ○ MID-FIELD 3
- ○ NEAR-FIELD
- ▨ DIAVIK FOOTPRINT
- ▨ WATERBODY

REFERENCE

HYDROGRAPHY DATA OBTAINED FROM CANVEC © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
PROJECTION: UTM ZONE 12 DATUM: NAD 83

5 0 5
SCALE 1:175,000 KILOMETRES

PROJECT

DIAVIK
DIAMOND MINES INC.

TITLE

AEMP VERSION 3.0 (2011-2013) SAMPLING STATIONS

Golder Associates

PROJECT		05-1328-008	FILE No.	
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GIS	SB	07 Oct. 2014	FIGURE: 2-4	
CHECK	TD	07 Oct. 2014		
REVIEW	CF	07 Oct. 2014		

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2.4 Comparison among AEMPs

Overlap of stations among the four main phases of monitoring since baseline is presented in Table 2-1. This overlap has allowed the use of a moderate proportion of historical monitoring data for evaluating trends over time.

Since the focus of Version 3.0 of the AEMP was to better delineate the extent of effects, several stations that were used in the AEMP Version 2.0 were re-allocated to better define the gradient along the three transects (Figures 2-3 and 2-4). The stations in Table 2-1 have been ordered according to these transects to help demonstrate this re-allocation. For example, given that the exposure and effects along the MF2-to-FF2 transect are relatively homogeneous, some of the now redundant stations along that transect were allocated along the MF3-to-FFB transect. In addition, three stations in Lac du Sauvage were added to the Version 3.0 AEMP to better define trends in the headwaters to Lac de Gras.

2.5 Sampling Schedule

With the exception of the fish surveys, the monitoring frequency for the AEMP Version 2.0 was annual. The four years of monitoring under the AEMP Version 2.0 (i.e., 2007 to 2010) provided data of consistent quality, providing reliable estimates of within-year, among-year and among-station variation. These data also allowed for a detailed assessment of Mine-related effects (Golder 2011a).

During these four years of monitoring, water quality and plankton sampling was conducted monthly during the open-water season, with an additional ice-cover sampling event for water quality. Variability in water quality and plankton data during the open-water season was evaluated over the four years of the AEMP Version 2.0. An objective of this evaluation was to determine if a single open-water sample is adequate for the open-water season and, if so, the best single period to sample during the open-water season. The analysis demonstrated that the variability among the three open-water periods for all areas of the lake is, for most variables, very small relative to that seen between ice-cover and open-water conditions, or between exposure and reference areas. Moreover, results of the assessment of effects were typically consistent across all three open-water periods. The ice-cover period proved to be the most sensitive time of year to asses effects on water quality (i.e., effects were more frequently observed under ice-cover conditions, compared to the open-water sampling periods). Given these results, the frequency of monitoring for the AEMP Version 3.0 was changed to one open-water period in addition to the ice-cover period, and the open-water sampling period was specified to occur during the period previously referred to as the Open 2 or Open 3 period in the AEMP Version 2.0 (i.e., from August 15 to September 15).

Table 2-1 List of Sampling Stations in Lac de Gras According to Monitoring Phase

Baseline (1996-1999)	AEMP Version 1.0 (2000-2006)	AEMP Version 2.0 (2007-2011)	AEMP Version 3.0 (2011-2013)
WQ-06, N7	LDG 42, LDG NF	NF area	NF area
-	LDG 13	MF1-1	MF1-1
-	LDG 40	MF1-2	-[(a)]
WQ-02	LDG 19	MF1-3	MF1-3
-	-	MF1-4	-
-	-	-	MF1-5
-	-	FF1 area	FF1 area
-	-	MF2-1	MF2-1
F14	LDG MF	MF2-2	-
-	-	MF2-3	MF2-3
-	LDG 45	MF2-4	-
-	-	FF2-1	-
-	-	FF2-2	FF2-2
-	-	FF2-3	-
-	-	FF2-4	-
-	-	FF2-5	FF2-5
-	-	MF3-1	MF3-1
WQ-07	LDG 43	MF3-2	MF3-2
-	-	-	MF3-3
WQ-05	LDG 41	MF3-4	MF3-4
-	-	-	MF3-5
-	-	MF3-6	MF3-6
-	-	-	MF3-7
-	-	FFB area	FFB area
-	-	FFA area	FFA area
LDG 48	LDG 48	LDG 48	LDG 48
Lac du Sauvage	Lac du Sauvage	Lac du Sauvage	Lac du Sauvage

a) - = Station not sampled.

Under AEMP Version 3.0, variables utilized as indicators of eutrophication, including plankton, were sampled on an annual basis (Table 2-2). In addition, water quality monitoring continued at a monthly frequency at the mixing zone boundary and at an annual frequency in the exposure areas (NF, FF2, MF) to retain the ability to detect early warning effects, or unexpected changes in water quality. Sediments (with the exception of annual sampling at the mixing zone boundary), benthic invertebrates and small-bodied fish were monitored at the frequency of once every three years.

The comprehensive sampling program, when all AEMP components are sampled at all stations, occurs every three years, in the year prior to submission of the study design update (Table 2-3). This schedule allows for a detailed assessment of effects and a continuation of trend analyses before submission of the next study design. The annual reports for the two interim years (i.e., the years in which comprehensive sampling is not undertaken) assess effects on water quality variables, indicators of eutrophication and plankton, by determining if an Action Level has been reached. This approach follows the concept of the tiered, three-year cycle approach that has been successfully applied in regulatory-driven, national-scale aquatic effects monitoring programs, such as the federal pulp and paper and metal mining EEM programs (Environment Canada 2010, 2012).

Table 2-2 Summary of the AEMP Version 3.5 Sampling Design

Component	Timing	Sampling Depth	Sample Type	Number of Samples per Station	Locations[a] (Number of Stations)	Frequency
Water Quality - Mixing Zone Boundary	Monthly	2-m intervals (5 depths)	Discrete	5	SNP 19A, B, C	Annually
Effluent Plume (conductivity)	Twice: 1 open water 1 ice-cover	2-m intervals	Profile	Profile	NF (5) MF (12) FF (17) LDS (3) LDG 48	Annually at NF, MF, FF2, and LDG 48 Once every 3 years at all stations
Water Quality – Routine, Nitrogen, and Metals	Twice: 1 open water 1 ice-cover	NF and MF: 3 depths • 2 m from surface • mid-depth • 2 m from bottom FF/Ref: 1 depth • mid-depth	Discrete	NF and MF: 3 FF: 1	NF (5) MF (12) FF (17) LDS (3) LDG 48	Annually at NF, MF, FF2, and LDG 48 Once every 3 years at all stations
Total Phosphorus, Total Nitrogen and Chlorophyll *a*	Twice: 1 open water 1 ice-cover[b]	10 m	Open water: depth-integrated Ice-cover: discrete	2 chlorophyll *a* 2 nutrients	NF (5) MF (12) FF (17) LDS (3) LDG 48	Annually at NF, MF, FF2, and LDG 48 Once every 3 years at all stations
Phytoplankton	Once: 1 open water	10 m	Depth-integrated	1 taxonomy	NF (5) MF (12) FF (17) LDS (3)	Annually at NF Once every 3 years at all stations
Zooplankton	Once: 1 open water	full water column	Depth-integrated Composite of 3 tows	2 taxonomy 2 biomass	NF (5) MF (12) FF (17) LDS (3)	Annually at NF Once every 3 years at all stations
Sediment Quality	Once: 1 open water	18 to 22 m Top 10-15 cm (full Ekman grab) for total organic carbon and particle size Top 1 cm (core) for chemistry	Composite of (minimum) 3 grabs Composite of (minimum) 3 cores	1 of each type	NF (5) MF (12) FF (17) SNP 19A, B, C	Once every 3 years Annually at SNP
Benthic Invertebrates	Once: 1 open water	18 to 22 m	Composite of 6 grabs	1	NF (5) MF (12) FF (17)	Once every 3 years
Large Bodied Fish -Fish Palatability and -Fish Tissue Chemistry	Once: 1 open water	(not applicable)	Individual fish, muscle and organs	10 fish	Lac de Gras	Once every 3 years

Table 2-2 Summary of the AEMP Version 3.5 Sampling Design

Component	Timing	Sampling Depth	Sample Type	Number of Samples per Station	Locations[(a)] (Number of Stations)	Frequency
Large Bodied Fish - Fish Tissue Mercury	Once: 1 open water	(not applicable)	Non-lethal muscle plugs	30 fish per lake, 2 plugs per fish	Lac de Gras and Lac du Sauvage	Once every 3 years
Large Bodied Fish - Fish Health	Once: 1 open water (occurs only when triggered by results for small bodied fish)	(not applicable)	Lethal survey: Non-lethal survey:	20 adult male 20 adult female 20 juvenile additional 40 fish	Lac de Gras and Lac du Sauvage	Once every 6 years
Small Bodied Fish - Fish Tissue Chemistry	Once: 1 open water	(not applicable)	composite by size, whole body	Min of 8	NF (1) FF (3)	Once every 3 years
Small Bodied Fish - Fish Health	Once: 1 open water	(not applicable)	Lethal survey: Non-lethal survey:	30 adult male 30 adult female 30 juvenile additional 50 fish	NF (1) MF (1) FF (3)	Once every 3 years
Snow Monitoring (Dust Deposition)	Once: 1 ice-cover	(not applicable)	Composite of required number of cores for analysis	1	Control (3) Transects (19)	Annually
Dust Gauge Monitoring (Dust Deposition)	3 per year: Mar, Aug, Dec	(not applicable)	Discrete	1	Control (2) Exposure (8)	Annually

a) Sampling locations are shown in Figure 5.6-2.

b) Sampling for chlorophyll *a* is not conducted during the ice-cover period.

Table 2-3 AEMP Sampling Schedule

Component(a)	AEMP Version 3.0						AEMP Version 3.5						AEMP Version 4.0(h)					
	2012		2013		2014		2015		2016		2017		2018		2019		2020	
	IC	OW	IC	OW	IC	OW	IC	OW	IC	OW	IC	OW	IC	OW	IC	OW	IC	OW
Water Quality - Mixing Zone Boundary(b)	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Sediment Quality - Mixing Zone Boundary		√		√		√		√		√		√		√		√		√
Effluent Plume (conductivity)	√	√	√	√(i)	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Water Quality - Routine, Nitrogen and Metals	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Water Quality - Routine, Nitrogen and Metals (comprehensive program)			√	√					√	√					√	√		
Total Phosphorus, Total Nitrogen and Chlorophyll *a* (c)	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
TP, Total Nitrogen and Chlorophyll *a* (c) (comprehensive program)			√	√					√	√					√	√		
Phytoplankton		√		√		√		√		√		√		√		√		√
Zooplankton		√		√		√		√		√		√		√		√		√
Sediment Quality				√						√						√		
Benthic Invertebrates				√						√						√		
Large Bodied Fish - Palatability and Tissue Chemistry		√						√						√				
Large Bodied Fish - Fish Tissue Mercury						√						√						√
Large Bodied Fish - Fish Health										(d)						(d)		
Small Bodied Fish - Fish Health				√						√						√		
Dust Deposition	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√

Table 2-3 AEMP Sampling Schedule

Component[(a)]	AEMP Version 3.0						AEMP Version 3.5						AEMP Version 4.0[(h)]					
	2012		2013		2014		2015		2016		2017		2018		2019		2020	
	IC	OW	IC	OW	IC	OW	IC	OW	IC	OW	IC	OW	IC	OW	IC	OW	IC	OW
TEK Program		√						√						√				
Annual AEMP Report[(e)]	√		√		√		√		√		√		√		√		√	
Aquatic Effects Re-Evaluation Report[(f)]						√						√						√
AEMP Design Document[(g)]				√								√						√

a) See Study Design Version 3.5 (Golder 2014a) Table 5.7-1 for sampling locations and frequency descriptions.

b) Water quality sampling at the mixing zone boundary (SNP 19) is conducted on a monthly basis.

c) Sampling for chlorophyll *a* is not conducted during the ice-cover period.

d) Sampling to be conducted only if triggered by 2013 small-bodied fish results.

e) Annual reports will be submitted by March 31st of the following year. For example, the annual report for 2013 was submitted on March 31, 2014.

f) Aquatic Effects Re-Evaluation reports will be submitted by October 15th of the following year.

g) Study design documents for the next AEMP Version will be submitted by October 15th of the last year covered by the present version.

h) The final structure of the AEMP Version 4.0 will be dependent on the findings from the AEMP Version 3.5, and may differ from that shown here.

i) Underlined check mark indicates that sampling is conducted under the comprehensive sampling program.

IC = ice-cover period; OW = open-water period.

2.6 Data Handling

Data screening is the initial phase of data handling when analyzing chemistry datasets, which are subject to occasional extreme values that are frequently incorrect, reflecting field or laboratory errors, data transcription or calculation errors, or extreme natural variability. This initial step is undertaken prior to data analysis and interpretation to verify that the data quality objectives established by the Quality Assurance Project Plan and the study design have been met. The purpose of this step is to initially identify unusually high or low values (referred to as anomalous data), correct them if possible, and make a decision whether to retain or exclude remaining anomalous data form further analysis.

2.6.1 Dust Data

Before statistical testing, dustfall gauge, snowdust and snow chemistry data were pre-screened using a Lilliefors test, which is a two-sided goodness-of-fit test suitable for determining if the dust data are normally distributed (an assumption of data used in parametric statistical testing). Data that were not normally distributed were $\log_{10}$ transformed and re-tested for normality. Potential analytical errors and/or statistical outliers were identified during data screening by centering and scaling the data and then computing the “z-score”, or relative distance from the mean, for each data point. Results indicating a z-score less than -3 or greater than +3 (i.e., farther than three standard deviations from the mean) were excluded from further analysis.

2.6.2 AEMP Data

In previous DDMI AEMP reports, the judgment whether to retain an anomalous value in the analysis was made based on a visual inspection of the data using scatter-plots, and logical consistency with results for other parameters. To prepare data for summaries presented in this version of the Re-evaluation Report, a revised approach was used to identify anomalous data to address concerns noted by the WLWB and other reviewers regarding the handling of outliers in AEMP datasets. The revised data screening approach includes a numerical method to aid in the identification of outliers, thus removing the subjectivity of classifying values based on visual evaluation of data alone. This initial screening is primarily applicable to chemistry data, because anomalous results are less common in biological (e.g., taxonomy) data and are typically resolved through contacting the taxonomist.

Initial screening of the annual AEMP datasets, was conducted using a method based on Chebyshev’s theorem (Mann 2010) combined with the visual examination of scatter-plots. This method allows for detection of multiple outliers at one time and assumes that the data being screened contain a relatively small percentage of outliers (Amidan et al. 2005). The theorem states that at least $1–1/k^2$ proportion of the data of any distribution (i.e., no assumption of normality) lies within k standard deviations (SD) of the mean. Setting $1–1/k^2 = 0.95$ and solving for k results in 4.47 SD, indicating that 95% of the data, regardless of distribution, will be within about 4.5 SD of the mean. In the case of a normal distribution, 95% of the data is expected to be within 2 SD, suggesting that the method based on Chebyshev’s inequality is conservative (i.e., identifies values that are far removed from the mean). The method is applied by first identifying data that lie outside the 4.47 SD on a scatter-plot of annual data, and then visually verifying the anomalous values based on potential spatial trends. No data were identified as anomalous based on visual evaluation alone.

In cases where the Chebyshev screening method identified an elevated value in the NF area or at the mixing zone boundary as anomalous, the identified value was conservatively retained in the dataset used for analysis if the SD distance from the mean was less than two times the 4.5 SD criterion discussed above. Hence, only very extreme values, which were greater than approximately 9 SDs from the mean were removed from the further analysis of NF area data. Finally, in cases where the annual datasets contained a large proportion of non-detect data, only values that were greater than or equal to 5 times the DL were considered anomalous and were removed from the analysis.

Results of the data screening for individual AEMP components are presented as an appendix to each section (chemistry datasets only), which consist of a table of anomalous data, and scatter-plots to allow visual review of anomalous data and provide transparency. Anomalous data points identified by the data screening were retained in the Project database maintained by Golder, and have been flagged as anomalous. These values were excluded from data analyses, data summary tables and figures prepared in support of the AEMP Re-evaluation report. Overall, the number of anomalous values identified by the data screening procedure was very low compared to the amount of data summarized, accounting for less than half of a percent of the total data points per component.

3 DUST

3.1 Introduction

3.1.1 Background

Air and water quality issues associated with airborne fugitive dust caused by mining activities has been identified as being of particular concern and is required to be included in the DDMI environmental monitoring programs (DDMI 2006a,b). Since there is the potential for dust from the Mine to deposit onto Lac de Gras, the dust deposition monitoring program has been included as a component of the AEMP.

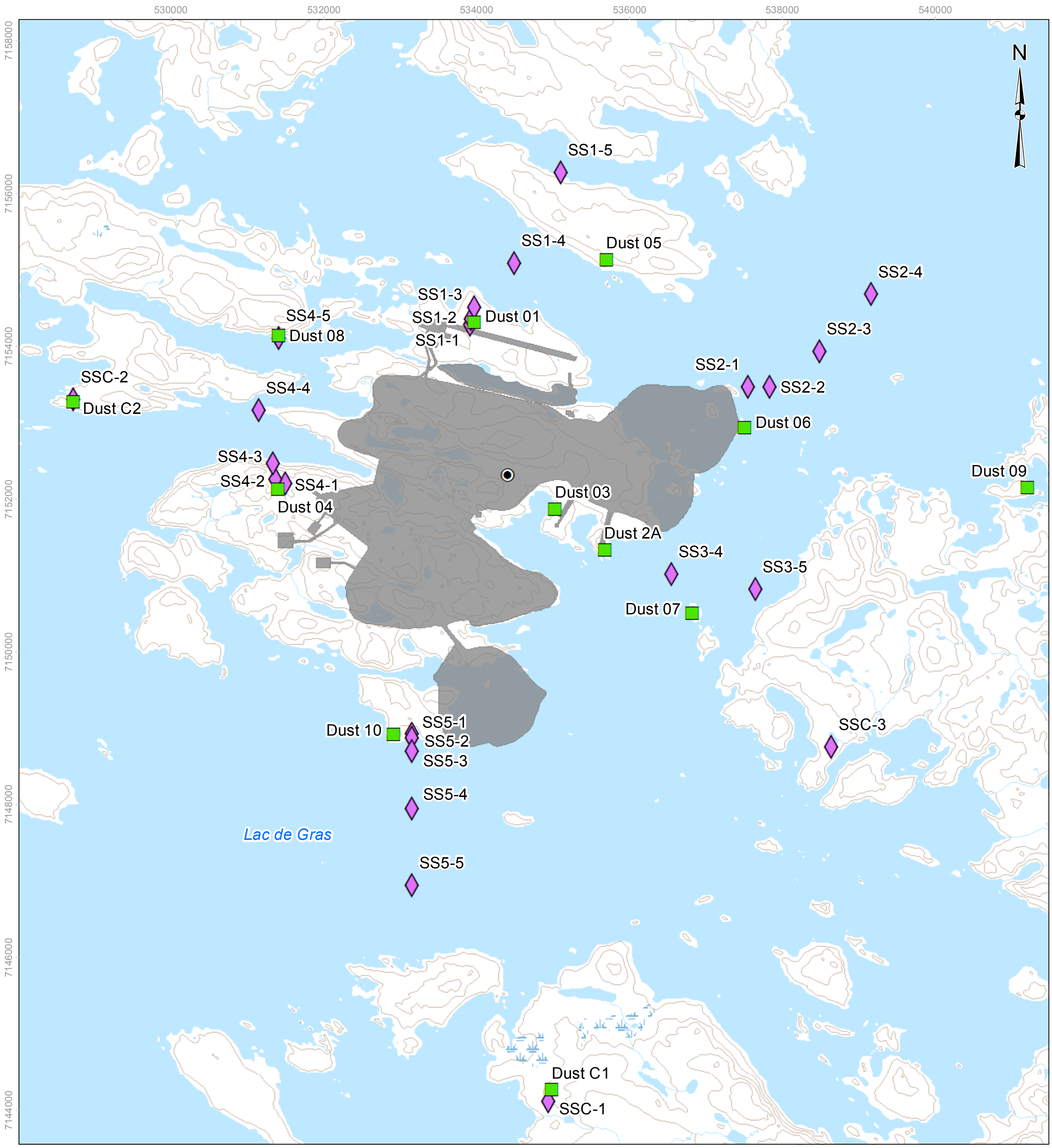
The objective of the dust deposition monitoring program is to monitor the levels of dust fall in the area surrounding the Mine and to confirm the predictions set forth in the EA (DDMI 1998b). More specifically, the program has been designed and implemented to identify:

- total particulate deposition rates at various distances from the Mine and to compare the observed deposition rates to predictions outlined in DDMI (1998b); and
- the physical and chemical characteristics of particulate material that may be deposited into Lac de Gras from mining activities.

3.1.2 Program History

Dust deposition has been monitored near the Mine since 2001. The design and sampling locations of the current program under the AEMP Version 3.5 (Figure 3-1) is essentially the same as the monitoring programs completed to date; however, modifications to the program have been made over the years, and are summarized below:

- **2001:** The 2001 dust monitoring program was based entirely on snow survey samples collected along four radial transects originating at the Mine footprint, to a distance of approximately 1000 metres from the Mine site. These transects included the following stations: SS1-1, -2 and -3; SS2-1, -2 and -3; SS3-1, -2 and -3; and, SS4-1, -2 and -3. All sample locations were analyzed for dust deposition, while only the locations on Lac de Gras were analyzed for snow water chemistry.
- **2002:** In response to recommendations made by the Mackenzie Land and Water Board, DDMI amended the dust monitoring program to include two snow survey control (i.e., reference) locations (SSC-1 and SSC-2). In addition, five dust gauges (passive dust collectors) were deployed, one along each of the snow survey transects and one at a control location (Dust 01, 02, 03, 04 and Dust C1).
- **2003:** In response to further recommendations, the dust monitoring program was further modified. All four snow survey transects were extended in length to a distance of approximately 2000 metres from the Mine footprint and a third snow survey control station was added (SS1-4 and -5, SS2-4, SS3-4 and -5, SS4-4 and -5, and SSC-3). An additional five dust gauges (Dust 05, 06, 07, 08), including one at a second control location (Dust C2), were deployed.



LEGEND

─	WATERCOURSE	🟩	DUSTFALL GAUGE LOCATION
▭	WATERBODY	◆	SNOW SURVEY LOCATION
		◉	DIAVIK FOOTPRINT CENTROID
		▬	DIAVIK FOOTPRINT

1.5 0 1.5

SCALE 1:75,000 KILOMETRES

REFERENCE

CANVEC BASE DATA: © DEPARTMENT OF NATURAL RESOURCES CANADA, 2012. ALL RIGHTS RESERVED.
PROJECTION: UTM ZONE 12 DATUM: NAD 83

PROJECT

DIAVIK™
DIAMOND MINES INC.

TITLE

DUSTFALL GAUGE AND SNOW SURVEY LOCATIONS

Golder Associates

PROJECT		1522041	FILE No.
DESIGN	TD	04/26/16	SCALE AS SHOWN REV. 0
GIS	VGV	04/26/16	**FIGURE: 3-1**
CHECK	TD	04/27/16	
REVIEW	ZK	04/27/16	

I:\2011\11-1328\11-1328-0038\Mapping\MXD\2015AEMP\1522041_Dustfall and Snow Survey Locations_Rev0.mxd Date: 4/27/2016 9:37:54 AM

- **2004:** Increased construction activity necessitated further changes to the dust monitoring program. One dust gauge (Dust 02) was removed from its location to accommodate Mine footprint expansion, and was subsequently relocated and redeployed (Dust 2A).
- **2005:** Dust deposition monitoring was carried out with no modifications to either the snow survey or the dust gauge portion of the program.
- **2006:** An additional dust gauge was deployed (Dust 09), bringing the total to eleven (including two controls). Mini-Vol portable air samplers were tested to determine the feasibility of incorporating them into the dust monitoring program. Preliminary findings proved the inclusion of the Mini-Vol samplers would be impractical.
- **2007:** The snow survey portion of the program was amended with an additional snow survey transect being incorporated (SS5-1, -2, -3, -4 and -5), bringing the total number of transects to five. As well, snow-water chemistry samples were collected adjacent to the pre-existing control locations as background references.

  Two additional dust gauges (temporary) were deployed adjacent to two pre-existing dust gauges. The intent of the temporary gauges was to compare results from the same location when sample collection frequency is altered.
- **2008:** All of the dust gauges were modified to accommodate the replacement of the polyacrylic dust gauge inserts with brass nipher gauge inserts, to minimize loss associated with damage during the collection and handling of the dust gauges. An additional dust gauge was added to the program (Dust 10), bringing the total to twelve permanently deployed (including two control) and two temporary (reference) dust gauges.

  Three snow survey sample points (SS3-1, SS3-2 and SS3-3) were not sampled, because they had become overtaken by construction activity and expansion of the Mine footprint; therefore, transect 3 consisted of two stations and a control station, with Station SS3-4 being the near-field station.
- **2009:** The two temporary dust gauges deployed in 2007 were decommissioned. All twelve permanent gauges were sampled quarterly. As a result of an error in collection/deployment, data were not collected at station Dust 03 between July 11 and September 9, 2009. In addition, an error with the collection and analysis of the dust deposition sample at station SS2-1 resulted in the sample being compromised; consequently, dust deposition data were not available for this location. The snow survey sampling was conducted in April for this year.
- **2010:** All twelve permanent dust gauges were sampled quarterly during 2010. Snow survey sampling was conducted throughout the month of April. An error in the collection or processing of samples resulted in two missing stations for the snow-water chemical analysis. The sample from station SS2-1 was compromised during processing in the lab, and the data collection at station SS5-2 was missed in the field.
- **2011:** All twelve permanent dust gauges were sampled quarterly during 2011. No data were collected at station Dust 5 in September due to a compromised sample following repairs to the sampler.

  Snow survey sampling was conducted throughout the month of April; however, samples from stations SS1-4, SS1-5, SS2-1, SS2-2, SS2-3, SS2-4 and SSC-3 arrived at the Maxxam laboratory past the recommended holding time.

- **2012:** All twelve permanent dust gauges were sampled quarterly during 2012. A sample was not collected from Station Dust 9 in June, because the sampler was found on its side. Snow survey sampling was conducted on April 30 and on May 4 and 5.
- **2013:** All twelve permanent dust gauges were sampled quarterly during 2013. Snow survey sampling was conducted from April 26 to April 29.

3.2 Methods

3.2.1 Data Sources

Three dust-related measurements related to the AEMP are collected at the Mine to assess potential impacts to the environment:

- seasonal dustfall gauge measurements of dust deposition rates ("dustfall gauge") measured at 10 exposure stations (Dust 1 to Dust 10) and at two reference stations (controls) (Dust C1 and Dust C2) (Figure 3-1);
- annual snow survey measurements of dust deposition rates to the snowpack ("snowdust") at 24 stations along five transects (SS1 to SS5) and at three reference stations (SSC1, SSC-2 and SSC-3) (Figure 3-1); and
- annual snow water chemistry analysis ("snow chemistry") on samples collected at the 17 stations located on ice along five transects (SS1 to SS5) and at three reference stations (SSC1, SSC-2 and SSC-3) (Figure 3-1).

Dustfall gauge, snowdust and snow chemistry data for years 2002 through 2013 were obtained from DDMI. Meteorological data used for the analysis of the dust data consisted of the on-site meteorological data previously reported by Golder (2011a) and ERM Rescan (2014).

3.2.2 Data Analysis

Dustfall gauge and snowdust data were analyzed in MATLAB, version 8.0 for Windows (MathWorks, Inc., Natick, Massachusetts). The objectives of the analysis were:

- to estimate the background rate of dust deposition;
- to determine if there are temporal trends in the rates of dust deposition (e.g., seasonal trends, annual trends);
- to determine if there are spatial trends in the rates of dust deposition; and
- to use the dust deposition rate data to evaluate snow chemistry data.

The background rate of dust deposition was estimated from both dustfall gauge data (Dust C1 and Dust C2 gauges) and snow data (snowdust survey locations SSC-1, SSC-2 and SSC-3). The background deposition rate was calculated as the geometric mean dust deposition rate (and 1-σ range) based on pooled data from both sampling devices, across all years of data (2004 to 2013).

Seasonal trends in dust deposition recorded at the dustfall gauges were evaluated based on a visual inspection of the data. Annual trends in dust deposition were evaluated using linear regression analysis.

A combined spatial-temporal analysis of the dustfall gauge and snowdust data was also completed. First, seasonal dustfall gauge data were aggregated into annual dust deposition rates, expressed in milligrams per square decimetre per year (mg/dm^2/year), to form a time-basis consistent with the annual snowdust measurements of dust deposition rates. Dustfall and snowdust data were then grouped into four-year temporal periods: 2002 to 2005, 2006 to 2009, and 2010 to 2013. Dust deposition rates were plotted against both the distance (in km) from the geographic centre of the Mine (i.e., the centroid shown in Figure 3-1) and the distance from the Mine boundary. Trends in dust deposition as a function of distance from the centroid and from the Mine boundary were fit using a first-order decay function, whose goodness-of-fit was evaluated using the coefficient of determination (r^2) from the least-squares regression. The 95% confidence intervals of the fit to a first order decay were also computed and displayed.

Analysis of the snow water chemistry data followed a similar procedure, but was informed by the results of the dust deposition analysis. Chemistry results from reference snowdust sampling locations were pooled with snow chemistry results from stations whose rates of dust deposition were identified as background, to group the data into "background" and "non-background" groups. Results for a subset of nutrient and metals data were compared, their statistics summarized and their concentrations as a function of distance from the Mine boundary were presented.

In addition to the above analyses, dust deposition rates (from both dust gauges and snowdust samples) were compared statistically between reference stations and exposed stations, to evaluate whether areas closer to the Mine experience deposition rates that differ from background values. As part of these comparisons, the reference stations were also compared to one another.

Before statistical testing, dustfall gauge, snowdust and snow chemistry data were pre-screened using a Lilliefors test, which is a two-sided goodness-of-fit test suitable for determining if the dust data are normally distributed (an assumption of data used in parametric statistical testing). Data that were not normally distributed were $\log_{10}$ transformed and re-tested for normality. Potential analytical errors and/or statistical outliers were identified during data screening by centering and scaling the data and then computing the "z-score", or relative distance from the mean, for each data point. Results indicating a z-score less than -3 or greater than +3 (i.e., farther than three standard deviations from the mean) were excluded from further analysis. This approach was primarily applied to results for background stations. Statistical tests were carried out at the 95% level of confidence (i.e., $\alpha = 0.05$).

Dust deposition rates at exposure dustfall gauge and snowdust sampling locations were compared to deposition rates observed at the reference locations using a two-tailed Student's *t*-test. This statistical method is used to determine which, if any, non-control dustfall gauge and snowdust locations have dust deposition rates that are statistically significantly different from the rates observed at the control locations. Where dustfall or snowdust data were significantly different from the control values, they were presumed to have been impacted by Mine activity. Conversely, where they were indistinguishable from control, dust deposition rates are presumed to be equivalent to "background" rates of dust deposition.

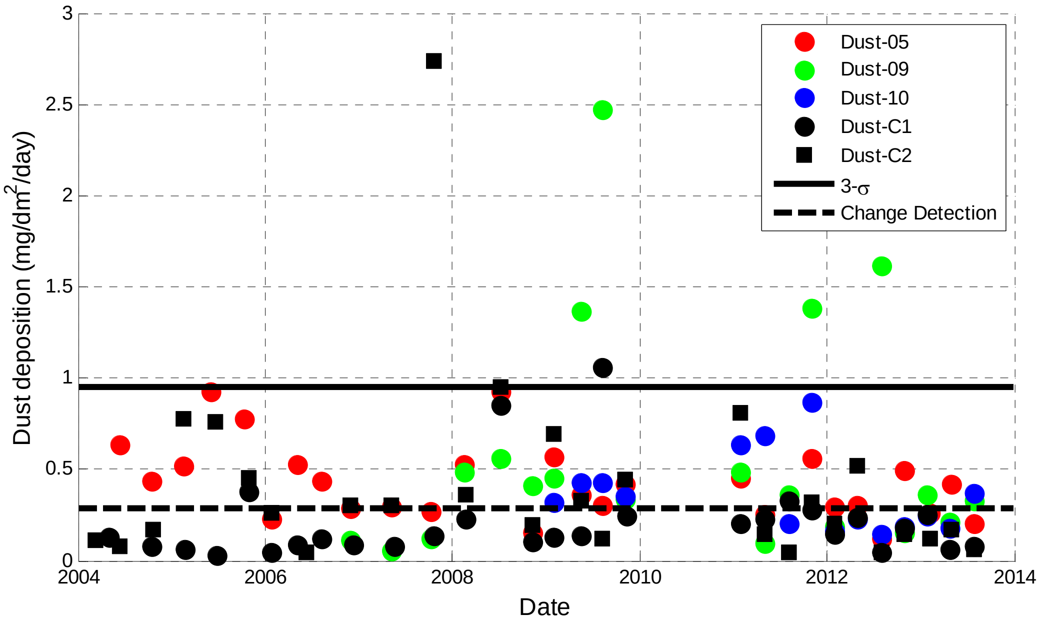
3.3 Results

3.3.1 Background Dust Deposition Rate

3.3.1.1 Dustfall Gauges

Dustfall gauges Dust C1 and Dust C2 are controls installed at reference locations where dust deposition values are expected to be indistinguishable from regional background values. The observations from gauges Dust C1 and C2, along with data from stations Dust 05, Dust 09 and Dust 10, are plotted in Figure 3-2.

Figure 3-2 Summary of Background Dust Deposition Rates for Selected Dustfall Gauges



Notes: 3-σ = three standard deviations of the geometric mean; “Change Detection” indicates the average dust deposition rate above which there is a 90% probability that average deposition rates are significantly different than background values estimated from rates observed at dustfall gauges Dust C1 and Dust C2. Data point from 2004 gauge DUST 05 (15.6 mg/dm^2/day is outside the scale and is not shown.

The dust deposition rate of 2.74 milligrams per decimetre squared per day (mg/dm^2/day) recorded at gauge Dust C2 in late 2007 appears to be an outlier (z-score = 2.7). It is likely that the data point is erroneous, potentially due to sample contamination (e.g., by insect parts or pollen) or laboratory error. Since the purpose of the Dust C1 and Dust C2 gauges is to estimate background dust deposition rates, this outlier was excluded from further analysis. Except where indicated, the exclusion of this data point does not alter the results of the analysis.

The background rates of dust deposition at Dust C1 and Dust C2 are both log-normally distributed. When evaluated using a two-tailed Student’s *t*-test, the results show that deposition rates at Dust C1 and Dust C2 are indistinguishable from one another. As a result, deposition rates for these two locations were pooled to create a single estimate of the background rate of dust deposition. Average background dust deposition at Diavik from 2004 to 2013 was estimated as 0.18 mg/dm^2/day (or 65 mg/dm^2/year), with a one standard deviation range between 0.07 and 0.44 mg/dm^2/day. Based on the number of samples (n = 57), power analysis indicates that there is 90% probability that rates greater than 0.29 mg/dm^2/day will be significantly different (P<0.05) than the average deposition rate of 0.18 mg/dm^2/day. This value is shown as "Change Detection" in Figure 3-2.

Average deposition rates (2004 to 2013) from exposure gauges were tested against the deposition rates at the control gauges to determine whether dustfall gauges closer to the Mine experience deposition rates that are indistinguishable from background values. Two stations, Dust 05 and Dust 10, met this criterion. One 2004 sample from gauge Dust 05 recorded a deposition rate of 15.6 mg/dm^2/day, which is off the scale of Figure 3-2. The dust deposition rate at gauge Dust 09 would have been classified as indistinguishable from the background values, had the 2007 outlier from gauge Dust C2 been retained in the analysis. After excluding the Dust C2 outlier, average dust deposition at Dust 09 was found to be significantly (P<0.05) greater than the background rate. Figure 3-2 also illustrates that there are four Dust 09 data points that are greater than three standard deviations (3-σ) from the pooled Dust C1 and Dust C2 deposition rates.

Prevailing wind direction at Diavik is aligned along a northwest to southeast axis (Golder 2011a; ERM Rescan 2014). The Dust 05 and Dust 10 gauges are located northeast and southwest of Project boundary, whereas Dust 09 is due east of the Project. Consistent with the locations of these dust gauges relative to wind direction, the results of the analysis indicate that dust deposition rates at gauges Dust 05 and Dust 10 are indistinguishable from background values measured at Dust C1 and Dust C2; while dust deposited at gauge Dust 09 appears to be occasionally affected by mining activities at Diavik.

3.3.1.2 Snowdust Data

Background rates of dust deposition to snow were estimated from the deposition rates observed at snowdust survey locations SSC-1, SSC-2 and SSC-3. Dust deposition rates observed at these three locations from 2002 through 2013 (n = 34) were log-normally distributed, with an average rate of 44 mg/dm^2/year (or 0.12 mg/dm^2/day) and a one standard deviation range of between 17 and 112 mg/dm^2/year. Two outliers were excluded from the mean calculation (a deposition rate of 461 mg/dm^2/year recorded at station SSC-3 in 2004 with a z-score of 3.2, and a rate of 526 mg/dm^2/year recorded at station SSC-1 in 2007 with a z-score of 2.9).

Snowdust transects SS1, SS2 and SS4 include continuous annual data since 2002 (station n =12). Transect SS3 has continuous data at stations SS3-4 and SS3-5 since 2002 (station n = 12), but snowdust measurements at SS3-1, SS3-2 and SS3-3 were discontinued in 2008. Data from snowdust stations SS3-1, SS3-2 and SS3-3 are not considered in this analysis. Transect SS5 was added in 2007 and has continuous data through 2013 (station n = 7).

According to results of a two-tailed Student's *t*-test, the following snowdust stations had significantly greater (P<0.05) rates of dust deposition than the control stations (Figure 3-3):

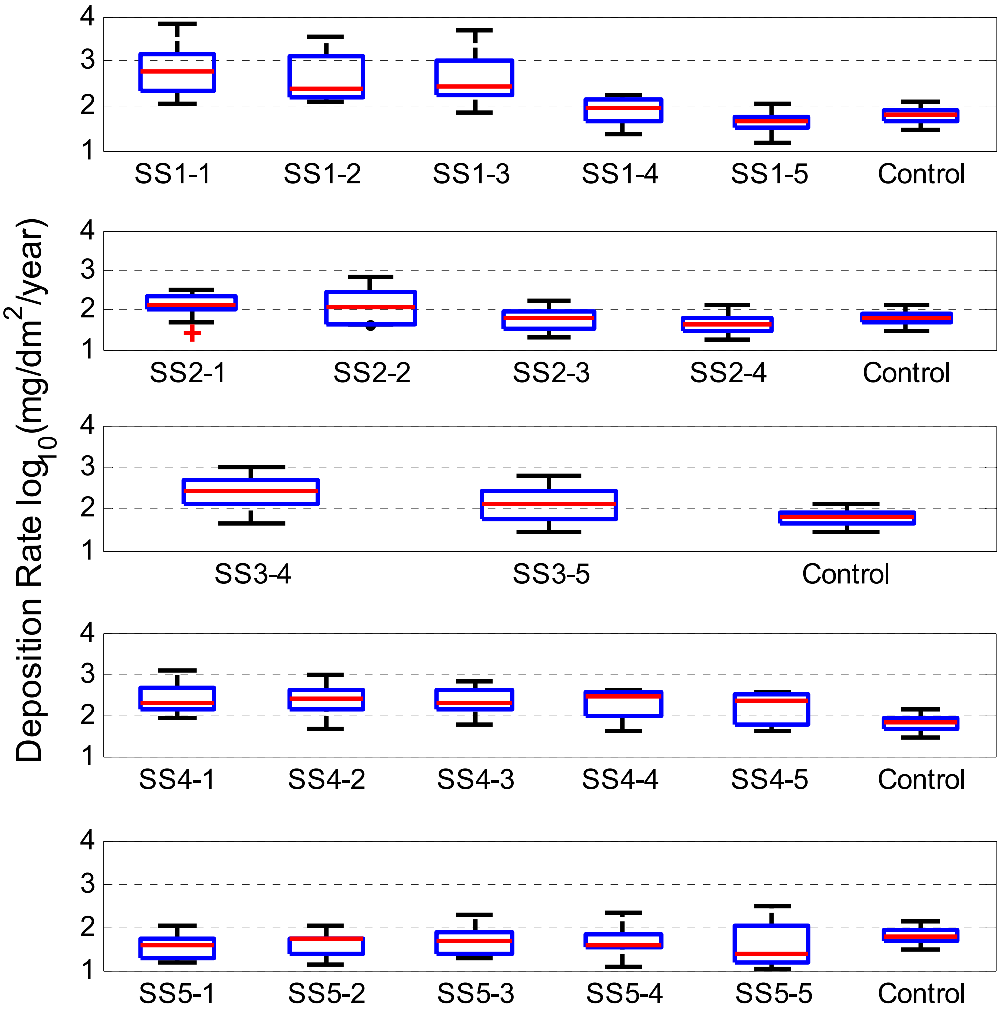
- SS1-1, SS1-2, SS1-3;
- SS2-1, SS2-2;

- SS3-4, SS3-5; and
- SS4-1, SS4-2, SS4-3, SS4-4 and SS4-5.

The results for all the stations with significantly greater dust deposition rates are robust, except for Station SS2-2. If the potential outliers from the control stations SSC-1 in 2004 and SSC-3 in 2007 were retained in the reference station data, then statistical testing would have found station SS2-2 to have a dust deposition rate indistinguishable from the rate at the background locations.

Results for each snowdust survey transect are illustrated graphically, as box and whisker plots in Figure 3-3. Log_{10} transformed dust deposition rates are plotted in this figure, such that the median value is indicated by a red line, the 25th to 75th percentiles are encompassed by the blue box, the 95% confidence intervals are shown by the black bars, and an outlier data point is identified by a red cross.

Figure 3-3 Box-and-Whisker Plot of Dust Deposition Rates Along the Five Snowdust Transects.



Note: Data were $\log_{10}$-transformed. See text for explanation of box and whisker plots.

The snowdust results are generally consistent with the seasonal dust fall gauge data. For example:

- The average background dust deposition rate calculated from snowdust survey data was 0.12 mg/dm^2/day, compared to 0.18 mg/dm^2/day based on dustfall gauge data. The data have the same variance and the means are indistinguishable when tested using a two-tailed student's t-test (P=0.013).
- Stations SS1-4 and SS1-5 are north-northeast of the Project Boundary and closest to dust gauge Dust 05, a dustfall gauge where dust deposition rate was found to be indistinguishable from the background rate.
- Stations SS2-2 through SS2-4 are northeast of the project boundary and lie between gauges Dust 05 and Dust 09, locations with dust deposition rates either indistinguishable from background rates or infrequently affected by dust generated at the Mine.
- Stations along transect SS5 are mostly south of dustfall gauge Dust 10, a gauge with dust deposition rates that cannot be distinguished from the background rate of dust deposition.

3.3.2 Temporal Trends

Only one dustfall gauge showed a seasonal trend in dust deposition rates: station Dust 01, located just north of the Diavik airport's runway. The seasonal nature of dust deposition at this location is potentially linked to reduced potential for aircraft to create dust in winter (i.e., when land adjacent to the runway is frozen or snow covered). The average dust deposition at Dust 01 is 1.0 mg/dm^2/d in winter, but increases to 2.5 mg/dm^2/d in summer.

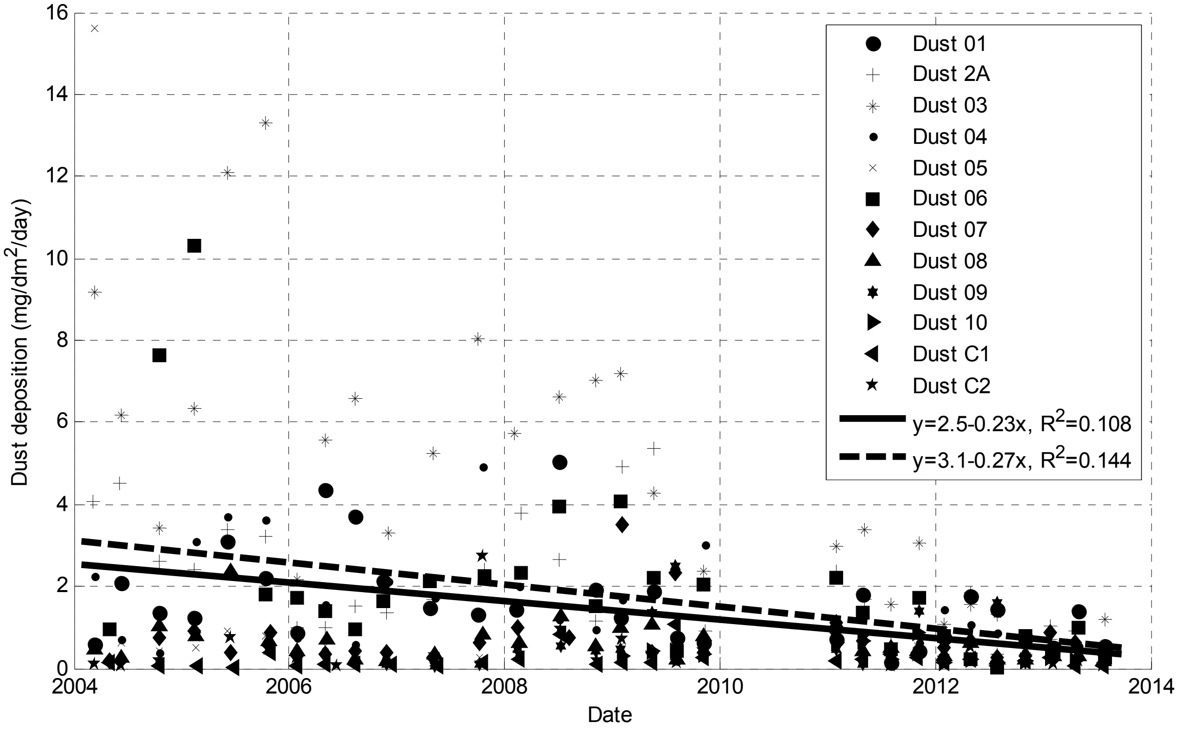
When considering all dustfall gauge data from 2004 to 2013, there appears to be a decreasing trend in the rate of dust deposition over the past 10 years (Figure 3-4). The rate of decrease is approximately -0.23 to -0.27 mg/dm^2/day per year. However, this relationship is weak (r^2 = 0.108), even when gauges with background rates of dust deposition (i.e., Dust 05, Dust 10, Dust C1 and Dust C2) are excluded from the regression analysis (r^2 = 0.144).

The low coefficients of determination for the apparent decreasing trend in dust deposition could have several causes. For example:

- not all measurement locations may have experienced equivalent reductions in dust deposition;
- seasonal and inter-annual meteorological variability could be contributing to spatial-temporal differences in dust deposition over time; and
- although dust deposition rates have been decreasing, their rate of decrease has not been constant.

In addition to the above considerations, the relative distances of the dustfall gauges to the dust sources on-site are not equal, and both mining intensity and location of developments within the mining footprint have changed over time. Thus, changing rates of dust deposition over time need to be evaluated in conjunction with analysis of the dustfall gauge's location, i.e., using spatial-temporal analysis. This analysis is presented in the next section.

Figure 3-4 Linear Regression of Dust Deposition Rates as a Function of Year



Note: solid line represents regression analysis which considers all dustfall gauge locations; dashed line represents regression analysis when dustfall gauges with background rates of dust deposition (i.e., Dust 05, Dust 10, Dust C1 and Dust C2) excluded.

Spatial-temporal Analysis of Dust Deposition

Seasonal dustfall gauge data were aggregated into annual values so that their time-base is consistent with that of the snowdust data. Data from each station were then averaged into three temporal bins spanning the time periods 2002 to 2005, 2006 to 2009, and 2010 to 2013. These temporal bins were selected based on the dominant type of mining activities occurring on site at that time. These activities include the following: 2002 to 2005 open pit mine construction and open pit mining; 2006 to 2009 underground mine construction and open pit mining; 2010 to 2013 open pit and underground mining.

Figure 3-5 plots dust deposition rates as a function of distance from the centroid of the Mine (i.e., centre of the Mine footprint), whereas Figure 3-6 plots the dust deposition versus distance from the Mine Boundary. Results of the fit to a first-order decay function are plotted as solid lines along with the 95% confidence intervals as dashed lines. Equations for the fit and the r^2 values are included as text within each sub-plot.

The first order decay function resulted in a more robust fit with respect to the distance from the centroid of the Mine (r^2 = 0.632 to 0.825) than as a function of distance from the Mine boundary (r^2 = 0.509 to 0.661). This is likely due meteorological variability, in particular, wind speed and direction. Local meteorology will tend to smooth seasonal and annual deposition rates to all locations within and around the Mine, but it can enhance local deposition at measurement locations closest to the dust sources (e.g., Dust 01 is close to airport, and Dust 02 and Dust 06 are close to the mining pits).

Figure 3-5 First-Order Decay Estimates of Dust Deposition as a Function of Distance From the Centre of the Mine Footprint (Top Panel: 2002 To 2005; Middle Panel: 2006 To 2009; Bottom Panel: 2010 To 2013)

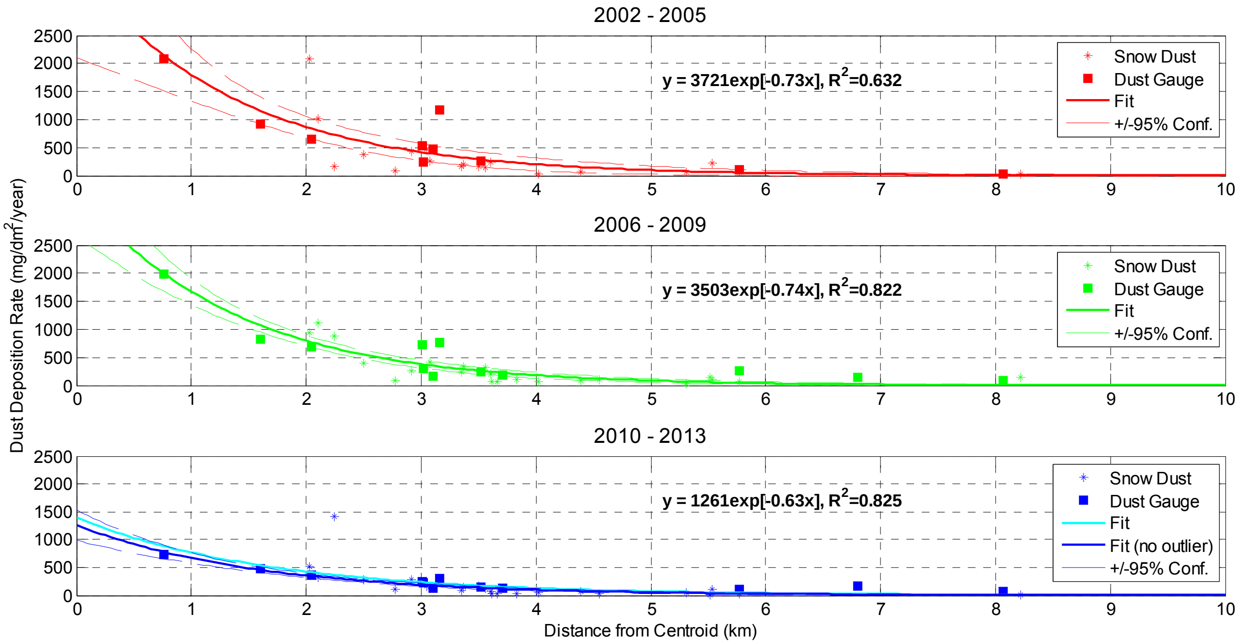
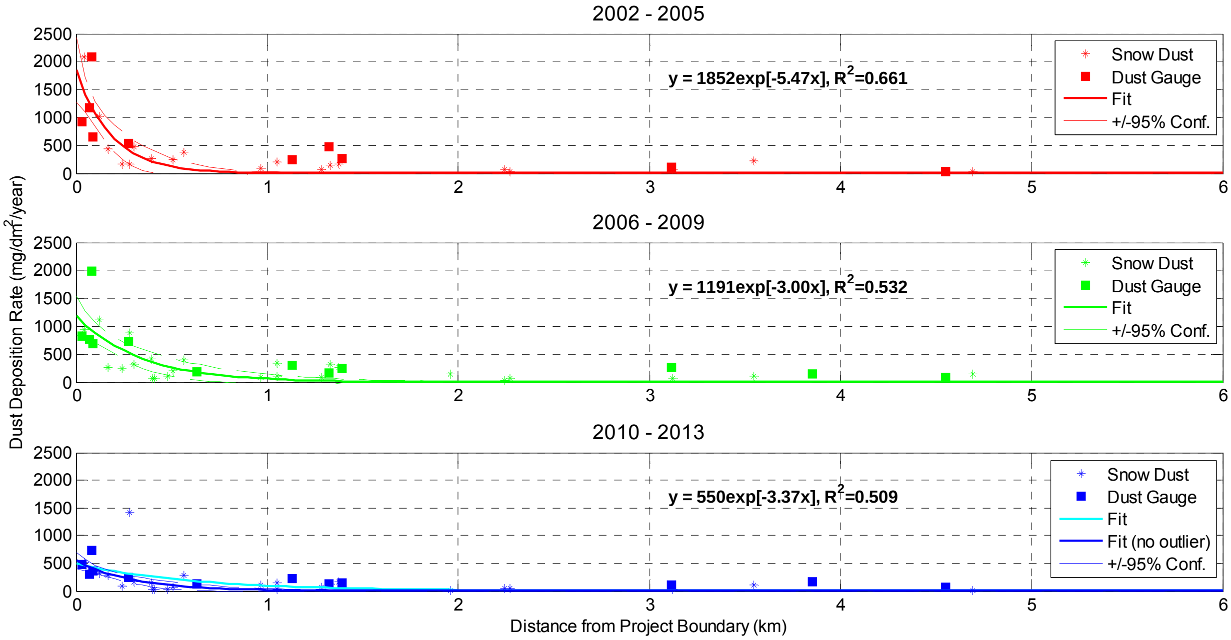


Figure 3-6 First-Order Decay Estimates of Dust Deposition as a Function of Distance From the Mine Boundary (Top Panel: 2002 To 2005; Middle Panel: 2006 To 2009; Bottom Panel: 2010 To 2013)



The top panel of Figure 3-5 suggests that there is one snowdust (SS1-1) and one dustfall location (Dust06) that have higher rates of dust deposition compared to other locations. The high 2002 to 2005 snowdust value is being driven by the 2005 SS1 transect data, which are elevated at snowdust sampling locations SS1-1 through SS1-3. Dust deposition rates at dustfall gauge Dust 06 were consistently elevated during the 2002 to 2005 averaging period. It appears that the elevated SS1-1 and Dust 06 results during the 2002 to 2005 period are valid, as these locations are close to the Mine boundary; therefore, they do not appear to be outliers when plotted in Figure 3-6.

Similarly, the bottom panel of Figures 3-5 and 3-6 indicate that dust deposition rates at snowdust location SS1-3 is unusually high. This temporal average is driven by a single dust deposition value of 4,851 mg/dm^2/year recorded at SS1-3 in 2012. This value is more than 28 times higher than the average deposition rate for all dustfall gauges and snowdust measurements. This deposition value is almost certainly an error (z-score=3.0), and it was eliminated from the SS1-3, 2010 to 2013 temporal average and the first-order decay function results plotted in Figures 3-5 and 3-6.

The background rate of dust deposition from the dustfall gauges was calculated to be 65 mg/dm^2/year (0.18 mg/dm^2/day), whereas the background snowdust deposition rate was determined to be 44 mg/dm^2/year (0.12 mg/dm^2/day). These data were pooled, along with dustfall gauges (Dust 05 and Dust 10) and snowdust stations (SS1-4 and -5; SS2-3 and -4; SS5-1, -2, -3, -4 and -5) that were statistically indistinguishable from background values (Section 3.3.1). This resulted in a composite 2002 to 2013 geometric mean dust deposition rate (and 1-σ range) of 60 mg/dm^2/year (24 to 149 mg/dm^2/year), or 0.16 mg/dm^2/day.

Using a dust deposition rate of 150 mg/dm^2/year (i.e., the geometric mean plus one standard deviation) as the threshold above which dust deposition rates are likely to be significantly above the background rates of deposition, the regressions in Figures 3-5 and 3-6 were used to estimate the Mine's zone of influence with respect to dust deposition (Table 3-1). Based on this spatial-temporal analysis of the Diavik data, the following conclusions may be drawn:

- Estimates of dust deposition rates at the Mine boundary have declined over time, for example:
    - 1,850 mg/dm^2/year for the 2002 to 2005 period;
    - 1,190 mg/dm^2/year for the 2006 to 2009 period; and
    - 550 mg/dm^2/year for the 2010 to 2013 period.
- Between 2002 and 2009, dust deposition rates beyond approximately 500 to 700 metres from the Mine boundary were, on average, indistinguishable from background values.
- From 2009 to 2013, dust deposition rates beyond approximately 400 metres from the Mine boundary were, on average, indistinguishable from background values.

Table 3-1 Length of the Zone of Influence of the Diavik Diamond Mine on Dust Deposition

Temporal Period	Zone of Influence[(a)] (from Centroid)	Zone of Influence[(a)] (from Mine Boundary)
2002 to 2005	4.4 km	460 m
2006 to 2009	4.2 km	690 m
2010 to 2013	3.4 km	385 m

a) Zone of influence was defined as the intersection between one standard deviation greater than the geometric mean of background rates of dust deposition (150 mg/dm^2/year) and the predicted decay rate of dust deposition with distance (Figures 3-5 and 3-6).

3.3.3 Snow Chemistry

To be consistent with the four-year groupings used in the foregoing dust deposition analysis, the snow melt chemistry analysis focussed on the last four years of data. Two different laboratories were used to analyze the snow water chemistry during the 2010 to 2013 period. ALS Environmental (ALS), in Edmonton, Alberta, was analyzed samples collected in 2010, and Maxxam Analytics (Maxxam) in Burnaby, British Columbia, analyzed samples collected in 2011 to 2013. Maxxam provided lower reportable detection limits for the elements analyzed in this study.

Chemical analysis of snow water chemistry from 2010 through 2013 was undertaken for snow samples collected at the following locations:

- SS1-4, SS1-5;
- SS2-1, SS2-2, SS2-3, SS2-4;
- SS3-4, SS3-5;
- SS4-4, SS4-5;
- SS5-3, SS5-4, SS5-5; and
- SSC-1, SSC-2, SSC-3

A subset of the snow water chemistry results were analyzed after grouping them into nutrients and metals. The nutrients and metals selected for analysis are those of potential concern for soil and water quality. Snow chemistry results for nutrients (ammonia [NH_3], nitrate plus nitrite [NO_3^- + NO_2^-] and total phosphorus [TP]) and metals (aluminum [Al], arsenic [As], cadmium [Cd], chromium [Cr], copper [Cu], lead [Pb], and Zinc [Zn]) were analyzed to determine whether there were significant differences in the concentrations of these elements in snow sampled from background versus exposure locations. Here background locations refer to snow survey control locations (i.e., SSC-1, SSC-2, SSC-3) as well as snow survey locations where the rates of dust deposition were indistinguishable from background rates of dust deposition observed at control stations (i.e., SS1-4 and -5; SS2-3 and -4; SS5-3, -4 and -5; Section 3.3.1). Differences were tested with a two-tailed Student's *t*-test on untransformed data.

3.3.3.1 Nutrients

The concentrations of TP in snow from exposure stations were higher than concentrations observed in snow sampled at the background stations (Table 3-2). Concentrations of NH_3 were significantly greater (*P*=0.003) at exposure stations than observed at the background stations (Table 3-2). Concentrations of NO_3^- + NO_2^- were indistinguishable between exposure and background stations (*P*=0.945). The concentrations of TP in snow from exposure stations were indistinguishable (*P*=0.068) from concentrations observed in snow sampled at the background stations (Table 3-2).

When plotted as concentration versus distance from the Mine boundary (Figure 3-7, top panel) snow water NH_3 concentrations appear somewhat greater closer to the Mine, despite background and exposure concentrations being statistically similar. Closer examination of the NH_3 data reveals that all snow water concentrations within 1.5 km of the Mine boundary (63 ± 31 µg/L) are significantly greater than concentrations observed beyond 1.5 km from the Mine (44 ± 23 µg/L) (Table 3-2). This indicates that ammonia emissions from the Mine are associated with other sources in addition to dust (dust deposition was above background to only about 400 m from the Mine boundary). As a basic gas, NH_3 will tend to react with acidic gases generated from combustion sources (McNaughton et al. 2009), and/or it can dry deposit directly to the snow surfaces without prior interaction with particulate matter. Compared to previous years, the 2013 median concentrations at exposure stations were relatively low (ERM Rescan 2014).

The greater average TP concentration at exposure stations was being driven by a concentration of 355 µg/L recorded at Station SS3-4 in 2010 (Figure 3-7). When this potential outlier (z-score = 4.6) is eliminated from the Student's *t*-test, the average exposure concentration of TP is greater than the average background concentration. The results of the Student's *t*-test indicate these differences are no longer significant (*P*=0.068; Table 3-2). The variability in the data, however, was relatively high and likely explains that lack of significance in the test. The TP data do show an apparent trend with distance (Figure 3-7), which likely reflects phosphorus associated with dust-related emissions. Compared to previous years, the 2013 median TP concentrations at exposure stations were relatively low (ERM Rescan 2014).

Total loadings of phosphorus to Lac de Gras from dust were calculated based on 2012 dust gauge and snow core monitoring data (Golder 2014a). Although the total loading of phosphorus from dust was greater than it was from effluent, the phosphorus entering the lake via dust does so as a pulse during the spring melt, and then intermittently over the four open-water months. Phosphorus that has accumulated in snow over an eight-month period will enter the lake as snow-melt water. Compared to the concentration of phosphorus in snowmelt water, the concentration in the effluent is greater.

The form of phosphorus is an important factor to consider when assessing effects. Approximately 40% of phosphorus in effluent is dissolved inorganic phosphorus (measured as SRP), the form that is readily assimilated by algae. The proportion of SRP in snow-melt water is approximately 12%. Dust does not contain any dissolved phosphorus. Furthermore, SRP concentrations in effluent are approximately an order of magnitude greater compared to snow-melt water, and input from effluent is continuous. Hence, a confounding effect from dust is not being observed because of the type of input (diffuse or non-point source) and the form of phosphorus (mainly particulate) in dust. When compared to the mass load of phosphorus from the watershed, some of which would be in the dissolved state, one would not expect dust to change the concentration of phosphorus in Lac de Gras.

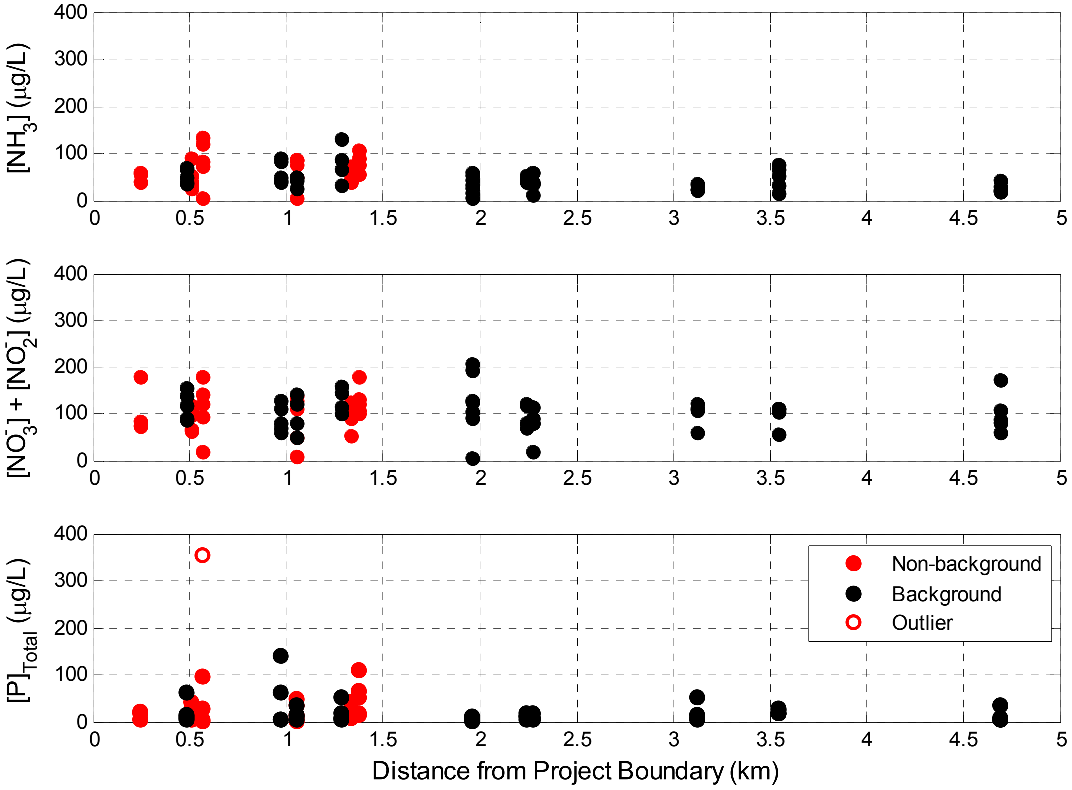
Table 3-2 Summary of Snow Water Nutrient Concentrations (µg/L)

Nutrient	Location	*n*	Mean	Standard Deviation	Minimum	Maximum	t-test Result (*P*-value)
Ammonia	Background	49	44	23	<5	130	Distinct (*P*=0.003)
	Exposure	27	63	31	<5	133	
Nitrate plus Nitrite	Background	49	103	39	6	207	Indistinguishable (*P*=0.945)
	Exposure	27	104	43	9	180	
Total Phosphorus	Background	49	18	23	<2	139	Indistinguishable[(a)] (*P*=0.068)
	Exposure	27 (26)[(a)]	40 (28)	69 (28)	<2	355 (110)	

a) Numbers in parentheses are values with an outlier removed.

n = number of samples; <= less than the detection limit shown.

Figure 3-7 Concentration (µg/L) of Nutrients (Ammonia [NH_3], Nitrate plus Nitrate [NO_3^- + NO_2^-] and Total Phosphorus [P_{total}]) in Snow Water versus Distance from the Mine Boundary



3.3.3.2 Metals

Table 3-3 summarizes results of the analysis of metals in snow water, including the results of Student's t-tests comparing the concentrations observed at the exposure stations versus concentrations measured at the background stations. The concentration of most metals observed in snow from exposure locations was significantly higher than in snow collected at background locations. The exceptions were the following:

- zinc, for which the difference in concentration in snow between the two locations was non-significant and likely due to a single outlier in the background data;
- cadmium, for which the concentrations differed, but there is a 4.3% chance the concentrations could be equal due to high variance in the observed background concentrations; and
- copper, for which the concentrations differed, but there is a 4.8% chance the concentrations could be equal due to high variance in the observed background concentrations.

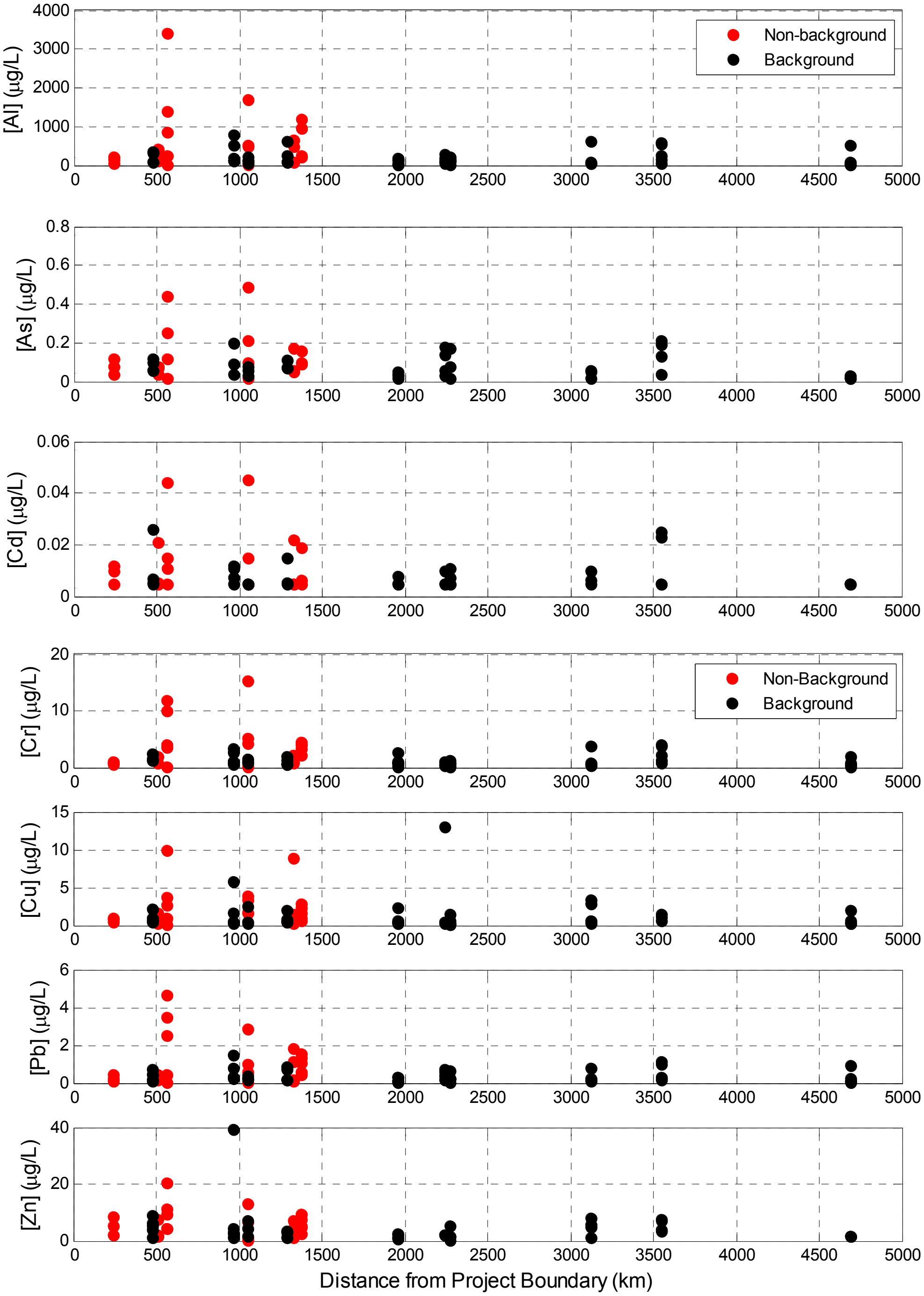
Metals concentrations in snow sampled at exposure locations often had values comparable with the background concentrations, but they were punctuated by a few results with higher concentrations (Figure 3-8). This observation is consistent with the interpretation of dust deposition rates and suggests that dust deposition events are episodic in nature, depending on mining intensity as well as local meteorology (e.g., prevailing wind speed and direction when dust was being generated). Compared to previous years, the 2013 median concentrations of metals at exposure stations were relatively low (ERM Rescan 2014).

Table 3-3 Summary of Snow Water Metal Concentrations (µg/L)

Nutrient	Location	*n*	Mean	Standard Deviation	Minimum	Maximum	t-test Result (*P*-value)
Aluminum	Background	49	188	190	2.6	788	Distinct (*P*=0.001)
	Exposure	27	559	727	0.6	3400	
Arsenic	Background	36	0.08	0.06	<0.02	0.21	Distinct (*P*=0.003)
	Exposure	21	0.13	0.13	<0.02	0.49	
Cadmium	Background	36	0.008	0.001	<0.005	0.026	Distinct (*P*=0.043)
	Exposure	21	0.013	0.012	<0.005	0.045	
Chromium	Background	49	1.2	1.0	0.09	4.1	Distinct (*P*<0.001)
	Exposure	27	3.2	3.7	<0.05	15.2	
Copper	Background	44	1.2	2.1	<0.05	13.1	Distinct (*P*=0.048)
	Exposure	27	2.0	2.4	<0.05	10.0	
Lead	Background	49	0.36	0.32	<0.005	1.48	Distinct (*P*<0.001)
	Exposure	27	0.98	1.17	<0.005	4.65	
Zinc	Background	40	4.2	6.1	<0.1	39.1	Indistinguishable (*P*=0.28)
	Exposure	25	5.7	4.6	0.4	20.6	

n = number of samples; <= less than the detection limit shown.

Figure 3-8 **Concentration (µg/L) of the Metals (Aluminum [Al], Arsenic [As], Cadmium [Cd], Chromium [Cr], Copper [Cu], Lead [Pb], and Zinc [Zn]) in Snow-melt Water versus Distance from Mine Boundary**



3.3.4 Comparison to EA Predictions

Overall, deposition rates of dust measured since 2001 have exceeded those predicted by the modelling in the EA (Table 3-4) (DDMI 1998b). The predictions were based on ambient air quality criteria at the time and did not take into account construction periods, which increased during the 2005 monitoring season and continued through 2006 to 2010. These were the periods in which the highest deposition rates were generally measured.

Direct comparison between the EA predictions and the dustfall observations is not necessarily appropriate for the following reasons:

1) Dustfall gauges and snow samples are often subject to contamination by non-dust material; for example, by insect parts and pollen.
2) The sample analysis employed by the laboratory makes no distinction between total dust, volatile dust and fixed dust. The volatile portion of dust refers to sulfate, nitrate and organic aerosol wet- and dry-deposited with or onto snow and into the dustfall gauges. The most appropriate means of comparing mineral dust deposition rates is to fixed dust, not total dust; the available laboratory data are for total dust deposition, not fixed dust deposition.
3) Strictly speaking, EA predictions of fugitive mineral dust should be compared to measurements of fixed dust, not total dust. Even so, EA predictions will be highly dependent on assumptions regarding the dust emissions rates, and the assumed mass distribution of the dust being generated.
4) There are no reliable peer-reviewed scientific estimates of background total or fixed dust deposition for this environment. As a result, there is no way to independently confirm whether or not the “background sites” are recording values comparable to expected background values.

Measured dust deposition rates from the reference locations further indicate inaccuracies in the original dust emissions modelling. Higher than predicted deposition values at all three control sites may indicate that naturally-occurring dust rates may be higher than originally estimated. Alternatively, this may suggest that mine-related dust-generating activities not identified during modelling may have been impacting a broader area than originally predicted. Dustfall deposition rates were expected to drop as construction activities decreased and the focus of operations switched to underground mining. In September 2012 mining of the A418 pit was completed and mining operations at Diavik are now completely underground.

Table 3-4 Predicted and Calculated Annual Dustfall Deposition Rates for Dust Gauges, 2002 to 2013

Dust Gauge	EA[a] (mg/dm^2/y)	Observed Dustfall Deposition (mg/dm^2/y)											
		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Dust 01	50	905	308	514	834	1051	521	774	420	501	281	430	262
Dust 02	100	464	797	1299	1118	444	748	953	1162	1023	481	285	155
Dust 03	100	810	1415	2062	4046	1605	2345	2335	1672	1169	995	430	315
Dust 04	20	369	179	338	1283	519	1195	500	686	257	210	371	122
Dust 05	40	113	47	1433	279	136	103	245	155	148	151	110	121
Dust 06	125	—	884	1442	1179	526	799	858	879	561	309	166	175
Dust 07	40	—	131	166	442	134	153	326	563	433	135	157	192
Dust 08	25	—	43	237	524	142	211	338	303	221	127	128	95
Dust 09	15	—	—	—	—	40	31	187	352	93	206	242	102
Dust 10	25	—	—	—	—	—	—	215	137	237	152	31	122
Dust C1	6	—	26	38	52	31	40	199	114	101	95	55	49
Dust C2	12	—	46	46	245	90	549	239	158	130	122	83	67

a) DDMI 1998a.

EA = Environmental Assessment.

3.4 Conclusions

Conclusions from the analysis of dust deposition and snow water chemistry at the Mine are summarized below.

Background Dust Deposition Rate

- The geometric mean background rate of dust deposition was estimated as 60 mg/dm^2/year, with a 1-σ range of 24 to 149 mg/dm^2/year, based on the pooled dustfall gauge and snowdust data collected at reference stations in 2002 to 2013.

Temporal Trends in Dust Deposition Rate

- Only one dustfall gauge showed a seasonal trend in dust deposition rates: station Dust 01, located just north of the Diavik airport's runway. The seasonal nature of dust deposition at this location could be linked to reduced potential for aircraft to create dust in winter.
- Estimates of dust deposition rates at the Mine boundary have shown a reduction from 1,850 mg/dm^2/year for the 2002 to 2005 period to 1,190 mg/dm^2/year for the 2006 to 2009 period, and 550 mg/dm^2/year for the 2010 to 2013 period.

Spatial Trends in Dust Deposition Rate

- Based on data from 2004 to 2013, dust deposition rates at dustfall gauges Dust 05 and Dust 10 were indistinguishable from background values measured at control gauges Dust C1 and Dust C2; dust deposited at gauge Dust 09 appears to be only infrequently affected by mining activities at Diavik.
- Snowdust stations that could not be distinguished from background values (based on the mean of the pooled 2002 to 2013 dust deposition rates) were: SS1-4, SS1-5; SS2-3, SS2-4; and SS5-1 through SS5-5.
- Between 2002 and 2009, dust deposition rates beyond approximately 500 to 700 metres from the Mine Boundary were, on average, indistinguishable from background values.
- From 2009 to 2013, dust deposition rates beyond approximately 400 metres from the Mine boundary were, on average, indistinguishable from background values.

Snow Chemistry

- Concentrations of ammonia and total phosphorus in snow were slightly greater at exposure stations compared to control stations. Concentration gradients in snow as a function of distance from the Mine boundary were also observed. There was evidence that ammonia emissions were not only associated with dust.
- Concentrations of metals measured in snow were significantly higher at exposure stations compared to background stations. However, greater metal concentrations at exposure locations occur only infrequently and are highly variable, likely due to variations in meteorology (e.g., local wind speed and direction). Metal concentrations in snow water have been decreasing over time.
- Compared to previous years, the concentrations of nutrients and metals at exposure stations in 2013 were relatively low and appear to be decreasing.

4 EFFLUENT ASSESSMENT

4.1 Introduction

Effluent and lake water quality data collected in support of the Mine's Surveillance Network Program (SNP) were evaluated to identify temporal trends in the loading rates and concentrations of key variables in the Mine effluent, as well as concentrations at the mixing zone boundary in Lac de Gras. The SNP monitoring period considered in this summary extends from March 26, 2002, when discharge of treated effluent began, to December 31, 2013. The results presented in this chapter will assist in the interpretation of temporal patterns identified in various components of the AEMP.

Treated effluent from the North Inlet Water Treatment Plant (NIWTP) is sampled from both diffusers. Sampling station SNP 1645-18 is for the original diffuser, which discharged continuously to Lac de Gras over the 2002 to 2013 SNP monitoring period. Monitoring station SNP 1645-18B provides data for the second diffuser, which became operational on September 13, 2009. Samples are collected approximately every six days at these stations. In addition to the chemical analysis of these samples, acute and chronic toxicity of samples from both monitoring stations are tested on a quarterly basis.

Water quality samples are collected at the mixing zone boundary at three stations (SNP 1645-19A, SNP 1645-19B/B2, and SNP 1645-19C), located along a semi-circle, approximately 60 m from the effluent diffusers. These stations represent the edge of the mixing zone, which covers an area of approximately 0.01 km^2. Station SNP 1645-19B2 was established in 2009 to replace Station SNP 1645-19B after the second diffuser became active in Lac de Gras. Lake water samples are collected monthly at the mixing zone boundary at each station, at the water surface and at 5-m depth intervals.

4.2 Approach

The temporal assessment of trends in effluent and at the mixing zone boundary focused on the 24 water quality variables that were identified as substances of interest (SOIs) for the 2011 to 2013 re-evaluation period (Section 5.2.2.1), and on key nutrients (nitrogen and phosphorus) examined in the indicators of eutrophication chapter (Section 6). General data handling procedures applied to the SNP data set prior to conducting analyses (e.g., initial screening for anomalous values and treatment of non-detect data) are the same as those described in Section 5.2.2 for the AEMP water quality data set. Initial screening for the effluent and mixing zone data sets was completed separately for each calendar year (2002 to 2013) because concentrations of SOIs and nutrients from the NIWTP often varied from one year to another.

Results of the initial screening for anomalous values for the SNP effluent chemistry (SNP 1645-18 and SNP 1645-18B) and Mixing Zone (SNP 1645-19A, SNP 1645-19B2, and SNP 1645-19C) data sets are presented in Appendix 4A, Tables 4A-1 (effluent) and 4A-2 (mixing zone). In total, 52 anomalous values were identified within the effluent chemistry dataset, and 30 anomalous values were identified within the mixing zone dataset, representing 0.18% and 0.05% of the total data points, respectively. In cases where outliers were identified within the annual data sets, scatter-plots were generated allow review of excluded data (Appendix 4A, Figures 4A-1 to 4A-88).

The analysis of nitrogen in SNP samples (i.e., effluent and mixing zone) did not include total nitrogen (TN) during several years of monitoring, which was analyzed in AEMP samples (i.e., lake water). Consequently, TN was calculated for SNP samples using the following formula:

TN = Total Kjeldahl Nitrogen (TKN) + Nitrate + Nitrite

The effluent was assessed in terms of quantity and quality. Trends in effluent quantity were evaluated graphically by plotting total annual discharge volumes (m^3 per year) and loading rates (kilograms per year) of SOIs and nutrients over time. Loading rates were calculated using the procedure described in the AEMP Study Design Version 3.5 (Golder 2014a). The total annual load of an SOI was estimated as the sum of monthly loads calculated in each year from 2002 to 2013. Three SOIs (specific conductivity, total hardness and turbidity) were excluded from this assessment because load is not a relevant measure for these variables. Annual loads were not calculated for variables with concentrations in effluent that were frequently below the detection limit (DL) (chloride, fluoride and antimony in 2002; soluble reactive phosphorus and chromium from 2002 to 2010; copper from 2008 to 2010; and cadmium and tin from 2002 to 2013)

Scatterplots showing the concentrations of SOIs and nutrients in effluent were generated for 2002 to 2013. Results for individual grab samples were plotted separately for each sampling station (i.e., SNP 1645-18 and SNP 1645-18B [2009 and later]). Water sampling at the mixing zone is completed monthly at 5-m depth intervals at the three stations. Hence, up to 15 samples were collected each month from 2002 to 2013. Results are summarized by showing the 5th percentile, median and 95th percentile concentrations in each month.

The quality of the effluent was assessed by comparing water chemistry results at Stations SNP 1645-18 and SNP 1645-18B with the Effluent Quality Criteria (EQC) defined in the Water Licence (Table 4-1). Unlike other analytes listed, Part H, Item 12 of the Water Licence specifies a discharge criterion for total phosphorus (TP) in terms of load (WLWB 2007). The Water Licence specifies that, during the life of the Mine, the load of TP should not exceed a monthly maximum of 300 kg/month, an annual average of 1,000 kg/yr, and an annual maximum of 2,000 kg/yr.

Finally, Part H, Item 7 of the Water Licence requires characterization of the toxicity of the effluent discharged to Lac de Gras. The results of lethal and sub-lethal toxicity testing carried out on effluent samples from Stations SNP 1645-18 and SNP 1645-18B were summarized from 2002 to 2013. Specific toxicity testing requirements are described in the AEMP Study Design Version 3.5 (Golder 2014a).

Table 4-1 Effluent Quality Criteria for the North Inlet Water Treatment Plant Discharge to Lac de Gras

Variable[(a)]	Units	Maximum Average Concentration	Maximum Concentration of Any Grab Sample
Total ammonia	µg/L	6,000	12,000
Total aluminum	µg/L	1,500	3,000
Total arsenic	µg/L	50	100
Total copper	µg/L	20	40
Total cadmium	µg/L	1.5	3
Total chromium	µg/L	20	40
Total lead	µg/L	10	20
Total nickel	µg/L	50	100
Total zinc	µg/L	10	20
Nitrite	µg/L	1,000	2,000
Total suspended solids	mg/L	15	25
Turbidity	NTU	10	15
Biochemical oxygen demand	mg/L	15	25
Oil and grease	mg/L	3	5
Fecal coliforms	CFU/100 mL	10	20

Source: WLWB 2007

a) The water licence also specifies that the effluent pH must be between 6.0 and 8.4.

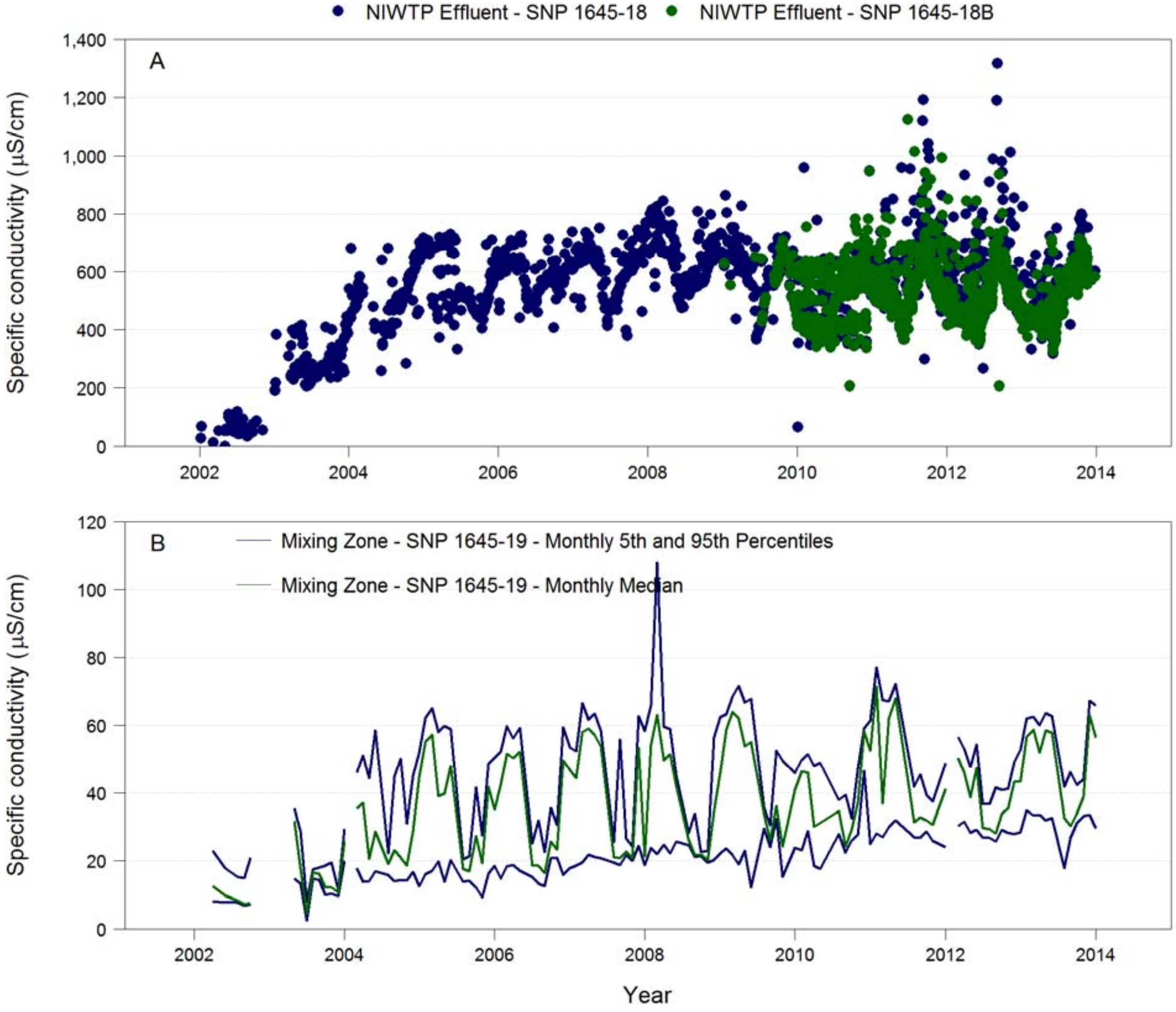
NTU = nephelometric turbidity unit; CFU = colony forming unit.

4.3 Temporal Trends in Treated Effluent and at the Mixing Zone Boundary

4.3.1 Conventional Parameters

The specific conductivity and total hardness of the effluent discharged from the NIWTP increased over time from 2002 to approximately 2005, and has remained in a similar seasonal range since that time (Figures 4-1 and 4-2). Conductivity was more variable in the last three years, compared to previous years. The turbidity of the effluent peaked during the first two years of operation (2002 to 2003) but declined gradually over the remainder of the monitoring period (Figure 4-3). At the mixing zone boundary, the conductivity and hardness of the water has become less variable over time and has remained in the same general range. Turbidity values at the mixing zone boundary were initially elevated, reflecting the increased values in effluent, but have remained with a similar seasonal range since that time.

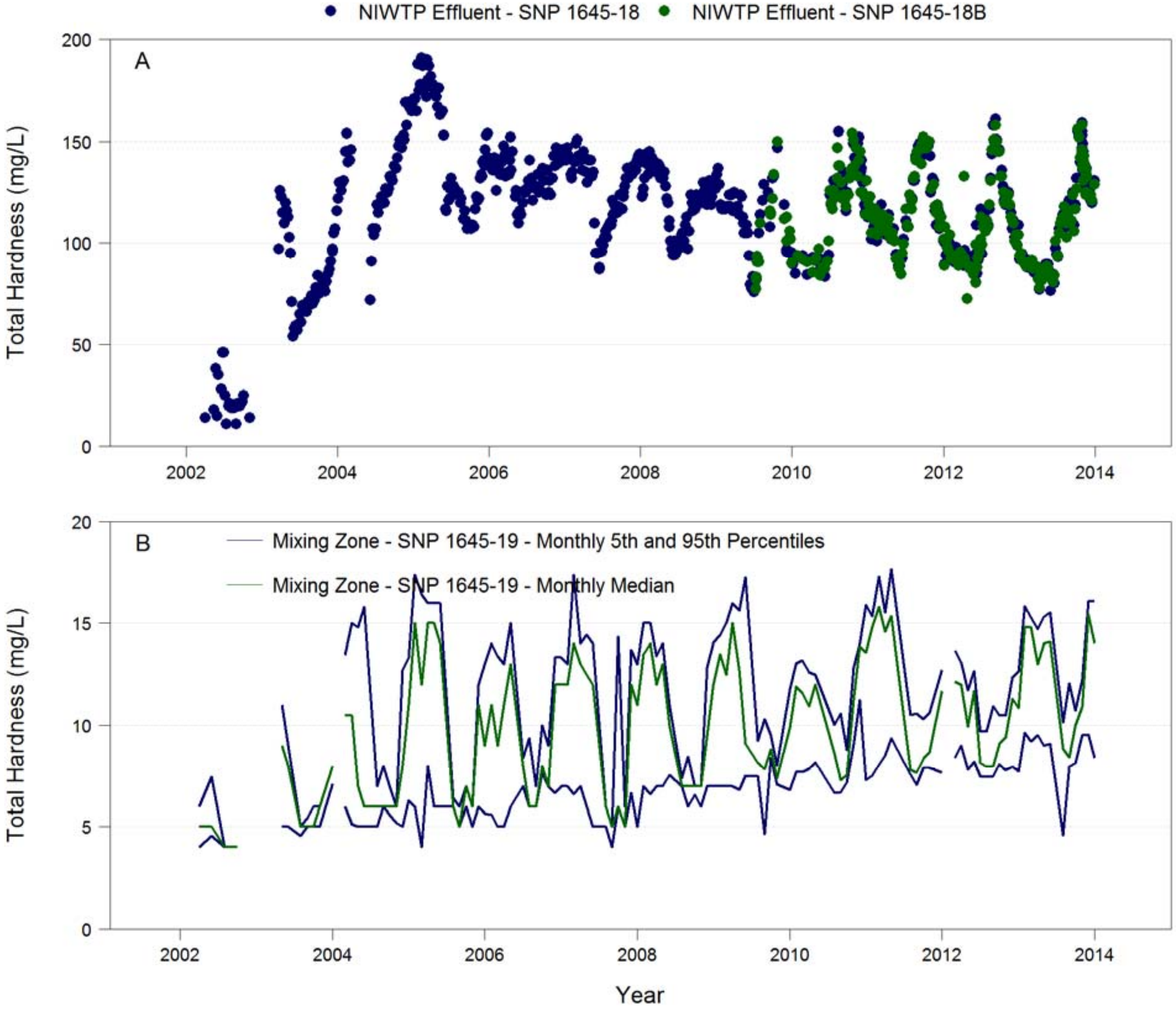
Figure 4-1 **Specific Conductivity in A) North Inlet Water Treatment Plant (NIWTP) effluent (SNP 1645-18 and SNP 1645-18B), and B) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013**



Note: Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m).

µS/cm = microSiemens per centimetre; SNP = surveillance network program.

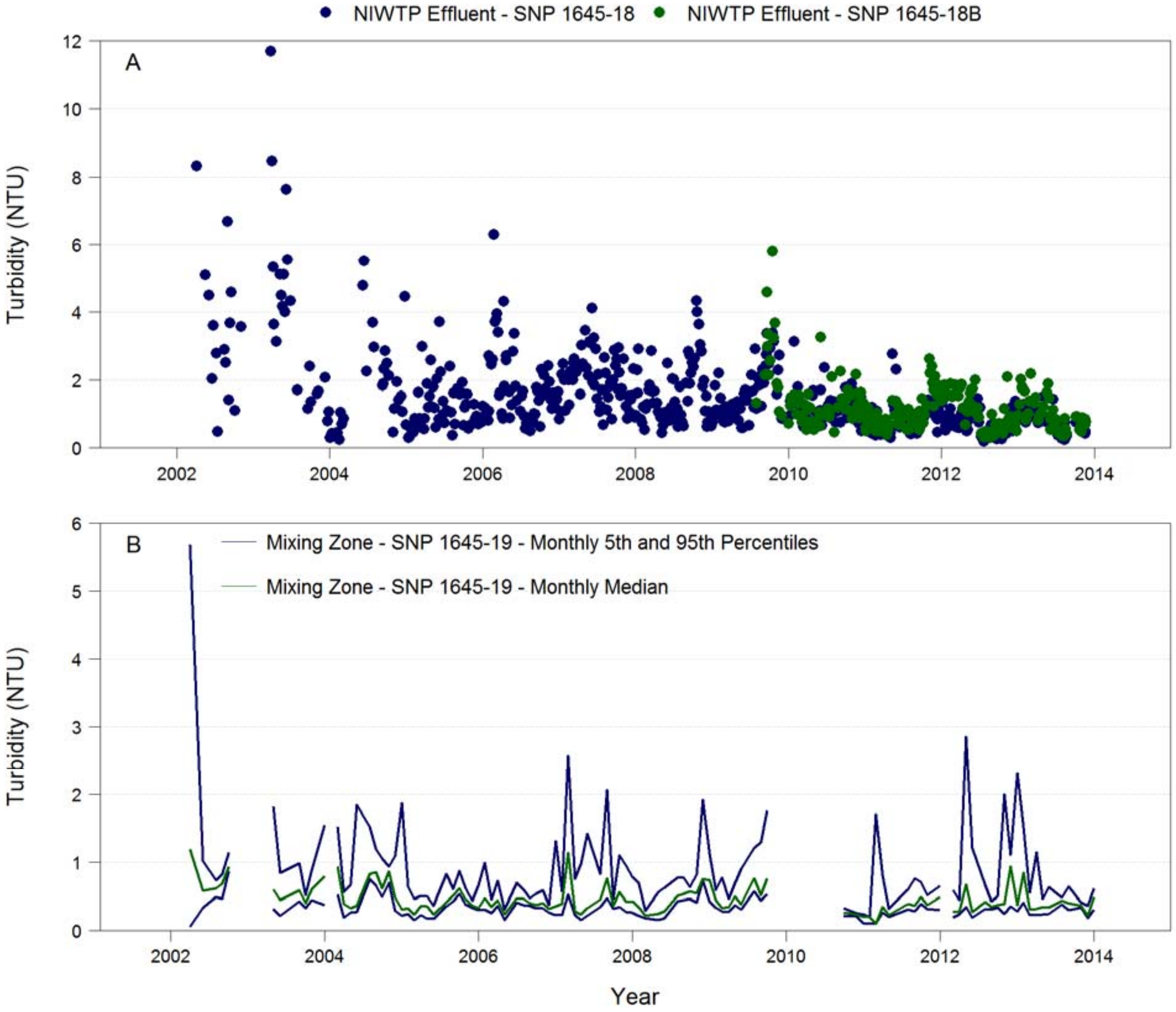
Figure 4-2 Total Hardness in A) North Inlet Water Treatment Plant (NIWTP) Effluent (SNP 1645-18 and SNP 1645-18B), and B) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013



Note: Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m).

SNP = surveillance network program.

Figure 4-3 **Turbidity in A) North Inlet Water Treatment Plant (NIWTP) Effluent (SNP 1645-18 and SNP 1645-18B), and B) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013**



Note: Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m).

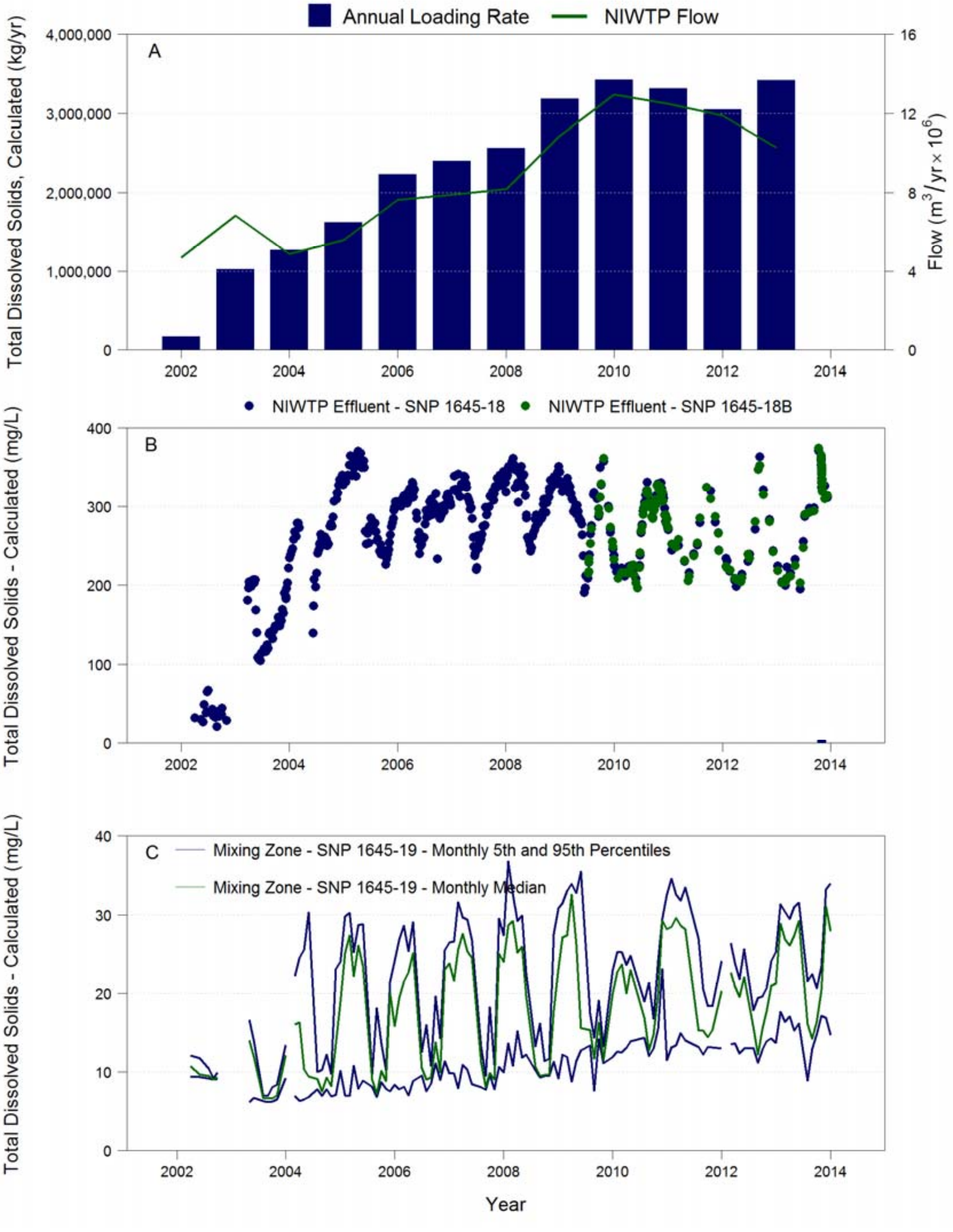
NTU = Nephelometric Turbidity Units; SNP = surveillance network program.

4.3.2 Total Dissolved Solids and Associated Ions

The annual loads of TDS and several associated ions (calcium, chloride, fluoride, magnesium and sodium) from the NIWTP increased over time from 2002 to approximately 2010 (Figures 4-4 to 4-9), reflecting the increase in the annual volume of effluent discharged. The increase in the annual loads of sulphate (Figure 4-10) to Lac de Gras was generally similar to that in TDS, but there was a more pronounced increase from 2008 that appears to reflect an increase in concentration. With the exception of fluoride, the loads of these SOIs have decreased or remained within a similar range since about 2010, as flow rates from the NIWTP have declined. There was an increase in effluent load of fluoride in 2011 and these levels remained high in 2012 and 2013.

With the exception of sulphate and fluoride, the concentration of TDS and its constituents in Mine effluent increased from 2002 to approximately 2005 and have since remained in a seasonal range, or declined slightly over the last five to eight years (Figures 4-4 to 4-9). The concentrations of calcium, chloride and sodium at the mixing zone boundary have slowly increased over time, whereas sulphate and fluoride have seen a more pronounced increase in concentration. These concentration increases reflect the increases in effluent loads. Mixing zone concentrations of TDS and magnesium have remained within a seasonal range over time. The concentration of fluoride at the mixing zone boundary was frequently below the DL (62% of samples analyzed) and no trends were evident during 2002 to 2013.

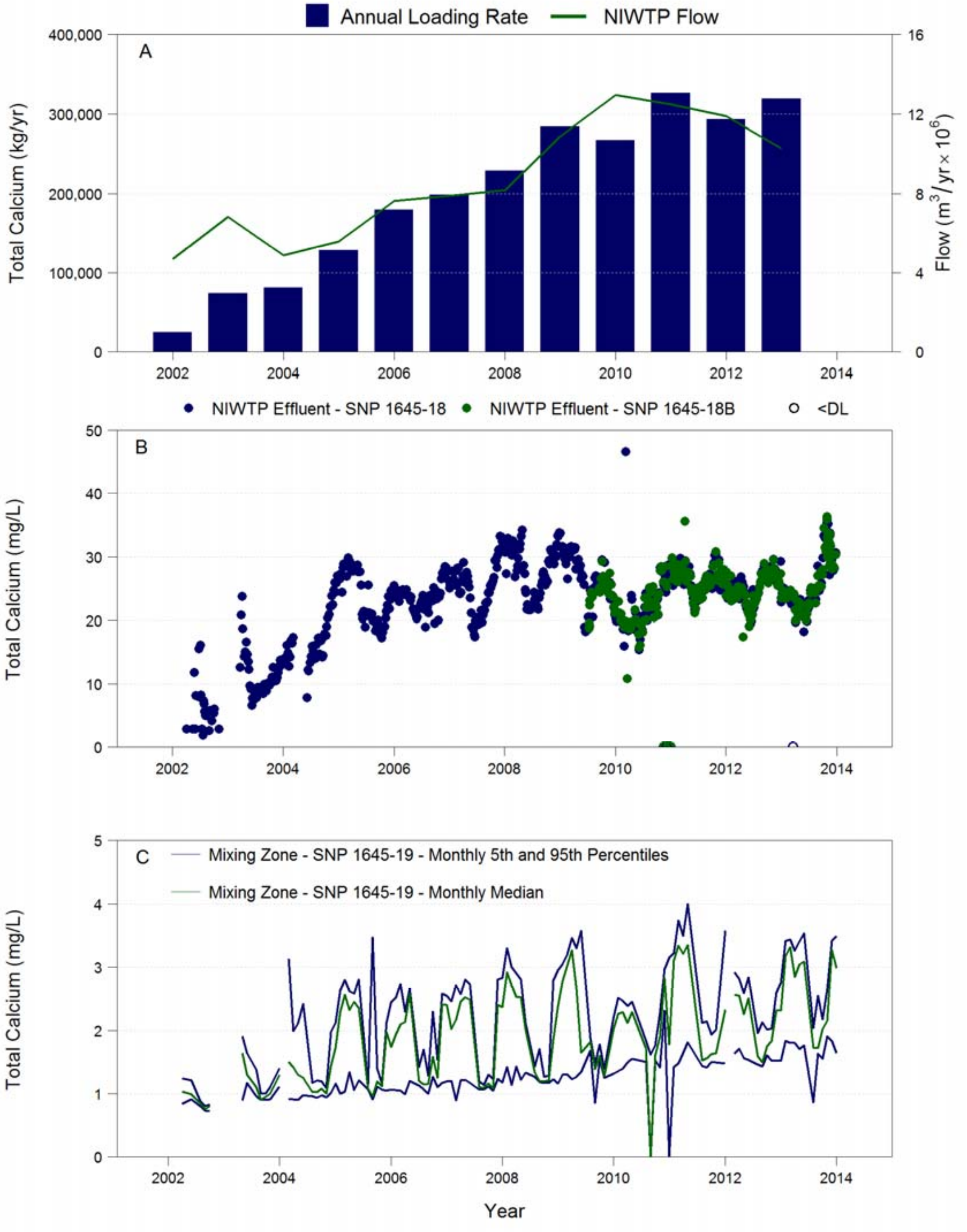
Figure 4-4 **A) Annual Loading Rate of Total Dissolved Solids, Calculated, from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013**



Note: Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m).

SNP = surveillance network program.

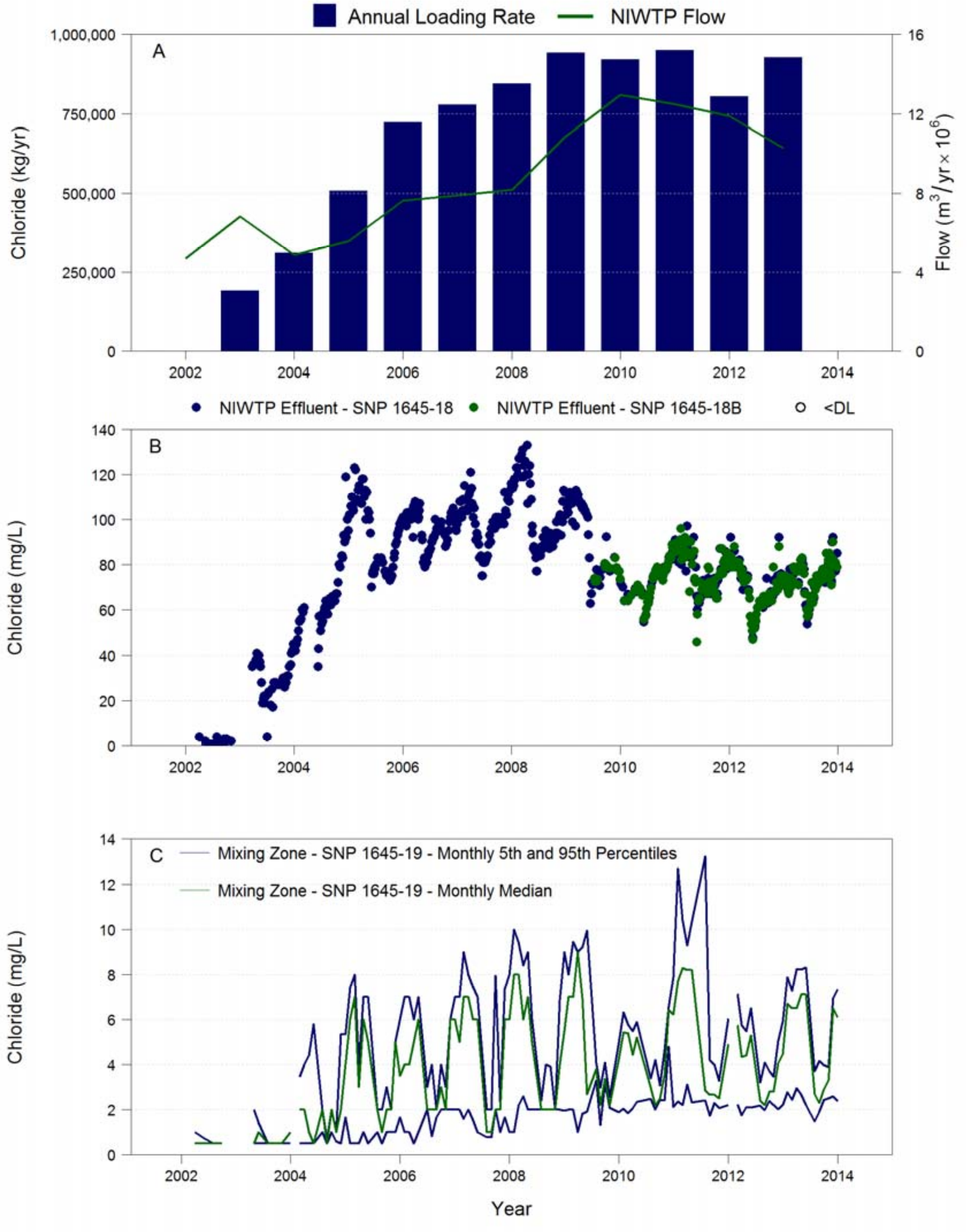
Figure 4-5 **A) Annual Loading Rate of Total Calcium from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013**



Note: Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m). Open symbols represent non-detectable values.

SNP = surveillance network program.

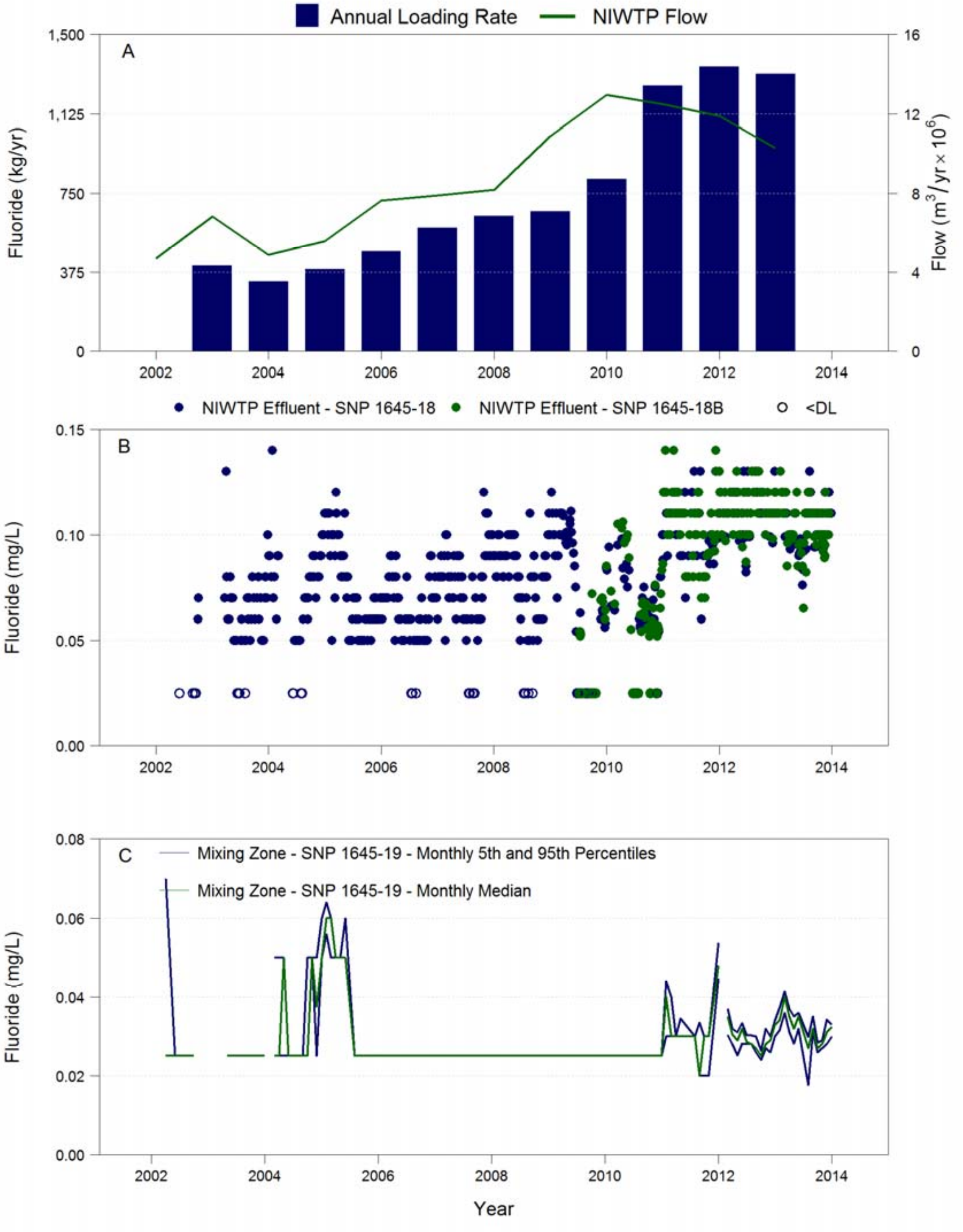
Figure 4-6 **A) Annual Loading Rate of Chloride from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013**



Note: The annual load for chloride in 2002 was not calculated because a large percentage of concentrations in effluent were below the detection limit. Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m). Open symbols represent non-detectable values.

SNP = surveillance network program.

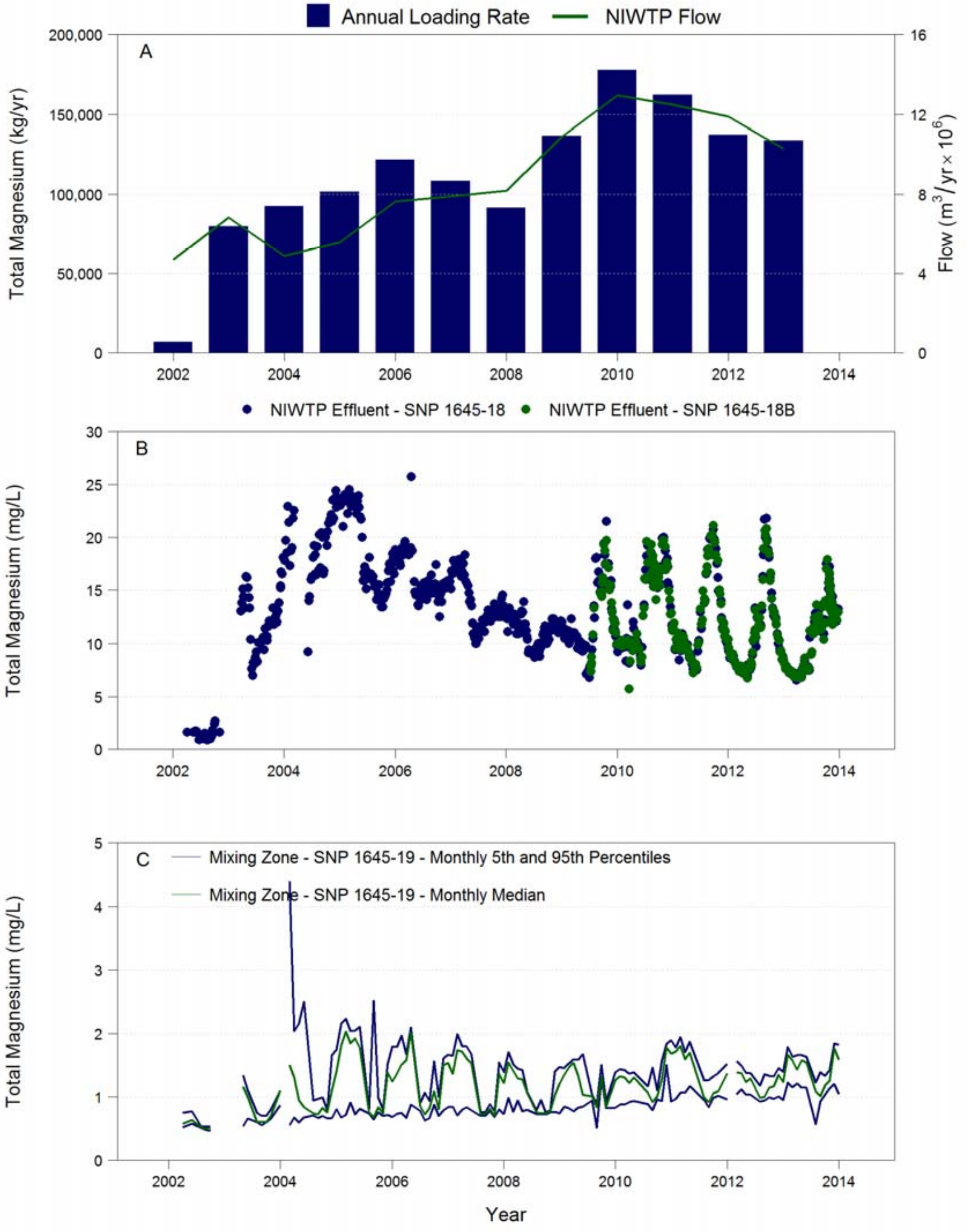
Figure 4-7 **A) Annual Loading Rate of Fluoride from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013**



Note: Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m). Open symbols represent non-detectable values.

SNP = surveillance network program.

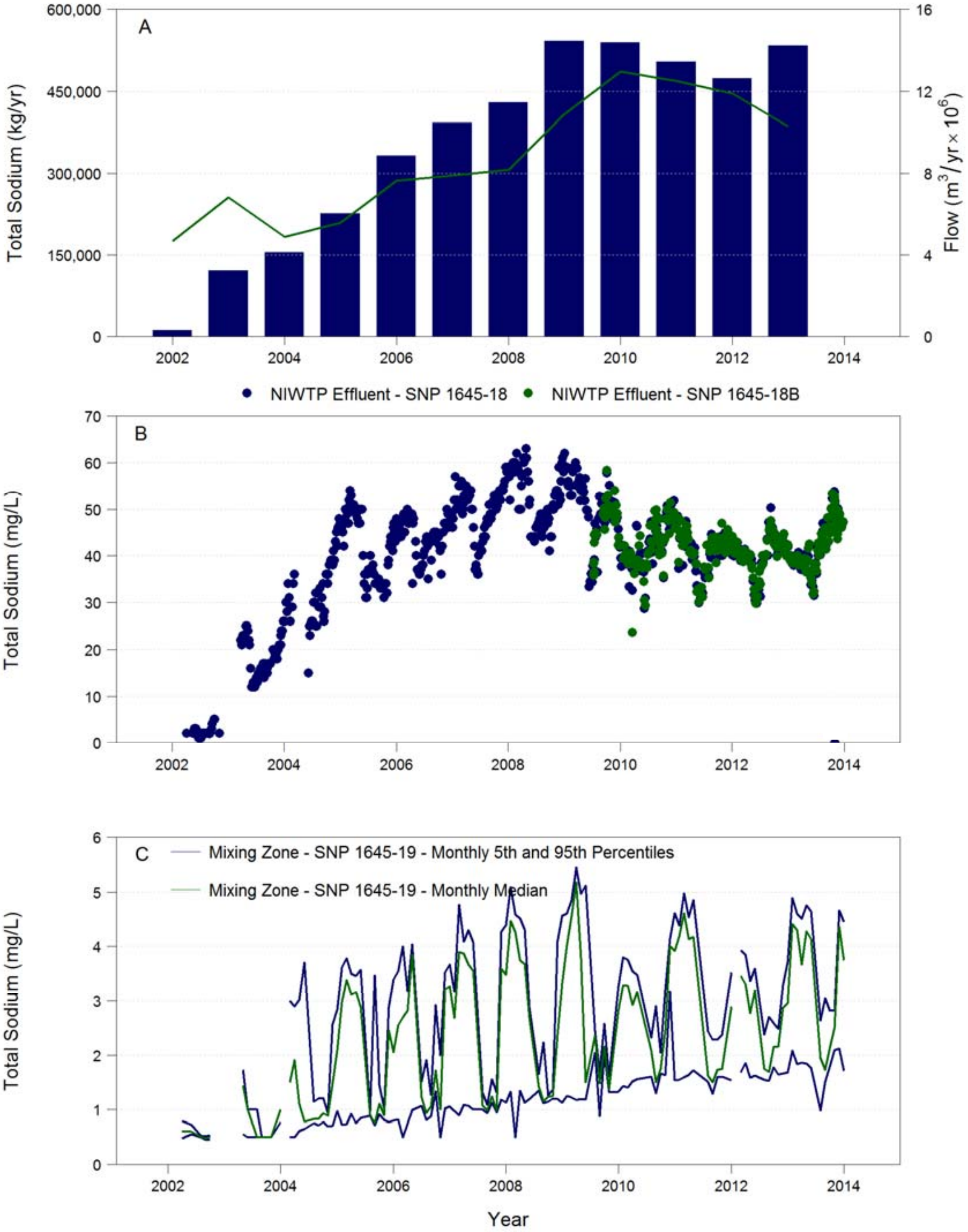
Figure 4-8 **A) Annual Loading Rate of Total Magnesium from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013**



Note: Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m).

SNP = surveillance network program.

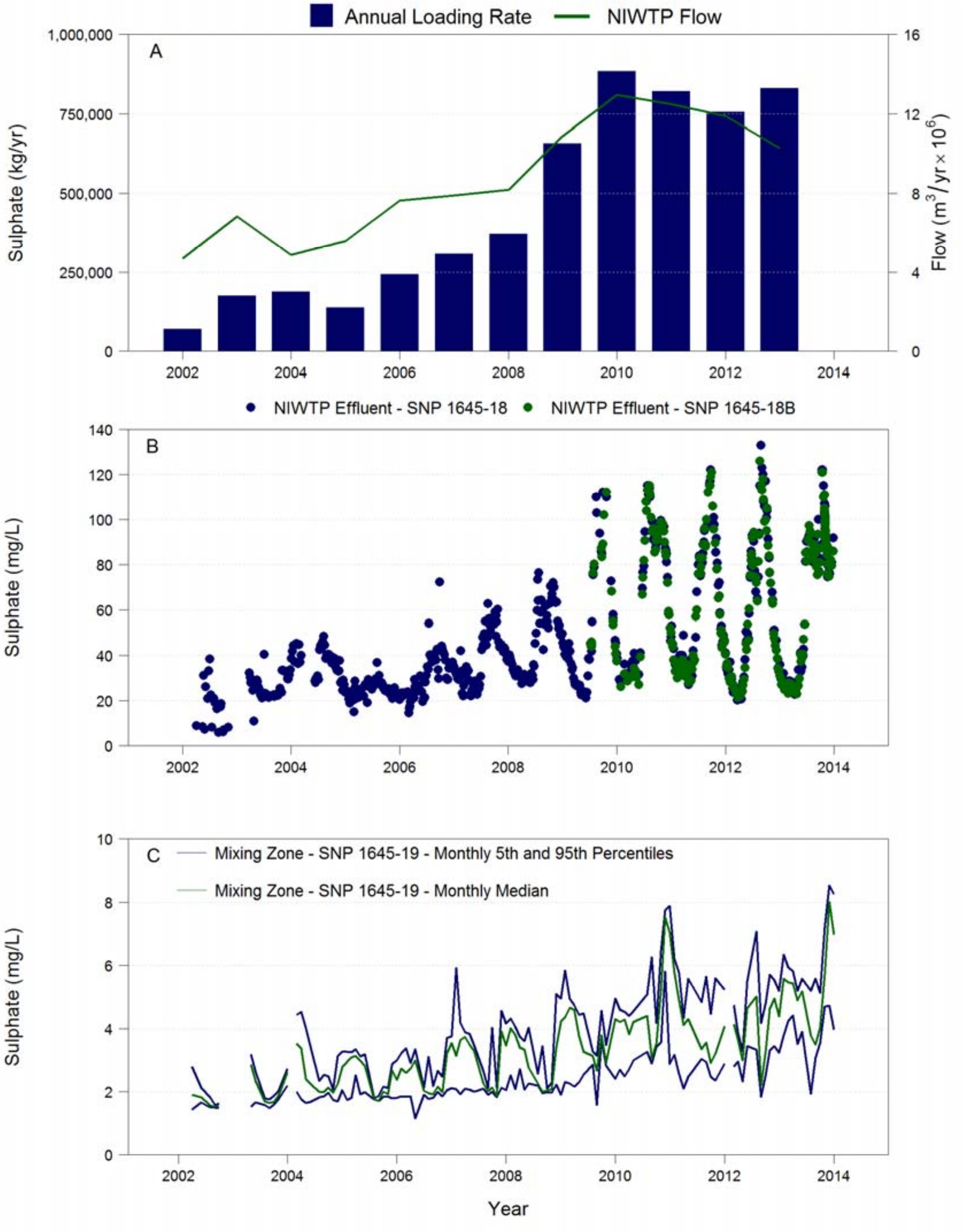
Figure 4-9 **A) Annual Loading Rate of Total Sodium from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013**



Note: Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m).

SNP = surveillance network program.

Figure 4-10 A) Annual Loading Rate of Sulphate from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013



Note: Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m).

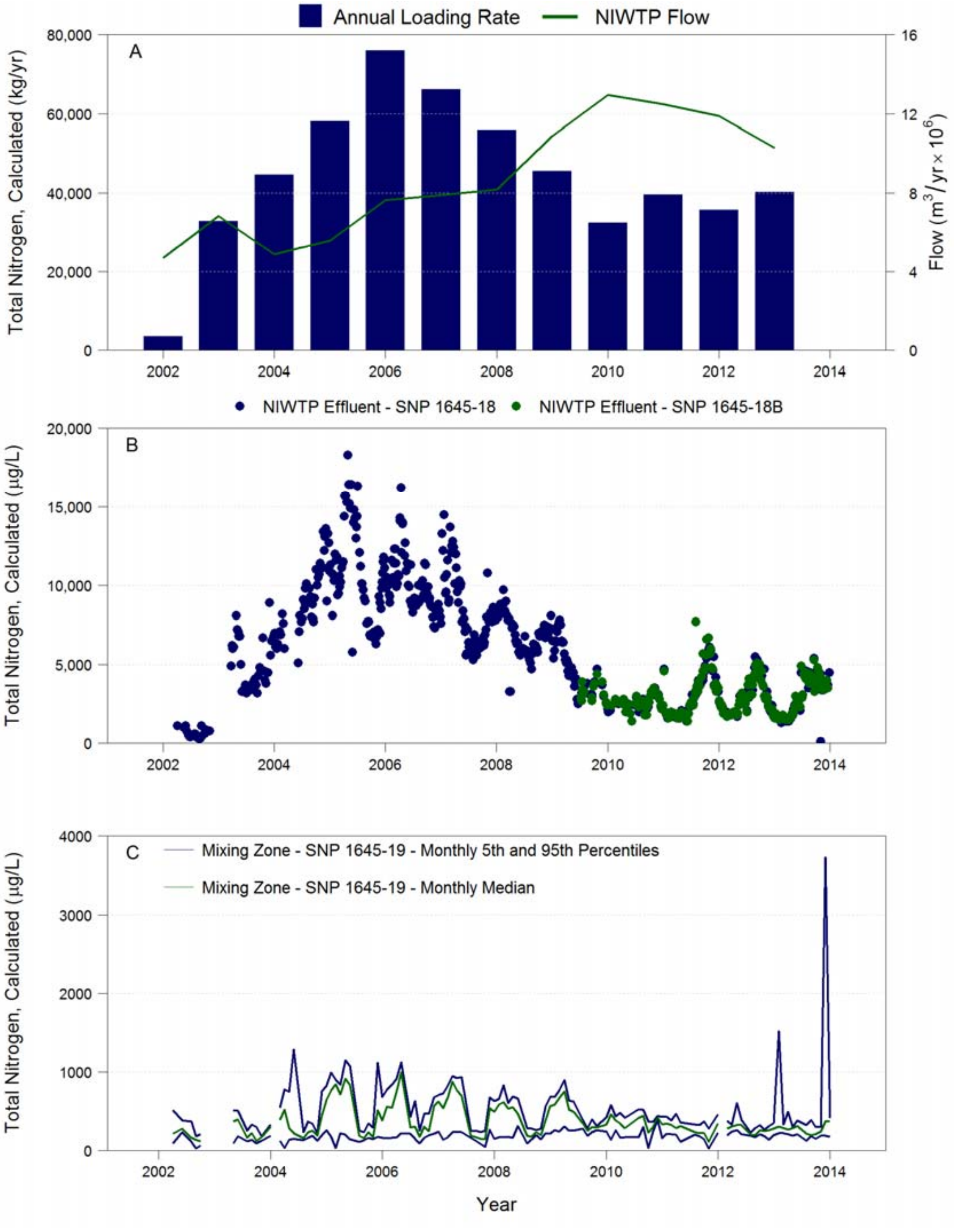
SNP = surveillance network program.

4.3.3 Nutrients

The annual loading rates of total nitrogen, ammonia, nitrate and nitrite to Lac de Gras increased over time from 2002 to 2006 or 2007, as the concentration of nitrogen in Mine effluent increased (Figures 4-11 to 4-14). The loads and concentrations of these compounds subsequently declined to 2010. Nitrogen loads have remained at similar levels since 2010, and concentrations have remained in a similar seasonal range since that time. Temporal patterns in the concentration of nitrogen at the mixing zone boundary generally reflected patterns observed in the Mine effluent.

The annual loading rate of TP to Lac de Gras has increased over time, reflecting the increase in flow and concentration of TP in effluent (Figure 4-15). The concentrations and loading rates of total dissolved phosphorus (TDP) were relatively stable during the first four years of monitoring, but increased from 2006 to 2013 (Figures 4-16). Annual loads were not estimated for soluble reactive phosphorus from 2002 to 2010 because concentrations in effluent were frequently below the DL (1 µg/L; Figure 4-17). At the mixing zone boundary, concentrations of total and dissolved phosphorus varied within a seasonal cycle until 2012, when concentrations increased. The concentration of SRP at the mixing zone was below the DL of 1 µg/L to 50 µg/L in most (~90%) samples analyzed from 2002 to 2013; however, results for several samples in 2012 and 2013 were greater than historic values.

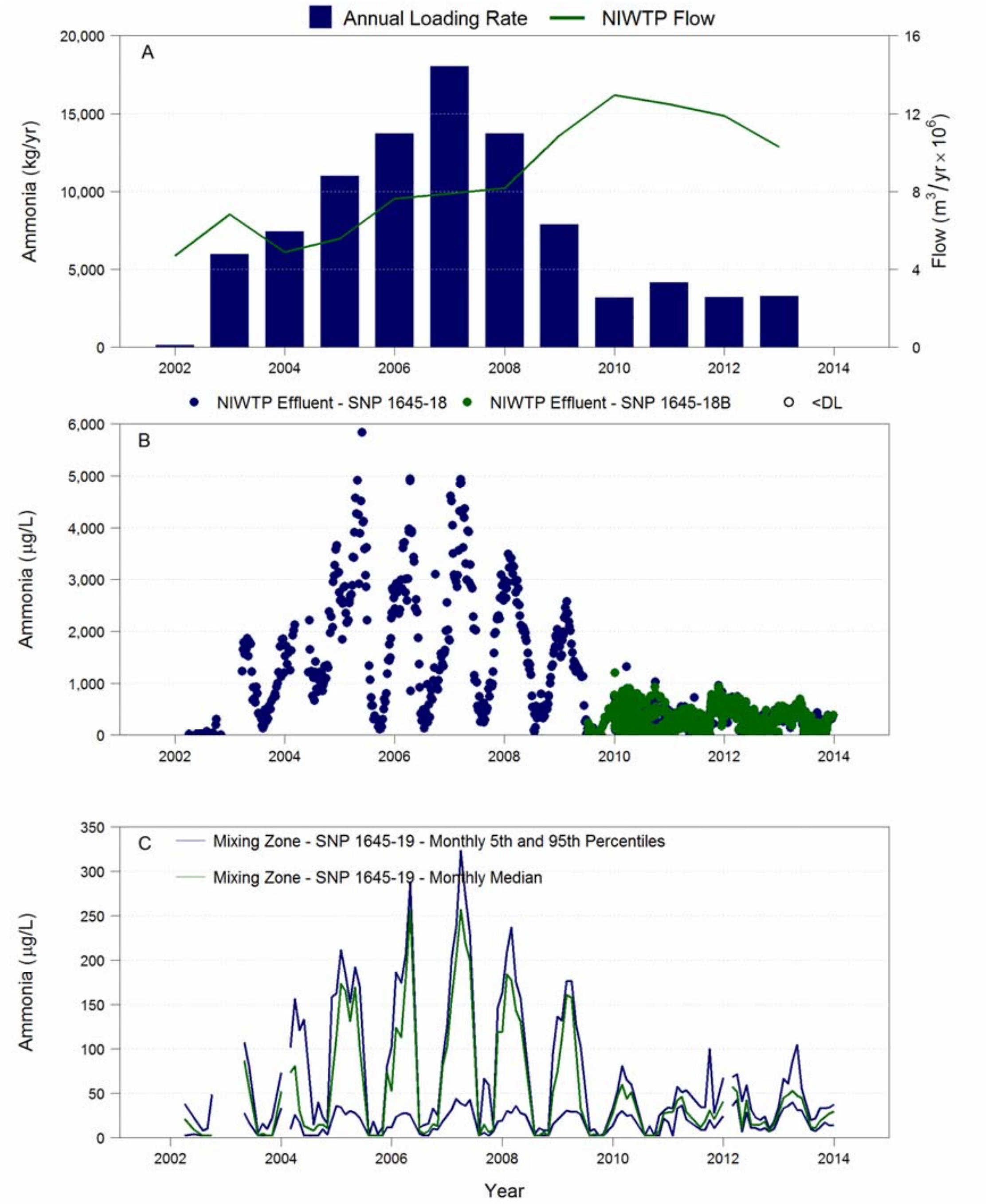
Figure 4-11 A) Annual Loading Rate of Total Nitrogen, Calculated, from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013



Note: Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m).

µg-N/L = micrograms-nitrogen per litre; SNP = surveillance network program.

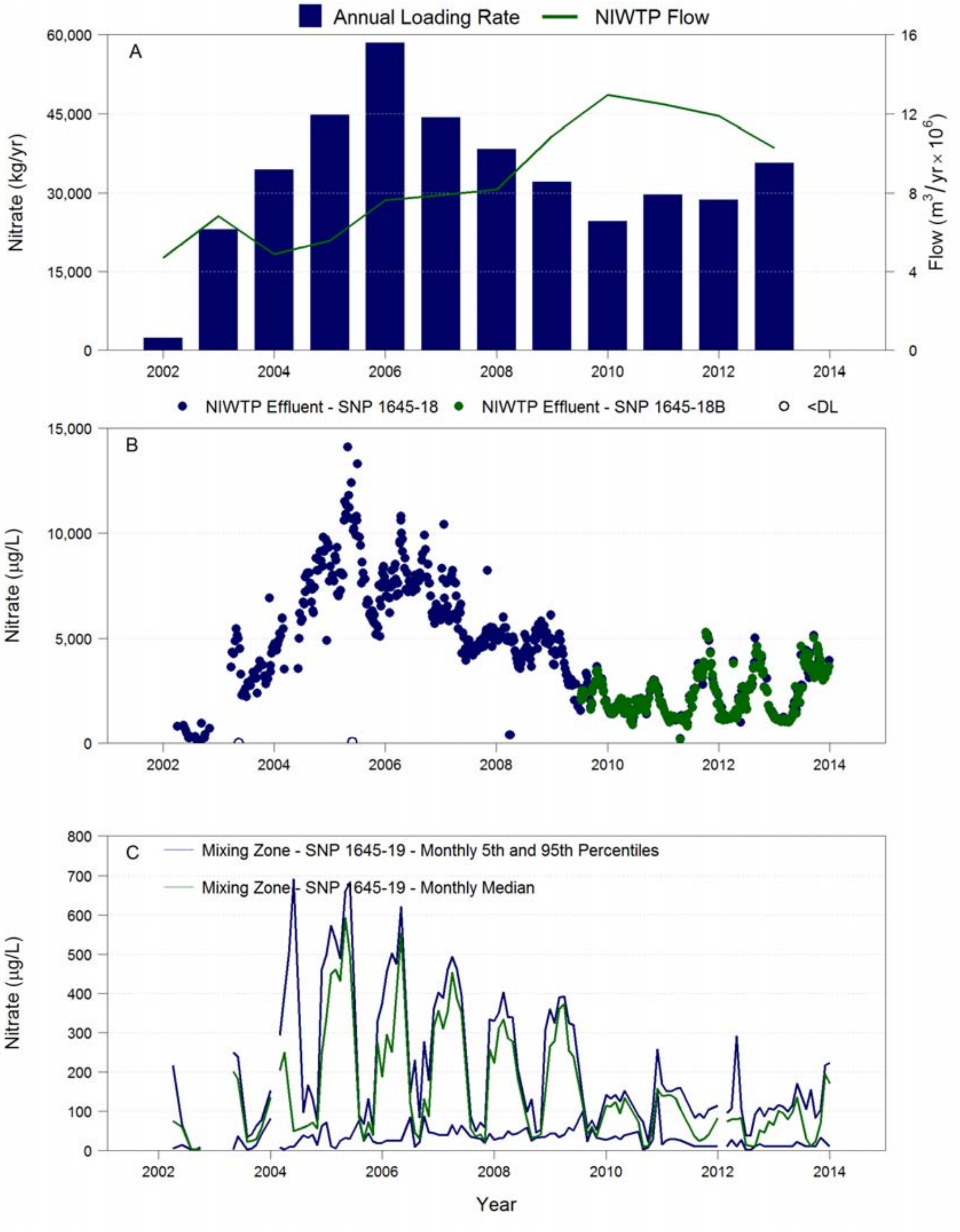
Figure 4-12 A) Annual Loading Rate of Ammonia from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013



Note: Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m).

µg-N/L = micrograms-nitrogen per litre; SNP = surveillance network program.

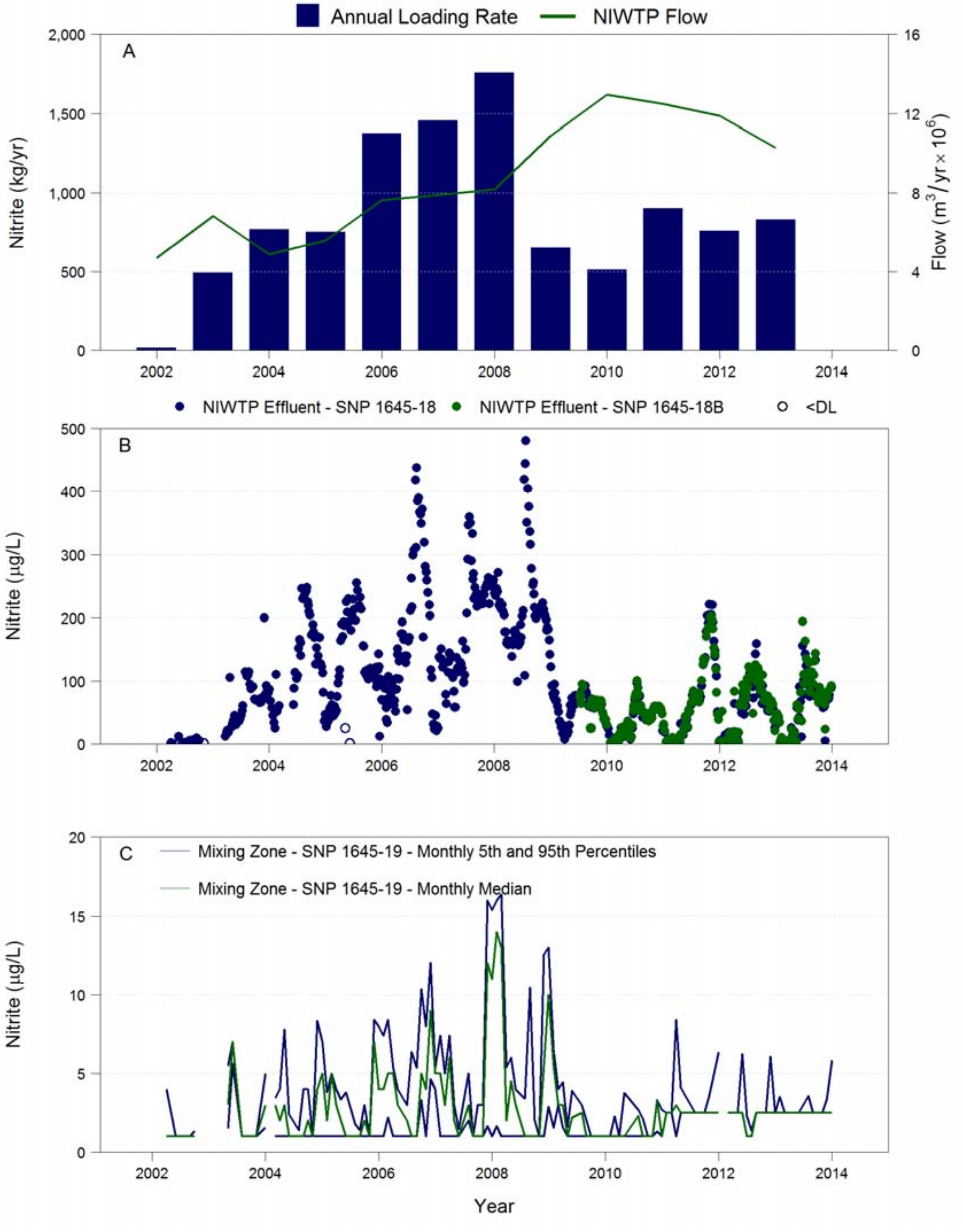
Figure 4-13 A) Annual Loading Rate of Nitrate from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013



Note: Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m). Open symbols represent non-detectable values.

µg-N/L = micrograms-nitrogen per litre; SNP = surveillance network program.

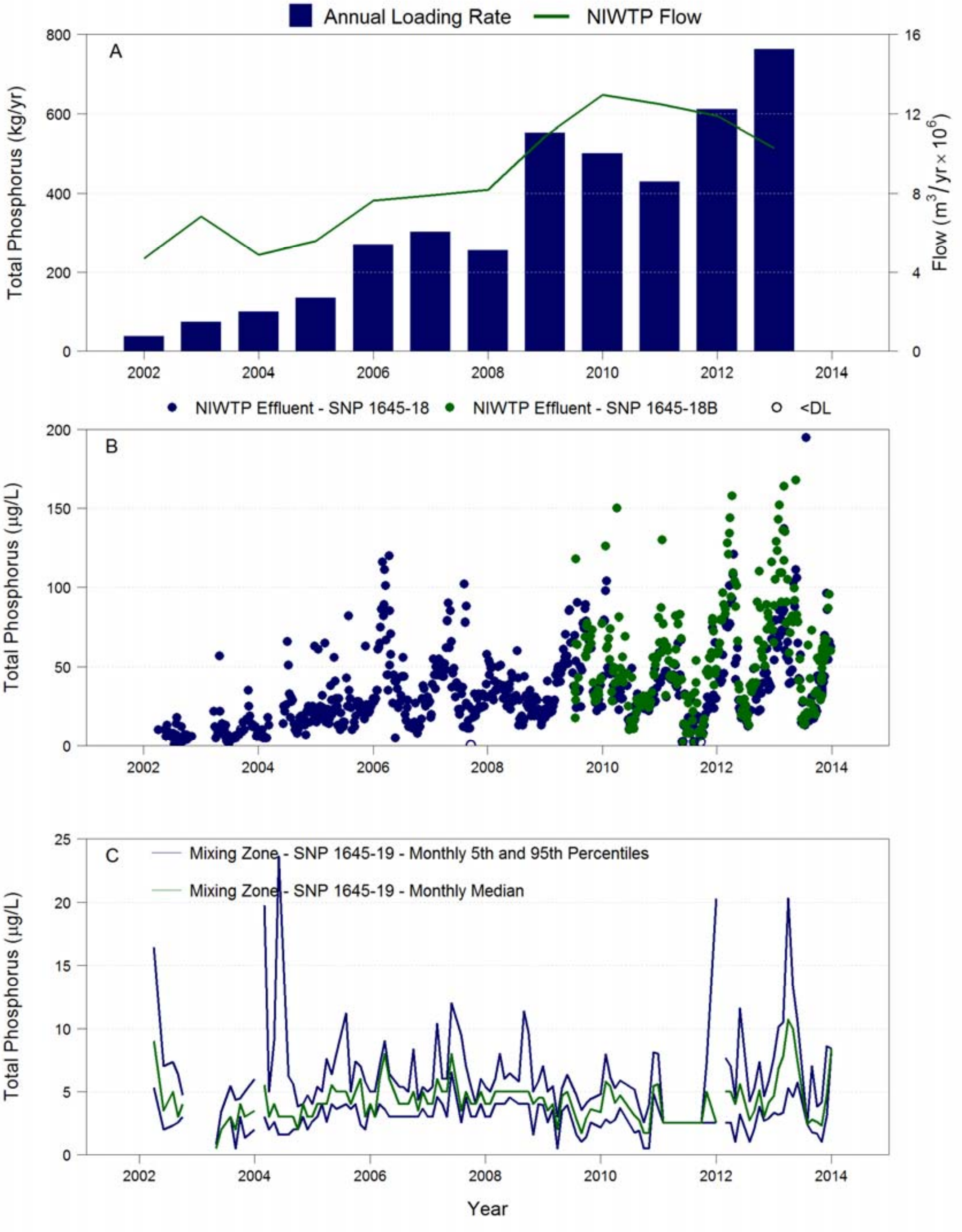
Figure 4-14 A) Annual Loading Rate of Nitrite from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013



Note: Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m). Open symbols represent non-detectable values.

µg-N/L = micrograms-nitrogen per litre; SNP = surveillance network program.

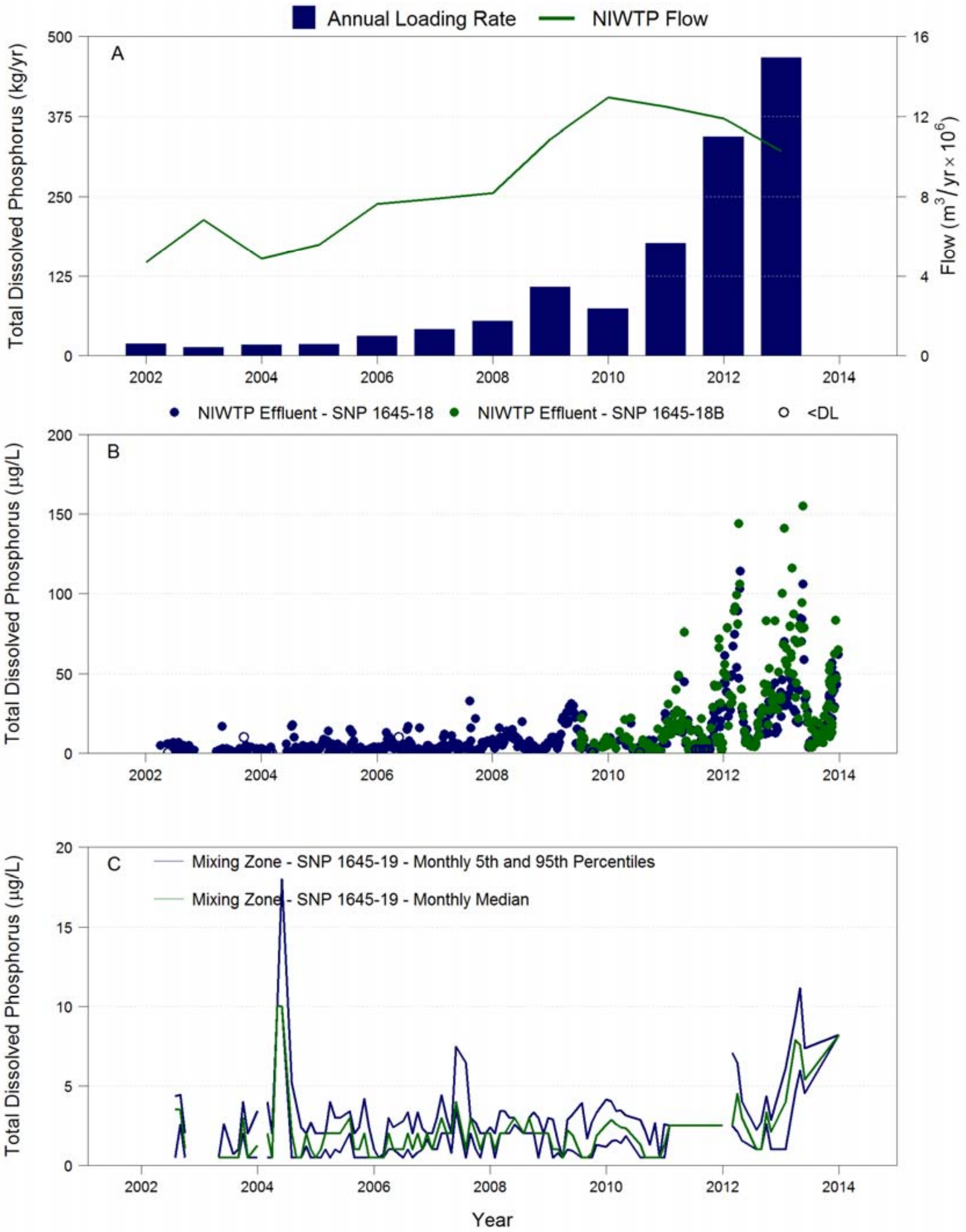
Figure 4-15 **A) Annual Loading Rate of Total Phosphorus from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013**



Note: Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m). Open symbols represent non-detectable values.

µg-P/L = micrograms-phosphorus per litre; SNP = surveillance network program.

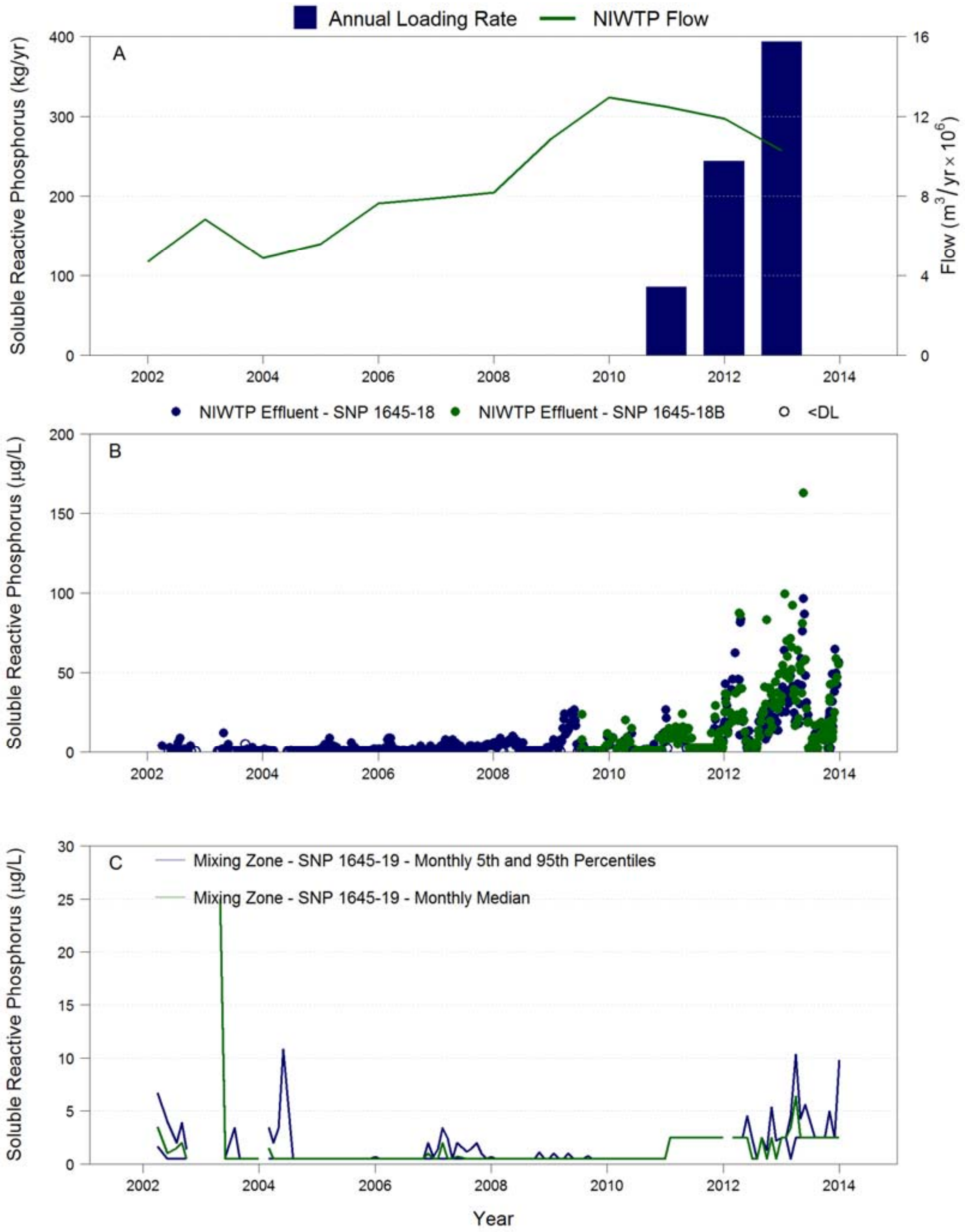
Figure 4-16 A) Annual Loading Rate of Total Dissolved Phosphorus from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013



Note: Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m). Open symbols represent non-detectable values.

µg-P/L = micrograms-phosphorus per litre; SNP = surveillance network program.

Figure 4-17 A) Annual Loading Rate of Soluble Reactive Phosphorus from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013



Note: Annual loads for soluble reactive phosphorus were not calculated from 2002 to 2010, because a large percentage of concentrations in effluent were below the detection limit. Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m). Open symbols represent non-detectable values.

SNP = surveillance network program.

4.3.4 Metals

Although effluent loads and/or concentrations of some metals (molybdenum, silicon and strontium; Figures 4-25, 4-26 and 4-27) have increased over time, most have either decreased (copper, manganese; Figures - 4-23 and 4-24), fluctuated over time (barium; Figure 4-20) or have remained at relatively similar levels (aluminum, antimony, chromium, uranium; Figures 4-18, 4-19, 4-22, -4-29). Effluent concentrations of two metals (cadmium and tin; Figures 4-21 and 4-28) were below DLs used for the SNP data set (cadmium = 0.005 to 0.1 µg/L, tin = 0.2 to 0.4 µg/L) in a large proportion of samples analyzed from 2002 to 2013 (85% and 98% of samples, respectively), which restricted interpretation of trends for these SOIs.

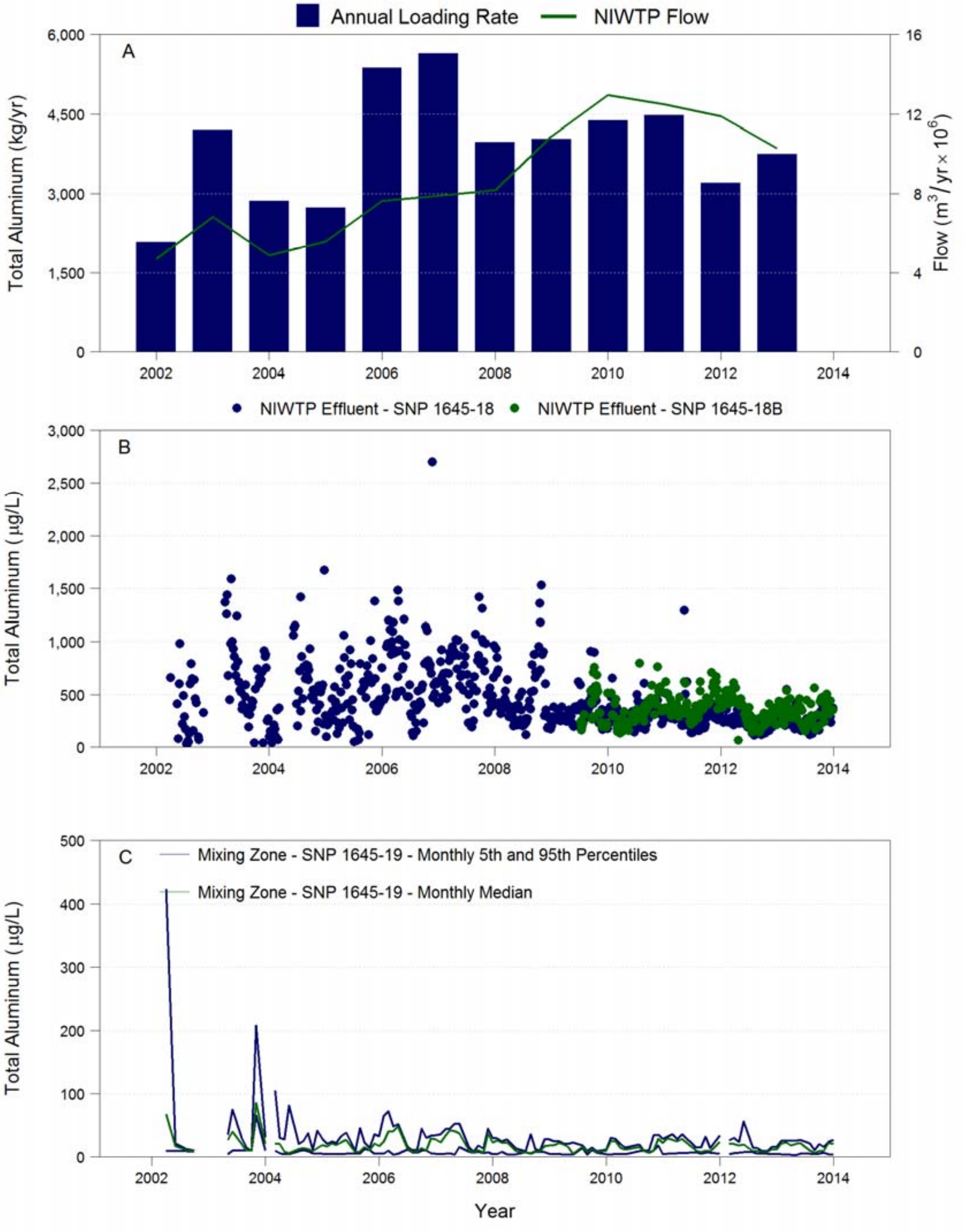
The annual loading rates of molybdenum and strontium followed the same general pattern described for TDS, reflecting the change in the annual volume of effluent discharged from the NIWTP (Figures 4-25 and 4-27). The concentration of molybdenum in effluent was relatively stable during initial monitoring, but it increased during the open-water season from 2009 to 2013. The concentration of strontium in effluent has remained in a seasonal range since 2005. At the mixing zone boundary, concentrations of both metals have been increasing since 2002.

Barium has been used as an effluent tracer in Lac de Gras for the AEMP since 2007. The annual loading rate and the concentration of barium from the NIWTP increased from 2002 to 2006, and both have subsequently declined from 2006. Loads and concentrations have stabilized since 2011 (Figure 4-20). Trends for barium at the mixing zone reflected those in effluent.

Data quality issues identified with antimony prior to 2007 interfered with the interpretation of trends at the mixing zone boundary (antimony concentrations reported from 2002 to 2006 were an order of magnitude greater than values reported from 2007 to 2013); however, concentrations have remained at similar levels since 2007 (Figure 4-19). The concentration of uranium at the mixing zone was elevated in 2002 but declined markedly after the first year of monitoring (Figure 4-29). Uranium concentrations continued to decline gradually until approximately 2009. Given the absence of trends for uranium in effluent, these data appear to confirm that the elevated uranium concentrations encountered at the mixing zone in 2002 originated from the A154 dike (DDMI 2011a).

Annual loads for chromium were not estimated from 2002 to 2010 because the majority of concentrations (~70%) were less than the DLs used during that period (0.6 µg/L to 5 µg/L). The annual loading rate of chromium to Lac de Gras was within a similar range from 2011 to 2012 (Figure 4-22). The annual loads of silicon to Lac de Gras were not available from 2002 to 2010, because silicon was not analyzed during that period. The annual loading rates calculated from 2011 to 2013 indicated that loads increased slightly over the period of available data; however, this increase was not reflected in the concentration of silicon in effluent (Figure 4-26). No temporal trends were observed in the concentrations of silicon at the mixing zone from 2011 to 2013.

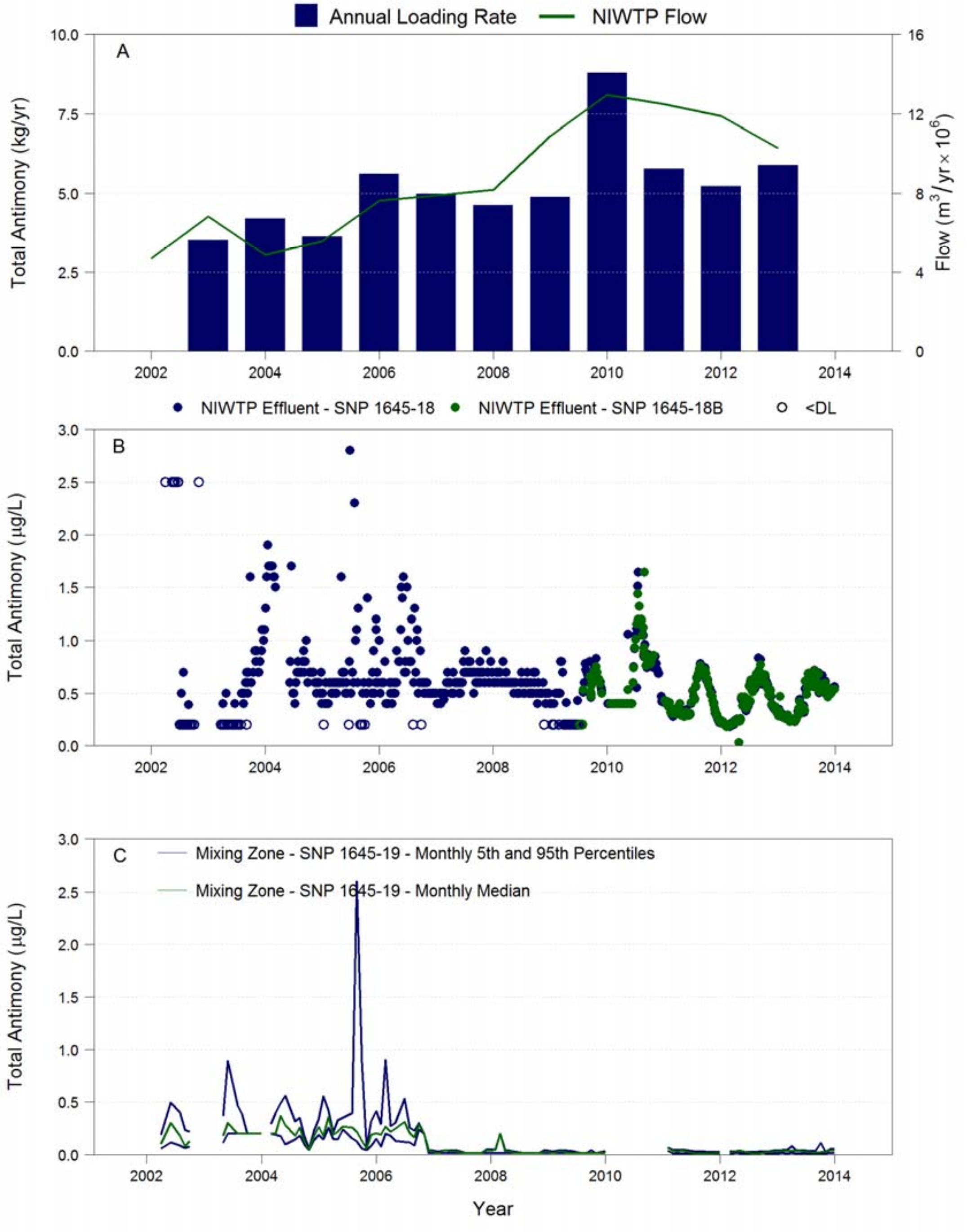
Figure 4-18 A) Annual Loading Rate of Total Aluminum from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013



Note: Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m).

SNP = surveillance network program.

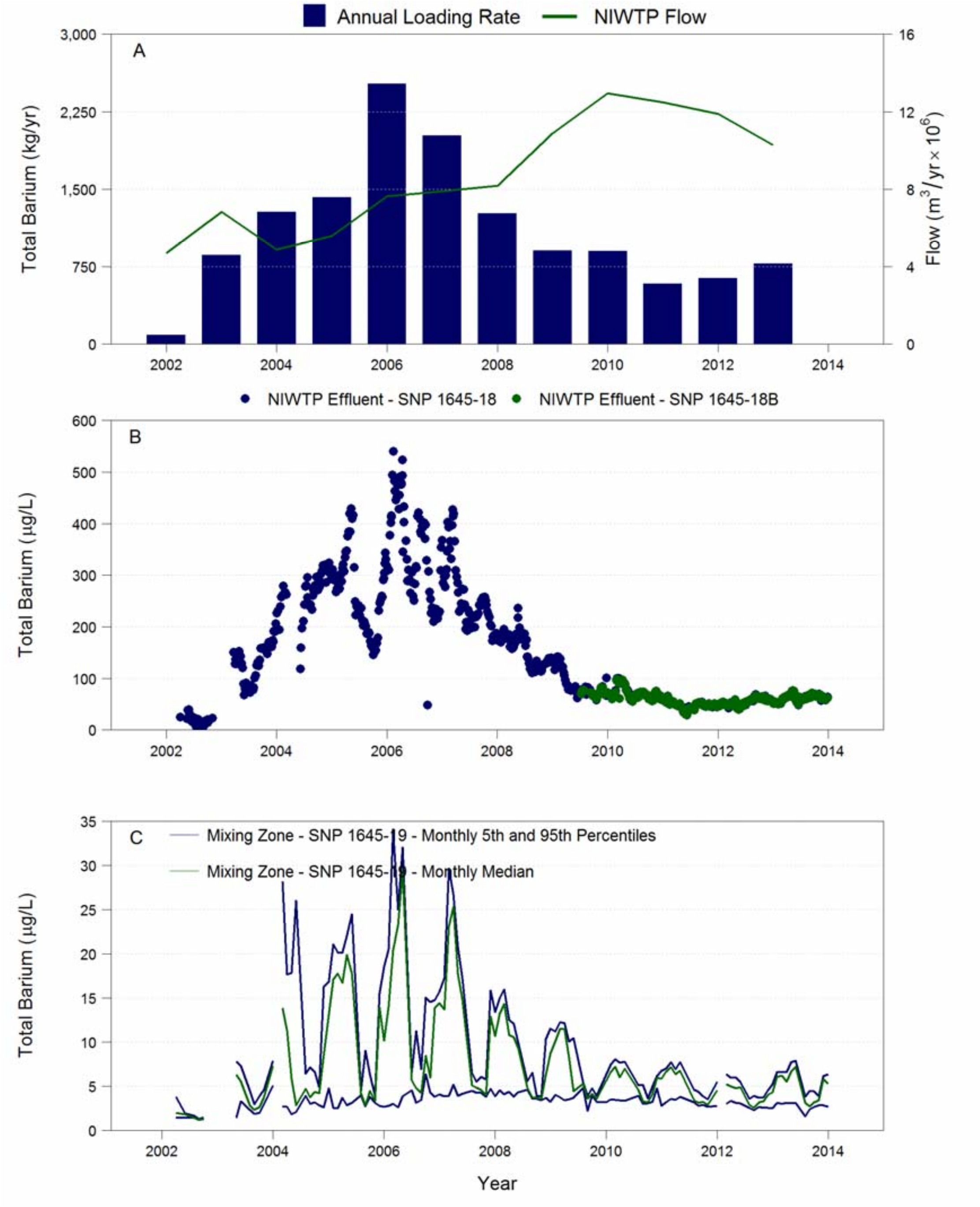
Figure 4-19 A) Annual Loading Rate of Total Antimony from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013



Note: The annual load for antimony in 2002 was not calculated because a large percentage of concentrations in effluent were below the detection limit. Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m). Open symbols represent non-detectable values.

SNP = surveillance network program.

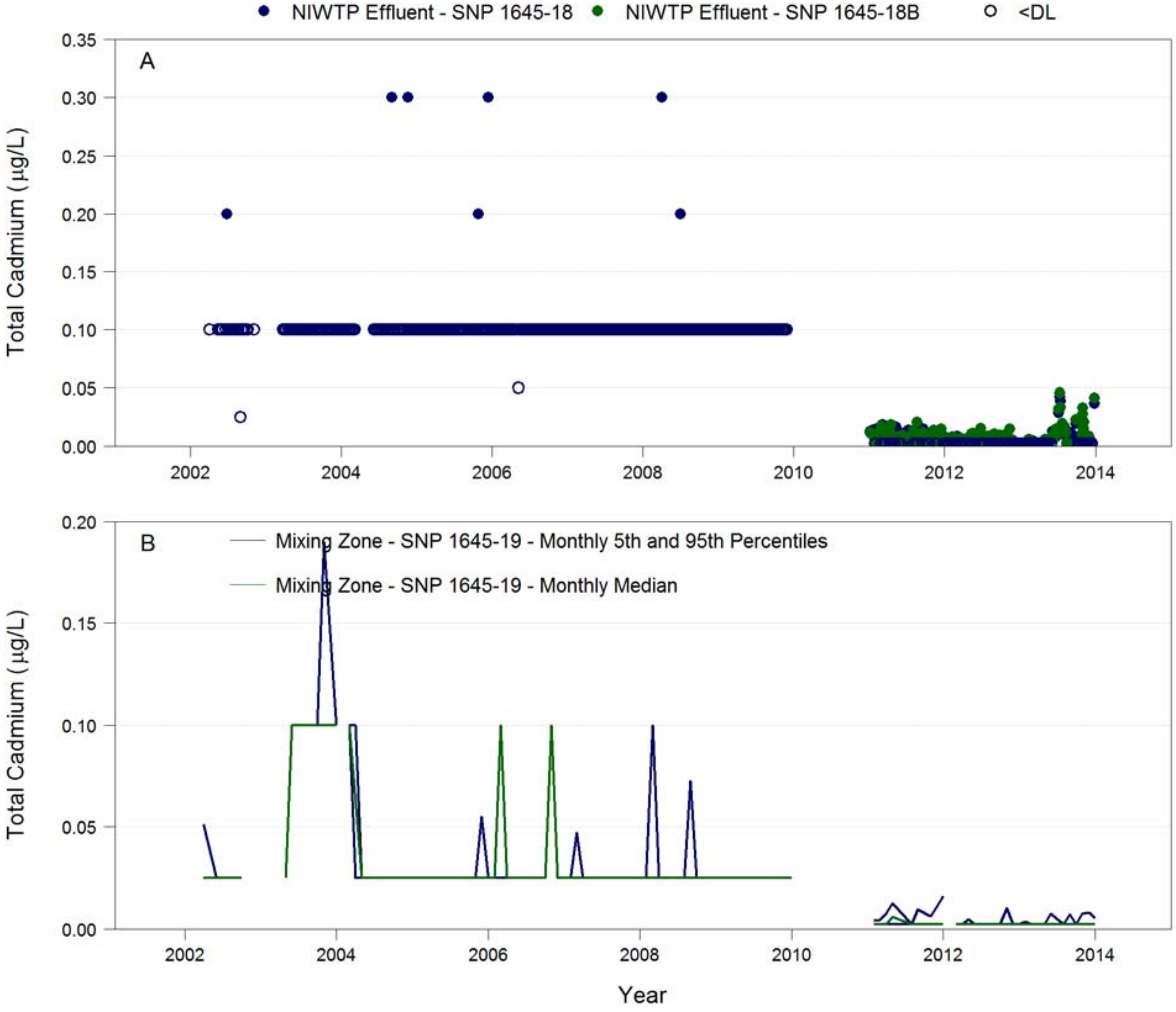
Figure 4-20 **A) Annual Loading Rate of Total Barium from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013**



Note: Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m).

SNP = surveillance network program.

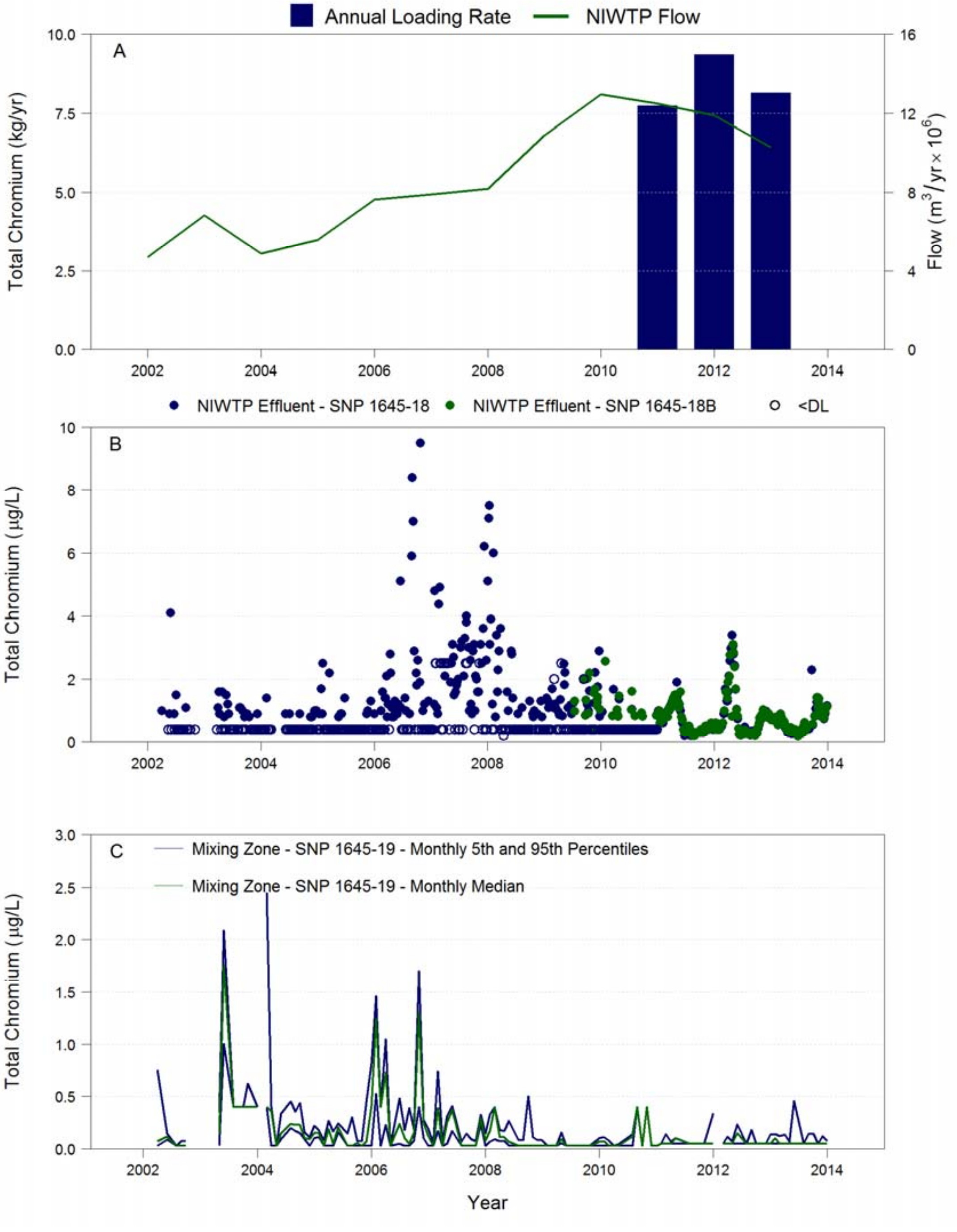
Figure 4-21 **A) Annual Loading Rate of Total Cadmium from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013**



Note: Annual loads were not calculated for cadmium because a large percentage of concentrations in effluent were below the detection limit. Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m). Open symbols represent non-detectable values.

SNP = surveillance network program.

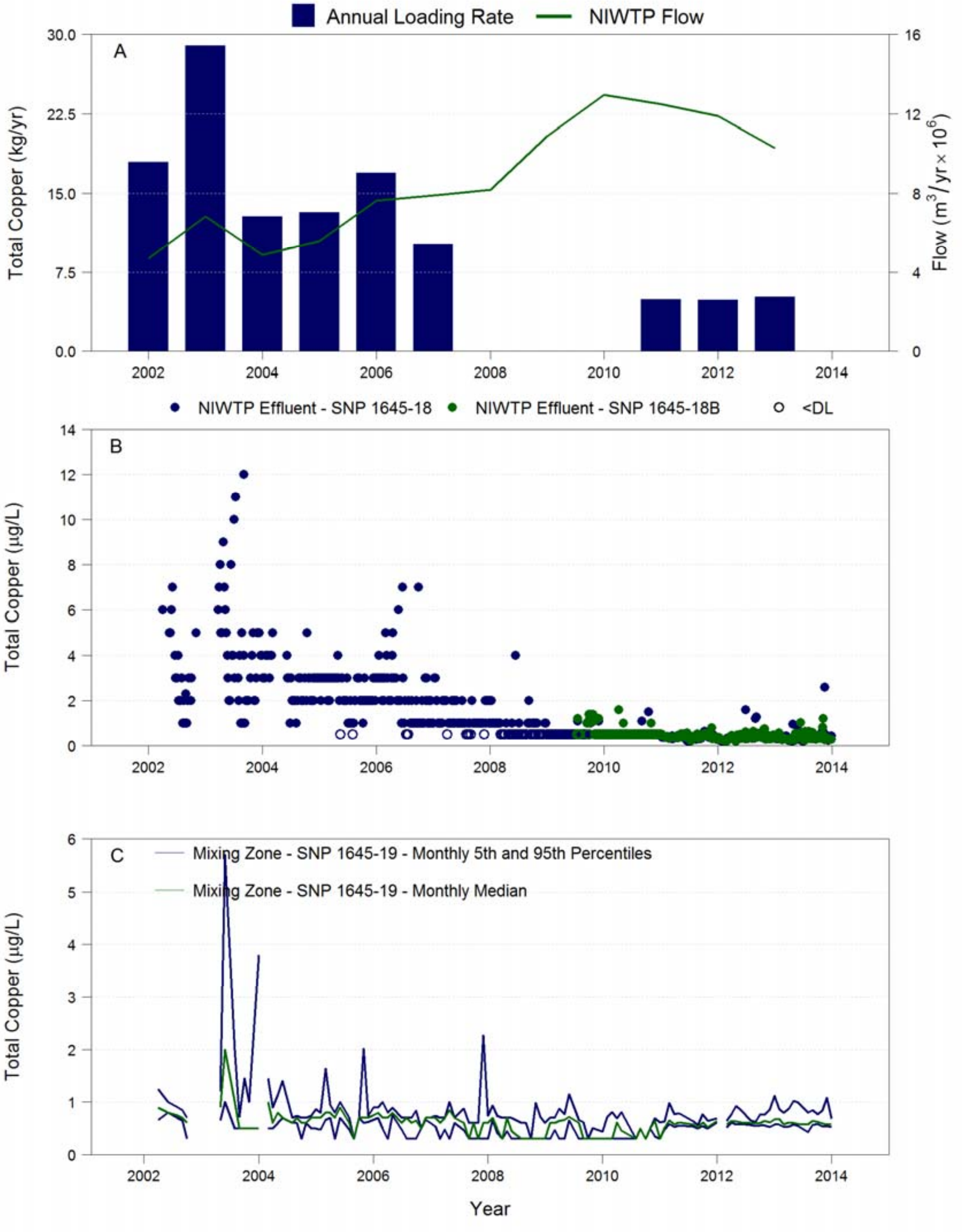
Figure 4-22 **A) Annual Loading Rate of Total Chromium from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013**



Note: Annual loads were not calculated for chromium from 2002 to 2010 because a large percentage of concentrations in effluent were below the detection limit. Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m). Open symbols represent non-detectable values.

SNP = surveillance network program.

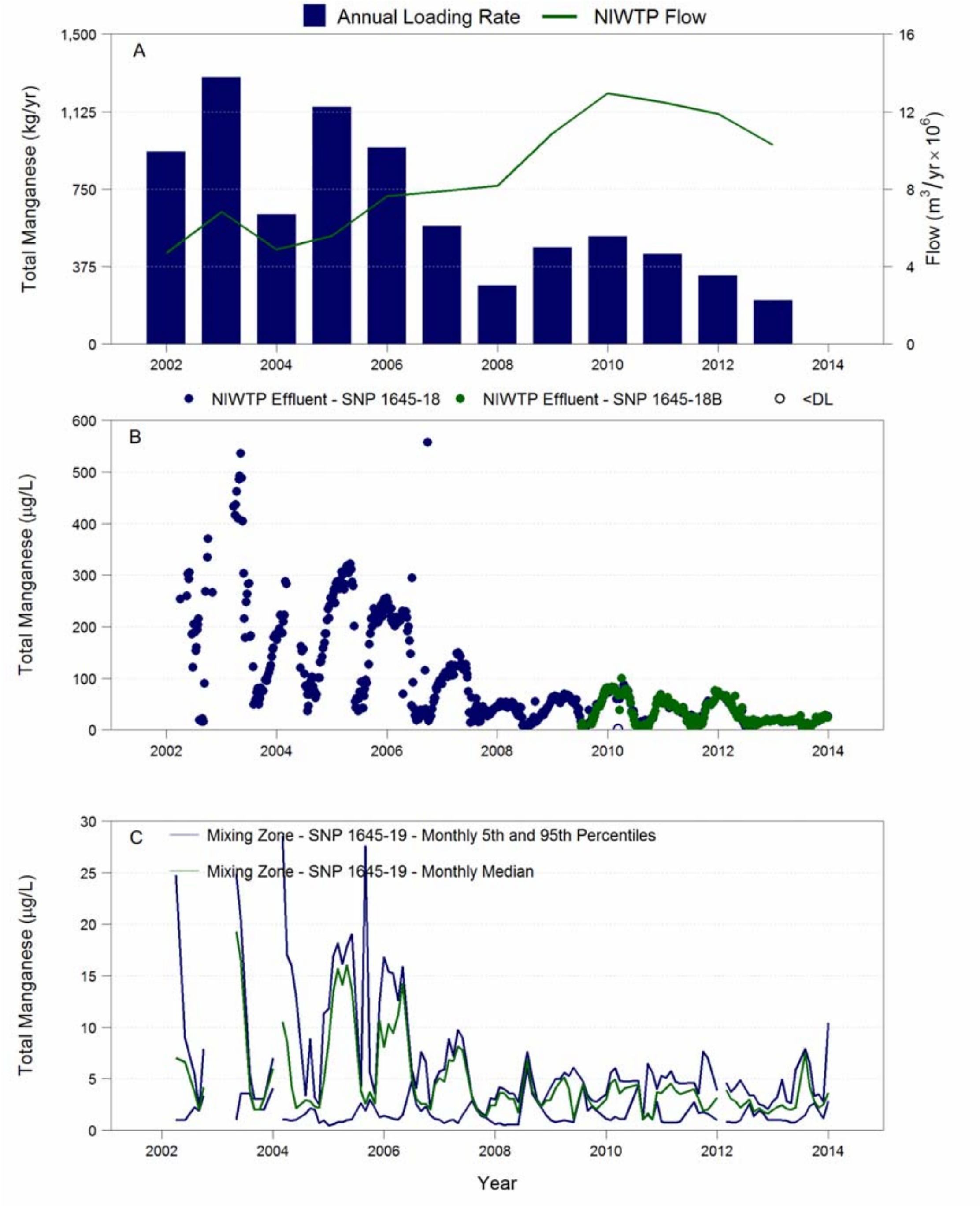
Figure 4-23 **A) Annual Loading Rate of Total Copper from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013**



Note: Annual loads were not calculated for copper from 2008 to 2010 because a large percentage of concentrations in effluent were below the detection limit. Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m). Open symbols represent non-detectable values.

SNP = surveillance network program.

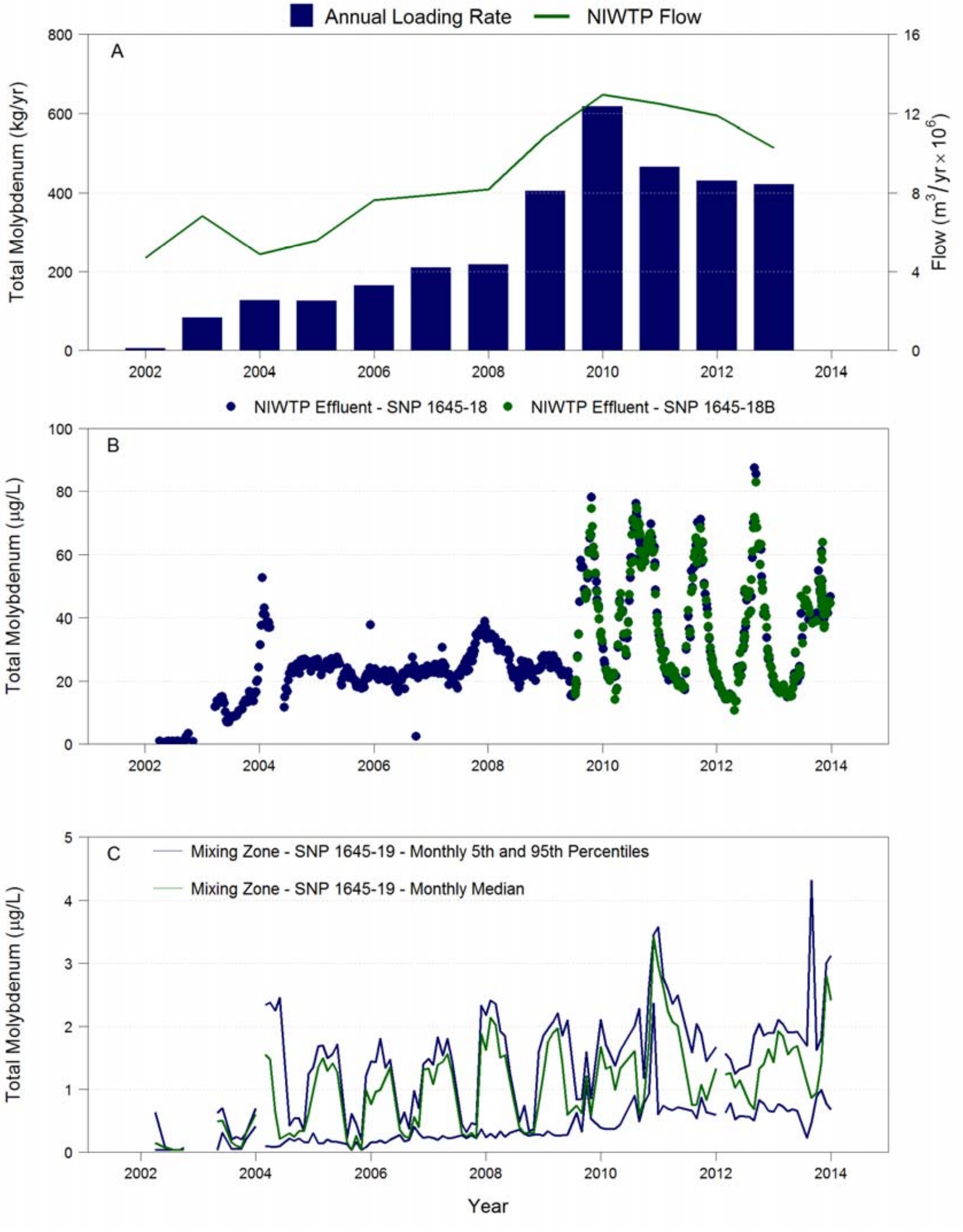
Figure 4-24 **A) Annual Loading Rate of Total Manganese from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013**



Note: Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m). Open symbols represent non-detectable values.

SNP = surveillance network program.

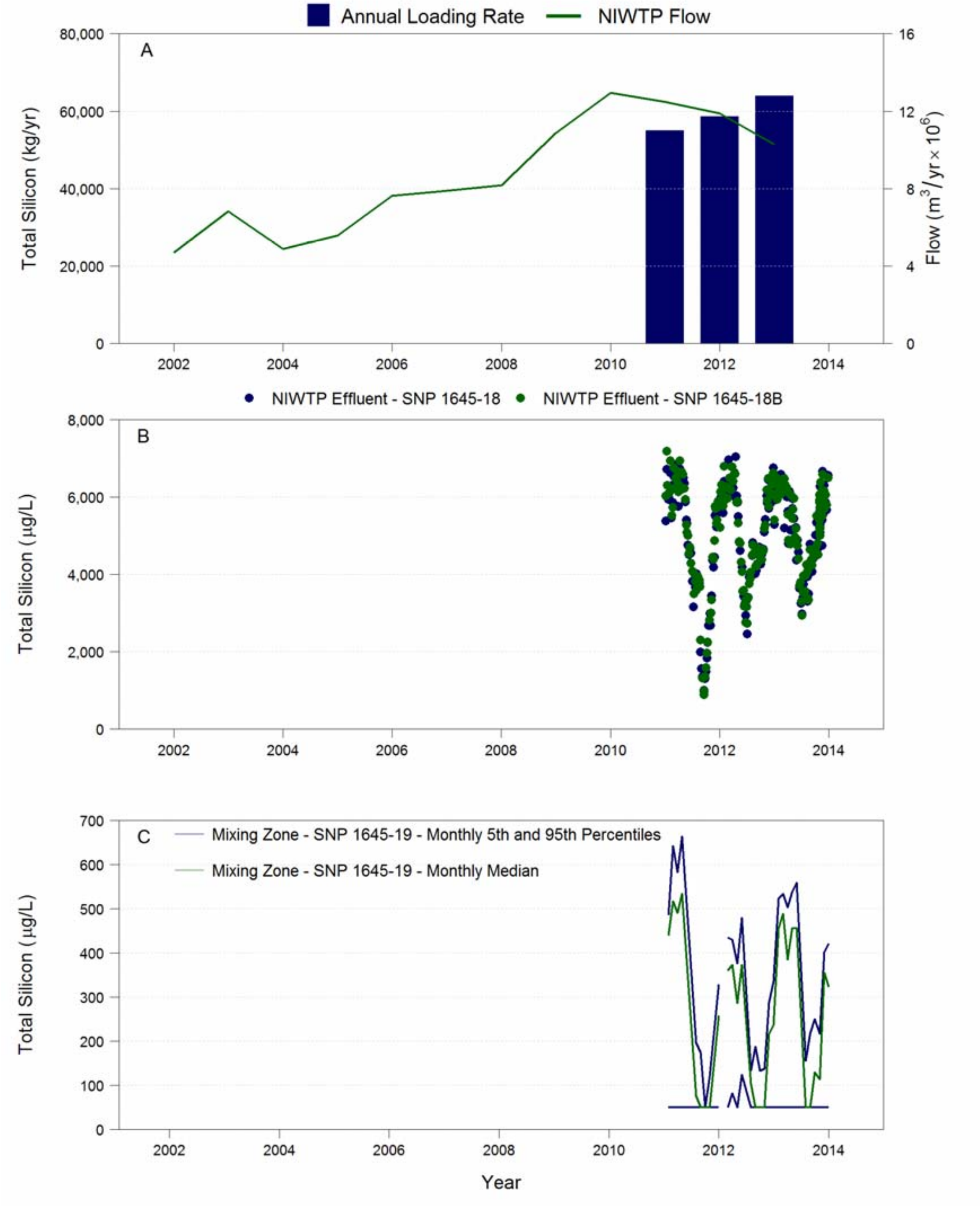
Figure 4-25 A) Annual Loading Rate of Total Molybdenum from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013



Note: Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m).

SNP = surveillance network program.

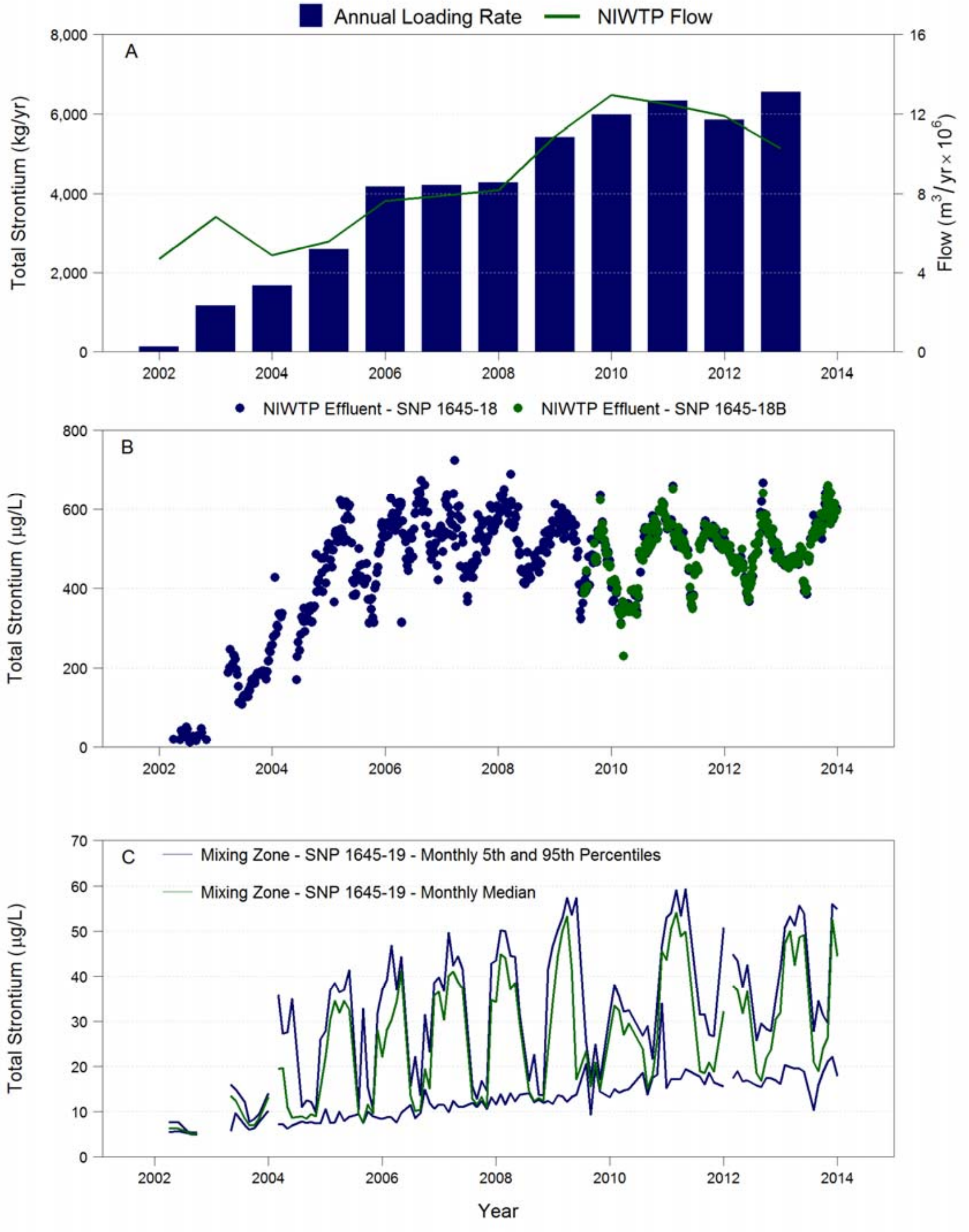
Figure 4-26 A) Annual Loading Rate of Total Silicon from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2011 to 2013



Note: Silicon was not analyzed prior to 2011. Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m).

SNP = surveillance network program.

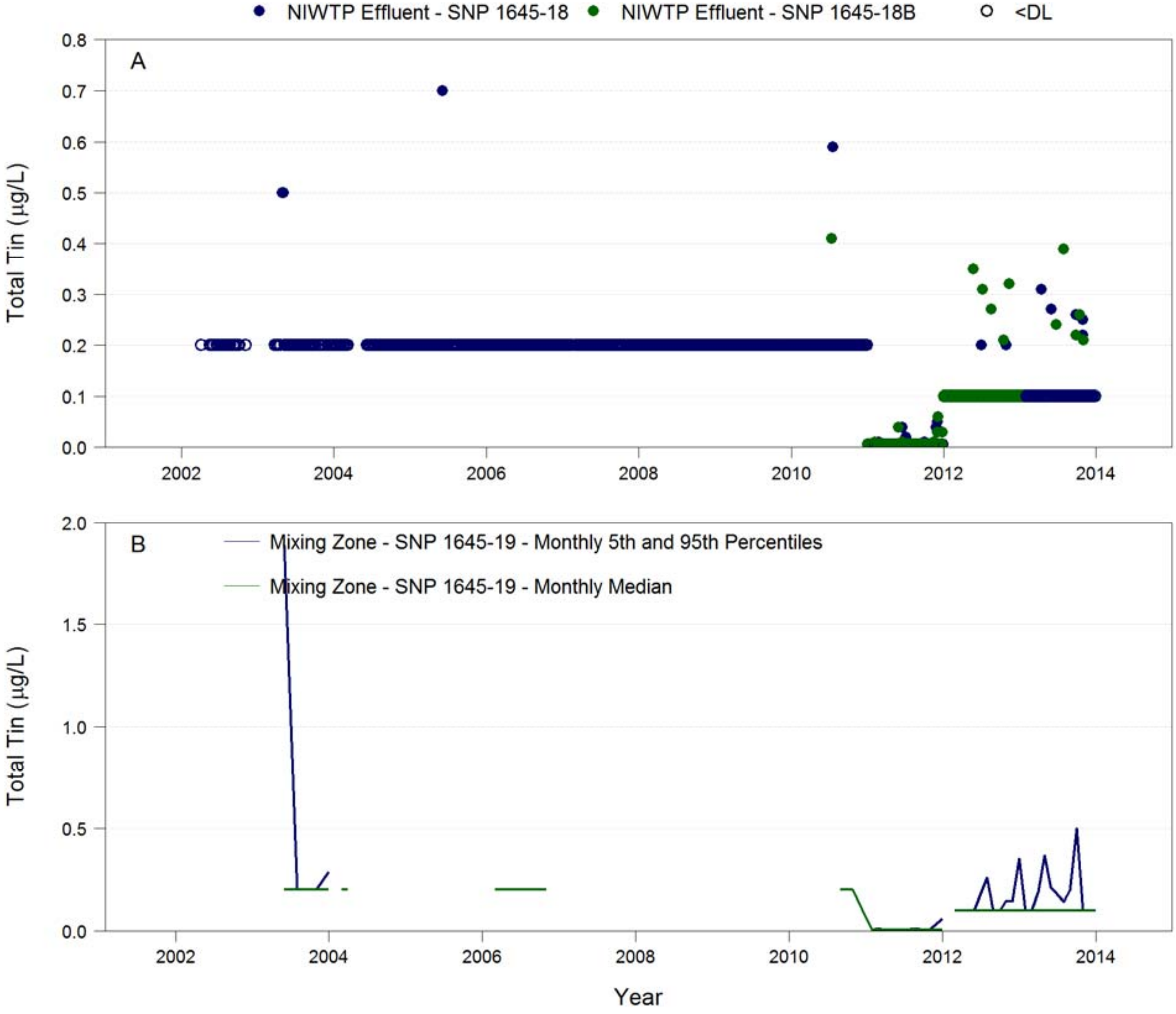
Figure 4-27 A) Annual Loading Rate of Total Strontium from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013



Note: Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m).

SNP = surveillance network program.

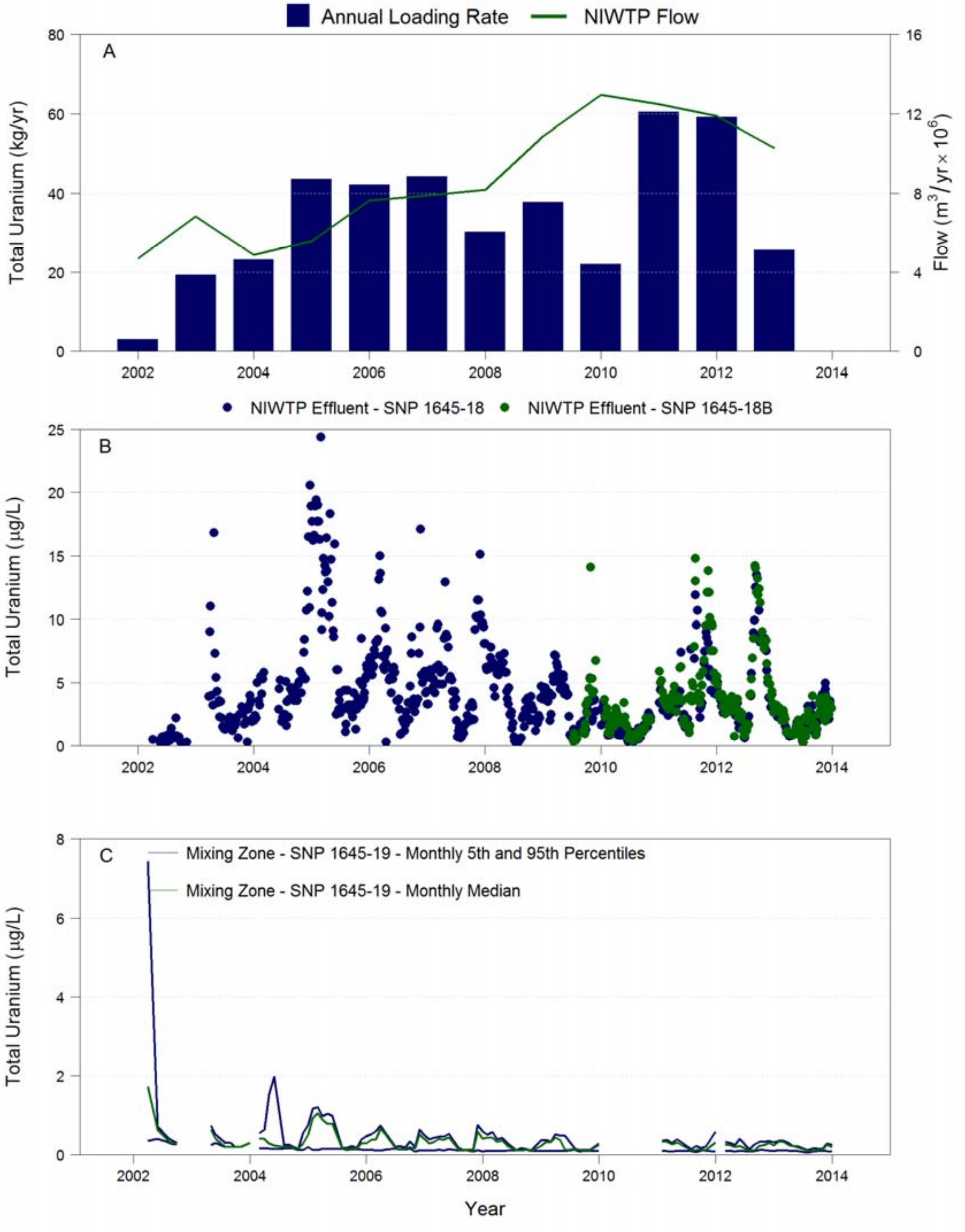
Figure 4-28 **A) Annual Loading Rate of Total Tin from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013**



Note: Annual loads were not calculated for tin because a large percentage of concentrations in effluent were below the detection limit. Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m). Open symbols represent non-detectable values.

SNP = surveillance network program.

Figure 4-29 **A) Annual Loading Rate of Total Uranium from the North Inlet Water Treatment Plant (NIWTP); and Concentration in B) Effluent (SNP 1645-18 and SNP 1645-18B), and C) at the Mixing Zone Boundary (SNP 1645-19), 2002 to 2013**



Note: Effluent values represent concentrations in individual samples. Mixing zone values represent the monthly 5th percentile, median and 95th percentile concentrations at three stations (SNP 1645-19A, SNP 1645-19B/B2, SNP 1645-19C) and five sampling depths (2 m, 5 m, 10 m, 15 m, and 20 m).

SNP = surveillance network program.

4.4 Comparison to Effluent Discharge Criteria

The concentrations of SOIs and nutrients in treated effluent have remained below both the maximum allowable concentration in any grab sample and the average monthly concentration (Table 4-1) for the 2011 to 2013 re-evaluation period. Additional parameters (i.e., non-SOIs) that have Water Licence limits were also within applicable discharge criteria throughout the 2011 to 2013 re-evaluation period. A single elevated oil and grease value of 16.7 mg/L collected at Station SNP 1645-18 on August 14, 2013 exceeded the maximum allowable concentration of 5 mg/L. However, further investigation indicated that the exceedance was due to a QA/QC issue (DDMI 2013a). Exceedances of EQC that have occurred throughout the historic operation of the NIWTP (i.e., from 2002-2010) are discussed in the AEMP annual reports for each year of monitoring.

The annual loads of TP from 2002 to 2013 were well below the average and maximum limits of 1,000 kg/yr and 2,000 kg/yr, respectively (Figure 4-14). Monthly loads of phosphorus are presented in the AEMP annual reports. The greatest monthly load of phosphorus reported to date was 140 kg in May 2013, which was below the maximum allowable limit of 300 kg/month.

4.5 Effluent Toxicity

Effluent toxicity has been tested since 2002. Toxicity tests on effluent samples from June 2002 to February 2008 were based on multiple effluent concentrations, whereas testing from March 2008 to December 2013 consisted of single-concentration (100% effluent) tests. The multi-concentration tests are reported in terms of the percentage of effluent concentration causing mortality, or a reduction in growth or reproduction endpoints in aquatic test organisms (Appendix 4B Tables 4B-1 and 4B-2). Toxicity in single-concentration tests is considered to occur if there is more than a 50% decrease in the mean response of test organisms in the undiluted effluent sample. Results for single-concentration tests are presented as a “pass” or “fail” (Tables 4-2 and 4-3).

The results of lethal and sub-lethal toxicity testing from 2002 to 2013 indicated that the Mine effluent was generally non-toxic to aquatic test organisms. From June 2002 to February 2008, a total of 160 treated effluent samples were submitted for acute and chronic lethality testing, and a total of 100 samples were submitted for sublethal testing. Toxicity test results demonstrated no toxic effects to aquatic test organisms in all but one of the samples submitted for lethal testing. Sub-lethal toxicity was observed in 12 samples during this period (Appendix 4B, Tables 4B-1 and 4B-2).

More recent results from March 2008 to December 2013 indicate that the effluent continues to be non-acutely toxic, with only one of the 168 samples submitted for testing demonstrating toxicity (Table 4-2). One *Daphnia magna* test in September 2010 at SNP 1645-18B had a result of greater than 50% mortality, indicating acute toxicity. To follow up on, and confirm, the September 2010 result, acute toxicity testing on *D. magna* was completed monthly in November and December 2010 and throughout 2011. Acute toxicity testing from November 2010 to October 2011 found no acute toxicity to *D. magna*.

Of the 115 effluent samples collected from March 2008 to December 2013, only one demonstrated sublethal toxicity (Table 4-3). Reductions in *Ceriodaphnia dubia* reproduction were detected in tests of effluent conducted in June 2009 and September 2010; however, a re-test of the June 2009 sample did not reproduce the toxicity. The September sample, however, was not re-tested, and the result was reported as a failure. All other *C. dubia* testing performed from 2009 to 2013 passed the tests.

Table 4-2 Acute and Chronic Lethality Toxicity Testing Results, North Inlet Water Treatment Plant Effluent, 2008 to 2013

Species	Month	2008(b)	2009		2010		2011		2012		2013	
		1645-18	1645-18	1645-18B	1645-18	1645-18B	1645-18	1645-18B	1645-18	1645-18B	1645-18	1645-18B
Rainbow Trout(a)	January	(c)	-	-	-	-	Pass	Pass	-	-	Pass	Pass
	February	(c)	-	-	-	-	-	-	-	-	-	-
	March	Pass	Pass	-	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
	April	Pass	-	-	-	-	-	-	-	-	-	-
	May	Pass	-	-	-	-	-	-	-	-	-	-
	June	Pass	Pass	-	Pass	Pass	-	-	Pass	Pass	Pass	Pass
	July	Pass	-	-	-	-	-	-	-	-	-	-
	August	Pass	-	-	-	-	Pass	Pass	-	-	-	-
	September	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
	October	(d)	-	-	-	-	-	-	-	-	-	-
	November	(d)	-	-	-	-	-	-	-	-	-	-
	December	Pass	Pass	Pass	Pass	Pass	Pass	-	Pass	Pass	-	-
Ceriodaphnia dubia(a)	January	(e)	-	-	-	-	-	-	-	-	-	-
	February	(e)	-	-	-	-	-	-	-	-	-	-
	March	(e)	(e)	(e)	(e)	(e)	(e)	(e)	Pass	Pass	Pass	Pass
	April	(e)	-	-	-	-	-	-	-	-	-	-
	May	(e)	-	-	-	-	-	-	-	-	-	-
	June	(e)	(e)	(e)	(e)	(e)	(e)	(e)	Pass	Pass	Pass	Pass
	July	(e)	-	-	-	-	-	-	-	-	-	-
	August	(e)	-	-	-	-	-	-	-	-	-	-
	September	(e)	(e)	(e)	(e)	(e)	(e)	(e)	Pass	Pass	Pass	Pass
	October	(e)	-	-	-	-	-	-	-	-	-	-
	November	(e)	-	-	-	-	-	-	-	-	-	-
	December	(e)	(e)	(e)	(e)	(e)	(e)	(e)	Pass	Pass	Pass	Pass

Table 4-2 Acute and Chronic Lethality Toxicity Testing Results, North Inlet Water Treatment Plant Effluent, 2008 to 2013

		2008(b)	2009		2010		2011		2012		2013	
Species	**Month**	**1645-18**	**1645-18**	**1645-18B**	**1645-18**	**1645-18B**	**1645-18**	**1645-18B**	**1645-18**	**1645-18B**	**1645-18**	**1645-18B**
Daphnia magna(a)	January	(c)	-	-	-	-	Pass	Pass	-	-	-	-
	February	(c)	-	-	-	-	-	-	-	-	-	-
	March	Pass	Pass	-	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
	April	Pass	-	-	-	-	Pass	Pass	-	-	-	-
	May	Pass	-	-	-	-	Pass	Pass	-	-	-	-
	June	Pass	Pass	-	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
	July	Pass	-	-	-	-	Pass	Pass	-	-	-	-
	August	Pass	-	-	-	-	Pass	Pass	-	-	-	-
	September	Pass	Pass	Pass	Pass	Fail(g)	Pass	Pass	Pass	Pass	Pass	Pass
	October	(d)	-	-	-	-	Pass	Pass	-	-	-	-
	November	(d)	-	-	Pass	Pass	-	-	Pass	Pass	-	-
	December	Pass	Pass	Pass	Pass	Pass	-	Pass	Pass	Pass	Pass	Pass
Hyalella azteca(a)	January	(f)	Pass	-	-	-	-	-	-	-	-	-
	February	(f)	Pass	-	-	-	-	-	-	-	-	-
	March	(f)	Pass	-	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
	April	(f)	Pass	-	-	-	-	-	-	-	-	-
	May	Pass	Pass	-	-	-	-	-	-	-	-	-
	June	Pass	Pass	-	Pass	Pass	-	-	-	-	Pass	Pass
	July	Pass	(d)	-	-	-	-	-	-	-	-	-
	August	Pass	(d)	-	-	-	Pass	Pass	-	-	-	-
	September	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	(h)	(h)
	October	Pass	-	-	-	-	-	-	-	-	-	-
	November	Pass	-	-	-	-	-	-	-	-	-	-
	December	Pass	Pass	Pass	Pass	Pass	Pass	Pass	-	-	Pass	Pass

a) Test is considered a "fail" if mortality is ≥50%.
b) Results for SNP 1645-18B are reported from 2009 and later.
c) Acute toxicity testing results in January and February of 2008 are shown in Appendix 4A, Table 4A-1.
d) Monthly testing was no longer required.
e) The *Ceriodaphnia dubia* test was not performed prior to March 2012.
f) The *Hyalella azteca* test was not performed prior to May 2008.
g) 100% mortality of test organisms reported.
h) The effluent sample collected in September for *Hyalella azteca* testing was misplaced in transit from the Mine to the analytical laboratory.
\- = data not available.

Table 4-3 Sub-lethal Toxicity Testing Results, North Inlet Water Treatment Plant Effluent, 2008 to 2013

Species	Month	2008	2009		2010		2011		2012		2013	
		1645-18	**1645-18**	**1645-18B**	**1645-18**	**1645-18B**	**1645-18**	**1645-18B**	**1645-18**	**1645-18B**	**1645-18**	**1645-18B**
Rainbow Trout(a)	January	-	-	-	-	-	-	-	-	-	Pass	Pass
	March	Pass	Pass	-	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
	June	Pass	Pass	-	Pass	Pass	-	-	Pass	Pass	-	-
	July	-	-	-	-	-	-	-	-	-	Pass	Pass
	September	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass(f)	Pass	Pass	Pass
	December	Pass	Pass	Pass	Pass	Pass	Pass	-	Pass	Pass	-	-
Ceriodaphnia dubia(b)	March	Pass	Pass	-	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
	June	Pass	Pass(c)	-	Pass	Pass	-	-	Pass	Pass	Pass	Pass
	September	Pass	Pass	Pass	Fail(d)	Pass	Pass	Pass	Pass	Pass	Pass	Pass
	October	-	-	-	-	-	-	-	-	-	-	-
	December	Pass	Pass	Pass	Pass	Pass	-	Pass	Pass	Pass	Pass	Pass
Pseudokirchneriella subcapitata(b)	March	Pass	Pass	-	Pass	Pass	Pass(e)	Pass(e)	Pass	Pass	Pass	Pass
	June	Pass	Pass	-	Pass	Pass	-	-	Pass	Pass	Pass	Pass
	September	Pass	Pass	Pass	Pass	Pass	-	Pass(e)	Pass	Pass	Pass	Pass
	October	-	-	-	-	-	-	-	-	-	-	-
	December	Pass	Pass	Pass	Pass	Pass	-	-	Pass	Pass	Pass	Pass

a) Trout embryo (Early Life Stage) survival test is considered a “fail”, if reduction in viable embryos is ≥50% compared to controls.

b) Test is considered a “fail” if reduction in growth compared to controls is ≥50%.

c) Initial test results indicated that% mortality was 60%. When the sample was reanalyzed to verify the results, mortality was 0%.

d) The% mortality was 70%.

e) Lab results indicate enhanced algal growth.

f) The result for this test was a marginal pass (reduction in viable embryos compared to the control was 48%).

4.6 Conclusions

- The annual loading rate of TDS and several associated ions (calcium, chloride, fluoride, magnesium and sodium) increased over time, from 2002 to approximately 2010. Since about 2010, the loads of these substances have decreased, or remained within a similar range. An exception was fluoride, which remained elevated from 2011 to 2013.
- Whereas effluent loads and/or concentrations of some metals have increased over time (molybdenum, silicon and strontium), most have either decreased (copper, manganese), fluctuated over time (barium), or have remained at relatively similar levels (aluminum, antimony, chromium, uranium). Effluent concentrations of two metals (cadmium and tin) were below the DLs used for the SNP data set in most samples analyzed.
- The annual loading rate and concentration of nitrogen parameters (TN, ammonia, nitrate and nitrite) peaked in Mine effluent in 2006 or 2007 and then declined until approximately 2010. The loading rate of nitrogen from the Mine has remained relatively stable over the last 3 to 4 years.
- The annual loading of phosphorus (TP, TDP and SRP) to Lac de Gras has increased over time, reflecting the increasing concentration of phosphorus in effluent.
- Trends in the concentrations of SOIs and nutrients at the mixing zone boundary generally reflected the temporal patterns described in the annual loading rates for these variables. The magnitude of the patterns observed at the mixing zone, however, was often less pronounced than those in effluent.
- Effluent tested between 2002 and 2013 was generally non-toxic to aquatic test organisms, as shown in over 300 acute toxicity tests and over 200 sub-lethal toxicity tests.
- Mine effluent continues to meet Effluent Quality Criteria specified in the Water Licence.

5 WATER QUALITY

5.1 Introduction

This chapter provides a summary of changes observed in the water chemistry of Lac de Gras. The objectives of this chapter are to:

- summarize Mine-related effects observed from 2011 to 2013 and compare these to effects observed previously (i.e., from 2007 to 2010); and
- analyze temporal trends in water chemistry for the period extending from baseline (i.e., 1996) to 2013.

The water chemistry component of the AEMP in 2012 and 2013 (under the AEMP Version 3.0) consisted of one sampling period during the ice-cover season and one sampling period during the open-water season. Due to seasonal changes in water chemistry over the course of the open-water period, sampling during open-water took place during a specific period (between August 15 and September 15). Sampling under AEMP Versions 1.0 and 2.0 was not restricted to these dates, although sampling did occur during this period. All historical open-water data and analyses presented in this chapter are based on samples collected from August 15 to September 15.

Water quality monitoring in Lac de Gras began in 1996 as part of the environmental baseline work completed to support the Environmental Assessment (EA). Results obtained from these studies, up to and including results from 2000, represented the baseline or pre-development conditions in Lac de Gras. Water quality in Lac de Gras has been monitored as part of the Mine's AEMP since 2001. The original AEMP (Version 1.0) included one water quality sampling event prior to the discharge the Mine effluent to Lac de Gras, which occurred in March 2002. The first water quality monitoring event during treated effluent discharge to Lac de Gras was in April 2002.

Annual analysis and reporting of water chemistry data under the AEMP is focussed on Substances of Interest (SOIs). These SOIs represent substances in Lac de Gras that may be affected by Mine effluent. Effects on water quality are identified by comparing concentrations of SOIs between exposure and reference areas using statistical tests, and by comparing SOI concentrations to background values and AEMP benchmarks. This AEMP re-evaluation report provides an opportunity to examine changes in SOI concentrations over time. A temporal assessment of SOIs in effluent and in the effluent mixing zone in Lac de Gras is provided in Section 4.

5.2 Methods

5.2.1 Substances of Interest

The intent of selecting SOIs is to identify a meaningful set of variables that will undergo further analyses, while limiting analyses on variables that are less likely to be affected. As described in the AEMP Study Design Version 3.5 (Golder 2014a), the process of developing the list of SOIs considered concentrations in the final effluent (at stations SNP 1645-18 and SNP 1645-18B), as well as in the fully-mixed exposure area of Lac de Gras:

- Effluent chemistry data collected at stations SNP 1645-18 and SNP 1645-18B were first compared to Water Licence discharge limits (Section 4, [Effluent]). Variables that exceeded limits during the 2011 to 2013 re-evaluation period were considered SOIs. Variables with effluent concentrations that exceeded AEMP Effects Benchmark values (Section 5.2.4.1.1) during the re-evaluation period were also included in the SOI list, provided there was not a high percentage of values below the DL (>90%).
- Water quality variables analyzed over the 2011 to 2013 re-evaluation period were assessed according to the Action Level framework (see Section 5.2.4.1.1). Variables that triggered Action Level 1 during the 2011 to 2013 re-evaluation period were added to the SOI list.

Integration of the Action Level assessment results into the process of selecting SOIs represented a change from SOI selection in previous AEMP annual reports. The SOI selection procedure used prior to 2013 employed a different set of criteria, which are described in the AEMP Version 2.0 Design Document (DDMI 2007a). As a result, the annual AEMP data were re-evaluated to establish the list of SOIs in each year of monitoring based on the revised selection process. Therefore, SOIs identified in this report differ from those listed in the AEMP annual reports.

5.2.2 Data Sources

Water chemistry data included in the evaluation of temporal trends were taken from the following data sources:

- Baseline data collected by DDMI from 1996 to 2000;
- Data collected during the AEMP Version 1.0 (2001 to 2006);
- Data collected during the AEMP Version 2.0 (2007 to 2011); and
- Data collected during the AEMP Version 3.0 (2012 to 2013).

Sampling methods and laboratory procedures used during the AEMP (2001 to 2013) were generally the same as those used during baseline (1996 to 2000), which allows comparisons over time. However, there have been some differences in methods over the years that have resulted in comparability issues between recent and historical data. These included differences in sampling locations, depth of sampling, timing of sample collection, analytical laboratories contracted for sample analyses, detection limits (DLs) and variables analyzed. These modifications to the AEMP design were introduced, as required, to allow the annual monitoring programs to meet the goals of the AEMP.

The sampling locations used throughout the baseline period (1996 to 2000) and during the AEMP Version 1.0 differ from the current AEMP stations, which were established initially in 2007 and then adjusted in 2012 (Golder 2011b). The pairing of historical stations with current AEMP stations is summarized in Table 5-1. Historical sampling stations not located in the vicinity of current AEMP stations were not included in the analysis. In addition, AEMP Version 2.0 stations no longer sampled in AEMP Version 3.0 were excluded from the analysis.

Sampling depths changed in AEMP Version 2.0. The 2007 to 2013 AEMP samples were collected at three depths (top, middle, and bottom) in exposure areas (Near-field [NF] and Mid-Field [MF] areas) and at a single depth (middle-depth) in the far-field (FF) reference areas. In contrast, all water quality samples collected during baseline and the AEMP Version 1.0 were collected at middle depth only.

The frequency and timing of water quality sampling in Lac de Gras has changed over the duration of the AEMP. There were three distinct open-water sampling periods in the AEMP Version 2.0 (DDMI 2007a). An analysis of these data demonstrated that one open-water sampling period and one ice-cover (April/May) sampling period would be adequate to detect Mine-related effects (Golder 2011b). Under the AEMP Version 3.0, annual open-water monitoring was conducted in late summer, from August 15 to September 15. Historical data used in this report are restricted to those collected within this period. An exception was made for baseline and AEMP Version 1.0 data, if there were no data for the late summer period. In this case, results for samples collected nearest to the target dates were used.

Table 5-1 List of Historical Water Quality Sampling Stations Included in the Temporal Assessment

Program	Year	Historical Station	Current AEMP Station
Baseline	1996	WQ-2	MF1-3
Baseline	1996, 1997 and 1999	WQ-5	MF3-2
Baseline	1996, 1997 and 1999	WQ-6	NF5
Baseline	1996, 1997 and 1999	WQ-7	MF3-2
AEMP	2000 and 2002 to 2006	LDG40	MF1-3
AEMP	2000 and 2002 to 2006	LDG41	MF3-4
AEMP	2000 and 2002 to 2006	LDG42	NF5
AEMP	2000 and 2002 to 2006	LDG43	MF3-2
AEMP	2000 and 2002 to 2006	LDG44	MF3-6
AEMP	2000 and 2002 to 2006	LDG45	FF2-2
AEMP	2000 and 2002 to 2006	LDG46	FFA
AEMP	2002 to 2006	LDG50	FFB

Samples included in this summary were analyzed by different analytical laboratories: Maxxam Analytics (Maxxam) in Calgary, Alberta (1996 to 1999 data); Enviro-Test Laboratories (ETL) in Edmonton, Alberta (2000 to 2006 data); ALS Environmental (ALS), in Edmonton, Alberta (2007 to 2010 data), which purchased the ETL facility in 2007; and Maxxam in Burnaby, British Columbia (2011 to 2013 data). Improvements in the analytical DLs over the 1996 to 2013 monitoring period confounded the temporal analysis for some variables. For these variables, data generated using the older, higher DLs could only be reported as <DL. Finally, the suite of variables analyzed since baseline has expanded. As a result, data for some analytes were not available during the baseline and earlier monitoring years.

5.2.3 Data Handling

Initial screening of the annual AEMP water quality data sets was completed before data analyses to identify unusually high (or low) values in the datasets and decide whether to retain or exclude anomalous data from further analysis. An explanation of the objectives and approach taken to complete initial screening is provided in Section 2.6. Results of the initial screening for anomalous values in the AEMP water quality dataset is presented in Appendix 5A, Table 5A-1. In total, 79 anomalous values were identified within the baseline and AEMP water quality data sets, representing 0.17% of the total dataset. In cases where unusual values were identified in the annual datasets, scatter-plots were generated allow a visual review of excluded data (Appendix 5A, Figures 5A-1 to 5A-79).

Prior to data analyses, non-detect values were multiplied by 0.5 times the DL. Substitution with half the DL is a common approach used to deal with censored data (US EPA 2000) and is consistent with the approved methods applied in the calculation of the normal range in the AEMP Reference Conditions Report Version 1.1. The non-parametric methods used in this re-evaluation report to assess Action Levels for water quality (Section 5.2.4.1.1) and test for the statistical significance of a temporal trend in SOI concentrations (Section 5.2.4.2.2) minimized the influence of using a substitution method for censored data.

5.2.4 Data Analysis

5.2.4.1 Summary of Effects

5.2.4.1.1 Action Levels

The importance of effects on water quality variables was categorized according to Action Levels described for water chemistry in the AEMP Study Design Version 3.5 (Golder 2014a). The Action Level classifications for water quality were developed to meet the goals of the Response Framework for Aquatic Effects Monitoring (WLWB 2010; Racher et al. 2011). The main goal of the Response Framework is to ensure that significant adverse effects never occur. This is accomplished by requiring proponents to take actions at pre-defined Action Levels, which are triggered well before significant adverse effects could occur.

The Action Level Framework for water chemistry was applied for the first time in the 2013 AEMP Annual Report (Golder 2014b). Based on recommendations made in that report, Action Level 2 was revised, because it was often triggered before Action Level 1. The revisions to Action Level 2 were approved by the WLWB on December 22, 2015 (WLWB 2015c). The updated Action Levels for water chemistry are shown in Table 5-2.

Magnitude of effects to water chemistry variables were determined by comparing analyte concentrations between exposure areas and reference areas, and to background values or benchmark values. Background values for Lac de Gras are those that fall within the range of natural variability, referred to as the *normal range*. The normal ranges used in the Action Level screening for water quality were obtained from the AEMP Reference Conditions Report, Version 1.1 (Golder 2015) and are summarized in Table 5-3. Likewise, the *2 X median of reference areas* criterion used at Action Level 1 (Table 5-2) was defined based on median values presented in the AEMP Reference Conditions Report. The water quality benchmark values used in the Action Level assessment, referred to herein as *AEMP Effects Benchmarks*, are shown in Table 5-4.

The annual AEMP water chemistry results from 2007 to 2013 were categorized according to the revised Action Levels to assess temporal trends in Mine-related effects on the water quality of Lac de Gras. Water chemistry results for years prior to 2007 were excluded from the Action Level assessment, because the sampling dates and station locations differed appreciably from the AEMP Versions 2.0 and 3.0. The full suite of water chemistry variables analyzed during the AEMP Versions 2.0 and 3.0 was evaluated, with the exception of field-measured variables and nutrients, which are evaluated in Section 6, (Eutrophication Indicators). Water quality variables triggered Action Levels if concentrations in the exposure area exceeded the relevant screening criteria in one or both sampling seasons (ice-cover or open-water).

Table 5-2 Action Levels for Water Chemistry, Excluding Indicators of Eutrophication

Action Level	Magnitude of Effect[a]	Extent of Effect	Action/Notes
1	Median of NF greater than 2X median of reference areas (open-water or ice-cover) and strong evidence of link to Mine	Near-field (NF)	Early warning.
2	5th percentile of NF values greater than 2X median of reference areas AND normal range[b]	Near-field	Establish *Effects Benchmark* if one does not exist.
3	75th percentile of MZ values greater than normal range plus 25% of Effects Benchmark[c]	Mixing zone (MZ)	Confirm site-specific relevance of Effects Benchmark. Establish *Effects Threshold*. Define the Significance Threshold if it does not exist. The WLWB to consider developing an Effluent Quality Criteria (EQC) if one does not exist
4	75th percentile of MZ values greater than normal range plus 50% of Effects Threshold[c]	Mixing zone	Investigate mitigation options.
5	95th percentile of MZ values greater than Effects Threshold	Mixing zone	The WLWB to re-assess EQC. Implement mitigation required to meet new EQC if applicable.
6	95th percentile of NF values greater than Effects Threshold + 20%	Near-field	The WLWB to re-assess EQC. Implement mitigation required to meet new EQC if applicable.
7	95th percentile of MF values greater than Effects Threshold + 20%	Mid-field (MF)	The WLWB to re-assess EQC. Implement mitigation required to meet new EQC if applicable.
8	95th percentile of FFB values greater than Effects Threshold + 20%	Far-field B (FFB)	The WLWB to re-assess EQC. Implement mitigation required to meet new EQC if applicable.
9	95th percentile of FFA values greater than Effects Threshold + 20%	Far-field A (FFA)	Significance Threshold.

a) Calculations are based on pooled data from all depths.

b) Normal ranges are obtained from the AEMP Reference Conditions Report Version 1.1 (Golder 2015); however, the normal range for open-water is based on the August 15 to September 15 period only.

c) Indicates 25% or 50% of the difference between the benchmark/threshold and the top of the normal range.

Table 5-3 Normal Ranges for Water Chemistry

Variable	Unit	Normal Range			
		Ice-cover		Open-water	
		Lower Limit	Upper Limit	Lower Limit	Upper Limit
Conventional Parameters					
Total Alkalinity	mg/L	3.2	6.0	3.1	4.7
Specific Conductivity	µS/cm	14.6	19.3	14.7	16.4
Total Hardness	mg/L	5.0	7.0	4.0	6.0
Total Dissolved Solids, Calculated	mg/L	2.9	6.5	3.8	5.8
Total Dissolved Solids, Measured	mg/L	0	24.0	0	20.0
Total Suspended Solids	mg/L	0	1.0	0	1.0
Total Organic Carbon	mg/L	2.0	3.1	1.9	3.0
Turbidity	NTU	0	0.18	0.13	0.29
Major Ions					
Calcium	mg/L	0.9	1.3	0.8	1.1
Carbonate	mg/L	0	0.5	0	0.5
Chloride	mg/L	0	1.0	0	1.0
Fluoride	mg/L	0.02	0.03	0.019	0.03
Hydroxide	mg/L	0	0.5	0	0.5
Magnesium	mg/L	0.6	0.8	0.6	0.8
Potassium	mg/L	0.5	0.8	0.4	0.7
Sodium	mg/L	0	1.0	0	1.0
Sulphate	mg/L	1.9	2.5	1.7	2.1
Nutrients					
Nitrogen - Ammonia	µg/L	14.3	23.0	0	5.0
Nitrate	µg/L	0	15.2	0	2.0
Nitrite	µg/L	0	2	0	2
Nitrate + Nitrite	µg/L	0	15.2	0	2.0
Total Metals					
Aluminum	µg/L	2.3	3.9	3.4	6.2
Antimony	µg/L	0	0.02	0	0.02
Arsenic	µg/L	0.15	0.22	0.16	0.19
Barium	µg/L	1.74	2.18	1.61	1.94
Beryllium	µg/L	0	0.01	0	0.01
Bismuth	µg/L	0	0.005	0	0.005
Boron	µg/L	0	5	0	5
Cadmium	µg/L	0	0.005	0	0
Calcium	mg/L	0.94	1.15	0.87	1.00
Chromium	µg/L	0	0.06	0	0.06
Cobalt	µg/L	0.01	0.02	0.01	0.04
Copper	µg/L	0	0.8	0	0.6
Iron	µg/L	0	5.0	0	7.6
Lead	µg/L	0	0.007	0	0.006

Table 5-3 Normal Ranges for Water Chemistry

Variable	Unit	Normal Range			
		Ice-cover		Open-water	
		Lower Limit	Upper Limit	Lower Limit	Upper Limit
Lithium	µg/L	1.2	1.5	1.2	1.3
Magnesium	mg/L	0.59	0.79	0.58	0.66
Manganese	µg/L	0.60	1.95	1.54	4.67
Mercury	µg/L	0	0.01	0	0.01
Molybdenum	µg/L	0.06	0.09	0.07	0.13
Nickel	µg/L	0.83	1.10	0.72	1.12
Potassium	mg/L	0.53	0.67	0.50	0.57
Selenium	µg/L	0	0.04	0	0.04
Silicon	µg/L	0	50	0	50
Silver	µg/L	0	0.005	0	0.005
Sodium	mg/L	0.56	0.75	0.55	0.68
Strontium	µg/L	6.70	8.78	6.51	8.01
Sulphur	mg/L	0.84	1.07	0.83	1.32
Thallium	µg/L	0	0.002	0	0.002
Tin	µg/L	0	0.01	0	0.01
Titanium	µg/L	0	0.5	0	0.5
Uranium	µg/L	0.027	0.030	0.024	0.029
Vanadium	µg/L	0	0.1	0	0.1
Zinc	µg/L	0.37	1.53	0.29	2.04
Zirconium	µg/L	0	0.05	0	0.05

µS/cm = microsiemens per centimetre; NTU = nephelometric turbidity unit.

Table 5-4 Effects Benchmarks for Water Quality Variables (Golder 2014a)

Variable	Units	Effects Benchmarks(i)	
		Protection of Aquatic Life	Drinking Water
Conventional Parameters			
pH	-	6.5 to 9.0	6.5 to 8.5
Dissolved oxygen	mg/L	Cold water: early life stages = 9.5; other life stages = 6.5	-
Total dissolved solids	mg/L	500(a)	500
Total alkalinity	mg/L	n/a(b)	
Total suspended solids	mg/L	+5 (24 h to 30 days); +25 (24-h period)(c)	-
Major Ions			
Chloride	mg/L	120	250
Sodium	mg/L	-	200
Fluoride	mg/L	0.12	1.5
Sulphate	mg/L	100(d)	500
Nutrients			
Ammonia as nitrogen	µg/L	4,730(e)	-
Nitrate as nitrogen	µg/L	3,000	10,000
Nitrite as nitrogen	µg/L	60	1,000
Total Metals			
Aluminum (total)	µg/L	-	100/200(f)
Aluminum (dissolved)	µg/L	Variable with pH (range = 12 to 50)(e)	-
Antimony	µg/L	-	6
Arsenic	µg/L	5	10
Barium	µg/L	1,000(d)	1,000
Boron	µg/L	1,500	5,000
Cadmium	µg/L	0.1(e)	5
Chromium	µg/L	1 (Cr VI)(g)	50
Copper	µg/L	2	1,000
Iron	µg/L	300	300
Lead	µg/L	1	10
Manganese	µg/L	-	50
Mercury	µg/L	0.026 (inorganic); 0.004 (methyl)	1
Molybdenum	µg/L	73	-
Nickel	µg/L	25	-
Selenium	µg/L	1	10
Silver	µg/L	0.1	-
Strontium	µg/L	30,000(h)	-
Thallium	µg/L	0.8	-
Uranium	µg/L	15	20
Zinc	µg/L	30	5,000

a) Adopted from Alaska DEC (2012).
b) Alkalinity should be no lower than 25% of natural background level. There is no maximum guideline (US EPA 1998).
c) Average increase of 5 (24 hours to 30 days) or maximum increase of 25 mg/L in a 24 h-period).
d) British Columbia Ministry of Environment (2013).
e) Site specific benchmark - see Appendix IV.1 in DDMI (2007a) for description.
f) 100 µg/L for conventional treatment and 200 µg/L for other treatment types.
g) Measurements of total chromium will be compared to the benchmark for chromium VI.
h) Based on results from HydroQual (2009) and Pacholski (2009).
i) Unless noted, benchmarks are derived from current CWQGs (CCME 1999a) and Canadian Drinking Water Quality Guidelines (Health Canada 1996, 2006). The Effects Benchmark is the lower of the two values.
\- = benchmark not available.

5.2.4.1.2 Weight of Evidence Effects Rankings

Results of the AEMP water quality surveys feed into the Weight of Evidence (WOE) assessment, which is described in Section 11. The WOE effects rankings for water quality incorporate results of statistical comparisons between the exposure and reference areas of Lac de Gras, as well as comparisons to AEMP Effects Benchmarks (Table 5-5).

In 2014, the criterion for determining a moderate effect ranking for water chemistry was refined to be consistent with the Action Level assessment for water chemistry. Water chemistry results from 2007 to 2013 were categorized according to the revised WOE rankings. The patterns of response observed in the WOE effects rankings over the 2007 to 2013 monitoring period were evaluated qualitatively to identify trends over time. The WOE effects rankings for water quality were applied only for variables that were identified as SOIs in a given year of monitoring. The selection procedure for identifying SOIs is described in Section 5.2.1.

Table 5-5 Weight of Evidence Effect Rankings for Water Chemistry

Effect Ranking	Guideline and Effect Sizes
Low	Statistically significant increase, NF vs reference
Moderate	Low Effect Ranking AND 5th percentile of NF area greater than 2 times greater than the reference median (2007-2010) AND 5th percentile of NF area greater than the normal range (2007-2010) AND 5th percentile of NF area greater than the benchmark
High	Statistically significant increase, MF vs. reference AND 75th percentile of MF area greater than the normal range (2007-2010) AND 75th percentile of MF area greater than the benchmark

NF = near-field; MF = mid-field; FF = far-field.

5.2.4.2 Temporal Trends

5.2.4.2.1 Time Series Plots

Temporal trends in SOIs in Lac de Gras were evaluated using time series plots. These plots were organized based on the AEMP sampling areas in Lac de Gras (Figure 2-2):

- the NF exposure area;
- three MF exposure areas (MF1, MF2 and MF3);
- one FF exposure area (FF2); and
- three FF reference areas (FF1, FFB and FFA).

Data from the five stations sampled in the NF area were plotted individually according to sample depth (top, middle and bottom). The maximum of the top, middle or bottom concentration at MF area stations was plotted for each transect (MF1, MF2 and MF3) on separate graphs. Data from the FF2 exposure area were incorporated into the figures for the MF2 area, because the FF2 area stations are located at the far northeast end of the MF2 transect. Data from the three FF reference areas (FF1, FFB and FFA) were also evaluated for the presence of temporal trends. Trends occurring in the reference areas may represent natural trends in water quality, or potentially, the presence of Mine effluent. Non-detect data were included in the time series plots (plotted at the DL) as open symbols. Time series plots were produced for each SOI, separately for each season, and trends were evaluated in relation to the normal range for Lac de Gras.

5.2.4.2.2 Statistical Analysis

The statistical significance of a temporal trend in SOI concentrations was tested with the Mann-Kendall test, which is a non-parametric rank based trend test for non-seasonal data. Mann-Kendall trend test results were considered significant at $P < 0.1$. Statistical testing was conducted with R software (R Core Team 2013).

Mann Kendall tests were performed on water quality data collected in the NF exposure area and FF reference areas (FF1, FFB, FFA), and at representative MF2 area stations (MF2-1 and FF2-2). Data from the MF1 and MF3 areas were not analyzed statistically to limit the number of tests performed, and because trends in these areas were generally similar to those in the MF2 area. Although time series plots show concentrations of SOIs over the complete period of available data (1996 to 2013), only results from the AEMP Versions 2.0 and 3.0 (2007 to 2013) were included in the trend analysis. This was required because of differences in sample collection methods and analytical procedures (e.g., sampling locations and timing, and DLs) used during earlier monitoring periods. Occasionally, trend tests were performed with fewer years of data due to the presence of non-detect values in the dataset, particularly in reference areas. Mann Kendall tests were performed where a minimum of 4 years of analytical data were available.

Mann Kendall tests were performed separately for ice-cover and open-water seasons. In the NF area, where three distinct depths were sampled at 5 replicate stations, the sampling depth with the greatest median concentration in each season and year (of top middle and bottom samples) was used in the analysis. At stations MF2-1 and FF2-2, the maximum concentration of top, middle, and bottom depths in each year of monitoring was used, since only a single station was sampled at each site. Mann Kendall tests on FF area data were run on the median concentration of five stations sampled at middle-depth (since reference area samples were collected at a single depth).

5.3 Results

5.3.1 Summary of Effects

5.3.1.1 Action Levels

5.3.1.1.1 Action Level 1

A variable triggered Action Level 1 if its concentration in the NF area was greater than two times the median concentration in the reference areas. In addition, the increase in concentration in the NF area had to be linked to the Mine to trigger Action Level 1. A total of 24 of 55 water quality variables assessed from 2007 to 2013 had NF area median concentrations that were greater than two times the reference area median concentrations (Table 5-6; Appendix 5B, Tables 5B-1 and 5B-2). Each of the 24 variables that triggered Action Level 1 was detected in the NIWTP effluent (Section 4). Several variables that triggered

Action Level 1 were also detected in dust, which may be deposited into Lac de Gras from mining activities (Section 3). This provided evidence of the linkage to the Mine that is required for an Action Level to be triggered. Hence, these 24 variables were considered SOIs for the year in which Action Level 1 was triggered. No management action is required under the Response Framework (Table 5-2) when a water quality variable triggers Action Level 1.

Table 5-6 Results of the Action Level Evaluation for Water Chemistry SOIs, 2007 to 2013

Substance of Interest	2007	2008	2009	2010	2011	2012	2013
Conventional Parameters							
Specific Conductivity	-	-	-	**AL1**	**AL1**	-	**AL1**
Total Hardness	-	-	-	-	**AL1**	-	**AL1**
Total Dissolved Solids, Calculated	-	**AL1**	**AL2**	**AL2**	n/a	**AL2**	**AL2**
Turbidity	**AL1**	-	**AL1**	**AL2**	n/a	**AL1**	**AL1**
Major Ions							
Chloride	**AL1**	**AL1**	**AL2**	**AL2**	**AL2**	**AL2**	**AL2**
Fluoride[(a)]	n/c	n/c	n/c	n/c	-	-	-
Sulphate	-	-	-	-	-	-	**AL1**
Nutrients[(b)]							
Nitrogen - Ammonia	**AL1**	**AL2**	**AL1**	-	(c)	(c)	(c)
Nitrate	**AL2**	**AL2**	**AL2**	**AL2**	**AL2**	**AL2**	**AL2**
Total Metals							
Aluminum	-	-	-	**AL1**	**AL2**	**AL1**	**AL1**
Antimony	n/c	n/c	n/c	n/c	**AL1**	**AL1**	**AL1**
Barium	**AL1**	**AL1**	**AL2**	**AL1**	**AL1**	-	**AL1**
Cadmium	n/c	n/c	n/c	n/c	**AL1**	-	(d)
Calcium	-	-	-	-	**AL1**	-	**AL1**
Chromium	**AL3**	-	-	-	n/c	n/c	**AL1**
Copper	**AL1**	-	-	**AL1**	**AL1**	-	**AL1**
Lead	n/c	n/c	**AL1**	n/c	-	-	-
Magnesium	-	-	-	-	**AL1**	-	-
Manganese	-	-	-	**AL1**	**AL1**	-	-
Molybdenum	**AL2**	**AL2**	**AL2**	**AL2**	**AL2**	**AL2**	**AL2**
Silicon	n/a	n/a	n/a	n/a	**AL1**	**AL2**	**AL1**
Sodium	-	**AL1**	**AL1**	**AL2**	**AL2**	**AL2**	**AL2**
Strontium	-	-	**AL1**	**AL1**	**AL2**	**AL2**	**AL2**
Tin	n/a	n/a	n/a	n/a	-	**AL1**	**AL2**
Uranium	**AL2**	**AL2**	**AL2**	**AL2**	**AL2**	**AL2**	**AL2**

Notes: - = did not trigger an Action Level; n/c = Action Level comparison could not be completed for one or both sampling seasons (i.e., ice-cover, open-water) due to an elevated detection limit; n/a = not analyzed in one or both sampling seasons; **AL1** = Action Level 1 triggered; **AL2** = Action Level 2 triggered; **AL3** = Action Level 3 triggered.

Detailed Action Level results for water chemistry are provided in Tables 5B-1 to 5B-6 of Appendix 5B.

a) Fluoride did not trigger an Action Level from 2007 to 2013; however, it is shown in table for context because it is the only variable added to the list of SOIs based on the results of the effluent assessment (Section 5.3.2).

b) Nutrients that are generally not toxic to aquatic organisms are evaluated in the Eutrophication Indicators section of this report (Section 6).

c) Action Level results for ammonia from 2011 to 2013 are uncertain due to laboratory quality control issues identified during that period (Section 5.3.1.1).
d) Action Levels comparisons could not be completed for the open-water season due to sample contamination (see Appendix BI of Golder 2013).

For some substances that appear in more than one form, or that appear in different fractions (e.g., total and dissolved; measured and calculated), the most representative of these was included in the Action Level evaluation. For example, both nitrite and nitrate were analyzed in water samples; however, since most samples (>99%) had nitrite concentrations below the DL and since the results for nitrate + nitrite were generally identical to those for nitrate, only nitrate was evaluated against the Action Levels. Although the dissolved fractions of calcium, magnesium and sodium triggered Action Level 1 in at least one year of monitoring, only the total fractions of these substances are presented as having triggered an Action Level. Historically, the DLs used for total concentrations were lower than those used for the dissolved fractions. As a result, there were fewer concentrations reported as below detect for the total fraction, thus allowing for a more complete evaluation across years. In addition, results for dissolved calcium, magnesium, and sodium were not available in 2011, because major ions were not analyzed in that year.

Data quality issues with ammonia from 2011 to 2013 confounded the determination of Action Levels. In all three years, ammonia concentrations in blank samples analyzed by Maxxam were at or above levels found in Lac de Gras, while concentrations reported for lake water samples were greater and more variable than values previously provided by ALS (2007-2010). As a result, ammonia data reported from 2011 to 2013 could not be compared to concentrations from 2007 to 2010, upon which background concentrations are based (Golder 2015). Given these issues with the ammonia analysis, ammonia was retained as an SOI for the 2011 to 2013 re-evaluation period.

5.3.1.1.2 Action Level 2

Variables that triggered Action Level 1 were evaluated against Action Level 2 (Table 5-6, Appendix 5B, Tables 5B-3 and 5B-4). Action Level 2 was triggered if the 5th percentile concentration in the NF area was greater than two times the reference area median and greater than the normal range. Of the 24 variables that triggered Action Level 1 in one or more AEMP year during 2007 to 2013, 14 (calculated TDS, turbidity, chloride, ammonia, nitrate, aluminum, barium, chromium, molybdenum, silicon, sodium, strontium, tin and uranium) triggered Action Level 2 in at least one year of monitoring during this period (Table 5-6).

Under the Response Framework, when a water quality variable triggers Action Level 2, the required management action is to establish an AEMP Effects Benchmark for that variable if one does not already exist. Five of the variables that triggered Action Level 2 (turbidity, sodium, and the total fractions of aluminum, silicon and tin) do not have existing AEMP Aquatic Life Effects Benchmarks. Therefore, DDMI will be required to develop AEMP Effects Benchmarks for these variables.

5.3.1.1.3 Action Level 3

The variables that triggered Action Level 2 were evaluated against Action Level 3. Action Level 3 was applied if the 75th percentile concentration at the mixing zone boundary is greater than the normal range plus 25% of the distance between the top of the normal range and the AEMP Effects Benchmark. Therefore, only water quality variables that have existing AEMP Aquatic Life Effects Benchmarks (Table 5-3) were evaluated against Action Level 3. Of the nine variables evaluated, chromium was the only variable that triggered Action Level 3, and only in 2007 (Table 5-6, Appendix 5B). The 75th percentile value for chromium at the mixing zone boundary (0.31 µg/L) was just above the screening value used at Action Level 3 (0.30 µg/L) during a single sampling event from 2007 to 2013 (ice-cover season, 2007). Since 2007, chromium concentrations have decreased at the mixing zone boundary (Section 4, Figure 4-22; Appendix 5B, Tables 5B-5 and 5B-6), with 75th percentile values measured at or below the DL (0.06 to 0.1 µg/L) in all sampling events from 2009 to 2013.

Chromium occurs in the environment in two valence states, trivalent chromium (Cr III) and hexavalent chromium (Cr VI), which is more toxic than chromium (III) (CCME 1999b). The AEMP Effects Benchmark for chromium is based on the CCME guideline for hexavalent chromium (Cr VI; 1 µg/L) and is applied to measurements of total chromium at the mixing zone boundary; the aquatic life guideline for trivalent chromium is 8.5 µg/L. Hence, the benchmark value used in the calculation of the screening criterion for Action Level 3 (normal range + 25% of Effects Benchmark) is very conservative. Total chromium concentrations at the mixing zone boundary were well below the guideline for chromium (Cr VI) in all samples during the 2007 to 2013 monitoring period (Section 4, Figure 4-22).

The management action required under the Response Framework when a water quality variable triggers Action Level 3 is to confirm the site specific relevance of the Effects Benchmark. In addition, the proponent is required to establish an *Effects Threshold* and define the *Significance Threshold* if one does not exist. Finally, the WLWB is to consider developing an Effluent Quality Criteria (EQC) if one does not exist. Chromium concentrations in effluent are were well below the existing EQC (40 µg/L) from the NIWTP discharge (Section 4, Figure 4-22) for the 2002 to 2013 discharge period.

In light of the lack of an Action Level 3 exceedance during the last six years of monitoring and the conservative nature of the benchmark, an action related to the observed concentrations of total chromium is not warranted at this time.

5.3.1.1.4 Summary

The number of variables that triggered at least Action Level 1 increased from 2007 to 2011, with nine variables in 2007 and 18 variables (including ammonia) in 2011. Thirteen variables that triggered at least Action Level 1 in 2012 and 21 variables triggered in 2013 (Table 5-6). Sulphate triggered Action Level 1 for the first time in 2013. The number of variables that triggered Action Level 2 increased from 2007 to 2010 (ranging from 3 variables in 2007 to 7 variables in 2010) and has remained constant over the 2011 to 2013 re-evaluation period. In general, variables triggered Action Levels more frequently during the ice-cover sampling season compared to the open-water season, consistent with the expectation of less effective mixing of effluent by diffusion and lake currents under ice, compared to wind-driven mixing during open-water conditions.

5.3.1.2 Weight-of-Evidence Effects Rankings

In general, SOIs identified in a given year satisfied the requirement for a low WOE effect ranking, because concentrations in the NF area were significantly greater than in reference areas in one or both sampling seasons (Table 5-7). Exceptions were copper and manganese, which did not trigger a low WOE ranking in all of the years when these variables were identified as SOIs by the Action Level screening (Table 5-6). Fourteen of the 25 variables that triggered a low ranking had 5th percentile concentrations in the NF area that were greater than both the normal range for Lac de Gras and two times the median of the reference areas; however, concentrations in all samples collected over the period of interest were within AEMP aquatic life and drinking water Effects Benchmarks. Therefore, a moderate ranking was not applied to any of the SOIs. Results of the WOE effects ranking for water quality feed into the WOE assessment described in Section 11.

Table 5-7 Weight of Evidence Effect Rankings for Water Chemistry Substances of Interest, 2007 to 2013

Substance of Interest	2007	2008	2009	2010	2011	2013
Conventional Parameters						
Specific Conductivity	0	0	0	↑	↑	↑
Total Hardness	0	0	0	0	↑	↑
Total Dissolved Solids, Calculated	0	↑	↑	↑	n/a	↑
Turbidity	↑	0	↑	↑	n/a	↑
Major Ions						
Chloride	↑	↑	↑	↑	↑	↑
Fluoride	0	0	0	0	↑(a)	↑(a)
Sulphate	0	0	0	0	0	↑
Nutrients						
Nitrogen - Ammonia	↑	↑	↑	0	↑(b)	↑(b)
Nitrate	↑	↑	↑	↑	↑	↑
Total Metals						
Aluminum	0	0	0	↑	↑	↑
Antimony	0	0	0	0	↑	↑
Barium	↑	↑	↑	↑	↑	↑
Cadmium	0	0	0	0	↑	0
Calcium	0	0	0	0	↑	↑
Chromium	↑	0	0	0	0	↑
Copper	0(c)	0	0	↑	↑	0(c)
Lead	0	0	↑	0	0	0
Magnesium	0	0	0	0	↑	0
Manganese	0	0	0	0(c)	↑	0
Molybdenum	↑	↑	↑	↑	↑	↑
Silicon	n/a	n/a	n/a	n/a	↑	↑
Sodium	0	↑	↑	↑	↑	↑
Strontium	0	0	↑	↑	↑	↑
Tin	n/a	n/a	n/a	n/a	0	↑
Uranium	↑	↑	↑	↑	↑	↑

Notes: 0 = no effect or not an SOI in that year; ↑ = low effect ranking (increase); n/a = not analyzed in one or both sampling seasons.

WOE results are not shown for 2012 because sampling of reference areas was not required in that year. Detailed Action Level results for water chemistry are provided in Tables 5B-1 to 5B-6 of Appendix 5B.

a) Fluoride was included as an SOI because concentrations in effluent exceeded the AEMP Effects Benchmark in 24% of samples collected during the 2011 to 2013 re-evaluation period. Fluoride concentrations in effluent were below the benchmark in most samples (>99%) collected prior to 2011.

b) WOE results for ammonia from 2011 to 2013 are uncertain due to laboratory quality control issues identified during that period (Section 5.3.1.1).

c) Variable identified as an SOI based on Action Level Results, but did not trigger a low effect ranking (increase).

5.3.2 Temporal Trends

The following SOIs from the 2011 to 2013 re-evaluation period are the focus of the temporal trend assessment:

- specific conductivity
- total hardness
- total dissolved solids, calculated
- turbidity
- chloride
- fluoride
- sulphate
- ammonia
- nitrate
- total aluminum
- total antimony
- total barium
- total cadmium
- total calcium
- total chromium
- total copper
- total magnesium
- total manganese
- total molybdenum
- total silicon
- total sodium
- total strontium
- total tin
- total uranium

With the exception of two variables (fluoride and ammonia), each of the variables identified as SOIs triggered Action Level 1 or greater during the 2011 to 2013 re-evaluation period (Section 5.3.1.1.1). Although total lead also triggered Action Level 1 in 2009, it was not included as an SOI because subsequent sampling has indicated that Action Level 1 was not triggered during the 2011 to 2013 re-evaluation period, which is the focus of this report. Data quality issues identified for ammonia from 2011 to 2013 (Section 5.3.1.1.1) confounded the determination of Action Levels. Given these issues with the ammonia analysis, ammonia was conservatively retained as an SOI for the 2011 to 2013 re-evaluation period. Fluoride was included in the list of SOIs because concentrations in effluent were greater than the AEMP Aquatic Life Effects Benchmark (0.12 mg/L) in 24 samples (7%) collected during the 2011 to 2013 re-evaluation period. Other variables with effluent concentrations that exceeded AEMP Aquatic Life Effects Benchmarks during the 2011 to 2013 re-evaluation period are already SOIs (sulphate, chromium, nitrate) or were primarily non-detect (>95% of samples) in Lac de Gras (nitrite, selenium, silver). All variables in effluent with Water Licence discharge criteria were within applicable limits during the 2011 to 2013 re-evaluation period (>99% of samples; Section 4.4); therefore, no additional variables were added to the SOI list from the effluent screening.

Results for nutrients that are generally not toxic to aquatic organisms (i.e., bicarbonate, nitrogen and phosphorus) are summarized in Section 6 (Eutrophication Indicators) and are not evaluated in the assessment of trends for water chemistry. Ammonia and nitrate were included in both sections because these variables have the potential to result in both nutrient enrichment and toxicological effects. Variables measured in the field (specific conductivity, dissolved oxygen, temperature and pH) were also not considered for inclusion as SOIs.

Time series plots showing concentrations of SOIs at exposure and reference areas of Lac de Gras are presented in Figures 5-1 to 5-48, and in Appendix 5C, Figures 5C-1 to 5C-48. In general, temporal trends that were identified in the previous AEMP summary report (Golder 2011a) persisted following the inclusion of the 2011 to 2013 data in the time series plots. The following general observations were made based on the updated time series plots:

- Pre-2007 data were occasionally more variable than 2007 to 2013 data, possibly reflecting improvements in analytical techniques (e.g., DLs) and refinements of the AEMP design.
- Concentrations of SOIs were generally greater and more variable during the ice-cover season than during the open-water season, particularly at exposure stations closest to the diffusers. Reduced mixing from wind and wave action during ice-cover conditions likely resulted in greater stratification of the effluent under ice.
- Concentrations of SOIs in the NF area during ice-cover conditions were generally lower near the surface and higher at middle and bottom-depth sampling locations.
- No single depth category could be identified as having the highest SOI concentration in the NF area during open-water conditions. The position of the effluent plume in the water column differed among years.
- Temporal patterns in the concentrations of SOIs at AEMP stations generally reflected trends identified in effluent and at the edge of the mixing zone boundary (Section 4).

The increase in concentrations over time previously observed for TDS, sulphate, molybdenum and strontium persisted with the inclusion of the 2011 to 2013 AEMP data. In addition, five variables that were not previously evaluated (conductivity, calcium, hardness, magnesium and sodium) showed patterns of increasing concentration over time. The observed increases for these nine SOIs were statistically significant at most exposure and reference areas tested from 2007 to 2013 (Table 5-8). Chloride also produced significant correlations with time; however, concentrations have not increased since 2011. Although trends in SOI concentrations were not evaluated statistically in the MF1 and MF3 areas, patterns in these areas generally reflected those in the MF2 area stations included in the correlations (Appendix 5C).

In the NF area, concentrations of the 10 SOIs with increasing trends increased above the normal range from approximately 2005 or thereafter, and remained above the normal range throughout 2011 to 2013. Stations in the MF areas showed less pronounced trends, although exceedances of the normal range occurred frequently for most of these SOIs.

The reference areas now appear to be demonstrating the presence of effluent. With the exception of chloride, the SOIs with positive temporal trends in the NF and MF2-FF2 areas also had significant temporal trends in the reference areas, and they demonstrated increasing temporal trends at most stations along the MF3 transect (Appendix 5C). Moreover, most of these SOIs now exceed the normal range at one or more of the three FF reference areas and at most stations along the MF3 transect. The presence of effluent in the reference areas represents the dispersion of effluent in the lake, rather than an increase in the load of the SOIs. Except for an increase in the effluent concentrations of sulphate and molybdenum, there has been no increase in the effluent load or concentration of these SOIs since 2010 (Section 4).

Table 5-8 **Results of Mann Kendall Trend Tests (2007-2013) in the Near-Field (NF) Sampling Area; at Sampling Stations MF2-1 and FF2-2; and at the Three Far-Field Reference Areas (FF1, FFB, and FFA)**

Substance of Interest	Season	Kendall's Rank Coefficient, τ(a)					
		NF(b)	**MF2-1(b)**	**FF2-2(b)**	**FF1(b)**	**FFB(b)**	**FFA(b)**
Conventional Parameters							
Specific Conductivity	Ice-cover	**0.71***	**0.71***	**0.62***	0.60	**0.73***	**0.87***
	Open-water	**0.91****	**0.97***(d)	**0.73***(d)	**0.73***	**0.87***	**0.83***
Total Hardness	Ice-cover	**0.71***	**0.62***	**0.71***	**0.83***	**0.97***	**0.83***
	Open-water	**0.62***	**1.00****	**1.00****	**0.97***	**0.97***	**0.8***(d)
Total Dissolved Solids, Calculated	Ice-cover	**1.00****	**0.80***(d)	**0.80***(d)	(c)	(c)	(c)
	Open-water	**0.87***(d)	**0.95***(d)	**1.00****	**0.8*** (d)	**1.00****	**1.00****
Turbidity	Ice-cover	-0.11(d)	(c)	(c)	(c)	(c)	(c)
	Open-water	-0.36(d)	-0.74(d)	-0.53(d)	-0.20(d)	**-0.95***(d)	(c)
Major Ions							
Chloride	Ice-cover	**0.78***	0.39	0.33(d)	0.12(d)	(c)	(c)
	Open-water	**0.68***	0.60(d)	**0.73***(d)	0.40(d)	(c)	(c)
Fluoride	Ice-cover	(c)	(c)	(c)	(c)	(c)	(c)
	Open-water	(c)	(c)	(c)	(c)	(c)	(c)
Sulphate	Ice-cover	**0.91****	**1.00****	0.52	-0.07	0.47	**0.73***
	Open-water	**0.62***	**0.97***(d)	**0.73***(d)	-0.33	**0.73***	0.14
Nutrients							
Nitrogen - Ammonia	Ice-cover	(e)	(e)	(e)	(e)	(e)	(e)
	Open-water	(e)	(e)	(e)	(e)	(e)	(e)
Nitrate	Ice-cover	0.05	0.05	0.33(d)	(c)	(c)	(c)
	Open-water	**-0.80***(d)	(c)	(c)	(c)	(c)	(c)
Total Metals							
Aluminum	Ice-cover	**0.71***	0.52	0.10	-0.07	-0.07	0.07
	Open-water	0.43	0.20(d)	-0.20(d)	0.20	-0.20	-0.33
Antimony	Ice-cover	(c)	(c)	(c)	(c)	(c)	(c)
	Open-water	(c)	(c)	(c)	(c)	(c)	(c)
Barium	Ice-cover	0.05	-0.33	-0.43	0.20	0.28	**0.73***
	Open-water	**-0.91****	**-0.87***(d)	**-0.87***(d)	0.14	0.55	0.07
Cadmium	Ice-cover	(c)	(c)	(c)	(c)	(c)	(c)
	Open-water	(c)	(c)	(c)	(c)	(c)	(c)
Calcium	Ice-cover	**0.81***	**0.75***	**0.62***	**0.73***	**0.87***	**1.00****
	Open-water	**0.81***	0.87*(d)	0.467(d)	**0.87***	**0.87***	**0.87***
Chromium	Ice-cover	(c)	(c)	(c)	(c)	(c)	(c)
	Open-water	(c)	(c)	(c)	(c)	(c)	(c)
Copper	Ice-cover	-0.20(d)	-0.53(d)	(c)	-0.60(d)	(c)	(c)
	Open-water	(c)	(c)	(c)	(c)	(c)	(c)
Magnesium	Ice-cover	**0.71***	**0.71***	**0.62***	0.6	**0.73***	**0.73***
	Open-water	**0.78***	**1.00****	**1.00****	**0.87***	**0.87***	**0.83***
Manganese	Ice-cover	0.49	0.33	-0.05	0.41	-0.07	-0.20
	Open-water	0.24	-0.40(d)	-0.20(d)	0.20	-0.20	-0.28
Molybdenum	Ice-cover	**0.71***	**0.62***	**0.97****	0.55	**0.87***	**0.87***
	Open-water	**0.97****	**1.00****	**1.00****	**0.80***(d)	**1.00****	0.6
Silicon	Ice-cover	(c)	(c)	(c)	(c)	(c)	(c)
	Open-water	(c)	(c)	(c)	(c)	(c)	(c)
Sodium	Ice-cover	**0.71***	**0.71***	**0.78***	**0.83***	**0.87***	**1.00****
	Open-water	**1.00****	**1.00****	**0.87***(d)	**0.87***	**1.00****	**0.87***

Table 5-8 Results of Mann Kendall Trend Tests (2007-2013) in the Near-Field (NF) Sampling Area; at Sampling Stations MF2-1 and FF2-2; and at the Three Far-Field Reference Areas (FF1, FFB, and FFA)

Substance of Interest	Season	Kendall's Rank Coefficient, τ(a)					
		NF(b)	**MF2-1(b)**	**FF2-2(b)**	**FF1(b)**	**FFB(b)**	**FFA(b)**
Strontium	Ice-cover	**0.81***	**0.81***	**0.91****	**0.97***	**1.00****	**0.87***
	Open-water	**0.91****	**0.87***(d)	**0.87***(d)	**1.00****	**1.00****	**1.00****
Tin	Ice-cover	(c)	(c)	(c)	(c)	(c)	(c)
	Open-water	(c)	(c)	(c)	(c)	(c)	(c)
Uranium	Ice-cover	0.29	0.33	0.05	(c)	(c)	(c)
	Open-water	-0.29	**-0.83***(d)	-0.33(d)	(c)	(c)	(c)

Note: τ = Kendall's Tau

a) Probability of type 1 error (two tailed): * = <0.1, ** = <0.01, *** <0.001. **Bolded** correlation coefficients indicate significant correlation between SOI concentration and time.

b) The median concentration in the NF, FF1, FFB and FFA areas and maximum concentration at stations MF2-1 and FF2-2 (top, middle, and bottom) in each year of monitoring were used in the correlations.

c) Correlations were not completed where *n* <4 due to removal of non-detect values from the analysis, or because variables were not analyzed for a portion of the 2007 to 2013 monitoring period.

d) Correlations were based on a reduced sample size (*n*<7 in exposure areas; *n* = 5 in reference areas) due to removal of non-detect data from the analysis, or because variables were not analyzed for a portion of the 2007 to 2013 monitoring period.

e) Ammonia was not analyzed statistically, because results from 2011 to 2013 were not comparable with the 2007 to 2010 data due to quality control issues.

The increasing concentrations of these nine SOIs in the reference areas cannot solely be attributed to Diavik effluent. The spatial trend is reversed as one moves west from the FFB area. These SOIs demonstrate an increase in concentration from reference area FFB to reference area FFA, and a further increase at sampling station LDG 48, which is located at the far northwest end of Lac de Gras (Appendix 5D, Figures 5D-1 to 5D-20). This pattern is especially prominent during the ice-cover season. These data suggest that an additional source of these substances must be present. The Slipper Lake outlet, which enters Lac de Gras at the northwest end is a possible influence on the SOI concentrations at LDG48 and FFA. Concentrations of several of these SOIs were elevated at the Ekati Mine monitoring stations (S2 and S3) in Lac de Gras (Figure 2-1). For example chloride concentrations at Ekati station S2 ranged from 2.98 to 3.12 mg/L under-ice in 2013 (ERM Rescan 2014), whereas the mean ice-cover chloride concentration in the FFB area in 2013 was 0.91 mg/L (Golder 2014b).

While concentrations of 10 of the 24 SOIs are demonstrating significant increases over time in Lac de Gras, the other 14 SOIs are not. Barium is an element of interest because it has been used as an effluent tracer since the AEMP program commenced in 2001. Concentrations of barium in the NF and MF exposure areas increased from 2000 to 2007, as the loading rate of barium from the Mine effluent increased (Section 4). However, concentrations in the lake have been decreasing since 2007 (Table 5-8), again reflecting the lower effluent loads and concentrations since 2007. Although the previous summary report observed increasing concentrations of barium over time in the FF reference areas (Golder 2011c), in general, this trend appears to be no longer occurring (Table 5-8; Figures 5-23c and 5-24c).

Fluoride concentrations in Lac de Gras were primarily below the DL used by ELT and ALS from 2002 to 2010 (0.05 mg/L; Figures 5-11 and 5-12). In 2011 a lower DL was used and detectable results were obtained for most samples. No consistent trend, however, was evident in the exposure areas during the 2011 to 2013 monitoring period, though exceedances of the normal range were noted during the ice-cover season.

Quality control issues identified with ammonia analyzed by Maxxam (2011 to 2013) means that these data are not comparable with ammonia data prior to 2011 (Golder 2014b). Peak ammonia loading to Lac de Gras occurred in 2007 (Figure 4-12), which is reflected by the peak concentrations observed in 2007 or 2008 in Figures 5-15 and 5-16. Similarly, nitrate demonstrated peak concentrations in Lac de Gras in 2007 or 2008 (Figures 5-17 and 5-18), following peak effluent loads in 2006 (Figure 4-13).

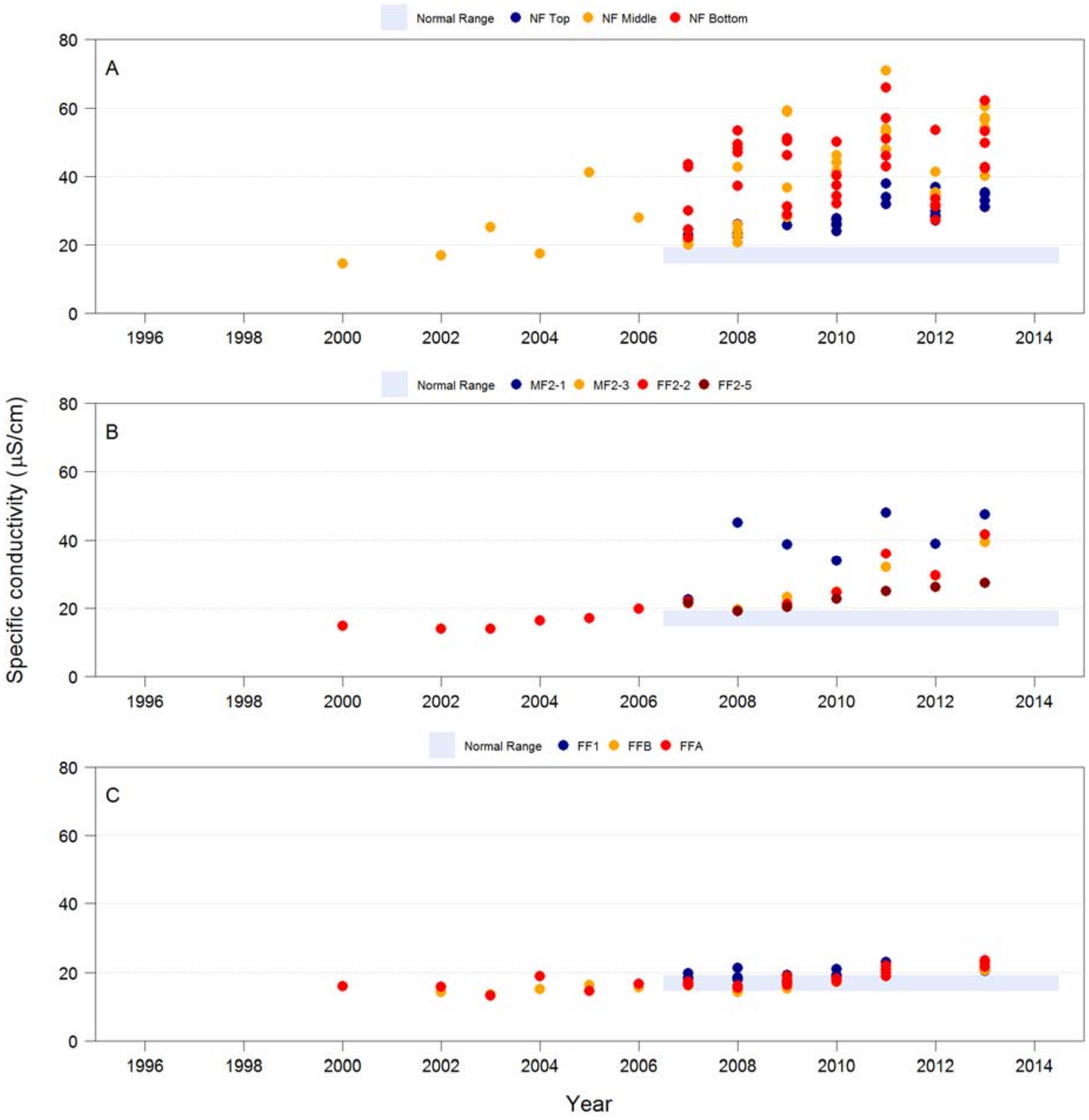
Aluminum, chromium, copper and manganese were generally within the range of concentrations observed historically, though exceedances of the normal range were noted in the exposure area for each of these SOIs. In particular, concentrations of aluminum, manganese and chromium in the NF area were frequently above the normal range. Annual loading rates of these SOIs from the NIWTP demonstrated no consistent trends over time (aluminum, chromium) or decreased over time (copper, manganese) (Section 4). Cadmium concentrations have remained below the DLs used by ALS and Maxxam in most samples analysed from 1996 to 2013.

Silicon was not analyzed during baseline sampling (1996 to 1999) and for several years of monitoring (2004 to 2010). Comparison of the 2011 to 2013 results relative to available historical data (2000, 2003 and 2004), however, suggests that concentrations at exposure stations have increased over baseline and early operational monitoring conditions (Figures 5-39 and 5-40). Concentrations in the NF area frequently exceeded the normal range during the ice-cover season. These increases were generally not present during open-water conditions, since silicon is taken up by algae (e.g., diatoms) during the open-water season.

Tin was added to the list of variables analyzed for the AEMP as a result of the change in labs in 2011. No temporal trends were evident for tin over the 2011 to 2013 monitoring period. Concentrations exceeded the normal range in most of the AEMP samples collected during that period, including in the reference areas (Figures 5-45 and 5-46).

Uranium concentrations in exposure areas peaked in 2002 and then declined over the duration of the AEMP Version 1 (Figures 5-47 and 5-48). Uranium concentrations have generally stabilized since then. A similar pattern was identified for uranium at the mixing zone boundary (Figure 4-29). Since effluent loads and concentrations have varied considerably over time without demonstrating any consistent trends, the concentrations of uranium in the exposure areas more likely reflect effects of the dikes (DDMI 2011a).

Figure 5-1 Specific Conductivity at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-cover Season

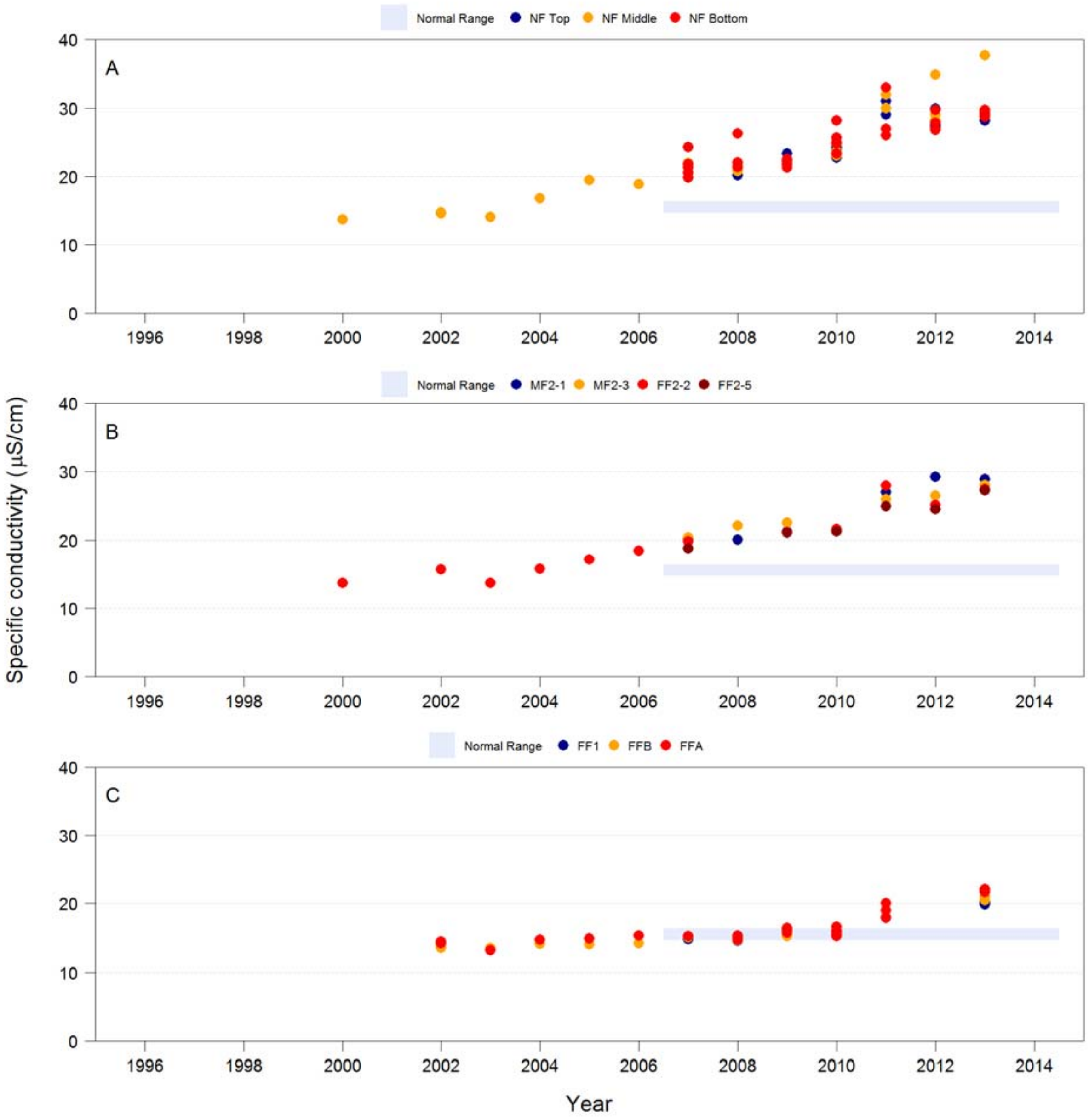


Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Abbreviations used in Figures 5-1 to 5-48:

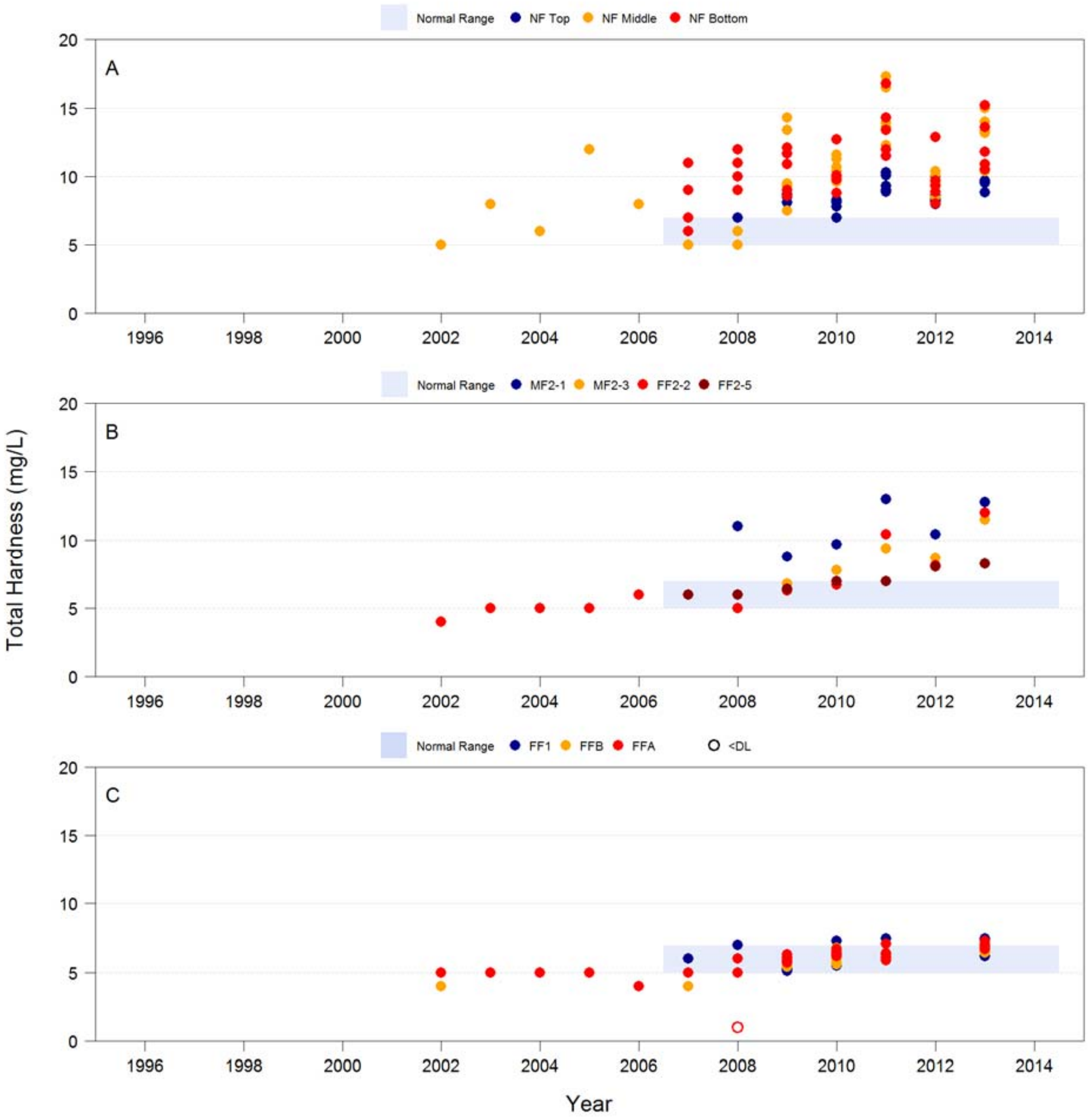
<DL = below detection limit	NF = Near-field
NTU = nephelometric turbidity unit	MF = Mid-field
Blue shading = normal range	FF = Far-field

Figure 5-2 Specific Conductivity at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season



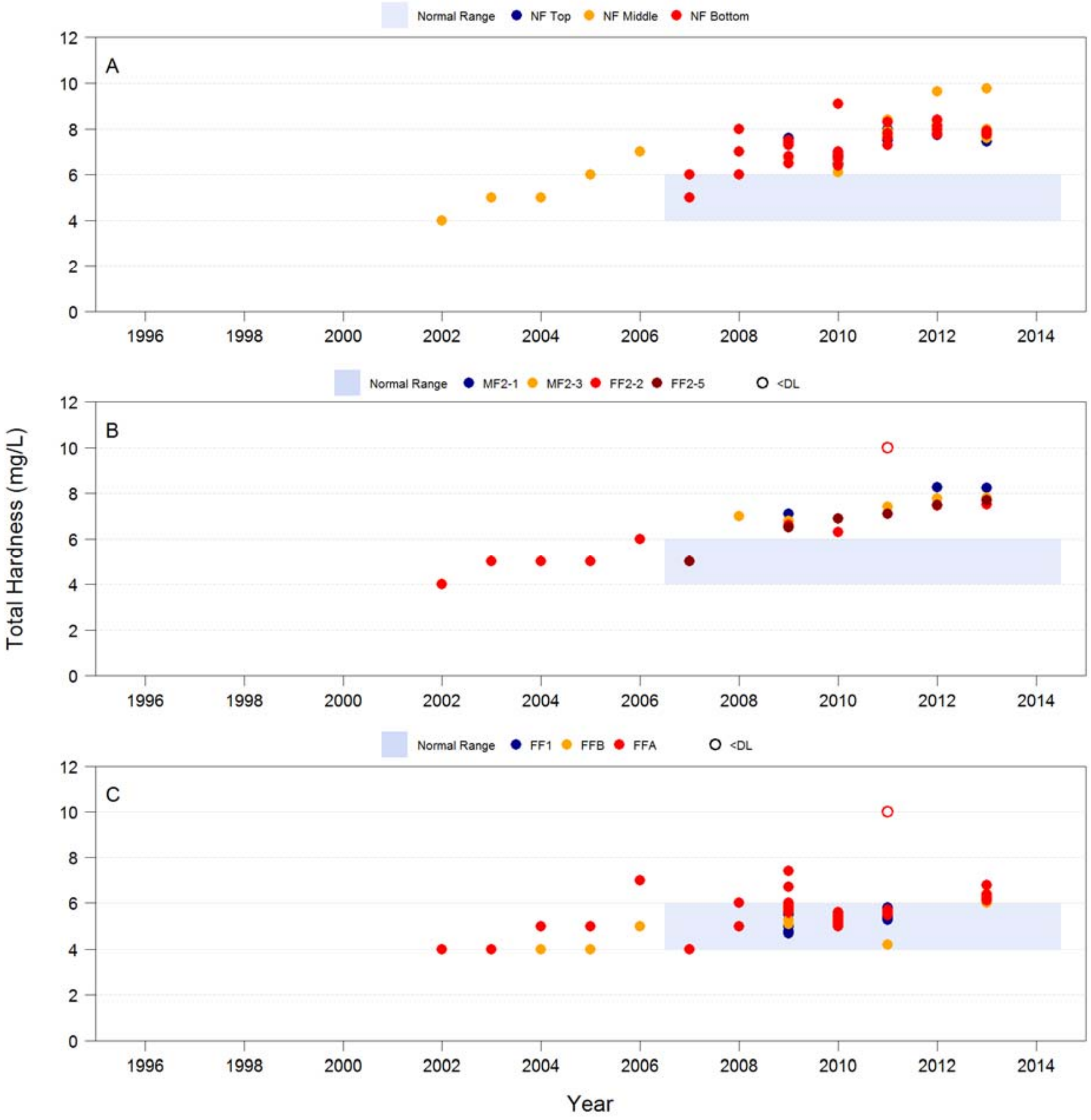
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-3 Total Hardness at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-cover Season



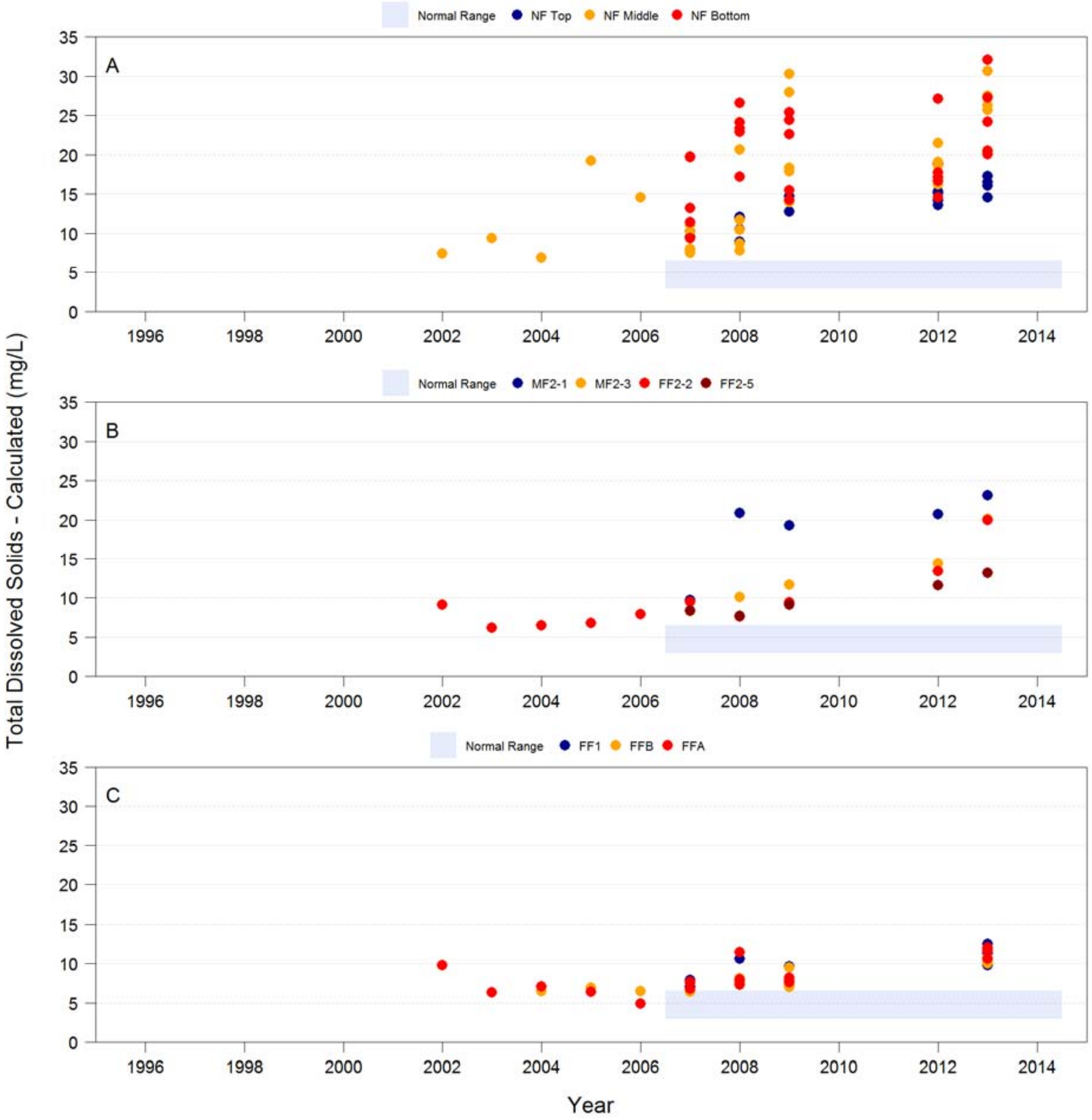
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-4 Total Hardness at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season



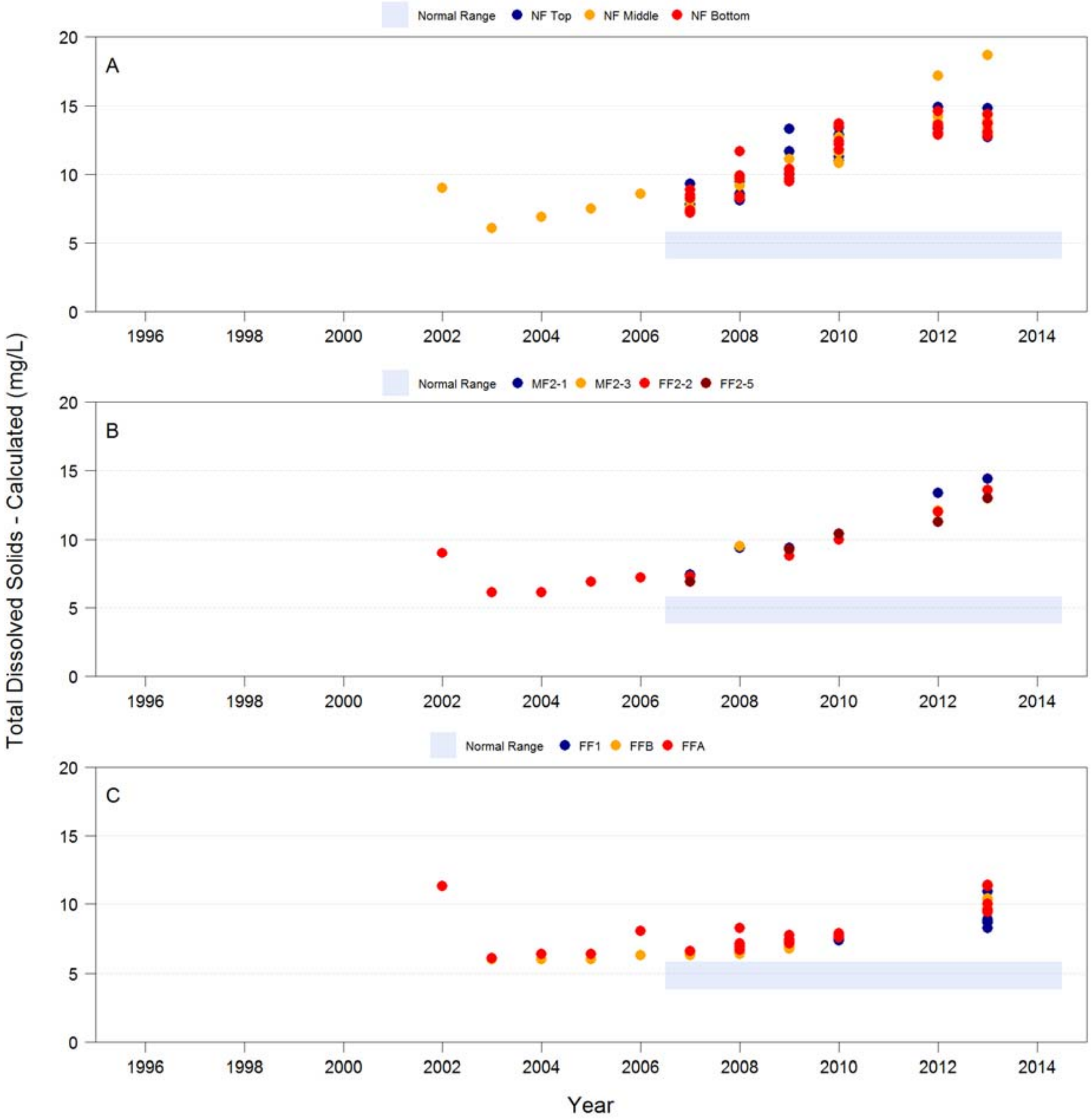
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-5 **Total Dissolved Solids, Calculated Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-cover Season**



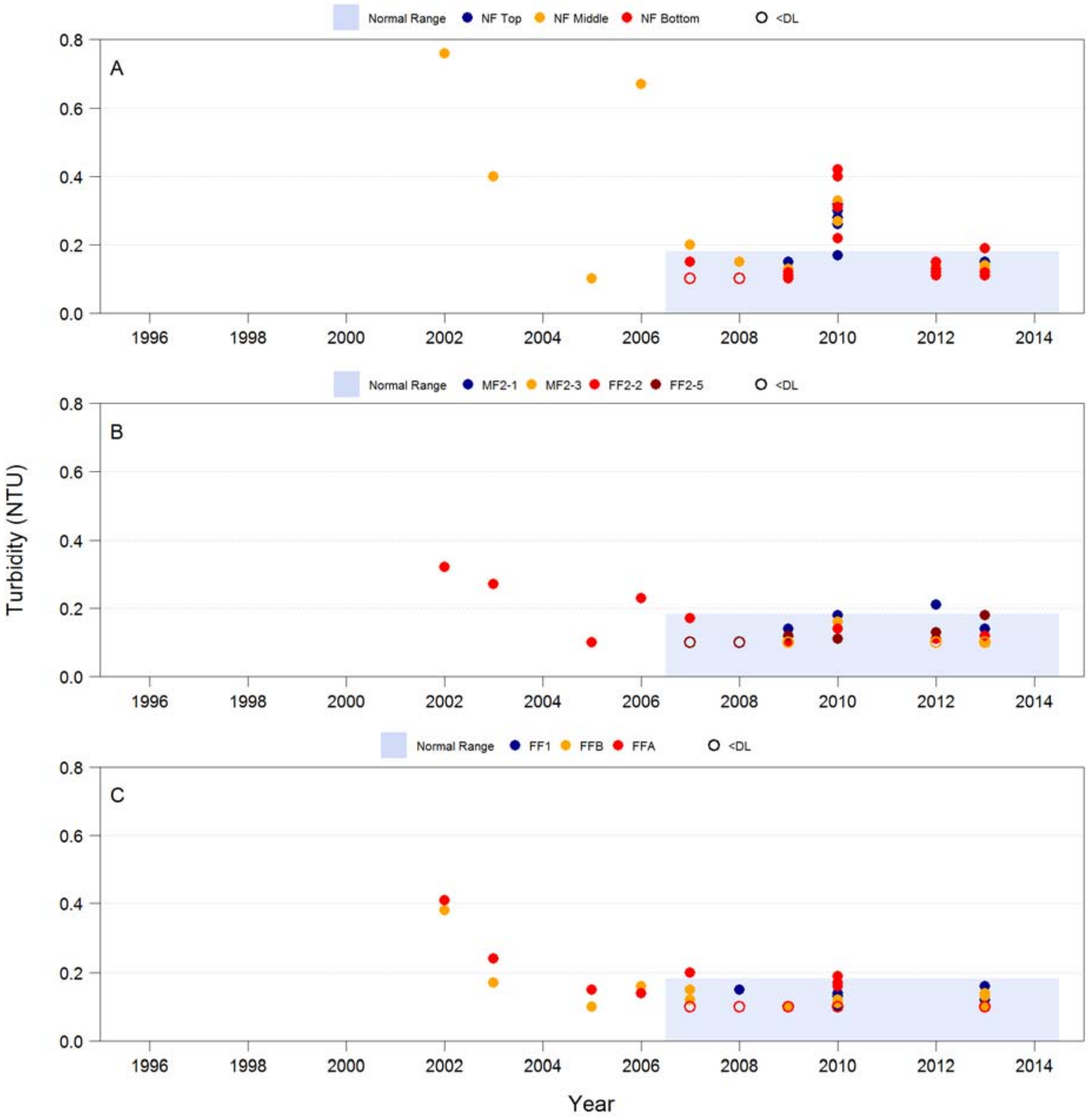
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-6 **Total Dissolved Solids, Calculated Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season**



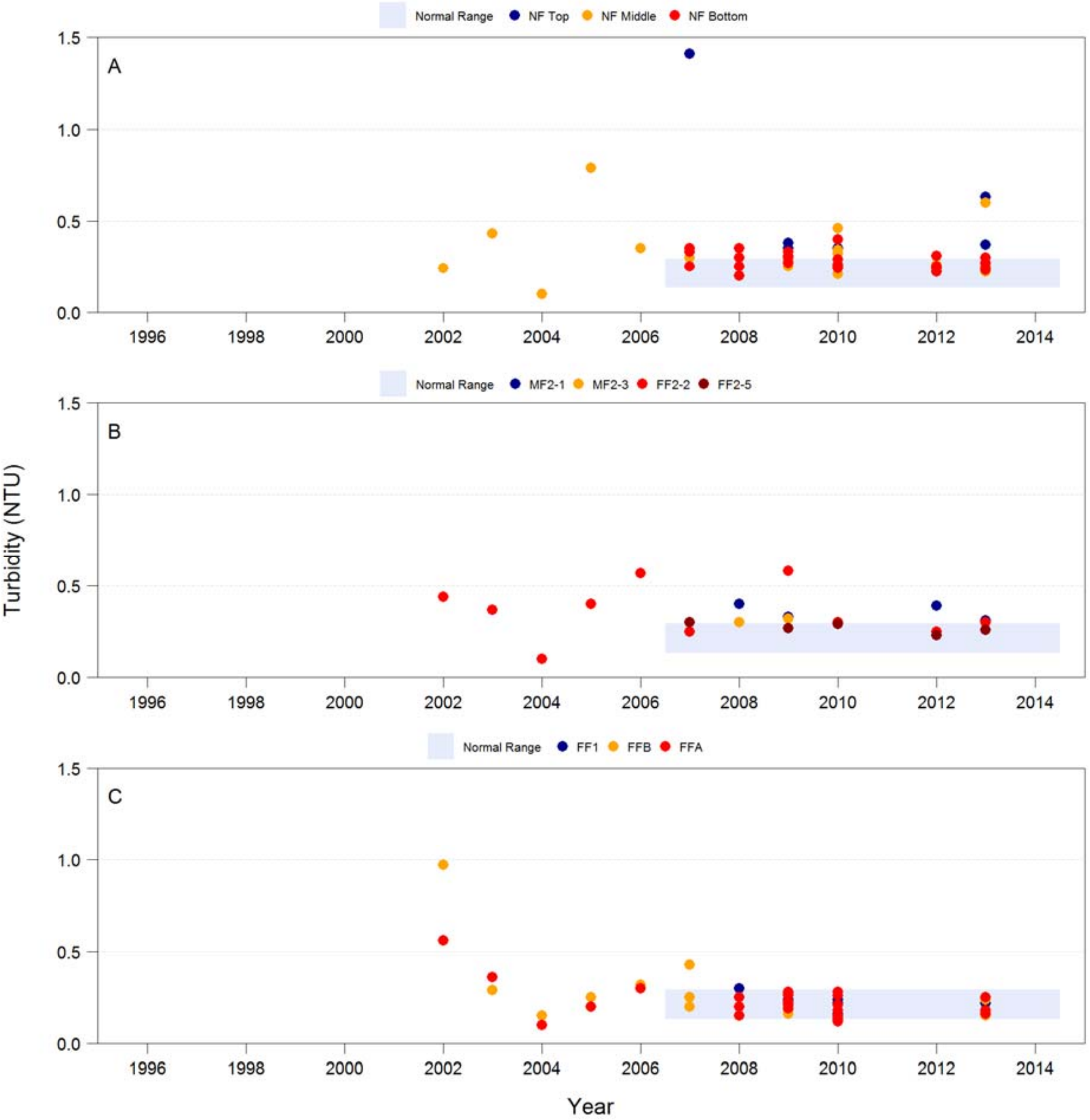
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-7 Turbidity at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-cover Season



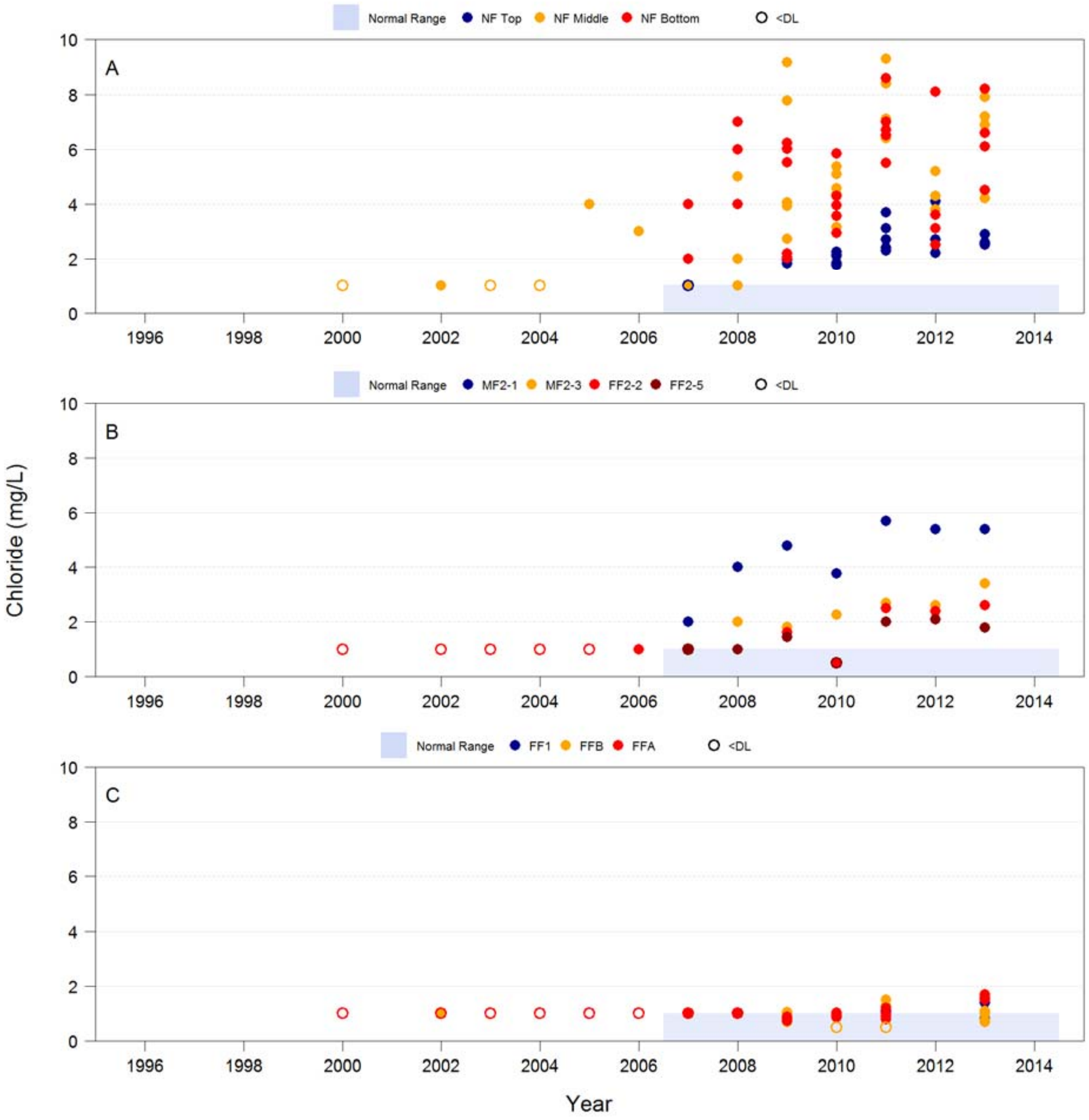
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-8 Turbidity at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season



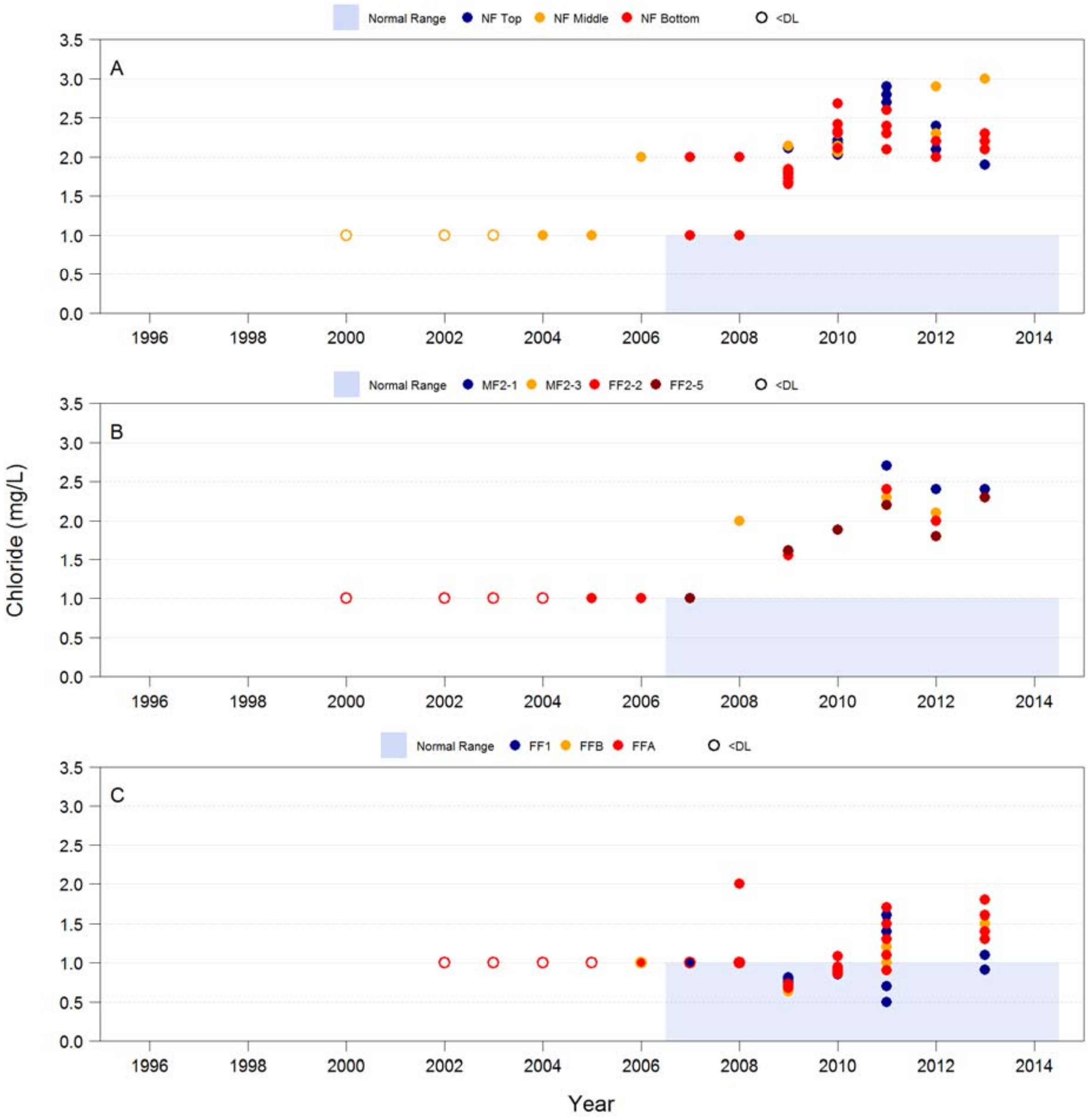
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-9 Chloride Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-cover Season



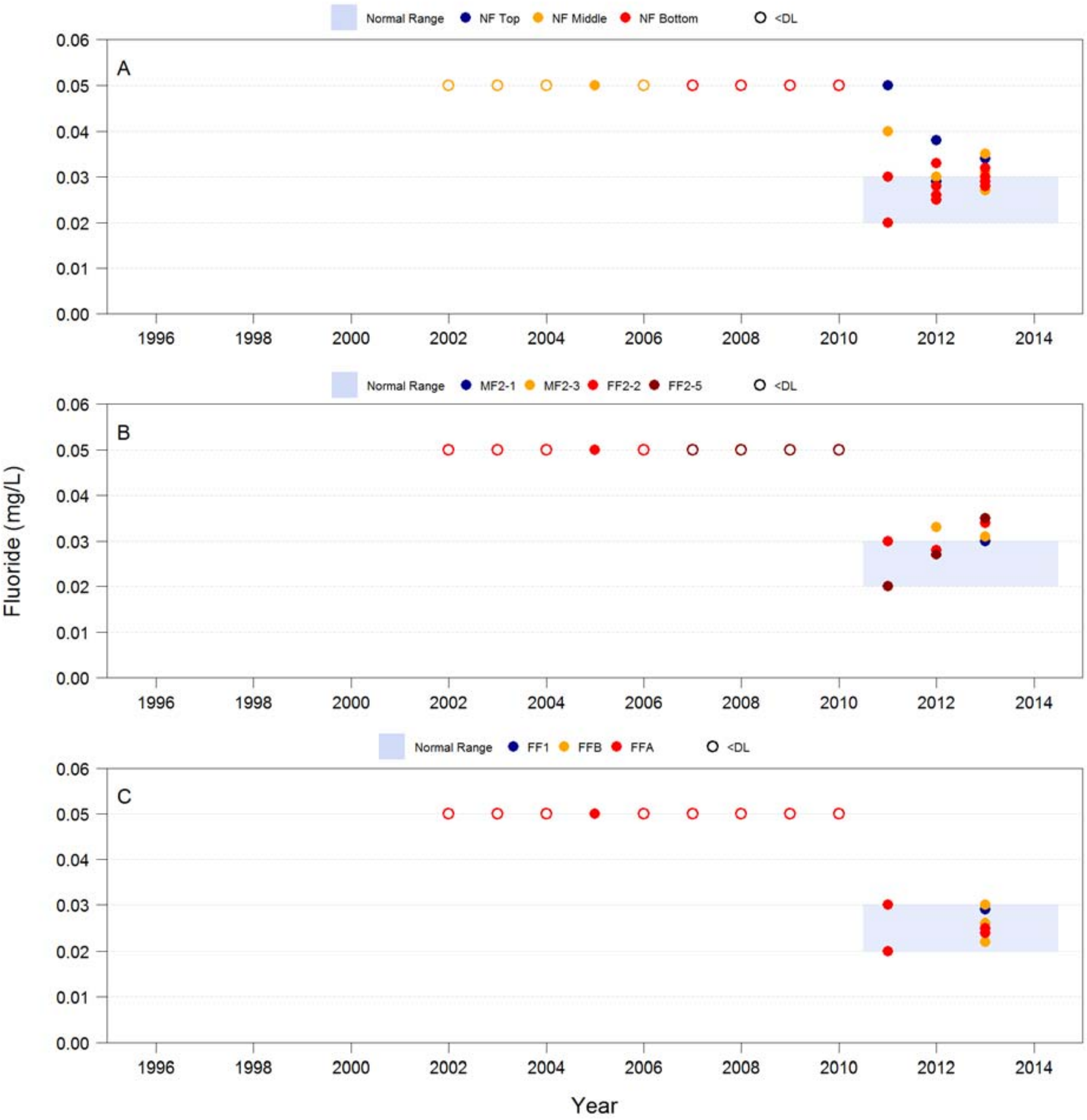
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-10 Chloride Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season



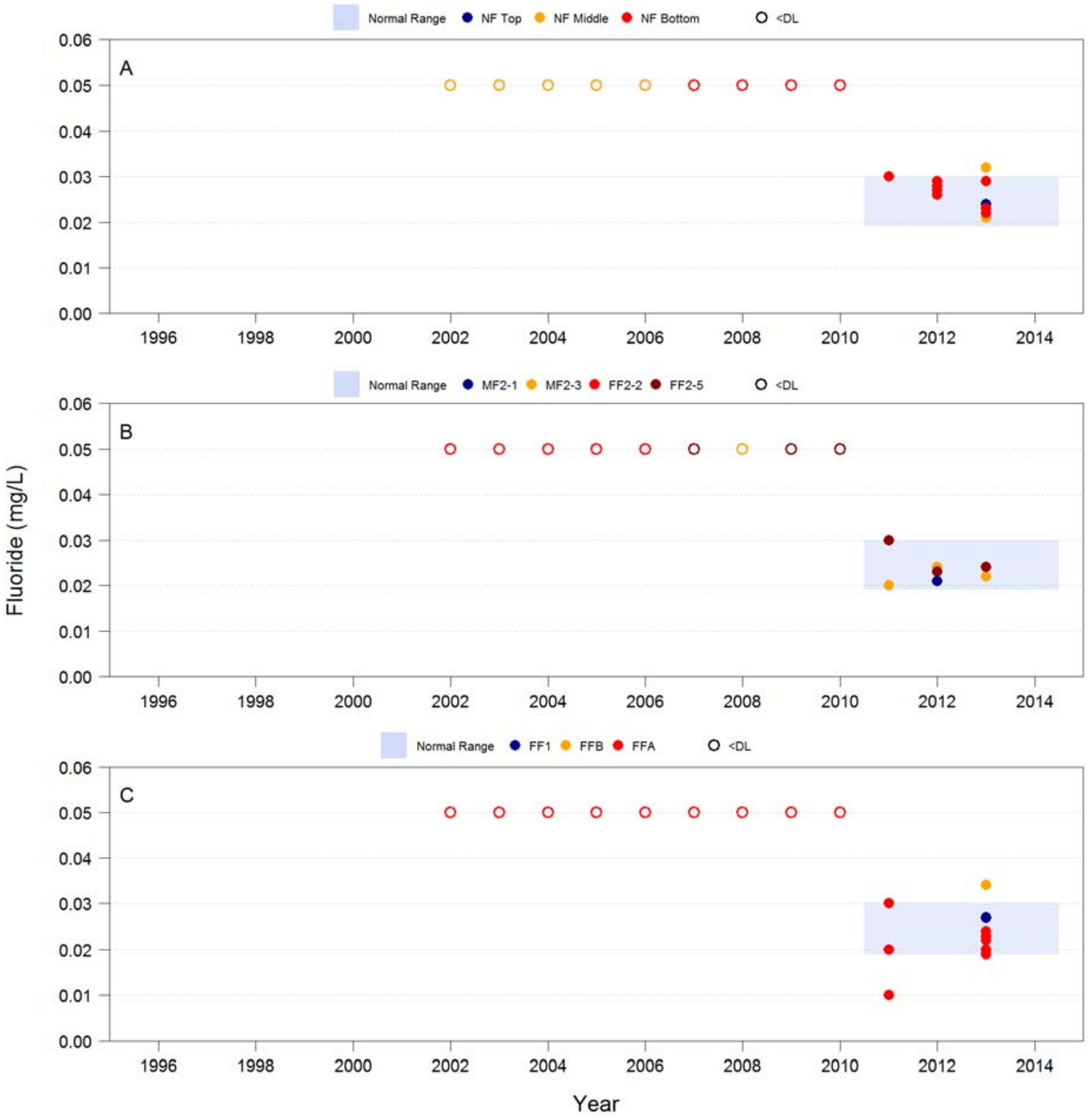
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-11 Fluoride Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-cover Season



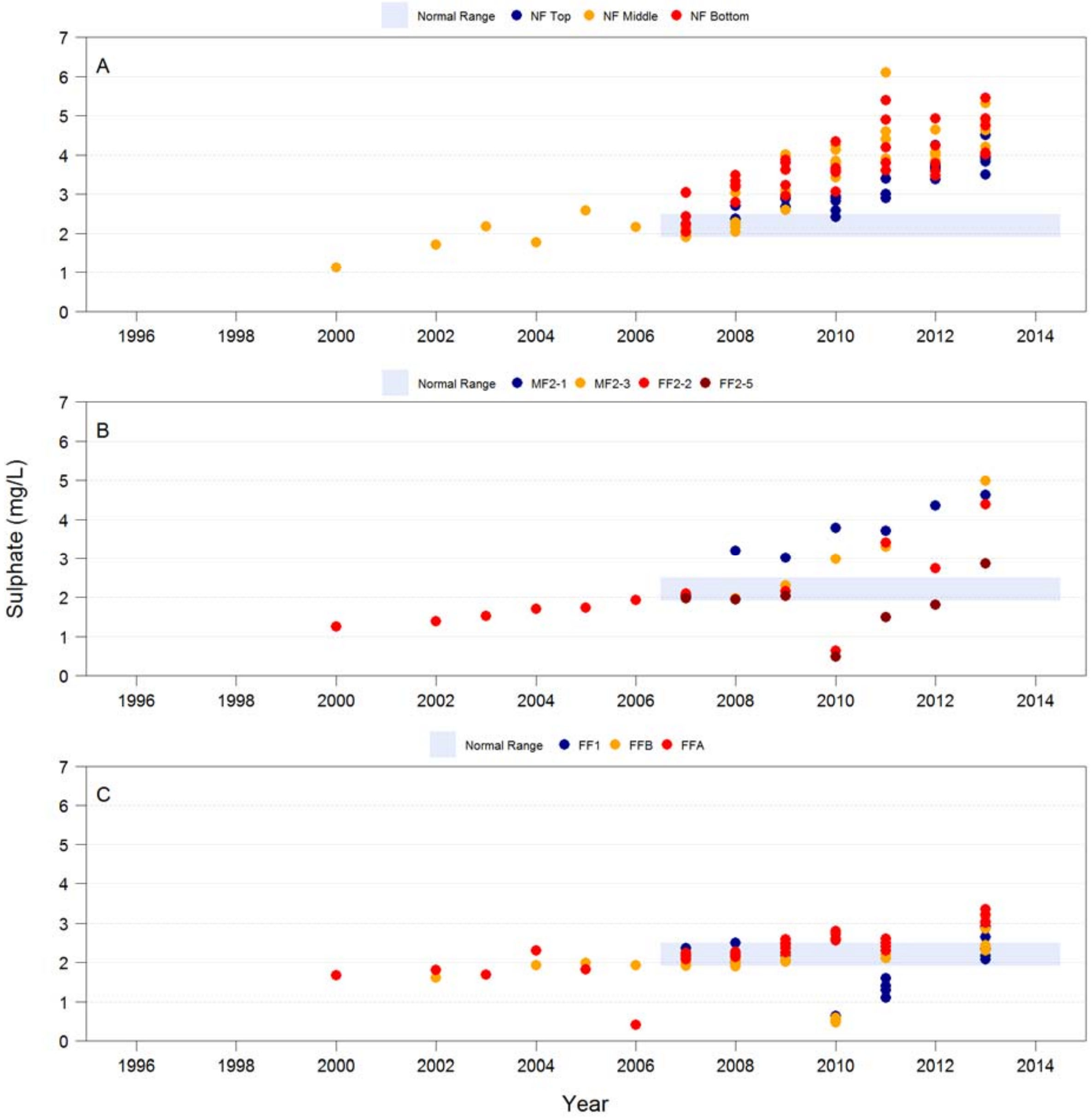
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-12 Fluoride Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season



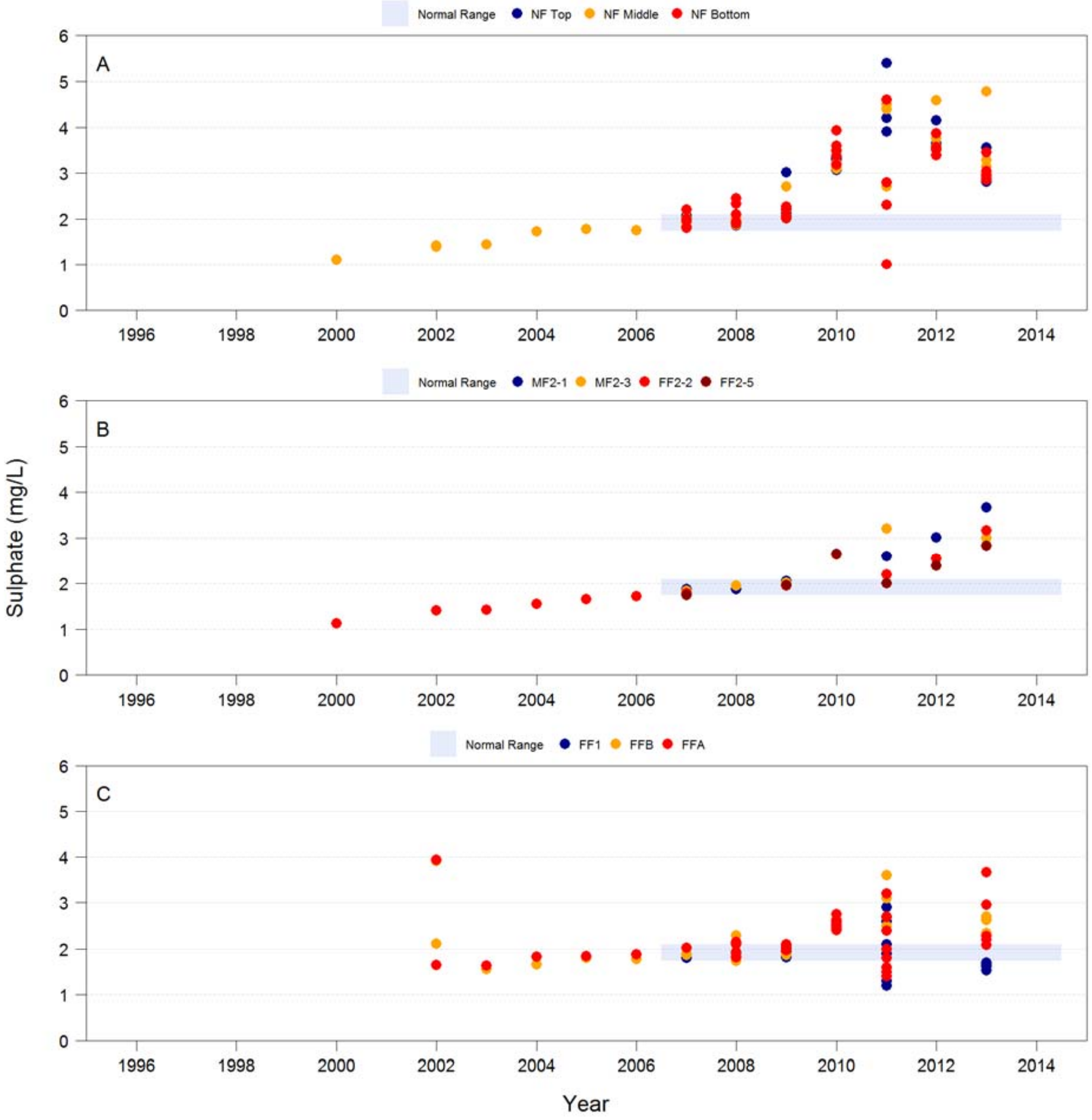
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-13 Sulphate Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-cover Season



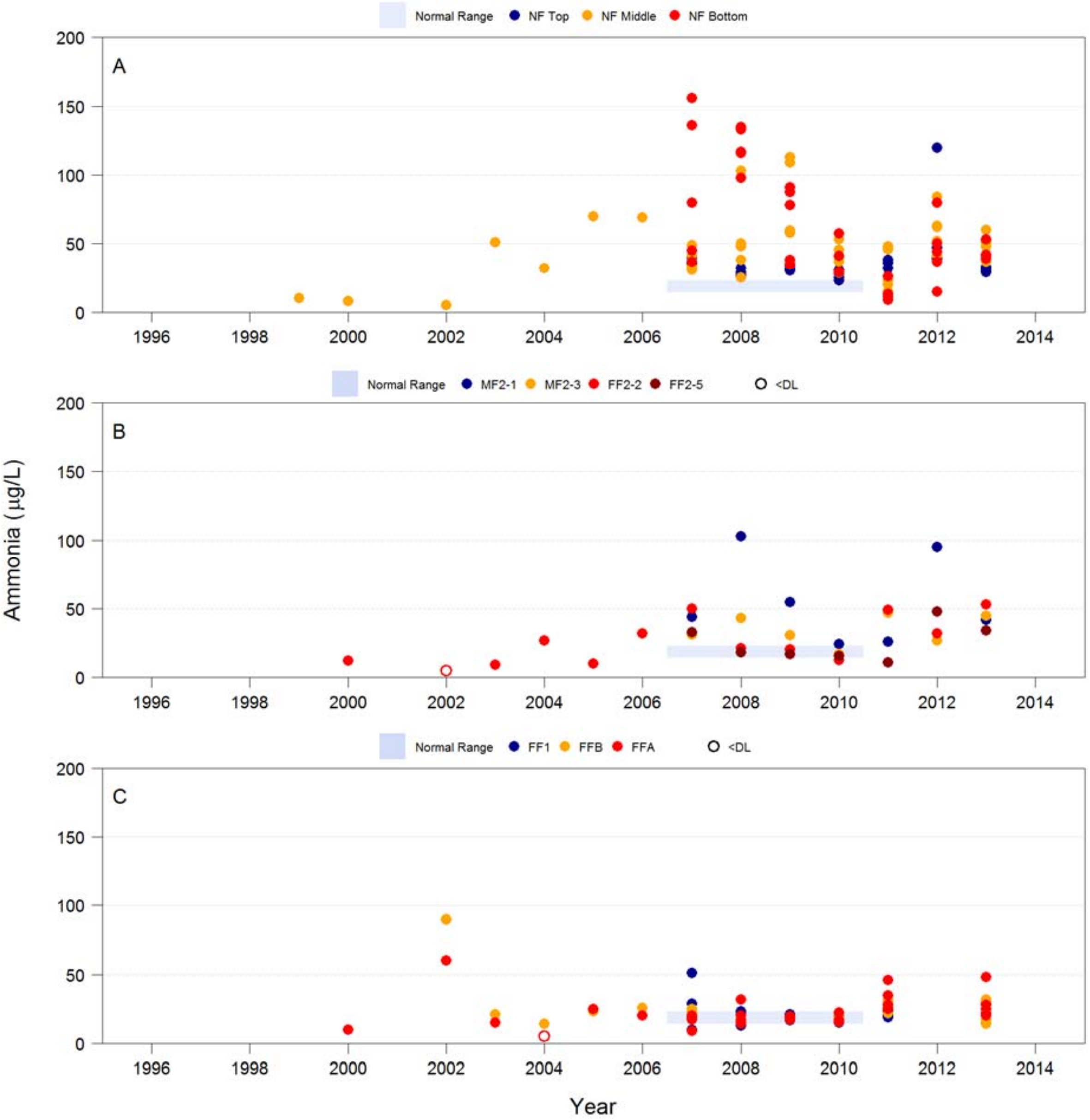
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-14 Sulphate Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season



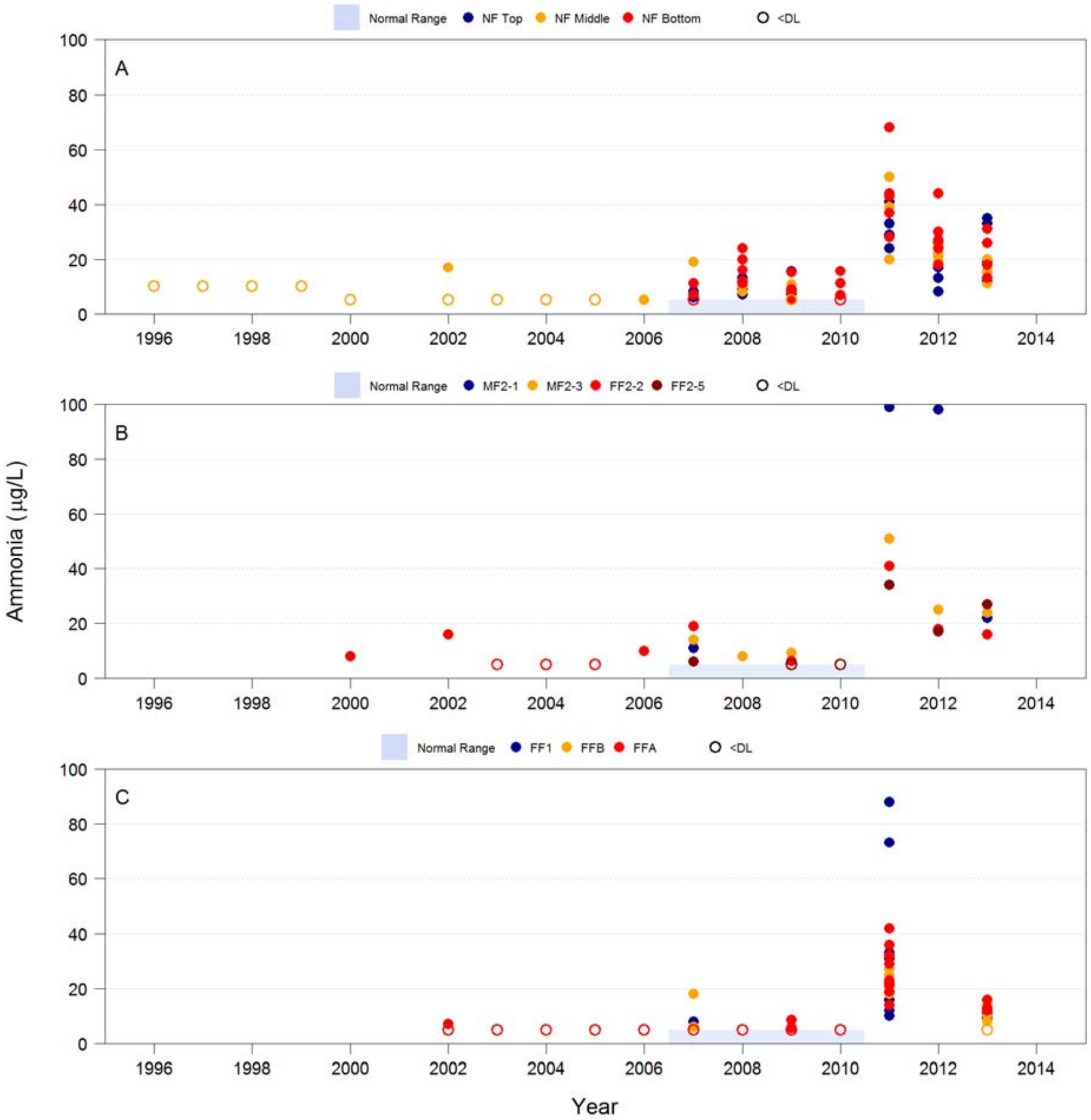
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-15 Nitrogen - Ammonia Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-cover Season



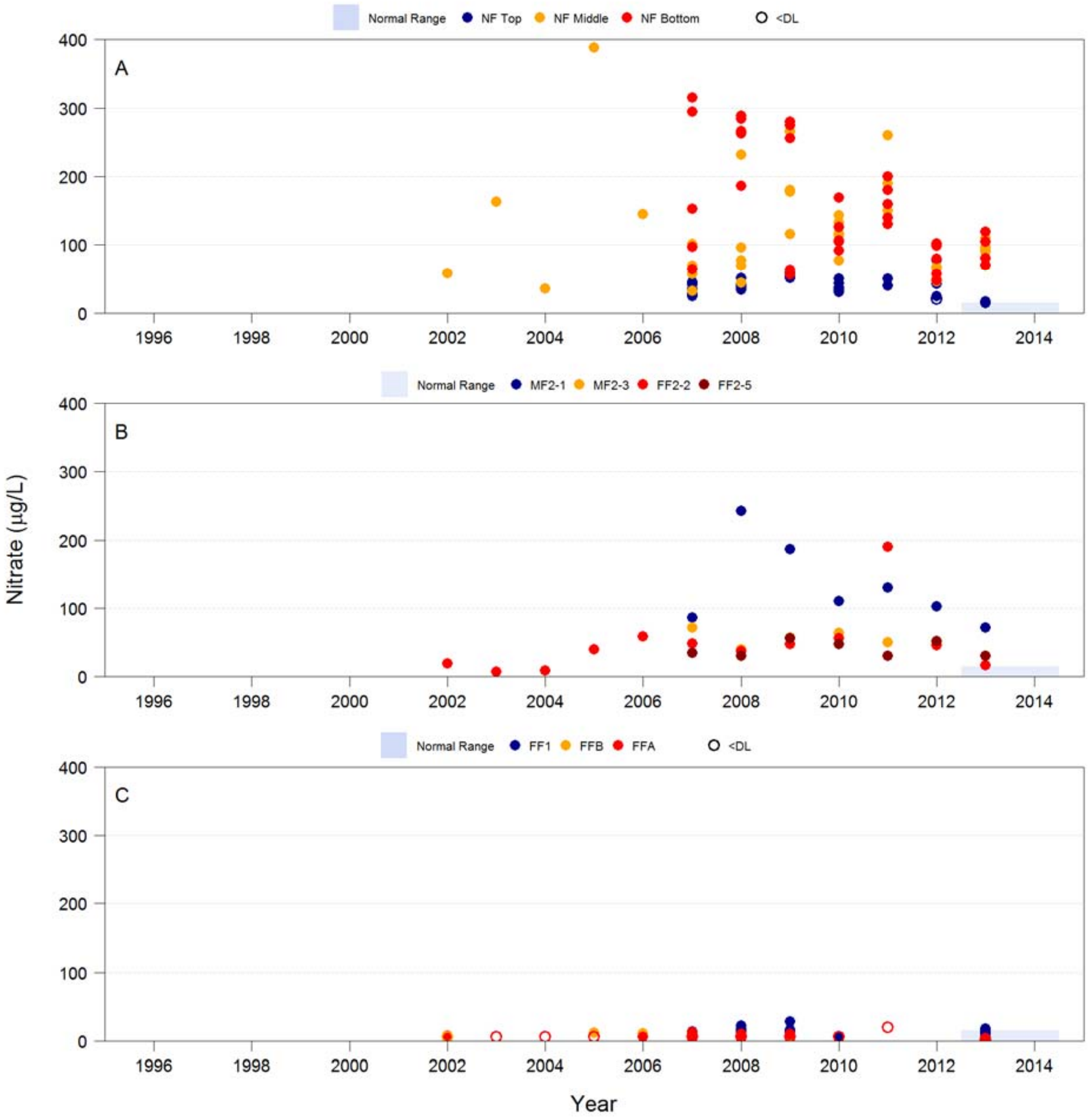
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations. The 2011 to 2013 Maxxam data were not compared to the normal range due to the QC issues described in Section 5.3.1.1.1

Figure 5-16 Nitrogen - Ammonia Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season



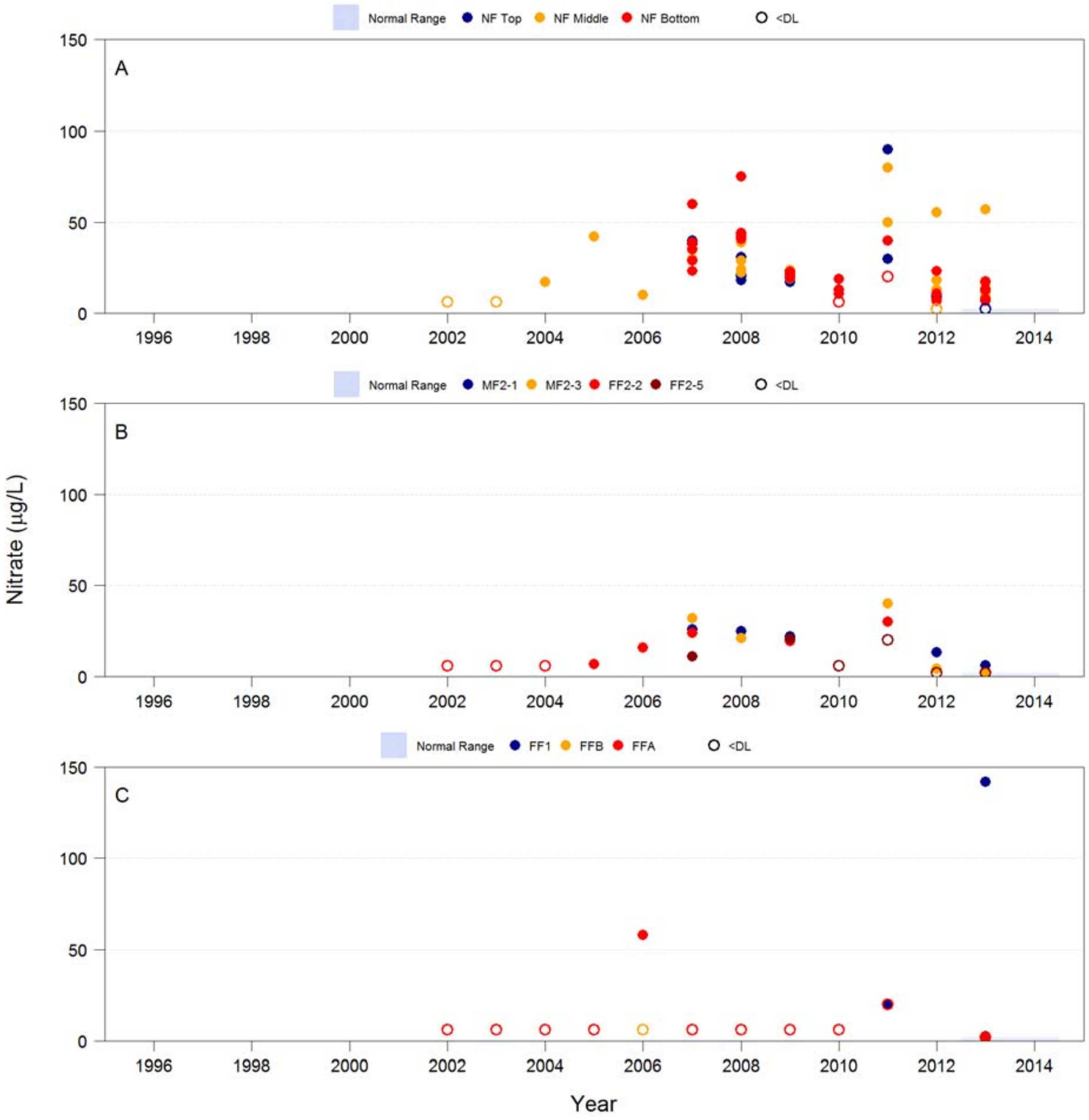
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations. The 2011 to 2013 Maxxam data were not compared to the normal range due to the QC issues described in Section 5.3.1.1.1.

Figure 5-17 Nitrate Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-cover Season



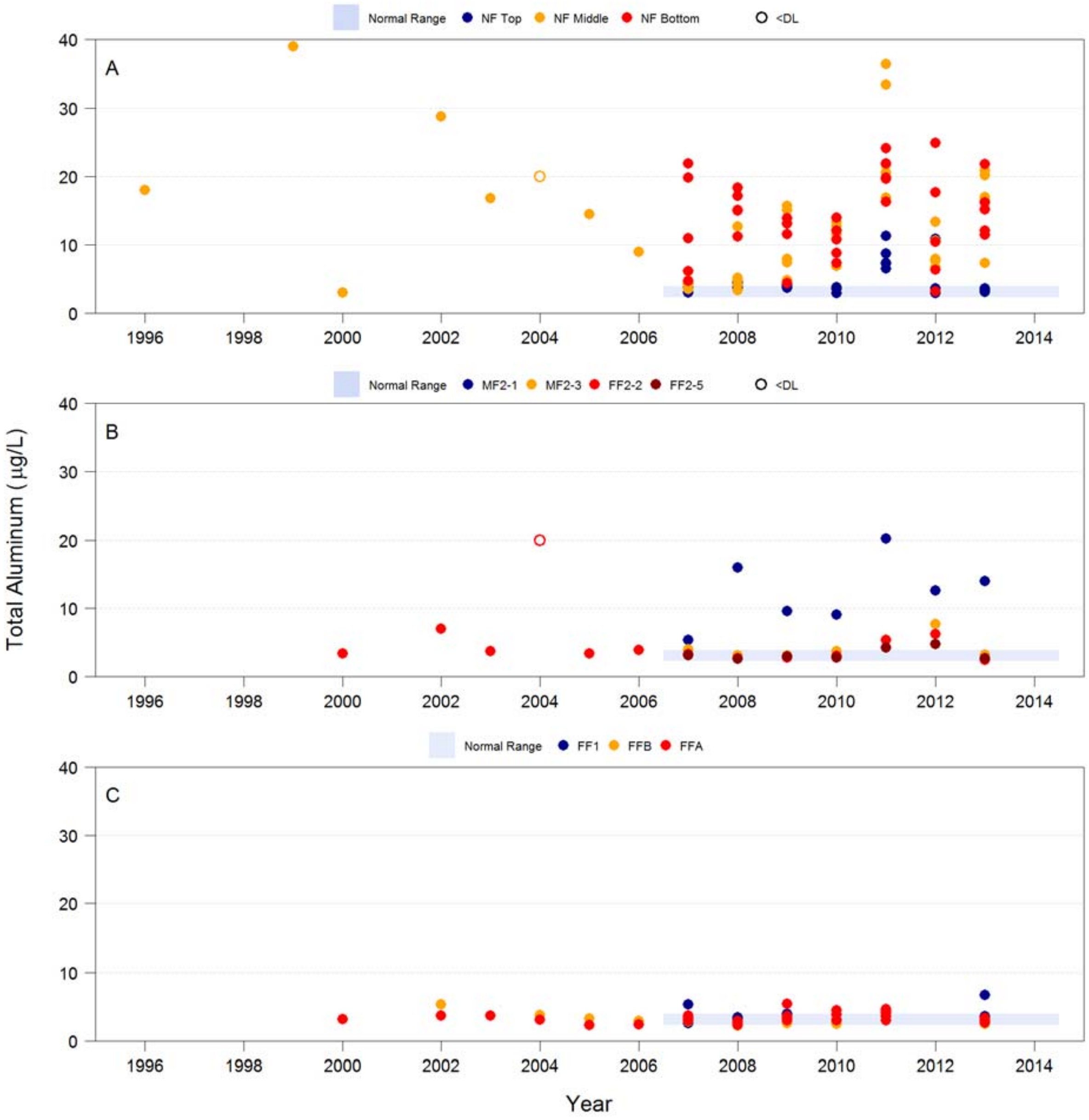
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-18 Nitrate Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season



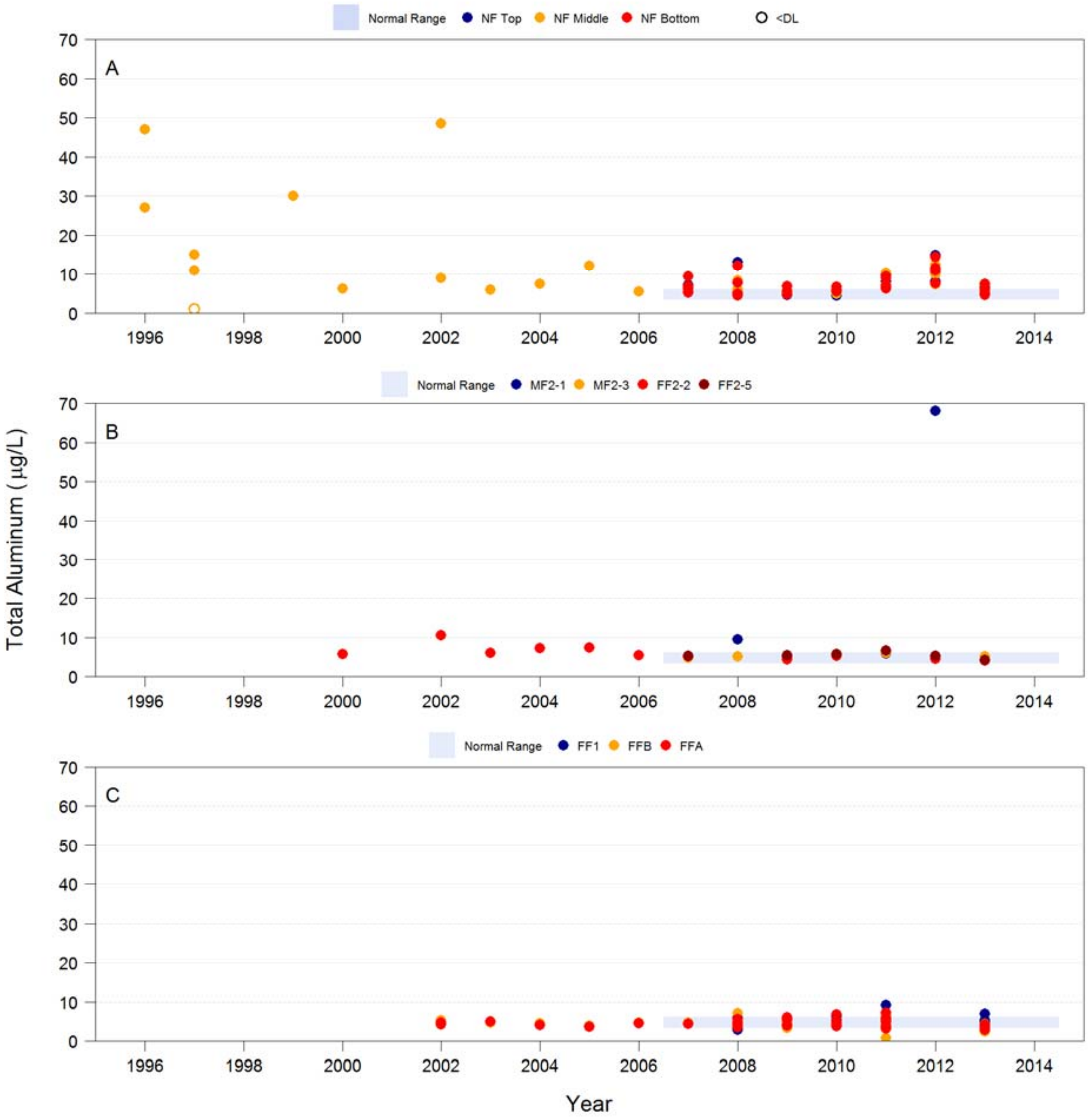
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-19 Total Aluminum Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-cover Season



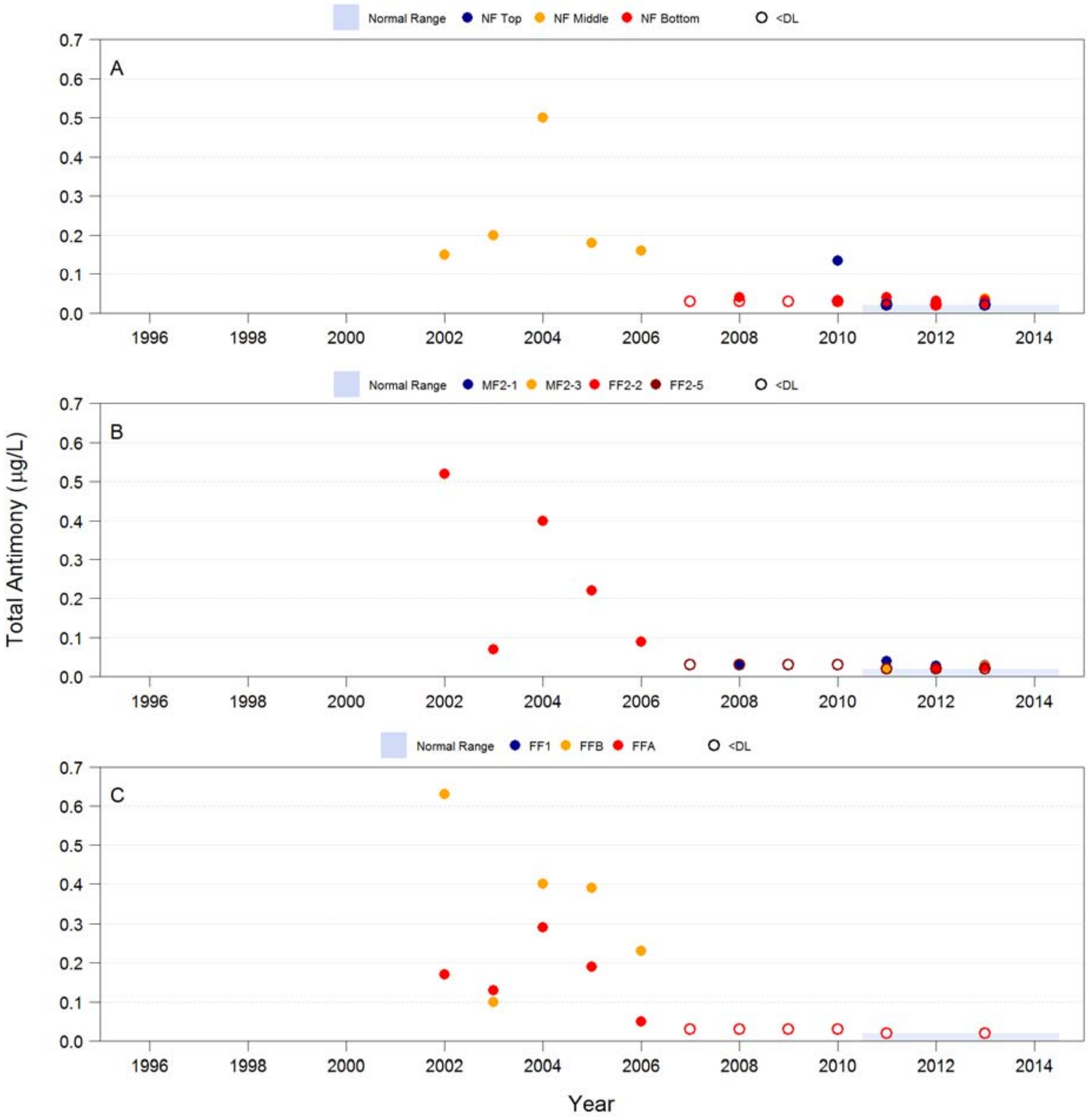
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-20 Total Aluminum Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season



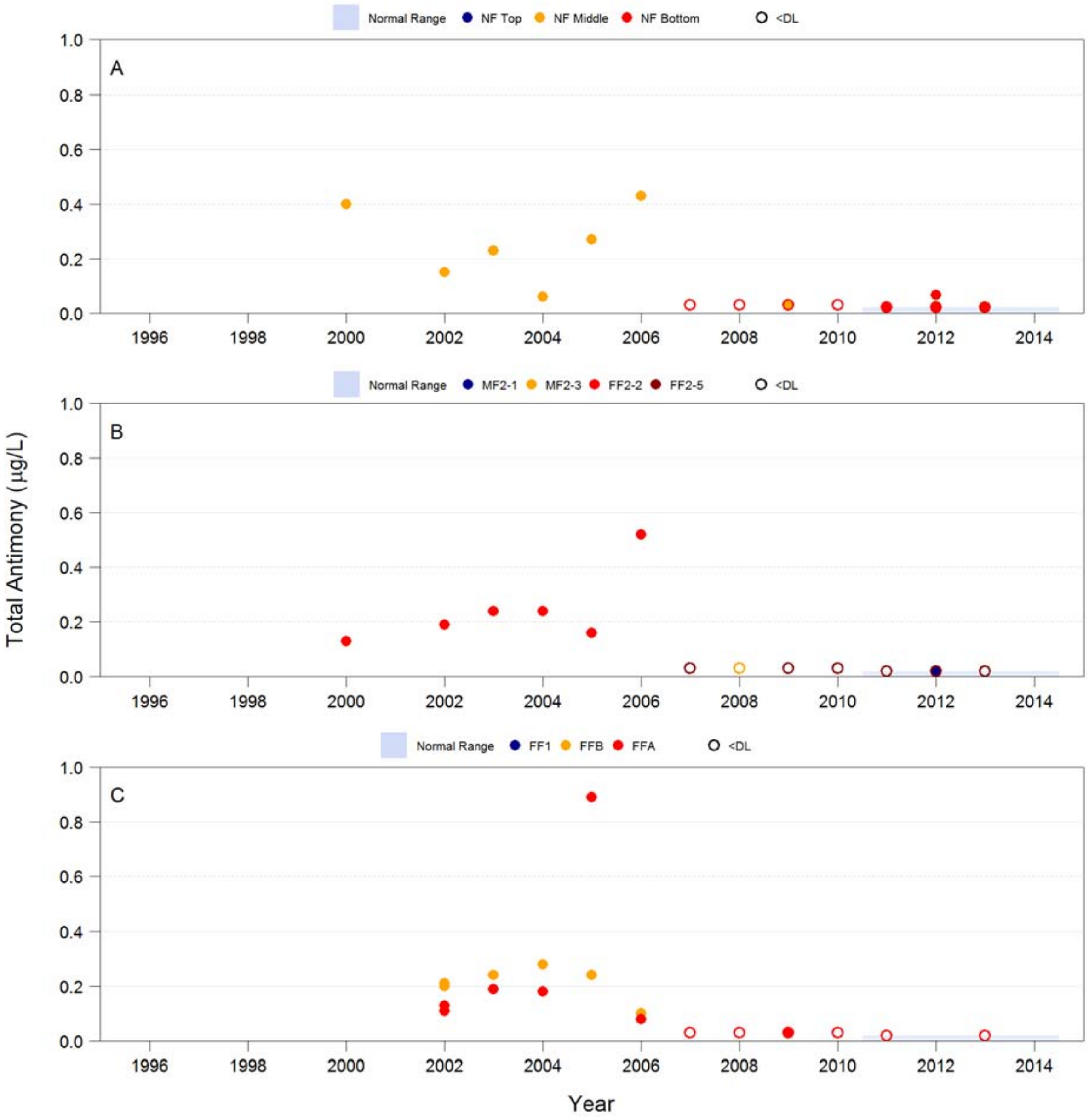
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-21 Total Antimony Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-cover Season



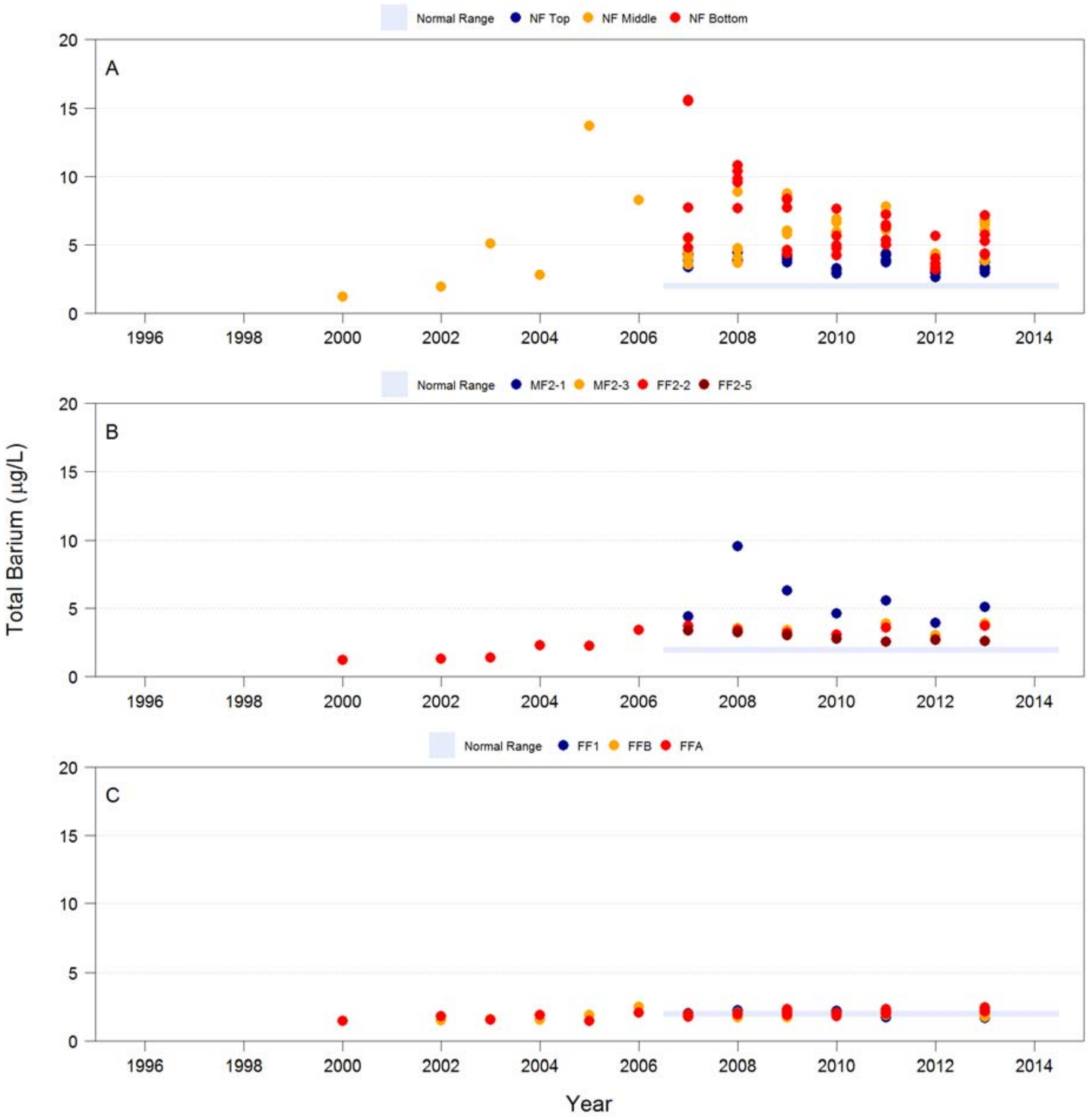
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-22 Total Antimony Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season



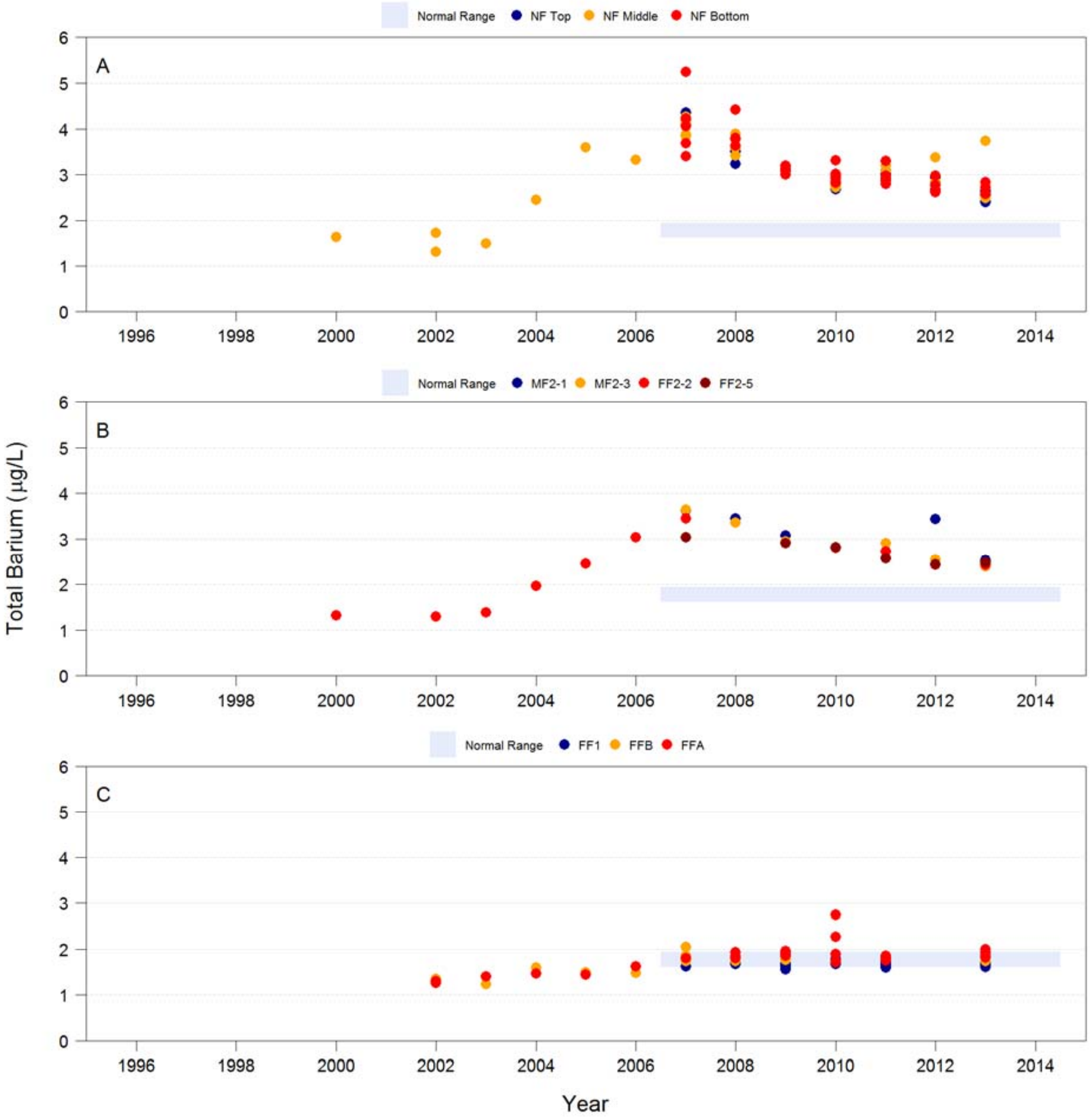
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-23 Total Barium Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-cover Season



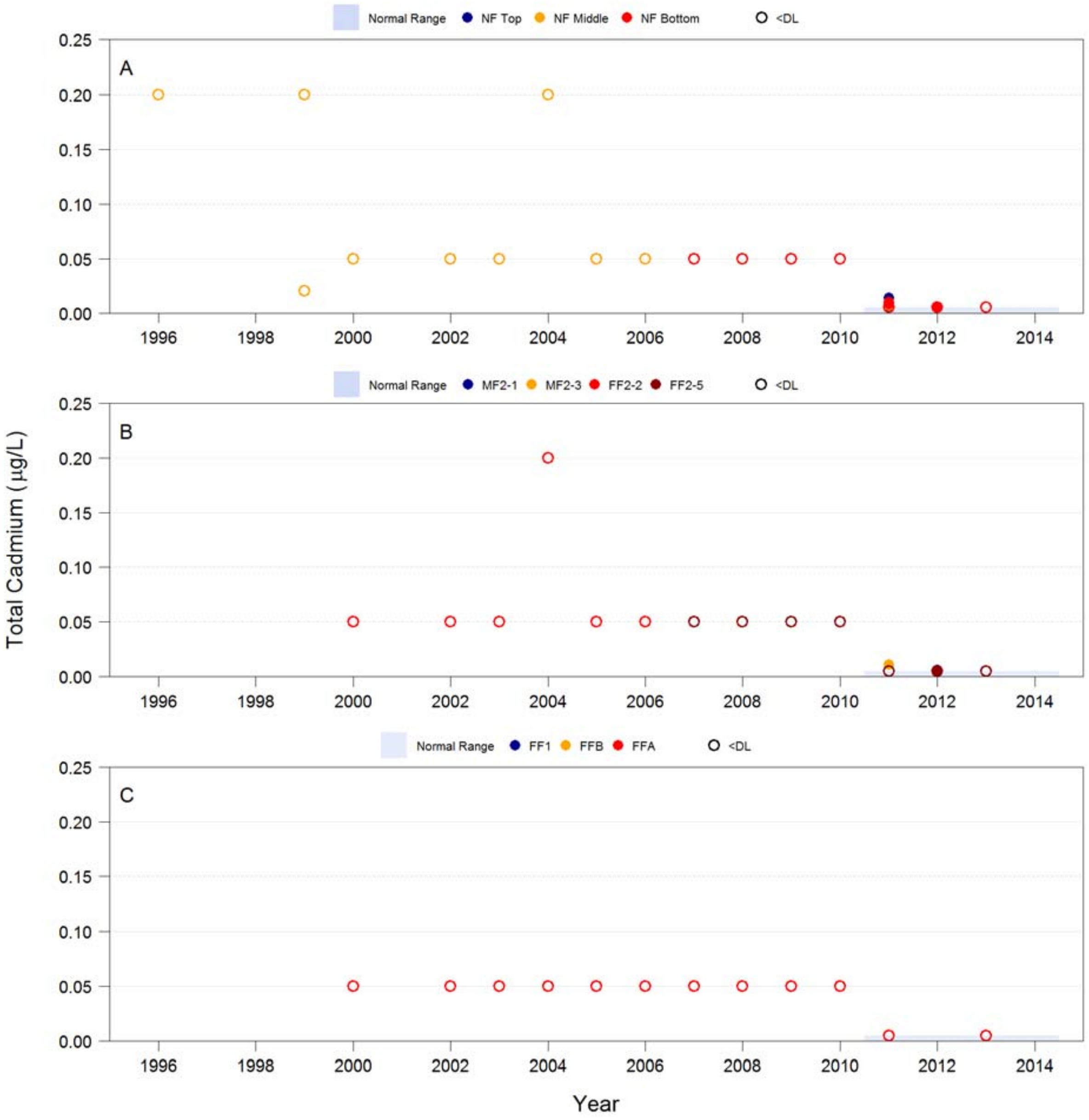
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-24 **Total Barium Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season**



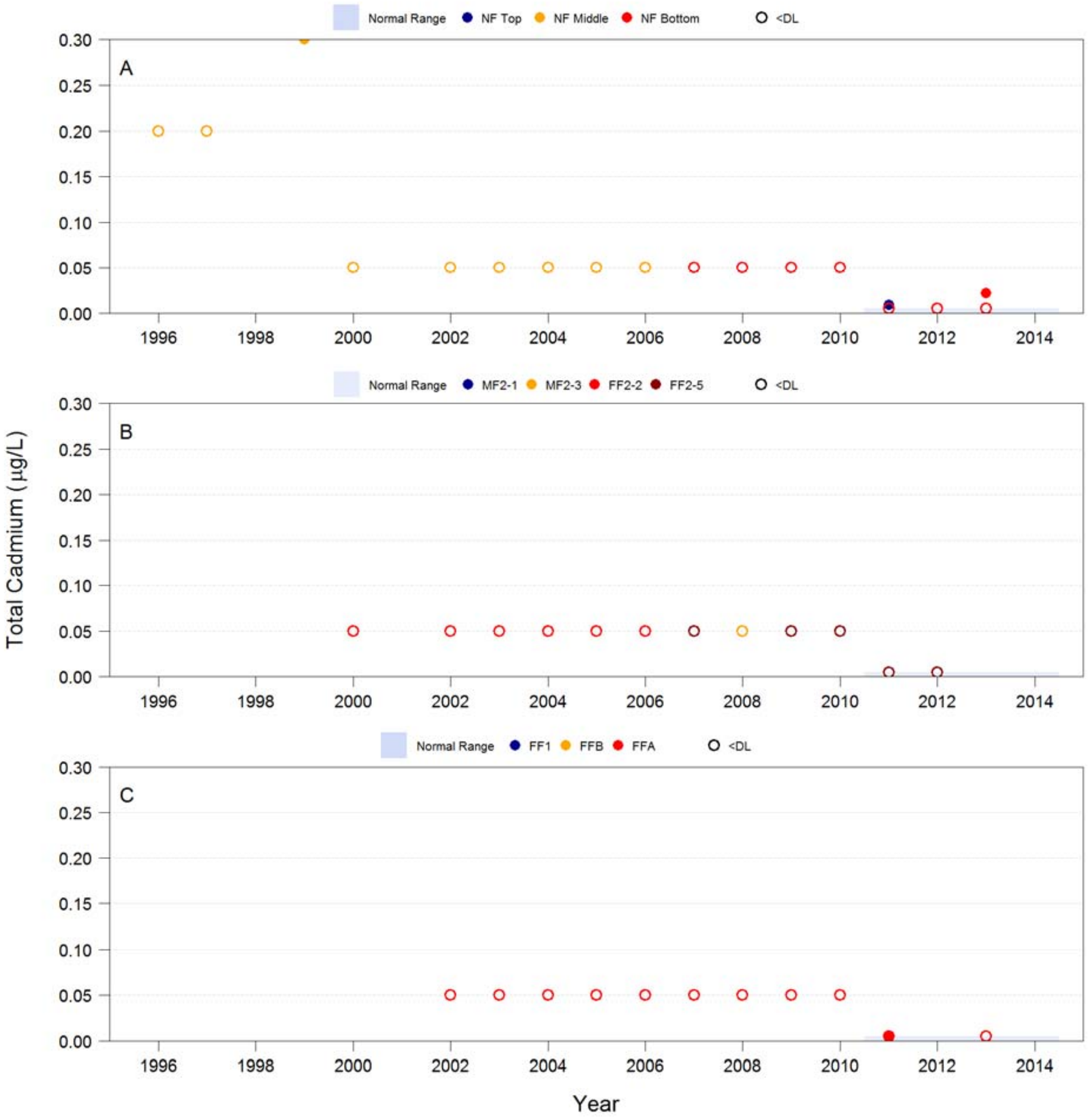
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-25 Total Cadmium Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-cover Season



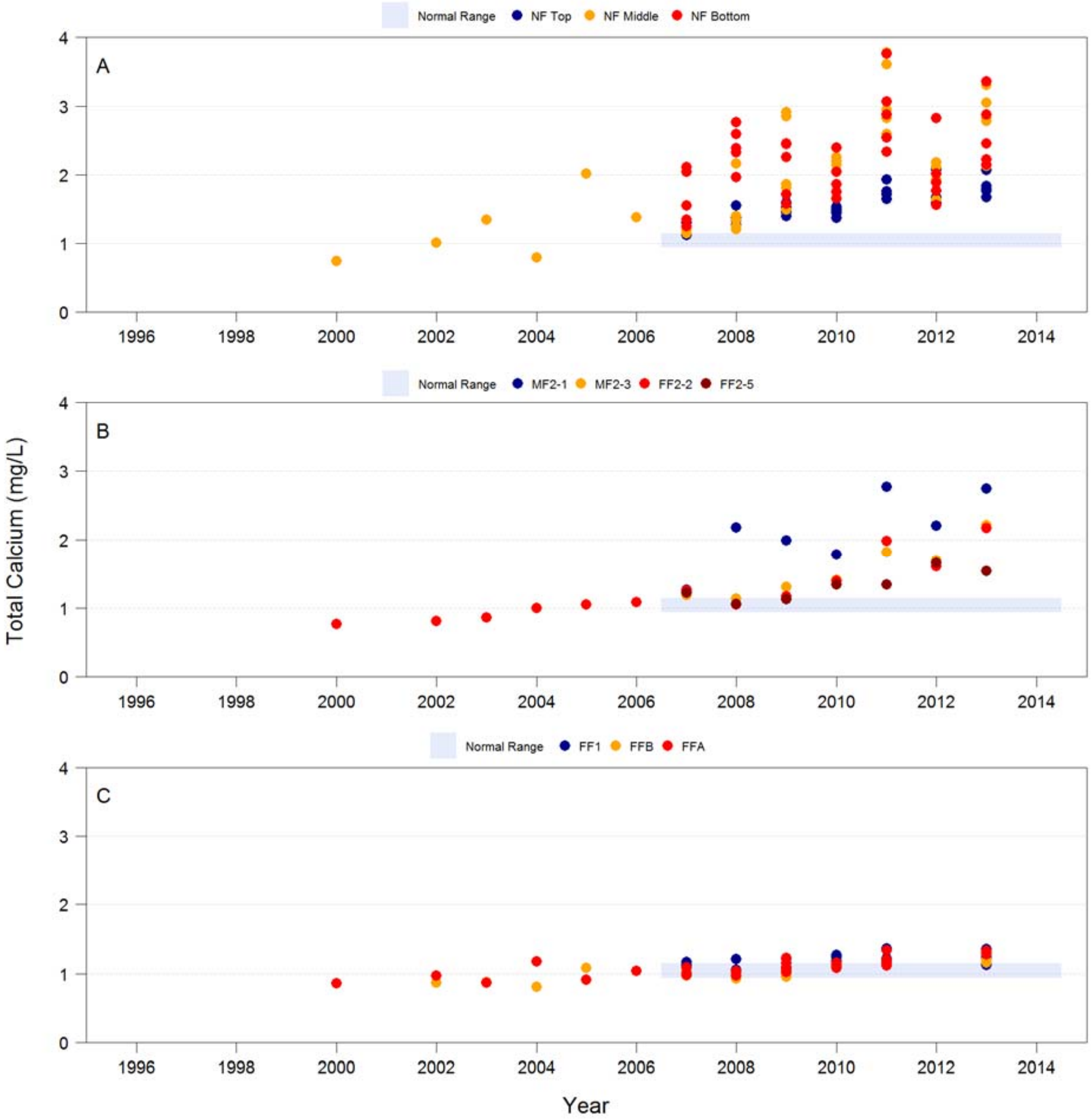
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-26 Total Cadmium Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season



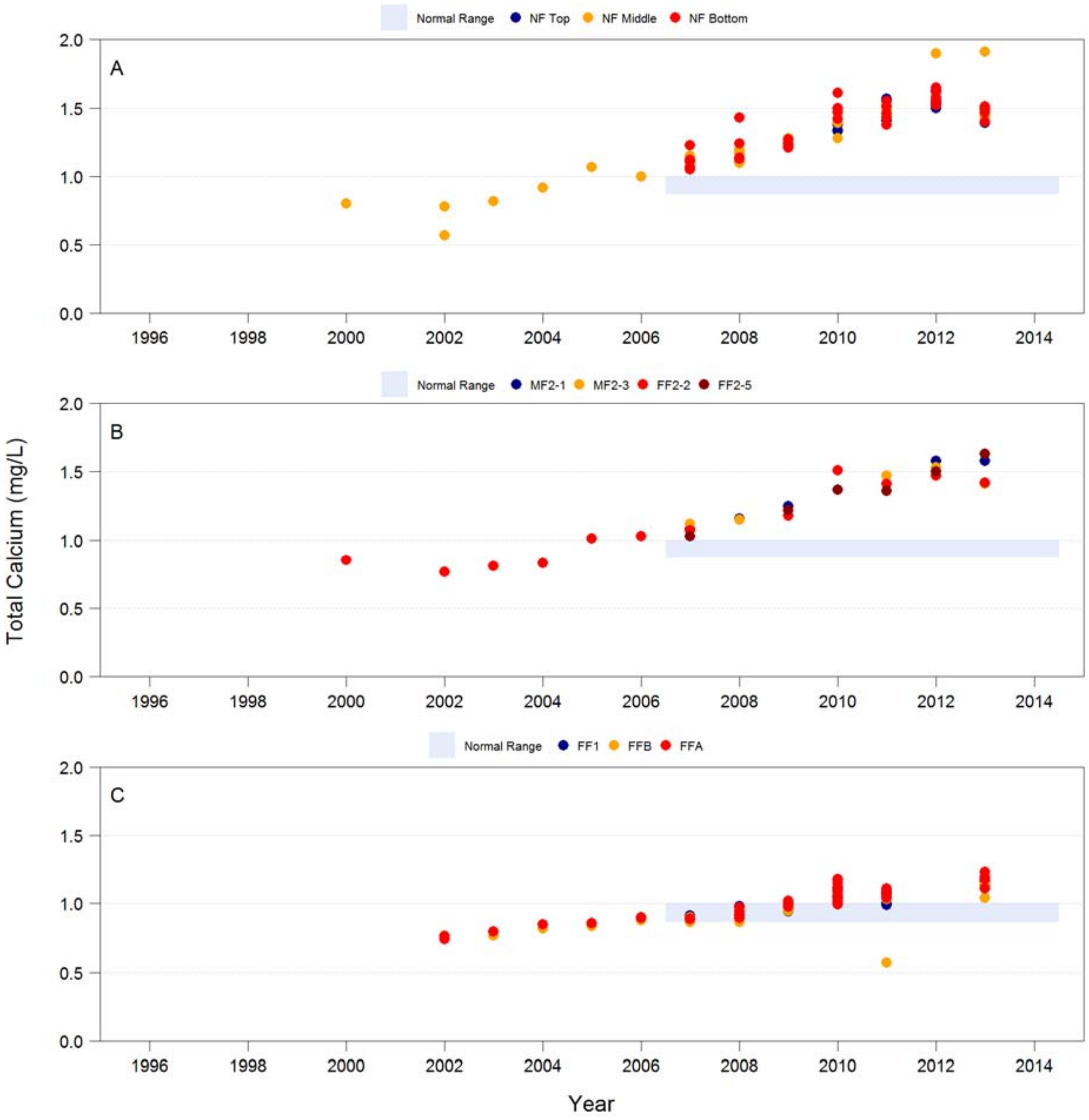
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-27 Total Calcium Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-Cover Season



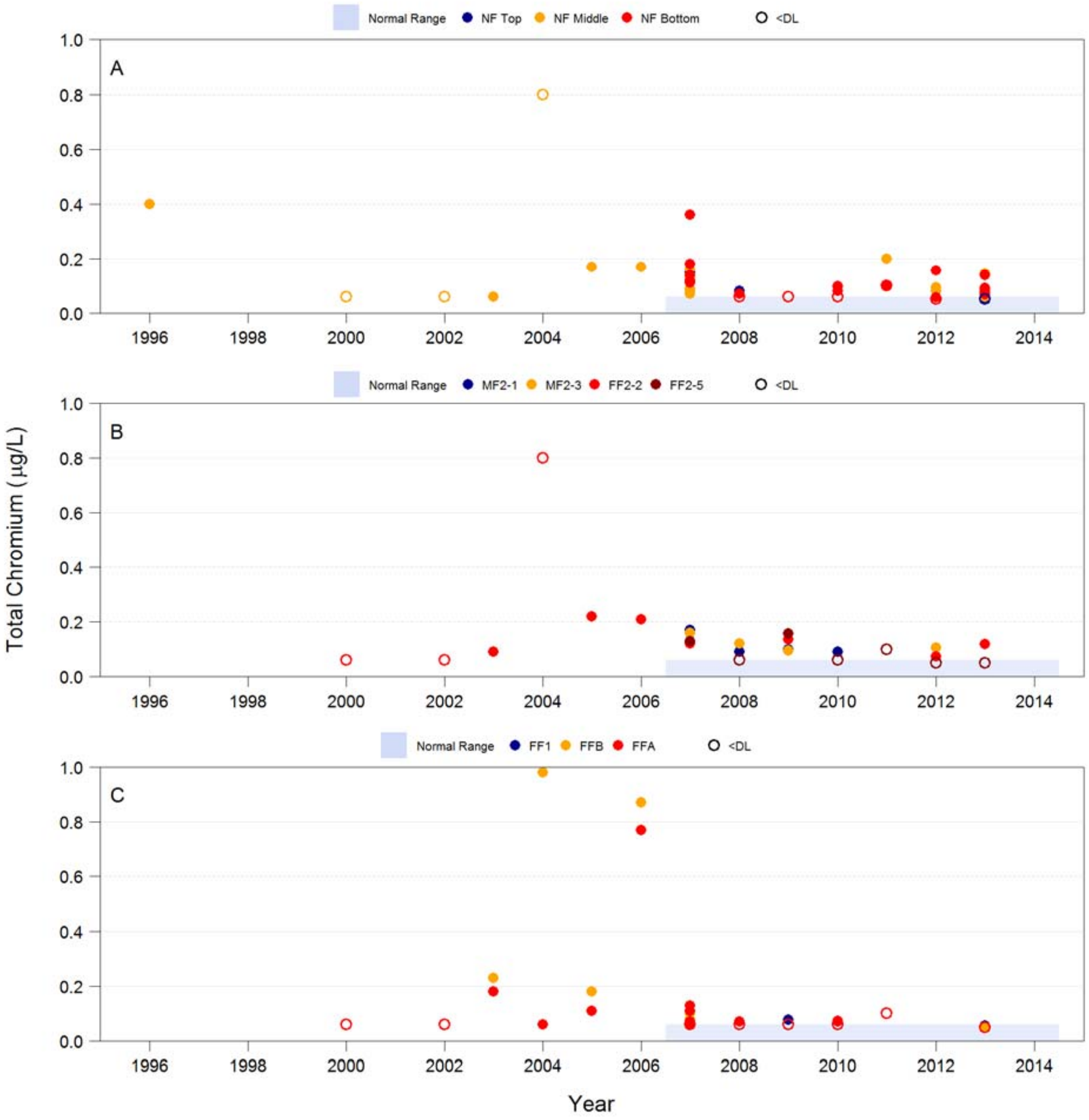
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-28 Total Calcium Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season



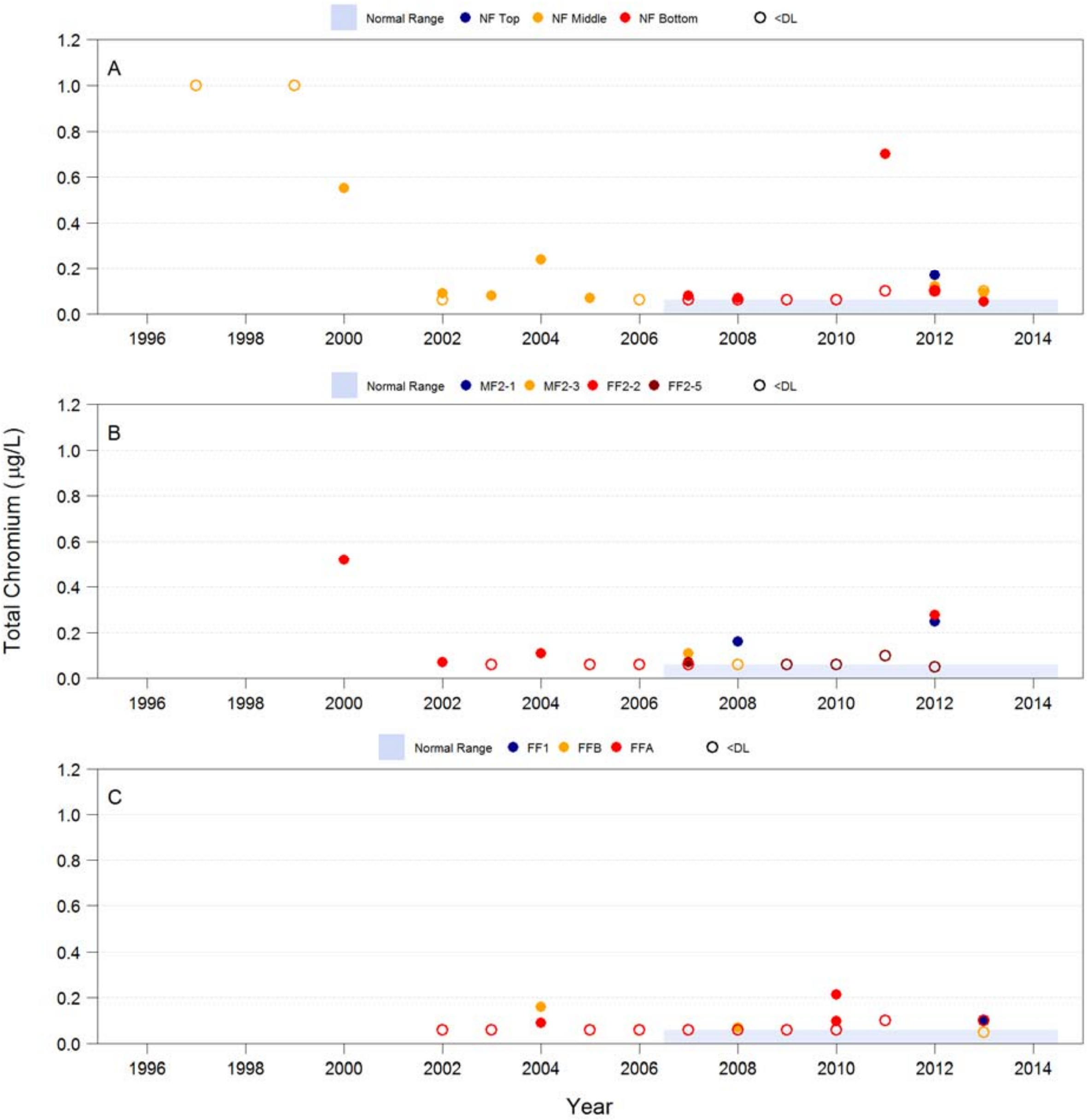
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-29 Total Chromium Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-Cover Season



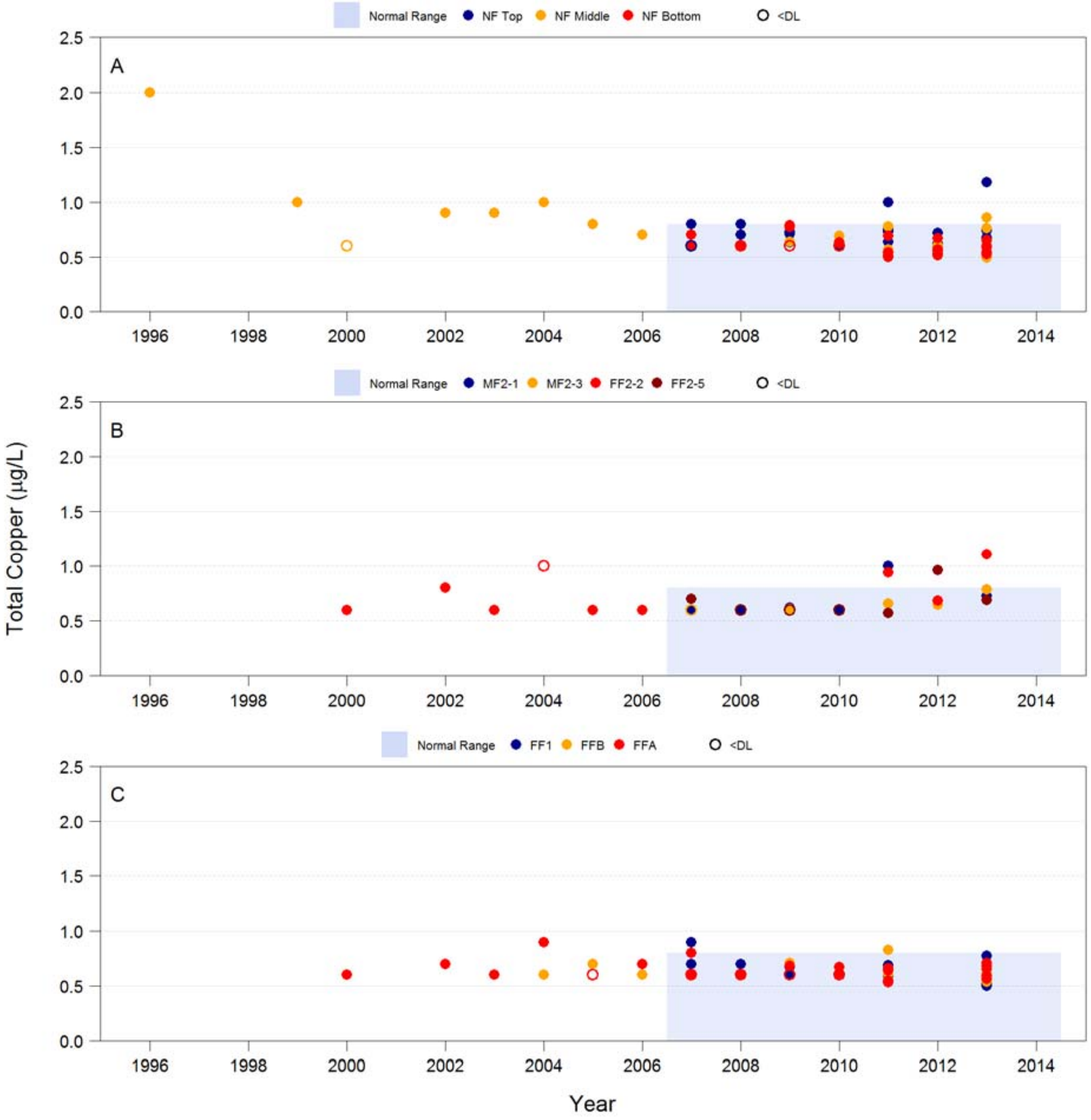
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-30 Total Chromium Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season



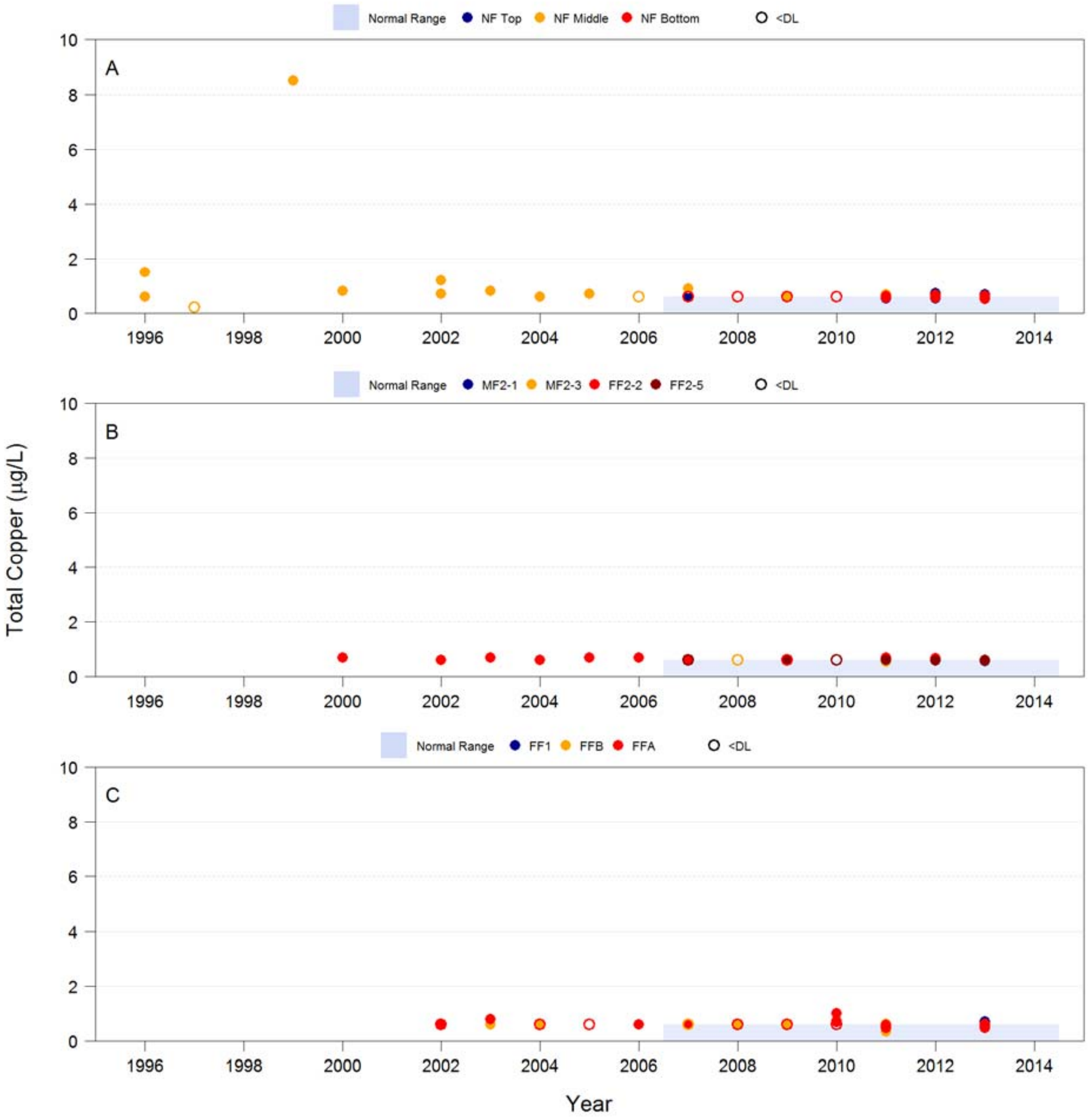
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-31 Total Copper Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-Cover Season



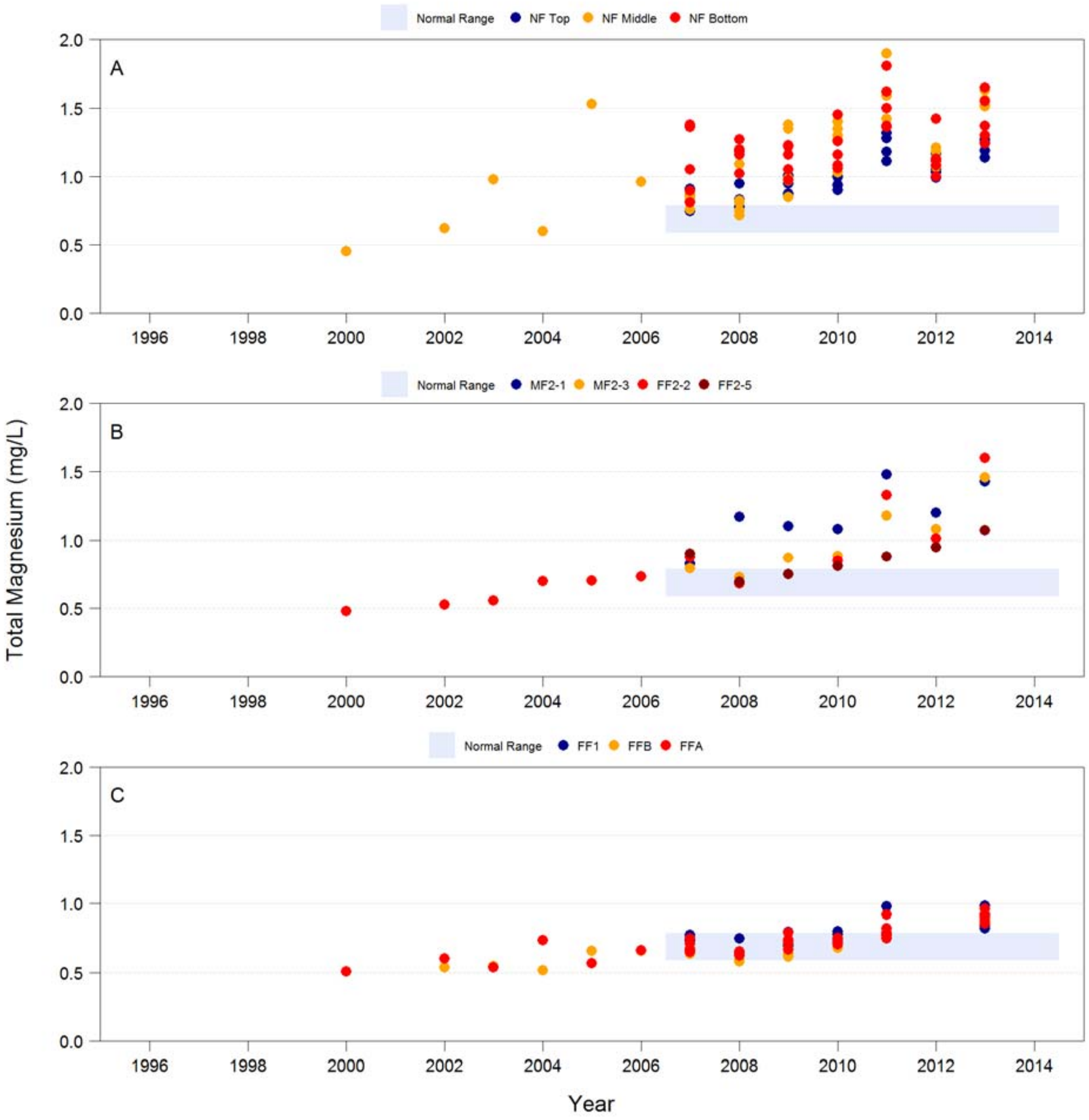
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-32 Total Copper Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season



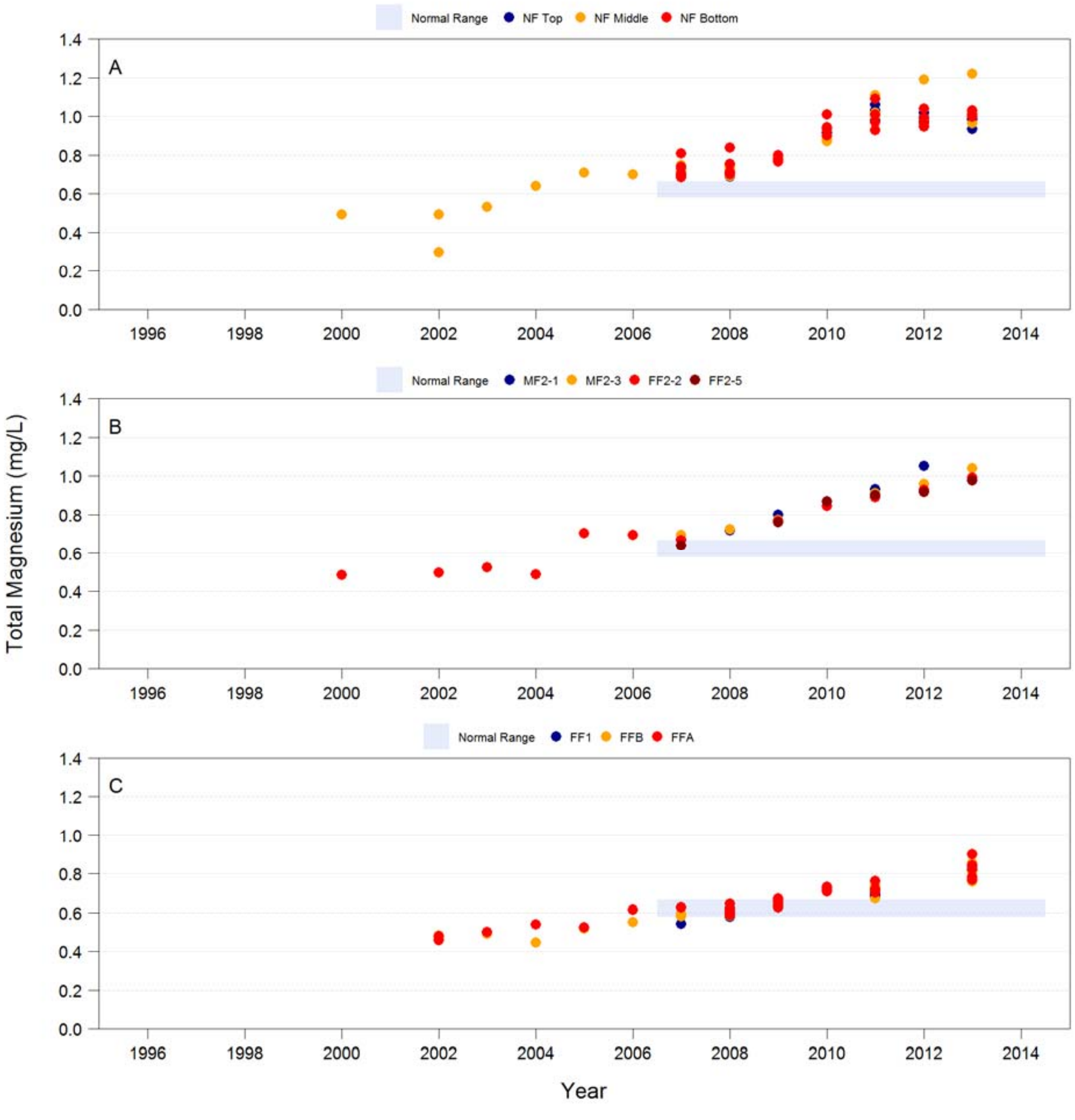
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-33 Total Magnesium Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-Cover Season



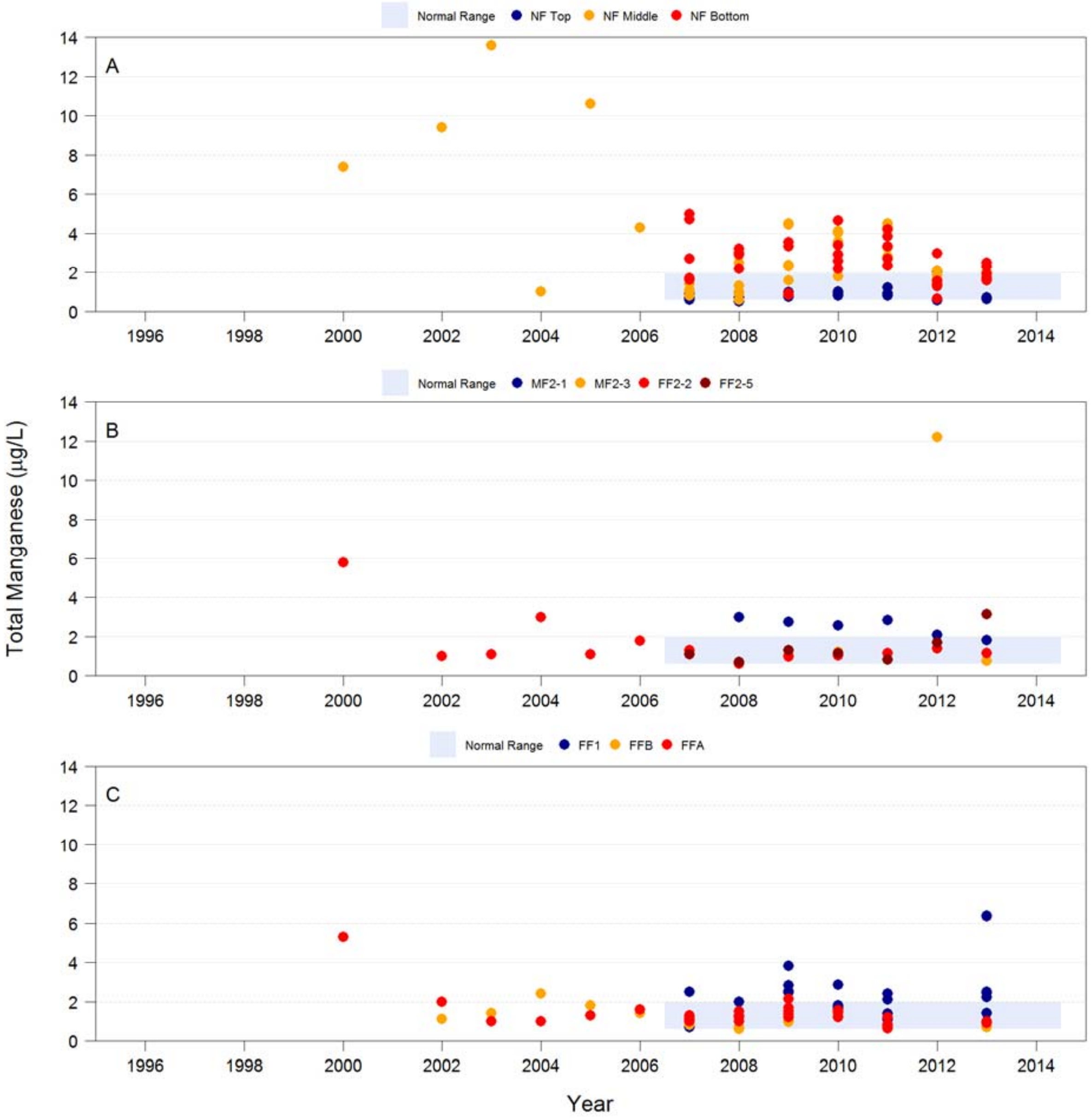
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-34 Total Magnesium Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season



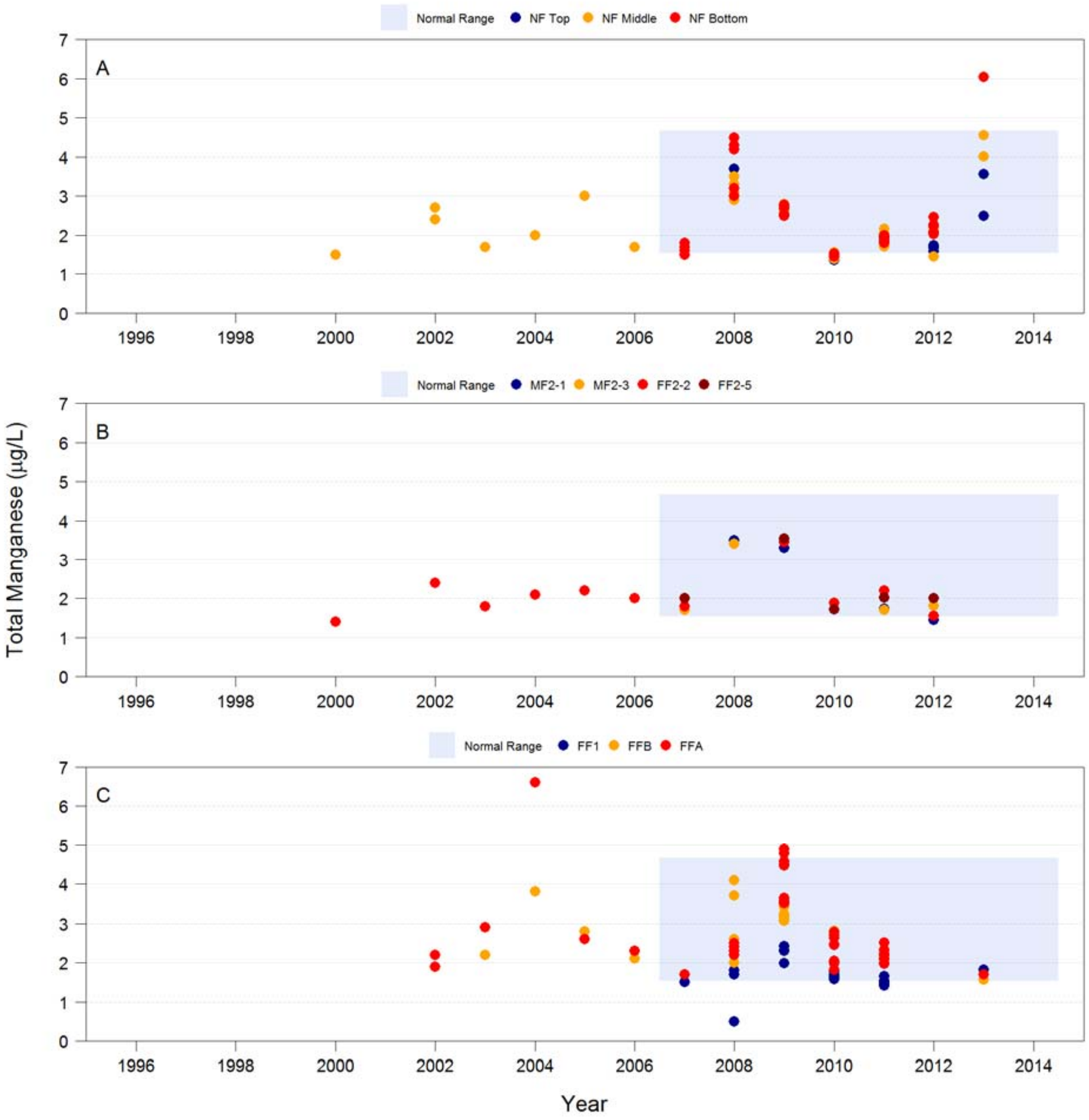
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-35 Total Manganese Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-Cover Season



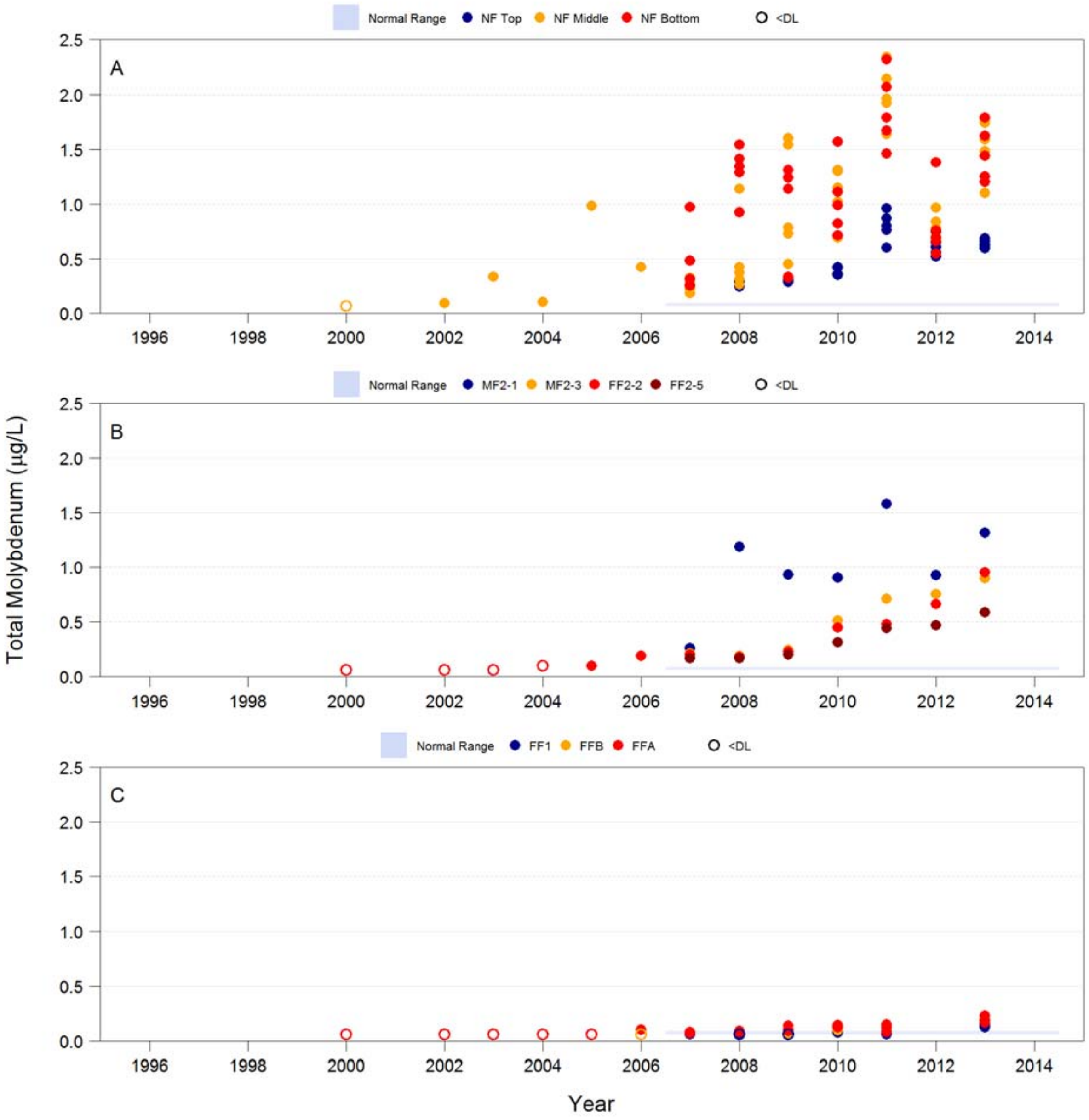
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-36 Total Manganese Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season



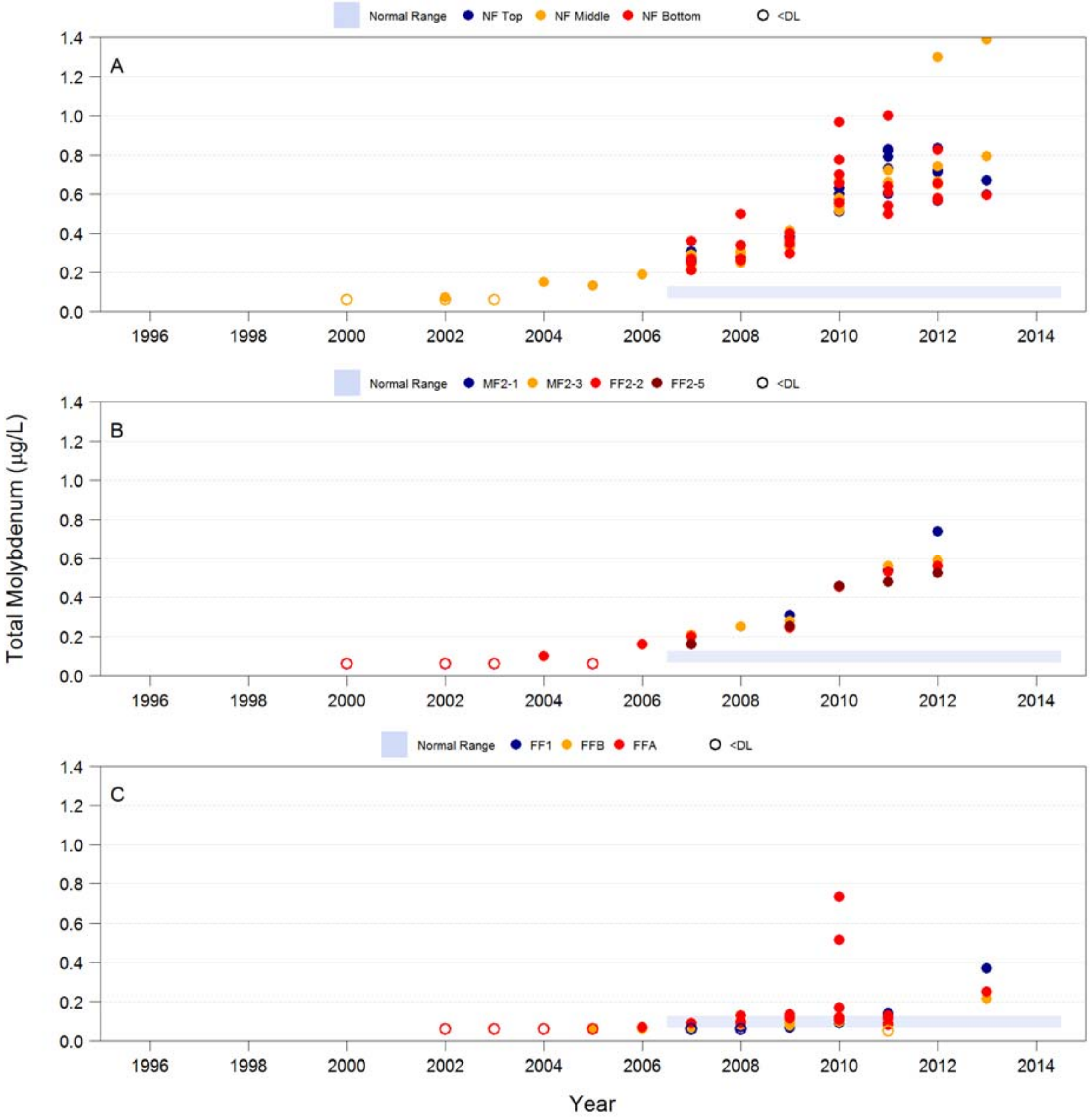
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-37 Total Molybdenum Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-Cover Season



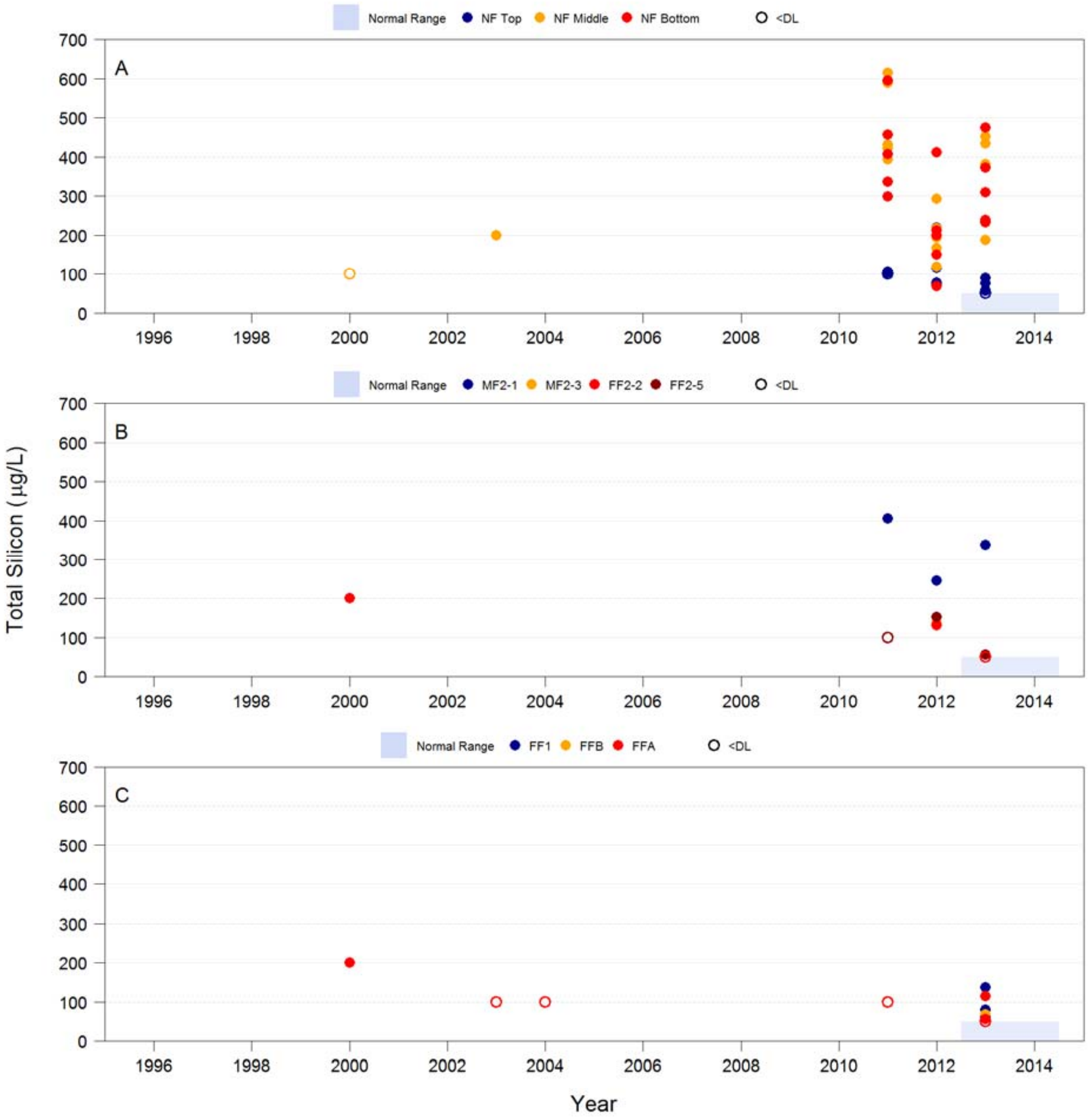
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-38 Total Molybdenum Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season



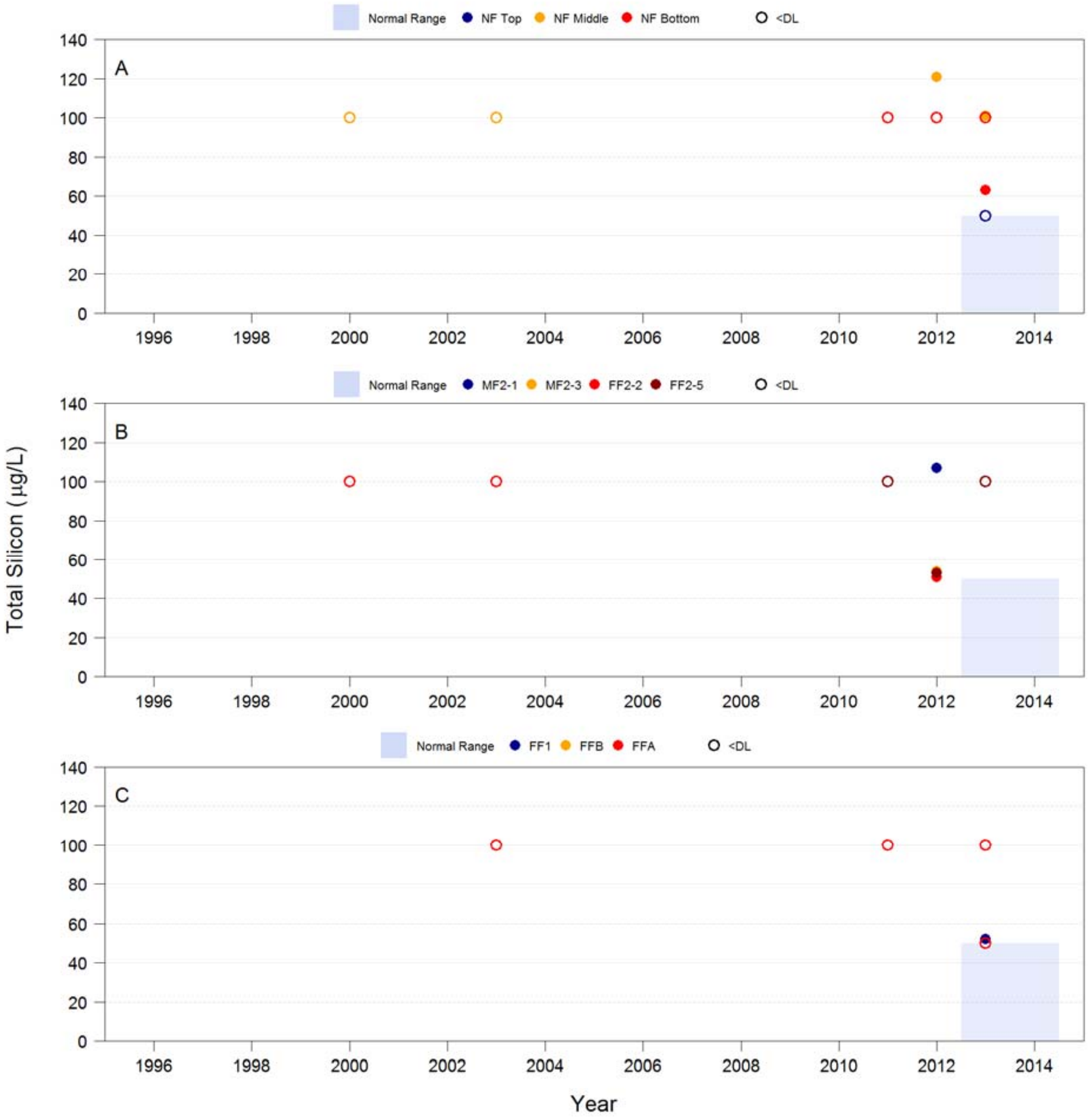
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-39 Total Silicon Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-Cover Season



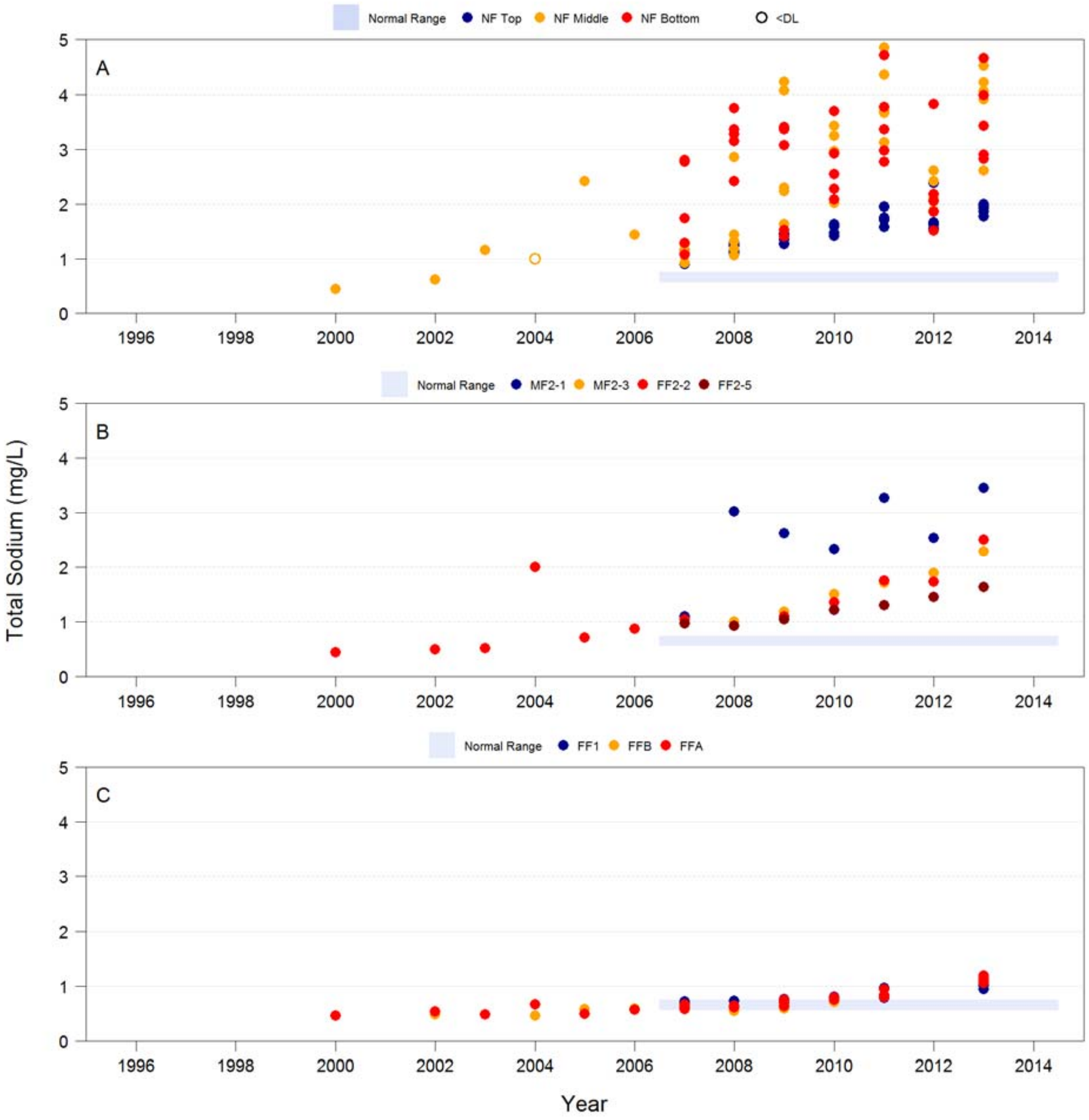
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-40 Total Silicon Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season



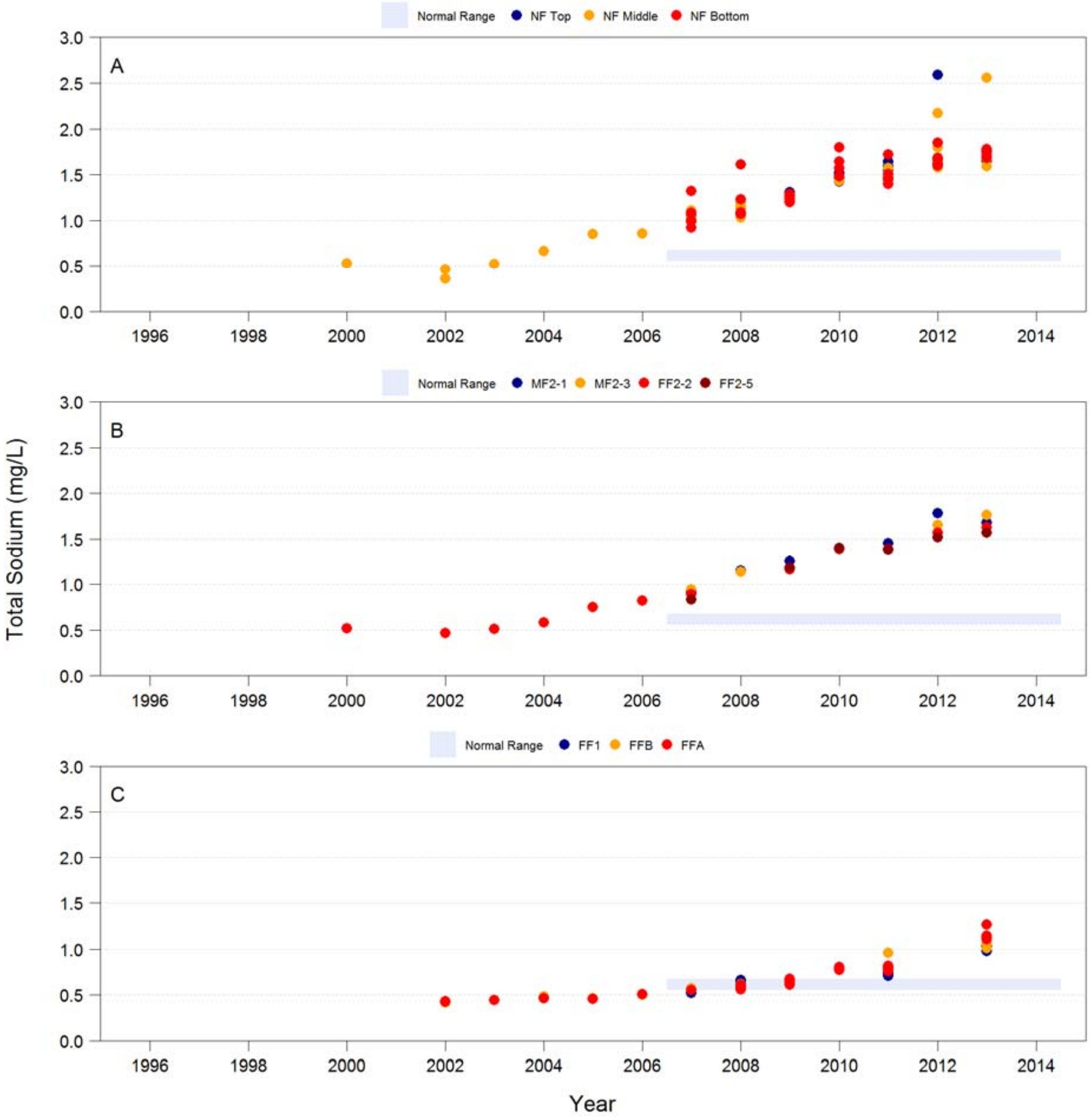
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-41 Total Sodium Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-Cover Season



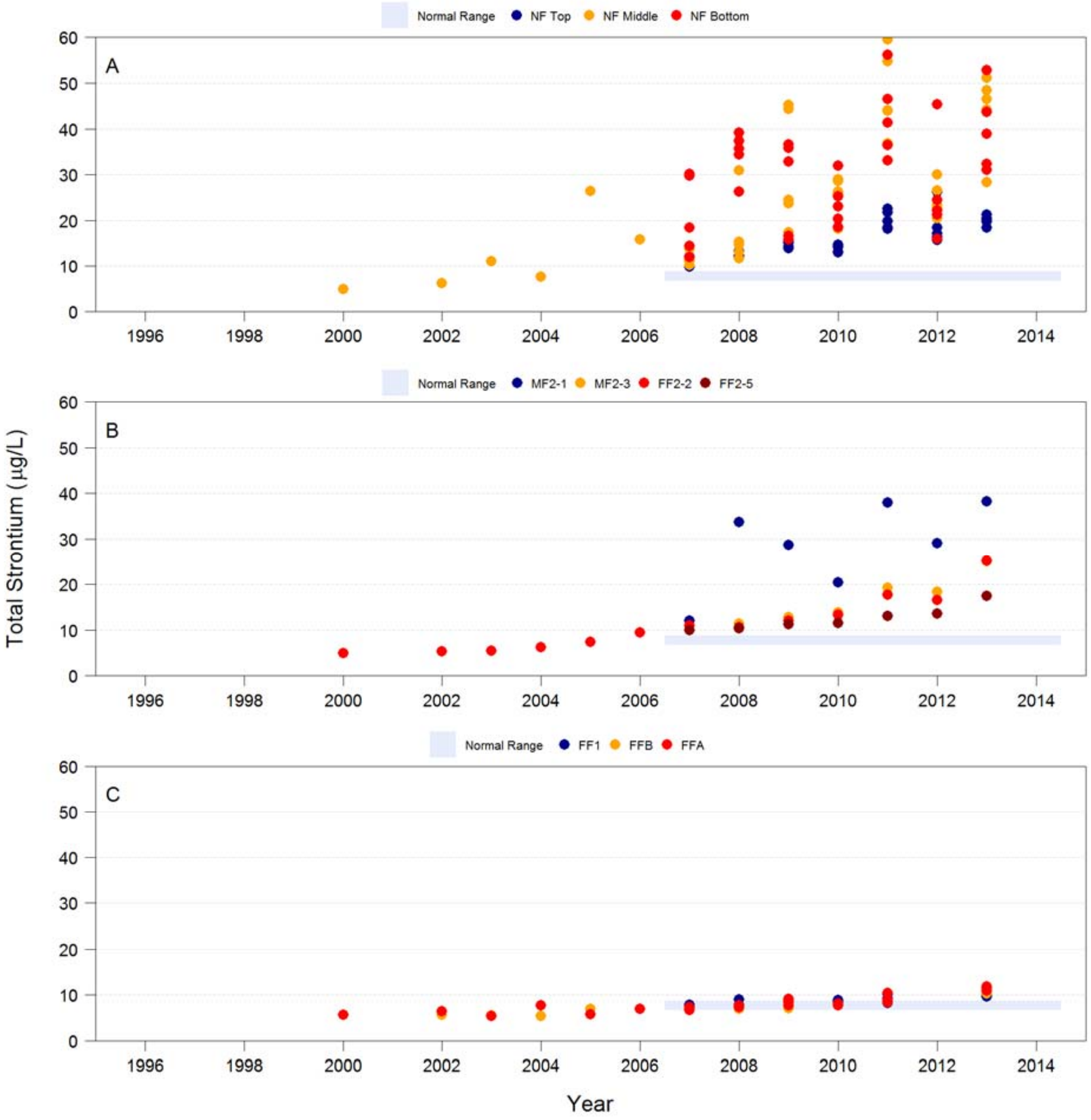
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-42 **Total Sodium Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season**



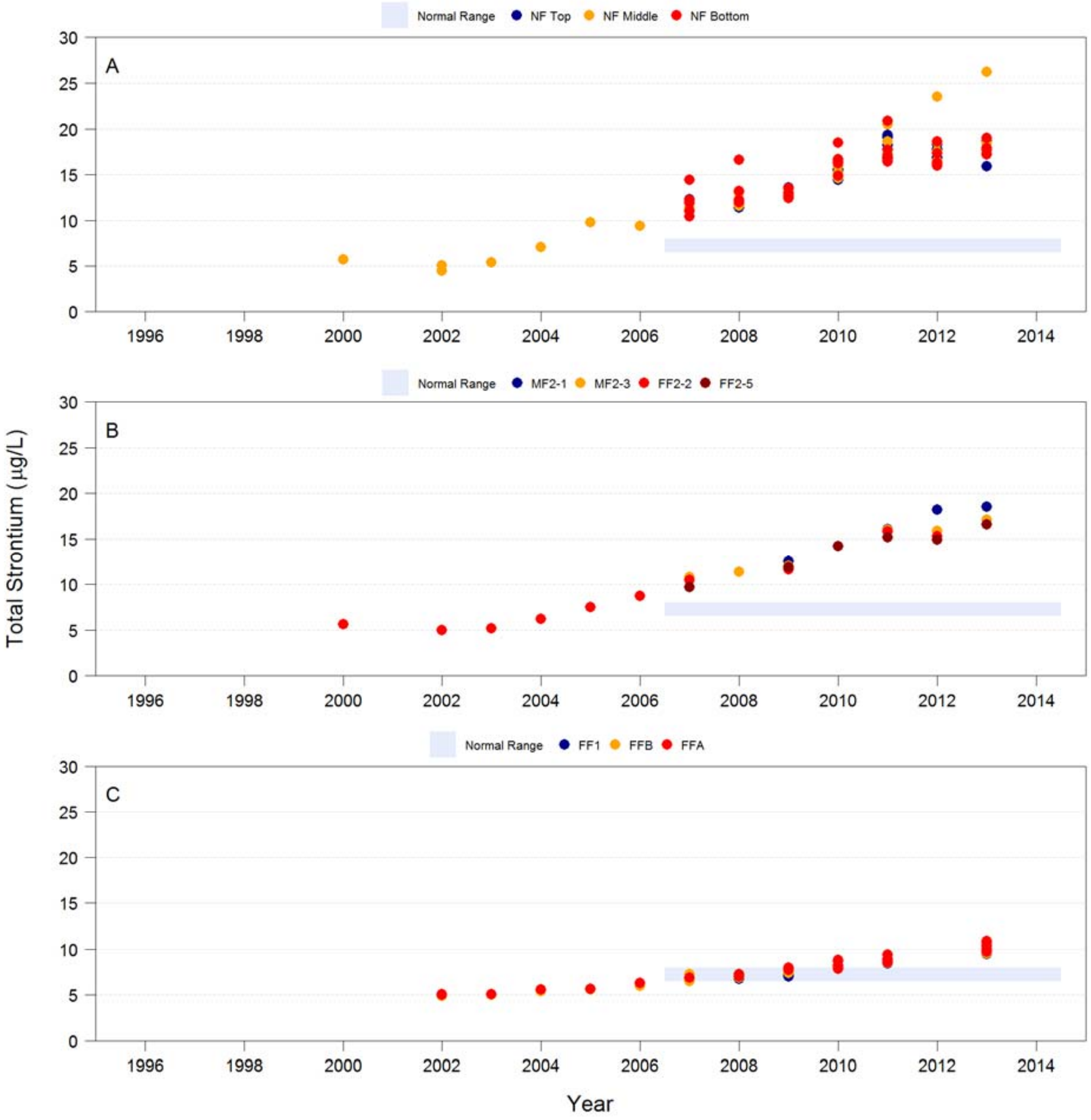
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-43 Total Strontium Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-Cover Season



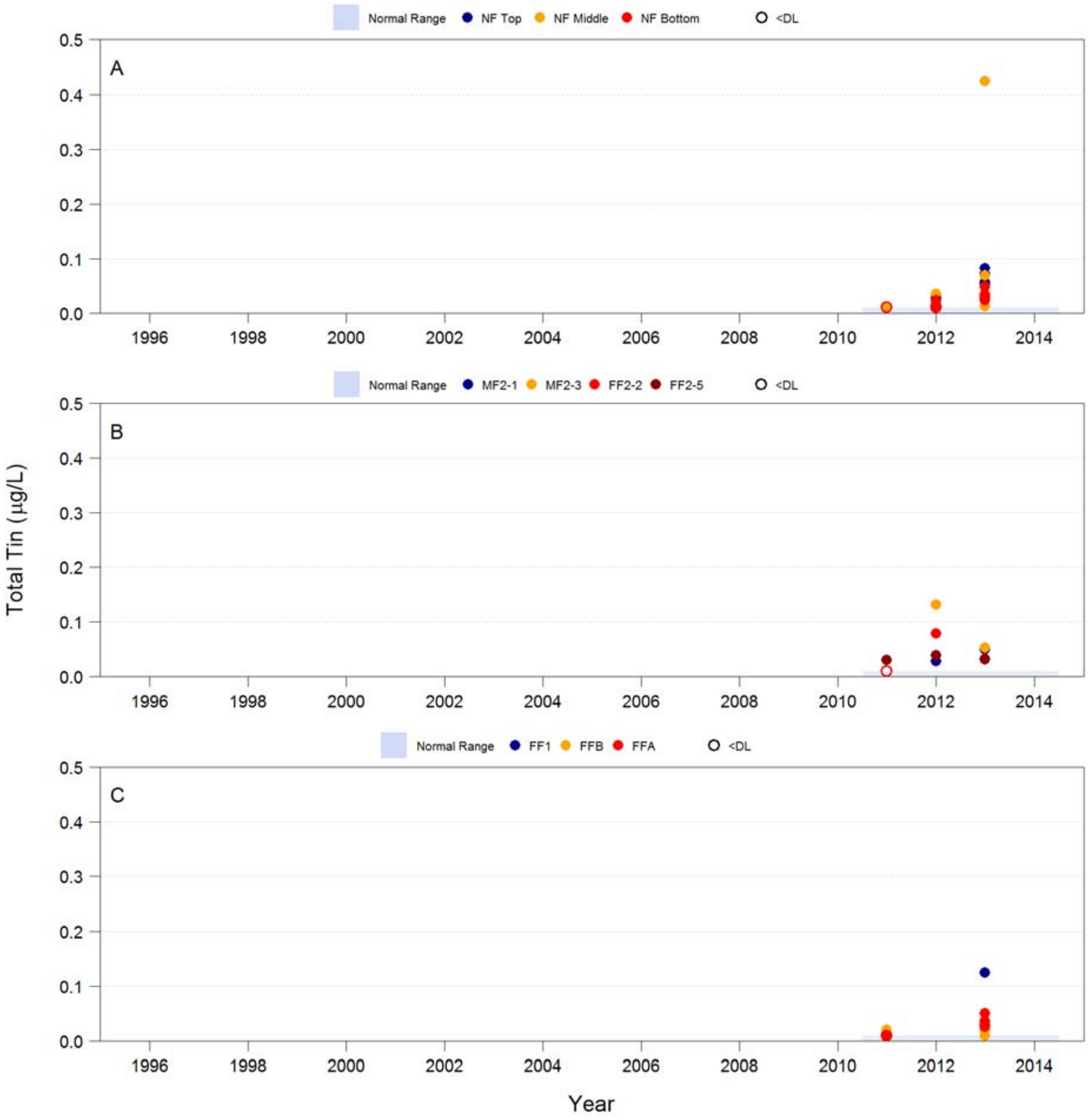
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-44 Total Strontium Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season



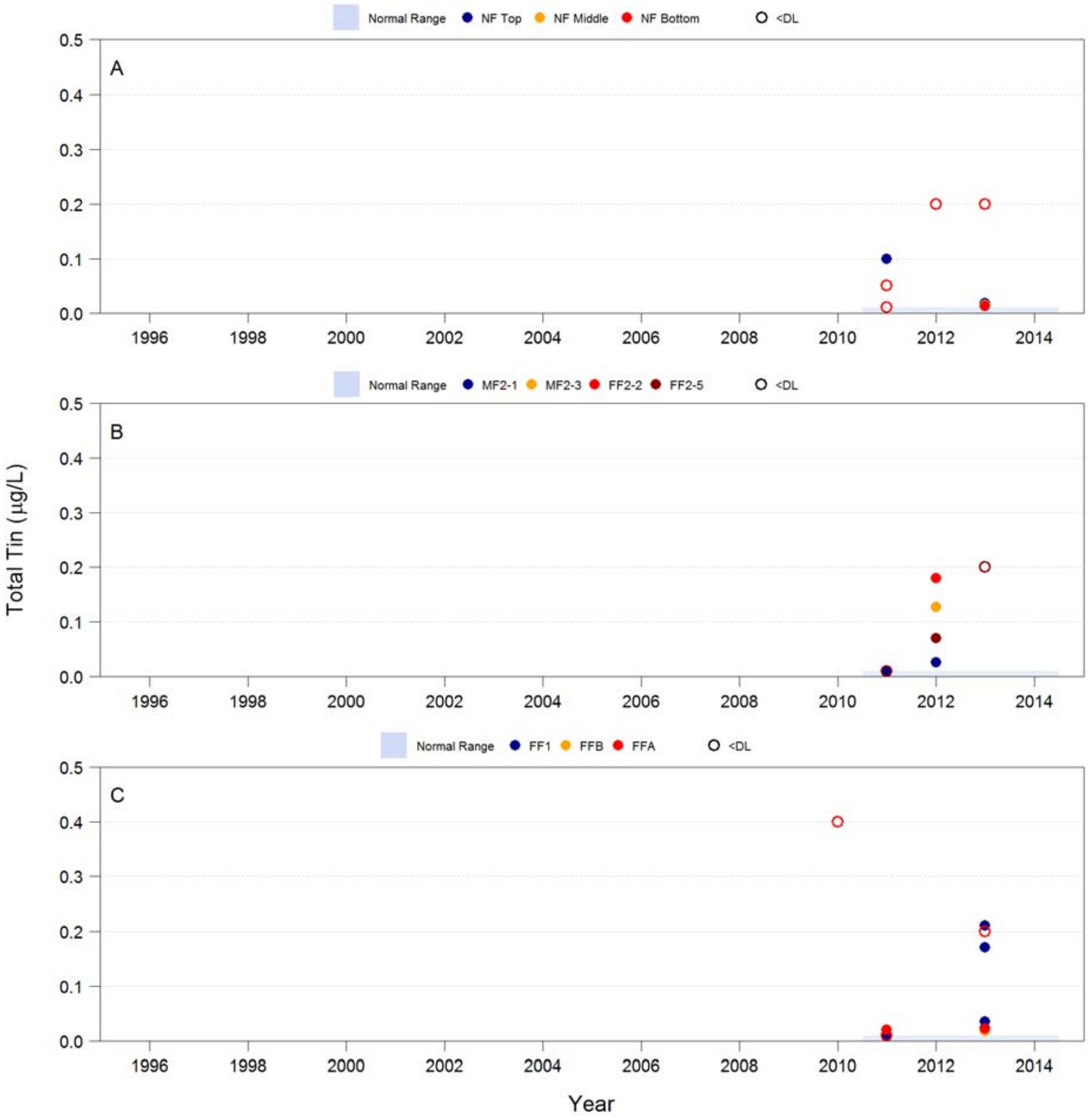
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-45 Total Tin Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-Cover Season



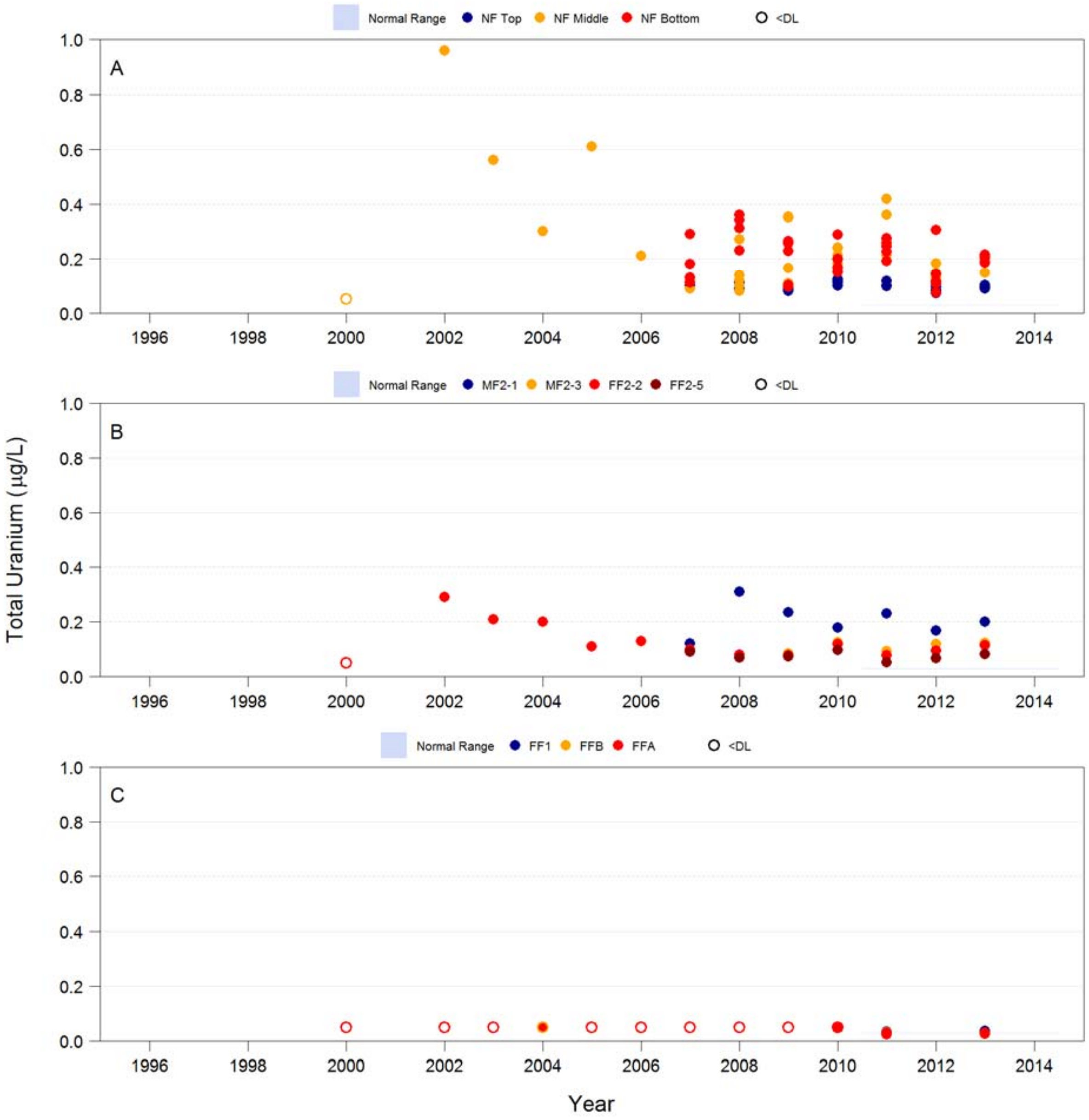
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-46 Total Tin Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season



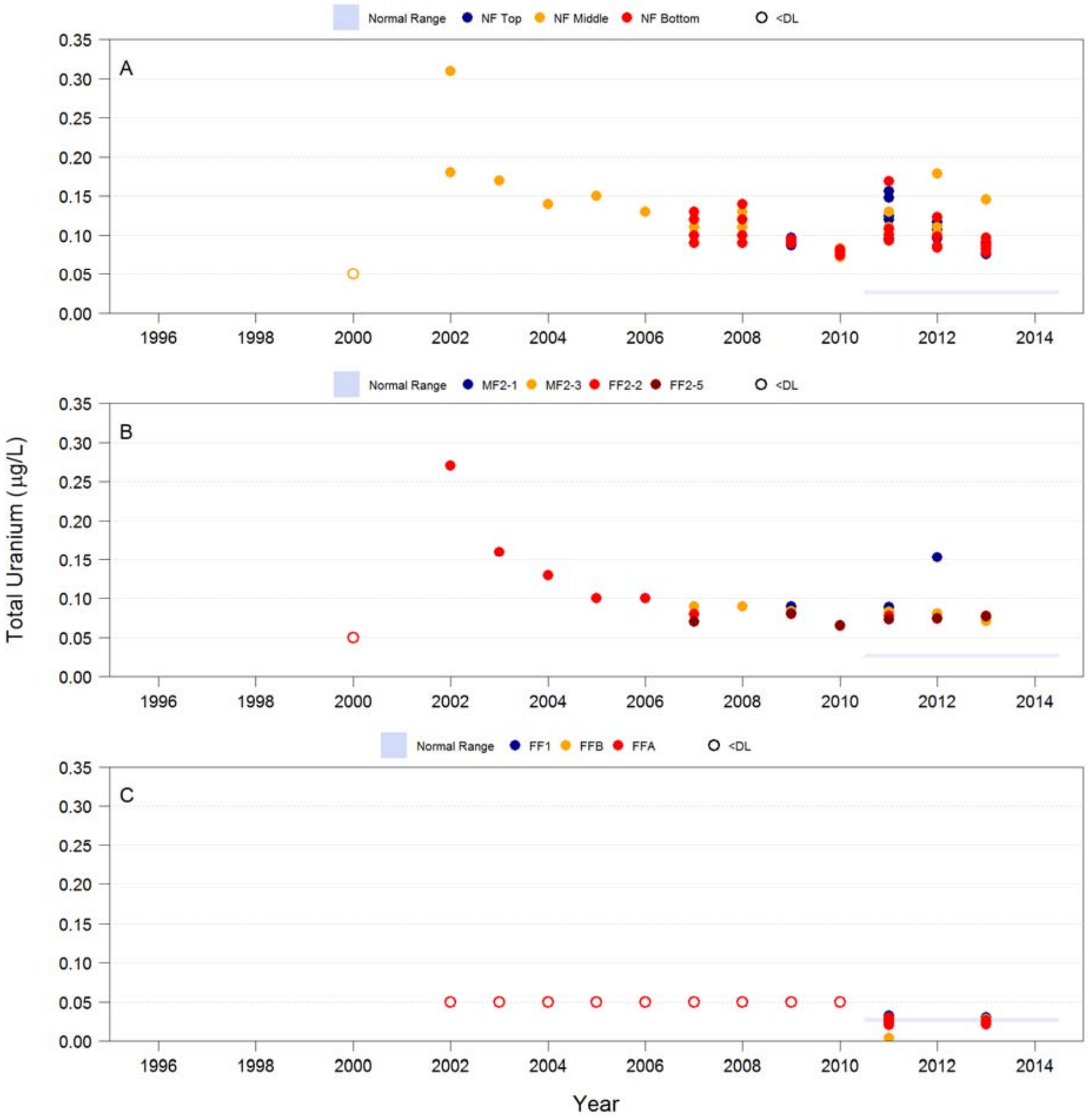
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-47 Total Uranium Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-Cover Season



Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 5-48 Total Uranium Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-Water Season



Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

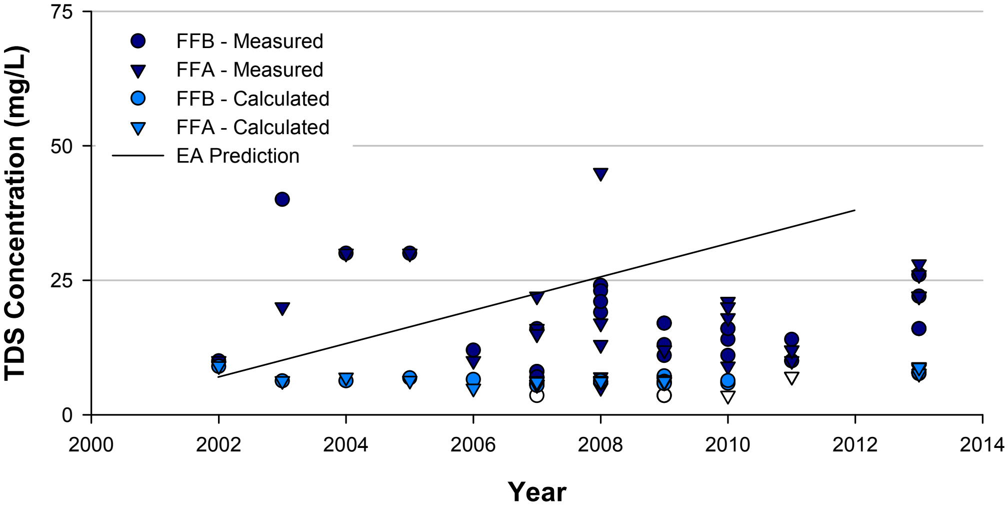
5.3.3 Comparison to EA Predictions

The EA predicted that concentrations of water quality variables at the mixing zone boundary would be below guidelines for the protection of aquatic life. Concentrations of SOIs at the edge of the mixing zone and in the NF area were compared to the Effects Benchmarks adopted for the AEMP (Table 5-3). The AEMP Effects Benchmarks are based on the CWQGs for the protection of aquatic life (CCME 1999a), the Canadian Drinking Water Quality Guidelines (Health Canada 1996 and 2006) and adaptations of general guidelines to site-specific conditions at Lac de Gras, and these are essentially revised, up-to-date benchmarks that were used for the EA predictions.

With the exception of chromium in 2004 and 2006, the monthly median concentration at the mixing zone boundary of all 13 SOIs with Effects Benchmarks were below benchmark values. The median concentration of chromium exceeded the AEMP aquatic life benchmark during two sampling events (January 2006 [median = 1.24 μg/L] and October 2006 [median = 1.30 μg/L]) during 2002 to 2013. Substance of interest concentrations in the NF area were below the AEMP Effects Benchmarks in all samples collected from 2002 to 2013.

Dispersion modelling during the EA was conducted for TDS (DDMI 1998c). For the modelling, TDS was simulated as a conservative variable that would act as an effluent tracer. Simulated TDS concentrations would reflect the effects of dispersion and dilution of the minewater discharge in Lac de Gras. Continuous dispersion modelling was conducted for a 10-year period. Although TDS from the effluent has reached the FF reference areas, concentrations are lower than those predicted by the modelling, and show a less pronounced trend (Figure 5-49).

Figure 5-49 Concentration of Total Dissolved Solids (TDS) at Sampling Stations FFB and FFA Relative to the Predicted Concentration in the EA



Notes: Open symbols represent non-detectable values. Measured TDS is estimated gravimetrically following analytical method SM 22 2540 C m. Calculated TDS is a calculated parameter estimated based on the sum of the concentrations of individually analyzed major cations and anions, using an adaptation to the approach defined in APHA 2005.

5.4 Conclusions

- The annual AEMP water quality data from 2007 to 2013 were evaluated according to Action Levels. The NF area median concentrations of 24 variables (specific conductivity, total hardness, calculated TDS, turbidity, chloride, sulphate, ammonia, nitrate; and the total fractions of aluminum, antimony, barium, cadmium, calcium, chromium, copper, lead, magnesium, manganese, molybdenum, silicon, sodium, strontium, tin and uranium) triggered Action Level 1 in at least one year of monitoring. No management action is required under the response framework when a water quality variable triggers Action Level 1. All but one of these variables (lead) demonstrated an effect equivalent to Action Level 1 during the 2011 to 2013 re-evaluation period. As a result, the remaining 23 variables were classified as Substances of Interest (SOIs).
- Of the 24 variables that triggered Action Level 1 during the 2007 to 2013 monitoring period, 14 (calculated TDS, turbidity, chloride, ammonia, nitrate, and total aluminum, barium, chromium, molybdenum, silicon, sodium, strontium, tin and uranium) triggered Action Level 2. Under the Response Framework, when a water quality variable triggers Action Level 2, the required management action is to establish an Effects Benchmark for that variable if one does not already exist. Five of the variables that triggered Action Level 2 (turbidity, sodium, aluminum, silicon and tin) do not have existing AEMP Aquatic Life Effects Benchmarks. Therefore, DDMI will be required to develop AEMP Effects Benchmarks for these five variables.
- Of the nine SOIs evaluated against Action Level 3 (i.e., those with existing AEMP Effects Benchmarks), Chromium was the only variable that triggered Action Level 3, and only in the 2007 ice-covered season. The concentration of chromium at the mixing zone boundary has since decreased, with most sample results reported below the DL. Concentrations in all samples from 2007 to 2013 were well below the AEMP Effects Benchmark for chromium. In light of the lack of Action Level 3 exceedances by chromium since 2007, no follow-up action is warranted.
- The variables that triggered Action Levels from 2007 to 2013 were categorized according to the WOE effects rankings, which feed into the WOE assessment (Section 11). All 24 variables satisfied the requirement for a low rank during at least one year, because concentrations in the NF were significantly greater than in reference areas in one or both sampling seasons. A moderate rank was not applied to any of the variables, because concentrations in all samples were below AEMP Effects Benchmarks.
- Temporal analyses were conducted on SOIs identified over the three year re-evaluation period (from 2011 to 2013). Nine SOIs identified in this period showed patterns of increasing concentration over time at most exposure and reference areas (specific conductivity, total hardness, calculated TDS, sulphate, calcium, molybdenum, magnesium, sodium and strontium). Correlation analysis found these increases to be statistically significant. Chloride also produced significant correlations with time; however, concentrations have not increased since 2011.
- In the NF area, concentrations of the 10 SOIs with increasing trends increased above the normal range from approximately 2005 or thereafter, and remained above the normal range throughout 2011 to 2013.
- The reference areas now appear to be demonstrating the presence of effluent. With the exception of chloride, the SOIs with positive temporal trends in the exposure areas also had significant temporal trends in the reference areas, and they demonstrated increasing temporal trends at most stations

along the MF3 transect. The presence of effluent in the reference areas does not reflect an increase in the load of the SOIs. Except for an increase in the effluent concentrations of sulphate and molybdenum, there has been no increase in the effluent load or concentration of these SOIs since 2010.

- The concentrations of these SOIs have been increasing at a greater rate at stations located farthest from the Mine (in the FFA area and at LDG48). The Slipper Lake outlet, which enters Lac de Gras at the north west end is a possible influence on the SOI concentrations at LDG48 and FFA.
- Exposure area concentrations of barium, which has been used as an effluent tracer in Lac de Gras, increased from 2000 to 2007, as the loading rate of barium from the Mine effluent increased. However, concentrations in the lake have been decreasing since 2007, again reflecting the lower effluent loads and concentrations since 2007.

6 EUTROPHICATION INDICATORS

6.1 Introduction

Indicators of eutrophication consist of nutrients (total phosphorus [TP], total nitrogen [TN], dissolved phosphorus and nitrogen, soluble reactive phosphorus [SRP], ammonia, nitrate+nitrite), chlorophyll *a* and zooplankton biomass. These indicators have been monitored in Lac de Gras as a component of AEMP since 2007. Selected nutrients were measured during the 1995 and 1996 baseline surveys (Acres and Bryant 1996, and Golder 1998, respectively) in support of the EA for the Mine, and during the AEMP Version 1.0, as part of the water quality component. Eutrophication indicators were added as a key component of the AEMP because the EA predicted that the discharge of nutrients in effluent from the Mine would cause a slight increase in productivity in up to 20% of the area of Lac de Gras (Government of Canada 1999).

During the AEMP Version 2.0, nutrient samples were collected in the ice-cover season (April/May) and throughout the open-water season in July, August, and September. Chlorophyll *a* and zooplankton biomass (as ash-free-dry-mass [AFDM]) samples were collected during the open-water season in July, August and September. A review of the four years of data collected during the AEMP Version 2.0 demonstrated that any open-water month would be equally appropriate for monitoring the indicators of eutrophication (Golder 2014a). As a result, one of the revisions in the Study Design Version 3.0 was a reduction in the frequency of monitoring to a single ice-cover and a single open-water (August 15 to September 15) sampling event (Golder 2014a). To account for the multiple samples collected during the AEMP Versions 1.0 (2002 to 2006) and 2.0 (2007 to 2010), only data for samples collected between August 15 and September 15 were included in the analysis for this report. All appropriate baseline data were presented regardless of season, to provide an estimate of the baseline conditions.

This chapter presents an analysis of the eutrophication indicators data collected during baseline conditions (where available) and during the AEMP Versions 1.0 through 3.0 (2002 to 2013, where appropriate). It addresses the main objective of the 2011 to 2013 AEMP Summary Report by assessing temporal Mine-related changes in the indicators of eutrophication in Lac de Gras.

6.2 Methods

6.2.1 Data Sources

6.2.1.1 Overview

Indicators of eutrophication data included in the evaluation of temporal trends were taken from the following data sources:

- baseline data collected from 1995 to 2000;
- data collected during the AEMP Version 1.0 (2001 to 2006);
- data collected during the AEMP Version 2.0 (2007 to 2011); and
- data collected during the AEMP Version 3.0 (2012 to 2013).

Sampling methods and laboratory procedures used during the AEMP (2001 to 2013) were generally the same as those used during baseline period (1996 to 2000), which allows comparisons over time. However, there have been some differences in methods over the years that have resulted in comparability issues between recent and historical data. These included differences in sampling locations, depth of sampling, timing of sample collection, analytical laboratories contracted for sample analyses, detection limits (DLs) and variables analyzed (Table 6-1). These modifications to the AEMP design were introduced, as required, to allow the annual monitoring programs to meet the goals of the AEMP.

6.2.1.2 Baseline and AEMP Version 1.0 Data (1995 to 2006)

The Mine's baseline program began in 1995, and all suitable data collected during the baseline program (1995 data: Acres and Bryant 1996; 1997 data: Golder 1998) were included in the analyses in this report. Data quality and comparability issues (based on analytical methods) were identified with the baseline data collected (DDMI 2007b). For example, much of the nutrient data were disqualified due to high detection limits and laboratory changes. As a result, only the ammonia data from the baseline period could be used.

Data from 2000 to 2006 included an annual set of ice-cover and open-water data collected from mid-depth in the water column. Laboratory changes and differences in field sampling methods limited the number of eutrophication indicator variables available from this period. Appropriate data from the 2000 to 2006 period were total ammonia, nitrate-nitrite and chlorophyll *a*; however, these variables were analyzed in mid-depth samples, as opposed to the depth-integrated samples collected during the open-water season under AEMP versions 2.0 and 3.0.

Some stations from the baseline programs and AEMP Version 1.0 were at the same locations as the AEMP stations established in 2007. The pairing of historical stations with present-day stations was:

- WQ-06 and LDG42 are equivalent to the NF stations;
- Station LDG13 is equivalent to MF1-1;
- Station LDG40 are equivalent to MF1-2;
- Stations WQ02 and LDG19 are equivalent to MF1-3;
- Stations WQ07 and LDG43 are equivalent to MF3-2;
- Stations WQ05 and LDG41 are equivalent to MF3-4; and
- Station LDG45 is equivalent to FF2-2.

Table 6-1 Analytical Laboratories and Detection Limits used for the Analysis of the Nutrients Presented in this Report

Nutrient	Year	Laboratory	Season	DL (µg/L)
Ammonia	1995 to1996	ETL	Ice-cover	10
	1995 to1996	ETL	Open-water	10
	2000 to 2006	ETL	Ice-cover	5
	2000 to 2006	ETL	Open-water	5
	2007	ALS	Ice-cover	5
	2007	ALS	Open-water	5
	2008	ALS	Ice-cover	5
	2008	DFO/UofA	Open-water	5
	2009 to 2010	UofA	Ice-cover	2
	2009 to 2010	UofA	Open-water	2
	2011 to 2013	UofA	Ice-cover	2
	2011 to 2012	UofA	Open-water	2
	2013	Maxxam	Open-water	2
Nitrate + Nitrite	2000 to 2006	ETL	Ice-cover	6
	2000 to 2006	ETL	Open-water	6
	2007	ALS	Ice-cover	6
	2007	ALS	Open-water	6
	2008	ALS	Ice-cover	6
	2008	DFO/UofA	Open-water	6
	2009 to 2010	UofA	Ice-cover	1
	2009 to 2010	UofA	Open-water	1
	2011 to 2013	UofA	Ice-cover	1
	2011 to 2012	UofA	Open-water	1
	2013	Maxxam	Open-water	2
Total Dissolved Nitrogen	2007	DFO	Ice-cover	1
	2007	DFO	Open-water	1
	2008	DFO; UofA	Ice-cover	1
	2008	DFO; UofA	Open-water	1
	2009 to 2010	UofA	Ice-cover	7
	2009 to 2010	UofA	Open-water	7
	2011 to 2013	UofA	Ice-cover	5
	2011 to 2012	UofA	Open-water	5
Total Nitrogen (µg/L)	2007	DFO	Ice-cover	1
	2007	DFO	Open-water	1
	2008	DFO; UofA	Ice-cover	10(a)
	2008	DFO; UofA	Open-water	10(a)
	2009 to 2010	UofA	Ice-cover	7(a)
	2009 to 2010	UofA	Open-water	7(a)
	2011 to 2013	UofA	Ice-cover	5(a)
	2011 to 2012	UofA	Open-water	5(a)
	2013	Maxxam	Open-water	20

Table 6-1 Analytical Laboratories and Detection Limits used for the Analysis of the Nutrients Presented in this Report

Nutrient	Year	Laboratory	Season	DL (µg/L)
Soluble Reactive Phosphorus	2007	DFO	Ice-cover	1
	2007	DFO	Open-water	1
	2008	DFO; UofA	Ice-cover	1
	2008	DFO; UofA	Open-water	1
	2009 to 2010	UofA	Ice-cover	1
	2009 to 2010	UofA	Open-water	1
	2011 to 2013	UofA	Ice-cover	1
	2011 to 2012	UofA	Open-water	1
	2013	Maxxam	Open-water	1
Total Dissolved Phosphorus	2007	DFO	Ice-cover	1
	2007	DFO	Open-water	1
	2008	DFO; UofA	Ice-cover	1
	2008	DFO; UofA	Open-water	1
	2009 to 2011	UofA	Ice-cover	1
	2009 to 2011	UofA	Open-water	1
	2012 to 2013	UofA	Ice-cover	3
	2012	UofA	Open-water	3
	2013	Maxxam	Open-water	2
Total Phosphorus	2007	DFO	Ice-cover	1
	2007	DFO	Open-water	1
	2008	DFO; UofA	Ice-cover	1(a)
	2008	DFO; UofA	Open-water	1(a)
	2009 to 2010	UofA	Ice-cover	1(a)
	2009 to 2010	UofA	Open-water	1(a)
	2011 to 2013	UofA	Ice-cover	1(a)
	2011	UofA	Open-water	1(a)
	2012	UofA	Open-water	3
	2013	Maxxam	Open-water	2

a) Calculated variable; therefore, detection limit based on the variable with the higher detection limit.

ETL = EnviroTest Laboratories, Edmonton, Alberta; ALS = ALS Canada Ltd., Edmonton, Alberta; DFO = Freshwater Institute (Fisheries and Oceans Canada), Winnipeg, Manitoba; UofA = University of Alberta Biogeochemical Analytical Laboratory, Edmonton, Alberta; Maxxam = Maxxam Analytics Inc., Burnaby, British Columbia.

6.2.1.3 AEMP Version 2.0 Data (2007 to 2010)

From 2007 to 2010, nutrient samples from exposure areas (NF, FF2, and MF) were collected from three discrete depths (top, middle and bottom) during the ice-cover season. In the reference areas water samples were collected from the middle of the water column. During the open-water season, depth-integrated samples for both nutrients and chlorophyll *a* were collected to provide a better estimate of the levels of nutrients to which phytoplankton are exposed. Depth-integrated samples were collected from the top 10 m of the water column.

The nutrient samples were analyzed by three analytical laboratories from 2007 to 2010 (Table 6-1). Total and dissolved forms of phosphorus, nitrogen and SRP were analyzed by the Freshwater Institute (Fisheries and Oceans Canada [DFO]), Winnipeg, Manitoba in 2007. In 2008, nutrients were analyzed by DFO and by the University of Alberta Biogeochemical Analytical Laboratory (UofA), Edmonton, Alberta. In 2009 and 2010, all nutrients were analyzed by UofA. Inorganic forms of nitrogen were analyzed by ALS Canada Ltd. (ALS), Edmonton, Alberta, in 2007 and 2008 and by the UofA in 2009 and 2010. Chlorophyll *a* was analyzed by UofA in all four years.

In 2009 there was a laboratory error in the nutrient data set, whereby particulate phosphorus values for the September samples were not corrected by the appropriate subtraction factor of 0.86 µg/L; therefore, in the 2009 annual AEMP report, TP values were inflated by a factor of 0.86 µg/L. This error was corrected in the 2007 to 2010 AEMP Summary Report (Golder 2011c), and the corrected data were used for analyses presented in this report.

Zooplankton biomass data were not available for 2007, because of field sub-sampling errors. In 2008, the zooplankton biomass samples consisted of composite hauls collected from the top 10 m of the water column, while in 2009 and 2010, zooplankton samples were collected from 1 m above the sediment to the top of the water column.

6.2.1.4 AEMP Version 3.0 (2011 to 2013)

Sampling methods for nutrients, chlorophyll *a* and zooplankton biomass in 2011, 2012, and 2013 were consistent with the AEMP Study Design Version 2.0, except that a single open-water sampling season was sampled. Samples collected during the ice-cover season of 2011 to 2013 were sent to the UofA for analysis of total and dissolved phosphorus and nitrogen, SRP, ammonia and nitrate+nitrite (Table 6-1). Depth-integrated samples collected during the open-water season in 2011 and 2012 were sent to the UofA, while open-water samples collected in 2013 were sent to Maxxam Analytics Inc. (Maxxam), Burnaby, British Columbia, for analysis of total and dissolved phosphorus and nitrogen, SRP, ammonia, and nitrate+nitrite. Chlorophyll *a* was analyzed by UofA, and zooplankton biomass (as AFDM) was analyzed by HydroQual Laboratories Ltd., Calgary, Alberta (now Nautilus Environmental) in all three years.

6.2.2 Data Handling

Initial screening of the annual nutrient, chlorophyll *a* and zooplankton biomass data sets was completed before data analyses to identify unusually high (or low) values in the datasets and decide whether to retain or exclude anomalous data from further analysis. An explanation of the objectives and approach taken to complete initial screening is provided in Section 2.6. Results of the initial screening for anomalous values in the AEMP eutrophication indicators dataset is presented in Appendix 6A, Table 6A-1. In total, 15 anomalous values were identified within the baseline and AEMP data sets, representing 0.09% of the total data points. In cases where unusual values were identified in the annual datasets, scatter-plots were generated allow a visual review of excluded data (Appendix 6A, Figures 6A-1 to 6A-9).

Prior to data analyses, duplicate data were averaged and non-detect values were multiplied by 0.5 times the DL. Substitution with half the DL is a common approach used to deal with censored data (US EPA, 2000) and is consistent with the approved methods applied in the calculation of the normal range in the AEMP Reference Conditions Report Version 1.1. The non-parametric methods used in this re-evaluation report to test for the statistical significance of temporal trends in nutrient concentrations (Section 6.2.3.4.2) minimized the influence of using a substitution method for censored data.

6.2.3 Data Analysis

6.2.3.1 Normal Range

Magnitude of effects to indicators of eutrophication were determined by comparing analyte concentrations between exposure areas and reference areas, and to background values. Background values for Lac de Gras are those that fall within the range of natural variability, referred to as the *normal range*. The normal ranges used to evaluate potential effects for indicators of eutrophication were obtained from the AEMP Reference Conditions Report, Version 1.1 (Golder 2015) and are summarized in Table 6-2.

Table 6-2 Normal Ranges for Eutrophication Indicators

Variable	Unit	Normal Range			
		Ice-cover		Open-water	
		Lower Limit	Upper Limit	Lower Limit	Upper Limit
Ammonia	µg/L	11	17	0	6
Nitrate + nitrite	µg/L	5	10	0	1
Total dissolved nitrogen	µg/L	130	166	105	133
Total nitrogen	µg/L	138	173	122	153
Soluble reactive phosphorus	µg/L	0	1.5	0	1.0
Total dissolved phosphorus	µg/L	1.1	3.2	0	3.5
Total phosphorus	µg/L	2.0	5.0	2.0	5.3
Chlorophyll *a*	µg/L	-	-	0.31	0.82
Zooplankton Biomass	mg/m^3	-	-	16.4	40.5

6.2.3.2 Weight of Evidence Effects Rankings

Concentrations of TP, TN and chlorophyll *a*, as well as zooplankton biomass, were assessed for Mine-related nutrient enrichment effects according to the Weight-of-Evidence (WOE) framework (Section 11). The WOE effect rankings for indicators of eutrophication incorporate comparisons of the exposure and reference areas in Lac de Gras (using statistical and normal range comparisons) and an evaluation of the aerial extent of effects (Table 6-3). The methods used to calculate the aerial extent of effects are discussed in the annual AEMP reports.

Table 6-3 Weight of Evidence Effect Rankings for Eutrophication Indicators

Measurement Endpoint	Low	Moderate	High
Total Phosphorus, Total Nitrogen, Chlorophyll *a*, and Zooplankton Biomass (AFDM)	Statistically significant increase in the NF vs reference	**Low** rank **AND** NF area mean greater than the normal range	**Moderate** rank **AND** >20% of the lake area greater than the normal range

AFDM = ash-free dry mass; NF = near-field; >= greater than; vs = versus.

6.2.3.3 Action Levels

The importance of effects to an assessment endpoint was categorized according to Action Levels described for indicators of eutrophication in the AEMP Study Design Version 3.5 (Golder 2014a). The Action Level classifications for indicators of eutrophication were developed to meet the goals of the *Response Framework for Aquatic Effects Monitoring* (WLWB 2010; Racher et al. 2011). The main goal of the AEMP Response Framework is to ensure that significant adverse effects never occur. This is accomplished by requiring proponents to take actions at predefined Action Levels, which are triggered well before significant adverse effects could occur.

A significant adverse effect for total phosphorus was defined in the EA (Government of Canada 1999) and is referred to as the *Significance Threshold* in the Action Level descriptions. The magnitude of effect for total phosphorus at the Significance Threshold level was defined as a concentration that exceeds the EA benchmark by more than 20%. In contrast to toxicological impairment responses to water chemistry (e.g., concentrations of metals), eutrophication responses are difficult to link to nutrient concentrations. As demonstrated by years of monitoring in Lac de Gras, concentrations of phosphorus do not predict the actual biological response to nutrient enrichment (Table 6-6). Rather, the increase in the biomass of algae as measured by chlorophyll *a* has been used as a measure of the biological effects of nutrient enrichment. Therefore, the Significance Threshold for the indicators of eutrophication is a concentration of chlorophyll *a* that exceeds the *Effects Threshold* by more than 20% in the FFA area of Lac de Gras (Table 6-4). Under the Response Framework, an Effects Threshold is a site-specific value at which unacceptable biological effects could occur (Golder 2014a). The Effects Threshold would be defined once a certain magnitude of effect occurs (i.e., at Action Level 3; Table 6-4).

6.2.3.4 Temporal Trends

6.2.3.4.1 Time Series Plots

Temporal trends in eutrophication indicators in Lac de Gras were evaluated using time series plots. These plots were organized based on the AEMP sampling areas in Lac de Gras (Figure 2-2):

- the NF exposure area;
- three MF exposure areas (MF1, MF2 and MF3);
- one FF exposure area (FF2); and
- three FF reference areas (FF1, FFB and FFA).

For the ice-cover season, data from the five stations sampled in the NF area were plotted individually according to sample depth (top, middle and bottom). The maximum of the top, middle or bottom concentration at MF area stations was plotted for each transect (MF1, MF2 and MF3) on separate graphs. Data from the FF2 exposure area were incorporated into the figures for the MF2 area, because the FF2 area stations are located at the far northeast end of the MF2 transect. For the open-water season where depth integrated samples were collected, a single value was plotted for each station. Data from the three FF reference areas (FF1, FFB and FFA) were also evaluated for the presence of temporal trends. Trends occurring in the reference areas may represent natural trends, or potentially, the presence of Mine effluent. Non-detect data were included in the time series plots (plotted at the DL) as open symbols. Time series plots were produced for each eutrophication indicator variable, separately for each season, and trends were evaluated in relation to the normal range for Lac de Gras.

6.2.3.4.2 Statistical Analysis

The statistical significance of a temporal trend in nutrient concentrations, chlorophyll a and zooplankton biomass was tested with the Mann-Kendall test, which is a non-parametric rank based trend test for non-seasonal data. Mann-Kendall trend test results were considered significant at P <0.1. Statistical testing was conducted with R software (R Core Team 2013).

Mann Kendall tests were performed on data collected in the NF exposure area and FF reference areas (FF1, FFB, FFA), and at representative MF2 area stations (MF2-1 and FF2-2). Data from the MF1 and MF3 areas were not analyzed statistically to limit the number of tests performed, and because trends in these areas were generally similar to those in the MF2 area. Although time series plots show values over the complete period of available data (1996 to 2013), only results from the AEMP Versions 2.0 and 3.0 (2007 to 2013) were included in the trend analysis. This was required because of differences in sample collection methods and analytical procedures (e.g., sampling locations and timing, and DLs) used during earlier monitoring periods. Occasionally, trend tests were performed with fewer years of data due to the presence of non-detect values in the dataset, particularly in reference areas. Mann Kendall tests were performed where a minimum of 4 years of analytical data were available.

Mann Kendall tests were performed separately for ice-cover and open-water seasons. The median value at the five stations in the NF and FF areas was used in the analysis. For trend tests on ice-cover season data, the maximum concentration at stations MF2-1 and FF2-2 (top, middle, and bottom) in each year of monitoring was used. A single depth integrated sample was available for these stations during open-water.

Table 6-4 Action Level Classification for Chlorophyll a

Action Level	Magnitude of Effect	Extent of Effect	Action/Notes
1	95th percentile of MF values greater than normal range[(a)]	Mid-field (MF) station	Early warning.
2	Near-field (NF) and MF values greater than normal range	20% of lake area or more	Establish *Effects Benchmark*.
3	NF and MF values greater than normal range plus 25% of Effects Benchmark[(b)]	20% of lake area or more	Confirm site-specific relevance of existing benchmark. Establish *Effects Threshold*.
4	NF and MF values greater than normal range plus 50% of Effects Threshold[(b)]	20% of lake area or more	Investigate mitigation options.
5	NF and MF values greater than Effects Threshold	20% of lake area or more	The WLWB to re-assess EQC for phosphorus. Implement mitigation required to meet new EQC if applicable.
6	NF and MF values greater than Effects Threshold + 20%	20% of lake area or more	The WLWB to re-assess EQC for phosphorus. Implement mitigation required to meet new EQC if applicable.
7	95th percentile of MF values greater than Effects Threshold + 20%	All MF stations	The WLWB to re-assess EQC for phosphorus. Implement mitigation required to meet new EQC if applicable.
8	95th percentile of FFB values greater than Effects Threshold + 20%	Far-field B (FFB)	The WLWB to re-assess EQC for phosphorus. Implement mitigation required to meet new EQC if applicable.
9	95th percentile of FFA values greater than Effects Threshold + 20%	Far-field A (FFA)	Significance Threshold.

a) Normal ranges were obtained from the AEMP Reference Conditions Report Version 1.1 (Golder 2015). The normal range for open-water is based on the August 15 to September 15 period.

b) Indicates 25% or 50% of the difference between the benchmark/threshold and the top of the normal range.

WLWB = Wek'èezhìi Land and Water Board; EQC = Effluent Quality Criteria.

6.3 Results

6.3.1 Summary of Effects

6.3.1.1 Weight of Evidence Effects Ratings

The effect ranking for TP was consistently moderate across years (Table 6-5). The effect ranking for TN was moderate in 2008, and from 2009 to 2013 TN concentrations exceeded the normal range in more than 20% of the lake (Table 6-6), resulting in a high effect ranking. The effect ranking for Chlorophyll *a* fluctuated between moderate and high between 2007 and 2013. Chlorophyll *a* concentrations in the NF area were above the upper bound of the normal range from 2007 to 2013, but the affected area exceeded 20% of the lake only in 2009 and 2013. The zooplankton biomass effect ranking was low in 2009 and fluctuated between moderate and high between 2010 and 2013.

Table 6-5 Summary of Weight of Evidence Effect Ratings for Eutrophication Indicators, 2007 to 2013

Endpoint	WOE Rating						
	2007	2008	2009	2010	2011	2012	2013
Total Phosphorus	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑
Total Nitrogen	n/a	↑↑	↑↑↑	↑↑↑	↑↑↑	↑↑↑	↑↑↑
Chlorophyll *a*	↑↑	↑↑	↑↑↑	↑↑	↑↑	↑↑	↑↑↑
Zooplankton Biomass (AFDM)	n/a	n/a	↑	↑↑	↑↑↑	↑↑	↑↑↑

Note: ↑ = low level effect; ↑↑ = moderate level effect; ↑↑↑ = high level effect; n/a = data not applicable (see text).

AFDM = ash-free dry mass; n/a= data not available.

Table 6-6 Spatial Extent of Effects on Concentrations of Total Phosphorus, Total Nitrogen and Chlorophyll *a*, and on Zooplankton Biomass, 2007 to 2013

Year	Total Phosphorus		Total Nitrogen		Chlorophyll *a*		Zooplankton Biomass (ash-free dry mass)	
	Area (km^2)	Lake Area (%)[(a)]	Area (km^2)	Lake Area (%)	Area (km^2)	Lake Area (%)	Area (km^2)	Lake Area (%)
2007	29.4	5.1	-	-	89	15.5	-	-
2008	112[(b)]	19.6	84.8	14.8	77.1	13.5	-	-
2009	53.5[(b)]	9.3	180	31.5	121	21.0	0	0
2010	23.8[(b)]	4.2	132[(b)]	23.1	88.5	15.5	52.3	9.1
2011	9.2[(b)]	1.6	213[(b)]	37.2	89.3	15.6	129	22.5
2012	3.6[(b)]	0.6	118	20.7	17.0	3.0	76.7	13.4
2013	80.6[(b)]	14.1	183[(b)]	31.9	129	22.6	355	62.1

a) Lake area reported is the greater of the area affected during the open-water or ice-covered seasons; the lake area affected represents the percentage of lake area experiencing levels greater than the normal range, and was calculated relative to the total surface area of Lac de Gras (573 km^2).

b) Area reported is for the ice-covered season.

- = data not available due to field subsampling errors (2007) and differences in sample collection procedures (2008; Section 6.2.1.3)

6.3.1.2 Action Levels

Chlorophyll *a* concentrations in the NF and MF areas were consistently greater than the upper bound of the normal range (0.82 µg/L) between 2007 and 2013. However, the total affected area differed among years (Table 6-6). In 2009 and 2013, over 20% of the lake experienced chlorophyll *a* concentrations that were greater than the upper bound of the normal range, resulting in Action Level 2 being triggered. Consequently an Effects Benchmark for Chlorophyll *a* (4.5 µg/L) was defined and has since been approved by the WLWB (Golder 2014a).

6.3.2 Temporal Trends

6.3.2.1 Nutrients

Results of the temporal trend analyses indicate that there are no consistent increasing or decreasing trends in nutrient concentrations in Lac de Gras from 2007 to 2013 (Table 6-7). Occasional statistically significant trends included negative trends in the concentrations of TDP in the NF area during ice-cover, TN at Station FF2-2 during open-water, and TDN in the FFA area during open-water. These significant results are discussed further below, in relation to time series plots and trends in effluent loads and chemistry.

Table 6-7 Results of Mann Kendall Trend Tests (2007 to 2013) for Nutrients in the Near-Field (NF) Area, Stations MF2-1 and FF2-2, and the Three Far-Field Reference Areas (FF1, FFB, and FFA)

Nutrient	Season	Kendall's Rank Coefficient, τ$^{(a)}$					
		NF$^{(b)}$	MF2-1$^{(b)}$	FF2-2$^{(b)}$	FF1$^{(b)}$	FFB$^{(b)}$	FFA$^{(b)}$
Total Phosphorus	Ice-cover	-0.24	-0.05	0.14	0.29	-0.07	-0.14
	Open-water	-0.29	-0.20	0.07	-0.47	-0.10	-0.20
Total Dissolved Phosphorus	Ice-cover	**-0.75***	-0.36	-0.55	-0.55	-0.45	-0.55
	Open-water	0.14	0.00	0.40	0.55	0.40	0.55
Soluble Reactive Phosphorus	Ice-cover	0.22	-0.63	-0.71	(c)	(c)	(c)
	Open-water	(c)	(c)	(c)	(c)	(c)	(c)
Total Nitrogen	Ice-cover	-0.20	0.07	0.07	-0.60	-0.07	-0.07
	Open-water	0.24	0.33	**-0.73***	-0.43	-0.24	-0.14
Total Dissolved Nitrogen	Ice-cover	-0.07	0.07	0.07	-0.60	-0.07	0.07
	Open-water	-0.43	-0.60	-0.60	-0.14	-0.33	**-0.68***
Ammonia	Ice-cover	0.00	0.33	0.40	0.32	-0.20	0.00
	Open-water	0.18	(c)	0.33	0.33	0.33	0.33
Nitrate + Nitrite	Ice-cover	-0.40	0.00	-0.60	0.00	-0.53	-0.74
	Open-water	-0.20	-0.67	-0.67	(c)	(c)	(c)

a) Probability of Type 1 error (two tailed): * = <0.1, ** = <0.01, *** <0.001. **Bolded** correlation coefficients indicate significant trends.

b) The median concentration in the NF, FF1, FFB and FFA areas was used in the analysis. For trend tests on ice-cover season data, the maximum concentration at stations MF2-1 and FF2-2 (top, middle, and bottom) in each year of monitoring was used. A single depth integrated sample was available for these stations during the open-water period.

c) Correlations were not completed where *n* <4 due to removal of non-detect values from the analysis, or because variables were not analyzed for a portion of the 2007 to 2013 monitoring period.

τ = Kendall's Tau.

Concentrations of TP in the NF area have remained mostly within or just above the upper limit of the normal range during the open-water season from 2007 to 2013 (Figure 6-1; Appendix 6B, Figure 6B-1). There were two conspicuously high values in the NF and MF2-1 areas in 2009 that did not meet the criterion for exclusion as anomalous values (Section 2.6), but were nonetheless highly atypical. These elevated values do not appear to reflect an increase in effluent loads or concentrations. Exceedances of the normal range occurred at several stations along the MF area transects, particularly in 2007 and 2012. Concentrations also exceeded the normal range at several FF area stations in 2010 and 2012.

The concentration of TP in the NF area was frequently above the normal range during the ice-cover season, from 2007 to 2013 (Figure 6-2). On average, the highest TP concentrations were observed in the NF area in 2013. Concentrations at several stations along the MF1, MF2-FF2 and MF3 transects also exceeded the normal range (Figure 6-2; Appendix 6B, Figure 6B-2). The increase in concentration observed in 2013 (although not statistically significant) reflected the increase in effluent loads and concentrations (Section 4, Figure 4-15). Total phosphorus concentrations were primarily within the normal range in the reference areas.

Total dissolved phosphorus concentrations in the NF area have remained within the normal range in most samples since 2007 during the open-water season. The atypically high concentration in the NF area was also present in the 2009 TDP data set. Occasional exceedances of the normal range occurred at stations along each of the MF area transects, and in the FFA and FFB areas (Figure 6-3; Appendix 6B, Figure 6B 3). Concentrations in the NF area during the ice-cover season exceeded the normal range in several samples from 2007 to 2013. As described for TP, concentrations of TDP increased in the NF area in 2013 reflecting the increase in effluent loads and concentrations. Despite this increase, there was an overall significant decreasing trend in the concentration of TDP in the NF area. Fewer exceedances of the normal range were noted in the MF areas. Concentrations were within the normal range at most stations in reference areas from 2007 to 2013 (Figure 6-4; Appendix 6B, Figure 6B-4).

Soluble reactive phosphorus concentrations were frequently reported at or below the detection limit (1 µg/L) during the open-water season from 2007 to 2013 (Figure 6-5; Appendix 6B, Figure 6B-5 and Figure 6-6; Appendix 6B Figure 6B-6, respectively). During the ice-cover season, concentrations often exceeded the normal range in all areas, including the reference areas.

Total nitrogen concentrations in the reference areas were generally within the normal range during the open-water season from 2007 to 2012 (Figure 6-7). Elevated concentrations were reported at several exposure and reference area stations in 2013, likely reflecting the change in labs from UofA to Maxxam. Reference area concentrations reported in 2005 and 2006 were above the normal range. Total nitrogen concentrations in the NF area exceeded the normal range in most years during open-water, as did most stations along the MF2-FF2 and MF1 transects (Figure 6-7 and Appendix 6B, Figure 6B-7). Stations along the MF3 transect have often exceeded the upper bounds of the normal range since approximately 2006, although concentrations below the normal range were encountered (Appendix 6B, Figure 6B-7). There was a significant decreasing trend in the concentration of TN at Station FF2-2 during the open-water season from 2007 to 2013 (Table 6-7), which may reflect a decrease in effluent loads and concentrations over the same period (Section 4, Figure 4-11).

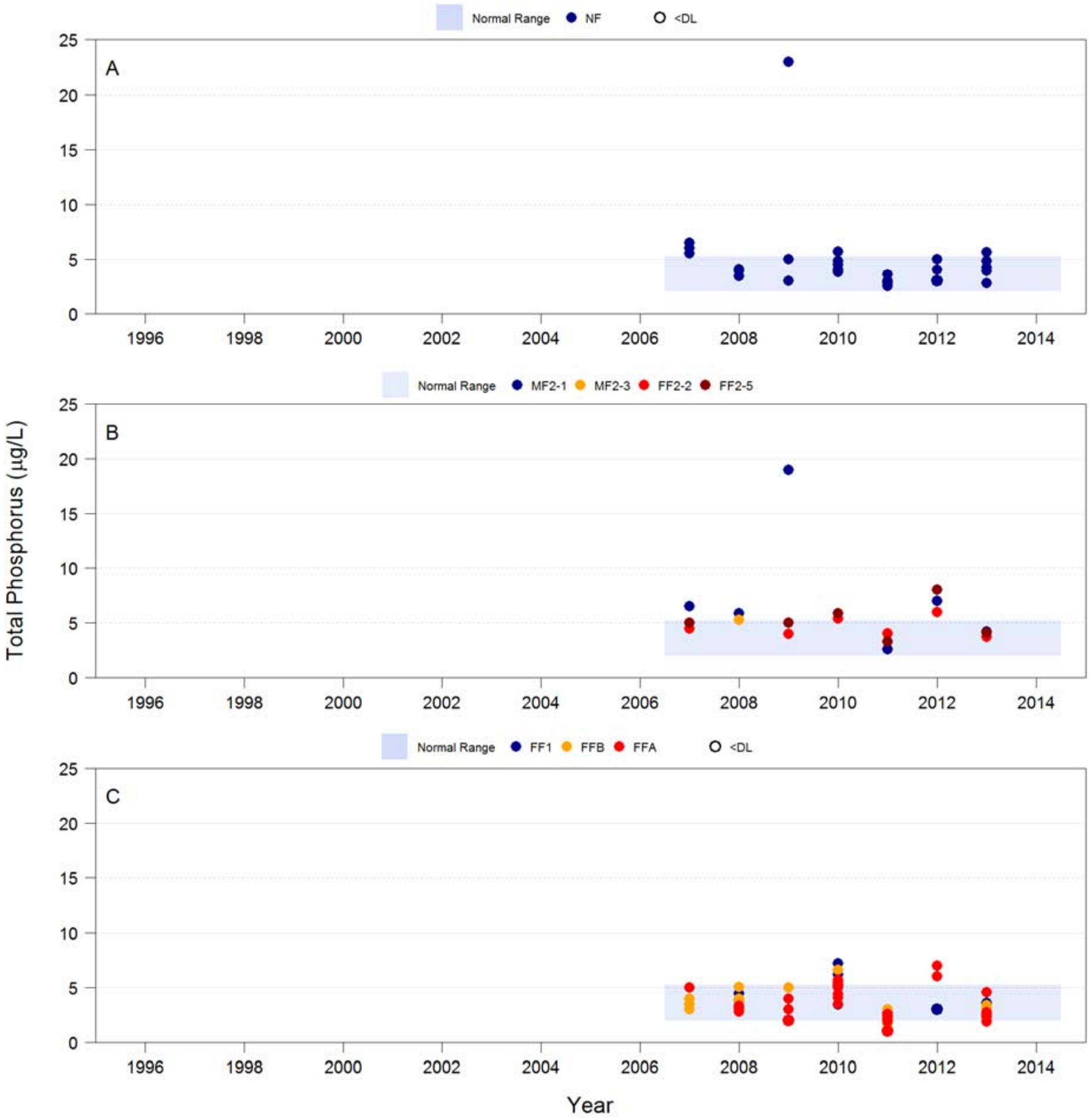
During the ice-cover season, TN concentrations in the reference areas generally remained within the normal range, whereas, exposure area concentrations have exceeded the normal range since approximately 2006 (Figure 6-8). Concentrations appear to have been decreasing since 2009, reflecting the pattern observed in effluent loads and concentrations (Figure 4-11).

While TDN concentrations in the reference areas have generally remained within the normal range during both the open-water and ice-cover seasons, concentrations in the NF area and at most stations along the MF2-FF2 and MF1 transects exceeded the normal range in most samples (Figures 6-9 and 6-10; Appendix 6B, Figures 6B-9 and 6B-10). Ice-cover concentrations of TDN in the NF area appear to be decreasing in parallel with TN; however the sharp declines in 2013 in TDN in all sampling areas during the open-water season may reflect switching the analytical laboratory from the University of Alberta to Maxxam Laboratories. A statistically significant decreasing trend was detected in TDN concentrations in the FFA area during the open-water season from 2007 to 2013 (Table 6-7); however, this trend may reflect the change in analytical laboratory in the summer of 2013. Open-water samples in 2013 were sent to Maxxam, which has produced nitrogen results that are at times incompatible with previous results (Golder 2014c).

Ammonia concentrations during the open-water season have exceeded the normal range in the majority of samples in the exposure areas since approximately 2010 (Figure 6-11; Appendix 6B, Figure 6B-11). Exceedances of the normal range were also noted in the reference areas beginning in the same year. Quality control issues identified with the open-water season ammonia data analyzed by Maxxam in 2013 suggest that these data are likely biased high. Concentrations in blank samples analyzed by Maxxam were at or above levels found in Lac de Gras, while concentrations reported for lake water samples were greater and more variable than values previously provided by the U of A. During the ice-cover season, ammonia concentrations in the NF area and at several stations along the MF2-FF2, MF1 and MF3 transects have exceeded the normal range over the years (Figure 6-12; Appendix 6B Figure 6B-12). Reference area concentrations have mostly been within the normal range.

Exposure area concentrations of nitrate+nitrite have been greater than the normal range for many years (Figures 6-12 and 6-13); however, in parallel with effluent concentrations and loads (Section 4, Figures 4-12 and 4-13), concentrations have been decreasing since approximately 2009. Concentrations in the reference areas also frequently exceeded the normal range during both sampling seasons, but to a much lower extent than observed at exposure stations.

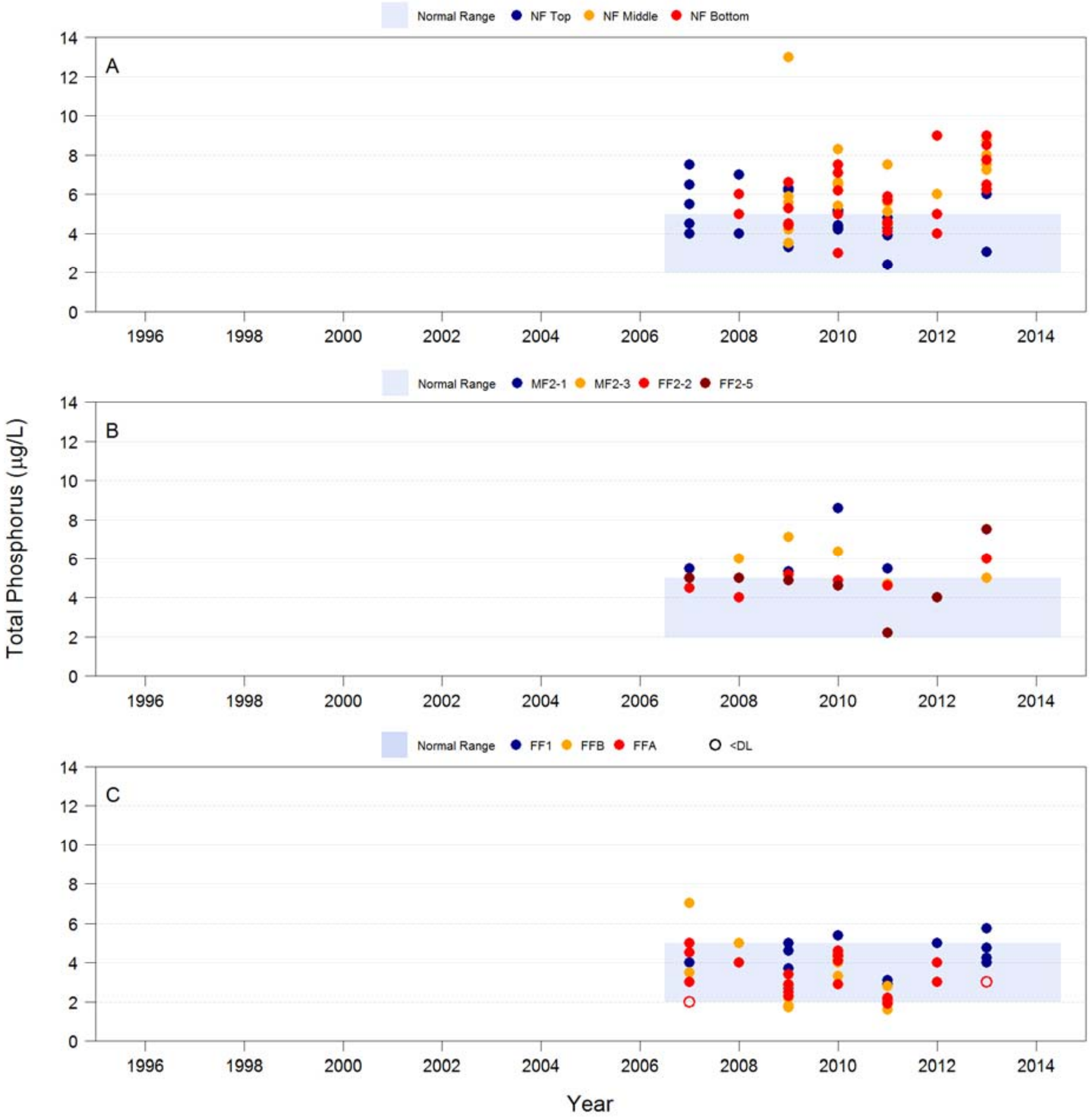
Figure 6-1 **Total Phosphorus Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-water Season**



Note: values represent concentrations in individual depth integrated samples.

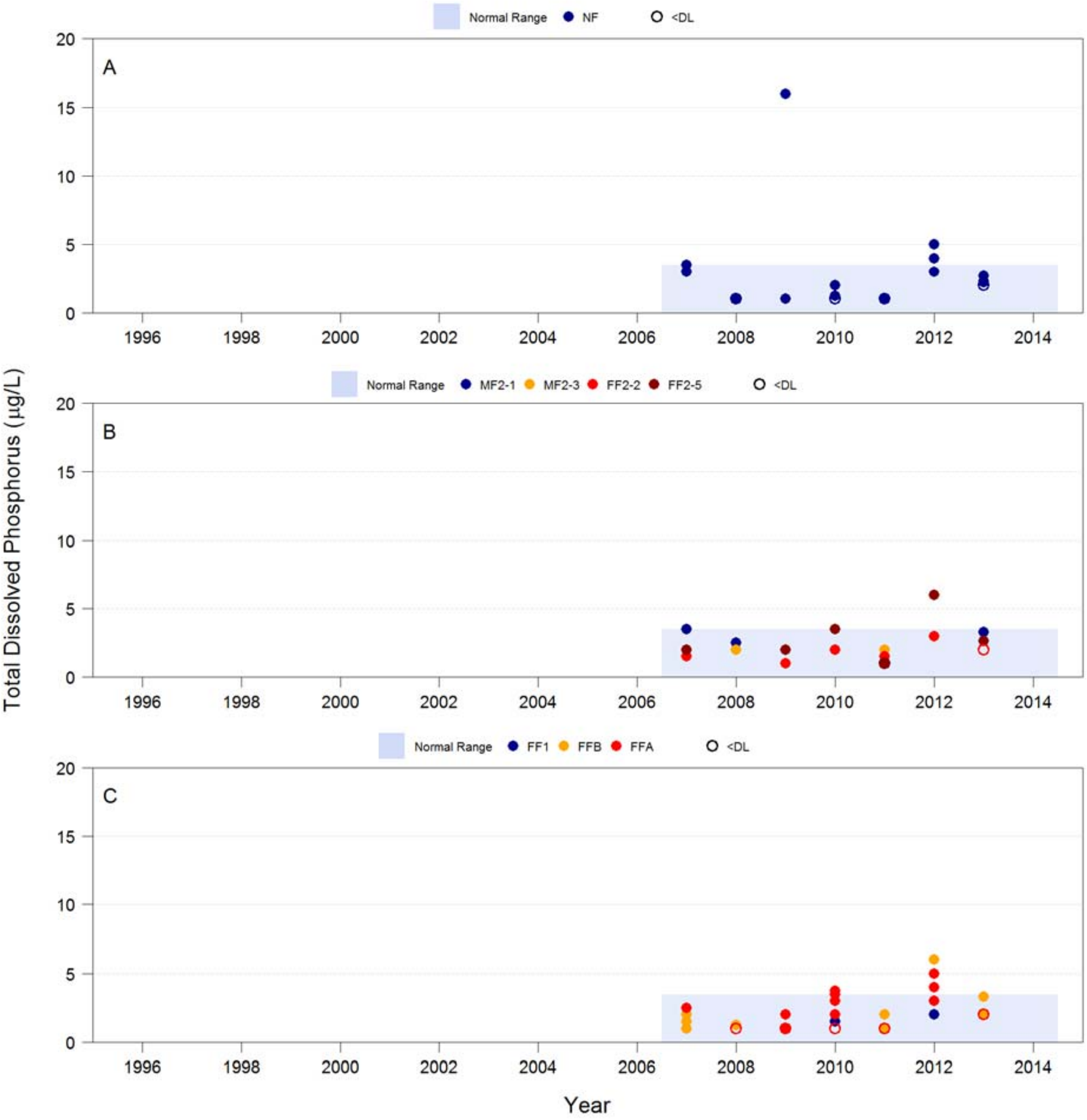
Abbreviations used in Figures 6-1 to 6-16: <DL = below detection limit; NF = Near-field; MF = Mid-field; FF = Far-field.

Figure 6-2 Total Phosphorus Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-cover Season



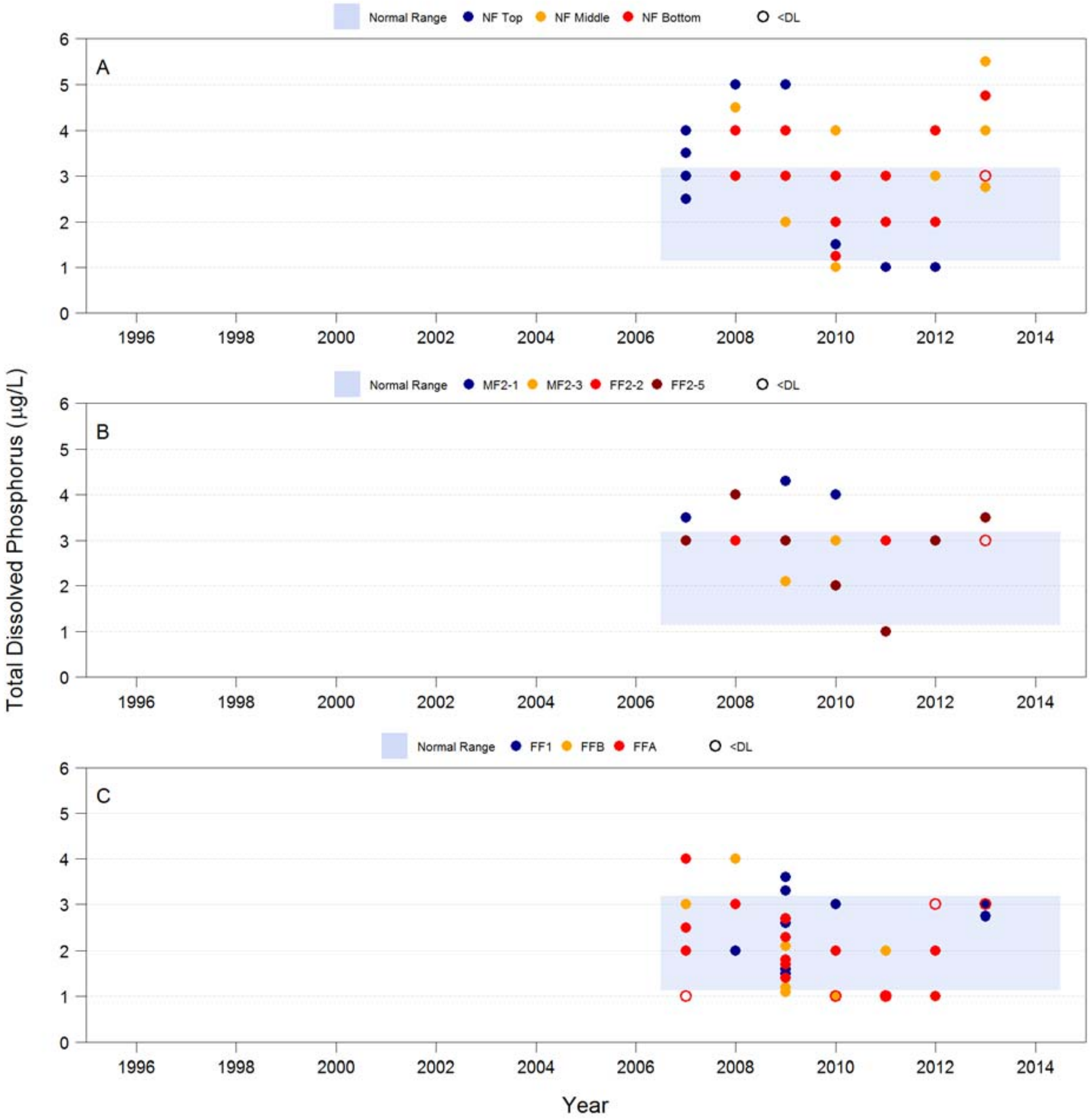
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 6-3 **Total Dissolved Phosphorus Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-water Season**



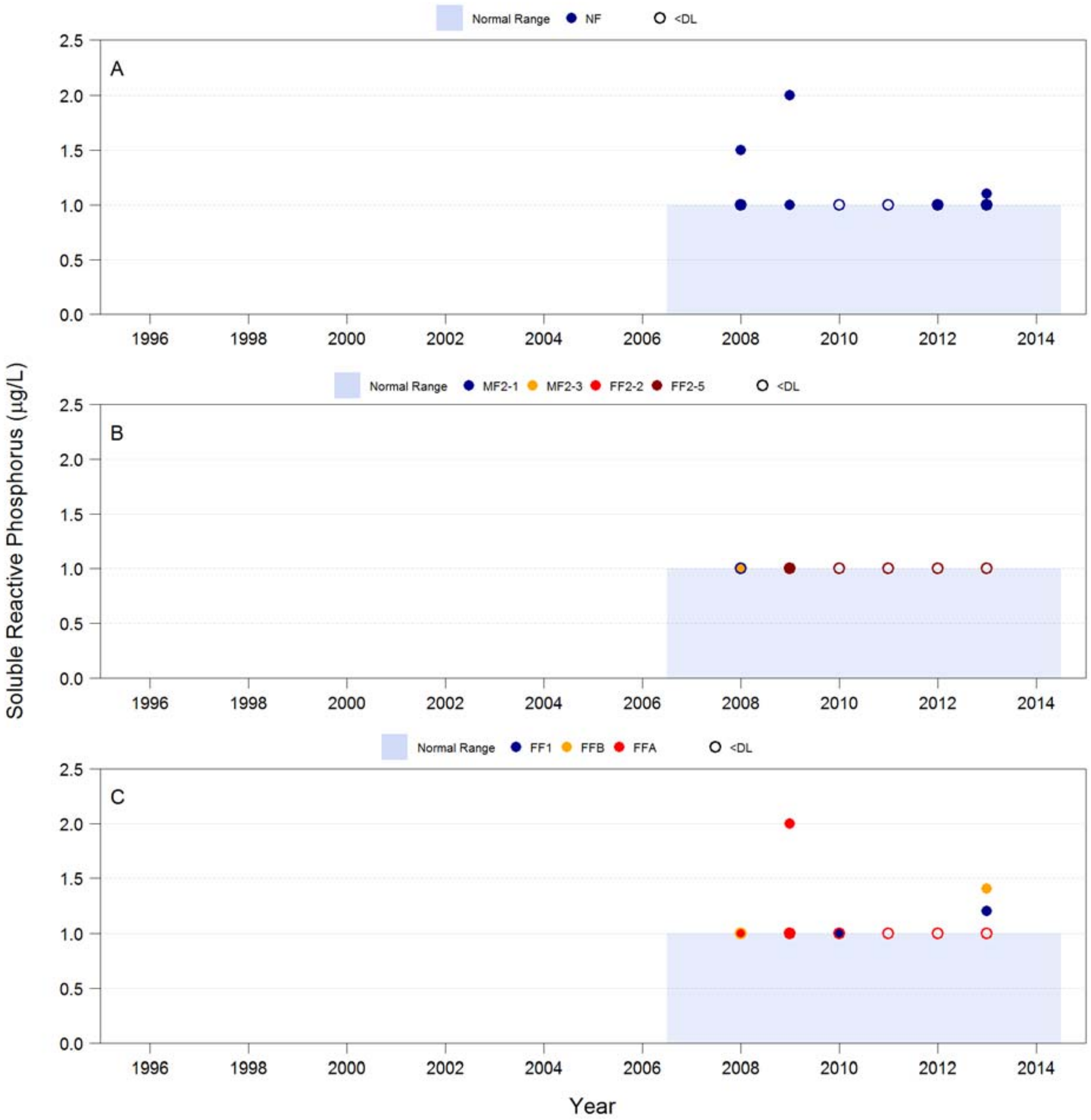
Note: Values represent concentrations in individual depth integrated samples.

Figure 6-4 Total Dissolved Phosphorus Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-cover Season



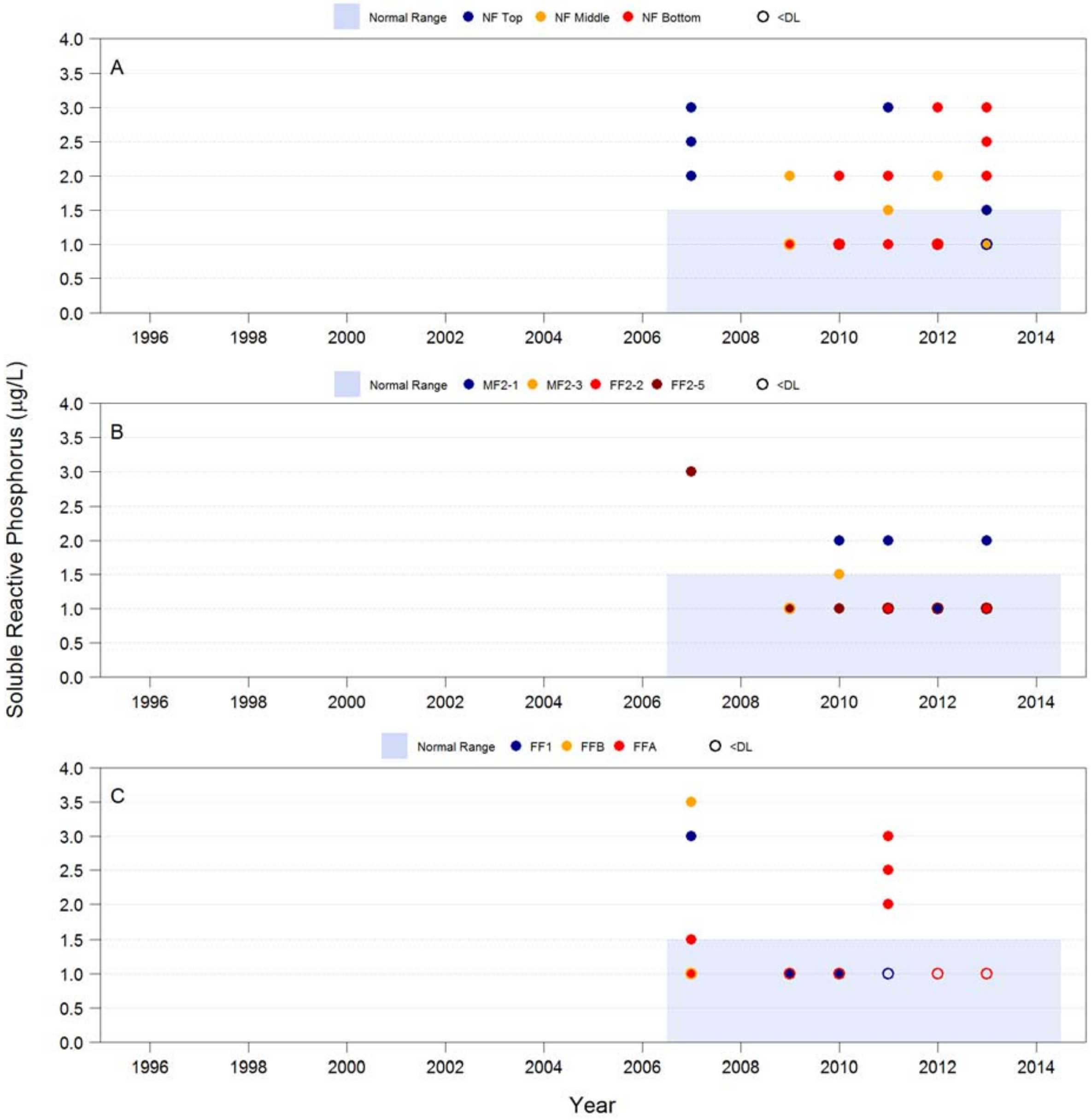
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 6-5 Soluble Reactive Phosphorus Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-water Season



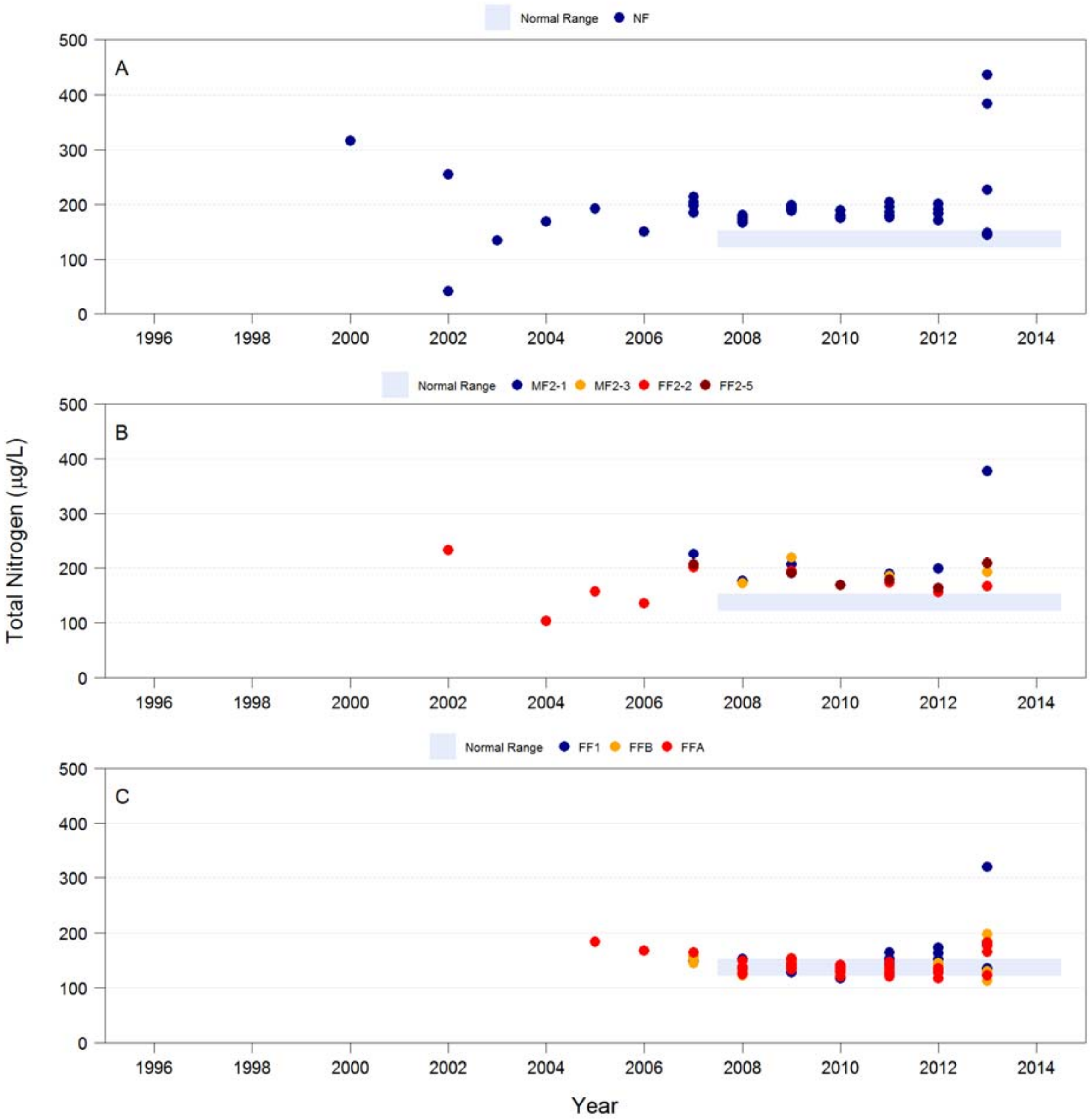
Note: Values represent concentrations in individual depth integrated samples.

Figure 6-6 Soluble Reactive Phosphorus Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-cover Season



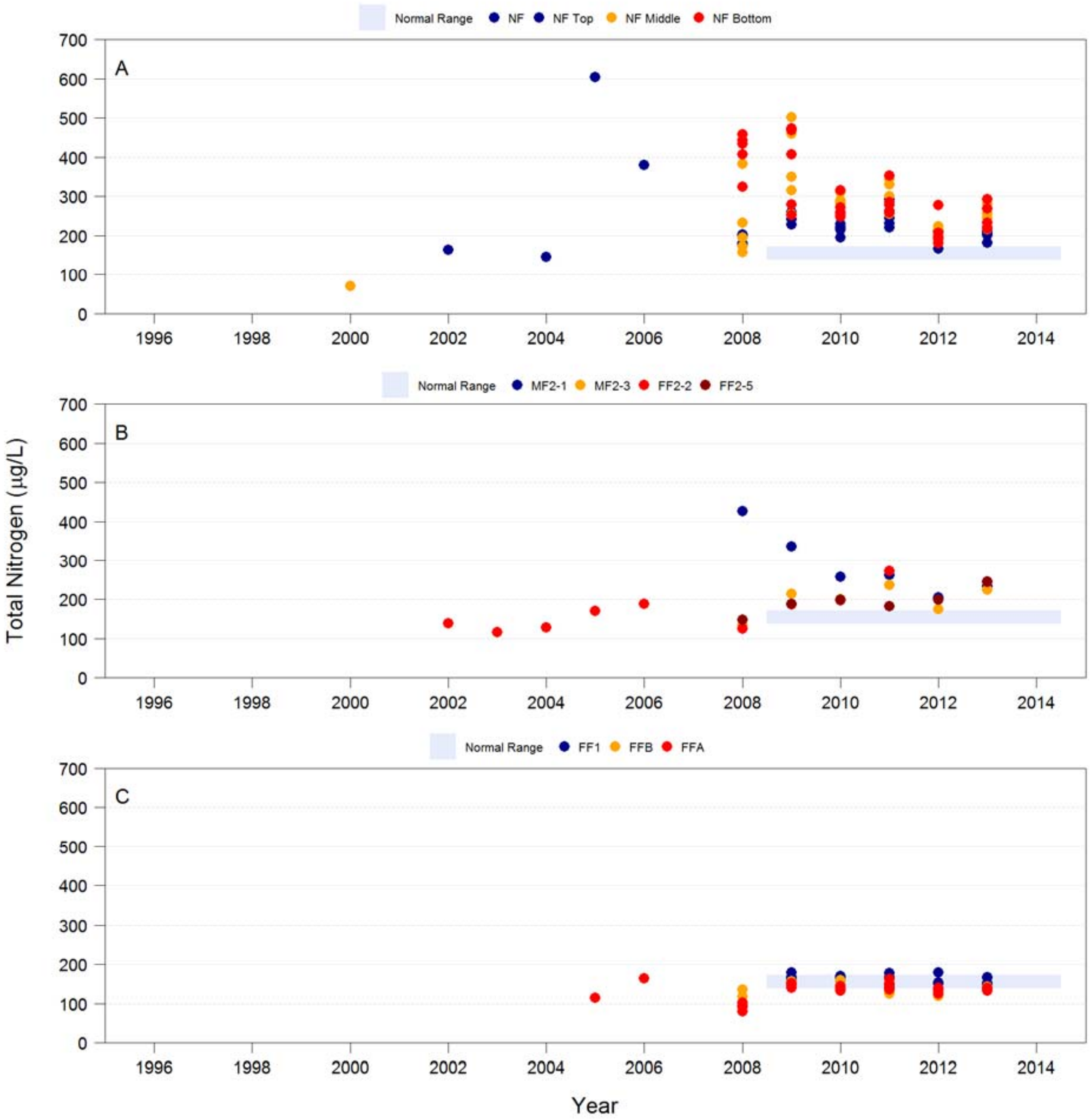
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 6-7 Total Nitrogen Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-water Season



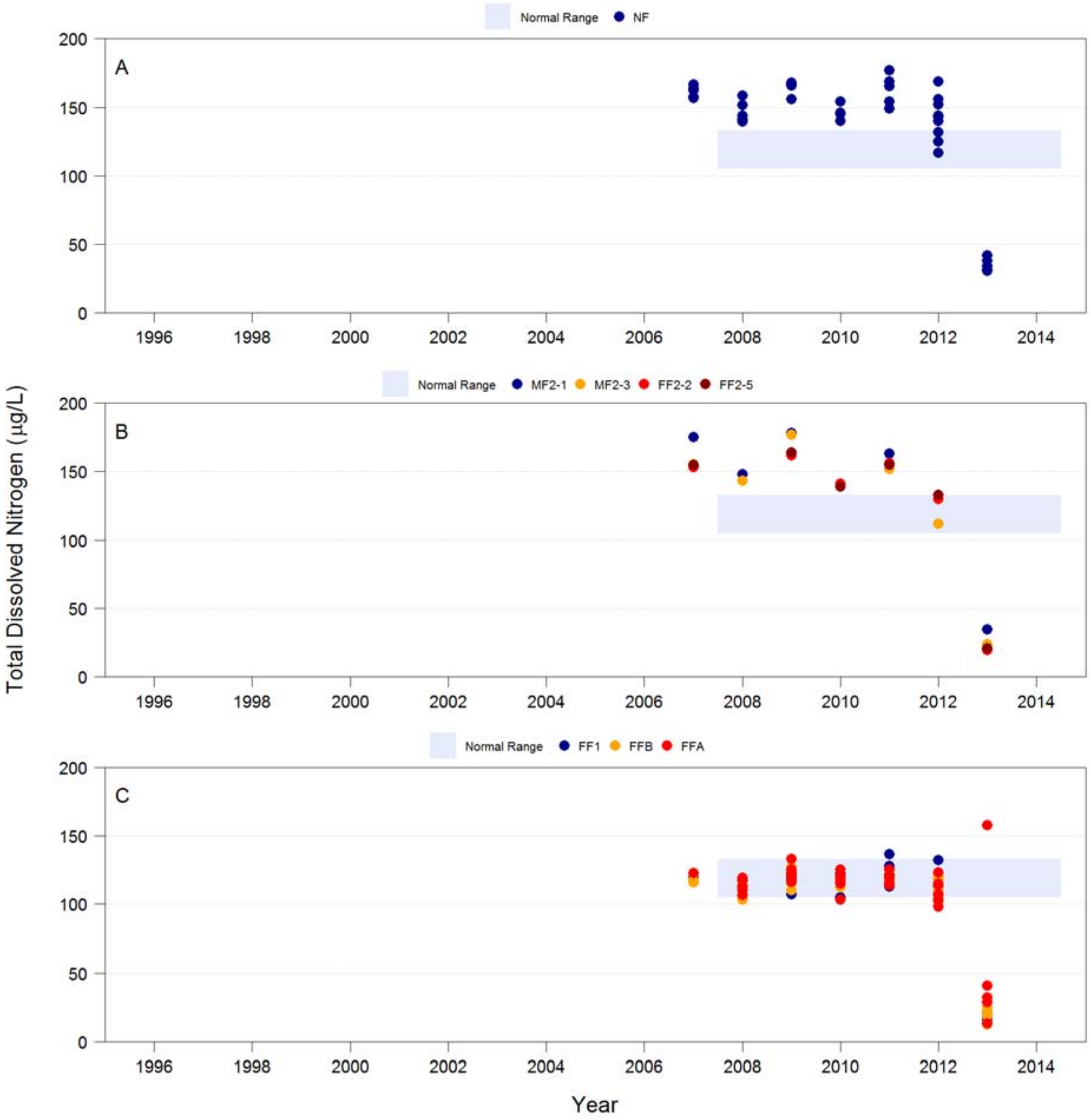
Note: Values represent concentrations in individual depth integrated samples.

Figure 6-8 Total Nitrogen Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-cover Season



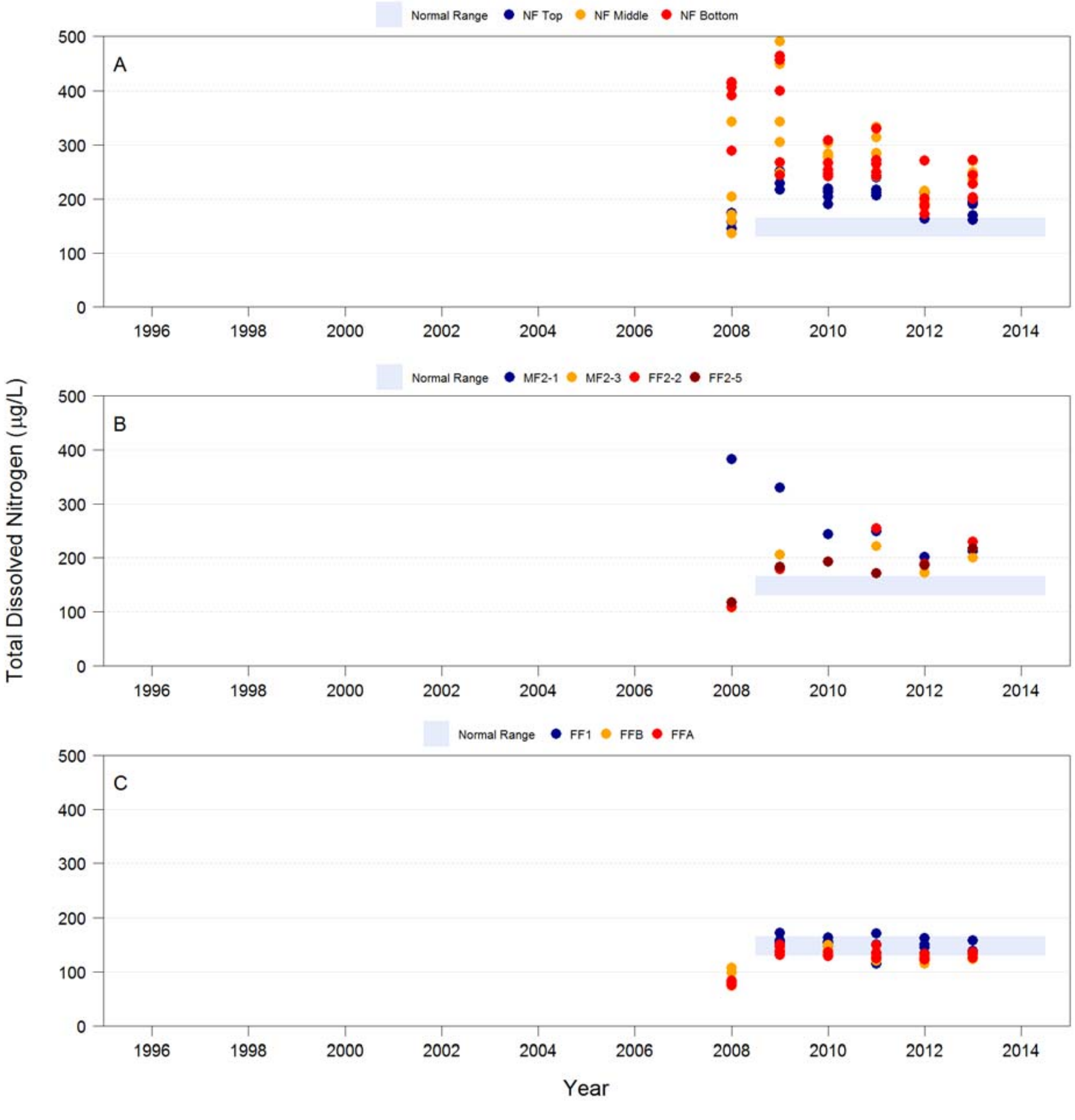
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 6-9 Total Dissolved Nitrogen Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-water Season



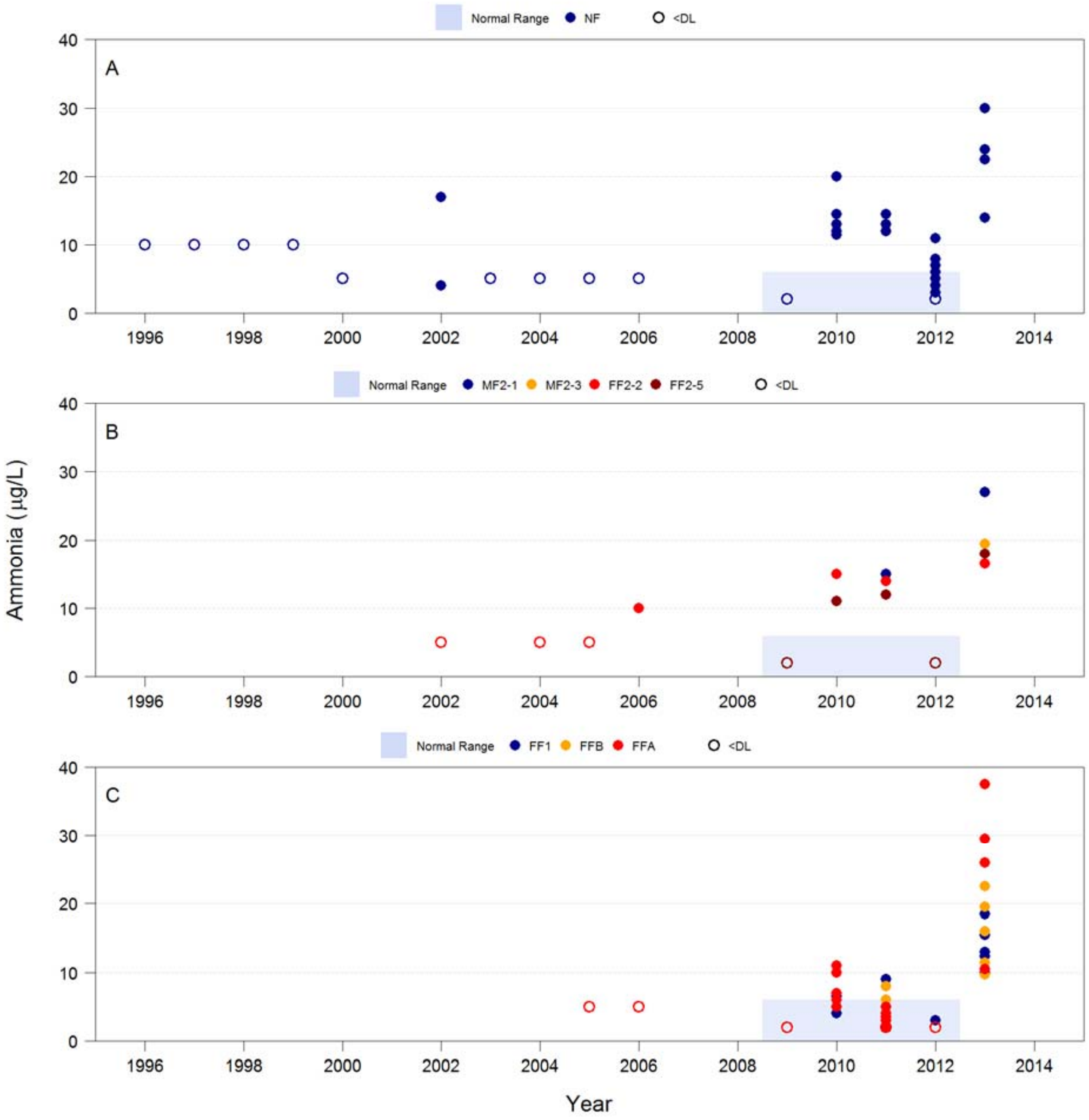
Note: Values represent concentrations in individual depth integrated samples.

Figure 6-10 Total Dissolved Nitrogen Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-cover Season



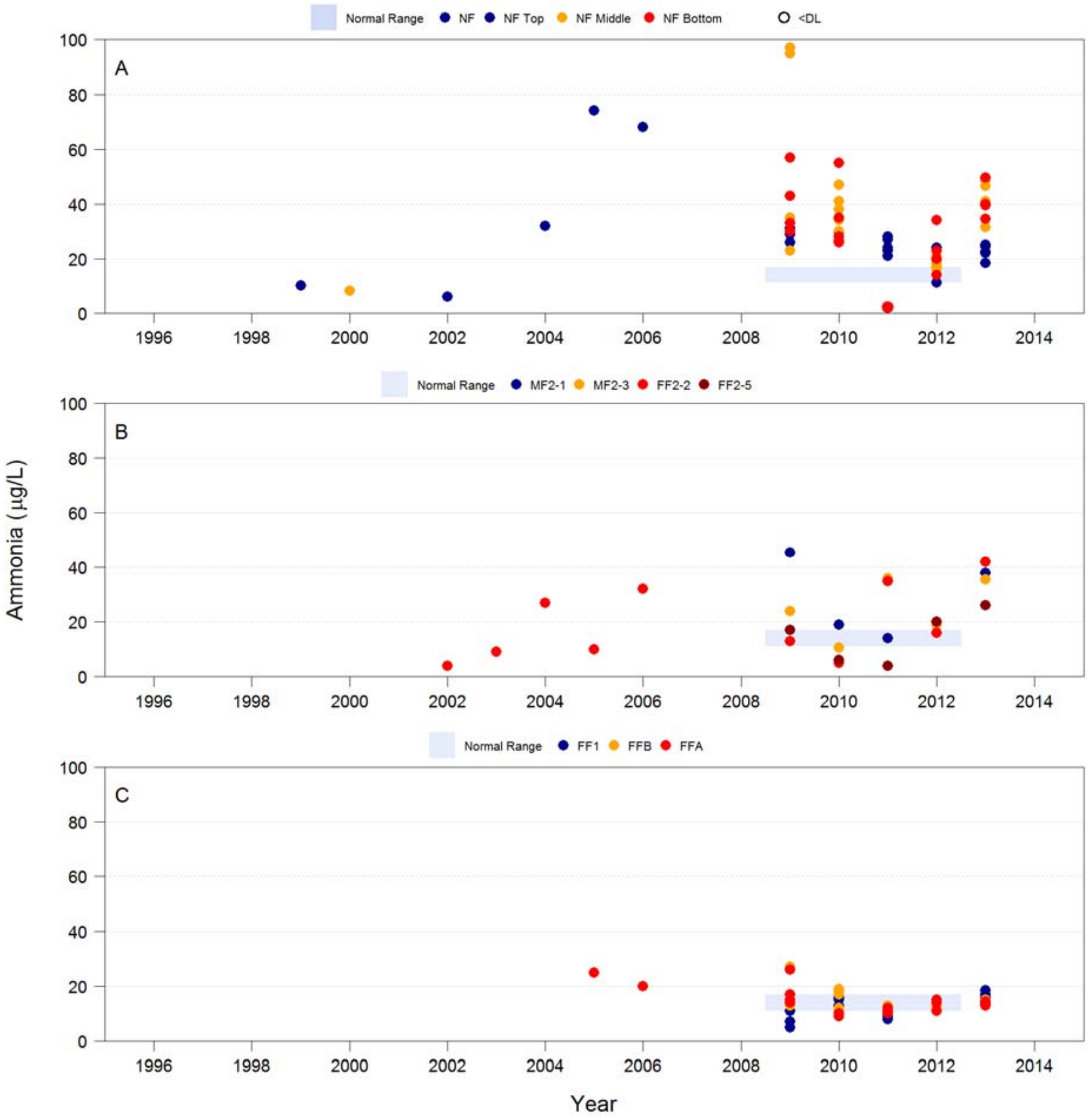
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 6-11 Ammonia Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-water Season



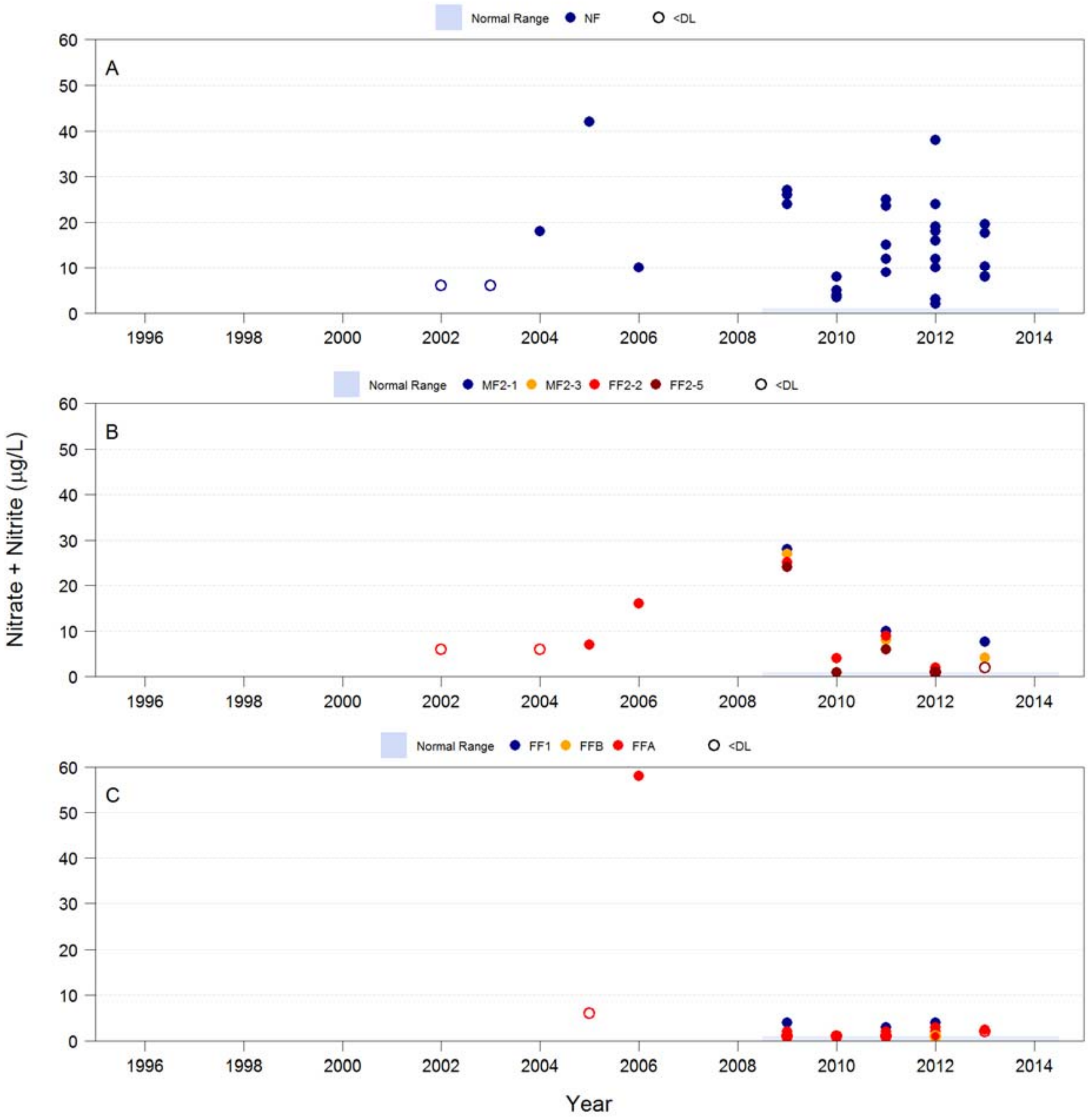
Note: Values represent concentrations in individual depth integrated samples.

Figure 6-12 **Ammonia Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-cover Season**



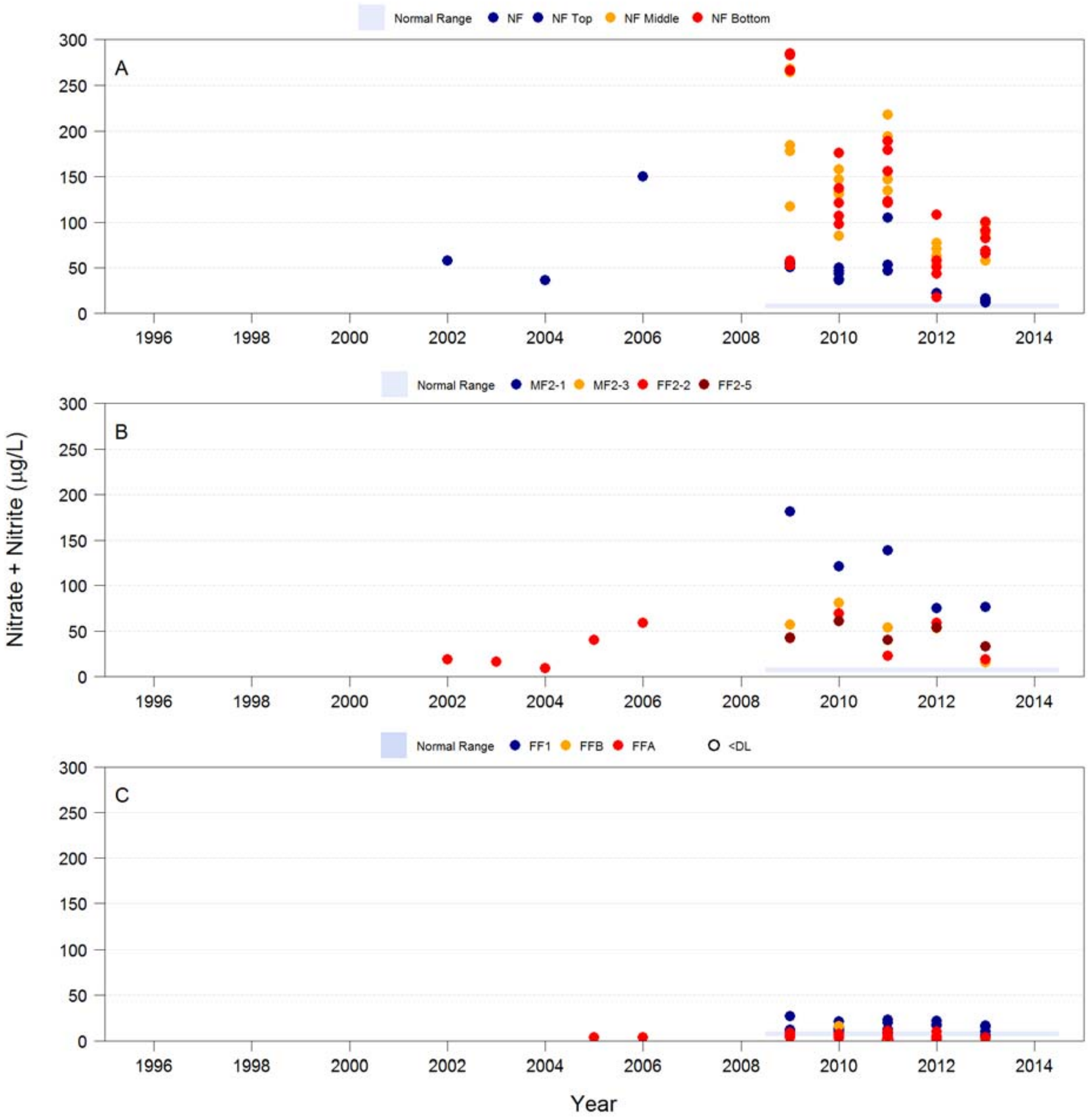
Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

Figure 6-13 Nitrate + Nitrite Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-water Season



Note: Values represent concentrations in individual depth integrated samples.

Figure 6-14 Nitrate + Nitrite Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Ice-cover Season



Note: NF and FF area values represent concentrations in individual samples; MF2-FF2 area values represent the maximum concentration of three depths (top, middle and bottom) at individual stations.

6.3.2.2 Chlorophyll *a* and Zooplankton biomass

Chlorophyll *a* concentrations in the NF area ranged from approximately 1 to 2 µg/L. Exceedances of the normal range occurred in all years (Figure 6-15). Concentrations along the MF2-FF2 transect were lower than in the NF area, although in 2013, concentrations reached similar levels. Chlorophyll *a* concentrations at most stations along the MF1 transect exceeded the normal range from 2007 to 2013 (Appendix 6B, Figure 6B-15). Several exceedances of the normal range were noted in the MF3 area.

Zooplankton biomass in the NF area increased from 2009 to 2011, exceeding the upper bound of the normal range in 2010; however, since 2011 zooplankton biomass has decreased (Figure 6-16). This pattern was also encountered along the MF2-FF2 transect. Zooplankton biomass along the MF1 and MF3 transects has increased since approximately 2008, and values at most stations exceeded the normal range in 2013 (Appendix 6B, Figure 6B-16). Although zooplankton biomass remained mostly within the normal range in the reference areas, a significant increasing trend was observed at Reference Area FFB.

Table 6-8 Results of Mann Kendall Trend Tests (2007-2013) for Chlorophyll a and Zooplankton Biomass in the Near-Field (NF) Sampling Area; at Sampling Stations MF2-1 and FF2-2; and at the Three Far-Field Reference Areas (FF1, FFB, and FFA), Open-water Season

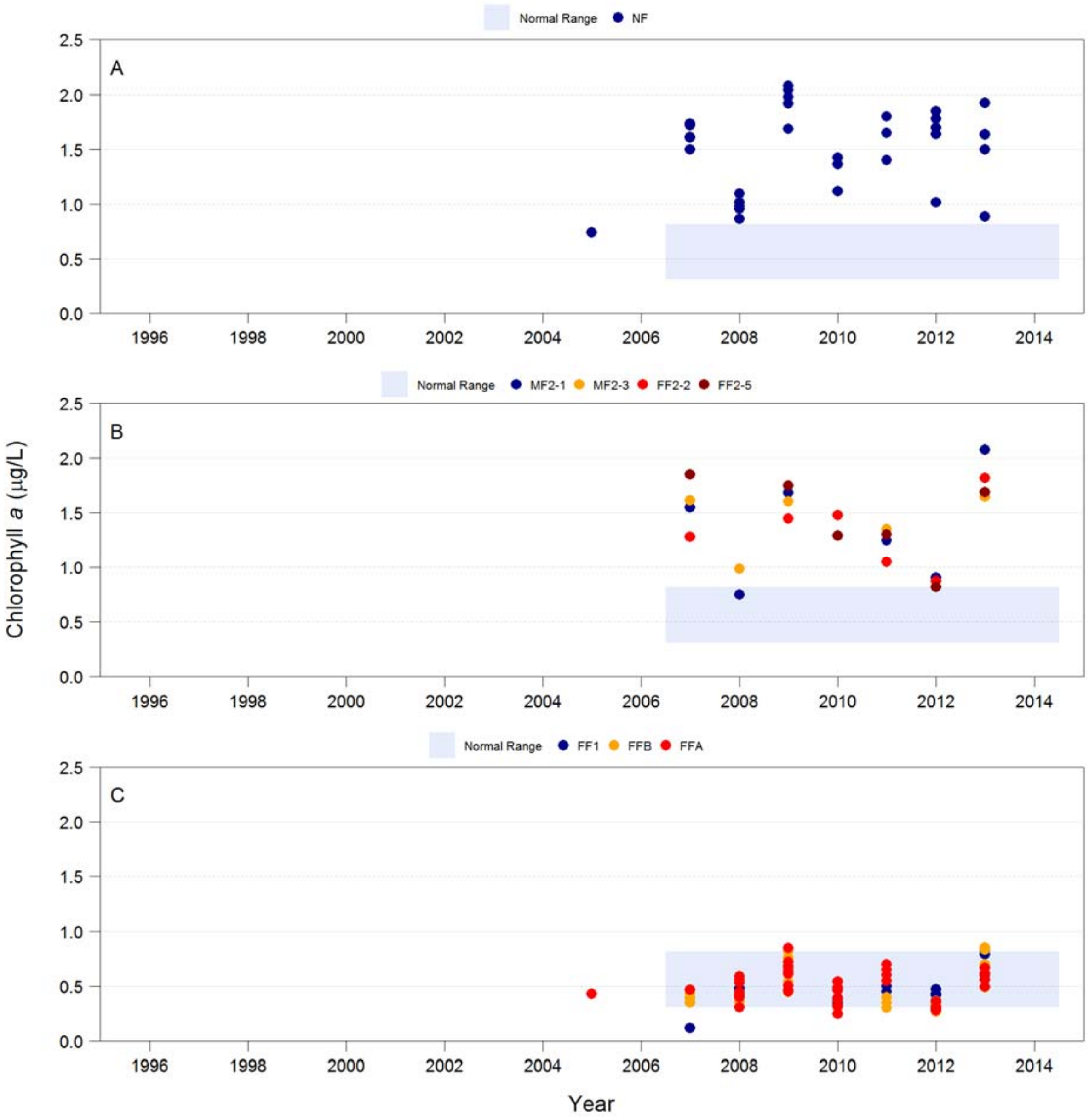
Variable	Kendall's Rank Coefficient, τ[(a)]					
	NF[(b)]	MF2-1[(b)]	FF2-2[(b)]	FF1[(b)]	FFB[(b)]	FFA[(b)]
Chlorophyll a	0.24	0.07	0.07	0.33	-0.14	-0.14
Zooplankton Biomass	0.47	0.40	0.00	0.60	**0.87***	0.47

a) Probability of type 1 error (two tailed): * = <0.1, ** = <0.01, *** <0.001. **Bolded** correlation coefficients indicate significant temporal trends.

b) The median concentration in the NF, FF1, FFB and FFA areas was used in the analysis. A single value was available stations MF2-1 and FF2-2.

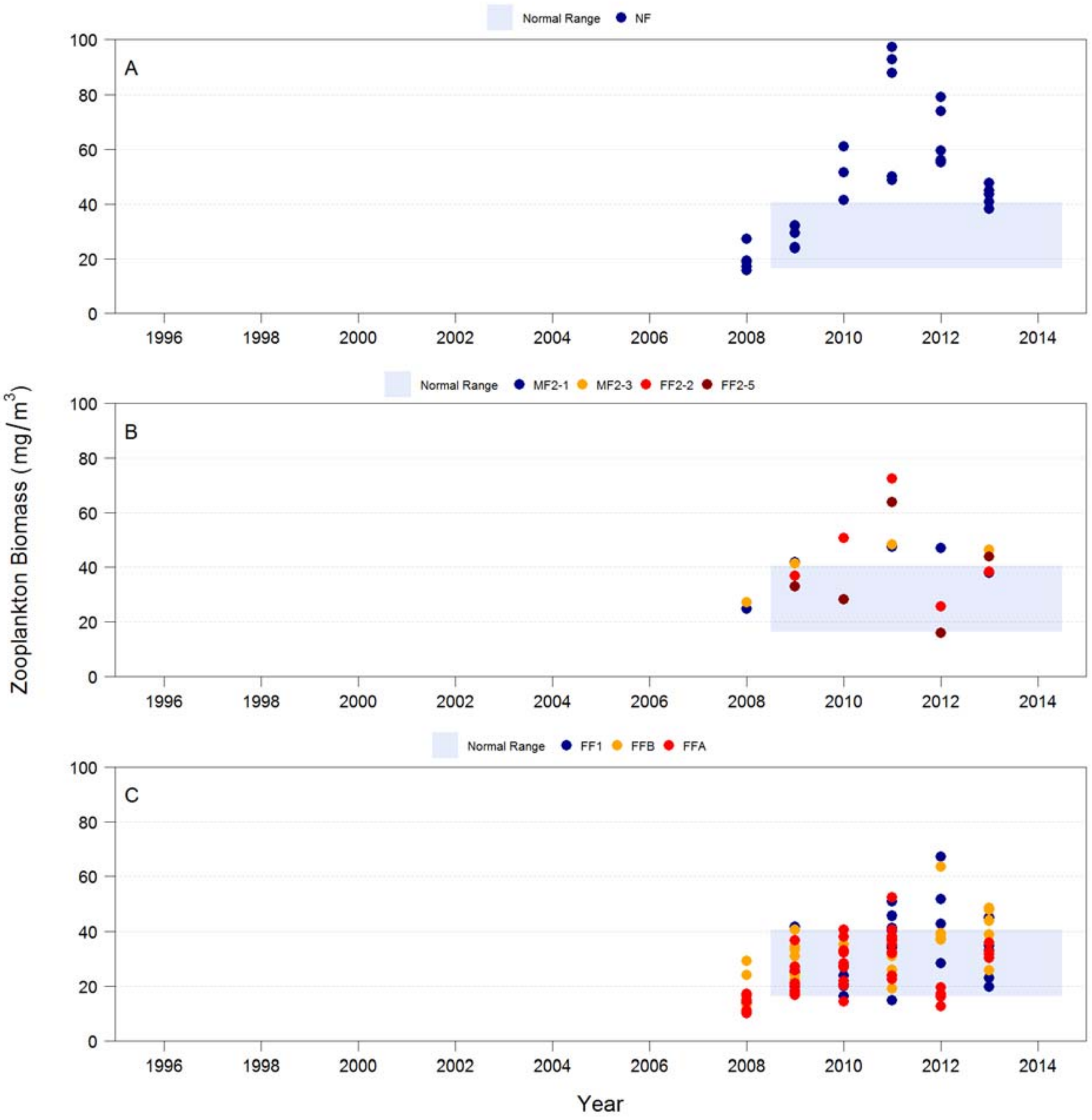
τ = Kendall's Tau.

Figure 6-15 Chlorophyll a Concentration at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-water Season



Note: Values represent concentrations in individual samples.

Figure 6-16 Zooplankton Biomass at Sampling Stations in the A) Near-field Area, B) MF2-FF2 Transect, and C) Three Far-field Reference Areas, Open-water Season



Note: Values represent biomass measurements in individual samples.

6.3.3 Comparison to EA Predictions

The maximum predicted concentration of TP at the edge of the mixing zone was 11.7 µg/L. The introduction of higher levels of nutrients, particularly phosphorus, was expected to result in an increase in primary productivity. Up to 20% of the surface area of Lac de Gras (116 km^2 during the open-water period and up to 64 km^2 during the ice-covered period) was expected to exceed the EA threshold for nutrient enrichment (i.e., 5 µg/L of TP). The EA predictions for TP at the edge of the mixing zone have not been exceeded (Table 6-9). The prediction for the extent of the lake area that would be subjected to TP concentrations above 5 µg/L has not been exceeded in open-water conditions but has been exceeded on two occasions in ice-cover conditions (2008 and 2013). Concentrations of TP greater than the normal range have never occurred in an area greater than 20% of the lake.

Table 6-9 Comparison of Environmental Assessment (EA) Predictions and Observations for Total Phosphorus (TP) Concentrations in Lac de Gras

Season or Location	EA Prediction[(a)]		Unit	Area affected or Concentration at Edge of Mixing Zone											
	TP (µg/L)	Area of Lake (km^2)		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Ice-cover	>5[(b)]	64	km^2	-	-	-	-	-	18.6	112	53.5	23.8	9.2	3.6	80.6
Open-water	>5.3[(b)]	116	km^2	-	-	-	-	-	29.4	0	16.2	9.2	0	-	0
Edge of mixing zone	maximum 11.7[(c)]	0.01	µg/L	9.0	4	5.5	6	8	8	5	5	6.2	5	5.6	10.7

a) DDMI 1998c.

b) In the Reference Conditions Report Version 1.1 (Golder 2015), the normal range was re-calculated and demonstrated that the EA threshold of 5 µg/L ([DDMI 1998c) was inappropriate given that it was within the normal range for the lake. Therefore, comparisons are being made to the top of the normal range (which should be considered conservative given that the EA predicted an increase of phosphorus over background concentrations).

c) Based on water column average concentration. The concentration shown under each year is the maximum water column median recorded in that year. The full range over the water column and the entire year is shown in Figure 4-15.

6.4 Conclusions

- Weight of Evidence Effect Rankings for TP have been at a moderate ranking since 2007. The WOE effect ranking for total nitrogen increased from moderate to high in 2008 and has remained at that ranking since. Effect rankings for chlorophyll *a* concentration and zooplankton biomass have fluctuated between moderate and high since 2007, though both had rankings of high 2013.
- An Action Level 1 was triggered for chlorophyll *a* because concentrations in the NF and MF areas were consistently greater than the upper bound of the normal range (0.82 µg/L) between 2007 and 2013. In 2009 and 2013, chlorophyll *a* concentrations in the NF and MF areas were greater than the upper bounds of the normal range in over 20% of the lake, resulting in an Action Level 2 being triggered.
- Total phosphorus concentrations in the NF area have remained at similar levels and were typically within the normal range during the open-water season since 2007. During the ice-cover season, TP concentrations in the NF area (at the top, mid, and bottom depths) often exceeded the normal range. The highest TP concentrations observed to date in the NF area were in 2009 and 2013. Although there was no statistically significant trend over the 2007 to 2013 period, the recent increase in TP concentrations in Lac de Gras appears to reflect the increasing trend in TP in the effluent.
- Total nitrogen concentrations in the NF area and at most mid-field stations (along the MF2-FF2 and MF1 transects) exceeded the normal range during the open-water season from 2007 to 2013. During the ice-cover season, total nitrogen concentrations in the NF area exceeded the upper bounds of the normal range from 2005 to 2013, though concentrations have been decreasing since 2009, again reflecting trends observed in concentrations and loads of nitrogen in effluent.
- Chlorophyll *a* concentrations in the NF area and at most mid-field stations (along the MF2-FF2, MF1 transect and stations MF3-1 and MF3-2 along the MF3 transect) exceeded the normal range in all years from 2007 to 2013. There has not been a temporal trend in concentrations, though the highest mid-field concentrations were encountered in 2013.
- Zooplankton biomass in all exposure areas peaked in 2011 and has decreased since then. Biomass values were still above the normal range in the NF area and at some mid-field stations in 2013.

7 SEDIMENT QUALITY

7.1 Introduction

This chapter provides a summary of changes in the sediment chemistry of Lac de Gras over time. The objectives of this chapter are:

- to summarize Mine-related effects observed from 2011 to 2013 and compare these to effects observed previously (i.e., from 2007 to 2010); and
- to analyze temporal trends in sediment chemistry for the period extending from baseline (i.e., 1996) to 2013.

Lac de Gras sediments were sampled in 1996 and 1997 to assess baseline sediment quality and complete the Environmental Assessment (EA) for the Mine. Sediments were also sampled in 1999 by the Department of Indian Affairs and Northern Development (DIAND; now Indigenous and Northern Affairs Canada, or INAC) providing an additional year of baseline sediment quality data. Results obtained from these early studies represent the pre-development conditions in Lac de Gras. Sediment quality has been monitored as part of the Mine's Aquatic Effects Monitoring Program (AEMP) since 2001. The original AEMP (Version 1.0) included one year of sediment data collection prior to initiation of the Mine effluent discharge to Lac de Gras, which occurred in March 2002. The first AEMP sediment quality monitoring event to occur with treated effluent being discharged to Lac de Gras was in August 2002. Sediment quality monitoring under the AEMP continued annually until 2010, at which time it switched to a three-year cycle (Golder 2014a). In addition, sediment quality has been monitored annually at the edge of the mixing zone in Lac de Gras since 2002, as part of the Mine's Surveillance Network Program (SNP).

The analysis and reporting of sediment chemistry data under the AEMP is focussed on Substances of Interest (SOIs). These SOIs represent substances in Lac de Gras sediments that may be affected (i.e., increase in concentration) by Mine effluent. Effects on sediment quality are identified by comparing concentrations of SOIs between exposure and reference areas using statistical tests, as well as by comparing SOI concentrations to background values and Sediment Quality Guidelines (SQGs). The present summary report provides an opportunity to examine SOI concentration changes over time.

7.2 Methods

7.2.1 Substances of Interest

The intent of defining SOIs was to identify a meaningful set of variables that will undergo further analyses, while limiting analyses on variables that were less likely to be affected. In the AEMP annual reports, sediment chemistry variables were identified as SOIs if concentrations in the near-field (NF) exposure area were significantly elevated relative to the far-field (FF) reference areas. The last comprehensive monitoring program that included collection of sediment quality samples took place in 2013 (sediment sampling was not a required component of the AEMP in 2011 and 2012 [Golder 2014a]). The assessment of temporal trends, therefore, focused on the SOIs identified for sediment quality in the 2013 AEMP Annual Report (Golder 2014d):

- aluminum
- bismuth
- boron
- calcium
- chromium
- lead
- lithium
- magnesium
- potassium
- sodium
- tin
- titanium
- uranium

Although not identified as SOIs in 2013, total phosphorus (TP) and total nitrogen (TN) were included in the temporal assessment for sediment chemistry, because assessment of the effects of nutrients discharged to Lac de Gras is a key objective of the AEMP (Golder 2014a). Hence, these analytes were retained in the temporal analyses to document nutrient enrichment in sediments over time. In addition, sediment physical variables (i.e., percentage of fine sediments [silt and clay] and TOC) were evaluated because these variables can influence the concentrations of metals and nutrients in bottom sediments and, therefore, could interfere with the interpretation of temporal trends.

7.2.2 Data Sources

Sediment chemistry data included in the evaluation of temporal trends were taken from the following data sources:

- baseline data collected by DDMI in 1996 and 1997;
- baseline data collected by DIAND in 1999;
- data from the Mine's SNP, which were collected annually beginning when the Mine effluent discharge was initiated in 2002, and including data up to 2013;
- data collected annually during the AEMP Version 1.0 from 2001 to 2006;
- data collected annually during the AEMP Version 2.0 from 2007 to 2010; and
- data collected during the AEMP Version 3.0 in 2013.

To allow for the comparison of data over time, sampling methods and laboratory procedures used during the AEMP (2001 to 2013) were generally the same as those used during baseline surveys (1996 to 1999); however, there have been some differences in methods over the years that resulted in comparability issues between recent and historical data. These issues included differences in sampling locations, sample collection methods, analytical laboratories contracted for sample analyses, detection limits (DLs), and variables analyzed. These modifications to the AEMP design were introduced, as required, to allow the annual monitoring programs to meet the goals of the AEMP.

The sampling locations used throughout the baseline monitoring period (1996 to 1999) and during the AEMP Version 1.0 differ from the current AEMP stations, which were established in 2007 and then adjusted in 2012 (Golder 2011b). The pairing of historical stations with current AEMP stations is summarized in Table 7-1. Historical sampling stations not located in the vicinity of current AEMP stations were not included in the analysis. In addition, AEMP Version 2.0 stations no longer sampled in AEMP Version 3.0 were excluded from the analysis.

Table 7-1 List of Historical Sediment Quality Sampling Stations Included in the Temporal Assessment

Program	Year	Historical Station	Current AEMP/SNP Station or Area
Baseline	1996	WQ2	MF1-3
Baseline	1996 to 1997	WQ6	NF
Baseline	1996 to 1997	WQ7	MF3-2
DIAND	1999	HCR-11	MF1-3
DIAND	1999	HCR-4	FF2-5
DIAND	1999	HCR-6	MF3-4
DIAND	1999	HCR-7	MF3-6
AEMP	2001 to 2006	LDG-MF1, LDG-MF2, LDG-MF3	MF2-1
AEMP	2001 to 2006	LDG-NF1, LDG-NF2, LDG-NF3	NF
AEMP	2001 to 2006	LDG-FF1, LDG-FF2, LDG-FF3	FFA
SNP	2002 to 2009	1645-19B	1645-19B2

Sediment collection methods differed among sampling programs. Sediment samples collected during the 1996 and 1997 baseline program, and the 2001 to 2006 AEMP, were collected using a sediment corer, and the top 5- to 6-cm fractions were analyzed. The 1999 samples were collected by DIAND using sediment traps. The 2007 to 2013 AEMP samples were collected using a sediment corer, and the top 1-cm fraction was analyzed. From 2007 to 2010, nitrogen, phosphorus and TOC were analyzed from the top 5-cm fraction of Ekman grab samples. The 2002 to 2012 SNP sediment samples were collected using an Ekman grab, and the top 5-cm fraction was analyzed. In 2013, SNP samples were analyzed from the top 1 cm fraction of sediment core samples.

Data presented in this summary were provided by different analytical laboratories: Enviro-Test Laboratories (ETL) in Edmonton, Alberta (2001 to 2006 data); ALS Environmental (ALS) in Edmonton, Alberta (2007 to 2010 data), which purchased the ETL facility in 2007; and, Maxxam Analytics (Maxxam) in Burnaby, British Columbia (2013 data). Improvements in the analytical DLs over the 1996 to

2013 monitoring period confounded the temporal analysis for some variables, as results obtained using older higher DLs could only be reported as <DL. Finally, the suite of variables analyzed since baseline has expanded. As a result, data for some analytes were not available for the earlier monitoring years.

7.2.3 Data Handling

Initial screening of the AEMP sediment quality data sets was completed before data analyses, to identify unusually high (or low) values in the datasets and decide whether to retain or exclude anomalous data from further analyses. An explanation of the objectives and approach taken to complete initial screening is provided in Section 2.6. Results of the initial screening for anomalous values in the AEMP sediment quality dataset is presented in Appendix 7A, Table 7A-1. A total of nine anomalous values were identified within the sediment quality data sets; these values occurred between 2007 and 2013. In cases where anomalous values were identified in the annual datasets, scatter-plots were generated to allow a visual review of excluded data (Appendix 7A, Figures 7A-1 to 7A-9).

Prior to conducting data analyses, data from field duplicate samples were removed, and non-detect data were multiplied by 0.5. Substitution with half the DL is a common approach used to deal with censored data (US EPA 2000) and is consistent with the approved methods applied in the calculation of the normal range in the AEMP Reference Conditions Report Version 1.1.

7.2.4 Data Analysis

7.2.4.1 Summary of Effects

Results of the AEMP sediment quality surveys contribute to the Weight of Evidence (WOE) assessment, which is described in Section 11. The WOE assessment is undertaken by applying a ranking scheme to determine the degree of change in individual sediment quality endpoints. The WOE effects rankings for sediment quality incorporate results of statistical comparisons between the exposure and reference areas of Lac de Gras, as well as comparisons to SQGs (Table 7-2).

In 2013, the criteria for determining a moderate and high effect ranking for sediment chemistry were modified to include a comparison of the exposure area data with SQGs. The ranking procedure now requires that sediment chemistry variable concentrations in the exposure area exceed the average of the CCME Interim Sediment Quality Guideline (ISQG) and of either the Probable Effect Level guideline (PEL) or another appropriate guideline (OMOEE 1993) before a moderate or high-level ranking can be applied. Sediment chemistry results from 2007 to 2013 were categorized according to the revised WOE rankings. The patterns of response observed in the WOE effects rankings over the 2007 to 2013 summary period were evaluated qualitatively to identify trends over time. Sediment chemistry results from prior to 2007 were excluded from the WOE effects rankings because the sample collection procedures and locations of stations differed appreciably from the AEMP Versions 2.0 and 3.0. The full suite of sediment chemistry variables analyzed during the AEMP Versions 2.0 and 3.0 was evaluated, with the exception of particle size.

Table 7-2 Weight of Evidence Effect Rankings for Sediment Chemistry

Effect Ranking	Guideline and Effect Sizes
Low	Statistically significant increase, NF vs reference
Moderate	Low AND NF >(ISQG[(a)]+PEL)/2 (or other appropriate guideline)[(b)] AND NF area mean >reference normal range (2007-2010)
High	MF >(ISQG+PEL)/2 (or other appropriate guideline) AND MF area mean >reference normal range (2007-2010) OR NF >PEL AND NF area mean >reference normal range (2007-2010)

a) CCME 2002; OMOEE 1993.

b) For example, the OMOEE [LEL+SEL]/2.

NF = near-field; MF = mid-field; LEL = Lowest effect level; PEL = Probable effect level, SEL = Severe effect level; ISQG = Interim sediment quality guideline; >= greater than; <= less than.

7.2.4.2 Temporal Trends

Temporal trends of SOIs in Lac de Gras were evaluated using time series plots. This assessment is a continuation of the temporal evaluation performed for the 2007 to 2010 AEMP Summary Report (Golder 2011a). In that report, results from recent and historical AEMP programs up to the 2010 AEMP were used to generate figures showing trends over time in the sediment chemistry of Lac des Gras. These plots were updated to include results of the 2013 AEMP sediment quality program (sediment was not a required component of the AEMP in 2011 and 2012).

Time series plots were organized according to the sampling areas of Lac de Gras. These areas consisted of:

- the NF exposure area;
- three mid-field (MF) exposure areas (MF1, MF2 and MF3);
- one FF exposure area (FF2); and
- three FF reference areas (FF1, FFB and FFA).

Sediment chemistry data collected at the mixing zone boundary (Stations 1645-19A, 1645-19B2, and 1645-19C; collectively referred to as SNP-19 in the figures) were included in time series plots to allow comparisons with the rest of the lake. Concentrations along the three MF area transects were plotted by individual station because each MF station is subject to a different degree of effluent exposure. A separate graph was produced for each transect (MF1, MF2 and MF3). Data from the FF2 exposure area were incorporated into the figures for the MF2 area, because the FF2 area stations are located at the far northeast end of the MF2 transect. Data from the three FF reference areas (FF1, FFB and FFA) were also evaluated for the presence of temporal trends. Trends occurring in the reference areas may represent natural trends in sediment quality, or potentially, the presence of Mine effluent. Non-detect data were included in the time series plots and are represented by open symbols.

Trends in sediment chemistry over time were evaluated in relation to the *normal range* for Lac de Gras, which was calculated based on percentiles using reference area (FF1, FFB, FFA) data (Golder 2015). The normal ranges for SOIs were calculated using reference area data collected during the AEMP Version 2.0 (2007 to 2010; Table 7-3).

Table 7-3 Normal Ranges for Sediment Variables

Variable	Year	Unit	Normal Range	
			Lower Limit	Upper Limit
Total organic carbon	2007 to 2010	% dw	0.7	4.7
Percent fine sediment	2007 to 2010	% dw	29.5	97.0
Total nitrogen	2007 to 2010	% dw	0.05	0.41
Total phosphorus	2007 to 2010	mg/kg dw	681	1,650
Aluminum	2007 to 2010	mg/kg dw	10,723	18,433
Bismuth	2010	mg/kg dw	0.31	0.59
Boron	2007 to 2009	mg/kg dw	2.2	7.0
Calcium	2007 to 2010	mg/kg dw	800	1,978
Chromium	2007 to 2010	mg/kg dw	32.5	67.4
Lead	2007 to 2010	mg/kg dw	4.5	9.5
Lithium	2010	mg/kg dw	24.9	54.2
Magnesium	2007 to 2010	mg/kg dw	4,180	9,127
Potassium	2007 to 2010	mg/kg dw	1,969	4,644
Sodium	2007 to 2010	mg/kg dw	100	259
Tin	2007 to 2010	mg/kg dw	0	2
Titanium	2007 to 2010	mg/kg dw	366	1,066
Uranium	2007 to 2010	mg/kg dw	3.0	5.4

Source: Golder 2015.

a) Lithium was not analyzed from 2007 to 2009.

dw = dry weight.

7.2.4.3 Correlations with Physical Variables

The physical characteristics of sediments (i.e., particle size and TOC) have the potential to influence sediment chemistry. To address this potential confounding factor, correlation analysis was used to investigate relationships between these physical variables and sediment chemistry. Since the data did not meet normality assumptions of parametric correlation analysis, the analysis was conducted with Spearman's coefficient of rank correlation, r_S. Correlations were considered significant at $P < 0.05$. All non-detect values were removed from the dataset prior to calculating the correlations. The correlation analysis was conducted with R software (R Foundation for Statistical Computing 2013).

7.3 Results

7.3.1 Summary of Effects

A total of 15 metals analyzed from 2007 to 2013 satisfied the requirement for a low effect ranking in at least one year of monitoring, because mean concentrations in the NF area were significantly greater than in the reference areas (Table 7-4). The number of SOIs having a low effect ranking from 2007 to 2013 varied among years (ranging from 6 variables in 2010 to 14 variables in 2008), but it has not increased over time.

Twelve of these 15 metals (aluminum, bismuth, boron, calcium, chromium, lead, magnesium, potassium, sodium, tin, titanium and uranium) were elevated above their respective normal ranges at one or more stations in at least one year from 2007 to 2013. Of these twelve metals, three (bismuth, lead and uranium) were consistently elevated above the normal range in most years, while the remaining nine metals exceeded the normal range by a relatively small margin in only a single year. None of the 15 metals had concentrations above SQGs. Considerations regarding SQGs included the following:

- SQGs do not currently exist for bismuth, titanium and tin, and information is not available regarding toxicity of these metals in aquatic sediments.
- SQGs do not exist for calcium, magnesium, sodium and potassium, which are common ions in freshwater.
- Guidelines do not exist for uranium, but Sheppard et al. (2005) reported a predicted no-effect level for freshwater benthos of 100 mg/kg dry weight (dw). The greatest annual average and maximum observed concentrations of uranium in the NF area were below this level (14.8 mg/kg and 26.7 mg/kg dw in 2013, respectively).

Table 7-4 Summary of Weight of Evidence Effect Rankings for Sediment Chemistry Substances of Interest, 2007 to 2013

Substance of Interest	2007	2008	2009	2010	2013
Aluminum	0	↑	0	0	↑
Bismuth	↑	↑	↑	↑	↑
Boron	↑	↑	↑	n/a	↑
Calcium	↑	↑	↑	↑	↑
Chromium	↑	↑	0	0	↑
Lead	↑	↑	↑	↑	↑
Lithium	n/a	n/a	n/a	0	↑
Magnesium	↑	↑	↑	0	↑
Potassium	↑	↑	↑	↑	↑
Sodium	0	↑	0	↑	↑
Strontium	0	↑	0	0	0
Tin	0	↑	0	0	↑
Titanium	↑	↑	↑	0	↑
Uranium	↑	↑	↑	↑	↑
Vanadium	↑	↑	0	0	0

Notes: 0 = no effect; ↑ = low effect ranking (increase); n/a = not analyzed. Weight of Evidence effects rankings are not reported in 2011 and 2012 because sediment quality sampling was not a required component of the AEMP in those years.

7.3.2 Temporal Trends

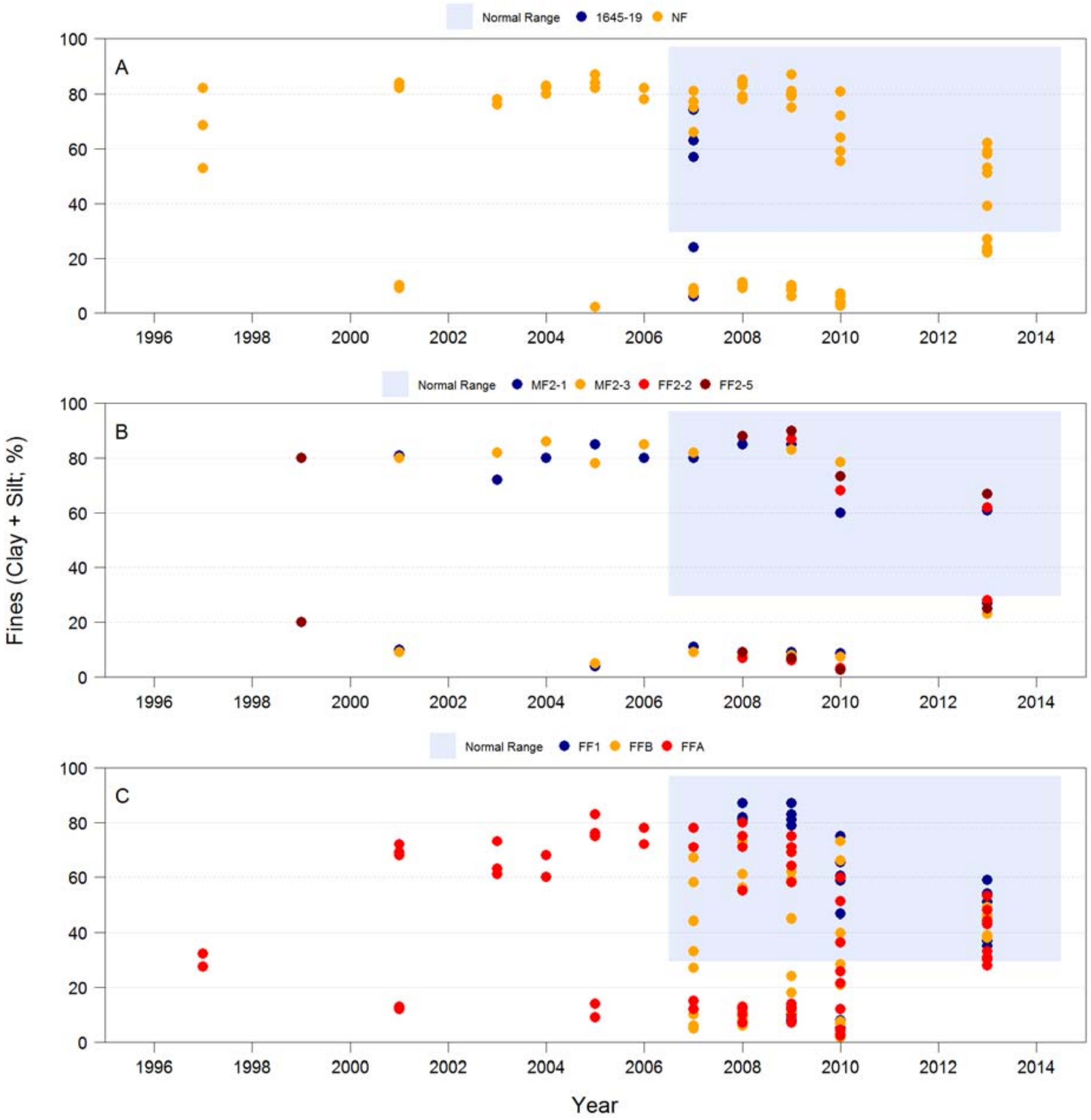
7.3.2.1 Physical Characteristics of Sediment

The amount of fine sediment (reported as percent fines) in samples collected at AEMP sampling stations has fluctuated over the years. The pattern in these temporal fluctuations have been similar across all areas, although they were more pronounced in the reference areas (Figure 7-1 and Appendix 7B, Figure 7B-1). Sediments in the reference areas to the west of the Mine (i.e., FFA and FFB) and along the MF3 transect were coarser, with percent fines values 10% to 20% lower than in other areas of Lac de Gras. In addition, stations in those areas generally had greater variability in percent fines than sampling areas located closer to the diffusers (i.e., NF, MF1, and MF2).

Sampling methods used to collect sediments for analysis of TOC were modified in 2013 to be consistent with collection procedures used for total metals and nutrients. From 1996 to 2010, TOC was analyzed from the top 5-cm portion of Ekman grab samples or core samples (Section 7.2.2), whereas in 2013, the top 1-cm portion of core samples was analyzed. Given that the historic TOC data were collected from a deeper sediment layer, TOC concentrations reported from 1996 to 2010 will be less representative of recent depositional conditions than samples collected in 2013. Comparison of the 2013 TOC data with results from 1996 to 2010, however, indicated that concentrations were generally within the range of values reported historically for top 5-cm samples (Figure 7-2 and Appendix 7B, Figure 7B-2).

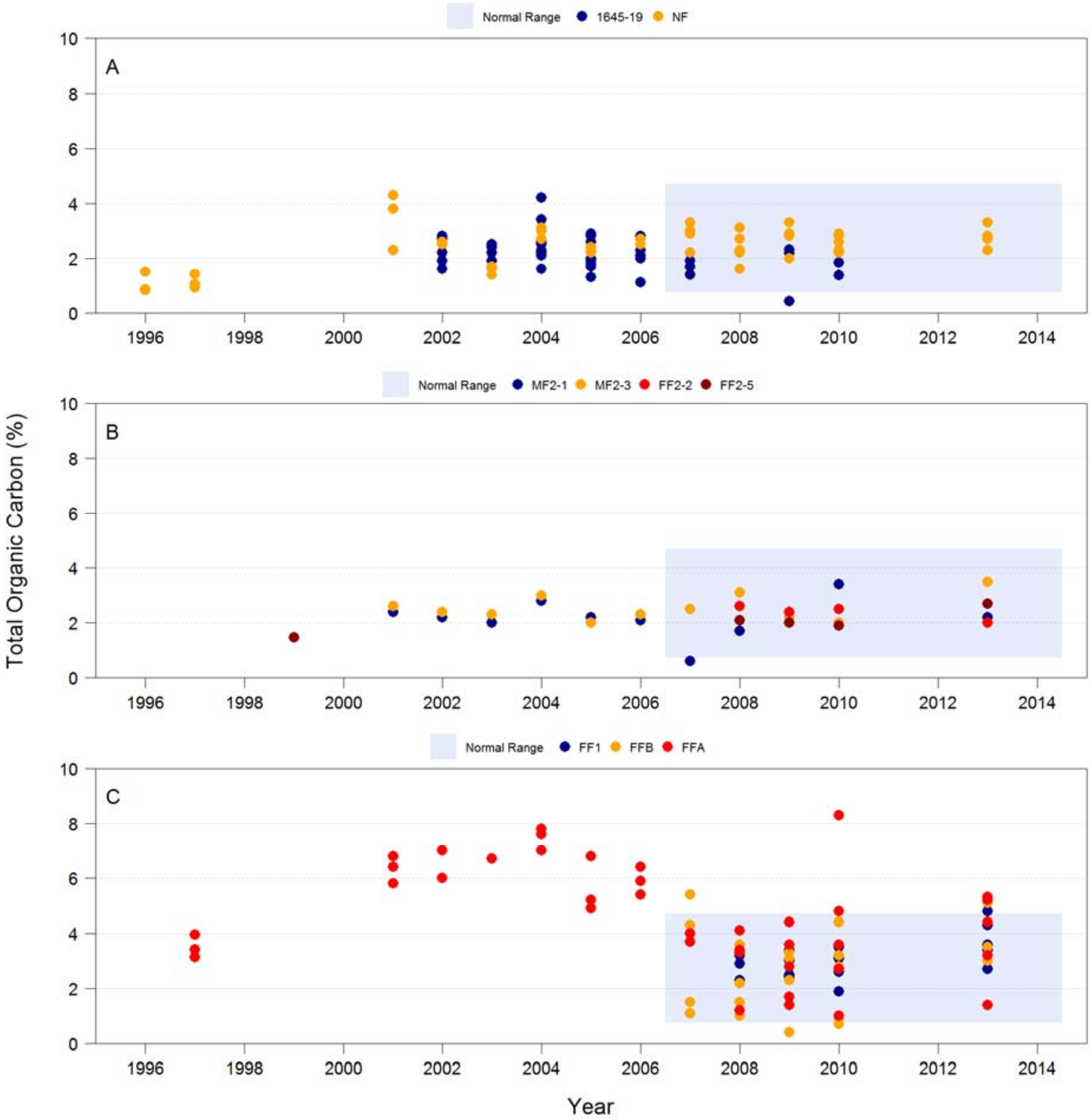
Time series plots for TOC show that the concentration of TOC in sediments has remained within a similar range over time at most sampling areas of Lac de Gras (Figure 7-2 and Appendix 7B, Figure 7B-2). An exception occurred in the FFA area where TOC concentrations were two to three times greater in samples collected from 2001 to 2006 than in samples collected from 2007 to 2013. Spatial differences in TOC concentrations were evident among sampling areas in Lac de Gras. Overall, the amount of TOC in exposure area sediments was lower (median = 2.5%) than that observed in reference areas (median = 3.8%). In addition, sediments in the MF3, FFA and FFB areas had greater variability in TOC content.

Figure 7-1 **Percentage of Fine Sediment (Silt + Clay) in the Top 5-cm Portion at A) the Near-field (NF) Sampling Area; B) Sampling Stations along the MF2-FF2 Transect; and C) at the Three Far-field (FF) Reference Areas**



Notes: In 1999 and in 2013, particle size was analyzed from sediment trap samples and from the top 1-cm portion of core samples, respectively. Particle size was not analyzed at mixing zone (SNP-19) stations.

Figure 7-2 **Total Organic Carbon in the Top 5-cm Portion at A) the Mixing Zone (SNP-19) and Near-field (NF) Sampling Areas; B) Sampling Stations along the MF2-FF2 Transect; and C) at the Three Far-field (FF) Reference Areas**



Note: In 1999 and in 2013, TOC was analyzed from sediment trap samples and from the top 1-cm portion of core samples, respectively.

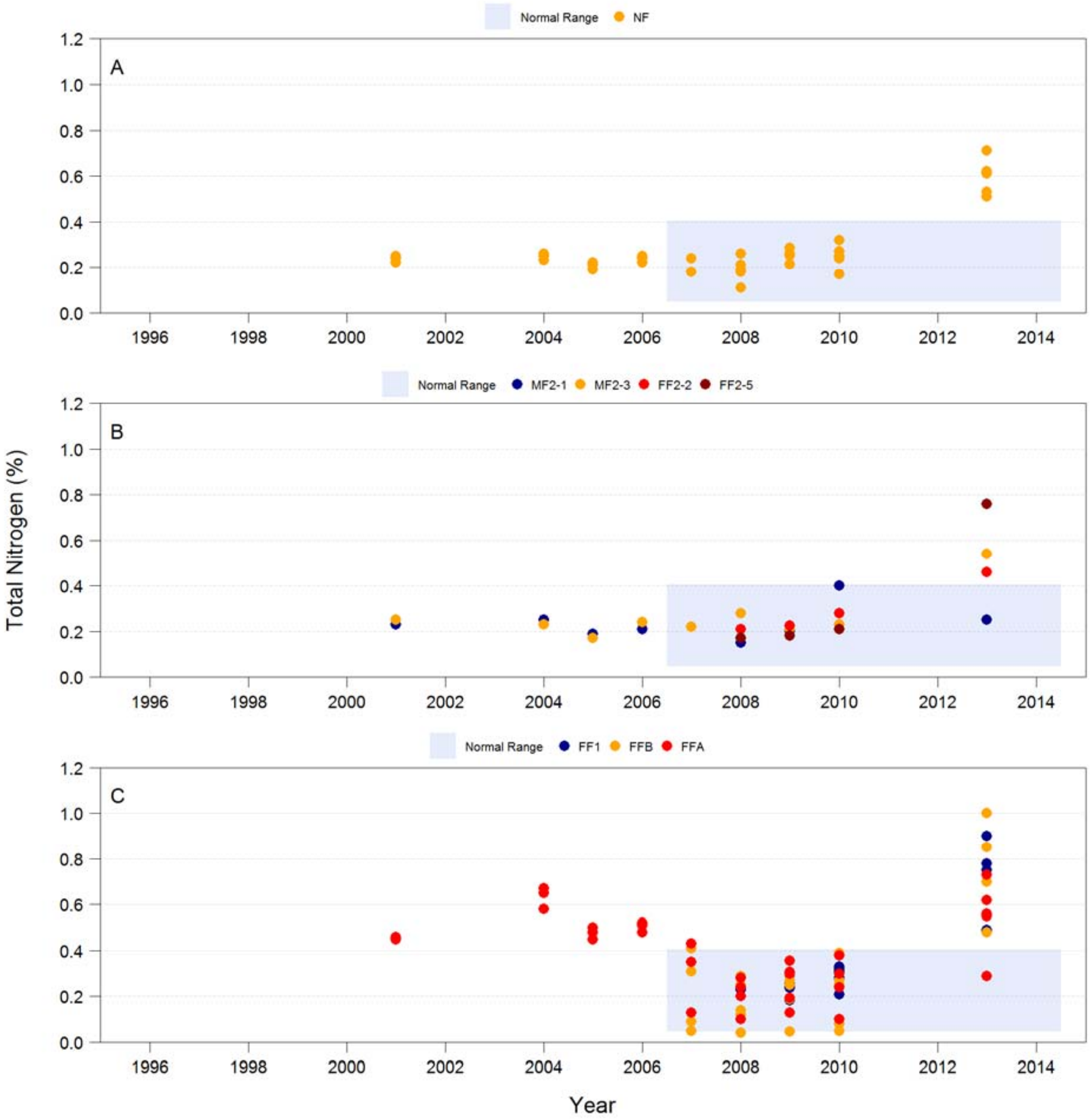
7.3.2.2 Nutrients

Concentrations of phosphorus and nitrogen have been monitored in Lac de Gras sediments since 1997 and 2001, respectively. Prior to 2013, samples for analysis of TP and TN were collected from a deeper sediment layer (top 5 cm) using the methods described in Section 7.3.2.1 for TOC. In 2013, sample collection methods were modified to target more recent sediment deposits, and only the top 1-cm portion of core samples was retained for chemical analysis.

Clear differences in the concentration of TN were observed between sediment sampling depths. Concentrations of TN reported in top 1-cm core samples collected in 2013 were two to three times greater than values reported in top 5-cm samples from 2001 to 2010. The magnitude of the increase in concentration, however, was similar between reference and exposure areas of Lac de Gras, indicating that although the concentration of nitrogen was greater in more recently deposited sediments, there was no spatial pattern linking the increase to the mine discharge. Temporal trends were not evident for TN based on evaluation of top 5-cm samples collected from 2001 to 2010 (Figure 7-3 and Appendix 7B, Figure 7B-3).

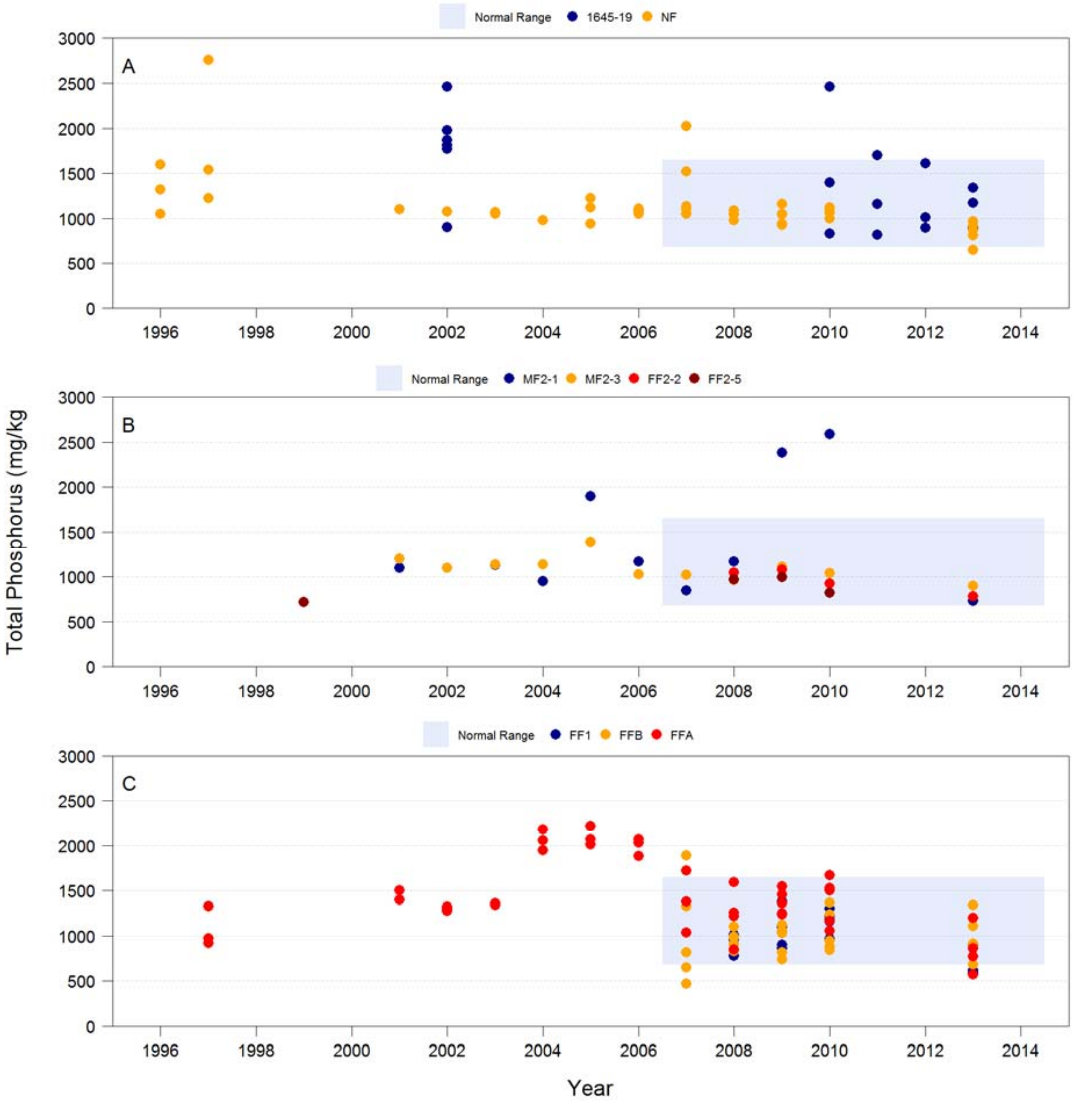
The concentration of TP in the top 1-cm portion of core samples collected in 2013 were slightly lower than values reported historically for 5-cm core or Ekman grab samples (Figure 7-4 and Appendix 7B, Figure 7B-4). Since 2007, concentrations at exposure and reference areas have been similar.

Figure 7-3 **Concentration of Total Nitrogen in the Top 5-cm Portion at A) the Near-field (NF) Sampling Area; B) Sampling Stations along the MF2-FF2 Transect; and C) at the Three Far-field (FF) Reference Areas**



Notes: In 2013, TN was analyzed from the top 1-cm portion of core samples. TN not analyzed at mixing zone (SNP-19) stations.

Figure 7-4 **Concentration of Total Phosphorus in the Top 5-cm Portion at A) the Mixing Zone (SNP-19) and Near-field (NF) Sampling Areas; B) Sampling Stations along the MF2-FF2 Transect; and C) at the Three Far-field (FF) Reference Areas**



Note: In 2013, TP was analyzed from the top 1-cm portion of core samples.

7.3.2.3 Substances of Interest

Time series plots show that the concentrations of most SOIs in the exposure and reference areas have remained within a similar range over the 1996 to 2013 monitoring period (Figures 7-5 to 7-17; and Appendix 7B, Figures 7B-5 to 7B-17). The concentration of lithium, which was only analyzed during the baseline program (1996 and 1997) and during the two most recent AEMP surveys (2010 and 2013), has not varied substantially since the baseline monitoring period (Figure 7-11 and Appendix 7B, Figure 7B-11). The concentrations of 10 of the 13 SOIs were within their respective normal ranges at most sampling locations and during most years. Occasional exceedances of the normal range were noted primarily during the baseline period (1996 to 1999) and AEMP Version 1.0 years (2001 to 2006), which were typically more variable than the 2007 to 2013 data. The other three SOIs (bismuth, lead and uranium) have had NF area concentrations consistently greater than the normal range over the last few years. Time series plots for bismuth, lead and uranium indicate that the concentrations of these metals increased at the mixing zone boundary and in the NF exposure area following initiation of the Mine discharge in 2002 (Figures 7-6, 7-10 and 7-17; and Appendix 7B Figures 7B-6, 7B-10 and 7B-17). In the MF areas, increasing concentrations of uranium was also observed in 2002, while increasing concentrations of bismuth and lead was observed in 2006 or 2007.

Uranium is a water quality SOI, and lead is regularly detected in the effluent; therefore, effluent is a likely source of these two metals. At the standard DL of 0.0002 µg/L, bismuth is typically not detected in the effluent or at AEMP water quality sampling stations. Hence, there is potentially another source of these metals found in sediments. The response patterns identified in this report for bismuth, lead and uranium in bottom sediments are consistent with the results of the dike monitoring studies (DDMI 2011b), which identified greater concentrations of these metals in the vicinity of the Mine effluent diffusers as well as near the A154 and A418 dikes. Results of the most recent dike monitoring study indicated that bismuth, lead and uranium concentrations were greatest along the two transects closest to the diffusers, and concentrations decreased with distance along each of these transects. Concentrations at transects farther away from the effluent discharge were lower, but they still demonstrated gradual decreases with distance away from the dikes. These results indicate that, in addition to Mine effluent, other factors such as dike construction and possible leaching from the dikes may have contributed to the increases in concentrations observed in this area.

Figure 7-5 **Concentration of Aluminum at A) the Mixing Zone (SNP-19) and Near-field (NF) Sampling Areas; B) Sampling Stations along the MF2-FF2 Transect; and C) at the Three Far-field (FF) Reference Areas**

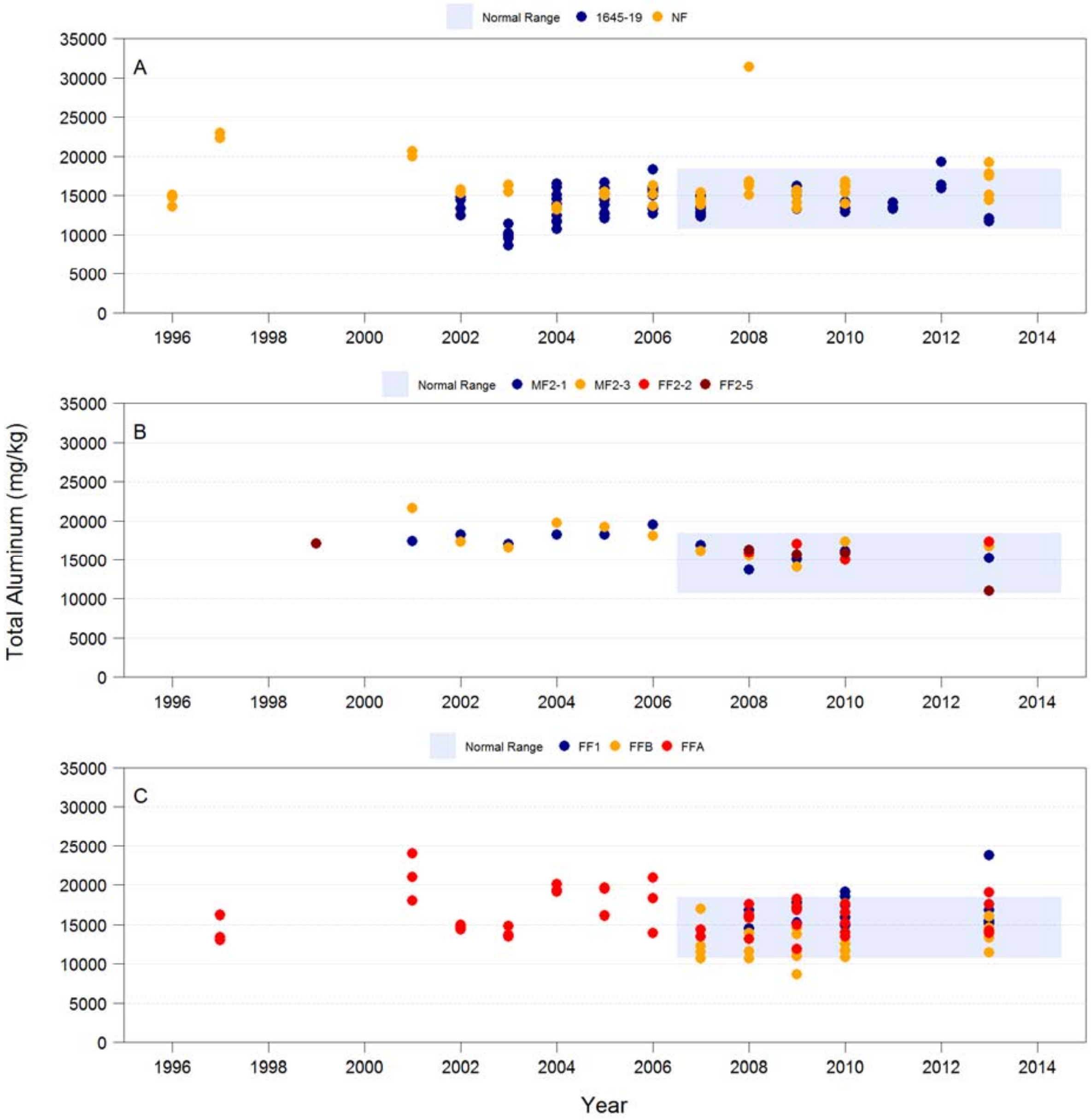


Figure 7-6 **Concentration of Bismuth at A) the Mixing Zone (SNP-19) and Near-field (NF) Sampling Areas; B) Sampling Stations along the MF2-FF2 Transect; and C) at the Three Far-field (FF) Reference Areas**

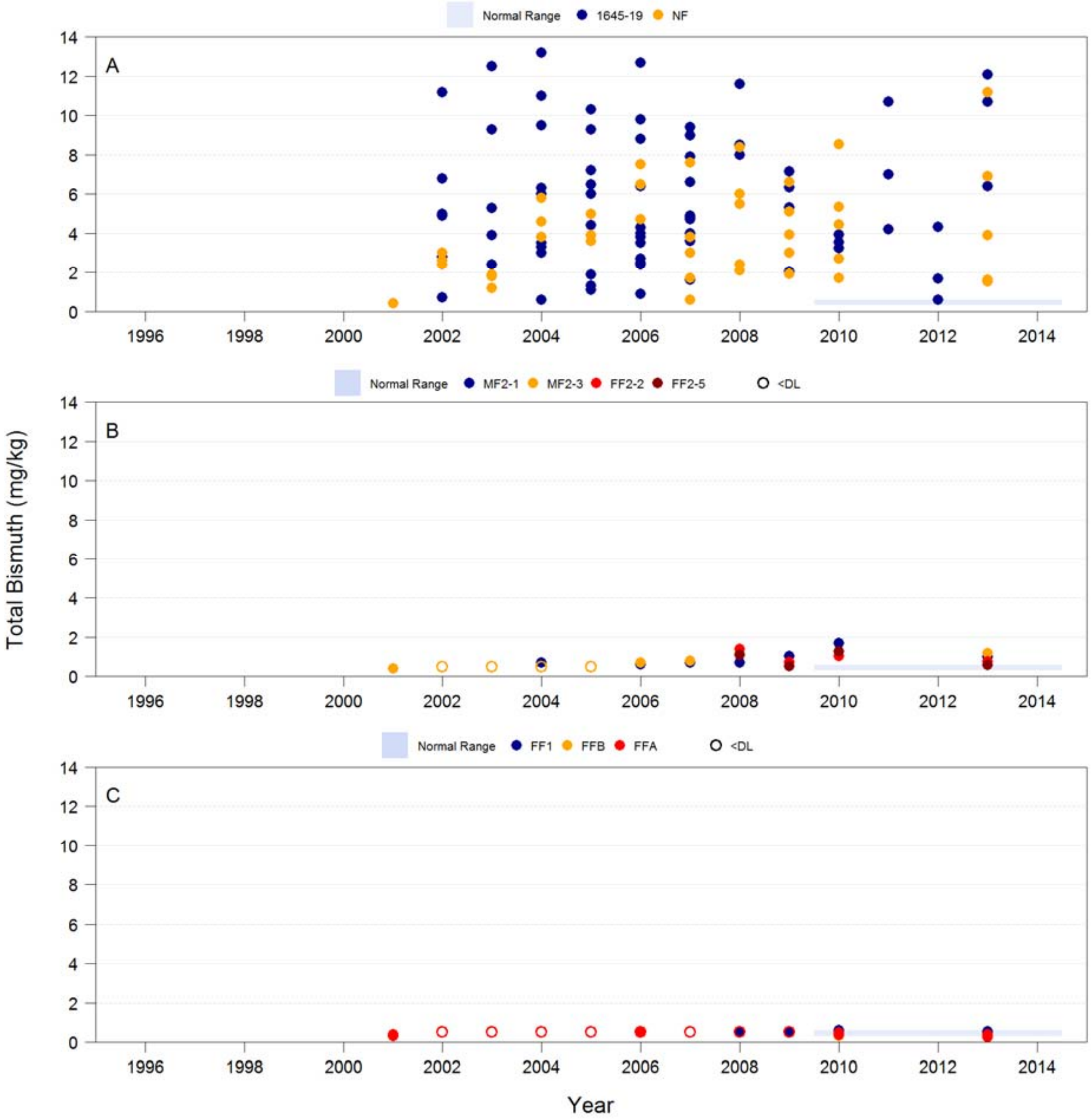


Figure 7-7 **Concentration of Boron at A) the Mixing Zone (SNP-19) and Near-field (NF) Sampling Areas; B) Sampling Stations along the MF2-FF2 Transect; and C) at the Three Far-field (FF) Reference Areas**

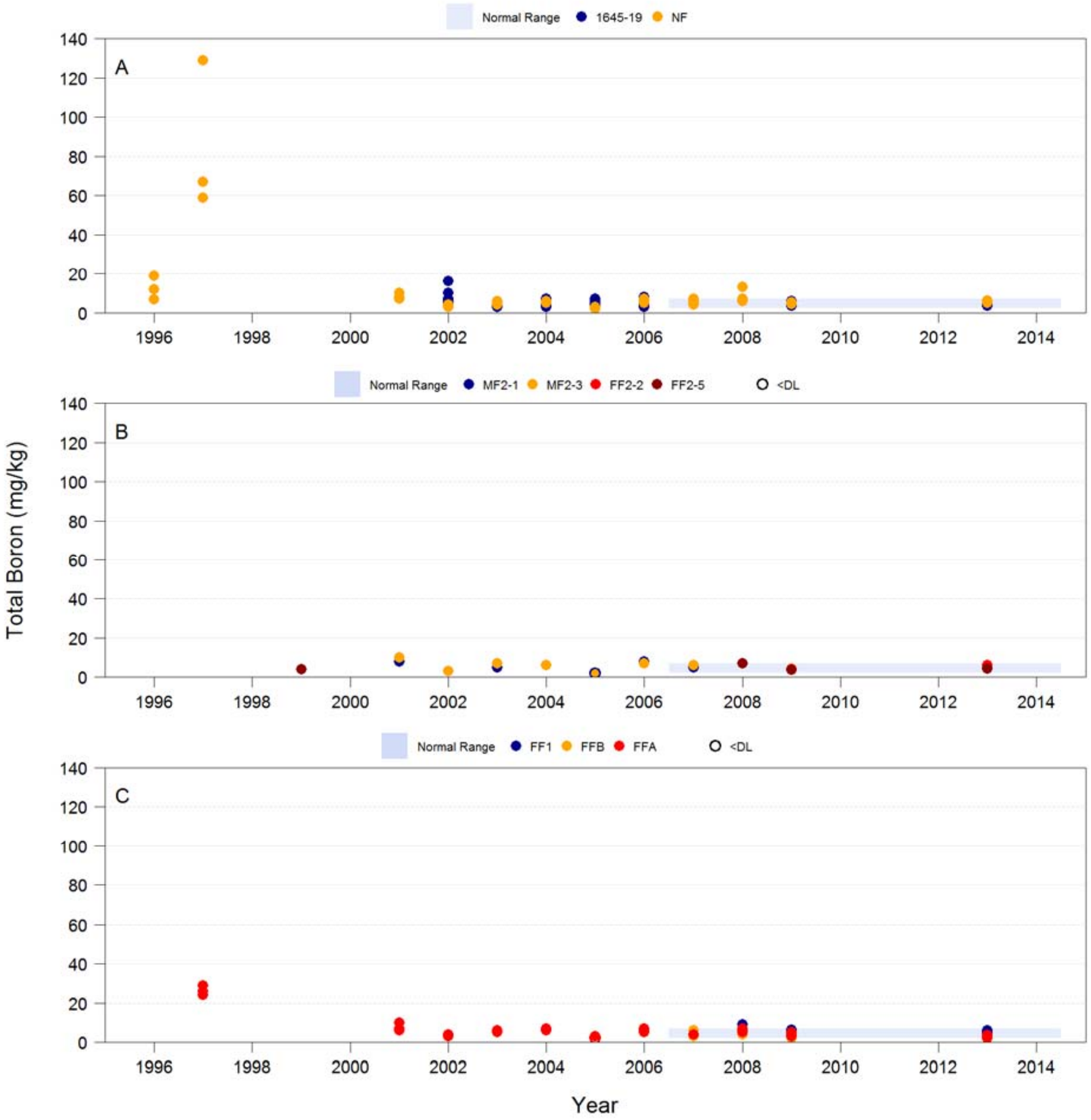


Figure 7-8 **Concentration of Calcium at A) the Mixing Zone (SNP-19) and Near-field (NF) Sampling Areas; B) Sampling Stations along the MF2-FF2 Transect; and C) at the Three Far-field (FF) Reference Areas**

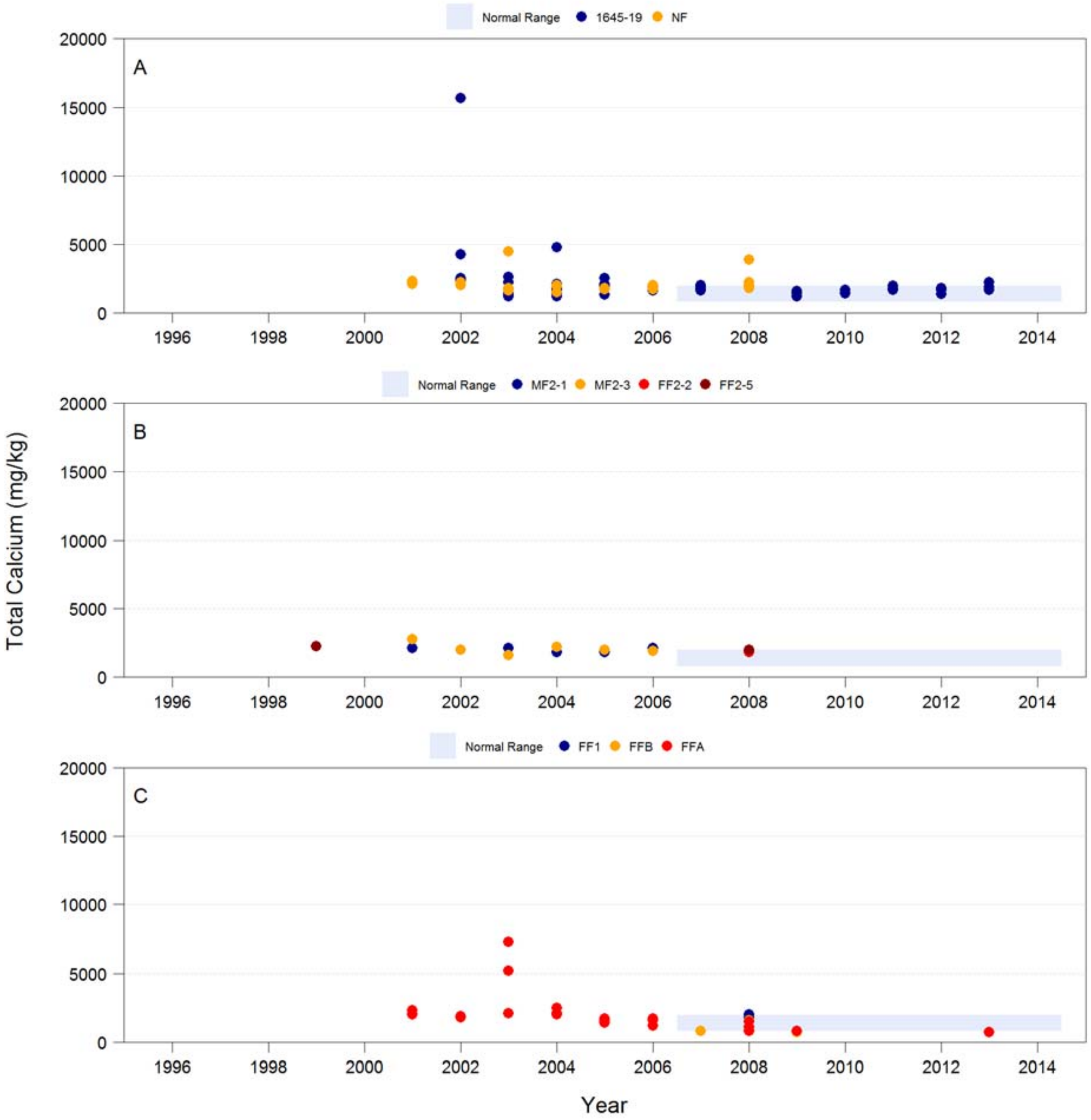


Figure 7-9 **Concentration of Chromium at A) the Mixing Zone (SNP-19) and Near-field (NF) Sampling Areas; B) Sampling Stations along the MF2-FF2 Transect; and C) at the Three Far-field (FF) Reference Areas**

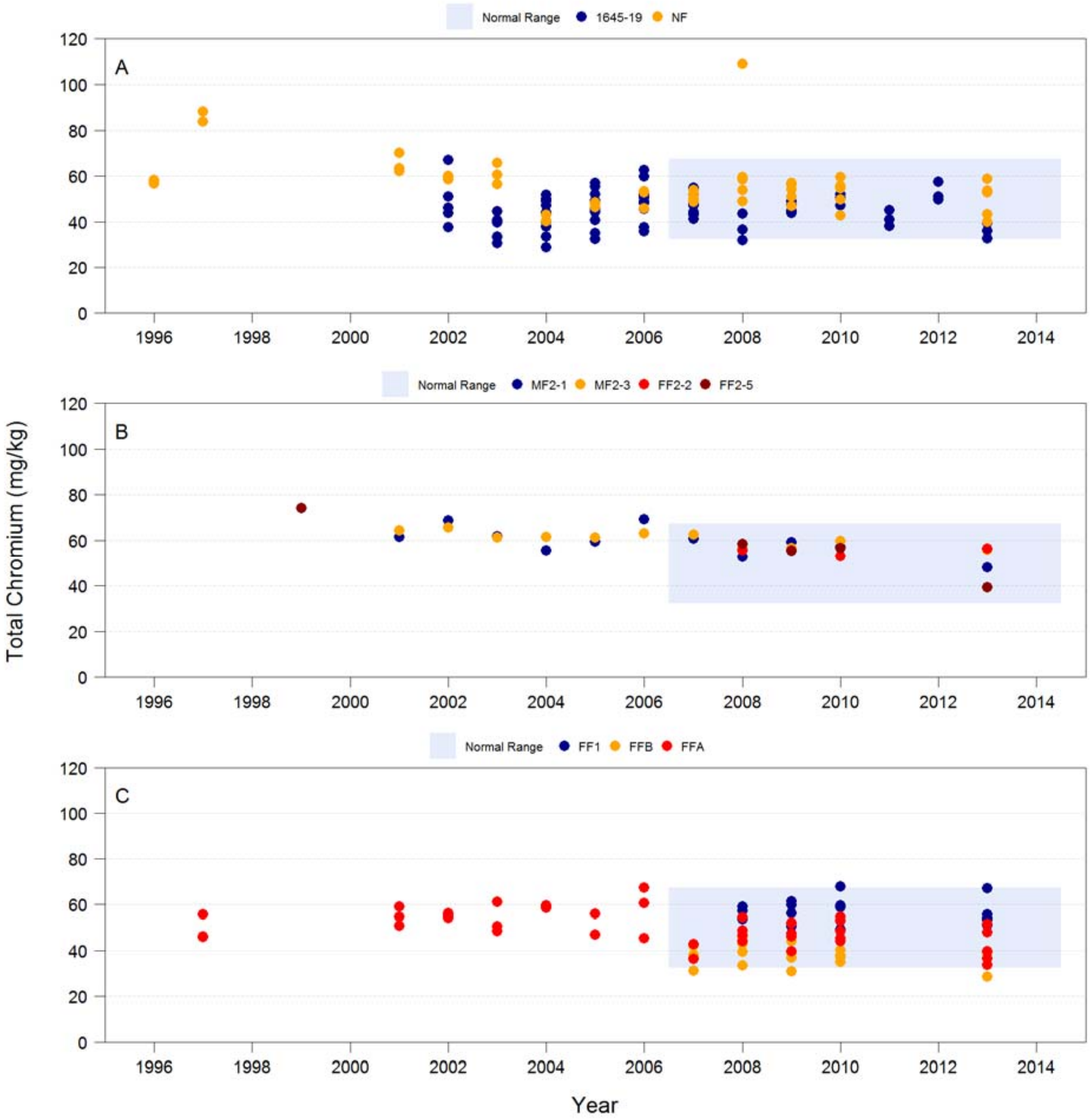


Figure 7-10 **Concentration of Lead at A) the Mixing Zone (SNP-19) and Near-field (NF) Sampling Areas; B) Sampling Stations along the MF2-FF2 Transect; and C) at the Three Far-field (FF) Reference Areas**

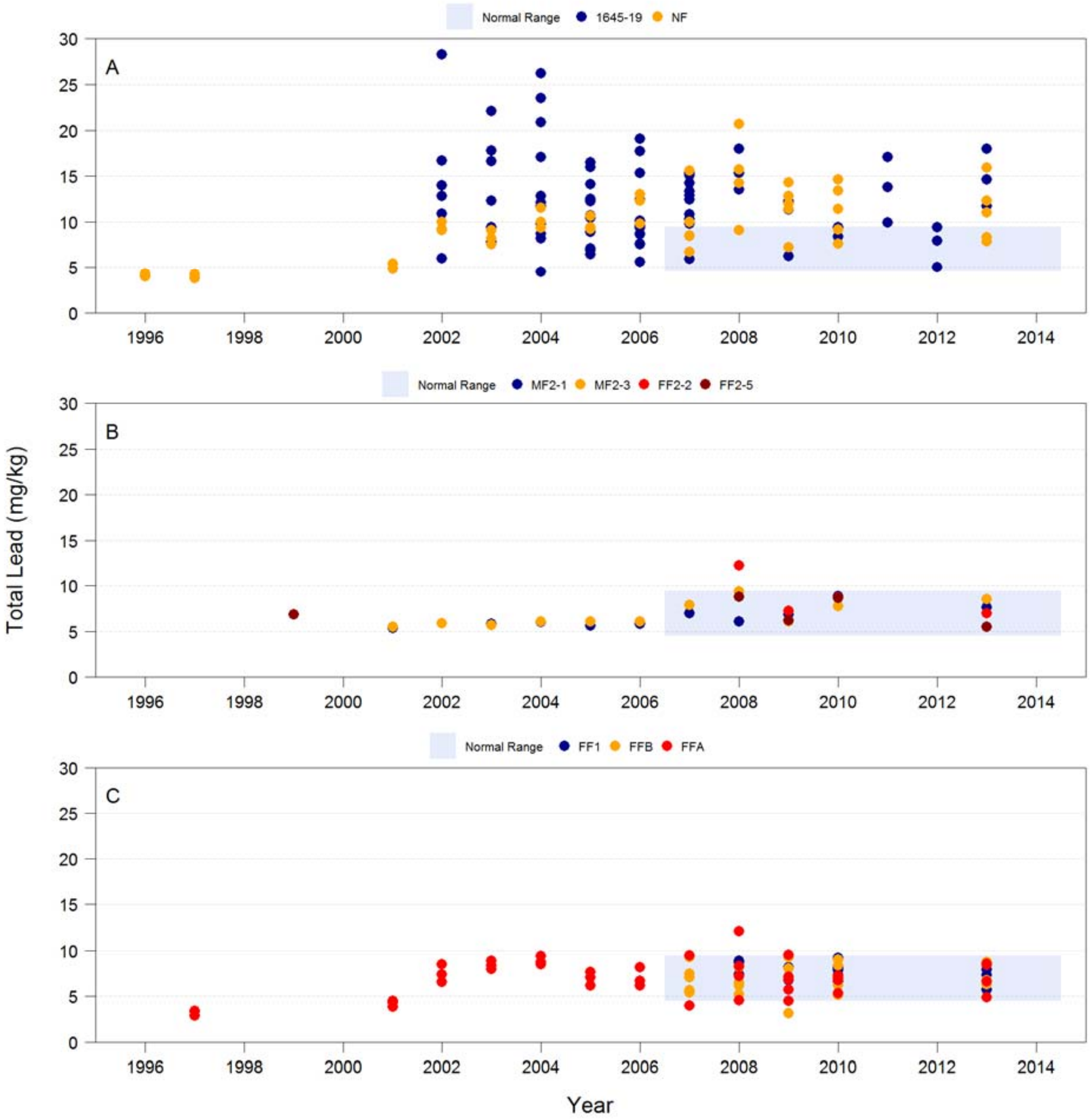


Figure 7-11 Concentration of Lithium at A) the Mixing Zone (SNP-19) and Near-field (NF) Sampling Areas; B) Sampling Stations along the MF2-FF2 Transect; and C) at the Three Far-field (FF) Reference Areas

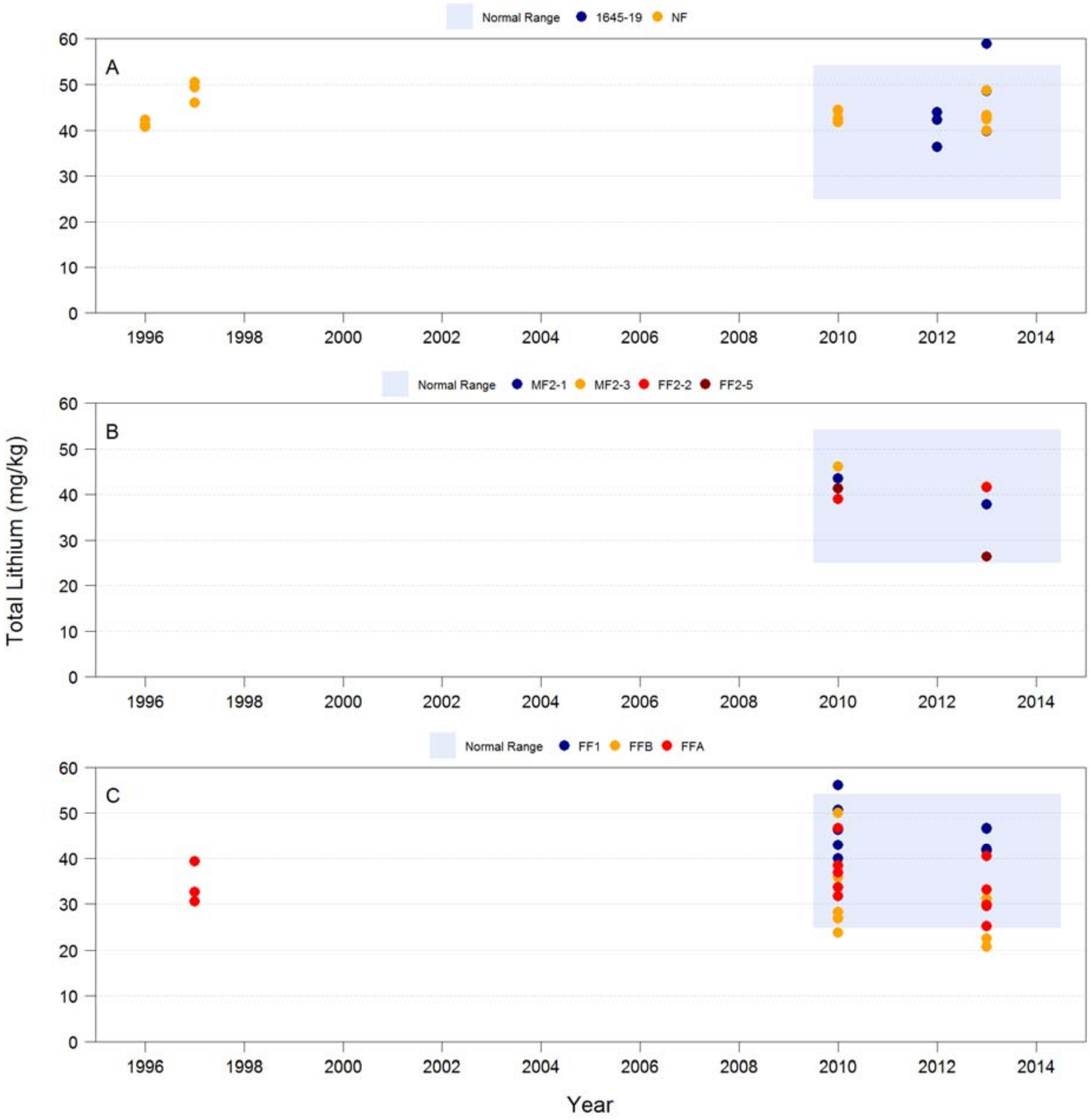


Figure 7-12 **Concentration of Magnesium at A) the Mixing Zone (SNP-19) and Near-field (NF) Sampling Areas; B) Sampling Stations along the MF2-FF2 Transect; and C) at the Three Far-field (FF) Reference Areas**

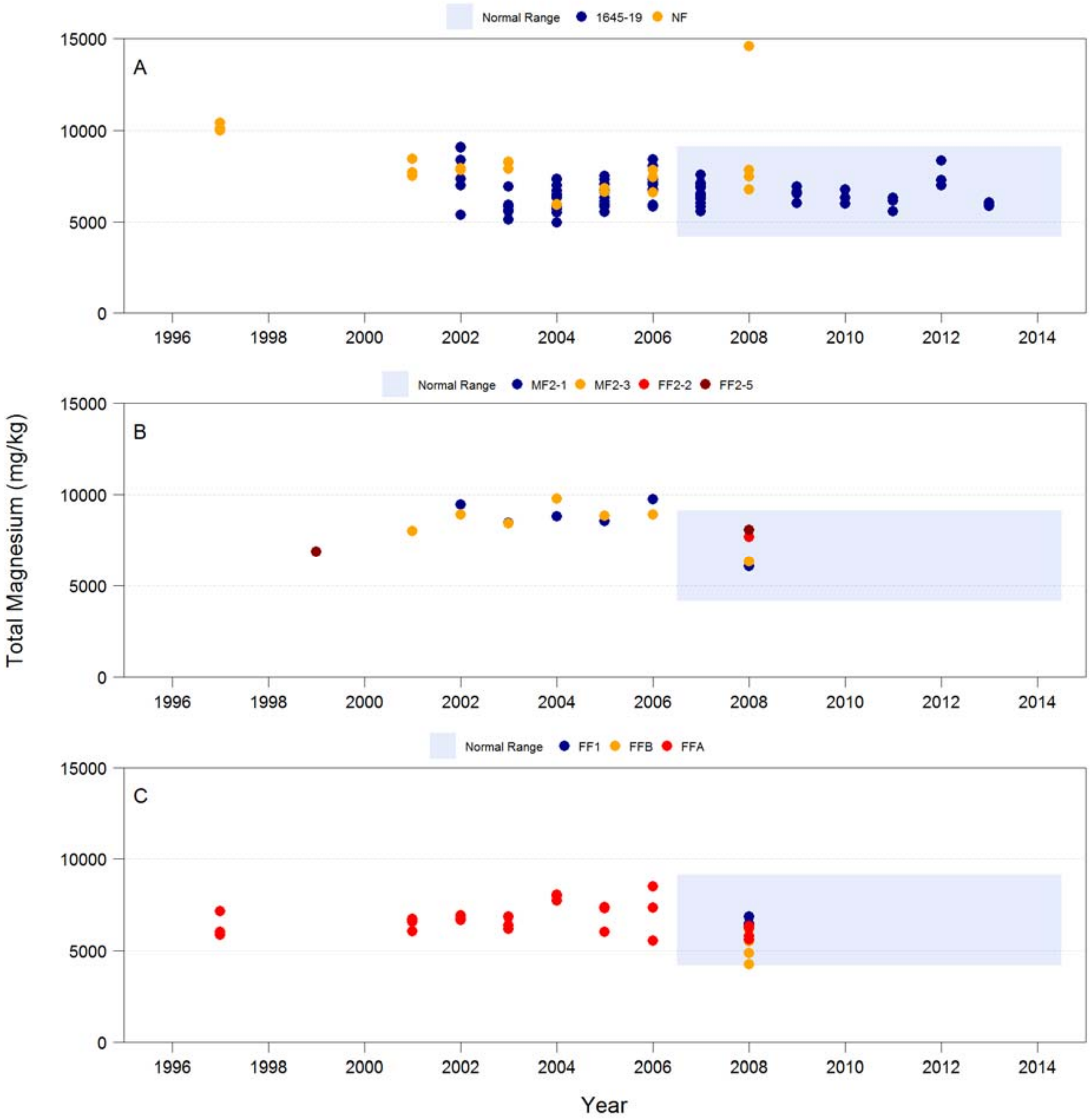


Figure 7-13 **Concentration of Potassium at A) the Mixing Zone (SNP-19) and Near-field (NF) Sampling Areas; B) Sampling Stations along the MF2-FF2 Transect; and C) at the Three Far-field (FF) Reference Areas**

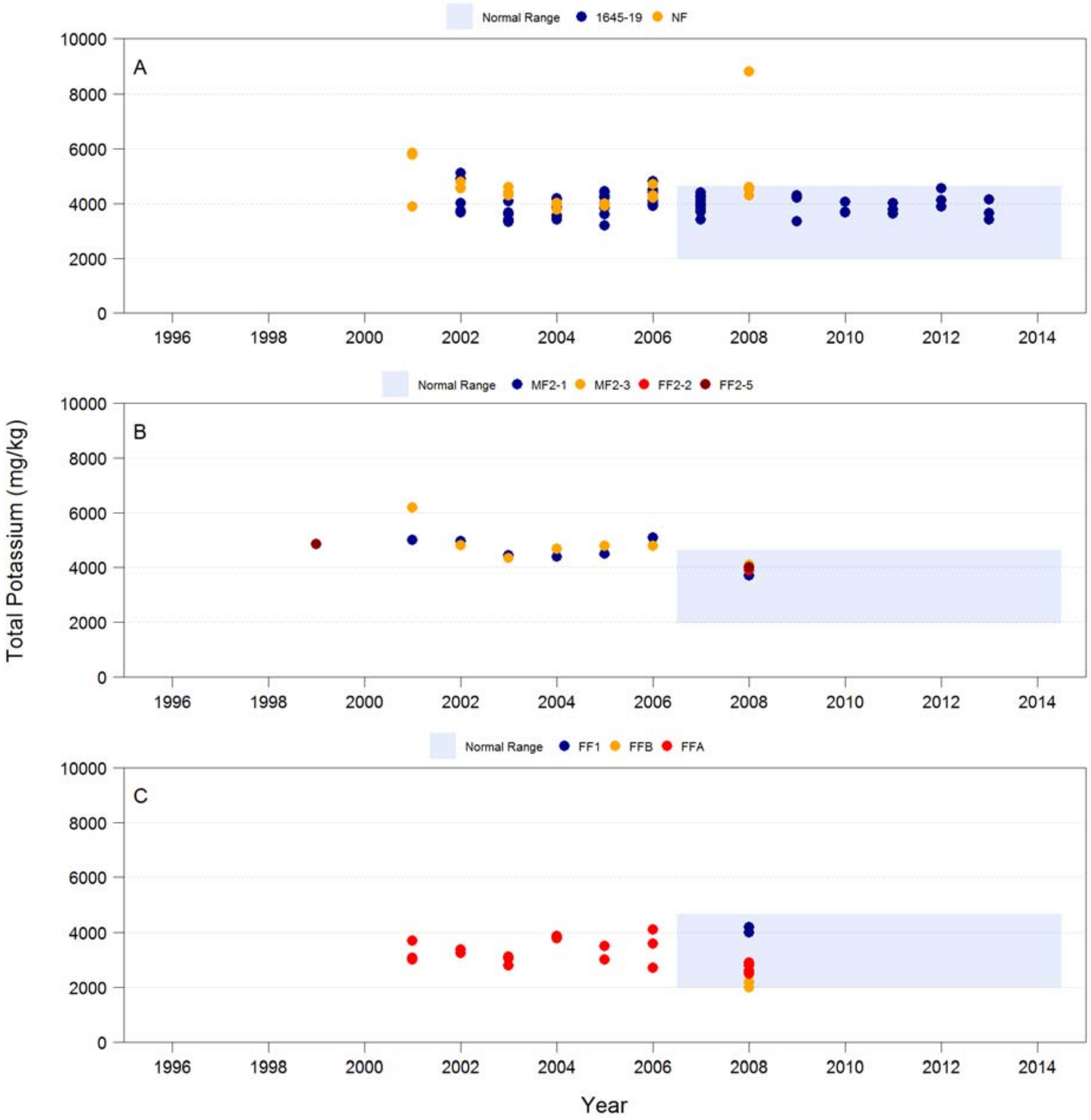


Figure 7-14 Concentration of Sodium at A) the Mixing Zone (SNP-19) and Near-field (NF) Sampling Areas; B) Sampling Stations along the MF2-FF2 Transect; and C) at the Three Far-field (FF) Reference Areas

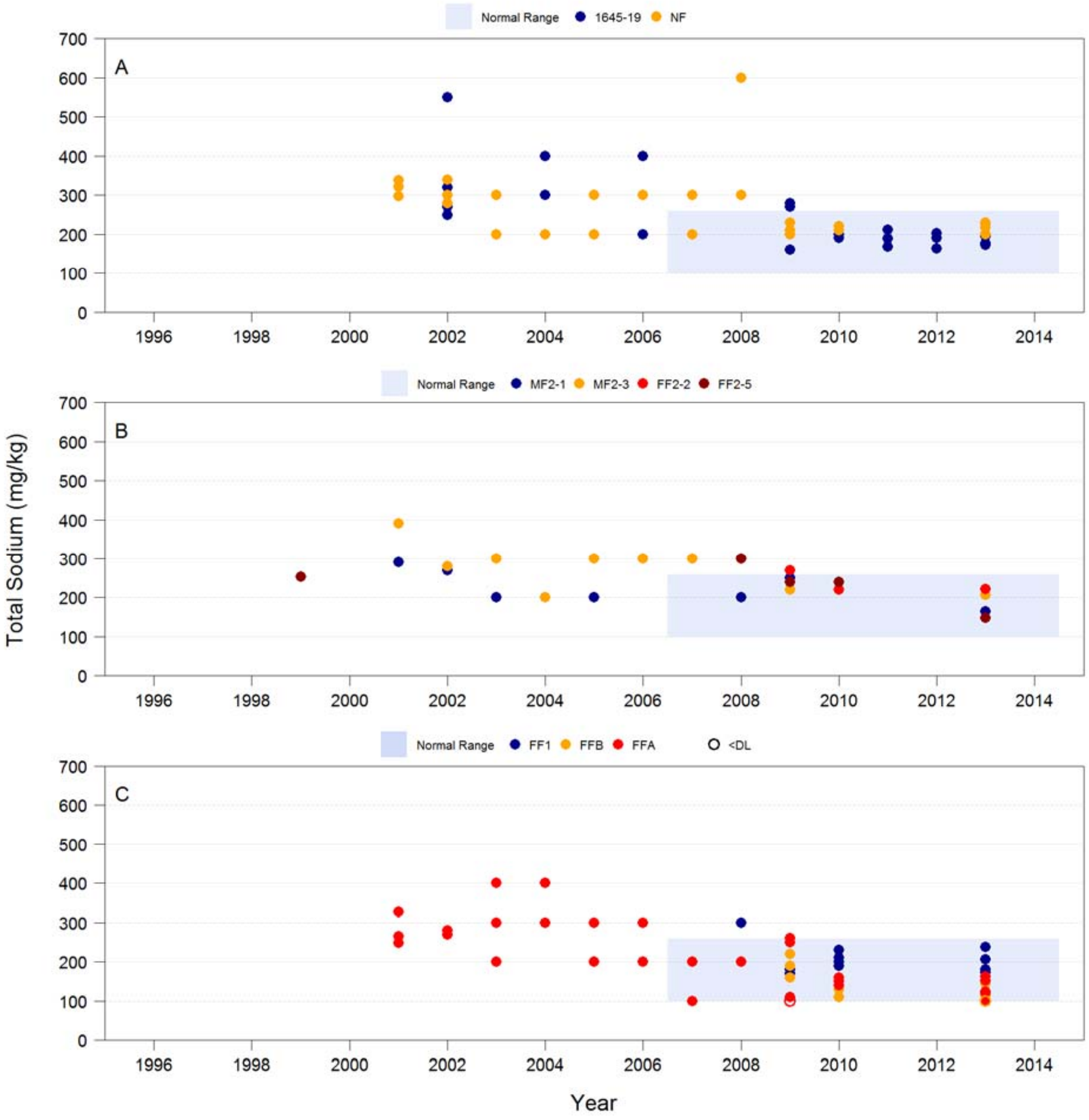


Figure 7-15 Concentration of Tin at A) the Mixing Zone (SNP-19) and Near-field (NF) Sampling Areas; B) Sampling Stations along the MF2-FF2 Transect; and C) at the Three Far-field (FF) Reference Areas

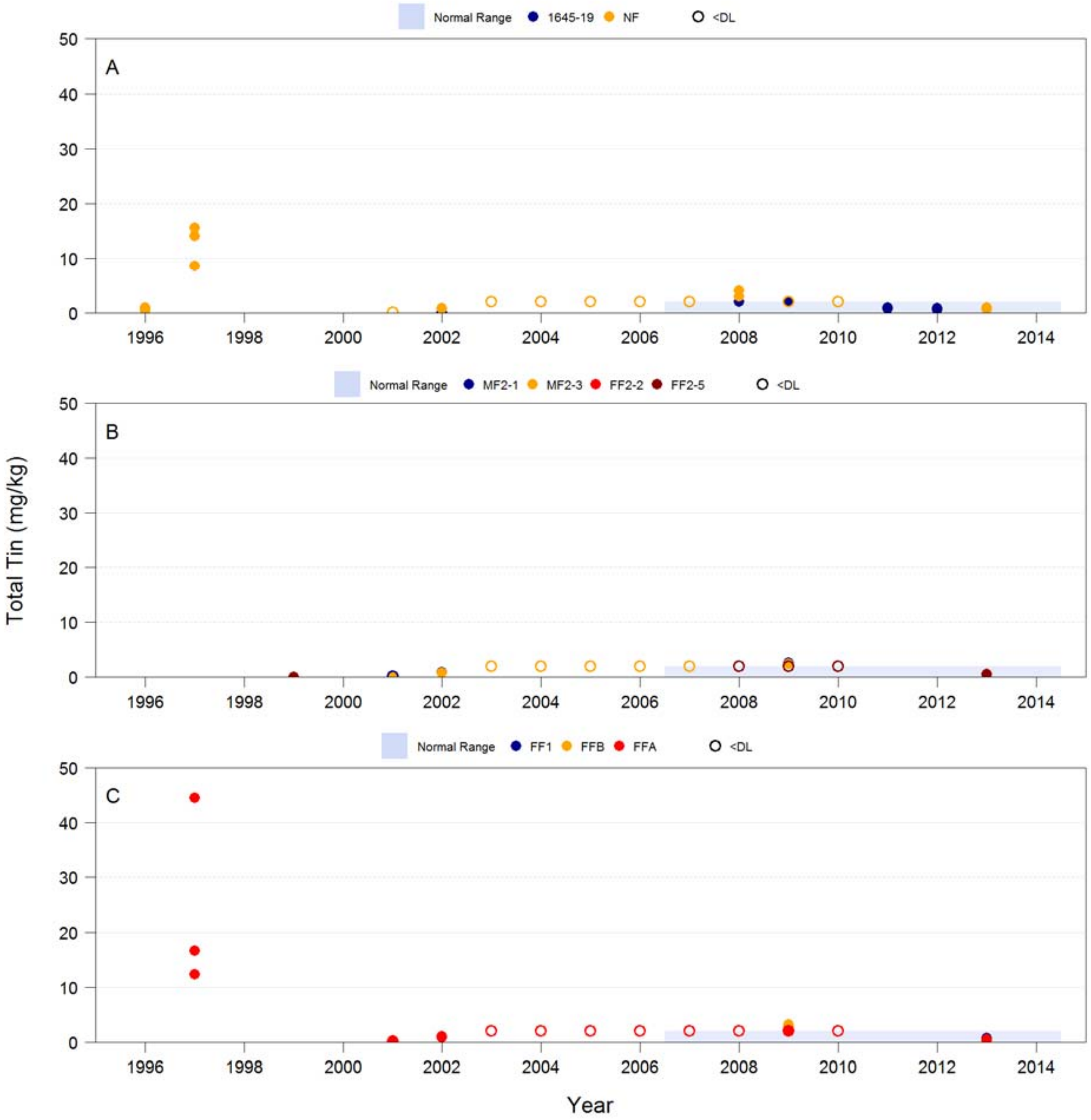


Figure 7-16 Concentration of Titanium at A) the Mixing Zone (SNP-19) and Near-field (NF) Sampling Areas; B) Sampling Stations along the MF2-FF2 Transect; and C) at the Three Far-field (FF) Reference Areas

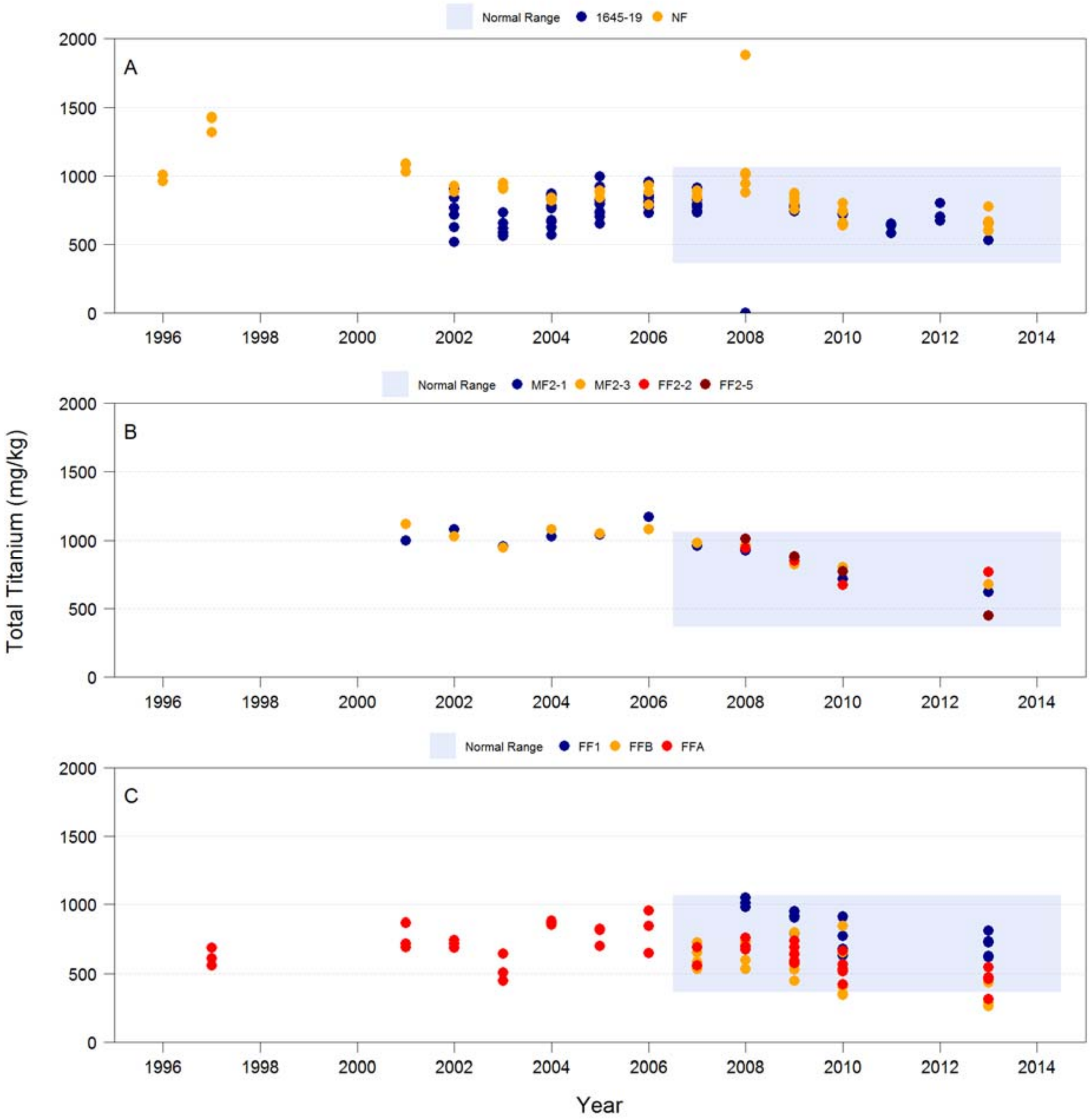
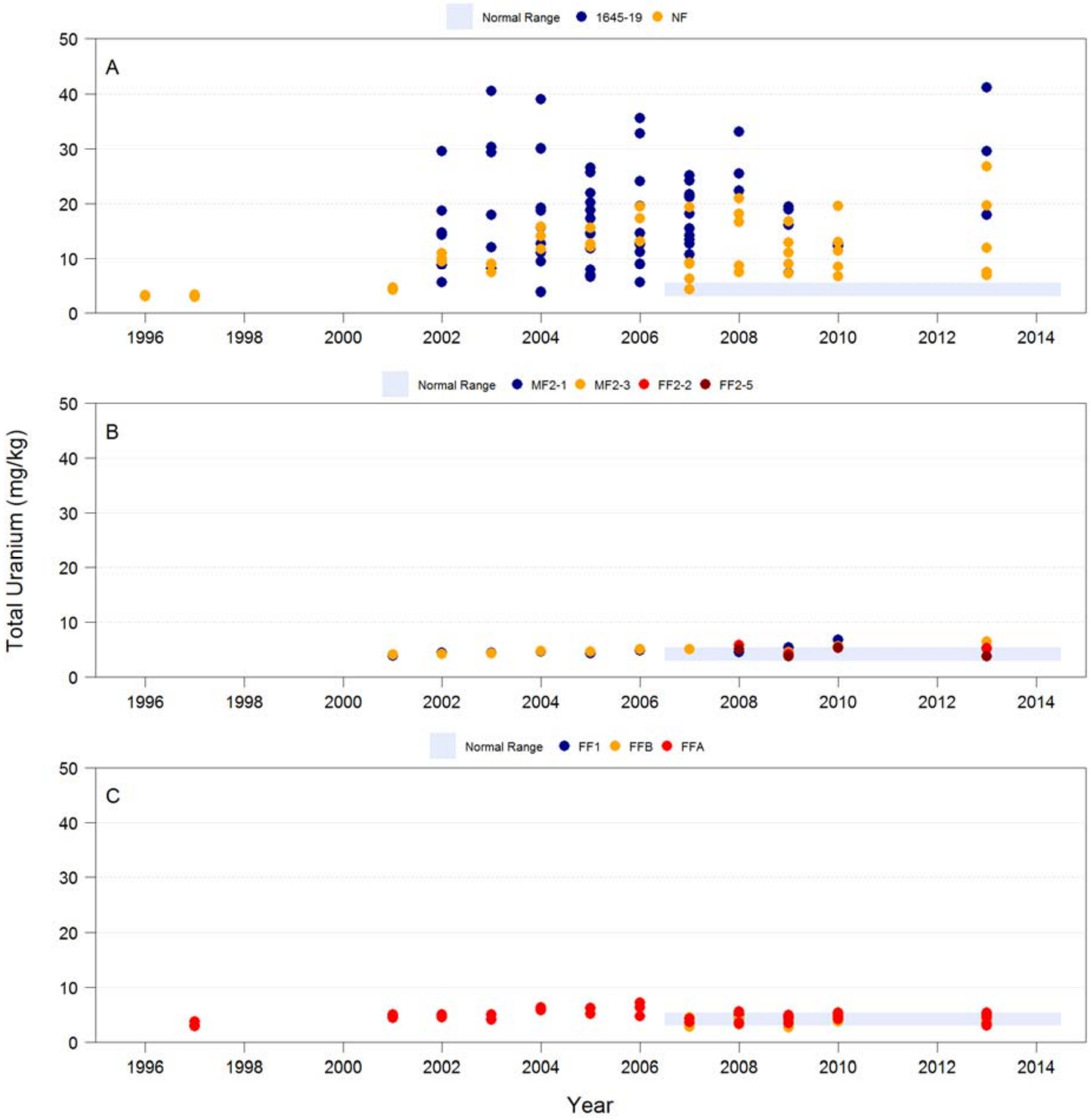


Figure 7-17 **Concentration of Uranium at A) the Mixing Zone (SNP-19) and Near-field (NF) Sampling Areas; B) Sampling Stations along the MF2-FF2 Transect; and C) at the Three Far-field (FF) Reference Areas**



7.3.3 Correlations with Physical Variables

Correlation analysis between sediment variables and percent fines indicated significant positive relationships for eight SOIs, although the strength of the correlations was variable (Table 7-5). The SOIs that were not correlated with percent fines were associated with pronounced Mine-related spatial and temporal trends in Lac de Gras (i.e., bismuth, lead and uranium), or were evaluated based on a reduced sample size (tin and lithium). The absence of a correlation between percent fines and the concentrations of bismuth, lead, and uranium suggests that the Mine effluent or the dikes better explain their concentration distributions within Lac de Gras.

Given that the percentage of fines was significantly correlated with the concentrations of several SOIs in Lac de Gras, it was possible that temporal trends for these variables were reduced or masked due to the influence of particle size on their concentrations. Time series plots for fine sediment, however, demonstrated that particle size distributions were generally similar among years. These results indicated that although particle size was influential on the sediment chemistry, substrate composition was not an influential factor in the assessment of temporal trends.

Spearman rank correlations between sediment chemistry variables and TOC indicated significant negative relationships for three of the 13 SOIs (Table 7-5). A significant positive correlation was also detected between TOC and TN. The direction of the relationship between TOC and the three SOIs was opposite of what would be expected for metals that tend to bind to organic matter in sediments. The significant negative correlations for these variables resulted from the combined influence of greater concentrations of these metals in the exposure area and generally lower concentrations of TOC in the exposure areas (Figure 7-2 and Appendix 7B, Figure 7B-2).

Table 7-5 Results of Spearman Rank Correlations between Sediment Quality Variables and Percent Fine Sediment and Total Organic Carbon

Variable	Fine Sediment (%)		Total Organic Carbon (%)	
	n	r_s	*n*	r_s
Substances of Interest				
Aluminum	99	**0.386******	113	0.069
Bismuth	72	-0.024	81	**-0.385*****
Boron	83	**0.36*****	96	-0.044
Calcium	44	**0.529*****	55	0.137
Chromium	99	**0.465******	114	-0.112
Lead	99	-0.076	114	0.136
Lithium(a)	35	0.147	38	-0.225
Magnesium	42	**0.608******	53	-0.091
Potassium	39	**0.372***	50	-0.195
Sodium	96	**0.403******	107	**-0.179***
Tin(b)	35	0.17	49	0.065
Titanium	95	**0.571******	110	**-0.316*****
Uranium	95	0.059	110	-0.007
Nutrients				
Total Nitrogen	85	-0.076	85	**0.668******
Total Phosphorus	98	0.184	107	0.143

Notes: Probability of type one error: * = <0.05, ** = <0.01, *** <0.001, ****<0.0001.

Bolded values indicate significant correlations between sediment chemistry variables and percent fines or TOC. Percent fine substrate is calculated as the sum of percent clay and silt in a sediment sample.

a) Correlations for lithium were based on a reduced sample size because lithium was not analyzed prior to 2010.

b) Correlations for tin were based on a reduced sample size because approximately half the dataset for tin consisted of non-detect values which were removed from the analysis.

n = number of samples; r_s = Spearman rank correlation coefficient.

7.3.4 Comparison to EA Predictions

No predictions were made in the EA regarding sediment quality.

7.4 Conclusions

- Fifteen variables (aluminum, bismuth, boron, calcium, chromium, lead, lithium, magnesium, potassium, sodium, strontium, tin, titanium, uranium and vanadium) satisfied the requirement for a low WOE effects ranking from 2007 to 2013. Concentrations of these variables in the NF area were significantly greater than in reference areas during at least one year of monitoring. A moderate ranking was not applied to any of the variables because concentrations were below SQGs. The number of sediment variables that reached a low effect ranking varied among years but has not increased over time.
- The temporal assessment for sediment quality focused on the 13 SOIs identified in the 2013 AEMP annual report and on two nutrients (nitrogen and phosphorus). There were no temporal trends in the concentrations of most SOIs and both nutrients. Concentrations of 10 of these SOIs and both nutrients were within the normal range at most stations and in most years.
- The concentrations of three variables (bismuth, lead, and uranium) increased in the NF exposure area from 2001 (bismuth) or 2002 until 2006 or 2008 (lead), and have remained at similar levels since then. Concentrations of these three variables at the mixing zone boundary have been elevated in most years since monitoring began in 2002.
- Concentrations of bismuth exceeded the normal range at most exposure area sampling stations from 2002 to 2013, while the concentration of lead and uranium exceeded the normal range primarily in the NF area.
- Results of the dike monitoring studies indicate that, in addition to Mine effluent, other factors such as dike construction and possible leaching from the dikes may have contributed to the increases in concentrations of bismuth, lead and uranium.
- Confounding variables (TOC and percent fine sediment) explained some of the variability in the concentrations of metals and nutrients that had no clear temporal patterns; however, these confounding variables did not interfere with the interpretation of Mine-related effects.

8 PLANKTON

8.1 INTRODUCTION

The term “plankton” refers to small, usually microscopic organisms that live suspended in lakes and ponds. For the purpose of this study, the term “phytoplankton” refers to the algal component of plankton and includes the following five major ecological groupings:

- cyanobacteria;
- chlorophytes (Chlorophyceae, Prasinophyceae, Euglenophyceae, Trebouxiophyceae, Pedinophyceae, Nephroselmidophyceae, Conjugatophyceae, and Klebsormidiophyceae);
- microflagellates (Chrysophyceae, Cryptophyceae, Coccolithophyceae, Xanthophyceae, and Haptophyceae);
- dinoflagellates (Dinophyceae); and
- diatoms (Bacillariophyceae).

The term “zooplankton” refers to small animals, ranging from microscopic to visible with the naked eye, and includes crustaceans (i.e., Cladocera [cladocerans], Cyclopoida [cyclopoids], Calanoida [calanoids]) and Rotifera (rotifers).

Baseline plankton sampling in Lac de Gras began in 1995 (Acres and Bryant 1996) and continued in 1997 (Golder 1998). The discharge of effluent into Lac de Gras began in 2002, and plankton community sampling also began in 2002 as part of a special effects study (SES) of the AEMP version 1.0. The plankton SES continued over the course of the AEMP Version 2.0 (DDMI 2007a). The main objective of the SES was to determine the feasibility and utility of using plankton community composition and biomass as sensitive indicators of biological effects of the Mine. A secondary objective was to determine if a single open-water sampling event could be used to collect data that are adequate to describe community metrics and detect effects.

A review of the four years of data collected during the AEMP Version 2.0 demonstrated that plankton could indeed be a useful and sensitive monitoring component (Golder 2011a). It also indicated that, based on the seasonal variation observed during the SES, any open-water period would be equally appropriate for plankton monitoring. Accordingly, plankton was added as a regular component of the AEMP in 2011 under the AEMP Version 3.0 (Golder 2011b). Under the present AEMP Version 3.5, plankton monitoring occurs during a single open-water monitoring season (from August 15th and September 15th) in concert with the other AEMP components (Golder 2014a). In addition, the sampling frequency for plankton at the reference areas (FF1, FFA and FFB) is every three years, to be consistent with the other AEMP components. To account for the multiple samples collected during the AEMP Versions 1.0 (2002 to 2006) and 2.0 (2007 to 2010), only data for samples collected from August 15th to September 15th were included in the analysis for this report. All appropriate baseline data were presented, regardless of season to provide an estimate of the baseline conditions.

This report presents an analysis of phytoplankton and zooplankton data collected during baseline conditions, and during the AEMP Study Design Versions 1.0 through 3.5 (2002 to 2013). It addresses the main objective of this re-evaluation report by assessing temporal Mine-related changes in the plankton community of Lac de Gras.

8.2 METHODS

8.2.1 Sampling Area

Plankton sampling areas were selected to be consistent with other AEMP components, and are based on exposure to the Mine effluent (Golder 2011b). Sampling areas consisted of the near-field (NF) exposure area and three far-field reference areas (FF1, FFA, and FFB). In addition, three transect lines (referred to as mid-field [MF] areas) between the NF and FF areas were sampled. The MF1-FF1 transect was sampled towards the FF1 reference area, northwest of the exposure area. The MF2-FF2 transect was sampled to the northeast, towards the FF2 area near the Lac du Sauvage inlet. The MF3-FFB-FFA transect was sampled south of the exposure area towards FFB and FFA reference areas. Within each sampling area, clusters of replicate stations were sampled. Five stations were sampled in the NF exposure area and in each of the three FF reference areas. The number of stations along the mid-field transects was changed from AEMP Version 2.0 to Version 3.0. To better delineate the extent of effects and define gradients along each transect, the number of stations along the MF3 transect was increased, and the number of stations along the MF1 and MF2 transects was decreased.

8.2.2 Data Sources

8.2.2.1 Phytoplankton

8.2.2.1.1 Baseline and AEMP Version 1.0 Data (1995 to 2006)

Baseline phytoplankton community data were collected in 1995 (Acres and Bryant 1996) and 1997 (Golder 1998). Phytoplankton samples were collected from the top 10 metres (m) of the water column. Abundance estimates were provided in 1995 and 1997; however, biomass estimates were only provided in 1997. Taxonomy was performed at a high taxonomic level, the results of which are not directly comparable to the more recently collected data. Therefore, baseline data summarized in this report are limited to biomass estimates for 1997.

The phytoplankton community data from the AEMP Version 1.0 (2002 to 2006) and from the first year of the AEMP Version 2.0 (2007) were previously compiled in the 2008 Plankton SES Report (DDMI 2008). The historical data were obtained from three sources:

- archived phytoplankton samples from 2003 to 2006 AEMP surveys, which were analyzed in 2008 (150 samples);
- phytoplankton samples collected and analyzed as part of the 2002 AEMP program (15 samples); and,
- phytoplankton samples collected and analyzed as part of the 2007 AEMP program (45 samples).

Sampling locations from baseline and from 2003 to 2006 were paired with current AEMP sampling areas (Tables 8-1 and 8-2). The 2002 to 2006 samples were collected from the top 10 m of the water column. If the water depth was less than 10 m, 80% of the water column was sampled. Taxonomic analyses of the 2002 to 2006 samples were completed by Bio-Limno Research and Consulting, Inc. (Bio-Limno), Halifax, Nova Scotia.

8.2.2.1.2 AEMP Version 2.0 Data (2007 to 2011)

Plankton communities were examined over the course of the AEMP Version 2.0 as part of a Plankton SES. Sampling for the AEMP Version 2.0 Plankton SES was to continue to follow the same procedures as outlined in the AEMP Version 1.0; however, during revisions to the DDMI specific operating procedures (SOP) for the summer sampling program (SOPENV-AQU-08), the phytoplankton sampling procedure was inadvertently changed to use the Secchi depth to determine the sampling depth (DDMI 2007b). Since the 2007 AEMP plankton program used Secchi depth to surface instead of the top 10 m of the water column, sampling depths were approximately 2 m shallower than those between 2003 and 2006. From 2008 to 2010, the methods reverted back to the original sampling protocol of sampling the top 10 m of water column.

Secchi depths in 2007 were approximately 8 m, and phytoplankton are found within the euphotic zone (estimated as two times the Secchi depth); therefore, it is likely that the 2007 samples were comparable to the 2008 to 2010 samples. A comparison of samples collected from the two different depths found that there was no significant difference for the chlorophyll *a* values from the two depths (Golder 2011b); consequently, the 2007 phytoplankton data were included in the evaluation of temporal trends.

Similar to previous years, taxonomic analyses of the 2007 to 2011 samples were completed by Bio-Limno, Halifax, Nova Scotia.

Table 8-1 Phytoplankton Samples Collected from August 15 to September 15 in the Near-field (NF) and Mid-field (MF) Areas of Lac de Gras from 2003 to 2013

Area[(a)]	AEMP Station	Archived Station	Year	*n*
NF	NF	LDG42	2003	5
	NF	LDG42	2004	2
	NF	LDG42	2006	5
	NF-1 to NF-5	-	2007	5
	NF-1 to NF-5	-	2008	5
	NF-1 to NF-5	-	2009	5
	NF-1 to NF-5	-	2010	5
	NF-1 to NF-5	-	2011	5
	NF-1 to NF-5	-	2012	5
	NF-1 to NF-5	-	2013	5
MF1	MF1-1, MF1-3	-	2007	4
	MF1-1, MF1-3	-	2008	2
	MF1-1, MF1-3	-	2009	2
	MF1-1, MF1-3	-	2010	2
	MF1-1, MF1-3		2011	2
	MF1-1, MF1-3, MF1-5	-	2012	3
	MF1-1, MF1-3, MF1-5	-	2013	3
MF2	MF2-1, MF2-3	-	2007	3
	MF2-1, MF2-3	-	2008	2
	MF2-1, MF2-3	-	2009	4
	MF2-1, MF2-3	-	2011	2
	MF2-1, MF2-3	-	2012	2
	MF2-1, MF2-3	-	2013	2
MF3	MF3-1	LDG43	2005	5
			2006	5
	MF3-2	LDG41	2004	2
			2005	5
			2006	1
	MF3-6	LDG 44	2003	5
			2005	2
	MF3-1, MF3-2, MF3-4, MF3-6	-	2007	4
	MF3-1, MF3-2	-	2008	2
	MF3-1, MF3-2, MF3-4, MF3-6	-	2009	6
	MF3-1, MF3-2, MF3-4, MF3-6	-	2010	4
	MF3-1, MF3-2, MF3-4, MF3-6	-	2011	4
	MF3-1 to MF3-7	-	2012	7
	MF3-1 to MF3-7	-	2013	7

a) Areas are defined according to the 2007 AEMP Study Design Version 2.0 (DDMI 2007a).
n = number of samples collected; NF = near-field; MF = mid-field; identifier (e.g., 1, A) denotes specific area.

Table 8-2 Phytoplankton Samples Collected from August 15 to September 15 in the far-field (FF) Areas of Lac de Gras from 2003 to 2013

Area[(a)]	AEMP Station	Archived Station	Year	*n*[(b)]
FF1	FF1	-	2007	1
	FF1-1 to FF1-3	-	2008	3
	FF1-1 to FF1-5	-	2009	5
	FF1-1 to FF1-5	-	2010	5
	FF1-1 to FF1-5	-	2011	10
	FF1-1 to FF1-5	-	2012	5
	FF1-1 to FF1-5	-	2013	5
FF2	FF2-1 to FF2-5	LDG45	2004	1
	FF2-1 to FF2-5	LDG45	2005	3
	FF2-1 to FF2-5	LDG45	2006	5
	FF2-2; FF2-5	-	2007	2
	FF2-2; FF2-5	-	2009	4
	FF2-2; FF2-5	-	2010	2
	FF2-2; FF2-5	-	2011	4
	FF2-2; FF2-5	-	2012	2
	FF2-2; FF2-5	-	2013	2
FFA	FFA-1 to FFA-5	LDG46	2003	5
	FFA-1 to FFA-5	LDG46	2004	5
	FFA-1 to FFA-5	LDG46	2006	5
	FFA-1 to FFA-5	-	2008	7
	FFA-1 to FFA-5	-	2009	10
	FFA-1 to FFA-5	-	2010	10
	FFA-1 to FFA-5	-	2011	10
	FFA-1 to FFA-5	-	2012	5
	FFA-1 to FFA-5	-	2013	5
FFB	FFB-1 to FFB-5	LDG50	2003	5
	FFB-1 to FFB-5	LDG50	2004	2
	FFB-1 to FFB-5	LDG50	2005	5
	FFB-1 to FFB-5	LDG50	2006	5
	FFB-1 to FFB-5	-	2007	5
	FFB-1 to FFB-5	-	2008	9
	FFB-1 to FFB-5	-	2009	5
	FFB-1 to FFB-5	-	2010	5
	FFB-1 to FFB-5	-	2011	5
	FFB-1 to FFB-5	-	2012	5
	FFB-1 to FFB-5	-	2013	5

a) Areas are defined according to the 2007 AEMP Study Design Version 2.0 (DDMI 2007a).

b) The number of samples (n) exceeds the number of stations because of multiple sampling periods occurring within the August 15 to September 15 period.

n = number of samples collected; FF = far-field; identifier (e.g., 1, A) denotes specific area.

8.2.2.1.3 AEMP Version 3.0 to 3.5 Data (2012 to 2013)

The phytoplankton community was sampled in 2012 and 2013 as part of an AEMP monitoring component under the AEMP Study Design Versions 3.0 (Golder 2011b). Sampling methods were consistent with the AEMP Study Design Version 2.0, except that a single sampling period was identified from August 15 to September 15, rather than three open-water sampling periods. In 2011 and 2012, taxonomic analyses were performed by Bio-Limno, Halifax, Nova Scotia. However, in 2012 a number of issues with data quality were observed; therefore, in 2013, the samples were sent to a new taxonomist, Eco-Logic Ltd., Vancouver, British Columbia. Differences between taxonomists exist and are unavoidable; therefore, an examination of temporal trends must be interpreted with the different taxonomic analyses in mind.

In addition to a change in taxonomists, a change in the level of taxonomic detail needed for assessing effects was investigated. It was determined that species-level data may be prone to errors, while genus-level taxonomic identification can provide the necessary data needed for monitoring programs. All species-level data from previous years were adjusted to the genus-level, and taxonomic richness calculations were performed at the genus-level, for comparison to the 2013 data (Golder 2014e).

8.2.2.2 Zooplankton

8.2.2.2.1 Baseline and AEMP Version 1.0 Data (1995 to 2006)

Baseline data for the zooplankton community was collected during the open-water seasons of 1995 (Acres and Bryant 1996) and 1997 (Golder 1998). The 1995 and 1997 baseline surveys collected zooplankton samples from 5-m and 10-m depths to the surface, respectively. The current sampling procedure consists of starting from 1 m above the sediment and extending up through the entire water column, which is not comparable to the 1995 and 1997 data; therefore, the 1995 and 1997 data were not included in this report. Archived zooplankton samples from 2000 to 2007 were not submitted for analysis due to laboratory sub-sampling errors discovered in 2008 (DDMI 2008).

8.2.2.2.2 AEMP Version 2.0 Data (2007 to 2011)

The 2007 data were excluded from the data analysis due to sub-sampling errors, which prevented accurate calculation of zooplankton biomass. From 2008 to 2011, zooplankton samples were collected starting from 1 m above the sediment, extending up through the water column (Table 8-3). A number of samples from the 2008 AEMP program were mistakenly collected from a 10-m depth, rather than from the bottom of the water column. Samples collected from 2008 to 2011 were analyzed by Salki Consultants Inc., Winnipeg, Manitoba.

Table 8-3 **Number of Zooplankton Samples Collected in Each Area or at Each Station from August 15 to September 15 in Lac de Gras, 2008 to 2013**

Year	NF	MF1	MF2	MF3	FF2	FF1[(a)]	FFA[(a)]	FFB[(a)]
2008	2	1	1	-	-	-	6	5
2009	5	2	4	6	4	5	12	10
2010	5	2	-	4	2	5	10	1
2011	5	2	2	4	4	9	10	5
2012	5	3	2	7	2	5	5	5
2013	5	3	2	7	2	5	5	5

Notes: Values are the number of samples collected; NF = near-field; MF = mid-field; FF = far-field; identifier (e.g., 1, A) denotes specific area.

a) The number of samples exceeds the number of stations because of multiple sampling periods occurring within the August 15 to September 15 period.

8.2.2.2.3 AEMP Version 3.0 to 3.5 Data (2012 to 2013)

The zooplankton community was sampled in 2012 and 2013 as part of an AEMP monitoring component under the AEMP Study Design Versions 3.0 (Golder 2011b). Sampling methods were consistent with those from the AEMP Version 2.0, except that there was only a single sampling period (from August 15th to September 15th), rather than three open-water sampling periods in AEMP Version 2.0. Each sample consisted of a composite of three vertical hauls of the entire water column (taken from a depth of 1 m above the sediment). Samples were analyzed by Salki Consultants Inc., Winnipeg, Manitoba.

8.2.3 Data Analysis

8.2.3.1 Data Preparation and Variable Selection

Plankton data were prepared for the trend evaluation by averaging subsamples within stations on a yearly basis. Consistency in taxonomic level of identification was evaluated among years, and adjustments were made where appropriate. For example, certain taxa at some stations were re-classified to a higher level to match the taxonomic resolution of the remainder of the data. Historical data (1996 and 1997; 2001 to 2006) were excluded from density and relative density analysis due to different taxonomic resolutions between those periods and the more recent years of monitoring.

Initial screening of the annual AEMP plankton community data sets were completed prior to conducting data analyses to identify unusually high (or low) values in the data sets, these values were flagged and are typically resolved through communication with the taxonomist. Decisions whether to retain or exclude these anomalous values from further analysis was determined through statistical analysis. An explanation of the objectives and approach taken to complete this initial screening is provided in Section 2.6. Results of the screening for anomalous values for the AEMP plankton community data set found no outliers in either the phytoplankton or zooplankton datasets and all data were included in the analyses.

The following plankton community variables were selected for the analysis of the phytoplankton and zooplankton data:

- total biomass;
- taxonomic richness (richness);
- biomass of major groups; and
- relative biomass of major groups.

8.2.3.2 Normal Ranges

Effects on plankton variables were evaluated by comparing each variable in the exposure areas to background values. Background values for Lac de Gras are those that fall within the range of natural variability, referred to as the normal range. The normal ranges used to evaluate potential effects on plankton communities were obtained from the AEMP Reference Conditions Report, Version 1.1 (Golder 2015) and are summarized in Tables 8-4 and 8-5.

Table 8-4 Normal Range Estimates for Phytoplankton

Endpoint	Unit	Normal Range	
		Lower Bound	Upper Bound
Total Phytoplankton Biomass	mg/m^3	140.0	351.6
Phytoplankton Taxonomic Richness	no. taxa	12	25
Diatom Biomass	mg/m^3	5.19	66.31
Microflagellate Biomass	mg/m^3	1.23	118.82
Cyanobacteria Biomass	mg/m^3	4.94	134.24
Dinoflagellate Biomass	mg/m^3	0	18.89
Chlorophyte Biomass	mg/m^3	26.26	174.51
Relative Diatom Biomass	%	2.3	25.3
Relative Microflagellate Biomass	%	0.5	49.3
Relative Cyanobacteria Biomass	%	3.4	47.6
Relative Dinoflagellate Biomass	%	0	5.1
Relative Chlorophyte Biomass	%	16.6	58.3

mg/m^3 = milligrams per cubic metre, wet weight; no. taxa = number of taxa.

Table 8-5 Normal Range Estimates for Zooplankton

Endpoint	Unit	Normal Range	
		Lower Bound	Upper Bound
Total Zooplankton Biomass	mg/m^3	131.5	539.8
Zooplankton Taxonomic Richness	no. taxa	11	17
Total Cladocera Biomass	mg/m^3	8.15	126.55
Total Calanoida Biomass	mg/m^3	60.85	359.06
Total Cyclopoida Biomass	mg/m^3	13.18	105.08
Total Rotifera Biomass	mg/m^3	1.58	7.31
Relative Cladocera Biomass	%	3.8	38.2
Relative Calanoida Biomass	%	39.8	72.2
Relative Cyclopoida Biomass	%	7.0	38.8
Relative Rotifera Biomass	%	0. 5	2.2

mg/m^3 = milligrams per cubic metre, wet weight; no. taxa = number of taxa.

8.2.3.3 Temporal Trends

To visually evaluate temporal trends, total phytoplankton and zooplankton biomass, taxonomic richness, total biomass and relative biomass of the major ecological groups were plotted against time (years). The time series plots included a shaded region showing the normal range obtained from the AEMP Reference Conditions Report Version 1.1 (Golder 2015). Although the main objective of the trend analysis was to assess trends in the exposure area, reference area plots were prepared to allow a visual evaluation of potential trends in areas unaffected by the Mine, and to verify that Mine-related effects are not occurring in these areas.

8.2.3.4 Statistical Analysis

Changes over time in the structure of the plankton community were explored using multivariate statistical analysis. Community structure was summarized by metric multidimensional scaling (mMDS), which is a non-parametric ordination method (Clarke 1993). Genus-level phytoplankton data and lowest level (genus or species) zooplankton data were log(x+1) transformed to improve the separation of the data among stations on the mMDS plots and to reduce weighting of the analysis by the most abundant taxa. Station groupings were based on the previous four-year summary (2007 to 2010). Area means were determined for each exposure area (NF, MF and FF2) and each reference area (FFA, FFB and FF1). A Bray-Curtis resemblance matrix was generated, and the mMDS procedure was applied to this matrix. Using rank order information, the mMDS data were scaled in Primer, version 7 for Windows (PRIMER-E Ltd., Plymouth, UK), and the relative positions of the area-year groupings were determined in two dimensions based on community composition. Goodness-of-fit was determined by examining the Shepard diagrams as well as the stress values, which were calculated from the deviations in the Shepard diagrams. Lower stress values (i.e., less than 0.10) indicate less deviation and a greater goodness-of-fit. Points that fall close together on the mMDS ordination plot represent samples with similar community composition, and points that are far apart from each other represent samples with dissimilar community composition.

A cluster analysis of the species similarity matrix was also used to define the species assemblages (i.e., groups of species that tend to co-occur in a parallel manner across the area-year groupings were clustered together). A similarity profile (SIMPROF) test was preformed to test the null hypothesis that within each clustering there is no genuine evidence of multivariate structure, which safeguards against over-interpretation of the data at finer-level clusters (Clarke et al. 2014). Clusters showing approximately 60% and 80% similarities were superimposed on the mMDS ordination plot to visually evaluate the similarity matrix in ordination space.

An analysis of similarities (ANOSIM) test, which is based on a non-parametric permutation procedure and is applied to the similarity matrix (rank) underlying the ordination or classification of the samples, was performed on the mMDS similarity matrix (Clarke et al. 2014). The ANOSIM test statistic (*R*) computes differences among the area-year groupings and contrasts these differences with the within area-year replicates. The significance level of the *R* statistic is based on the probability of a particular permutation occurring out of 1000 permutations (*P* = 0.001).

8.2.3.5 Weight of Evidence Effects Rankings

Phytoplantkon and zooplankton were assessed for Mine-related effects according to the WOE effects rankings described in Section 11 and summarized in Table 8-6. The WOE framework addresses two broad impact hypotheses for Lac de Gras, the toxicological impairment hypothesis and the nutrient enrichment hypothesis. The WOE effect rankings incorporate statistical comparisons of the exposure and reference areas, and comparisons of exposure areas to the reference area normal range.

Table 8-6 Weight of Evidence Effect Rankings for Plankton

Measurement Endpoint	Low	Moderate	High
Biomass Phytoplankton Biomass Zooplankton Biomass	Statistically significant change in the NF vs reference	**Low** rank **AND** NF area mean outside normal range	**Moderate** rank **AND** >20% of the lake area is impacted
Community Structure Phytoplankton Community Composition Zooplankton Community Composition	Divergent community structure at the species or genus level in the NF vs reference, **AND** Statistically significant change in taxonomic richness in the NF vs reference	A shift in community structure at the ecological grouping$^{(a)}$ level between the NF and reference areas	**Moderate** rank **AND** a statistically significant change in taxonomic richness >2 SD

a) ecological grouping: phytoplankton ecological groupings include cyanobacteria, chlorophytes, microflagellates, dinoflagellates, and diatoms; zooplankton groupings include cladocerans, cyclopoids, calanoids, and rotifers.
NF = near-field; >= greater than; SD = standard deviation; vs = versus.

8.2.3.6 Action Levels

The importance of effects to a phytoplankton or zooplankton assessment endpoint (i.e., biomass or taxonomic richness) was categorized according to the Action Levels described by Golder (2014a). The Action Level classifications were developed to meet the goals of the *Response Framework for Aquatic Effects Monitoring* (WLWB 2010; Racher et al. 2011). The goal of the AEMP Response Framework is to ensure that significant adverse effects never occur. A significant adverse effect, as it pertains to aquatic biota, was defined in the Environmental Assessment as a change in fish population(s) that is greater than 20% (Government of Canada 1999). This effect must have a high probability of being permanent or long-term in nature and must occur throughout Lac de Gras. The

Significance Thresholds for all aquatic biota, including plankton, are therefore related to impacts that could result in a change in fish population(s) that is greater than 20%. Although the AEMP addresses two broad impact hypotheses for Lac de Gras, the toxicological impairment hypothesis and the nutrient enrichment hypothesis (Golder 2014c), the Action Levels for plankton address the toxicological impairment hypothesis. The nutrient enrichment hypothesis is assessed in the Eutrophication Indicators component (Section 6).

Phytoplankton and zooplankton biomass and taxonomic richness were assessed annually to evaluate effects according to the Action Levels (Table 8-7). This involved testing biomass and richness in the NF exposure area against those in the three FF reference areas (FF1, FFB, and FFA). The occurrence of an Action Level 1 was determined by finding significantly lower biomass or richness in the exposure area compared to those in the reference areas.

Table 8-7 Action Levels for Plankton Effects

Action Level	Criteria	Extent	Action
1	Mean biomass or richness significantly less than reference area means	Near-field	Confirm effect
2	Mean biomass or richness significantly less than reference area means	Nearest Mid-field station	Investigate cause
3	Mean richness less than normal range	Near-field	Examine ecological significance Set Action Level 4 Identify mitigation options
4	TBD[(a)]	n/a	Define conditions required for the Significance Threshold
5	Decline in biomass or richness likely to cause a >20% change in fish population(s)	Far-field A (FFA)	Significance Threshold

>= greater than; n/a = not applicable.
a) To be determined if Action Level 3 is reached.

8.3 RESULTS

8.3.1 Summary of Effects

8.3.1.1 Weight-of-Evidence Effects Rankings

Effect rankings for phytoplankton biomass have consistently demonstrated a nutrient enrichment response across years, but the extent of this response has varied, fluctuating between moderate to high most years and a low ranking in 2013. (Table 8-8). Greater than 20% of the lake has been affected in 2009 and 2011, as demonstrated by the high effects ranking. A low effect ranking on phytoplankton community structure was observed in 2008 and 2010 to 2013. The changes in community structure could be associated with either nutrient enrichment or a toxicological response.

The response of zooplankton biomass has been inconsistent over the years, ranging from no response to a moderate nutrient enrichment ranking (Table 8-8). As with the phytoplankton community, the zooplankton community has demonstrated inconsistent responses over the years, and the changes observed were not of a nature that could be categorized as either a nutrient enrichment or toxicological response. Low effect rankings were observed in 2010 and 2011 and a moderate effect ranking was observed in 2013.

Table 8-8 Annual Weight of Evidence Effects Rankings for Plankton, 2007 to 2013

Endpoint	WOE Ranking						
	2007	2008	2009	2010	2011	2012	2013
Phytoplankton Biomass (based on enumeration)	↑↑	↑↑	↑↑↑	↑↑	↑↑↑	↑↑	↑
Phytoplankton Community Structure	0	↑/↓	0	↑/↓	↑/↓	↑/↓	↑/↓
Zooplankton Biomass (based on enumeration)	n/a	↑↑	0	↑	↑↑	↑	0
Zooplankton Community Structure	n/a	0	0	↑/↓	↑/↓	0	↑↑/↓↓

Notes: 0 = no response; ↑ /↓ = low level ranking; ↑↑/↓↓ = moderate level ranking; ↑↑↑/↓↓↓ = high level ranking; n/a= data not available. The direction of the sign (↑ or ↓) indicates the direction of difference relative to the reference areas. For community structure the direction of the change (↑/↓ or ↑↑/↓↓) could not be established.

8.3.1.2 Action Levels

The response of biomass and taxonomic richness for both phytoplankton and zooplankton indicate that an Action Level 1 was not reached between 2007 and 2013. An Action Level 1 would have been reached if significantly lower biomass or richness was observed in the exposure area compared to the reference areas.

8.3.2 Temporal Trends

8.3.2.1 Phytoplankton Taxonomic Richness

A temporal trend in phytoplankton taxonomic richness has not been observed in any of the sampling areas of Lac de Gras (Figure 8-1). This was also the case for the reference areas. Taxonomic richness in the NF exposure area generally remained within the normal range, with excursions outside the normal range occurring more frequently since 2009. Similarly, stations along the MF2-FF2 exposure transect were generally within the normal range, with multiple stations and years exceeding the normal range after 2009. An exception to the above is observed in the MF2-FFE exposure transect in 2011, where the MF2 stations were below the normal range. A number of stations in the MF1 transect were outside the historical normal range from 2008 to 2012, whereas the majority of the stations along the MF3 transect were within the historical normal range between 2007 to 2011. It is noted that increased richness was observed at most stations in 2012 and 2013 in the MF3 transect (Appendix 8B Figure 8B-1).

8.3.2.2 Phytoplankton Biomass

Phytoplankton biomass increased in the NF exposure area from 2003 to 2010, peaking in 2010 and exceeding the normal range from 2006 to 2012. From 2011 to 2013 phytoplankton biomass decreased, and by 2013 phytoplankton biomass was within the normal range. Biomass at the majority of stations along the MF2-FF2, and MF1 transects have been above the normal range since 2006 (Figure 8-2 and Appendix 8B, Figure 8B-2), while biomass along the MF3 transect followed a similar pattern to that seen in the NF exposure area (Appendix 8B Figure 8B-2).

Microflagellate biomass demonstrated a peak in the NF area in 2007, and in 2011 along the MF2-FF2 transect; no peak was apparent in the reference areas (Figure 8-3). The NF area has seen a decline in biomass since 2010, with the mean value returning to within the normal range in 2013. However, Microflagellate biomass values in the MF2 and FF2 areas mostly remained above the normal range. Cyanobacteria biomass peaked in the NF area in 2010 and declined thereafter (Figure 8-4). Some mid-field stations have seen an increase in cyanobacteria biomass over time and were greater than the normal range from 2010 to 2013. No trend is apparent in the reference areas. The chlorophytes and the dinoflagellates had biomass peaks in the NF area in 2006 or 2007 (Figures 8-5 and 8-7). Diatoms do not show a trend in the NF area, though along the MF2-FF2 transect, diatom biomass had a peak in 2007 (Figure 8-6). Since the early 2000s, many stations along the MF2-FF2 transect had biomass values above the normal range for chlorophyte, diatom, and dinoflagellate biomass, with a few smaller excursions occurring in the NF exposure area.

Relative biomass of the major ecological groups demonstrated few patterns throughout the time series available to date. The relative biomass of the cyanobacteria appears to be increasing with time along the MF2-FF2 transect, but this is not seen in the NF area (Figure 8-9). Cyanobacteria relative biomass was also increasing the reference areas, but this trend peaked in 2010. The time series plots suggest that the community composition (based on major groups) is not undergoing a change with time. The relative biomass of all groups has remained within the normal range in the NF area, with few exceptions (Figures 8-8 to 8-12).

Figure 8-1 **Phytoplankton Taxonomic Richness (Genus-level) in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas**

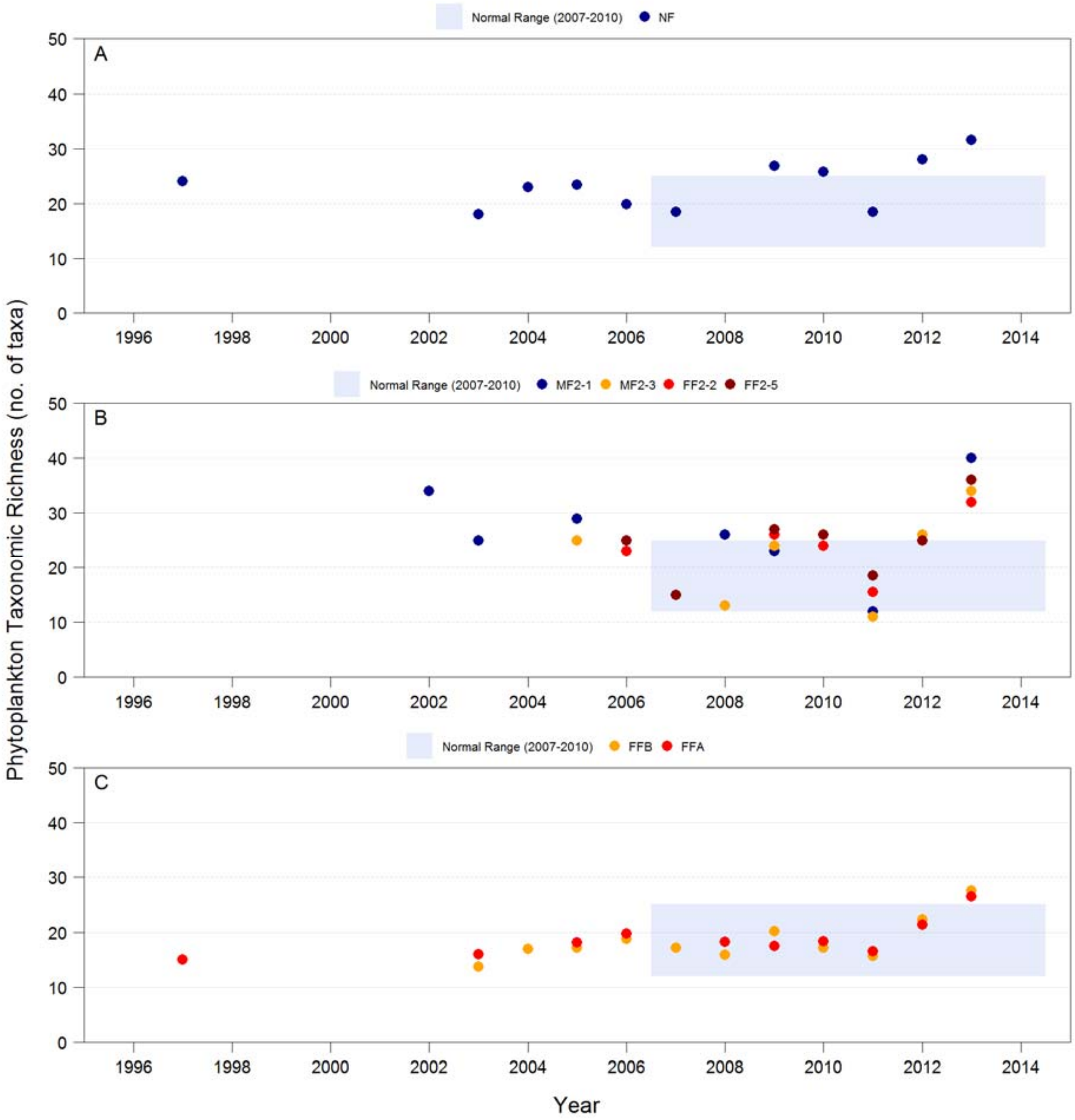


Figure 8-2 **Phytoplankton Biomass in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas**

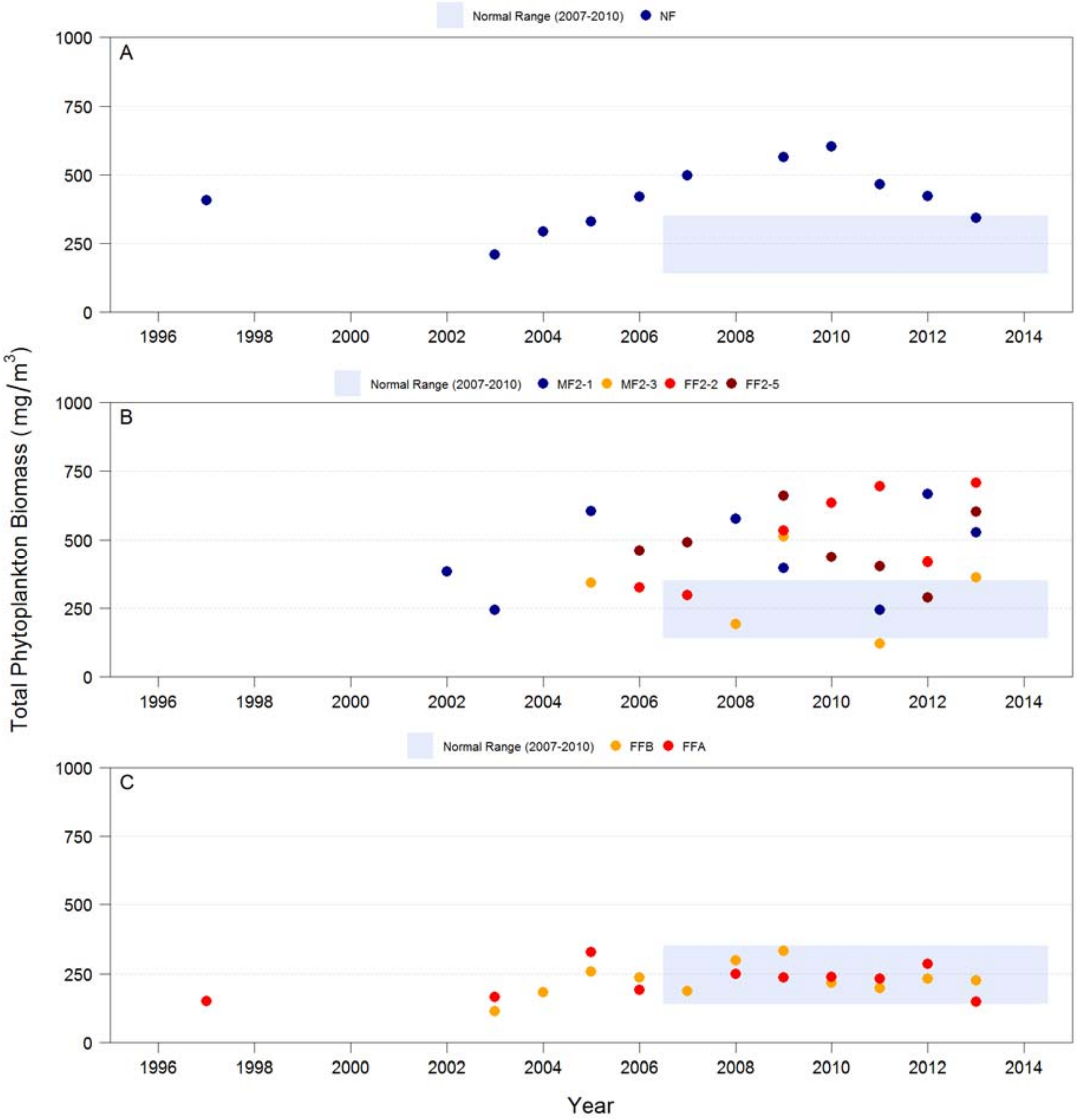


Figure 8-3 Microflagellate Biomass in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas

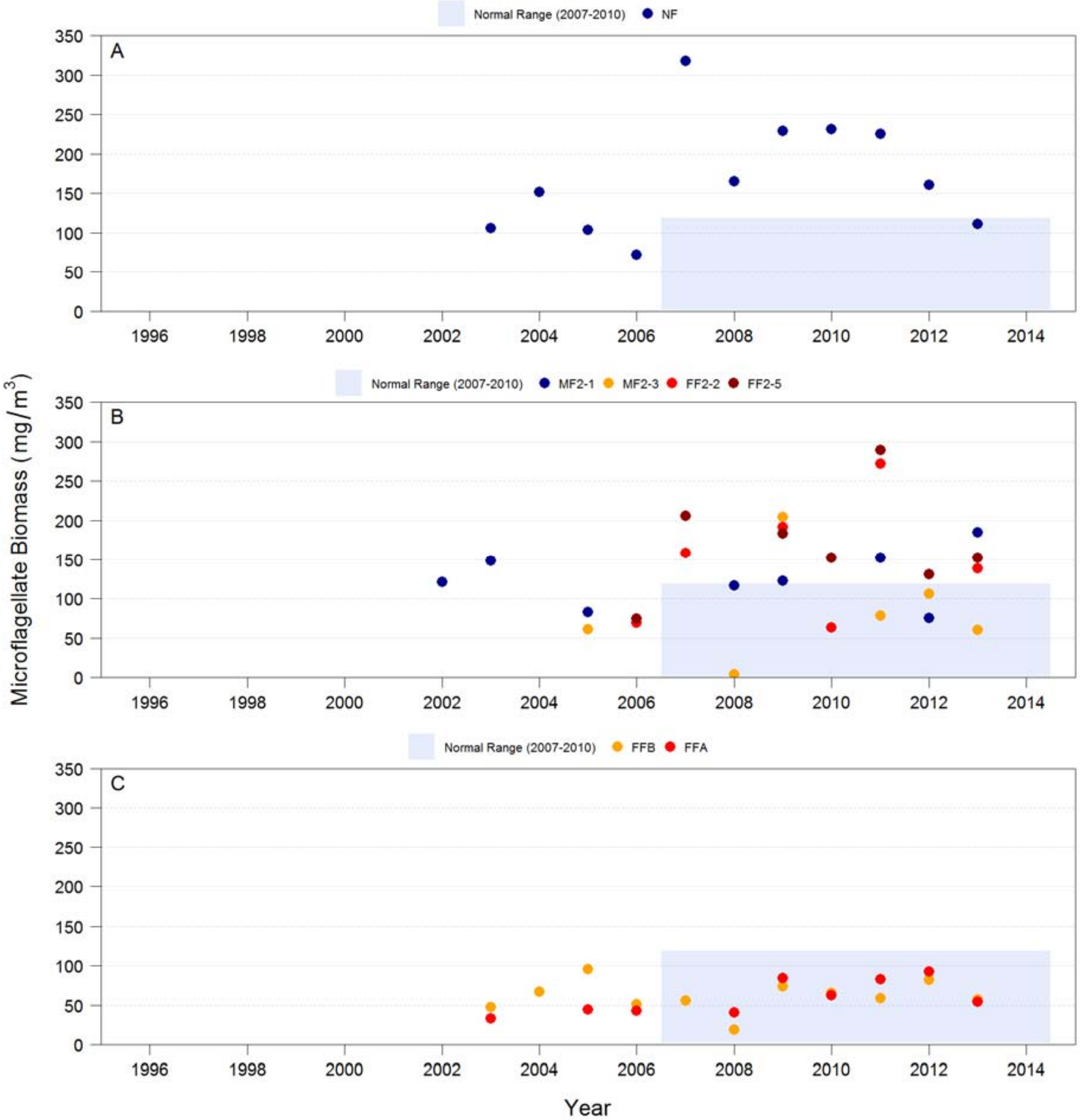


Figure 8-4 **Cyanobacteria Biomass in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas**

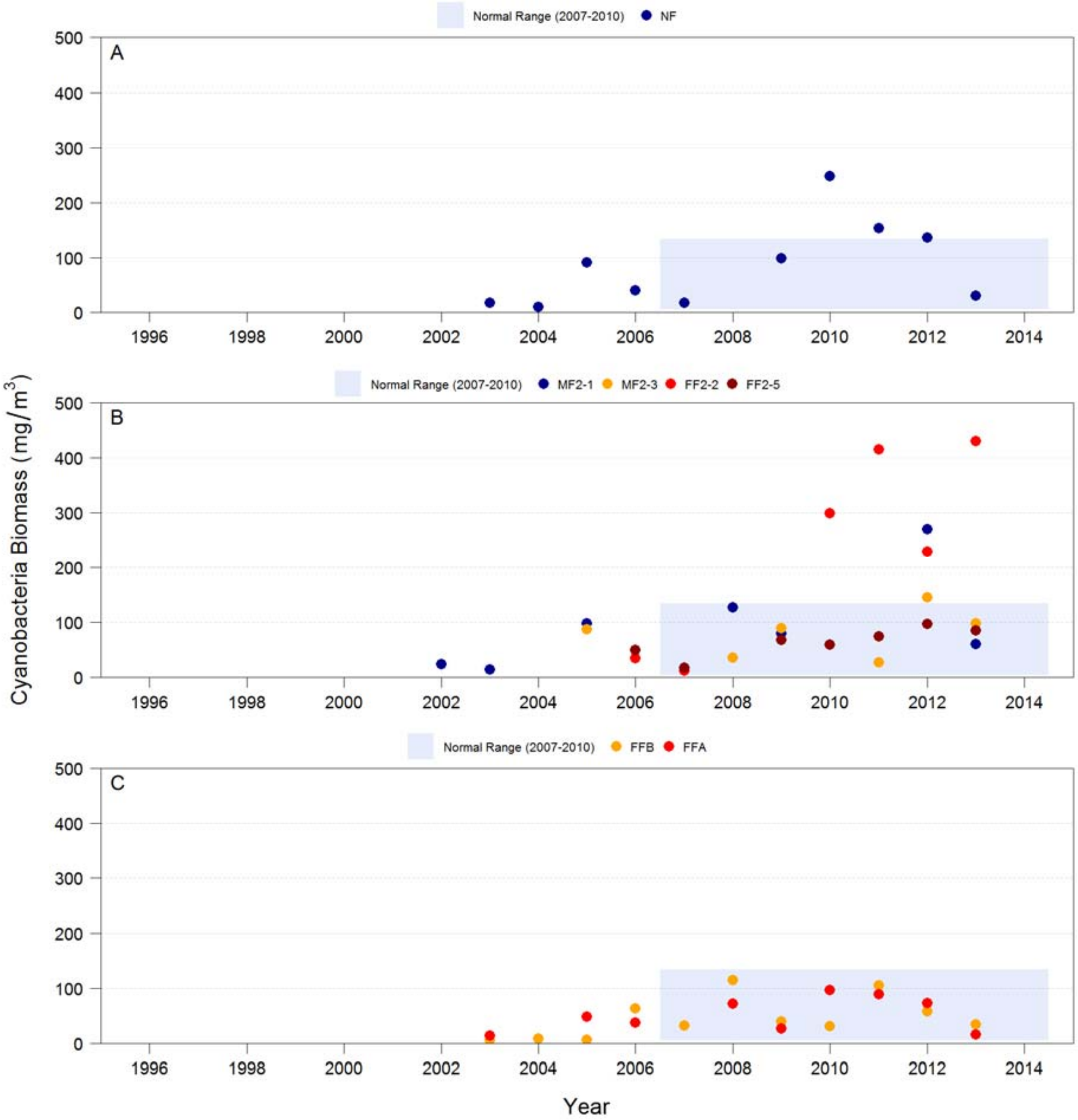


Figure 8-5 **Chlorophyte Biomass in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas**

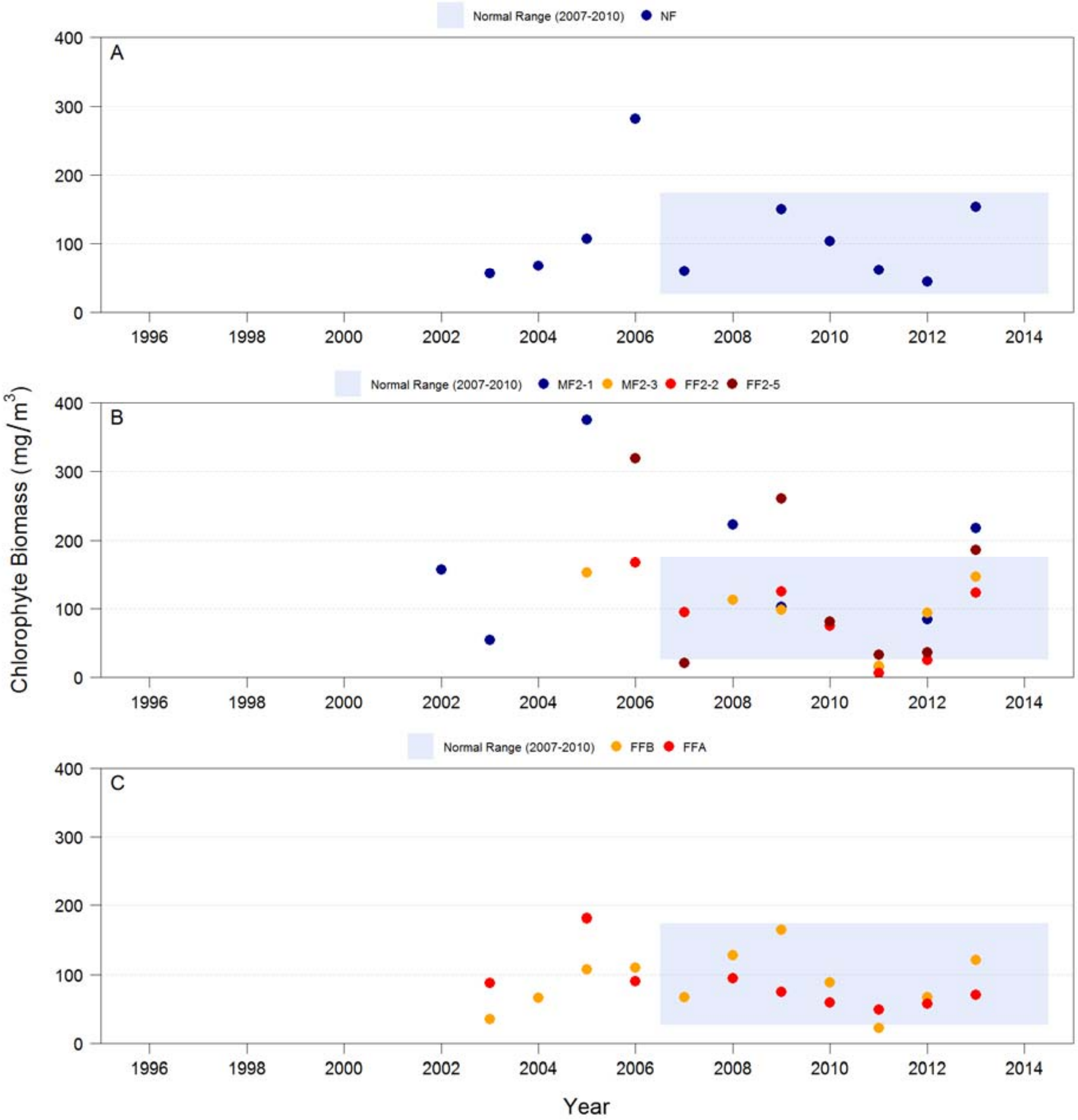


Figure 8-6 **Diatom Biomass in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas**

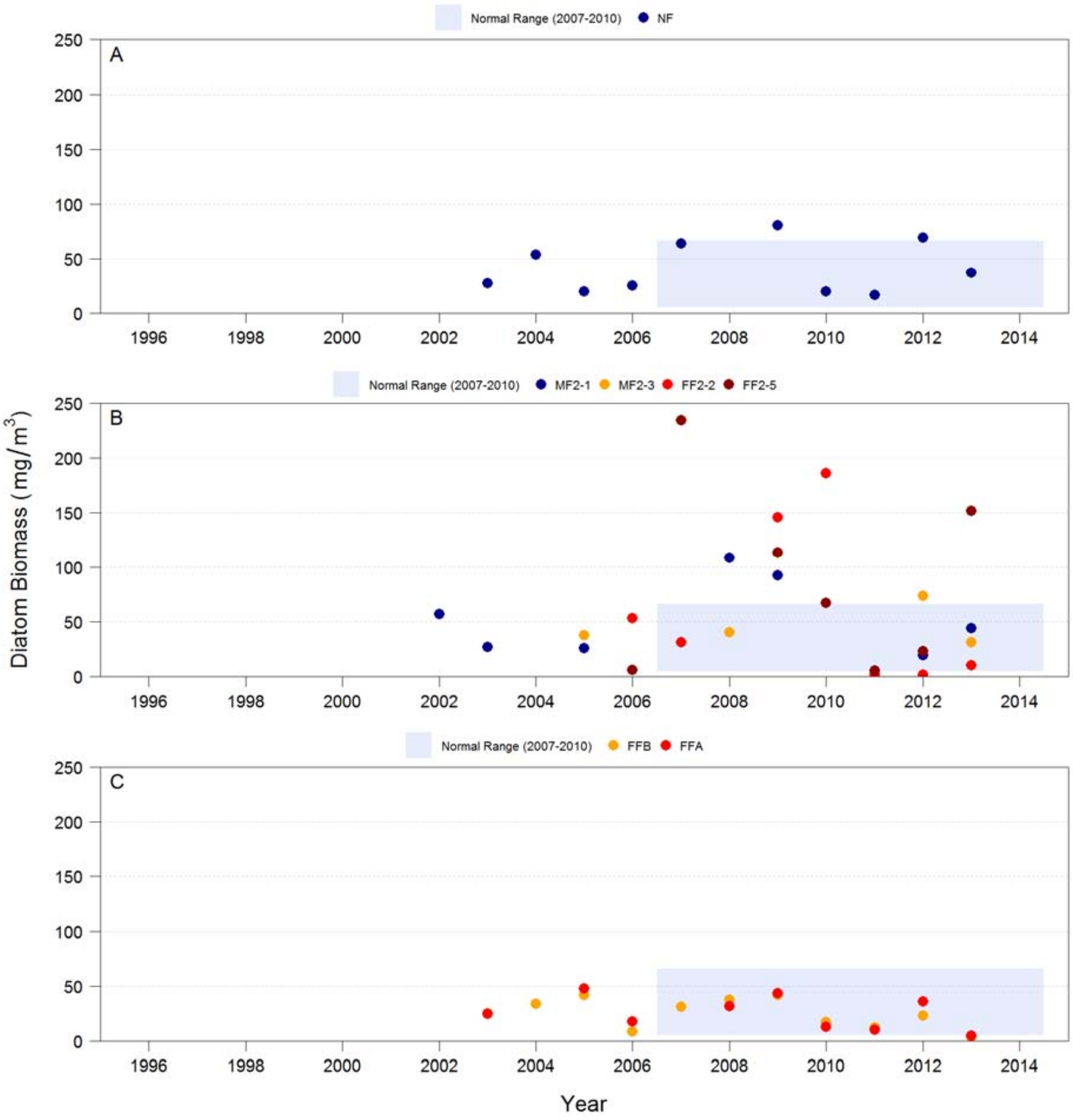


Figure 8-7 **Dinoflagellate Biomass in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas**

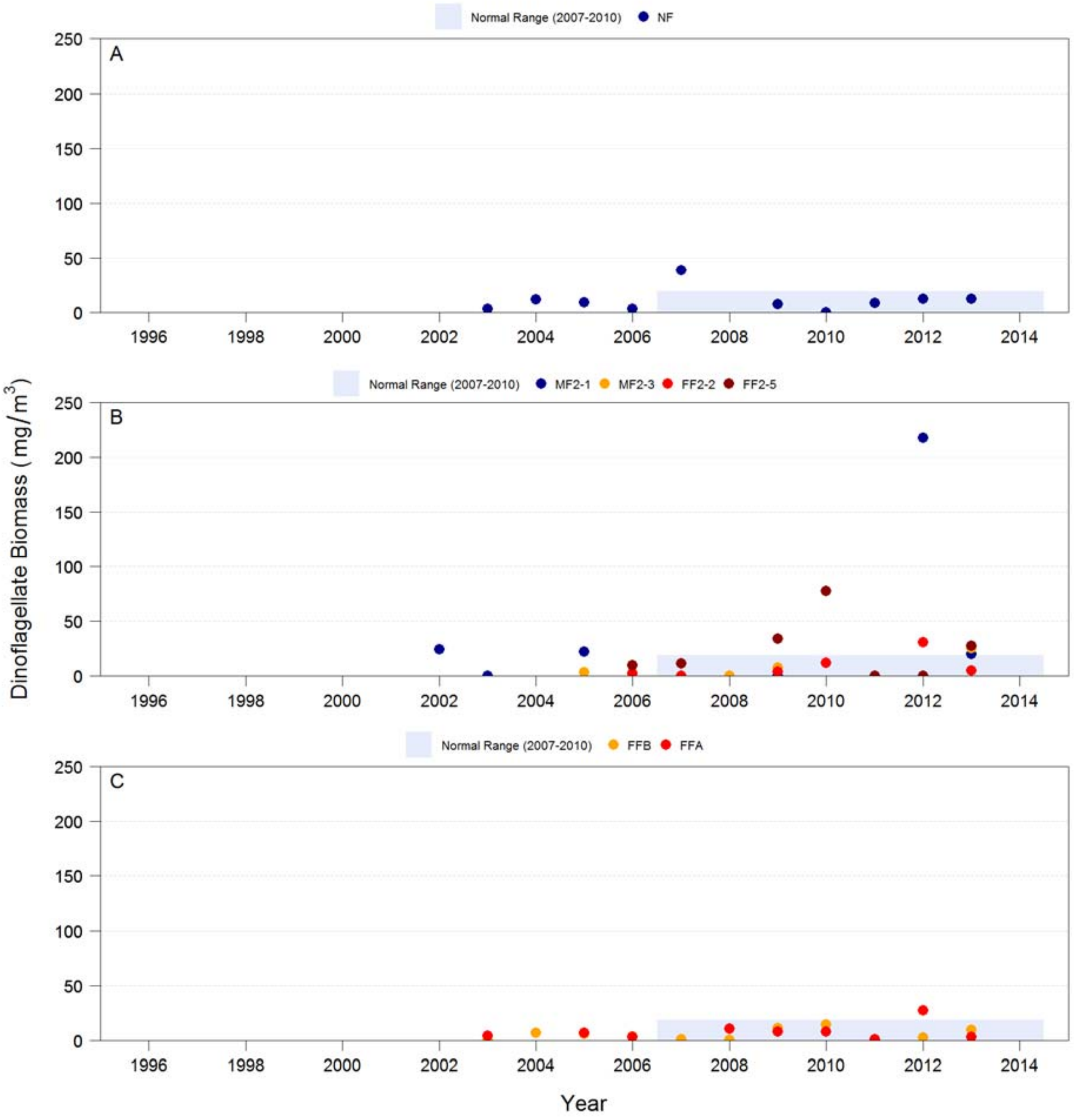


Figure 8-8 **Relative Biomass of Microflagellates in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas**

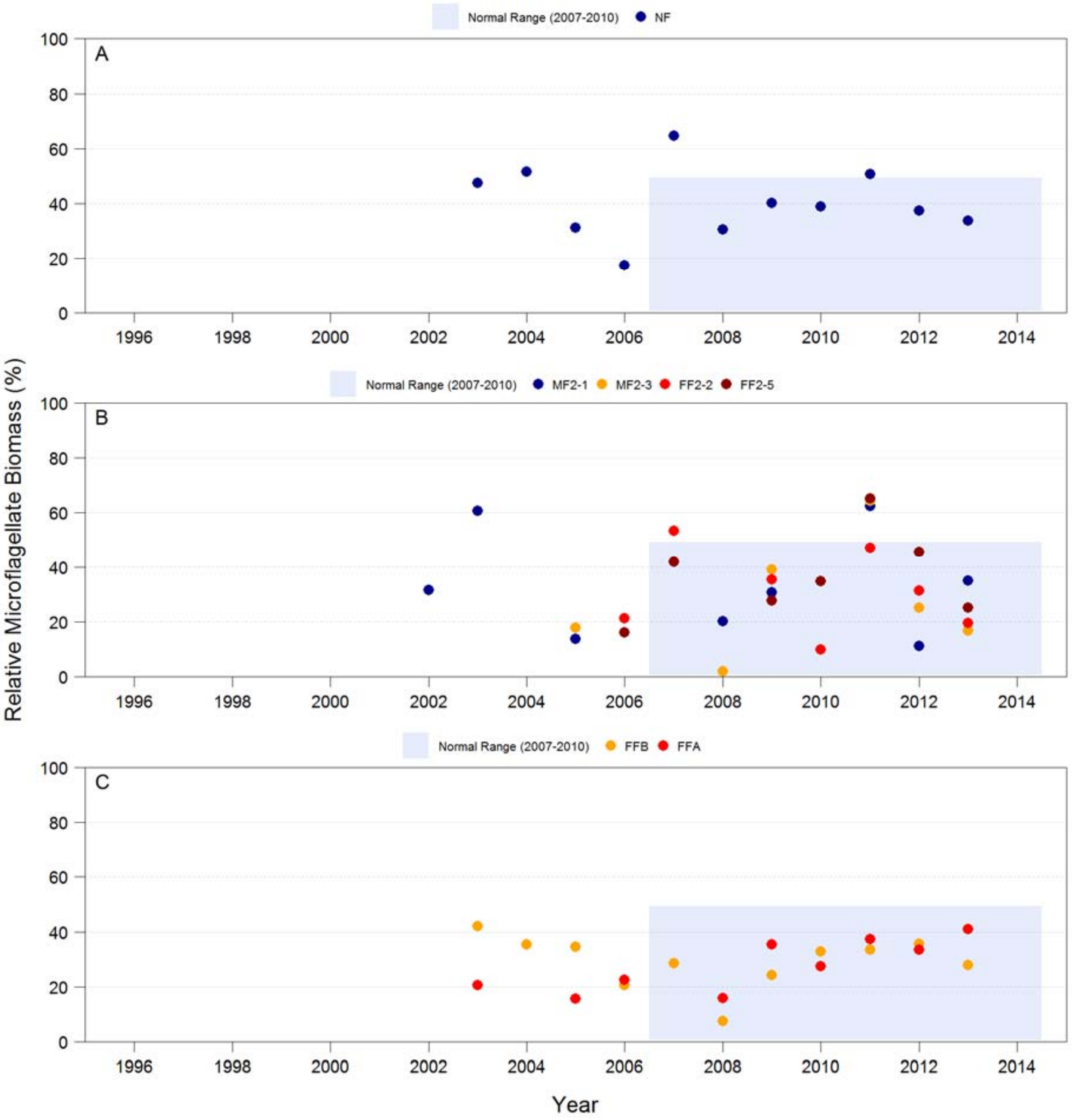


Figure 8-9 **Relative Biomass of Cyanobacteria in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas**

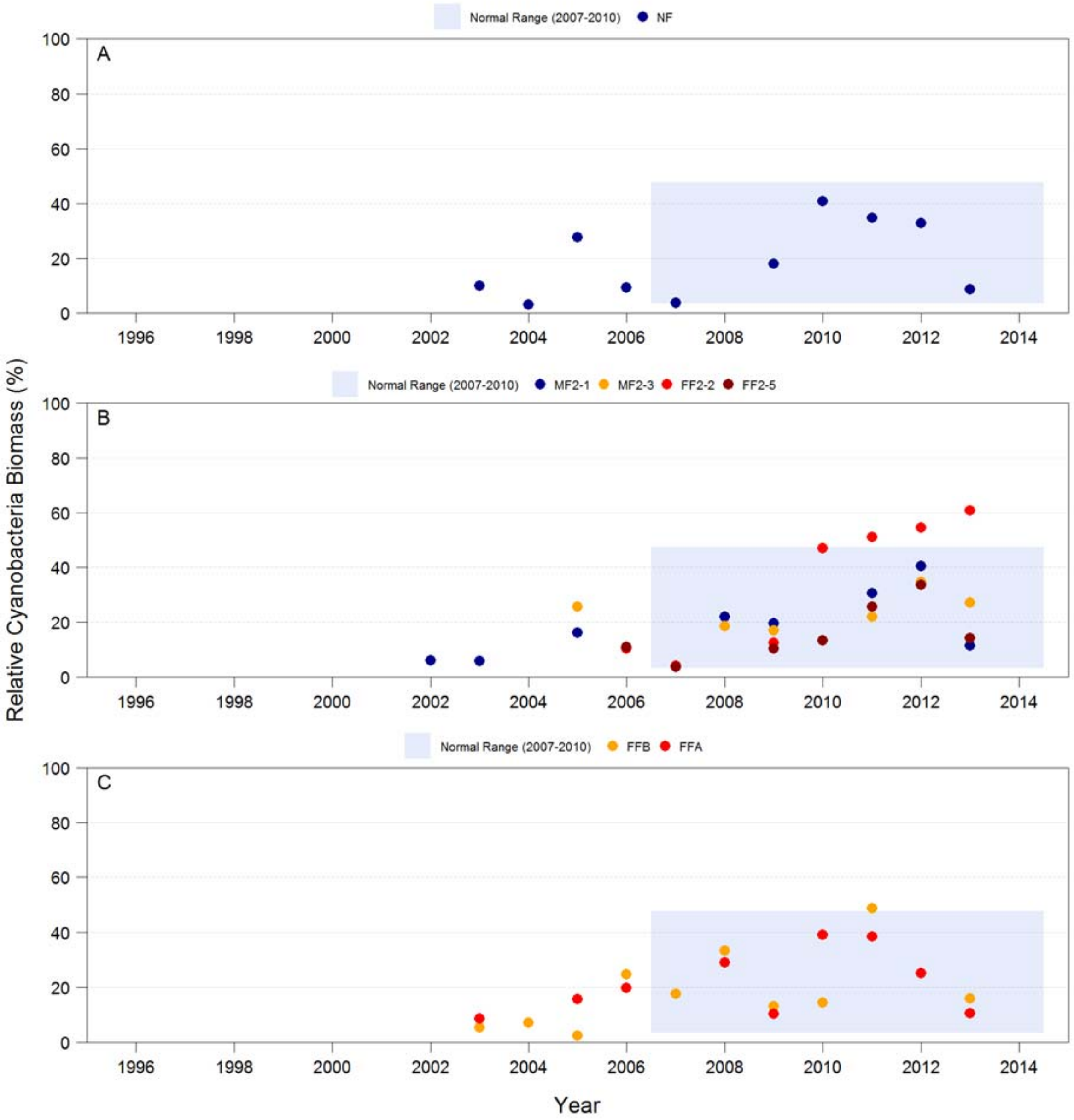


Figure 8-10 Relative Biomass of Chlorophytes in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas

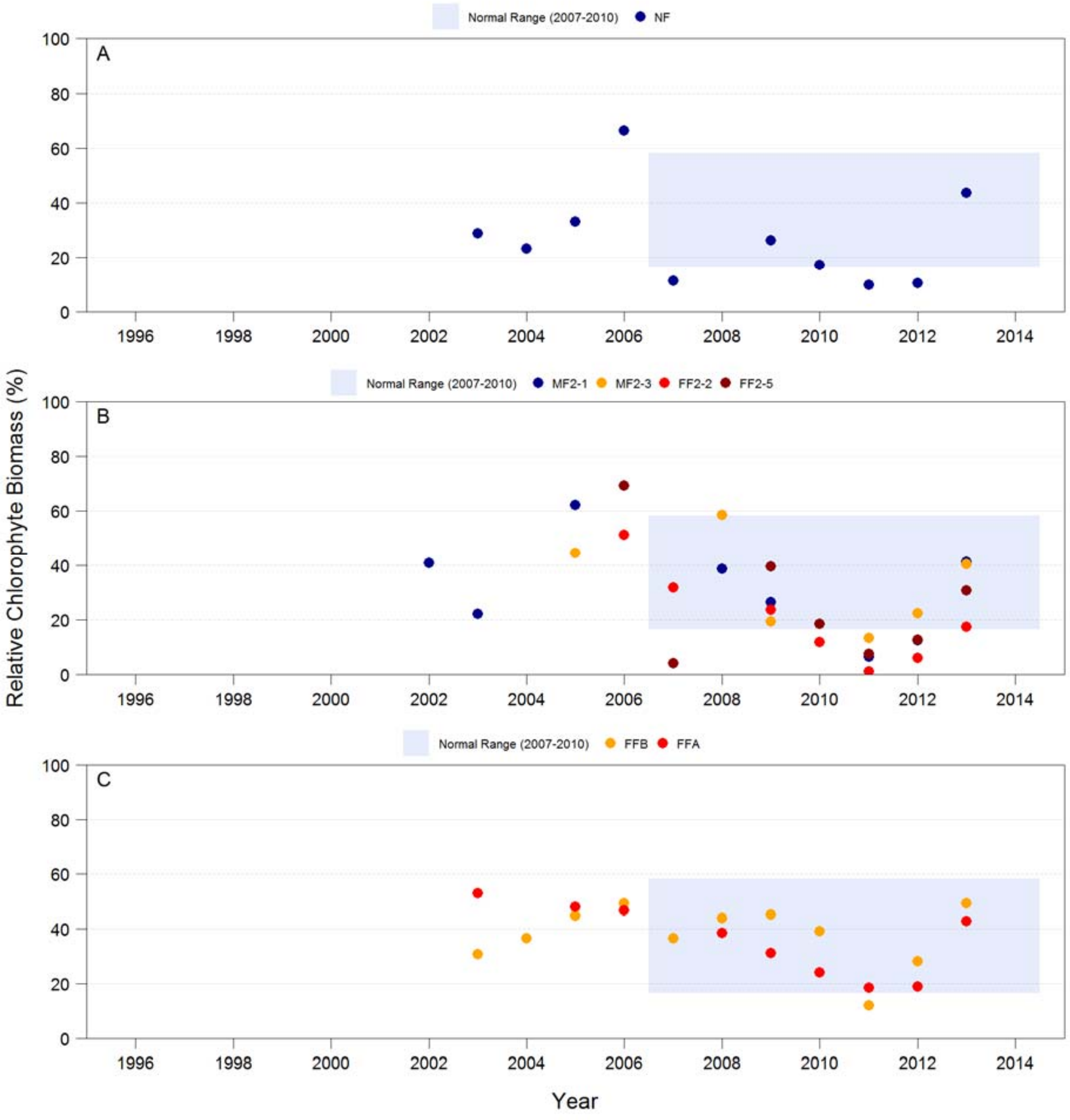


Figure 8-11 Relative Biomass of Diatoms in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas

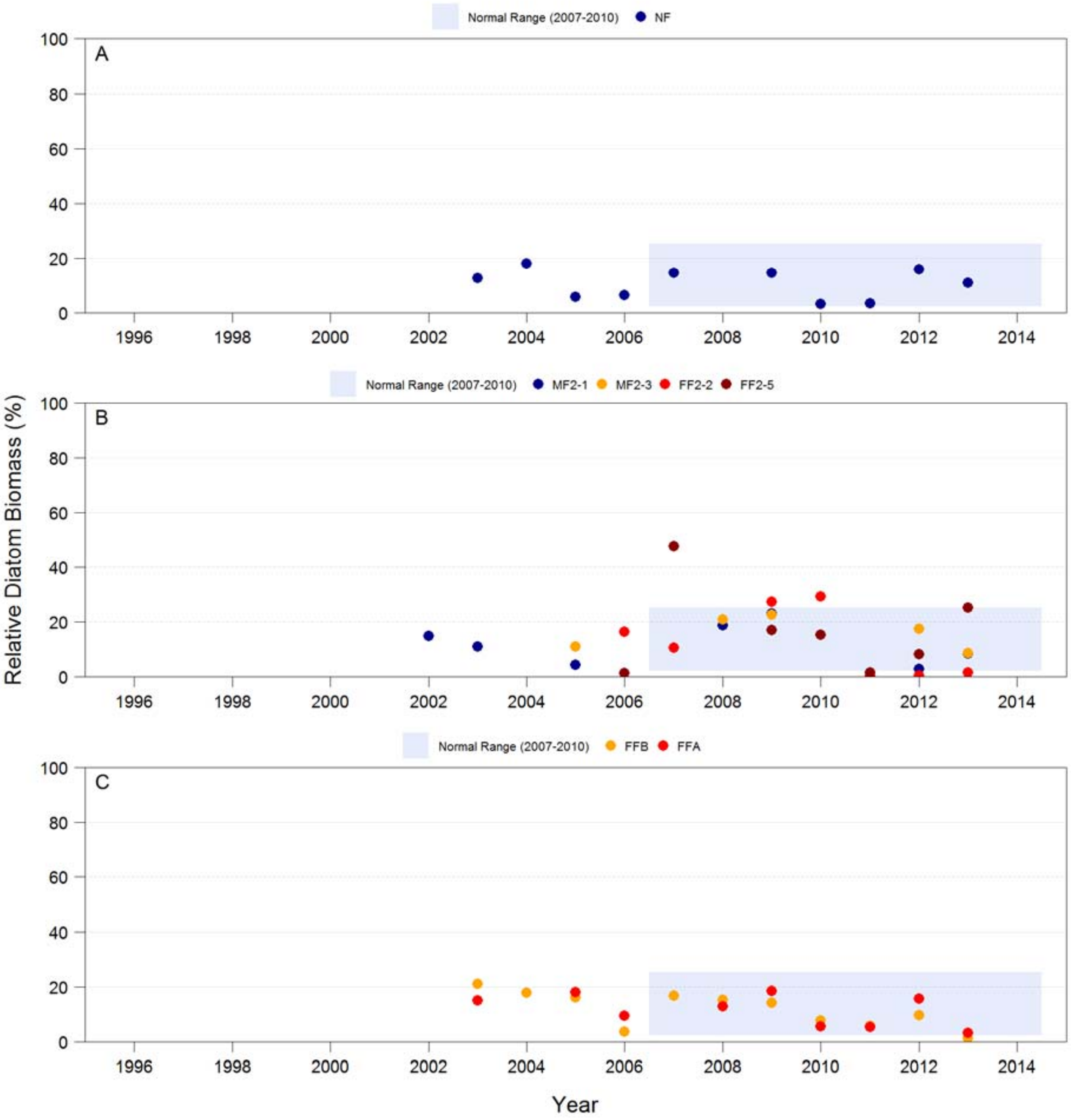
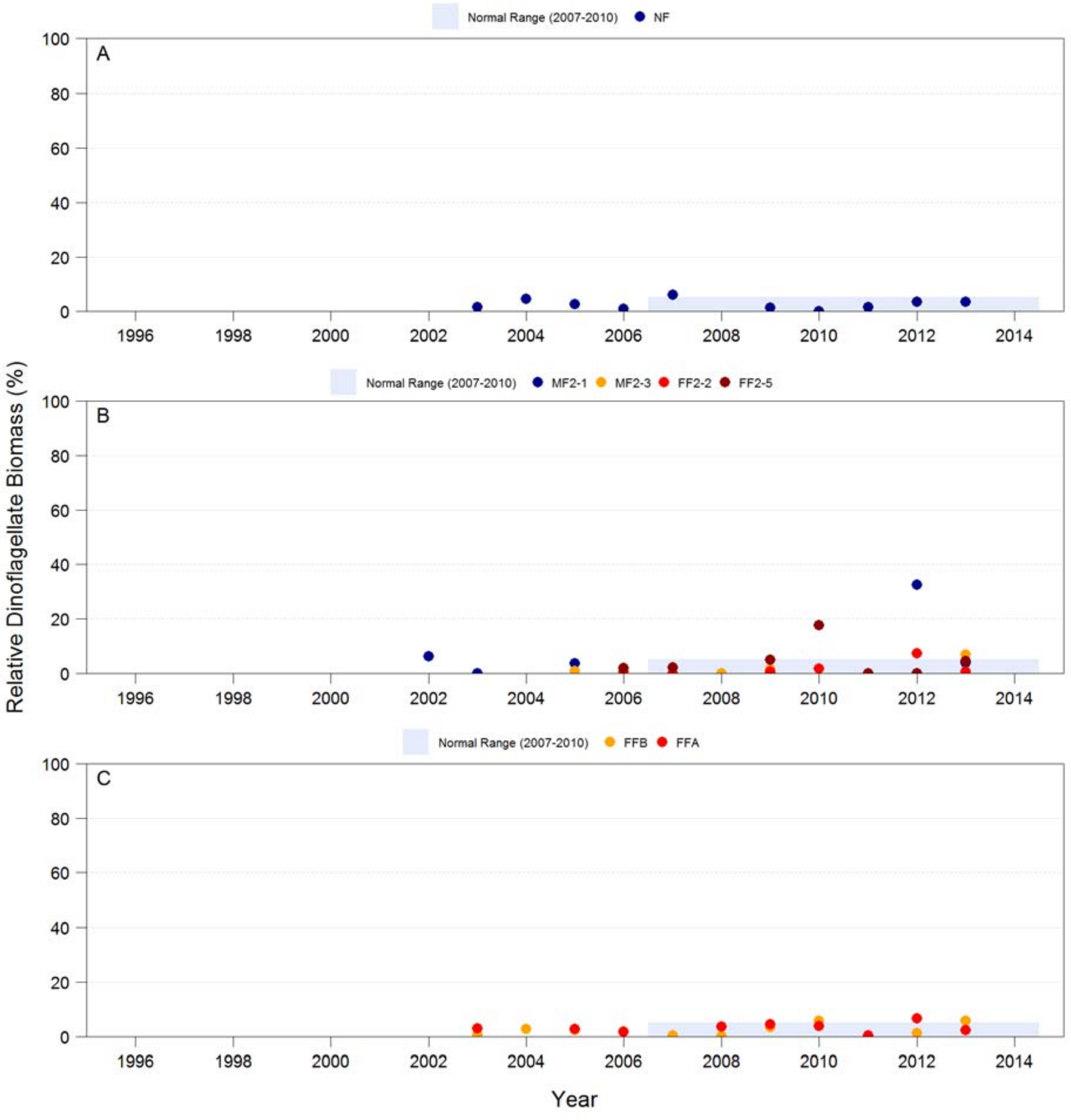


Figure 8-12 Relative Biomass of Dinoflagellates in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas



8.3.2.3 Phytoplankton Community Structure

The two dimensional mMDS configuration for phytoplankton biomass from 2007 to 2012 had a stress value of 0.17, indicating a reasonable level of fit to the original dataset (Figure 8-13). The SIMPROF test result (*P*<0.05) indicated that the level of interpretation of the clusters is acceptable and over-interpretation is unlikely. The ordination plot demonstrates separation in phytoplankton biomass between the two area-year groupings i.e., the 2007 to 2010 data is separate from the 2011 to 2012 data. Areas within the area-year data groupings clustered together indicating 60% similarity to one another; however, the 2007 to 2010 and 2011 to 2012 data differed from one another and clustered separately. An 80% similarity was observed between the FFA and FFB 2011 to 2013 area-year data; all other data were within the 60% clusters are between 60% and 80% similar. Under both area-year clusters, the exposure areas (NF, MF, FF2) grouped together, while the reference areas (FFA, FFB, and FF1) were separate from the exposure areas and grouped together, indicating differences in community composition between the exposure and reference areas and between the 2007 to 2010 data and the 2011 to 2012 data. The overall analysis of similarities (ANOSIM) test (*R* = 0.67; *P* = 0.001) shows that all the replicates within the area-year grouping are more similar to one another than any replicates from different areas, i.e., data for each individual year for the NF area are similar to one another, but different from data for the individual years for the FFA, FFB, FF1, FF2, or MF2 areas.

The 2013 data were analyzed separately because of a change in taxonomists in 2013; therefore, a separate mMDS ordination plot was produced for the 2013 data. The 2013 two dimensional mMDS configuration for phytoplankton biomass had a stress value of 0.11, also indicating a reasonable level of fit to the original dataset (Figures 8-14). The separation observed in 2007 to 2010 and in 2011 to 2012, between the exposure area and the reference areas was also observed in 2013 (Figure 8-14), indicating that there was a difference in the phytoplankton community between the exposure reference areas.

Figure 8-13 Metric Multidimensional Scaling of Phytoplankton Biomass in Lac de Gras from 2007 to 2012

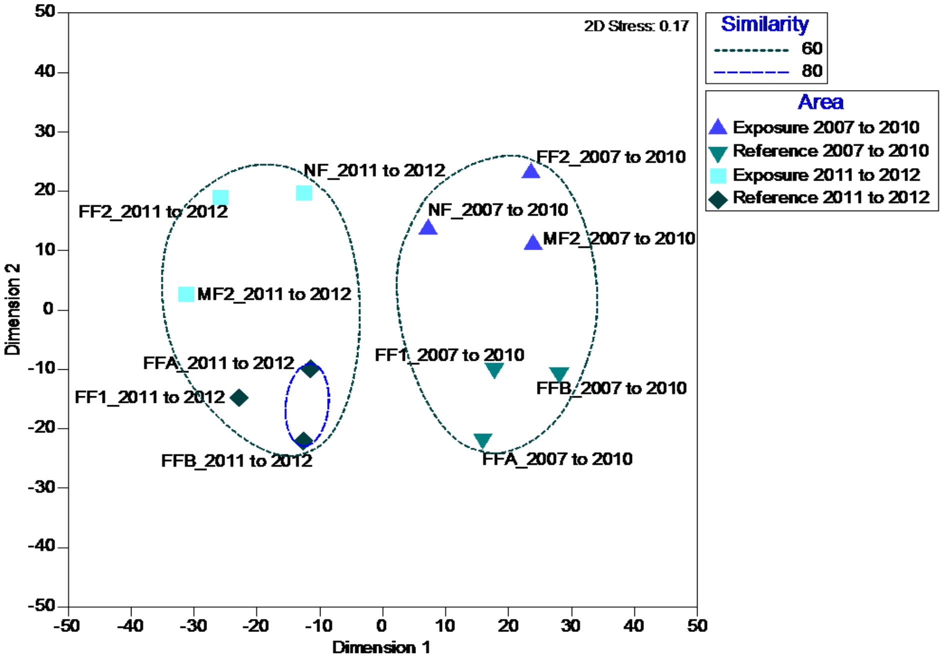
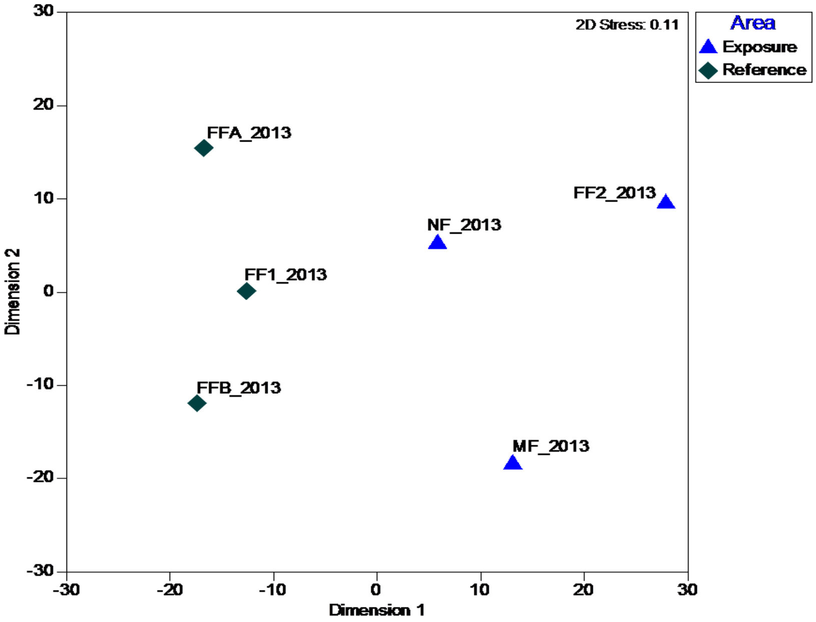


Figure 8-14 Metric Multidimensional Scaling of Phytoplankton Biomass in Lac de Gras in 2013



8.3.2.4 Zooplankton Taxonomic Richness

Zooplankton taxonomic richness generally remained within the normal range in the NF and FF area from 2008 to 2013 (Figure 8-15). The majority of the stations along the MF2-FF2, MF1, and MF3 transects remained within the normal range with the exception of FF2-5 in 2012 and MF1-1 in 2007 (Figure 8-15 and Appendix 8B, Figure 8B-13). No trends were observed in taxonomic richness in any area of Lac de Gras.

8.3.2.5 Zooplankton Biomass (based on enumeration)

There has been no temporal trend in total zooplankton biomass (Figure 8-16). Zooplankton biomass has been more variable in the exposure areas compared to the reference areas, but generally remained within the normal range. Excursions in all exposure areas above the normal range occurred in 2008 and 2011 (Figure 8-16 and Appendix 8B, Figure 8B-14).

In the NF exposure area, cladoceran biomass was above normal range in all years from 2008 to 2013, with the exception of 2009 (Figure 8-17). An increasing temporal trend was observed along the MF1 transect from 2010 to 2013, with cladoceran biomass exceeding the normal range in 2011 and peaking in 2013 (Appendix 8B, Figure 8B-15). A number of excursions from the normal range were also observed along the MF2-FF2 and MF3 transects; however, a clear increasing trend was not observed (Figure 8-17 and Appendix 8B, Figure 8B-15). Since 2011, cladoceran biomass declined to mostly within the normal range along the MF2-FF2 transect.

Calanoid biomass has been generally decreasing in all areas from 2008 to 2013, and has remained near the lower limit of the normal range in 2012 and 2013 (Figure 8-18 and Appendix 8B, Figure 8B-16). Cyclopoid biomass was variable throughout the time series in the NF area and appears to vary with no trend in the mid-field and reference areas (Figure 8-19 and Appendix 8B, Figure 8B-17). Rotifer biomass exhibited a decline and recovery in the NF and MF2-FF2 areas over time, and a similar, but less pronounced pattern in the reference areas and, for the most part, has been within the normal range. The peaks in Rotifer biomass observed in 2008 and 2013 at multiple stations were above the normal range (Figure 8-20 and Appendix 8B, Figure 8B-18).

Relative biomass values for major zooplankton groups showed generally similar trends as biomass. Relative cladoceran biomass has increased over time in the exposure and reference areas (Figure 8-21), and along the MF1 and MF3 transects (Appendix 8B Figure 8B-19). In the NF exposure area, values in 2011 and 2013 were above the normal range, while along the MF1 and MF3 transects, the majority of stations in 2012 and 2013 were above the normal range. Relative biomass of this group was also above the normal range in 2011 and 2012 along the MF2-FF2 transect. In contrast, relative calanoid biomass has decreased in the exposure and reference areas and along all three MF transects over time, with the majority of the NF exposure area and the MF stations, and some of the FFB area stations falling below the lower limits of the normal range (Figure 8-22 and Appendix 8B, Figure 8B-20). No clear treads were observed in relative cyclopoid biomass, although NF values were above the normal range in 2009 and 2012 (Figure 8-23). Relative rotifer biomass has remained within or near the upper limit of the normal range from 2008 to 2013, with excursions occurring in most areas for the first time in 2013 (Figure 8-24).

Figure 8-15 **Zooplankton Taxonomic Richness in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas**

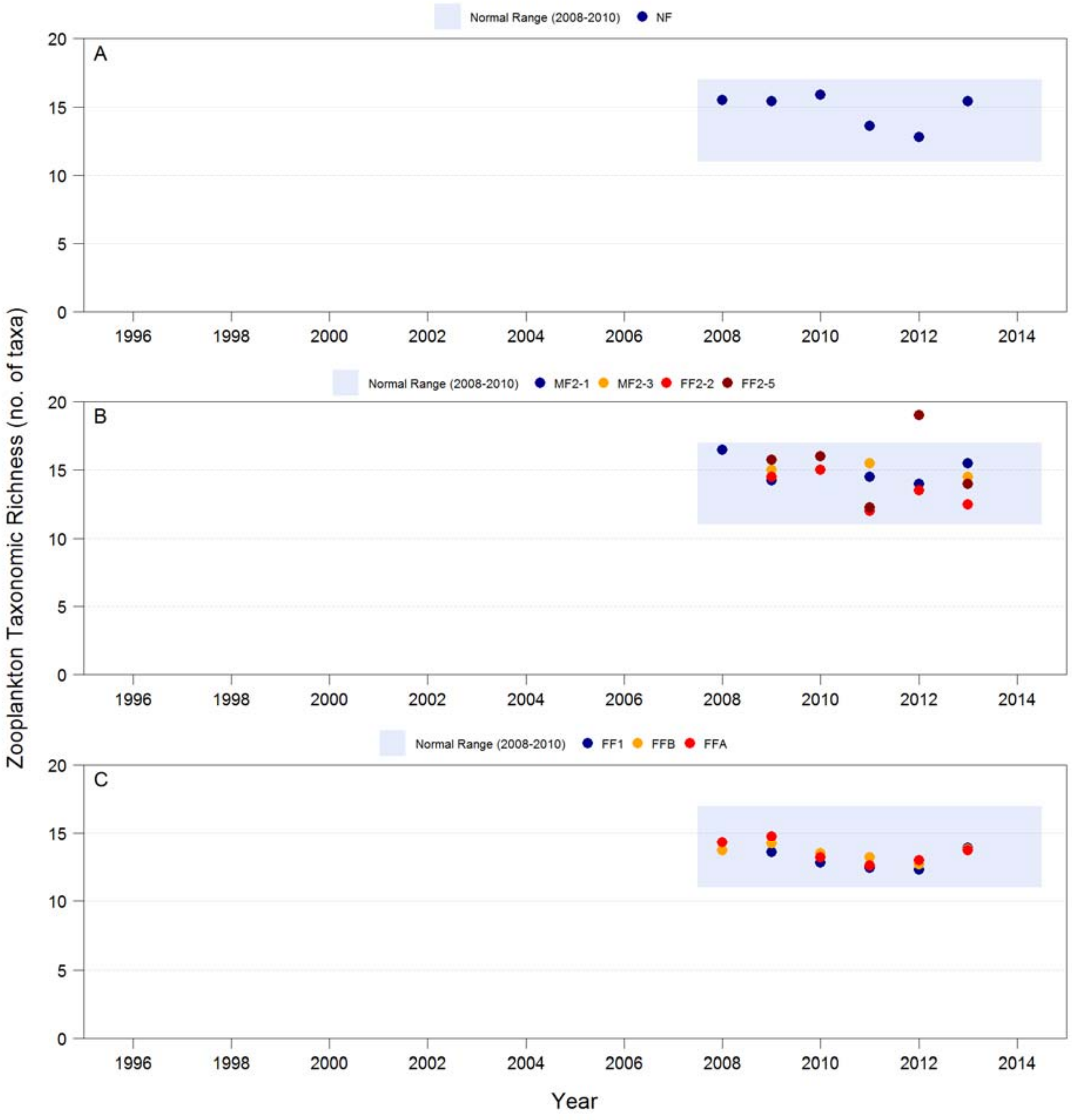


Figure 8-16 **Total Zooplankton Biomass in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas**

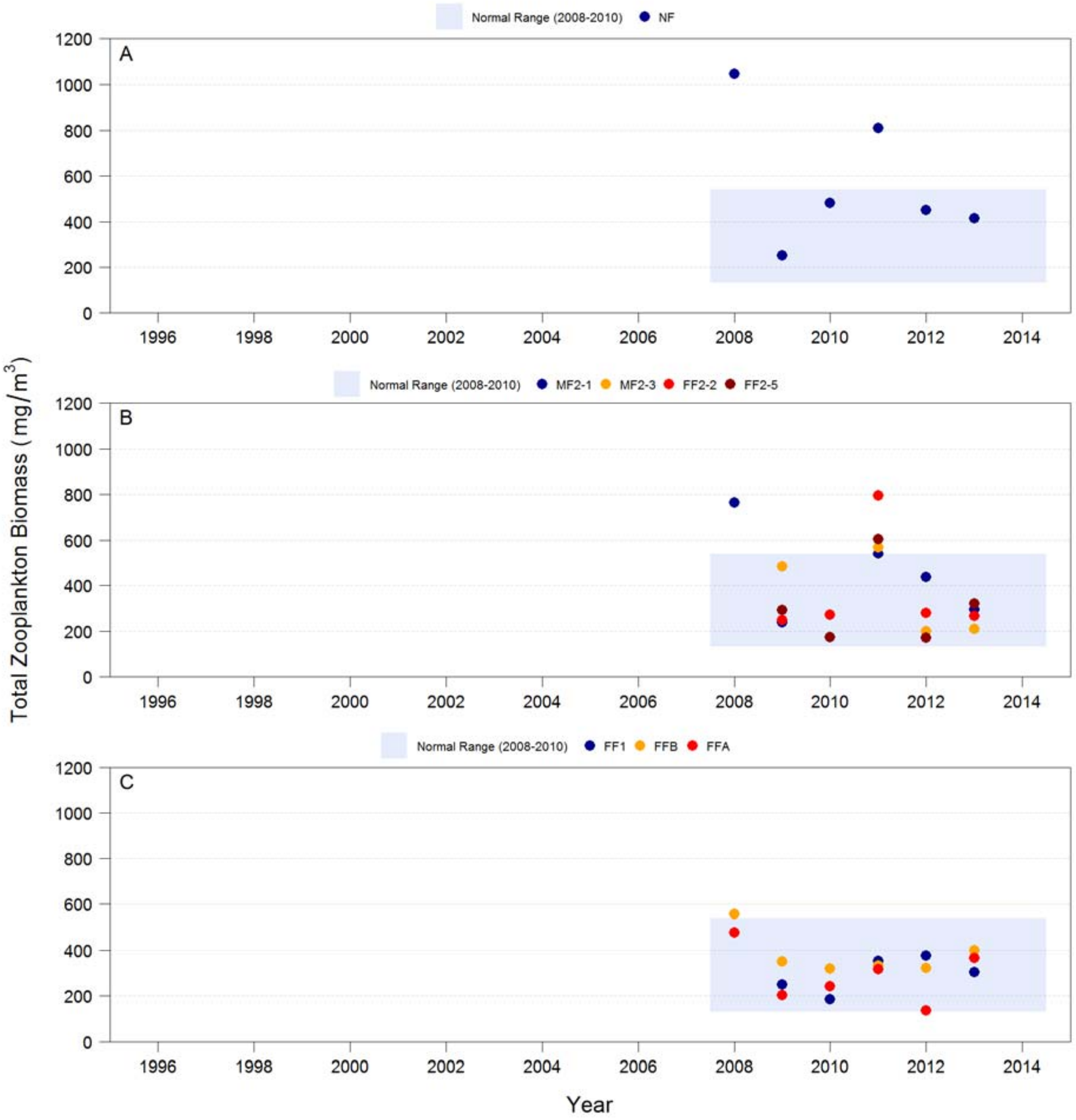


Figure 8-17 Cladoceran Biomass in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas

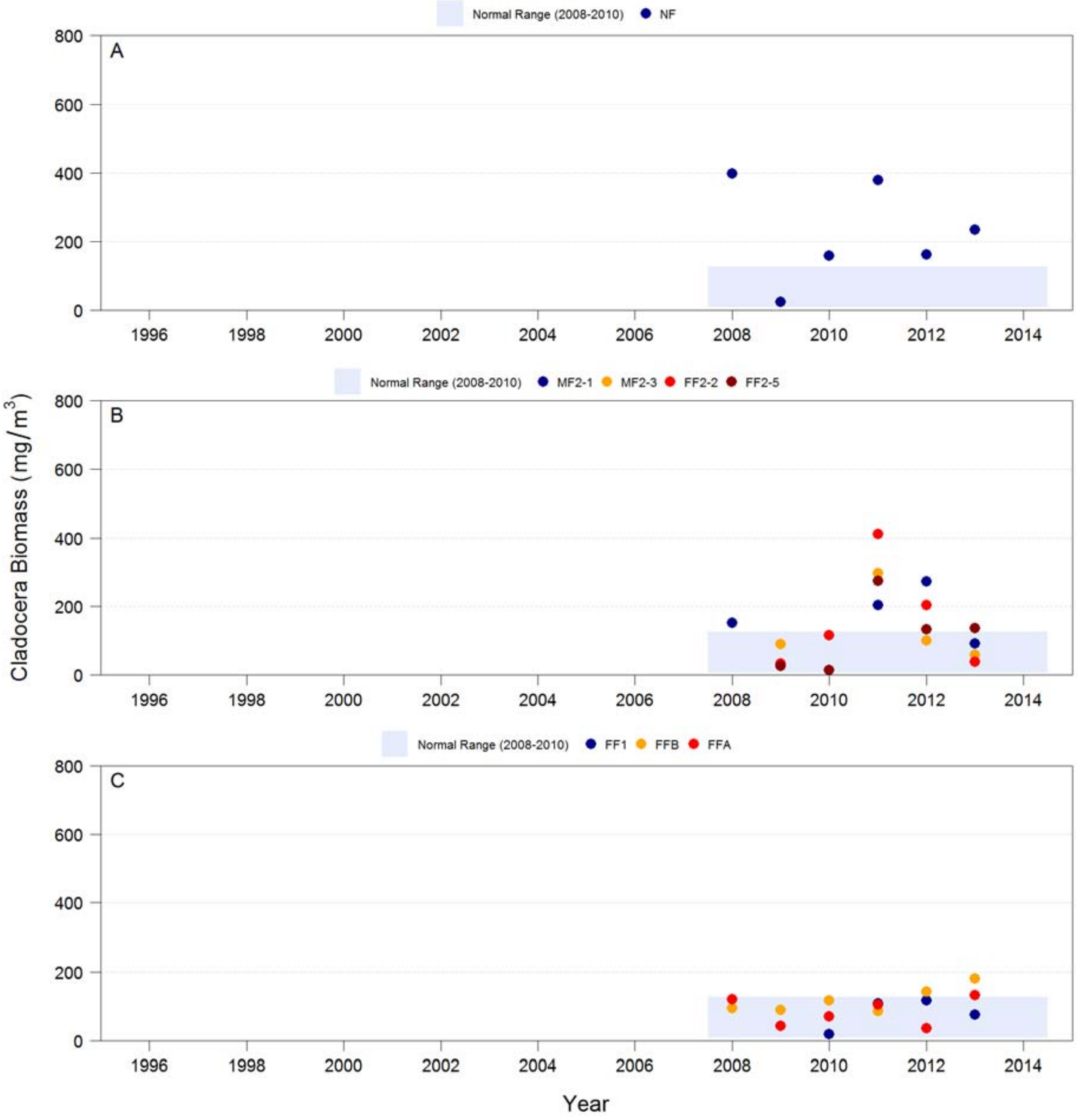


Figure 8-18 **Calanoid Biomass in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas**

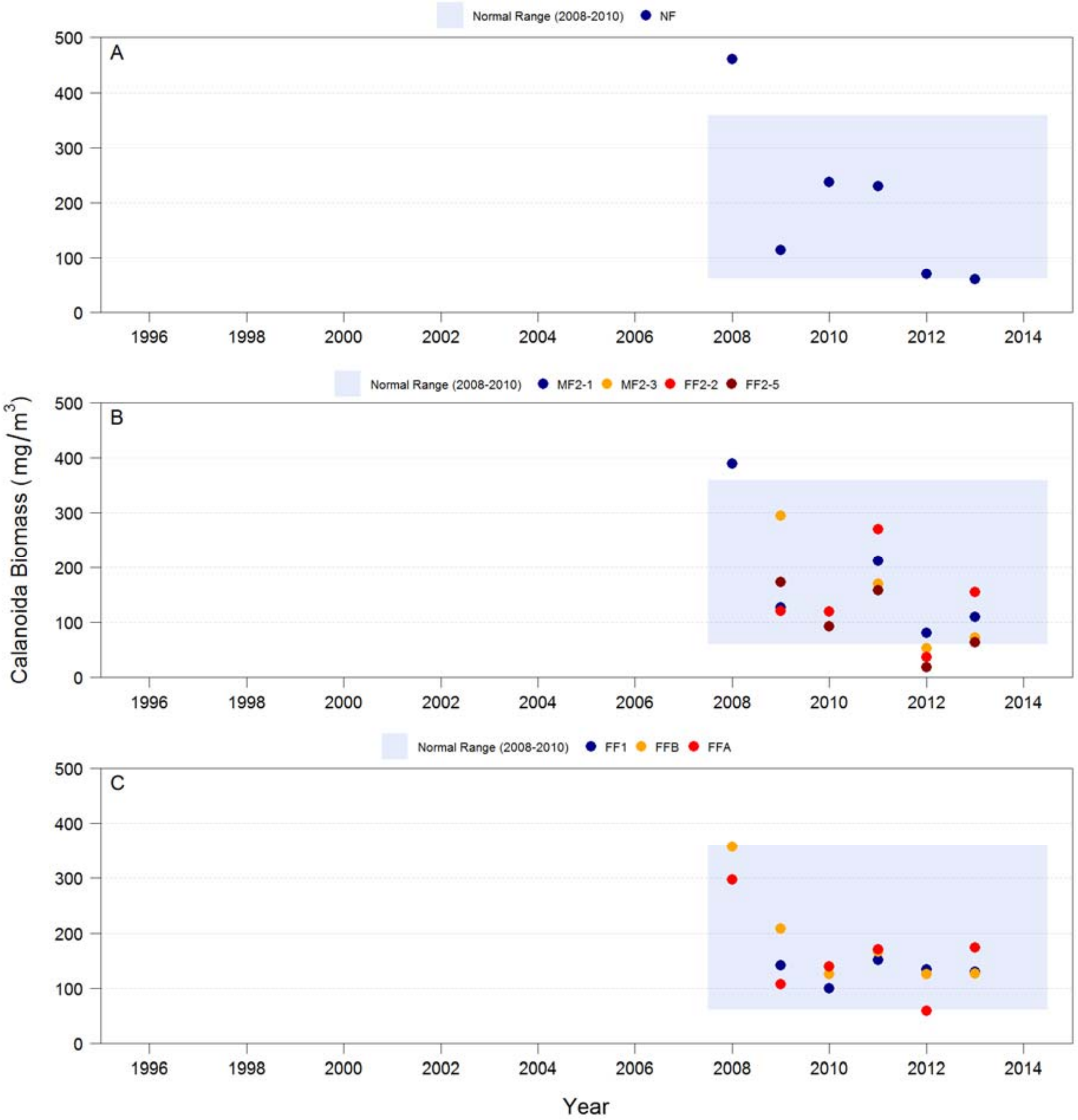


Figure 8-19 **Cyclopoid Biomass in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas**

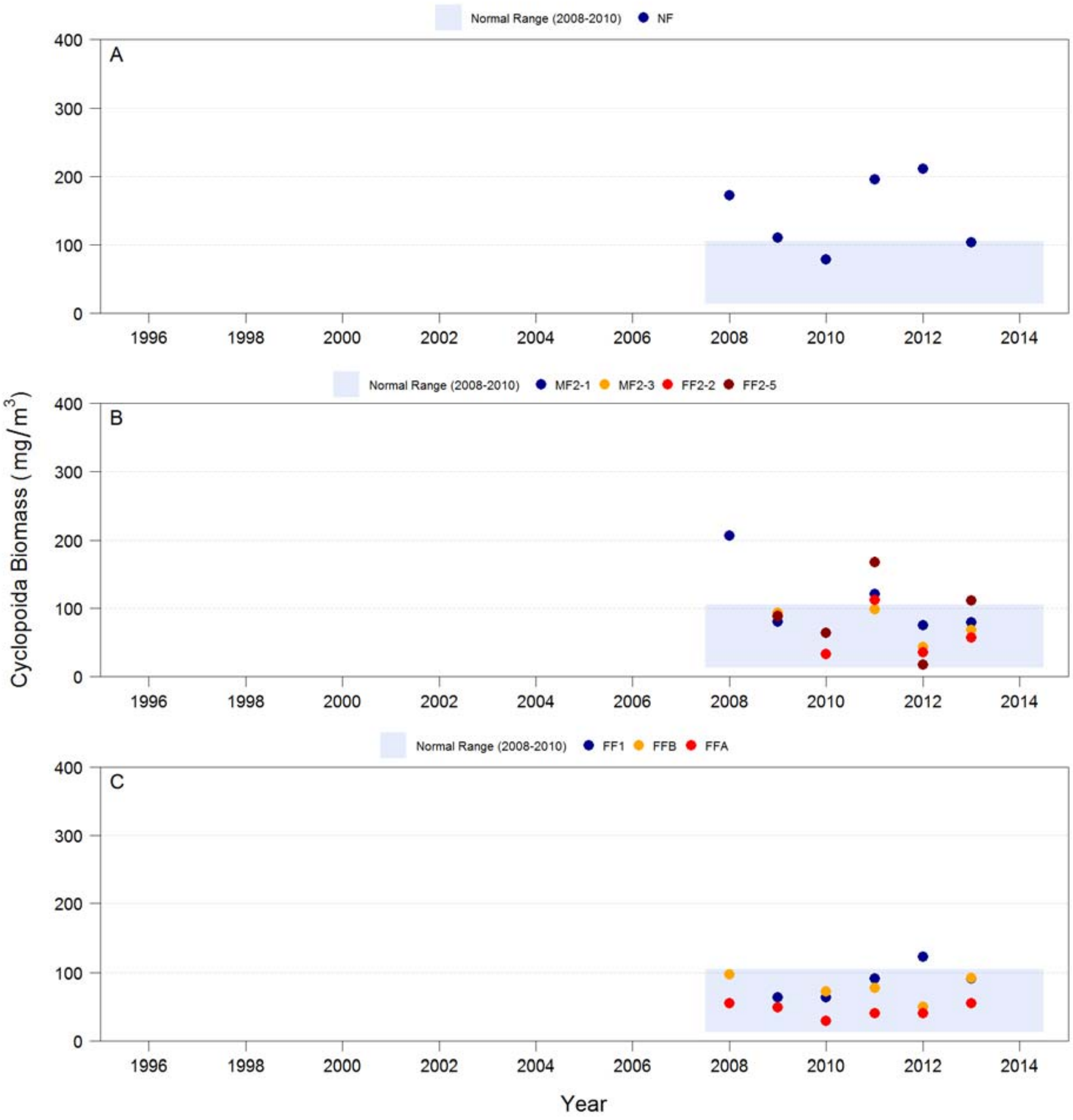


Figure 8-20 Rotifer Biomass in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas

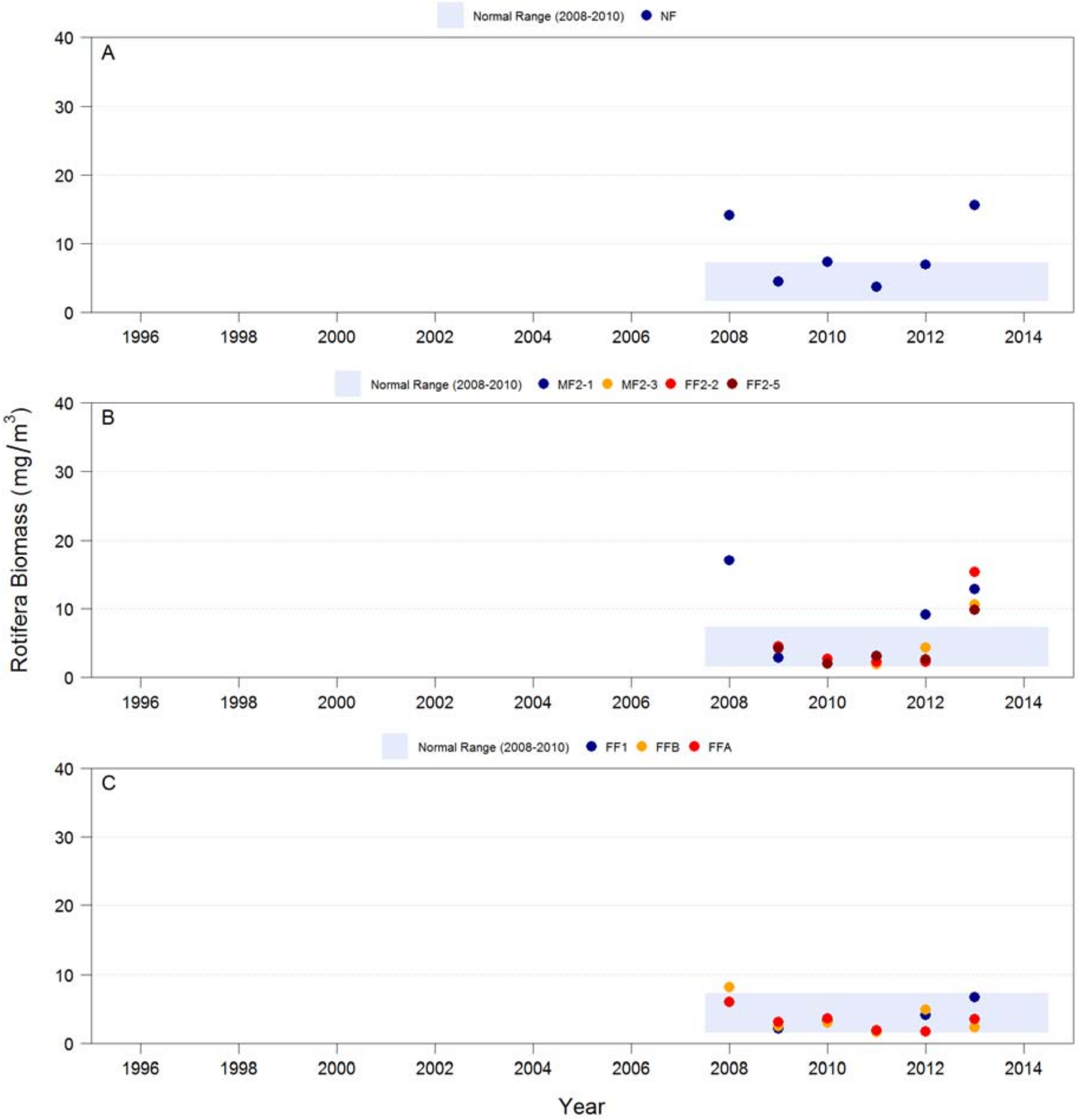


Figure 8-21 Relative Biomass of Cladocerans in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas

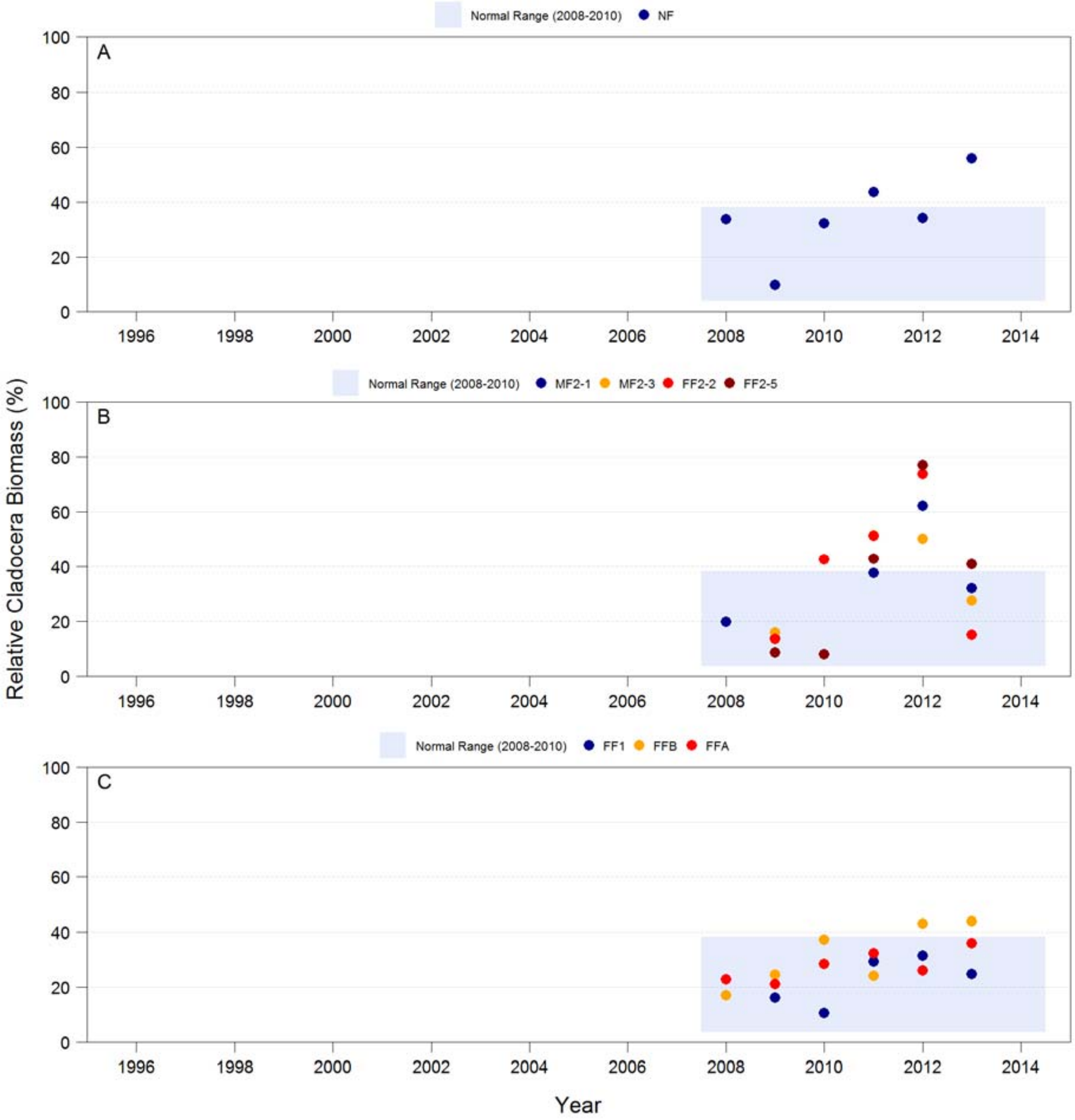


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Figure 8-22 **Relative Biomass of Calanoids in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas**

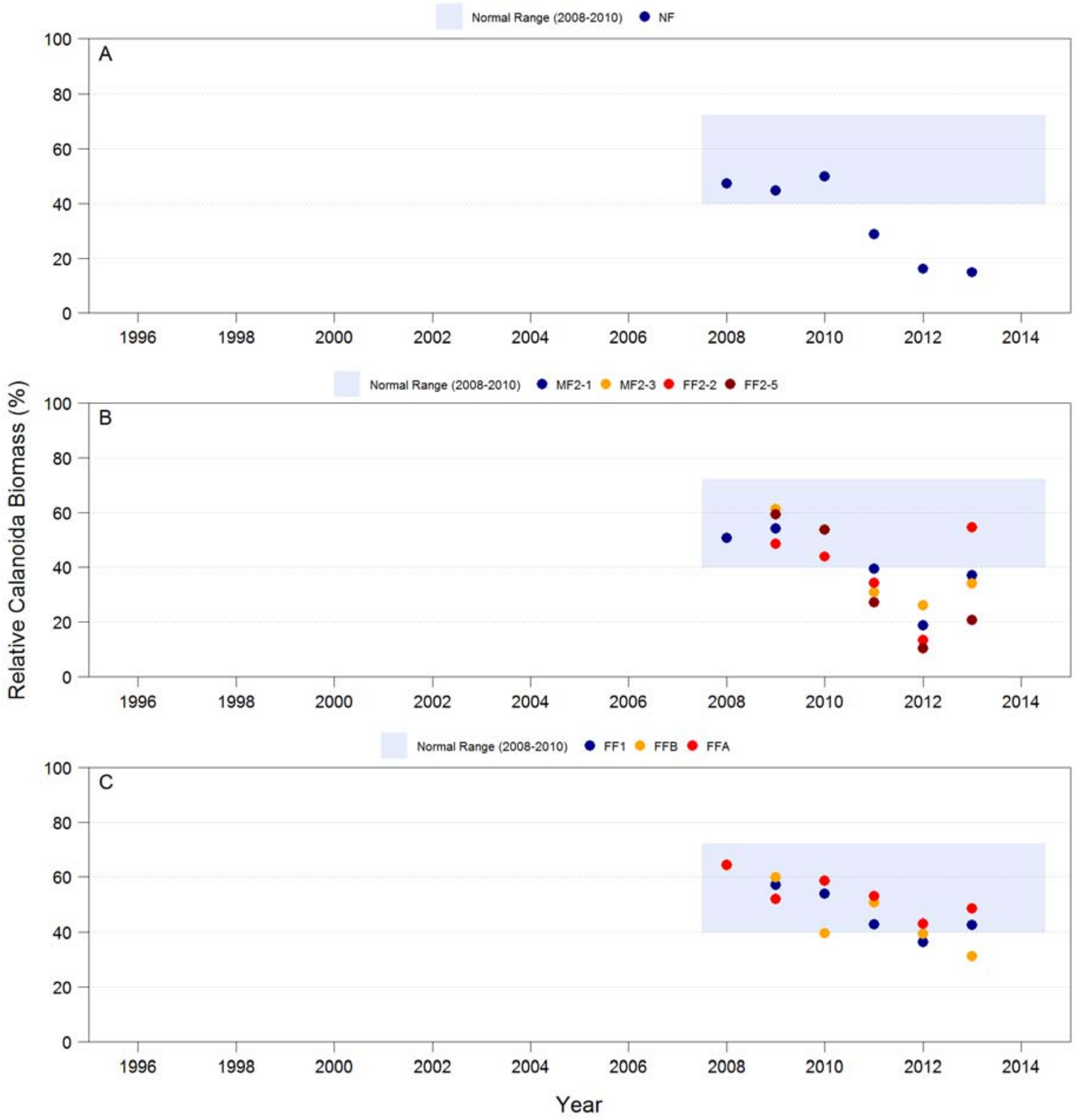

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Figure 8-23 **Relative Biomass of Cyclopoids in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas.**

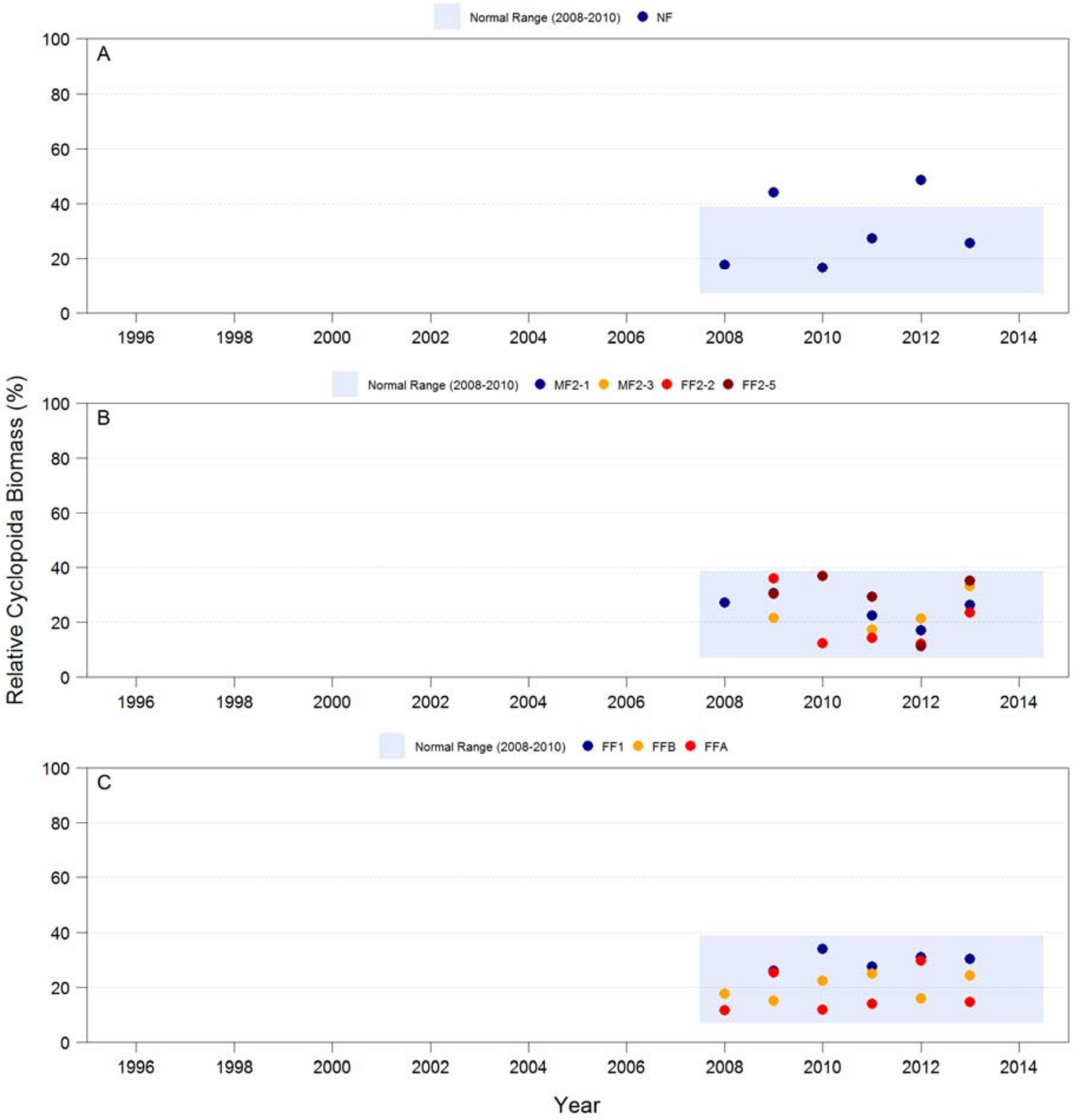
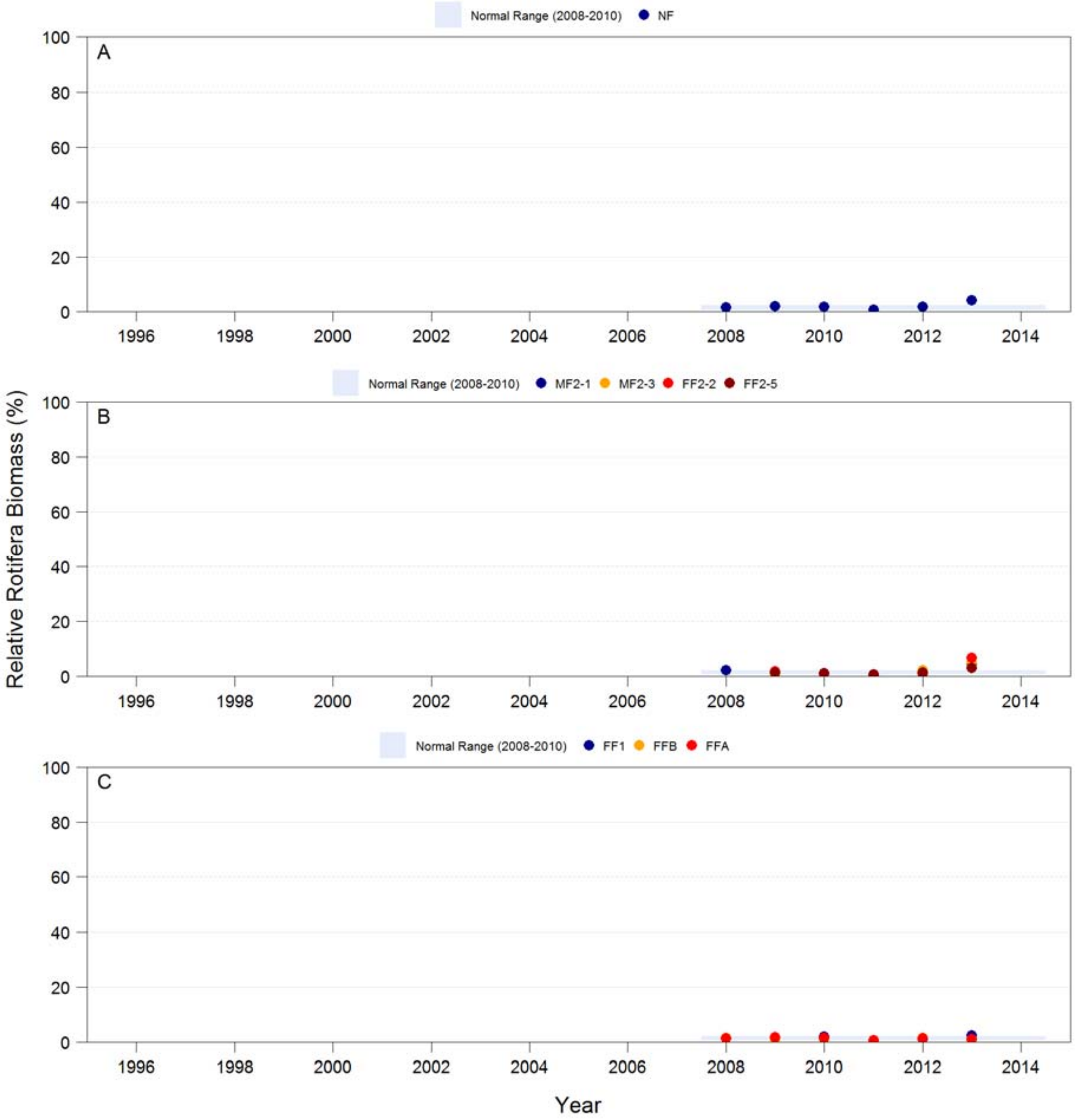


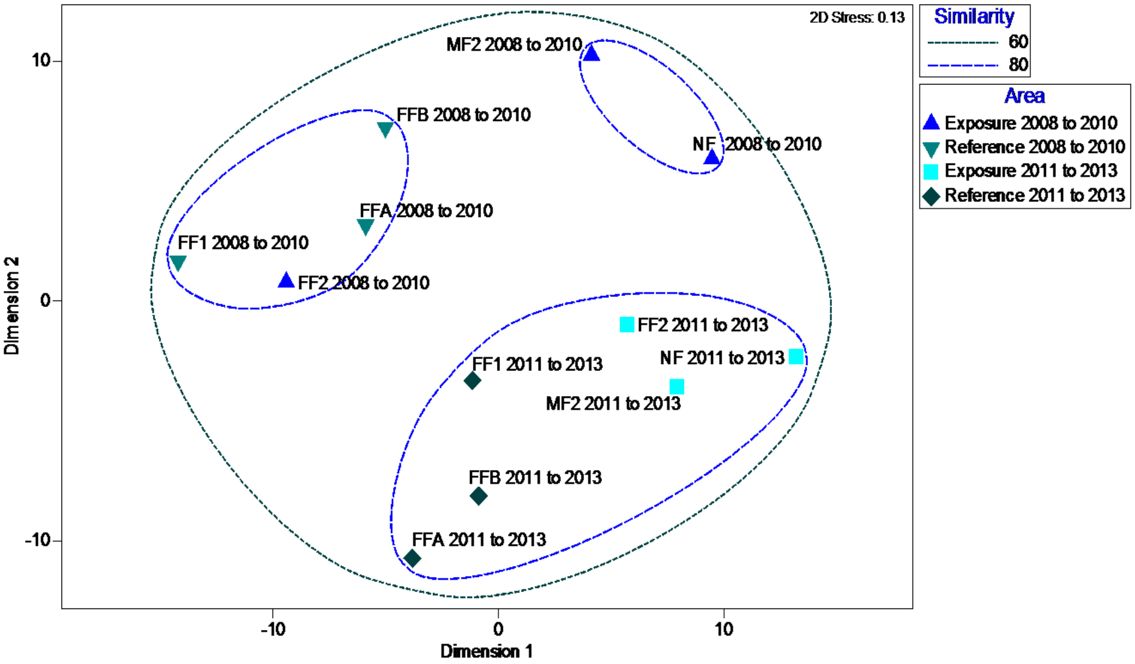
Figure 8-24 **Relative Biomass of Rotifers in the A) Near-field (NF) Sampling Area; at Stations along the B) MF2 and FF2 transect; and in the C) Three Far-field (FF) Reference Areas.**



8.3.2.6 Zooplankton Community Structure

The two dimensional mMDS configuration for zooplankton biomass from 2007 to 2012 had a stress value of 0.13, indicating a reasonable level of fit to the original dataset (Figure 8-25). The SIMPROF test (*P*<0.05) indicated that the level of interpretation of the clusters is acceptable and over-interpretation is unlikely. The ordination plot indicates separation between the area-year groupings in terms of zooplankton community composition, i.e., the 2008 to 2010 data were separate from the 2011 to 2013; however, all area-years clustered within a 60% similarity ellipse. The 2008 to 2010 NF and MF2 areas grouped together showing 80% similarity, while the reference areas (FF1, FFA, and FFB) and the FF2 exposure area grouped together within an 80% similarity ellipse. The 2011 to 2013 data were all within an 80% similarity ellipse, although the exposure areas were separate from the reference areas. The overall analysis of similarities (ANOSIM) test (*R* = 0.78; *P* = 0.001) shows that all the replicates within the area-year grouping are more similar to one another than any replicates from different areas, i.e., data for each individual year for the NF area are similar to one another, but different from data for the individual years for the FFA, FFB, FF1, FF2, or MF2 areas.

Figure 8-25 Metric Multidimensional Scaling of Zooplankton Biomass in Lac de Gras, 2008 to 2013



8.3.3 Comparison to EA Predictions

No specific predictions were made in the EA regarding plankton communities, other than an increase in primary productivity in up to 20% of the surface area of Lac de Gras resulting from the input of nutrients (particularly phosphorus) from the Mine effluent discharge. This increase can be expected to also result in increased secondary productivity (i.e., zooplankton and benthic invertebrates). Increased phytoplankton biomass was observed in exposure areas of Lac de Gras, above the normal range in 2009 to 2013, which is consistent with EA predictions regarding primary productivity. Occasional peaks in zooplankton biomass in exposure areas (in 2009 and 2011) were also consistent with the increased phytoplankton productivity. A more detailed evaluation of EA predictions related to nutrient enrichment is provided in Section 6 (Eutrophication Indicators).

8.4 CONCLUSIONS

- Effect rankings for the WOE assessment have remained within the low to moderate level from 2007 to 2013, with the exception of phytoplankton biomass in 2009 and 2011, which yielded a high ranking, with greater than 20% of the lake being affected.
- The assessment of effects according to Action Levels addresses the toxicological impairment hypothesis. Neither phytoplankton nor zooplankton community variables have demonstrated a toxicological effect in Lac de Gras; therefore, an Action Level 1 for plankton has not been reached.
- The plankton communities in Lac de Gras continue to be exhibiting a Mine-related nutrient enrichment effect in the exposure areas.
- There has been no clear temporal trend in phytoplankton taxonomic richness, which has been increasing in variability and in extent outside the normal range with growing frequency.
- Phytoplankton biomass increased in the NF exposure area from 2003 to 2010, exceeding the normal range in 2006. From 2011 to 2013, phytoplankton biomass decreased, and by 2013, phytoplankton biomass was within the normal range.
- Based on the major phytoplankton groups, there were few temporal trends evident. Some groups (e.g., microflagellates and chlorophytes) had biomass values that exceeded the normal range at many exposure area stations, and MF2 and FF2 stations (microflagellate biomass only) but recent values have been lower. Biomass at stations along the MF2-FF2, and MF1 transects were highly variable and with multiple years and stations outside the normal range for many of the phytoplankton groups..
- The phytoplankton mMDS ordination plot confirmed that there continue to be differences in the phytoplankton community assemblage between exposure and reference areas.
- There were no temporal trends in zooplankton biomass, which remained within the normal range in most years.
- A decrease over time was observed in calanoid copepod biomass and relative biomass in all areas, including the reference areas. This was more pronounced in the exposure areas, where both calanoid biomass and relative biomass declined below the normal range.

- Cladoceran biomass exceeded the normal range in the NF exposure area in most years from 2008 to 2013, and their relative biomass appears to be increasing, with a reversal of the trend in 2013.
- The zooplankton mMDS ordination plot confirms that there continues to be a difference in the zooplankton community assemblage between exposure and the reference areas, though this difference was less pronounced in the 2011 to 2013 period.

9 BENTHIC INVERTEBRATES

9.1 Introduction

This chapter provides a summary of changes observed in the benthic invertebrate communities of Lac de Gras over time. The objectives of this chapter are:

- summarize Mine-related effects observed from 2011 to 2013 and compare them to effects observed previously (i.e., from 2007 to 2010); and
- analyze temporal trends in benthic invertebrate indices for the period extending from the baseline period (i.e., 1996) to 2013.

The benthic invertebrate component of the AEMP over the past three years consisted of one sampling period in 2011 (under the AEMP Version 2.0) and one sampling period in 2013 (under the AEMP Version 3.0), completed during the late open-water season in both years. Benthic invertebrate monitoring in Lac de Gras was conducted in 1996 and 1997 as part of the environmental baseline work supporting the Environmental Assessment (EA). Results from these surveys represented the baseline or pre-development conditions in Lac de Gras. Benthic invertebrates in Lac de Gras have been monitored as part of the Mine's AEMP since 2001. The original AEMP (Version 1.0) included one year of monitoring prior to initiation of the Mine effluent discharge to Lac de Gras in March 2002. The first benthic invertebrate monitoring event to occur with treated effluent being discharged to Lac de Gras was during the open-water season of 2002.

Effects on benthic invertebrates are identified during AEMP surveys by comparing community indices between exposure and reference areas using statistical tests and visual comparisons of spatial trends within Lac de Gras. The present summary report provides an opportunity to examine changes to the nature of effects on the benthic invertebrate community over time.

9.2 Methods

9.2.1 Data Sources

Baseline benthic invertebrate surveys using quantitative methods in areas of Lac de Gras that were also sampled in subsequent years were completed in 1996 and 1997. These surveys used a 15 x 15-cm Ekman grab to sample benthic invertebrates in deep-water areas of Lac de Gras. Three grabs per station were taken from three stations in 1996, and six grabs per station were collected from four closely-spaced stations in 1997. Two of the baseline sampling locations were close to present-day AEMP sampling stations; these were N7 (1996; near the current NF-2 station) and F14 (1996 and 1997); near the current MF2-1 station).

Using field methods similar to those used in the baseline studies, the 2001 to 2006 AEMP programs sampled benthic invertebrates at three closely-spaced stations in the NF area (LDG-NF; near the current NF-5 station), MF2 area (LDG-MF; near the current MF2-1 station) and just north of the FFA reference area (LDG-FF; near the current FFA-5 station).

Although field methods were similar among sampling programs and were also similar to those used during the most recent AEMP survey, three factors limit comparability of data among programs:

- During the 1996 and 1997 baseline surveys, a 250-μm mesh sieve was used to screen samples in the field and during sample processing in the laboratory, whereas 500-μm mesh screens were used in 2001 to 2013. Although results of an analysis of differences in data sets collected with different mesh sizes indicated that effects can be reliably detected using either mesh size (DDMI 2011b), abundances in the 1996 and 1997 data sets are expected to be greater than those reported during subsequent surveys.
- Large numbers of midges (Chironomidae) in the 1996 and 1997 baseline samples were only identified to subfamily/tribe or family taxonomic levels, whereas taxonomists processing samples from 2001 to 2013 identified midges to genus, with very few organisms left at higher taxonomic levels. Although the 1996 and 1997 data were included in the calculation of summary variables for the temporal trend analysis, these data were not included in the multivariate analysis, which requires consistent taxonomy of all samples to provide accurate results.
- Sampling designs varied among programs, which may affect representativeness, spatial coverage and temporal variation of the summarized data. For example, the NF area mean for richness (i.e., the number of invertebrate taxa present) is based on the richness from the five NF stations. In contrast, the NF area richness for 1996 and 1997 is based on a single station. Consequently, the baseline data are expected to exhibit lower richness and more variation over time compared to area means calculated from multiple stations.

9.2.2 Data Analysis

9.2.2.1 Data Preparation and Variable Selection

Benthic invertebrate data were prepared for the trend evaluation by deleting non-benthic (i.e., planktonic and terrestrial) organisms and meiofauna (Nematoda, Harpacticoida, Ostracoda), converting numbers per sample to numbers per square metre, and averaging data for closely-spaced stations in the 1996 to 2006 data sets. Consistency in taxonomic level of identification was evaluated among years, and adjustments were made where appropriate. For example, certain taxa at some stations were re-classified to a higher level to match the taxonomic resolution of the remainder of the data. Historical data (1996 and 1997; 2001 to 2006) were excluded from Bray Curtis distance measures due to different taxonomic resolutions between those periods and the more recent years of monitoring.

The following benthic community variables were included in the analysis:

- total density;
- taxonomic richness (richness);
- dominance (percent contribution of the dominant taxon);
- Simpson's diversity index;
- evenness;
- Bray-Curtis distance;

- percent Chironomidae;
- Pisidiidae density;
- *Procladius sp.* density;
- *Heterotrissocladius sp.* density; and
- *Micropsectra sp.* density.

These variables included standard benthic community variables (total density and richness), community indices (dominance, diversity, evenness, Bray-Curtis distance and percent Chironomidae) and densities of common invertebrates that together accounted for close to 80% of the total abundance at stations in Lac de Gras.

9.2.2.2 Changes from 2007 to 2010 Summary Report

Bray-Curtis distance values have historically been calculated by comparing the benthic community of each station to the median reference area community (using pooled reference area data). This method was formerly recommended by the technical guidance document for metal mining EEM (Environment Canada 2012). In 2011 and 2013, Bray-Curtis distance values were calculated using the “all pair-wise comparisons” method, which is described in the 2011 AEMP Benthic Invertebrate Report (Golder 2012a). Huebert et al. (2011) pointed out that using the reference median value as the basis for calculating Bray-Curtis distance values would result in frequently finding effects where none exist, referred to as a Type I error. To correctly calculate Bray-Curtis distance, Huebert et al. (2011) recommended that pairwise, among-area comparisons of individual reference and exposure stations be conducted to generate Bray-Curtis distance values for statistical comparisons. To allow results of the 2011 and 2013 AEMPs to be compared to earlier AEMP results, Bray-Curtis distances for 2007 to 2010 were re-calculated using the pairwise method.

Gradient analyses have been conducted during annual AEMP data analyses of benthic invertebrate data to help link changes in the benthos to Mine effluent. These analyses were conducted with a linear regression of benthic community variables against the concentration of barium (an indicator of effluent concentration) along each transect (i.e., each MF area). Given that the reliability of barium as an effluent tracer has been questioned (Section 5) due to decreasing concentrations in effluent (Section 4), recent AEMP reports (i.e., 2011 and 2013) have used distance from the diffuser as the measure of effluent exposure. Therefore, the regressions were re-run for previous years against distance from the diffuser to be consistent with the new method (Appendix 9B).

This change in the regression analysis led to a change in the moderate level criterion for the Weight of Evidence Effects Rankings (See Section 9.2.2.4.1). In previous years, a significant regression combined with a coefficient of determination (r^2) >0.5 indicated a moderate effect ranking. A moderate effect ranking now requires that there be a statistical difference in slopes among years and that this difference be indicative of a more pronounced effect.

9.2.2.3 Normal Ranges

In addition to comparisons of benthic communities between reference and exposure areas, and evaluation of spatial trends, magnitudes of effects on benthic invertebrate variables were also evaluated by comparing each variable in the exposure areas to background values. Background values for Lac de Gras are those that fall within the range of natural variability, referred to as the normal range. The normal ranges used to evaluate potential effects on the benthic invertebrate community were obtained from the AEMP Reference Conditions Report, Version 1.1 (Golder 2015) and are summarized in Table 9-1.

Table 9-1 Normal Range Values for Benthic Invertebrate Endpoints

Variable	Units	Normal Range	
		Lower Limit	Upper Limit
Total Density	no/m^2	110	998
Richness	no of taxa	4.3	15.0
Dominance	%	21.7	57.3
Simpson's Diversity Index	-	0.60	0.86
Evenness	-	0.23	0.76
Bray-Curtis Distance	-	0.45	0.81
Percent Chironomidae	%	46.9	91.3
Pisidiidae Density	no/m^2	0	206
Procladius sp. Density	no/m^2	0	150
Heterotrissocladius sp. Density	no/m^2	0	203
Micropsectra sp. Density	no/m^2	0	172

no./m^2 = number per square metre; for density variables, the reference area data were $\log_{10}$+1 transformed for calculating normal ranges and then the upper and lower limits were back-transformed. Sample sizes were n = 51 for normal range calculations.

9.2.2.4 Summary of Effects

9.2.2.4.1 Weight of Evidence Effects Rankings

Benthic invertebrates were assessed for Mine related effects according to the WOE effects framework described in Section 11 and summarized in Table 9-2. The benthic community analysis annually evaluates two types of potential effects on the benthic community: nutrient enrichment and toxicological impairment. The type of effect is based on the direction of differences in benthic community variables between exposure and reference areas. For example, greater invertebrate densities and taxonomic richness in exposure areas would reflect nutrient enrichment, whereas lower densities and richness could indicate toxicological impairment.

Table 9-2 Weight of Evidence Effect Rankings for Benthic Invertebrates

Analysis	Effect Ranking	Guidelines and Effect Sizes
Comparison to Reference Areas: Indices	Low	Statistical difference between NF and reference areas
	Moderate	**Low** level effect **AND** NF area mean outside normal range
	High	A **moderate** level effect beyond the NF area
Comparison to Reference Areas: Relative Abundances	Low	Difference in relative abundances of major taxa between NF and reference areas
	Moderate	Difference in relative abundances of major taxa in NF and first MF stations compared to reference areas
	High	Difference in relative abundances of major taxa extending farther into the MF area, or loss of a major taxon from community in the NF area
Gradient Analysis	Low	Significant regression between endpoint and distance from the diffuser (an indicator of effluent exposure)
	Moderate	**Low** level effect **AND** a significant change in the slope from previous data (e.g., 2007 to 2010) that is indicative of a more pronounced effect
	High	Not defined

NF= Near field; MF= Mid-field.

9.2.2.4.1 Action Levels

The importance of effects to benthic invertebrate assessment endpoints was categorized according to Action Levels described in Golder (2014a). The goal of the Response Framework is to ensure that significant adverse effects never occur. A significant adverse effect, as it pertains to aquatic biota, was defined in the Environmental Assessment as a change in fish population(s) that is greater than 20% (Government of Canada 1999). This effect must have a high probability of being permanent or long-term in nature and must occur throughout Lac de Gras. The Significance Thresholds for all aquatic biota, including benthic invertebrates, are therefore related to impacts that could result in a change in fish population(s) that is greater than 20%. Although the AEMP addresses two broad impact hypotheses for Lac de Gras, the toxicological impairment hypothesis and the nutrient enrichment hypothesis, the Action Levels for benthic invertebrates address the toxicological impairment hypothesis.

Benthic invertebrates are assessed by comparing variables in the NF exposure area against those in the three FF reference areas (FFA, FFB, and FF1). The occurrence of an Action Level 1 is determined by finding a significantly lower mean value in the exposure area compared to all of the reference areas for that year (Table 9-3). If a benthic invertebrate community variable is lower in the NF area compared to all reference areas, then the subsequent year of monitoring must demonstrate the same effect to confirm that an Action Level 1 has occurred (i.e., that there is a toxicological effect present). Conditions required for Action Levels 1 to 3 are defined in Table 9-3, and Action Level 4 will be defined if Action Level 3 is reached.

Table 9-3 Action Levels for Benthic Invertebrate Effects

Action Level	Criteria	Extent	Action
1	The mean of a community variable [(a)] significantly lower than reference area means.	Near-field	Confirm effect
2	The mean of a community variable [(a)] significantly lower than reference area means.	Nearest Mid-field stations	Investigate cause
3	The mean of any community variable [(a)] lower than normal range.	Near-field	Examine ecological significance Set Action Level 4 Identify mitigation options
4	To be determined [(b)]	-	Define conditions required for the Significance Threshold
5	Decline of community variables [(a)] likely to cause a >20% change n fish populations(s).	Far-field A (FFA)	Significance Threshold

a) Refers to variables such as total density, richness, Simpson's diversity index, Bray-Curtis index and densities of dominant taxa; the criterion for the Bray-Curtis index is a significantly higher mean value compared to the reference areas;

b) To be determined if an Action Level 3 effect is reached.

>= greater than.

9.2.2.5 Temporal Trends

9.2.2.5.1 Time Series Plots

Temporal trends in benthic invertebrate community variables were evaluated using time series plots. Five plots were created for each variable:

- Mean of the NF area;
- MF2-1, MF2-3, FF2-2 and FF2-5 station data;
- Mean of the FF1, FFA, and FFB reference areas;
- MF1-1 to MF1-5 station data (MF1-5 was not sampled in 2007 to 2011; MF1-2 and MF1-4 were not sampled in 2013); and
- MF3-1 to MF3-7 station data (only four stations were sample along this transect from 2007 to 2011).

Benthic community variables at each MF station were plotted individually, because each MF station is subject to a different level of effluent exposure. All plots included a shaded region showing the normal range (Table 9-3) determined in the AEMP Reference Conditions Report Version 1.1 (Golder 2015). Although the main objective of the trend analysis was to assess trends in the exposure area, reference area plots were prepared to allow a visual evaluation of potential trends in areas unaffected by the Mine, and to verify that Mine-related effects are not occurring in these areas.

Temporal trends in community composition were also examined graphically. Relative abundances of major invertebrate groups for each year were plotted as stacked bar graphs.

9.2.2.5.2 Statistical Analysis

The statistical significance of a temporal trend in the NF area was tested with the Mann-Kendall test, which is a nonparametric rank based trend test for non-seasonal data. Mann-Kendall trend test results were considered significant at $P < 0.1$. Statistical testing was conducted with SYSTAT, version 13.0 for Windows (SPSS Inc., Chicago, IL).

Changes over time in the structure of the benthic invertebrate community were further explored with multivariate statistical analysis. Benthic invertebrate community structure was summarized by nonmetric multidimensional scaling (nMDS), which is a non-parametric ordination method (Clarke 1993). Data were log (x+1) transformed to improve the separation of the data among stations on the nMDS plots and to reduce weighting of the analysis by the most abundant taxa. Station groupings were based on the previous four-year summary (2007 to 2010) and the current three-year summary (2011 to 2013). Area means were determined for each of the exposure (NF, MF and FF2) areas and each of the reference (FFA, FFB, and FF1). A Bray-Curtis resemblance matrix was generated, and the nMDS procedure was applied to this matrix. Using rank order information, the nMDS data were scaled in Primer, version 7 for Windows (PRIMER-E Ltd., Plymouth, UK), and the relative positions of the area-year groupings were determined in two dimensions based on community composition. Goodness-of-fit was determined by examining the Shepard diagrams as well as the stress values, which were calculated from the deviations in the Shepard diagrams. Lower stress values (i.e., less than 0.10) indicate less deviation and a greater goodness-of-fit. Points that fall close together on the nMDS ordination plot represent samples with similar community composition, and points that are far apart from each other represent samples with dissimilar community composition.

A cluster analysis of the species similarity matrix was also used to define the species assemblages (i.e., groups of species that tend to co-occur in a parallel manner across the area-year groupings were clustered together). A similarity profile (SIMPROF) test was preformed to test the hypothesis that within each clustering there is no genuine evidence of multivariate structure, which safeguards against over-interpretation of the data at finer-level clusters (Clarke et al. 2014). Clusters showing approximately 60% and 80% species similarities were superimposed on the nMDS ordination plot to visually evaluate the similarity matrix in the ordination space.

An analysis of similarities (ANOSIM) test, which is based on a non-parametric permutation procedure and is applied to the similarity matrix (rank) underlying the ordination or classification of the samples, was performed on the nMDS similarity matrix (Clarke et al. 2014). The ANOSIM test statistic (R) computes differences among the area-year groupings and contrasts these differences with the within area-year replicates. The significance level of the R statistic is based on the probability of a particular permutation occurring out of 1,000 permutations ($P = 0.1$).

9.3 Results

9.3.1 Summary of Effects

9.3.1.1 Weight-of-Evidence Effects Rankings

9.3.1.1.1 Comparison to Reference Areas

Annual monitoring during 2007 to 2013 identified mine-related effects of varying degrees in the NF area (Table 9-4). Total density, richness, and densities of *Procladius* sp. and *Heterotrissocladius* sp. have exhibited at least low effect rankings in most years of monitoring, and the direction of the effect has been consistent with the exception of that for richness. The direction of the effect for richness has alternated from a negative direction to a positive direction and back to a negative in 2011. There was no effect on richness in 2013. Other variables such as dominance, diversity, densities of Pisidiidae and *Micropsectra*, and percent Chironomidae have shown effects, but these have been inconsistent over the years. Relative abundance of the major invertebrate groups only exhibited effects in 2007 and 2008. The magnitude of the effect rankings has remained the same or has decreased in the last two years of monitoring.

Table 9-4 Summary of Weight of Evidence Effect Rankings for Benthic Invertebrate Endpoints Based on Comparisons of Reference and Exposure Areas

Variable	2007	2008	2009	2010	2011	2013
Total Density	0	↑	↑↑	↑↑↑	↑↑	↑
Richness	0	↓	↓	↑	↓	0
Dominance	0	0	↑	0	0	0
Simpson's Diversity Index	0	0	↓	0	0	0
Evenness	0	0	0	0	0	0
Bray-Curtis Distance	0	0	0	0	0	0
Pisidiidae Density	0	↑↑	↑↑	↑↑↑	0	0
Procladius sp. Density	↑↑↑	↑↑↑	↑↑↑	↑↑↑	↑↑↑	↑↑↑
Heterotrissocladius sp. Density	0	↓	↑↑	↑↑	↑↑	↑
Micropsectra sp. Density	N/A	0	↑	↑↑	0	0
Percent Chironomidae	0	↓	0	0	↑	0
Relative Abundance of Major Taxa	0	0	0	0	↑(C)	↑(C)/↓(P)

Notes: The direction of the arrow indicates the direction of change or relationship, where a positive direction indicates potential eutrophication and a negative direction indicates a potential toxic effect.

0 = No effect; ↑/↓ = Low effect ranking; ↑↑/↓↓ = Moderate effect ranking; ↑↑↑/↓↓↓ = High effect ranking; N/A = Not analyzed; (C) = Chironomidae; (P) = Pisidiidae; arrows in last row indicate direction of >10% difference in NF area relative to range in reference area.

9.3.1.1.2 Gradient Analysis

Total density and *Procladius* sp. density had low level effects in the direction of nutrient enrichment during all years, with greater densities in the NF area and declining with distance away from the diffuser (Table 9-5). Similar effects were seen on densities of the major groups, but not in all years. Richness was unaffected, except in 2009, when a low level effect occurred indicating lower richness in the NF area compared to reference areas.

Community indices varied among years and variables. Dominance, Bray-Curtis distance and percent Chironomidae have indicated the potential for low level nutrient enrichment, while both Simpson's diversity index and evenness indicated low level effects consistent with toxicity (Table 9.5). These responses did not occur consistently every year, nor did the various responses occur at the same time.

Directions of effects detected by both the reference/exposure comparisons and gradient analyses were consistent for densities and dominance, which were greatest in exposed areas. These variables, therefore, support the nutrient enrichment hypothesis. The Simpson's diversity index and evenness were at times lower in the NF area according to the gradient analysis; however, statistical comparisons between exposure and reference areas did not reveal statistical differences (except for diversity in 2009). Therefore, the evidence is inconclusive about these responses (when they occur) representing toxicological effects. Moreover, it is possible to encounter lower diversity and evenness under nutrient enriched conditions, because enrichment can result in increased dominance by species that can readily take advantage of the increased primary productivity.

Table 9-5 Summary of Weight of Evidence Effect Rankings for Benthic Invertebrate Endpoints Based on Gradient Analysis

Variable	2007	2008	2009	2010	2011	2013
Total Density	↓	↓	↓	↓	↓	↓
Richness	0	0	↑	0	0	0
Dominance	↓	0	↓	0	↓	0
Simpson's Diversity Index	↑	0	↑	0	↑	0
Evenness	↑	0	0	↑	0	↑
Bray-Curtis Distance	0	0	↓	0	0	0
Pisidiidae Density	0	↓	↓	↓	0	0
Procladius sp. Density	↓	↓	↓	↓	↓	↓
Heterotrissocladius sp. Density	0	0	↓	0	↓↓	0
Micropsectra sp. Density	↓	↓	0	0	↓	0
Percent Chironomidae	↑	0	0	0	↓	↓

0 = No effect; ↑ = Low effect ranking, positive slope; ↓ = Low effect ranking, negative slope; ↓↓ = Moderate effect ranking with a greater negative slope compared to slopes from 2007 to 2010.

9.3.1.2 Action Levels

Richness, *Heterotrissocladius* sp. density and percent Chironomidae in 2008; richness, Simpson's diversity index in 2009; and richness in 2011 met the criterion for an Action Level 1 (NF area significantly lower than reference area). These responses were not encountered in subsequent years, except in richness. The effect on richness was not detected again in 2013. Thus the Action Level 1 exceedances were transient for all affected variables.

9.3.2 Assessment of Trends

9.3.2.1 Total Invertebrate Density and Richness

Total invertebrate density increased sharply from 2001 to 2004, fluctuated widely between 2004 and 2007, finally stabilizing after 2007. Although values were above the normal range in 2009, 2010 and 2011 in the NF area, values for 2013 were back within the normal range for most areas (Figure 9-1). The greater variation in historical NF data may in part reflect the smaller number of stations in the NF area, which consisted of three closely-spaced stations. The NF mean presented for 2007 to 2013 was based on five stations. In general, no obvious trends are apparent in the MF or reference areas. The Mann-Kendall trend test indicated no significant trend for total density in the NF Area, or for any other variables (Table 9-6).

Table 9-6 Mann-Kendall Trend Analysis for Benthic Invertebrate Endpoints for the Near-field Area

Variable	Tau (τ)	*P*-value
Total Density	-0.07	0.547
Richness	0.33	0.207
Dominance	0.14	0.352
Simpson's Diversity Index	0.47	0.119
Evenness	-0.47	0.119
Bray-Curtis Distance	-0.47	0.880
% Chironomidae	0.07	0.453
Pisidiidae Density	-0.33	0.212
Procladius sp. Density	-0.33	0.212
Heterotrissocladius sp. Density	-0.33	0.212
Micropsectra sp. Density	-0.20	0.679

Notes: Mann-Kendall test results were considered significant at $P<0.1$.

Tau = Kendall's rank correlation co-efficient.

Richness values from 2001 to 2006 appeared to be greater than those since 2007, with the highest values occasionally above the upper limit of the normal range in 2004 and 2006 (Figure 9-2). More recently (2010 onward), richness values have remained near the middle of the normal range, with the exception of the FF1 area in 2011. Mann-Kendall trend tests indicated no significant trends for richness for the NF area (Table 9-6).

Figure 9-1 Mean Total Invertebrate Density over Time at A) the Near-field (NF) Area, B) Mid-field Stations along the MF2-FF2 Transect, and C) at the three Far-field Reference Areas

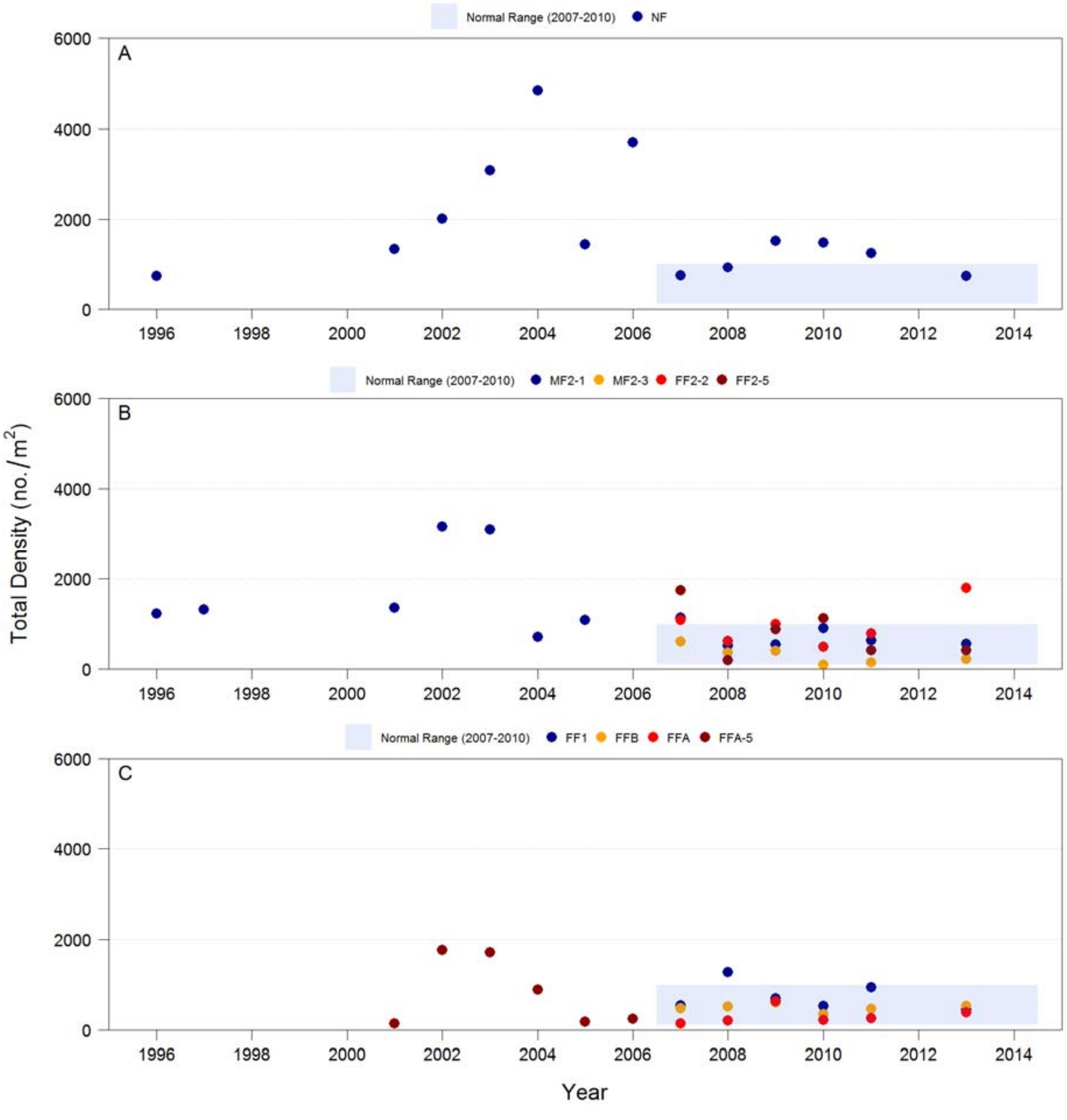
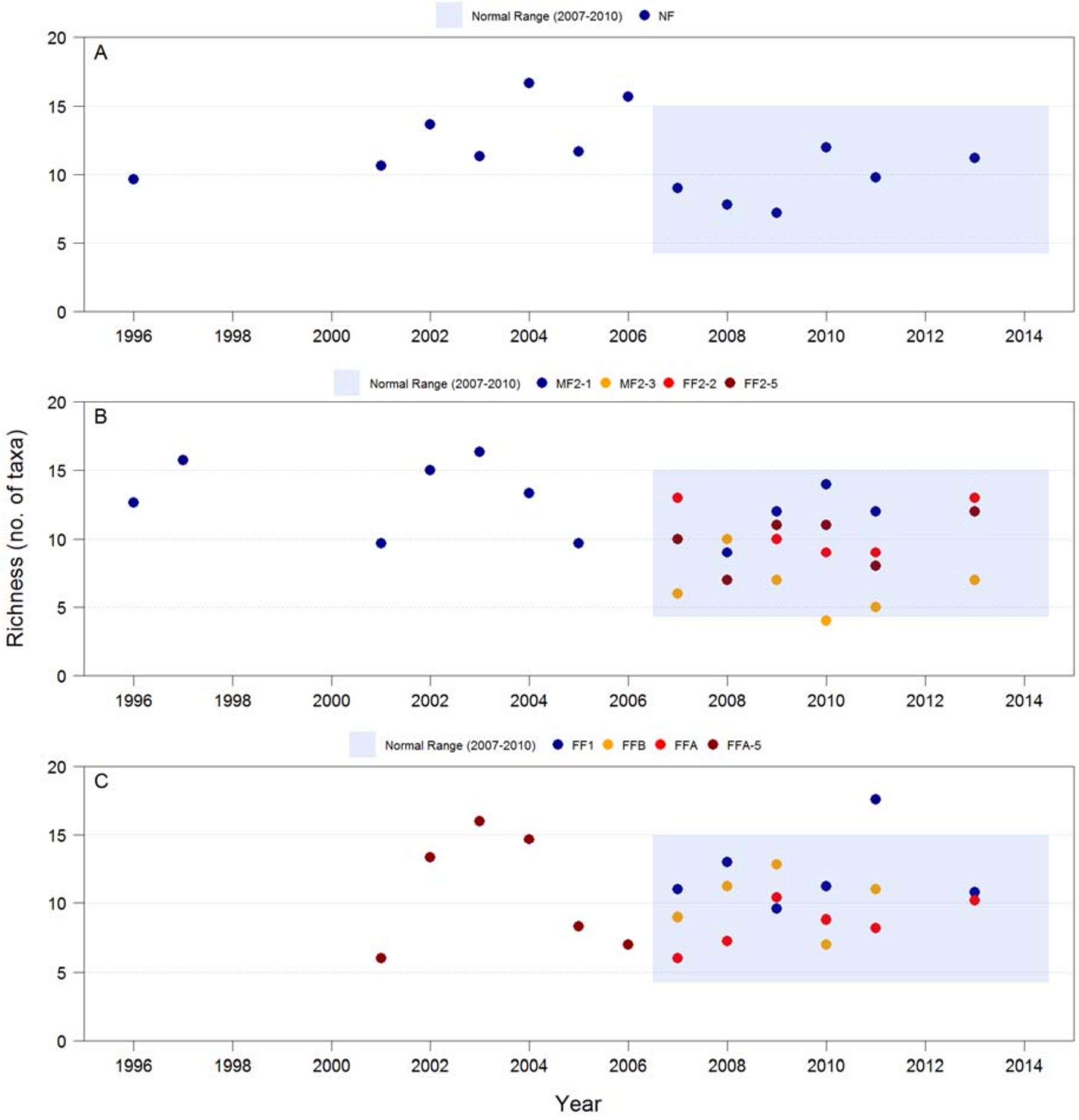


Figure 9-2 **Mean Richness over Time at A) the Near-field (NF) Area, B) Mid-field Stations along the MF2-FF2 Transect, and C) at the three Far-field Reference Areas**



9.3.2.2 Benthic Community Indices

Dominance in the NF area demonstrated considerable variability up until 2007, with values exceeding the normal range in 2003 (Figure 9-3). The lowest value occurred in 1996. Since 2007, values have remained within the normal range. The greatest dominance values were encountered along the MF2-FF2 transect, and from 2007 to 2011, values were often above the upper limits of the normal range at the FF2-2 station. By 2013, dominance was less variable among stations, and values were within the normal range. Trend analysis indicated no significant trends in the NF area (Table 9-6).

The Simpson's diversity index showed the opposite pattern to dominance, with exposure area values occurring below the normal range in 2003 in the NF area, and up until 2009 at stations in the FF2 area (Figure 9-4). Nevertheless, exposure area values have remained relatively unchanged in recent years. No significant trends were detected by the Mann-Kendall trend analysis (Table 9-6).

Evenness in the NF area and at the MF2-2 station was below the normal range until 2004 and then increased and remained within the normal range since 2007 (Figure 9-5). Evenness along the MF2-FF2 transect was variable among stations, though the lowest values have consistently been encountered at Station FF2-2. Bray-Curtis distance in the NF area has been similar to that in the reference areas with all values occurring within the normal range (Figure 9-6). Similarly to evenness, the Bray-Curtis distance exhibited the lowest values in the FF2 area, with most values below the normal range. Trend analysis revealed no significant result for both evenness or Bray-Curtis distance (Table 9-6).

The proportion of the benthic community in Lac de Gras composed of chironomids appears to undergo substantial natural variation (Figure 9-7C). The mean percent Chironomidae in the NF area has consistently been within the normal range for Lac de Gras, as has percent Chironomidae along the MF2-FF2 transect (with three exceptions at individual stations). Trend analysis revealed no significant result for this variable (Table 9-6).

All benthic community variables remain within normal ranges in the reference areas, demonstrating no effects of the effluent in these areas.

Figure 9-3 Mean Dominance over Time at A) the Near-field (NF) Area, B) Mid-field Stations along the MF2-FF2 Transect, and C) at the three Far-field Reference Areas

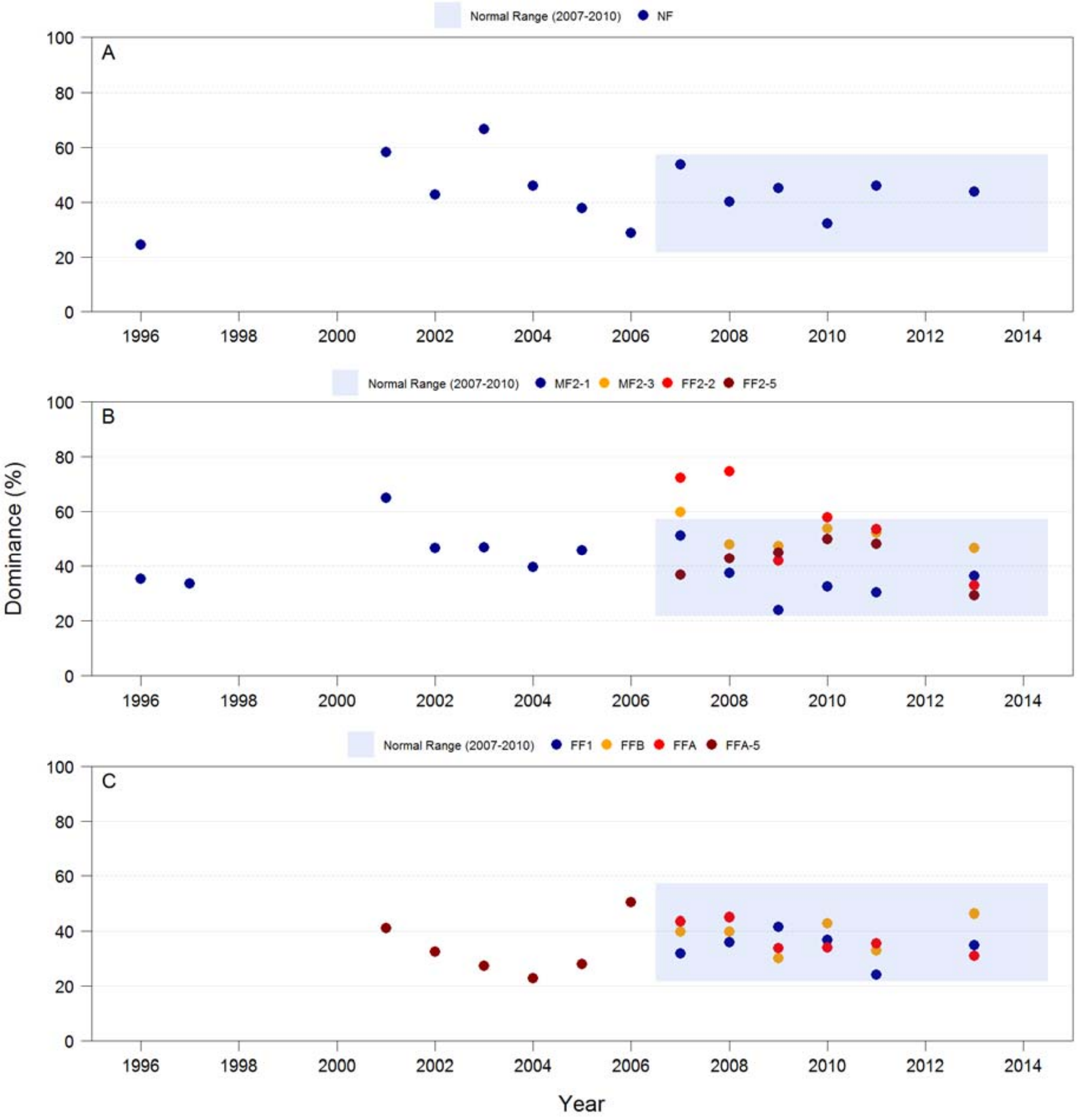


Figure 9-4 Mean Simpson's Diversity Index over Time at A) the Near-field (NF) Area, B) Mid-field Stations along the MF2-FF2 Transect, and C) at the three Far-field Reference Areas

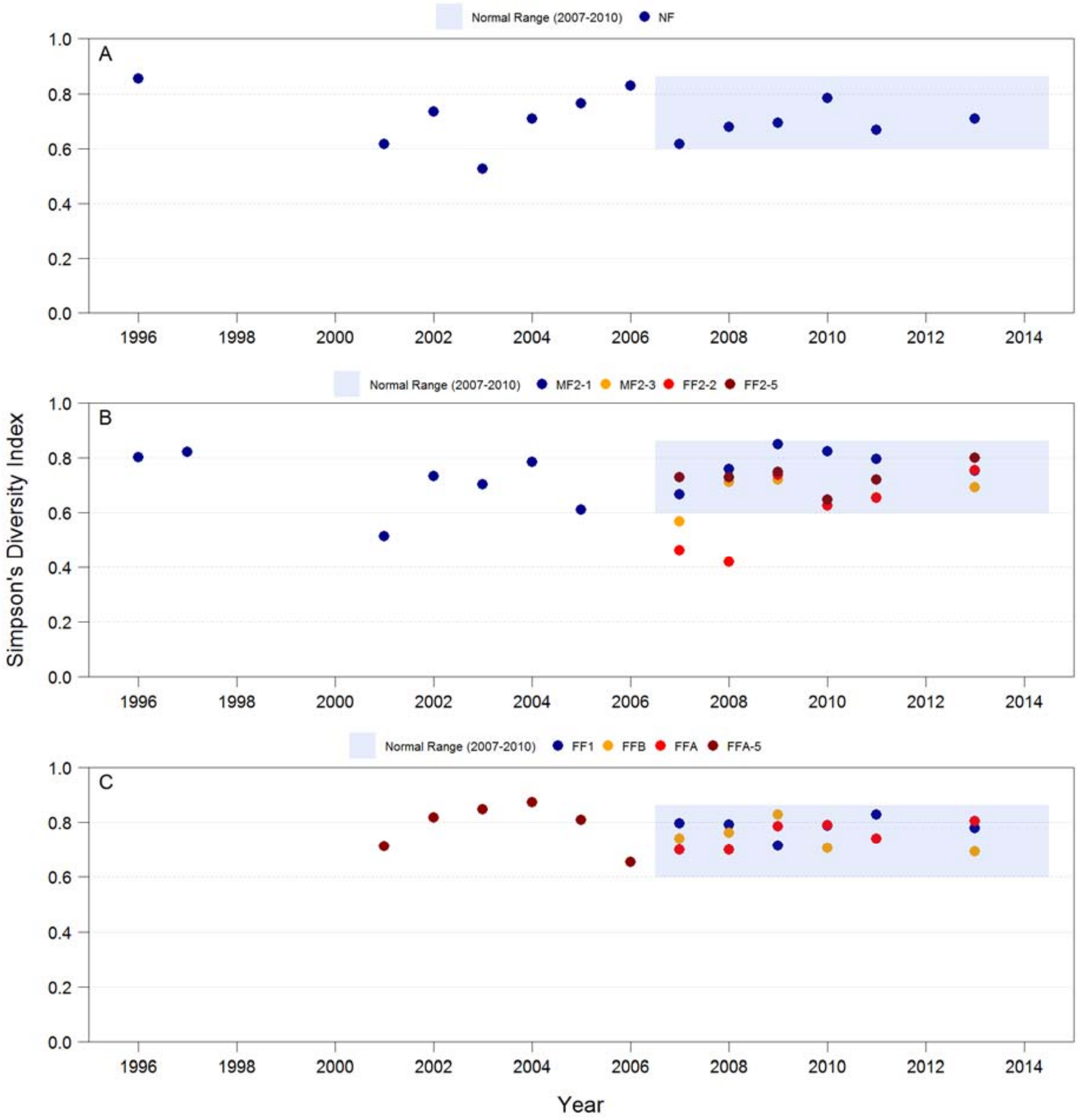


Figure 9-5 **Mean Evenness over Time at A) the Near-field (NF) Area, B) Mid-field Stations along the MF2-FF2 Transect, and C) at the three Far-field Reference Areas**

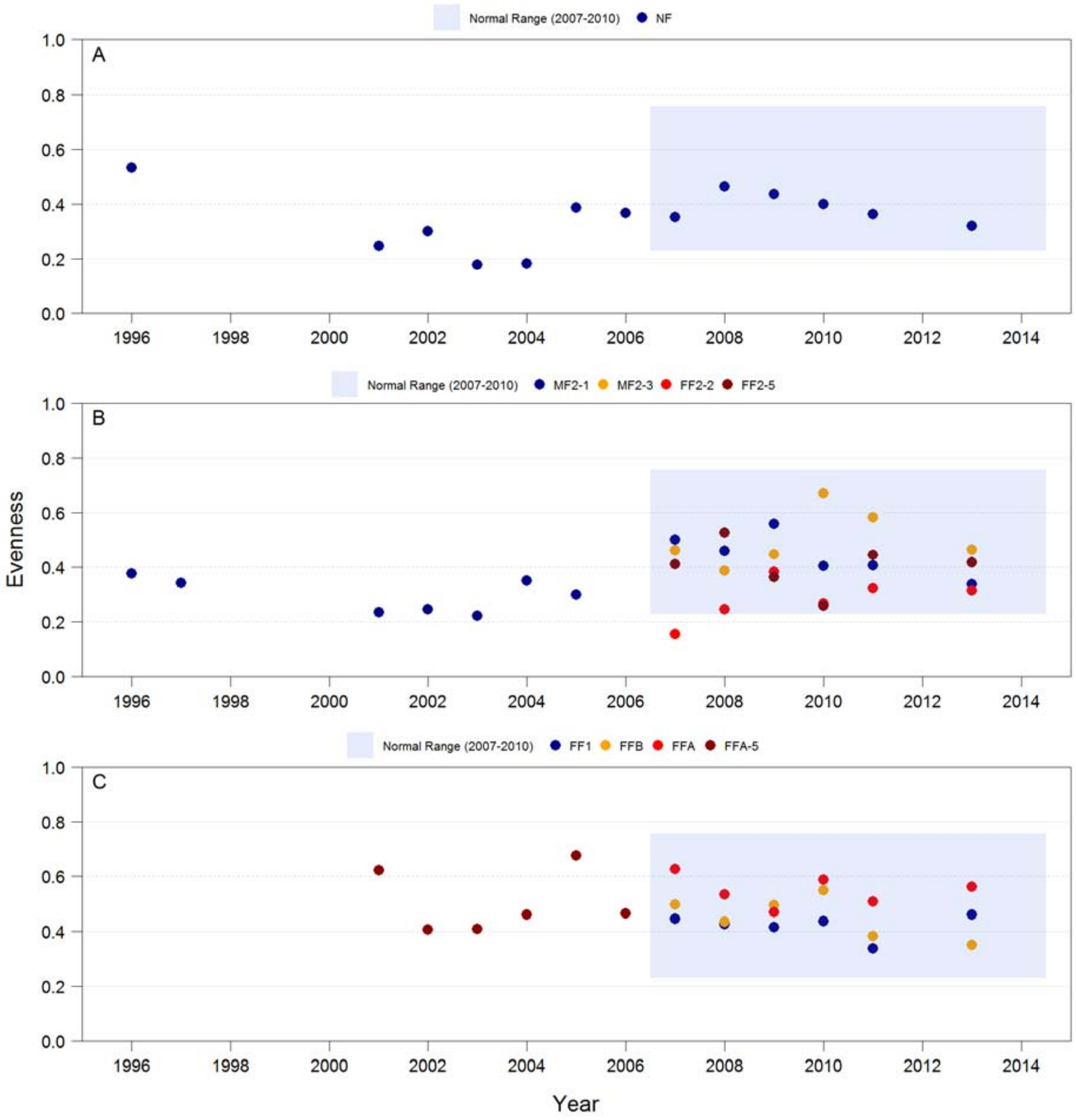


Figure 9-6 **Mean Bray-Curtis Distance over Time at A) the Near-field (NF) Area, B) Mid-field Stations along the MF2-FF2 Transect, and C) at the three Far-field Reference Areas**

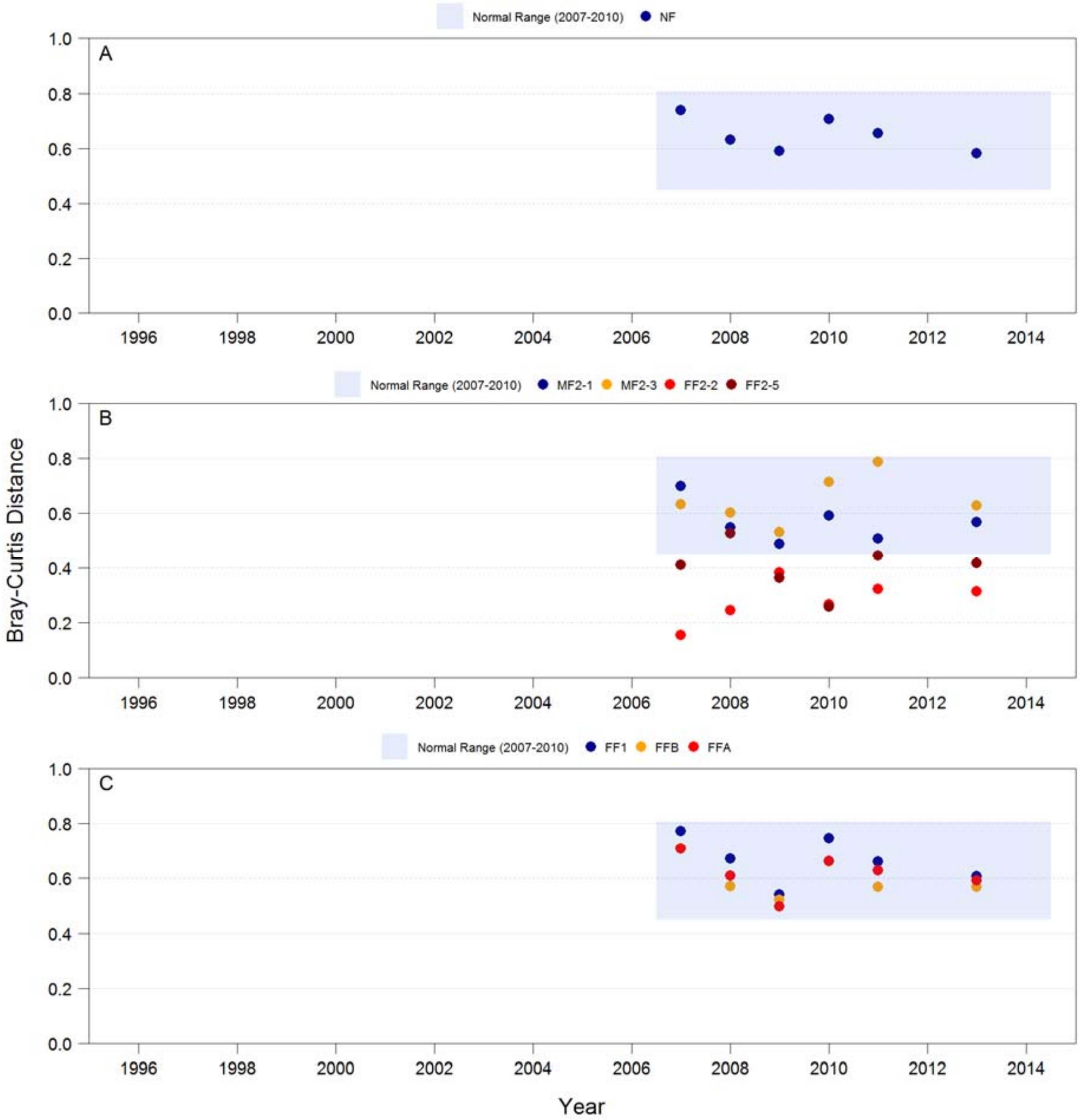
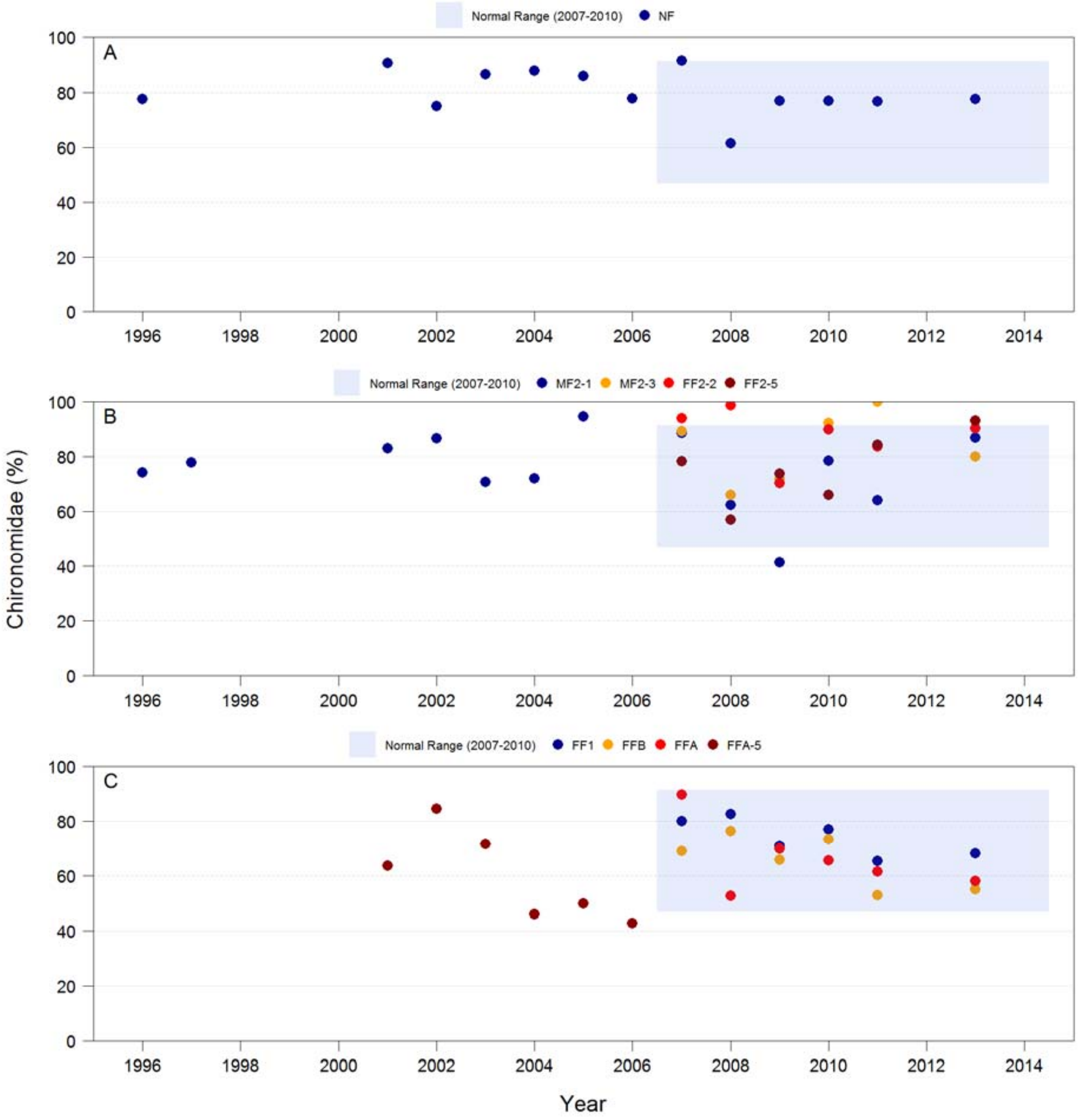


Figure 9-7 Mean Percent Chironomidae over Time at A) the Near-field (NF) Area, B) Mid-field Stations along the MF2-FF2 Transect, and C) at the three Far-field Reference Areas



9.3.2.3 Densities of Common Invertebrates

The density of Pisidiidae varied without a long-term trend in the NF area over time, with densities above the normal range in seven of the years with available data, and in six years along the MF2-FF2 transect (Figure 9-8). Densities have at times been near zero (e.g., 2005 and 2007), but these appear to reflect the low values seen in the reference areas. The low normal range for this taxon suggests that the absence of Pisidiidae in areas of Lac de Gras can be expected periodically. Since 2008, Pisidiidae densities have declined in exposure areas to the levels seen in the reference areas.

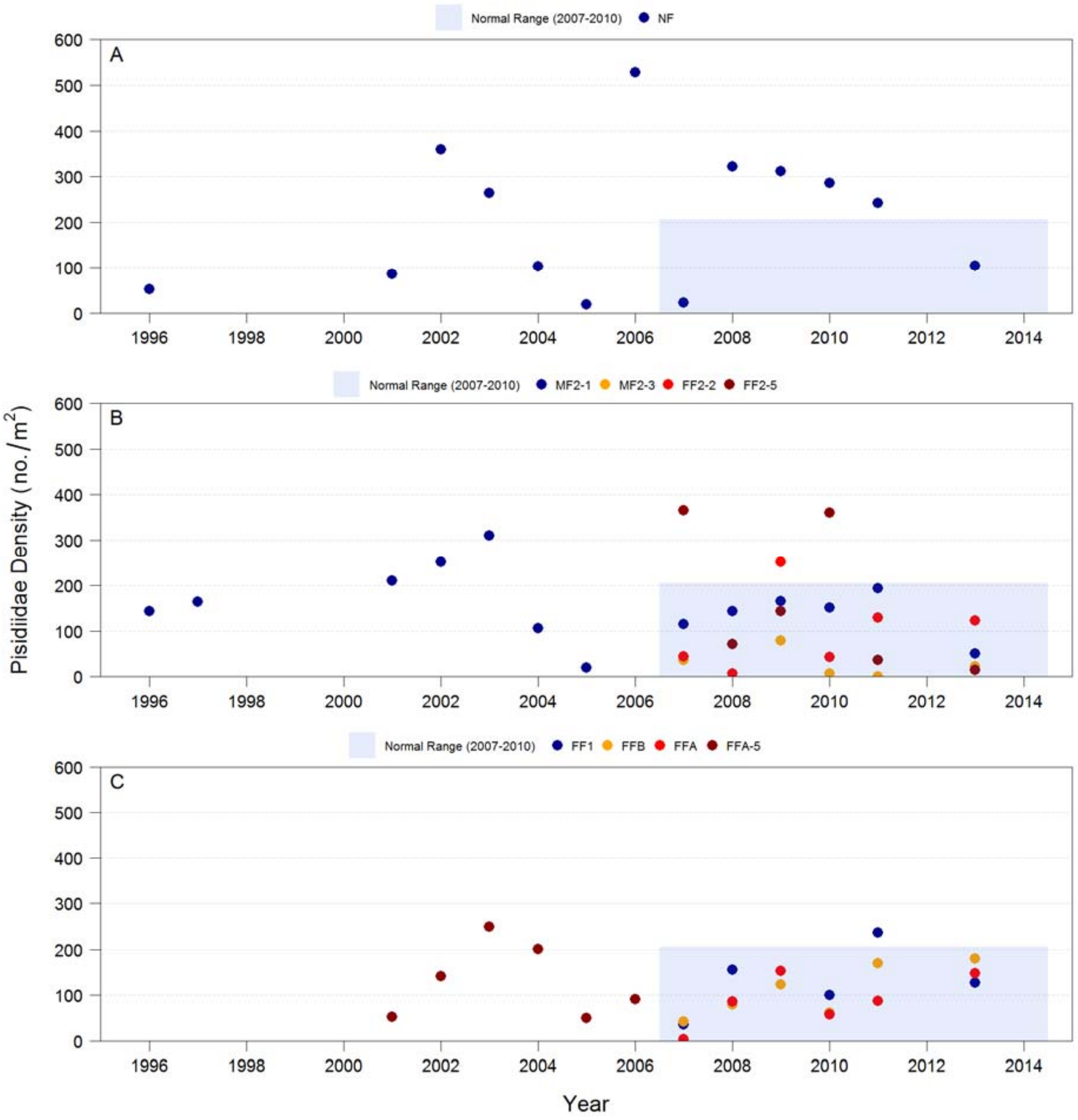
Procladius sp. midge densities have fluctuated from 2001 to 2006 in the NF area and have remained above the normal range since 2007 (Figure 9-9). Both FF2 stations also exhibited densities above the normal range from 2007 to 2013. No apparent long-term trend is evident in *Procladius* sp. density.

Densities of *Heterotrissocladius* sp. have been variable and higher in the NF area compared top reference areas since 2001 (Figure 9-10). Densities of this group have fluctuated in this area, but have remained above the normal range for the majority of sampling years. Densities along the MF2-FF2 transect were similarly elevated until 2007, after which declined to within the normal range.

Micropsectra sp. densities demonstrate considerable natural variability, with no consistent long-term trend in any sampling area (Figure 9-11C). Densities in exposure areas have demonstrated similar variability, and they have fluctuated mostly within the normal range.

Statistical analyses of trends did not indicate a significant result in the NF area for densities of any of the common invertebrates (Table 9-6).

Figure 9-8 Mean Pisidiidae Density over Time at A) the Near-field (NF) Area, B) Mid-field Stations along the MF2-FF2 Transect, and C) at the three Far-field Reference Areas



no./m^2 = number per square metre.

Figure 9-9 **Mean *Procladius* sp. Density over Time at A) the Near-field (NF) Area, B) Mid-field Stations along the MF2-FF2 Transect, and C) at the three Far-field Reference Areas**

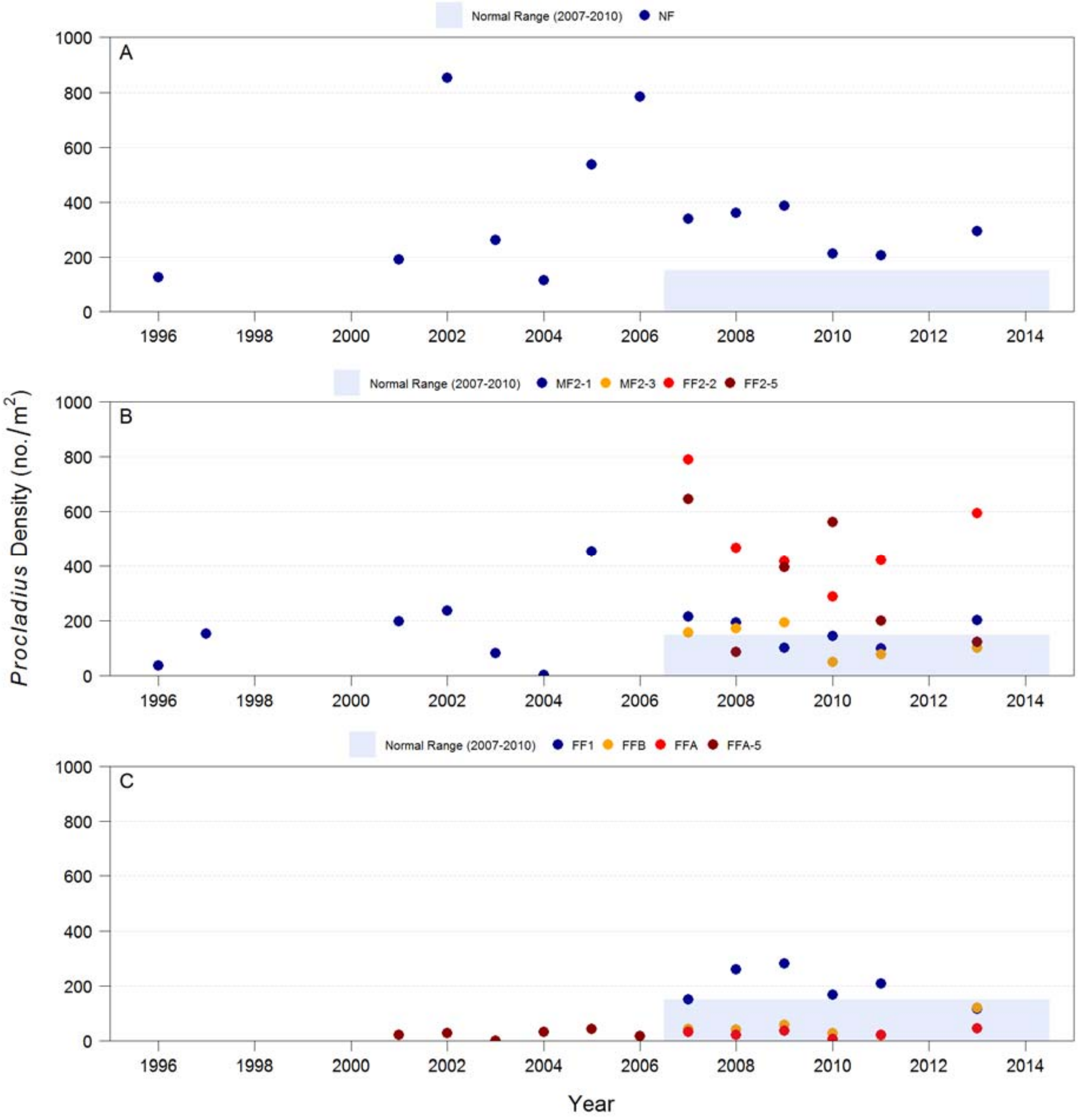


Figure 9-10 **Mean *Heterotrissocladius* sp. Density over Time at A) the Near-field (NF) Area, B) Mid-field Stations along the MF2-FF2 Transect, and C) at the three Far-field Reference Areas**

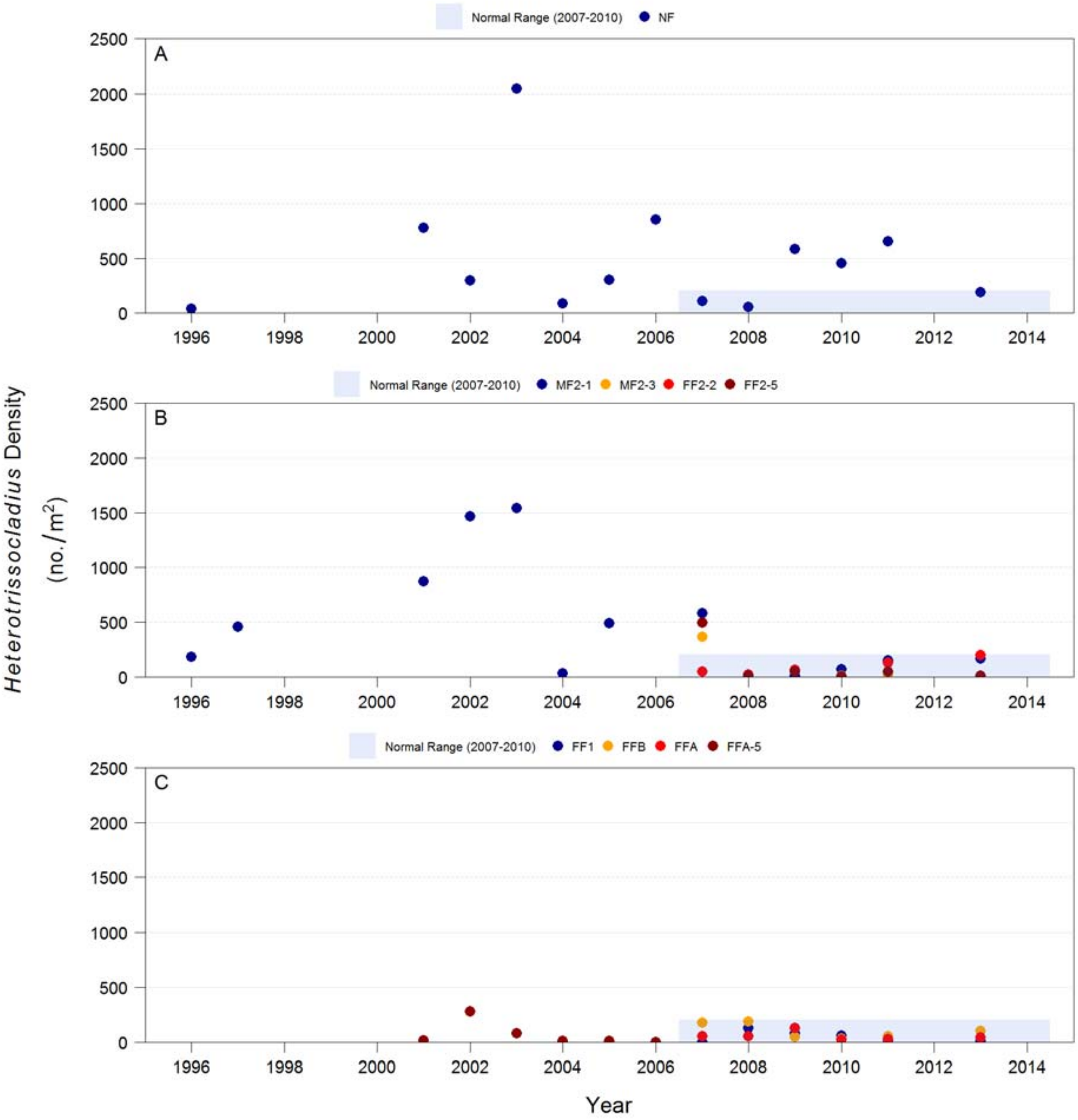
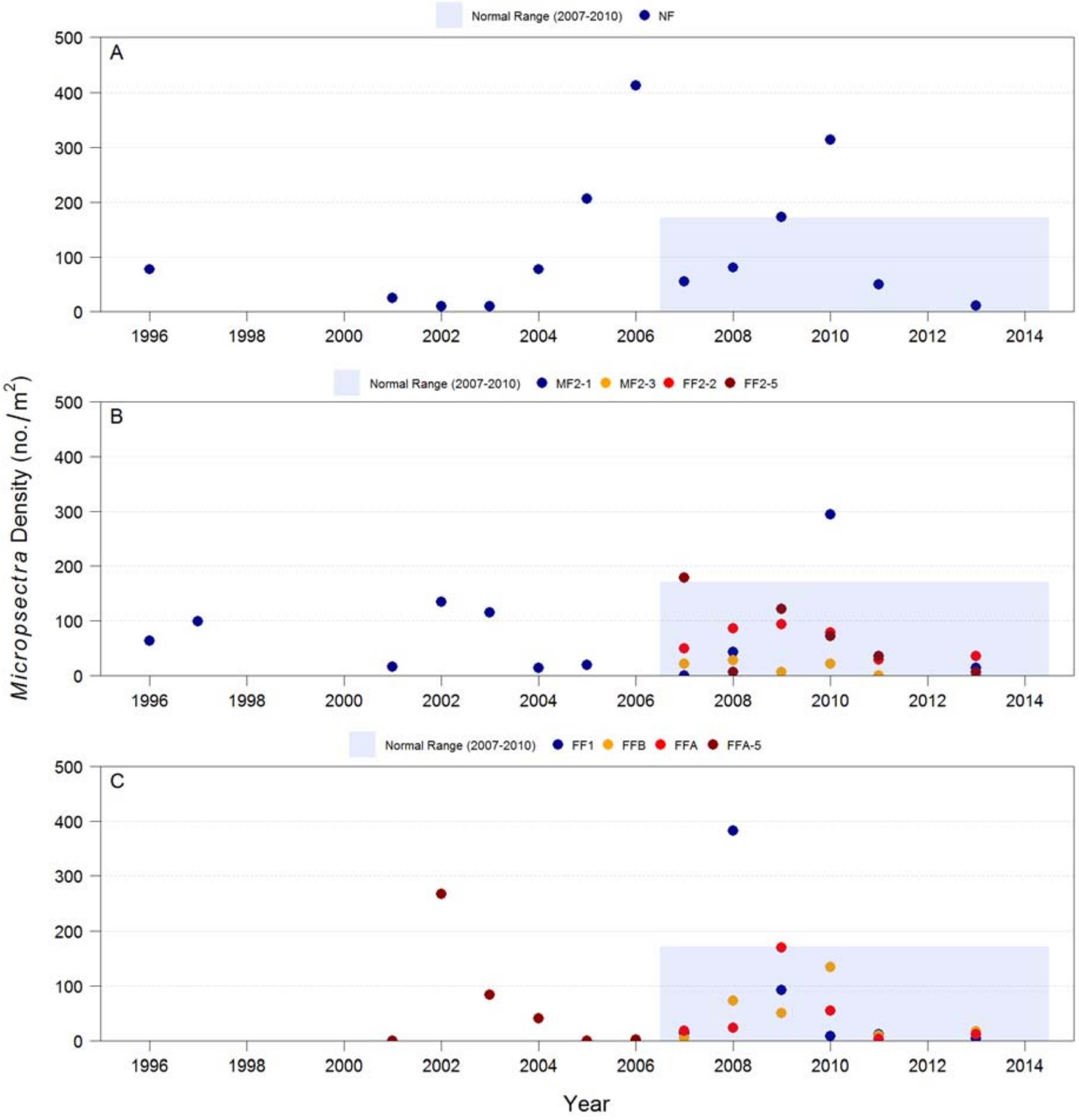


Figure 9-11 **Mean *Micropsectra* sp. Density over Time at A) the Near-field (NF) Area, B) Mid-field Stations along the MF2-FF2 Transect, and C) at the three Far-field Reference Areas**



9.3.2.4 Community Composition by Major Group

The benthic communities of all AEMP sampling areas have been dominated by the Chironomidae (midges) in all years. This group, together with the Pisidiidae (clams), frequently accounted for over 90% of the abundance in each area (Figure 9-12). Other common but less abundant groups included the Oligochaeta (aquatic worms) and Hydracarina (water mites). Near-field area communities were strongly dominated by midges from 1996 to 2007. Subsequently, the relative density of Pisidiidae increased and remained above 20% from 2008 to 2011. In 2013, there appeared to be a slight decrease in Pisidiidae and a resulting increase in oligochaetes. Chironomidae relative densities along the MF2-FF2 transect decreased until 2009 and have increased since then (Figure 9-3B, C). In contrast to the NF and FF2 areas, oligochaetes at the MF2-1 station have accounted for a larger proportion of the community, while the relative density of Pisidiidae has declined.

Benthic community composition by major group was variable in the FFA area from 2001 to 2007 (Figure 9-13), perhaps reflecting the availability of data from only three closely-spaced stations, rather than the five widely-spaced stations sampled subsequently. Less variability is apparent in all reference areas from 2008 to 2013. The main difference observed from exposure areas is the larger relative densities of Pisidiidae, which reached more than 25% of the total abundance.

Figure 9-12 **Relative Abundances (%) of Major Invertebrate Groups in the A) Near-field Area, B) MF2-1 Station and C) FF2 Area**

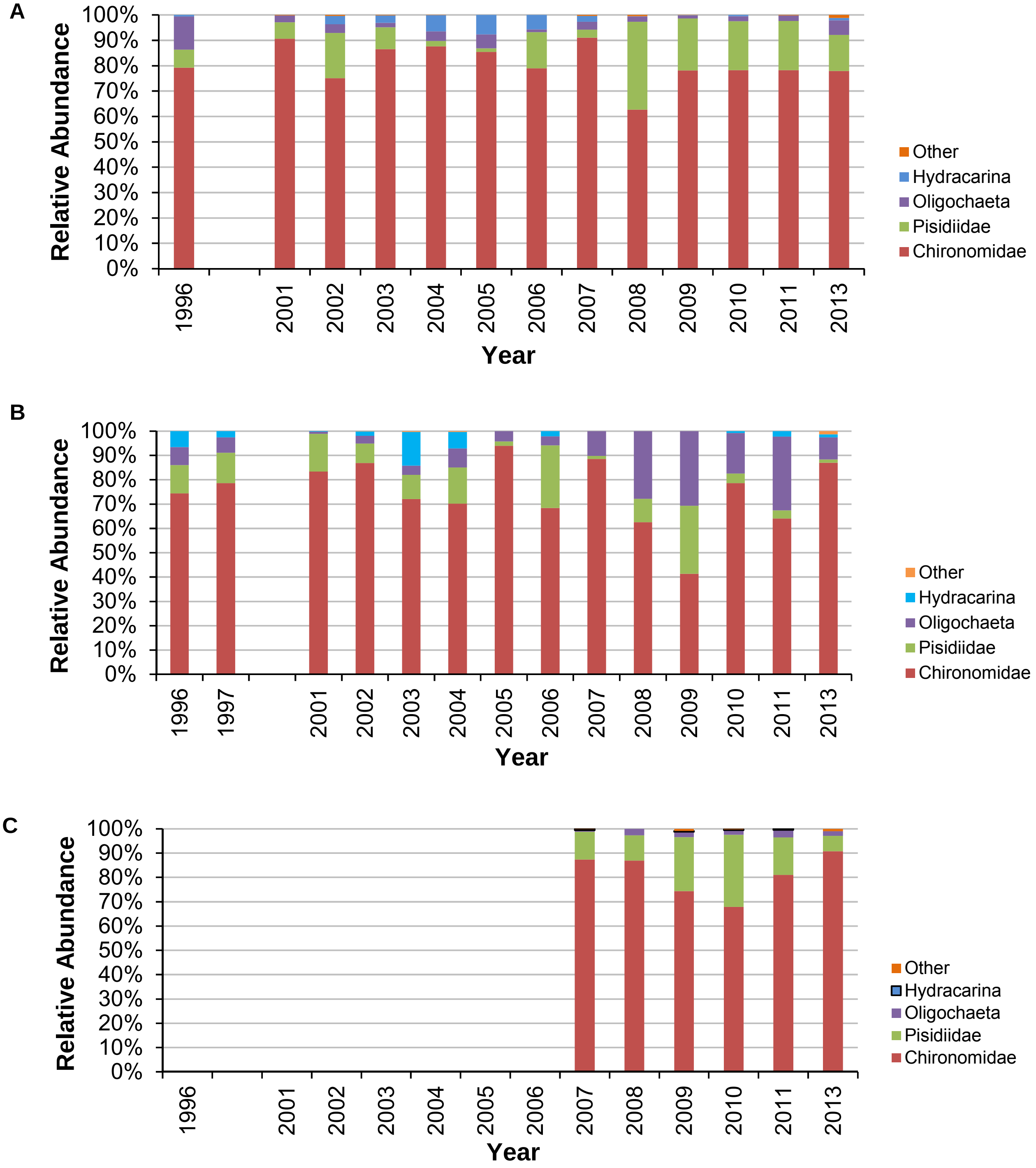
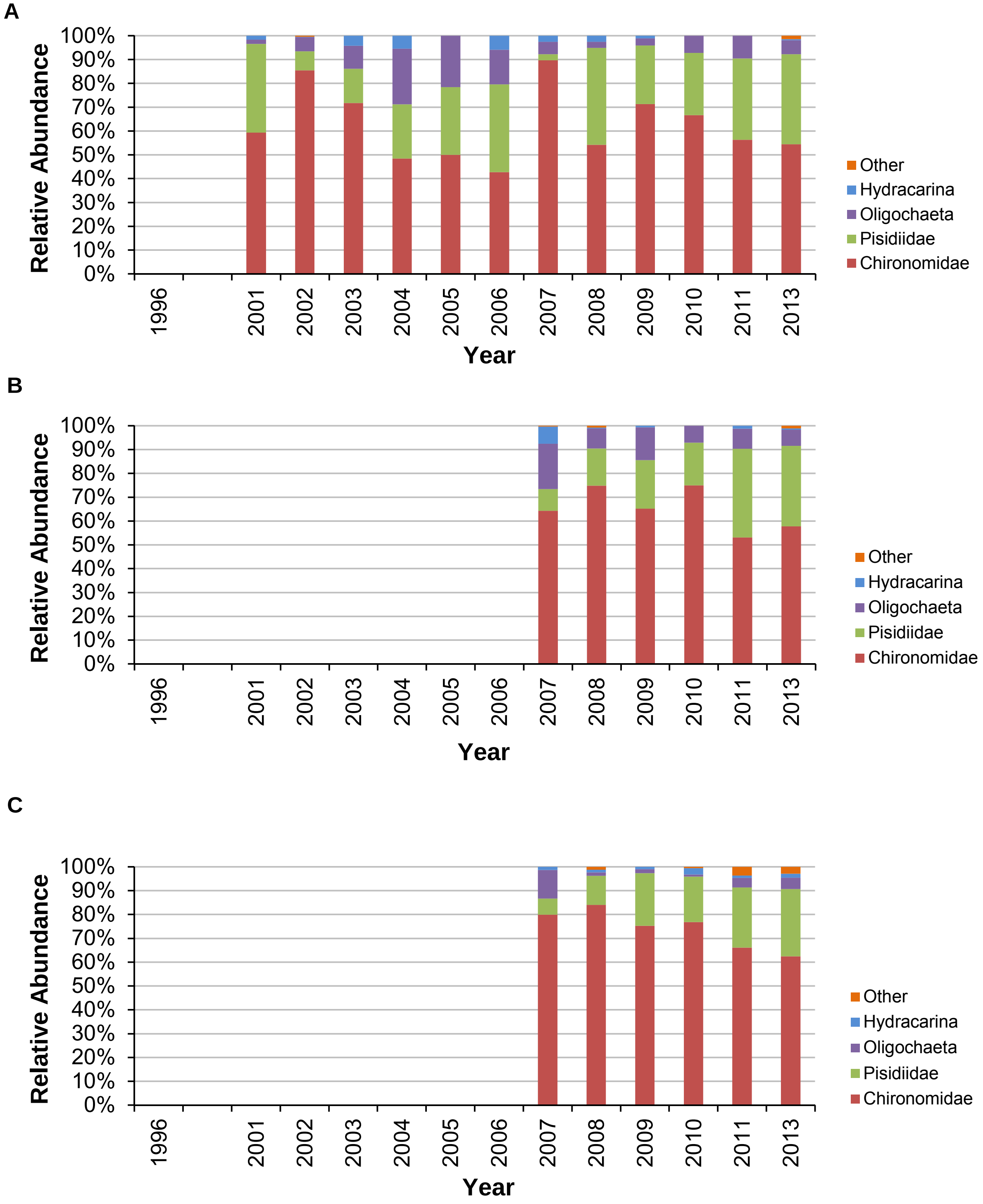


Figure 9-13 **Relative Abundances (%) of Major Invertebrate Groups in the A) Far-Field A Area, B) Far-Field B Area and C) Far-Field 1 Area**

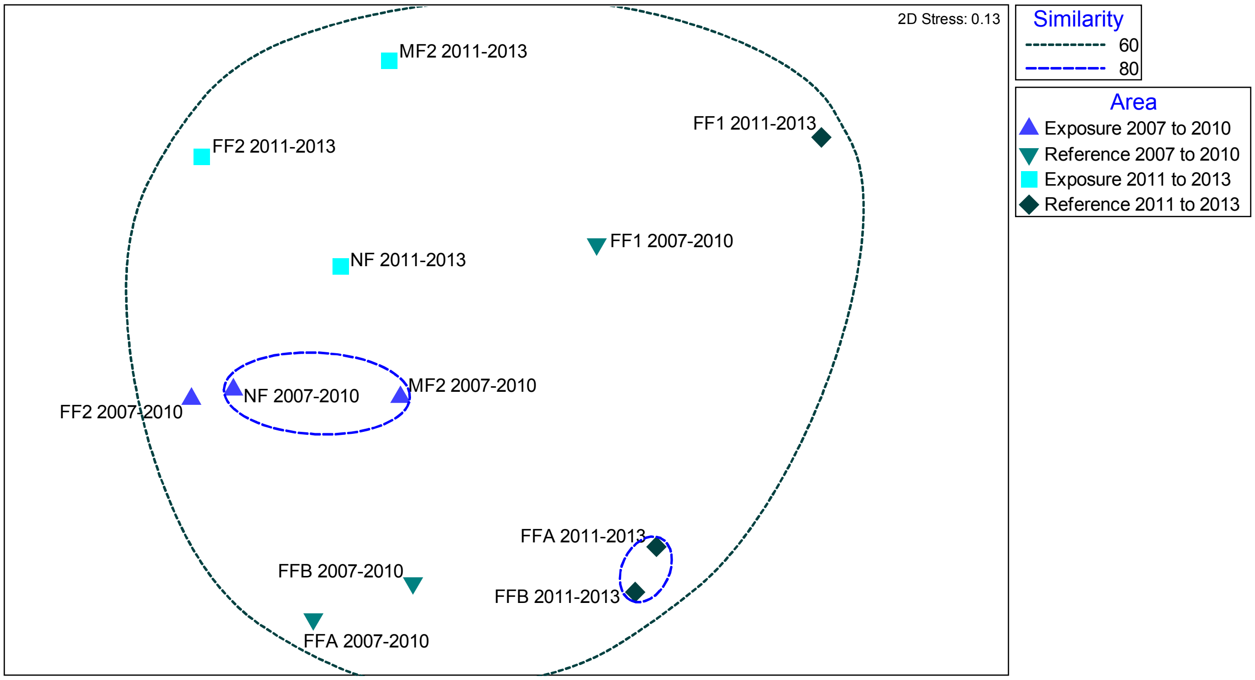


9.3.2.5 Multivariate Analysis

The nMDS ordination reflects the general patterns of response to effluent seen in the individual benthic invertebrate variables (Figure 9-14): the exposure areas (NF, FF2 and MF2) are distinct from the other areas, being located near the left of the plot; the FFA and FFB areas, which tend to be similar, are located near the bottom of the plot; and the FF1 reference areas, which represent a different part of the lake compared to FFA and FFB, are located near the top right of the plot. Within each of these three groupings, there was further separation (or clumping) of areas by sampling period. Areas with the most similar communities to one another were the NF and MF2 areas from 2007 to 2010 and the FFA and FFB areas from 2011 to 2013, with 80% of the community being the same between the two areas (as seen by the 80% similarity ellipse).

Overall, the benthic invertebrate community in both the reference and exposure areas differed between the two sampling periods (i.e., 2007 to 2010 and 2011 to 2013), as indicated by their different positions on the nMDS ordination plot. Reference stations have shifted towards the right of the plot and exposure stations have shifted upwards. This indicates that the there was a possible divergence between the exposure and reference areas from 2007 to 2010 compared to 2011 to 2013.

Figure 9-14 Nonmetric Multidimensional Scaling Ordination of the Benthic Invertebrate Community Data in the Near-Field, Mid-Field 2, Far-Field 2 and Reference Areas, 2007 to 2013



9.3.3 Comparison to EA Predictions

No predictions were made in the EA regarding benthic invertebrates.

9.4 Conclusions

Results of the second three-year review of benthic invertebrate community data have led to the following conclusions:

- Total invertebrate density and densities of most major benthic invertebrate groups have been consistently greater in the NF area compared to the reference areas since 2008.
- This effect was confirmed as being Mine-related since total density, and densities of Pisidiidae, *Procladius* sp. and *Heterotrissocladius* sp. were higher at the NF stations relative to stations farther from the effluent discharge. These variables demonstrated significant regressions with distance from the Mine.
- Taxonomic richness was lower in the NF area for three of the six years analyzed; however, the regression of richness with distance from the Mine was only significant in one year (2009).
- Analysis of community composition by multivariate analysis (nMDS) and visual evaluation of relative abundance indicate a change in community structure over time. Community composition varied between the reference and exposure areas in all years, and the community composition further varied between the AEMP Version 2.0 monitoring period (2007 to 2010) and the AEMP Version 3.0 monitoring period (2011 to 2013). This change over the two periods was seen in both exposure and reference areas, suggesting that the community structure undergoes natural changes over time.
- Temporal trends were not detected in any of the benthic invertebrate community measures, although densities in the NF area and along the MF2-FF2 transect have decreased to within the normal range in recent years.

10 FISH

10.1 Introduction

The fish chapter provides a summary of changes observed on fish health and fish tissue in Slimy Sculpin (*Cottus cognatus*) in Lac de Gras over time. It also provides an update on the monitoring of mercury concentration in Lake Trout (*Salvelinus namaycush*). These fish have been monitored in Lac de Gras as a component of the AEMP since 2007. The objectives of this chapter are the following:

- summarize Mine-related effects observed from 2011 to 2013 and compare these to effects observed previously (i.e., from 2007 to 2010); and
- analyze temporal trends in fish health and fish tissue for the period extending from baseline (where possible) to 2013.

The fish component of the AEMP over the past three years was conducted under the AEMP Version 2.0 [2007 to 2011] and AEMP Version 3.0 [2011 to 2013], and consisted of a Slimy Sculpin fish health and fish tissue program in 2013, and mercury in Lake Trout program in 2011. The results presented in the fish chapter include the most recent information collected from 2011 to 2013. Metals in Lake Trout were summarized in the previous AEMP Version 2.0 (2007 to 2010) Summary Report (Golder 2011c), and are not presented here because no new data were collected under the AEMP Version 3.0.

10.2 Fish Health

10.2.1 Methods

10.2.1.1 Data Sources

Three AEMP fish health surveys were completed with Slimy Sculpin in Lac de Gras. The first was conducted in the late summer (August 22 to September 2) of 2007 (Golder 2008), the second was conducted in the spring (June 28 to July 20) of 2010 (Golder 2011d), and the most recent survey was conducted in the late summer (August 27 to September 10) of 2013 (Golder 2014f). The 2010 fish survey was conducted in the spring in an attempt to capture fish prior to spawning. The 2010 fish survey began June 28, which was the earliest date at which sufficient ice had melted to be able to access all sampling areas by boat. This survey found that the Slimy Sculpin had already spawned and that these fish likely spawn under ice-covered conditions; therefore, the 2013 fish survey was conducted in late summer to allow the gonads to develop to the early stages of development for the next spawning period.

In addition to the three surveys conducted under the AEMP, one other study on Slimy Sculpin in Lac de Gras has been undertaken. A fish survey was performed in 2004 by Gray et al. (2005) where Slimy Sculpin were collected from East Island on Lac de Gras and assessed using non-lethal techniques for length, weight, condition and population structure. These data are not included in the current review, due to incompatibility in data collection between this study and the AEMP design Version 2.0 and 3.0 (e.g., age determination, data handling method of infected fish).

10.2.1.2 Data Analysis

10.2.1.2.1 Summary of Effects

Results of the 2007 fish survey demonstrated that characteristics of the fish infected with the parasite *Ligula intestinalis* were different from those of non-infected fish. In addition, there was evidence that some of the response variables measured in Slimy Sculpin were negatively affected by infection with *L. intestinalis*. Consequently, the 2010 survey focused on non-infected fish to control for this confounding factor. Results of the power analysis in 2010 demonstrated that the power of the survey to detect Mine-related effects was increased by removing the additional variability caused by *L. intestinalis*. The 2007 survey included both infected and non-infected fish, whereas the 2010 and 2013 surveys were done on non-infected fish. To allow direct comparisons between the 2007 and 2013 fish surveys, which were conducted during the same season, the 2007 fish survey data were re-analyzed following the methods of the 2013 fish survey data analysis. Fish infected with *L. intestinalis* were removed from the analysis, and the life stage/sex groupings were defined as age 1+ (based on length frequency distributions) and adult (older than age 1+) male and female.

The juvenile life stage was defined based on maturity for the 2010 fish population survey. Since the 2010 data are not directly comparable to the 2007 and 2013 data due to differences in sampling periods, the 2010 data were not re-analyzed using the life stage/sex groupings defined above. The fish categorized as juvenile in 2010 were compared to the age 1+ (assumed to be juvenile) fish in 2007 and 2013 in the summary of effects.

Fish health endpoints were assessed for a mine related effect according to the WOE effects framework described for fish health in the AEMP study design Version 3.5 (Golder 2014a). The WOE effect rankings for fish health incorporate results of statistical comparisons between the exposure and reference areas of Lac de Gras and comparisons to the normal range (Table 10-1).

Table 10-1 Weight of Evidence Effect Rankings for Slimy Sculpin Fish Population Health

Effect Ranking	Effect Description
Low	Statistical difference between the NF exposure area relative to the reference areas.
Moderate	Statistical difference between the NF exposure area relative to the reference areas. **AND** NF area mean outside the normal range.
High	Persistent, moderate-level effects linked to the Mine that pose a risk to the long-term viability of fish populations.

Notes: NF = near-field.

10.2.1.2.2 Action Levels

The importance of effects to a fish health endpoint has been categorized according to Action Levels described in Golder (2014a). The Action Level classifications were developed to meet the goals of the *Response Framework for Aquatic Effects Monitoring* (WLWB 2010; Racher et al. 2011). The goal of the AEMP Response Framework is to ensure that significant adverse effects never occur. A significant adverse effect, as it pertains to aquatic biota, was defined in the Environmental Assessment as a change in fish population(s) that is greater than 20% (Government of Canada 1999). This effect must have a high probability of being permanent or long-term in nature and must occur throughout Lac de Gras. The Significance Thresholds for all aquatic biota are therefore related to impacts that could result in a change in fish population(s) that is greater than 20%.

Although the AEMP addresses two broad impact hypotheses for Lac de Gras, the toxicological impairment hypothesis and the nutrient enrichment hypothesis (Golder 2014g), the Action Levels for fish health address the toxicological impairment hypothesis.

Fish health responses are assessed every three years to evaluate effects as described in the *Action Levels for Biological Effects* section of the AEMP Study Design Version 3.5 (Golder 2014a). This involves measuring responses in the NF exposure area against those in the two FF reference areas (FF1 and FFA). The occurrence of an Action Level 1 is determined by finding significant differences in fish health responses in the exposure area compared to those in the reference areas that are indicative of a toxicological effect. Conditions required for Action Levels 1 to 3 are defined in Table 10-2. Action Level 4 will be defined if Action Level 3 is reached. Defining higher Action Levels after initial effects are encountered is consistent with the draft guidelines for preparing a response framework in AEMPs (WLWB 2010; Racher et al. 2011).

10.2.1.2.3 Normal Ranges

Magnitudes of effects on fish health were evaluated by comparing each variable in the exposure areas to background values. Background values for Lac de Gras are those that fall within the range of natural variability, referred to as the normal range. The normal ranges used to evaluate potential effects on fish health were obtained from the AEMP Reference Conditions Report, Version 1.1 (Golder 2015) and are summarized in Table 10-3.

The sampling periods for the fish population surveys were similar in 2007 and 2013 (LS = late summer). The normal ranges for these surveys were calculated using the pooled 2007 and 2013 reference area data, and are presented as the LS normal range (Table 10-3). Since the 2010 survey was conducted at a different time of the year (SP = spring) compared to the 2007 and 2013 surveys, the normal range for 2010 was calculated using the 2010 reference area data only, and are presented as the SP normal range.

10.2.1.2.4 Temporal Trends

Time series plots were generated for each endpoint by life stage/sex using data from 2007, 2010, and 2013 for the two exposure areas (NF and FF2), mid-field area (MF3) (2013 only), and the reference areas (FF1 and FFA) of Lac de Gras. The mean values were plotted for each endpoint and were compared to the normal ranges (Table 10-3). A mean value outside the normal range can be interpreted as a change that may be biologically significant.

Due to differences in sampling periods among years and the different normal range for 2010, trends over time were assessed by comparing the position of the exposure and mid-field area means relative to the normal range. The exposure area and mid-field area means were converted to a percentile rank (PR) relative to the normal range as:

$$PR = \frac{mean - NR_L}{NR_U - NR_L} \times 100$$

where, NR_L is the lower bound of the normal range and NR_U is the upper bound of the normal range.

Table 10-2 Action Levels for Slimy Sculpin Fish Population Health

Action Level	Fish Health	Extent	Action
1	Statistically significant difference from reference indicative of a toxicological response[(a)]	NF	Confirm effect
2	Statistically significant difference from reference indicative of a toxicological response[(a)]	Nearest MF station	Investigate cause
3	The mean of a measurement endpoint beyond the normal range	NF	Examine ecological significance Set Action Level 4 Identify mitigation options
4	To be determined[(b)]	To be determined[(b)]	Define conditions required for the Significance Threshold
5[(c)]	Indications of severely impaired reproduction or unhealthy fish likely to cause a >20% change in fish population(s)	FFA	Significance Threshold

a) Such a response could include a decrease in recruitment (fewer young fish), reduced gonad size, reduced fecundity, changes to liver size, changes in condition, increased incidence of pathology, reduced growth, and reduced survival.

b) To be determined if Action Level 3 is reached.

c) Significance Threshold.

>= greater than;; NF = near-field; MF = mid-field; FF = far-field.

Table 10-3 Normal Ranges Slimy Sculpin Fish Health

Variable	Life Stage/Sex	Season	Unit	Normal Range	
				Lower Limit	Upper Limit
Total Length	Age 1+	LS	mm	34	50
	Juvenile	SP	mm	32	46
	Female	LS	mm	50	82
	Female	SP	mm	43	72
	Male	LS	mm	52	77
	Male	SP	mm	43	56
Fresh Weight	Age 1+	LS	g	0.29	0.96
	Juvenile	SP	g	0.22	0.70
	Female	LS	g	0.91	4.24
	Female	SP	g	0.56	1.78
	Male	LS	g	1.09	3.61
	Male	SP	g	0.58	1.33
Carcass Weight	Age 1+	LS	g	0.24	0.79
	Juvenile	SP	g	0.17	0.56
	Female	LS	g	0.79	3.61
	Female	SP	g	0.44	1.49
	Male	LS	g	0.95	2.86
	Male	SP	g	0.47	1.09
Condition Factor	Age 1+	LS	-	0.64	0.94
	Juvenile	SP	-	0.43	0.74
	Female	LS	-	0.59	0.78
	Female	SP	-	0.48	0.71
	Male	LS	-	0.55	0.82
	Male	SP	-	0.54	0.85
LSI	Age 1+	LS	%	1.12	3.63
	Juvenile	SP	%	1.16	5.99
	Female	LS	%	2.04	6.05
	Female	SP	%	2.05	6.85
	Male	LS	%	1.17	3.74
	Male	SP	%	1.61	5.50
GSI	Female	LS	%	1.00	3.16
	Female	SP	%	0.19	4.30
	Male	LS	%	0.73	2.69
	Male	SP	%	0.23	1.30

LSI = liver somatic index; GSI= gonadosomatic index; LS = late summer; SP = spring.

10.2.2 Results

10.2.2.1 Summary of Effects

10.2.2.1.1 Weight of Evidence Effects Rankings

Weight of evidence effects rankings varied during each fish survey. No consistent effect was observed in 2007. In 2010, a low-level enrichment effect was observed, while in 2013, a low level toxicological effect was documented.

In 2007, inconsistent responses were observed among endpoints and life stage/sex groups. Effects were not observed in the same direction for more than one life stage/sex group in the exposure area (Table 10-4). Overall, there was no evidence of any effect in 2007. In 2010, low level enrichment effects were observed for body size, growth, condition, liver size and pathology (i.e., proportion of fish with abnormalities). The effects were considered low level because statistical differences were found between Slimy Sculpin populations from exposure and reference areas, but the exposure area means were mostly within the normal range of the reference areas, with the exception of male body size. In 2013, low level toxicological effects were observed for body size, liver size and gonadosomatic index (GSI).

In 2010, fish generally had a greater condition (i.e., were fatter) at the exposure areas, male fish were larger, and female fish had larger livers. This pattern could reflect the increased availability of food resulting from nutrient enrichment at the NF exposure areas. The hypothesis of increased availability of food is supported by the increased productivity and greater densities of benthic invertebrates in those areas (Golder 2014f). The frequency of abnormalities was higher at the exposure areas relative to the reference areas in 2010.

Low level toxicological effects were generally observed in more than one life stage/sex group in the exposure areas in 2013. Body size and liver size were consistent among life stage/sex groups in the exposure areas, showing a decrease in both of these endpoints. Female GSI and age 1+ abundance were both significantly lower in the NF area. The response of lower body size and lower reproductive endpoints in 2013 is consistent with a toxicological effect; however this response is not consistent with results of other AEMP components, which were indicative of slight nutrient enrichment. The pathology occurrence, or frequency of abnormalities, was similar for males and females in the NF area relative to the reference areas in 2013.

Table 10-4 Summary of Weight of Evidence Effects Rankings for Slimy Sculpin Fish Population Health, 2007 to 2013

Year	Endpoint	Rating[(a,b)]				Type of Effect
		Age 1+/Juv[(c)]	Male	Female	Overall	
2007	Length Frequency – Survival	↑/↓			0	None
	Body Size	↓	0	0	0	None
	Energy Stores – Condition Factor	↑	↓	0	0	None
	Energy Stores – Liver Size	0	↑	0	0	None
	Reproductive Success – Age 1 Abundance	↓	n/a	n/a	0	None
	Reproductive Investment – GSI	n/a	0	0	0	None
	Pathology – Occurrence	0	0	0	0	None

Table 10-4 Summary of Weight of Evidence Effects Rankings for Slimy Sculpin Fish Population Health, 2007 to 2013

Year	Endpoint	Rating[(a,b)]				Type of Effect
		Age 1+/Juv[(c)]	Male	Female	Overall	
2010	Length Frequency – Survival	↑/↓			0	None
	Body Size	0	↑↑	0	↑	Enrichment Effect
	Growth – Age 1+ and Age 2+ Size at Age	↑			↑	Enrichment Effect
	Energy Stores – Condition Factor	0	↑	↑	↑	Enrichment Effect
	Energy Stores – Liver Size	0	0	↑	↑	Enrichment Effect
	Reproductive Success – Age 1 Abundance	0	n/a	n/a	0	None
	Reproductive Investment – GSI	n/a	n/a	n/a	n/a	n/a
	Pathology – Occurrence	↑	0	↑	↑	Stress?
2013	Length Frequency – Survival	↑/↓			0	None
	Body Size	↓	↓	↓	↓	Toxicological Effect
	Energy Stores – Condition Factor	↓	0	0	0	None
	Energy Stores – Liver Size	↓	↓	↓	↓	Toxicological Effect
	Reproductive Success – Age 1 Abundance	↓	n/a	n/a	0	None
	Reproductive Investment – GSI	n/a	0	↓	↓	Toxicological Effect
	Pathology – Occurrence	0	0	0	0	None

a) Only the NF area is included in the WOE assessment.

b) ↑ = increase; ↓ = decrease; ↑/↓ = change not associated with a direction; 0 = no change. The number of these characters represents effect level (one = low level, two = moderate level, and three = high level).

c) In 2007 and 2013, juvenile fish were defined age1+ fish and adult fish were defined as fish older that age 1+ based on length frequency distributions.

GSI = gonadosomatic index; n/a = not applicable; Juv = juvenile.

Action Levels

In 2007 age 1+ body size and male condition were significantly lower in the NF area relative to the reference areas, but these effects were not confirmed in 2010. Effects observed in 2010 were indicative of a nutrient enrichment response and as such, Action Level 1 was not reached in 2010. In 2013, Action Level 1 was reached, based on body size for all maturity/sex stages, age 1+ condition and liver size, and the reproductive endpoints of female GSI and age 1+ abundance. Statistical differences were observed between the NF area and reference areas for these endpoints, which is equivalent to an Action Level 1. Length was significantly lower for age 1+ fish at the mid-field station MF3, but weight was not significantly different from reference for MF3. This single difference in length for age 1+ fish in the mid-field area was not sufficient to be indicative of a toxicological effect for body size; therefore, effects for age 1+ fish were determined to be at Action Level 1.

10.2.2.2 Temporal Trends

Body Size

Time series plots (Figure 10-1 to Figure 10-8) and the summary of trends relative to the normal range for the body size endpoints (Table 10-5) indicate that there are no temporal trends in Slimy Sculpin body size endpoints. Mean total weight (Figure 10-2) and mean carcass weight (Figure 10-8) for male Slimy Sculpin collected from the NF and FF2 exposure areas exceeded the normal range in 2010. Mean length also exceeded the normal range for male Slimy Sculpin (Figure 10-5) collected from the NF area in 2010. These normal range exceedances were not observed for female or juvenile Slimy Sculpin in 2010, and were not observed in any life stage/sex in 2007 or 2013. Length for female Slimy Sculpin decreased from 2007 to 2013 at FF2 (Table 10-5). Mean total weight for age 1+/juvenile Slimy Sculpin decreased from 2007 to 2013 at FF2 from a percentile rank of 53 to 27 (Table 10-5). A similar trend was not observed for the other areas.

Condition

Mean condition factor was within the normal range for age 1+/juvenile (Figure 10-9), male (Figure 10-10), and female (Figure 10-11) Slimy Sculpin in all years. Age 1+ condition decreased relative to the normal range from 2007 to 2013 in the NF area from a percentile rank of 87 to 5; male condition factor increased relative to the normal range from 2007 to 2013 in the NF area from a percentile rank of 47 to 55 (Table 10-5).

Liver Size

Mean liversomatic index (LSI) decreased relative to the normal range in 2013, though still remained within the normal range. Mean LSI for age 1+ and male Slimy Sculpin from the NF area decreased relative to the normal range from 2007 to 2013 (Table 10-5).

Gonad Size

Mean GSI was within the normal range for the reference means for male (Figure 10-15) and female (Figure 10-16) Slimy Sculpin in all years. Mean GSI for male Slimy Sculpin from the FF2 area decreased relative to the normal range from 2007 to 2013 from a percentile rank of 77 to 49.

Table 10-5 Summary of Trends for Slimy Sculpin Fish Population Health Relative to the Normal Range, 2007 to 2013

Endpoint	Life Stage/Sex	Area	Percentile Rank (%) Relative to the Normal Range			Trend[(a)]
			2007	2010	2013	
Total Weight	Age 1+/Juv	NF	30	38	14	0
		FF2	**53**	**41**	**27**	**-**
		MF3	na	na	33	na
	Male	NF	40	179	14	0
		FF2	86	134	8	0
		MF3	na	na	44	na
	Female	NF	39	64	10	0
		FF2	79	68	13	0
		MF3	na	na	31	na
Length	Age 1+/Juv	NF	31	43	25	0
		FF2	60	28	31	0
		MF3	na	na	39	na
	Male	NF	40	115	18	0
		FF2	79	95	11	0
		MF3	na	na	48	na
	Female	NF	39	40	11	0
		FF2	**75**	**40**	**16**	**-**
		MF3	na	na	35	na

Table 10-5 Summary of Trends for Slimy Sculpin Fish Population Health Relative to the Normal Range, 2007 to 2013

Endpoint	Life Stage/Sex	Area	Percentile Rank (%) Relative to the Normal Range			Trend[a]
			2007	2010	2013	
Carcass Weight	Age 1+/Juv	NF	38	39	24	0
		FF2	61	29	34	0
		MF3	na	na	42	na
	Male	NF	34	172	17	0
		FF2	92	128	11	0
		MF3	na	na	53	na
	Female	NF	35	61	10	0
		FF2	**76**	**63**	**12**	**-**
		MF3	na	na	29	na
Condition Factor[b]	Age 1+/Juv	**NF**	**87**	**56**	**5**	**-**
		FF2	62	76	24	0
		MF3	na	na	17	na
	Male	**NF**	**47**	**52**	**55**	**+**
		FF2	64	55	55	0
		MF3	na	na	59	na
	Female	NF	39	70	39	0
		FF2	37	81	25	0
		MF3	na	na	31	na
LSI	Age 1+/Juv	**NF**	**49**	**22**	**21**	**-**
		FF2	34	41	39	0
		MF3	na	na	38	na
	Male	NF	97	35	36	0
		FF2	**58**	**50**	**41**	**-**
		MF3	na	na	57	na
	Female	NF	42	52	20	0
		FF2	47	69	22	0
		MF3	na	na	19	na
GSI	Male	NF	35	61	52	0
		FF2	**77**	**57**	**49**	**-**
		MF3	na	na	50	na
	Female	NF	58	63	32	0
		FF2	65	54	64	0
		MF3	na	na	62	na

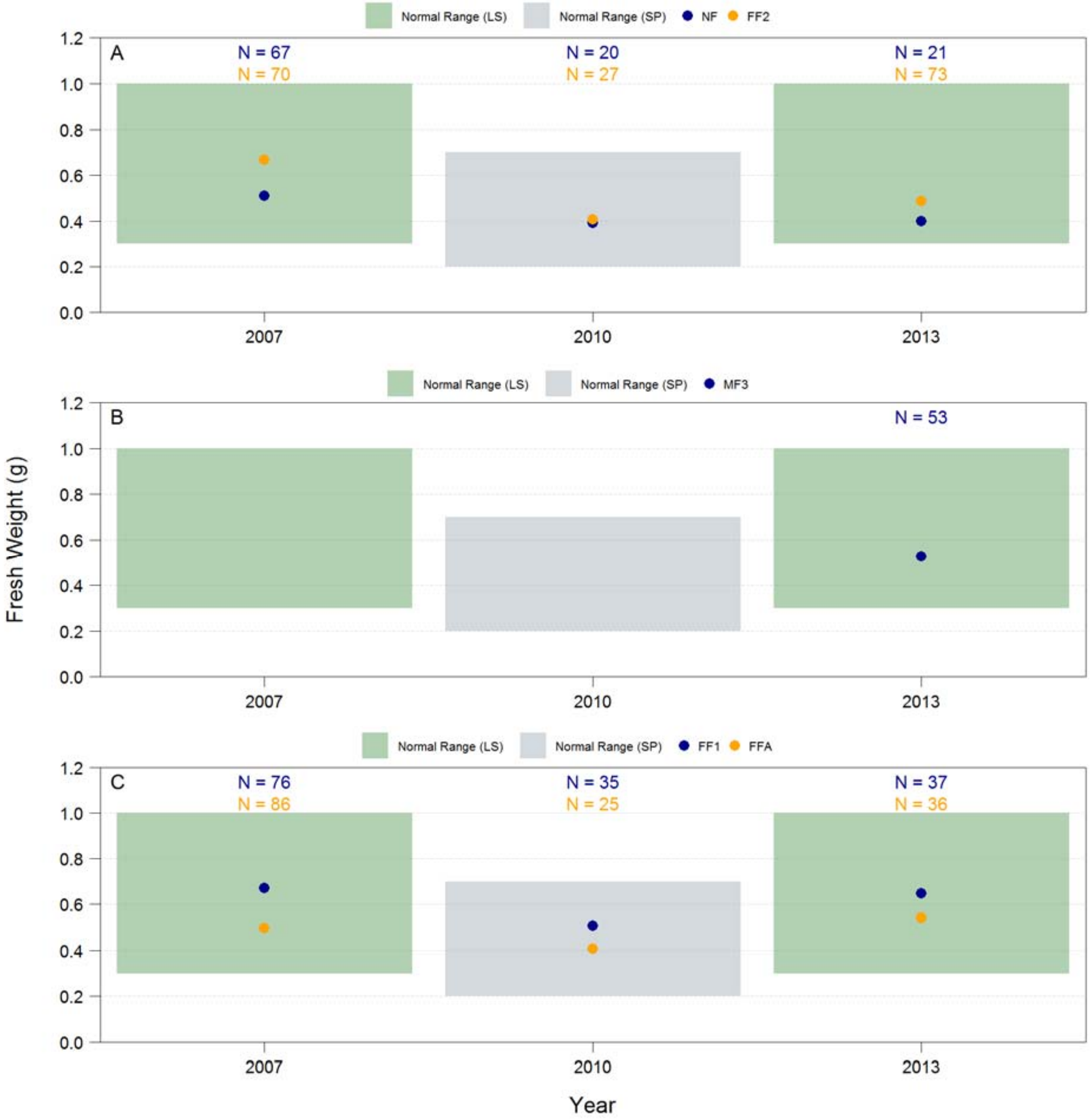
Notes: **Bolded and shaded** text indicates a trend.

a) na = not applicable, 0 = no trend; + = increase from 2007 to 2010 and from 2010 to 2013; - = decrease from 2007 to 2010 and from 2010 to 2013.

b) Condition Factor for Age 1+/Juvenile fish from 2007 and 2013 was calculated using total weight.

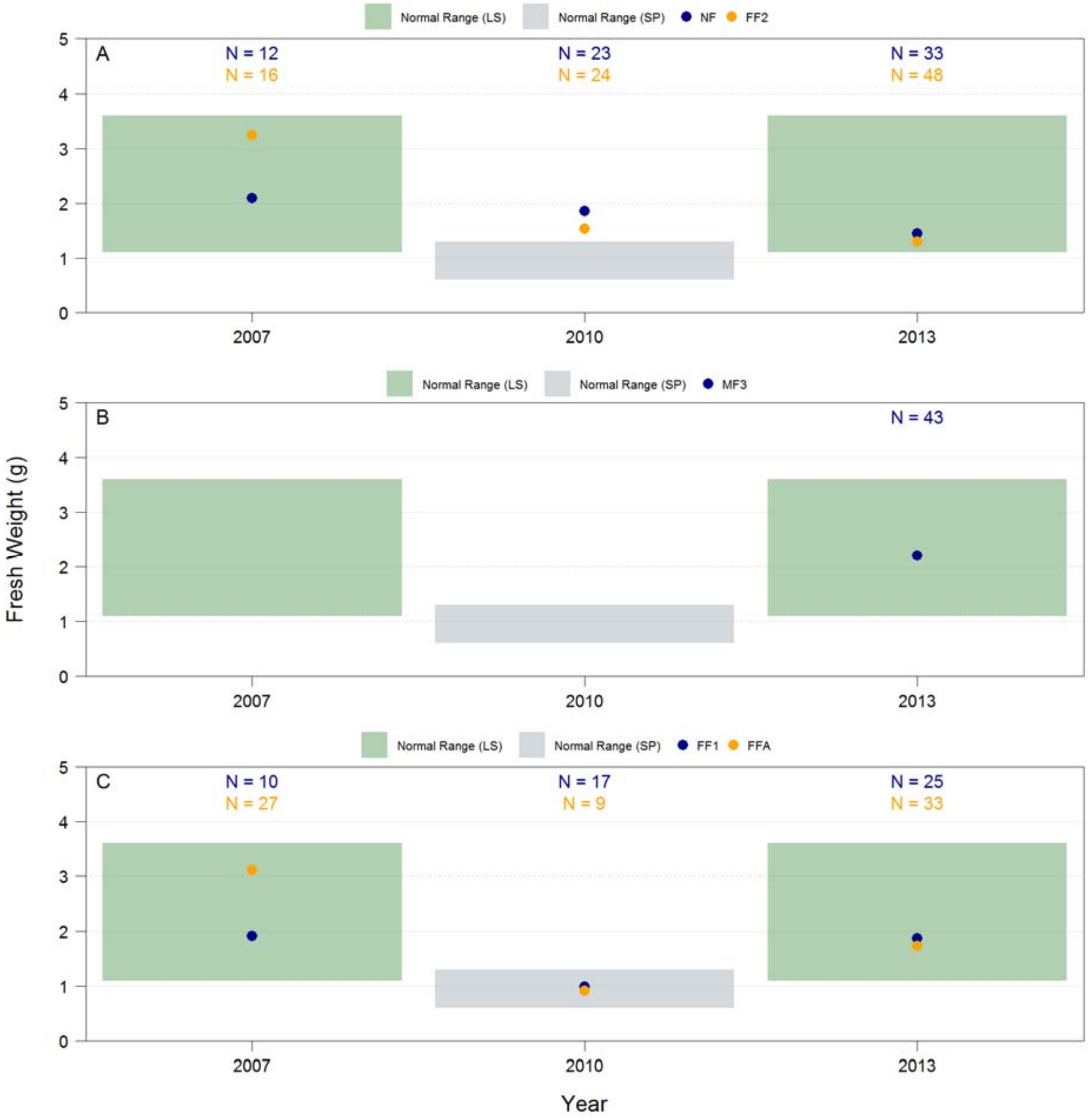
NF = near-field; FF = far-field; MF = mid-field, Juv = juvenile; LSI = liversomatic index; GSI = gonadosomatic index.

Figure 10-1 Mean Fresh Weight of Age 1+/Juvenile Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



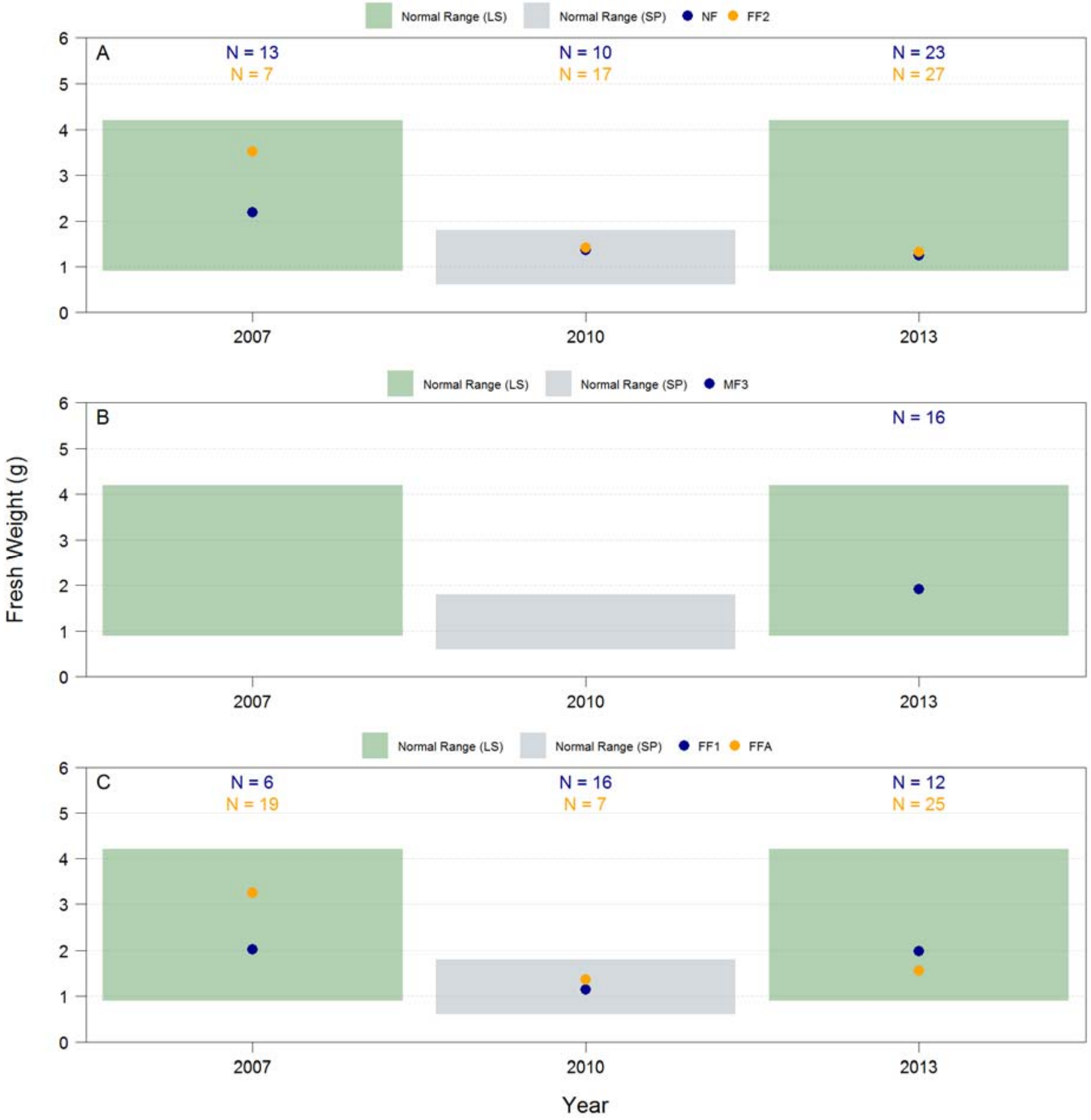
LS = late summer; SP = spring.

Figure 10-2 **Mean Fresh Weight of Male Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras 2007 to 2013**



LS = late summer; SP = spring.

Figure 10-3 Mean Fresh Weight of Female Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013

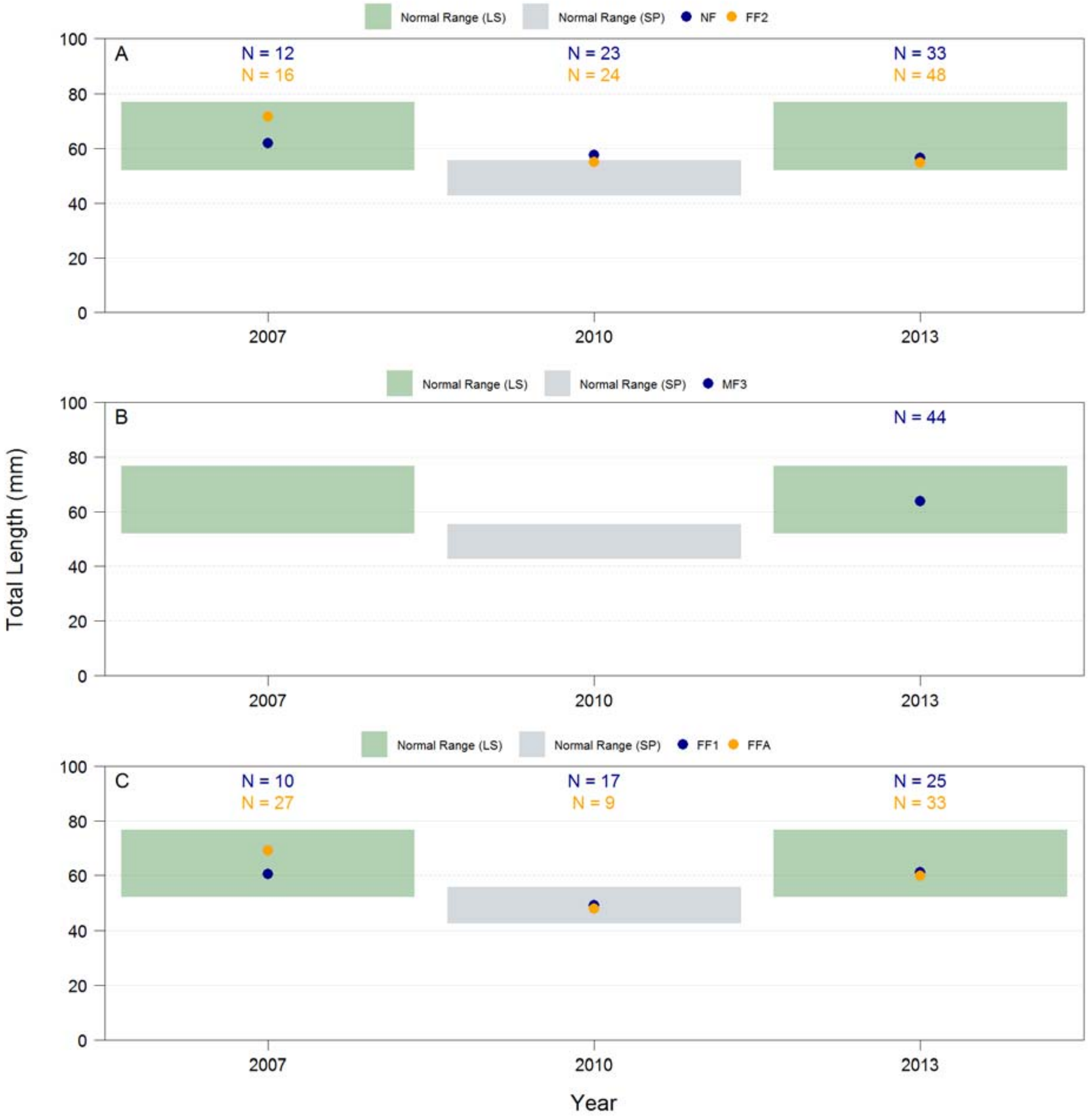


LS = late summer; SP = spring.

Figure 10-4 Mean Total Length of Age 1+/Juvenile Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013

LS = late summer; SP = spring.

Figure 10-5 **Mean Total Length of Male Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013**

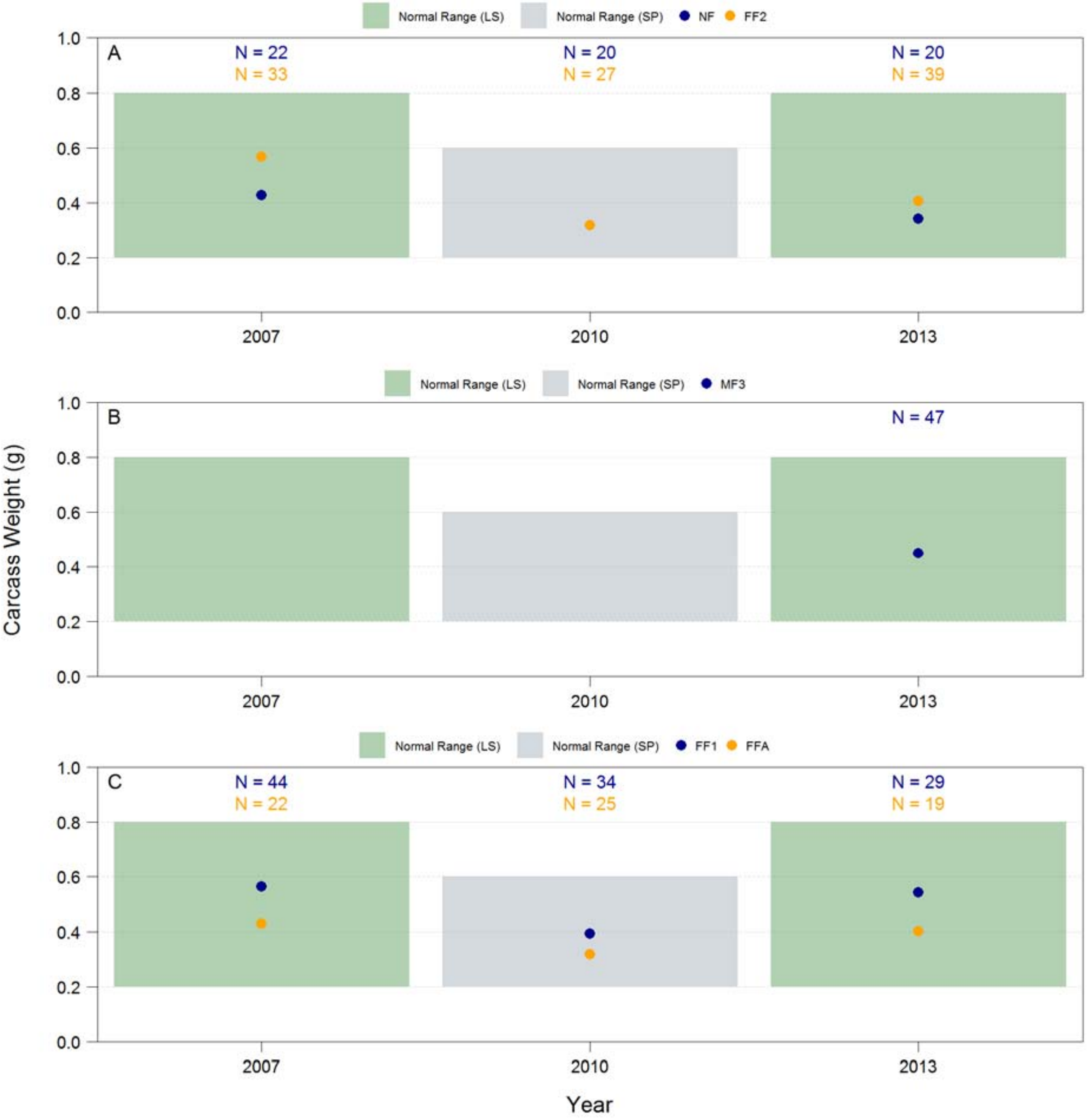


LS = late summer; SP = spring.

Figure 10-6 Mean Total Length of Female Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013

LS = late summer; SP = spring.

Figure 10-7 Mean Carcass Weight of Age 1+/Juvenile Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013

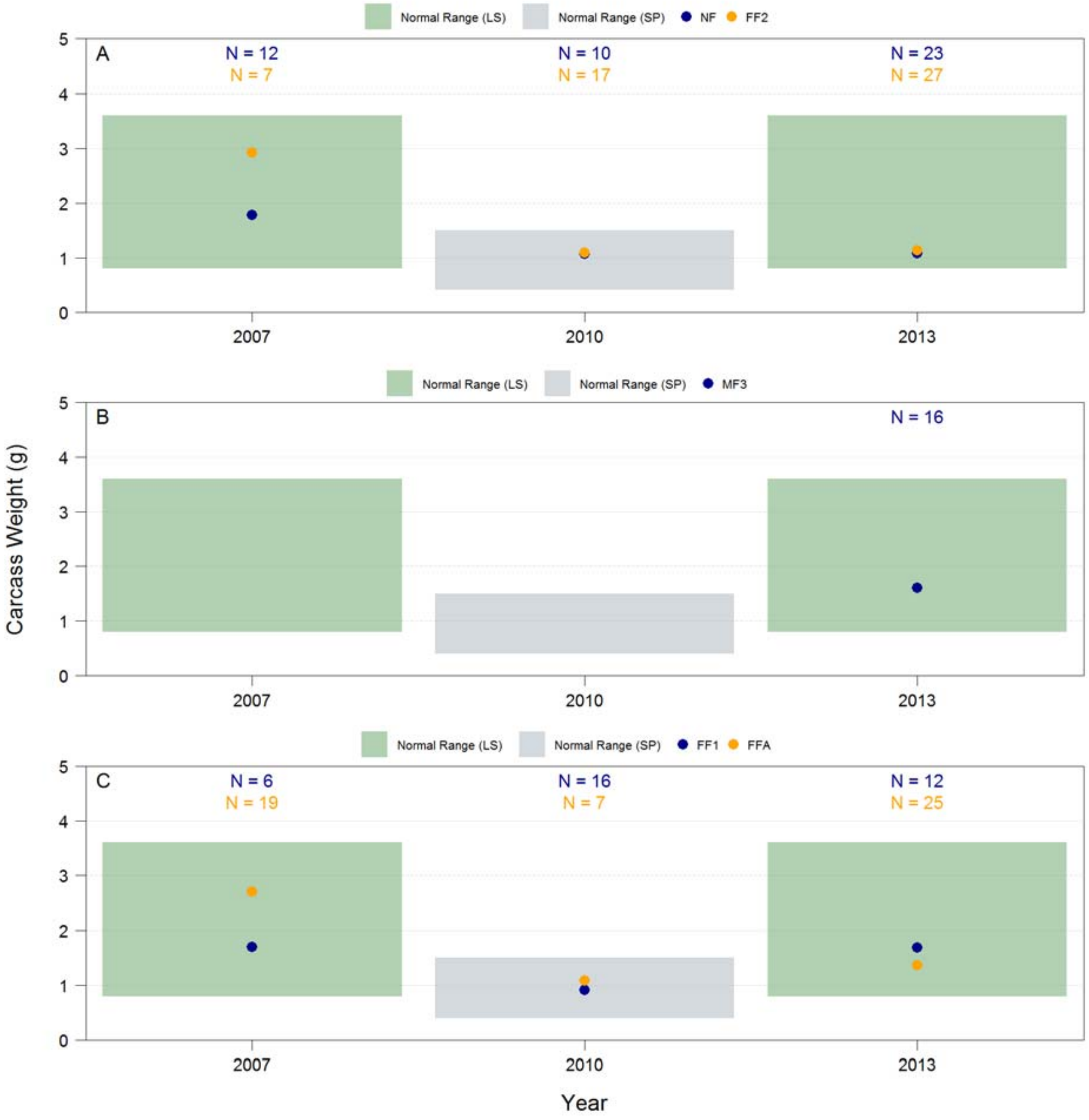


LS = late summer; SP = spring.

Figure 10-8 Mean Carcass Weight of Male Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013

LS = late summer; SP = spring.

Figure 10-9 Mean Carcass Weight of Female Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



LS = late summer; SP = spring.

Figure 10-10 Mean Condition Factor of Age 1+/Juvenile Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013

LS = late summer; SP = spring.

Note: Condition Factors for Age 1+ fish from 2007 and 2013 were calculated using total weight.

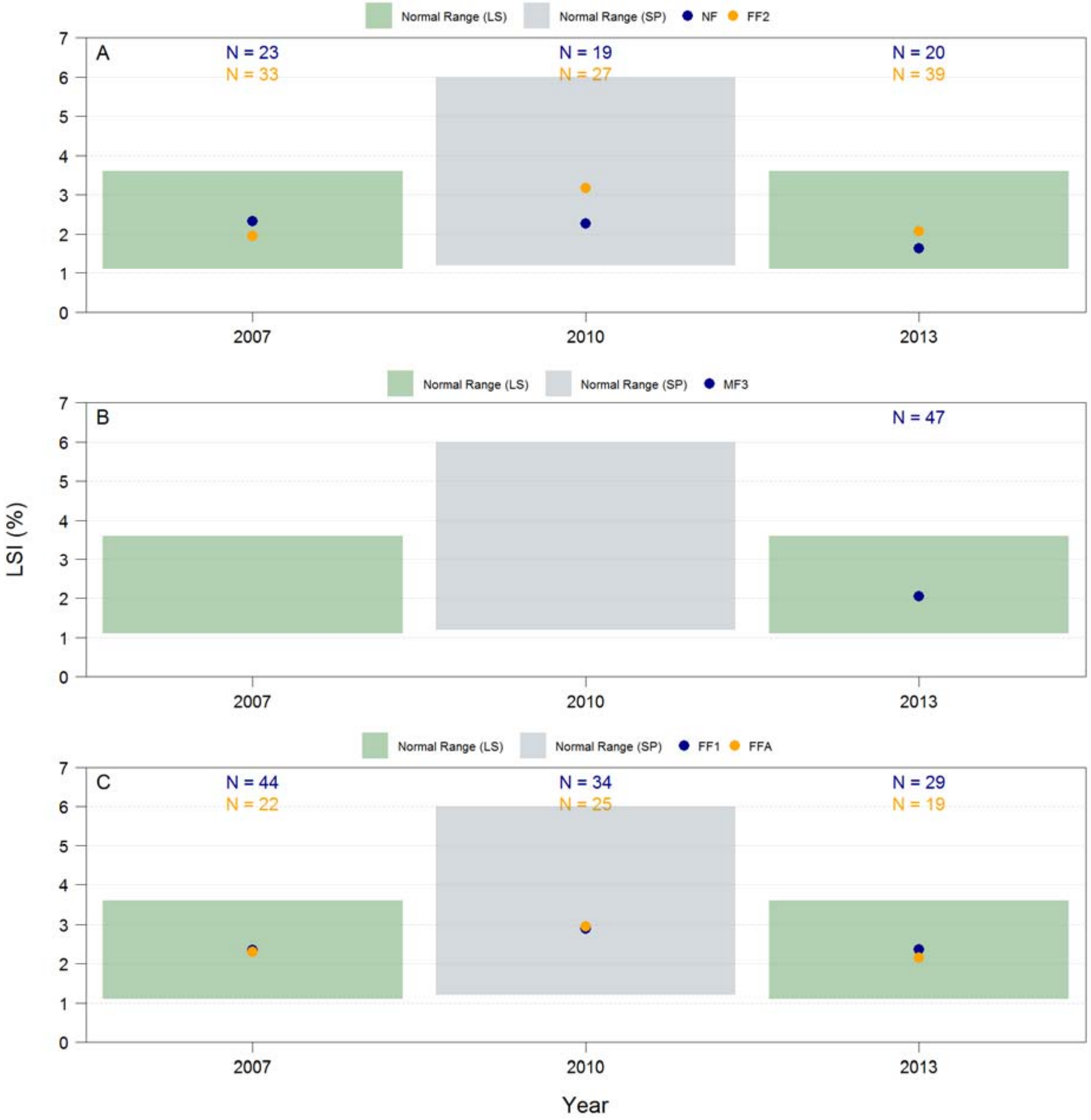
Figure 10-11 Mean Condition Factor of Male Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013

LS = late summer; SP = spring.

Figure 10-12 Mean Condition Factor of Female Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013

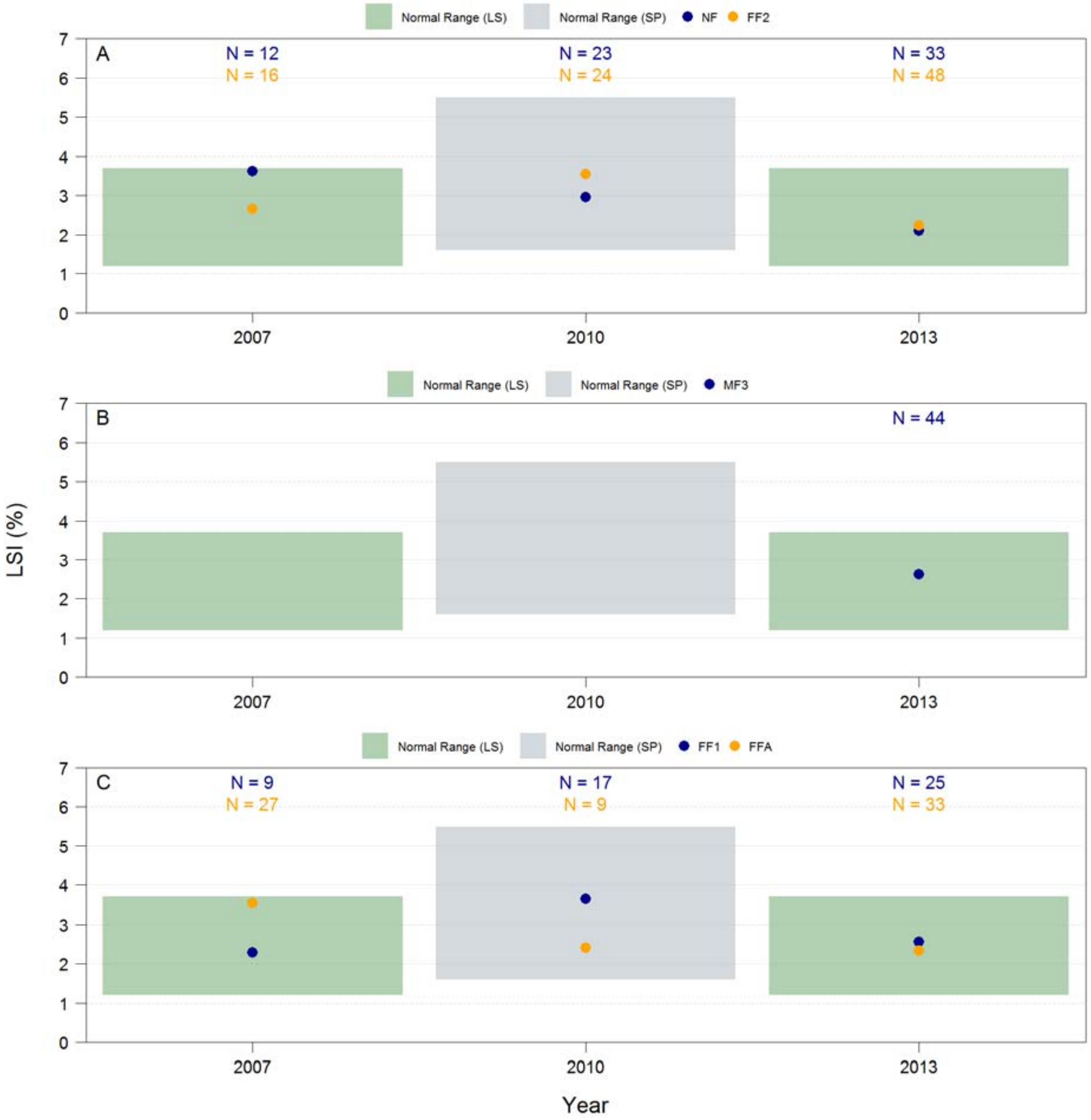
LS = late summer; SP = spring.

Figure 10-13 Mean Liversomatic Index (LSI) of Age 1+/Juvenile Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



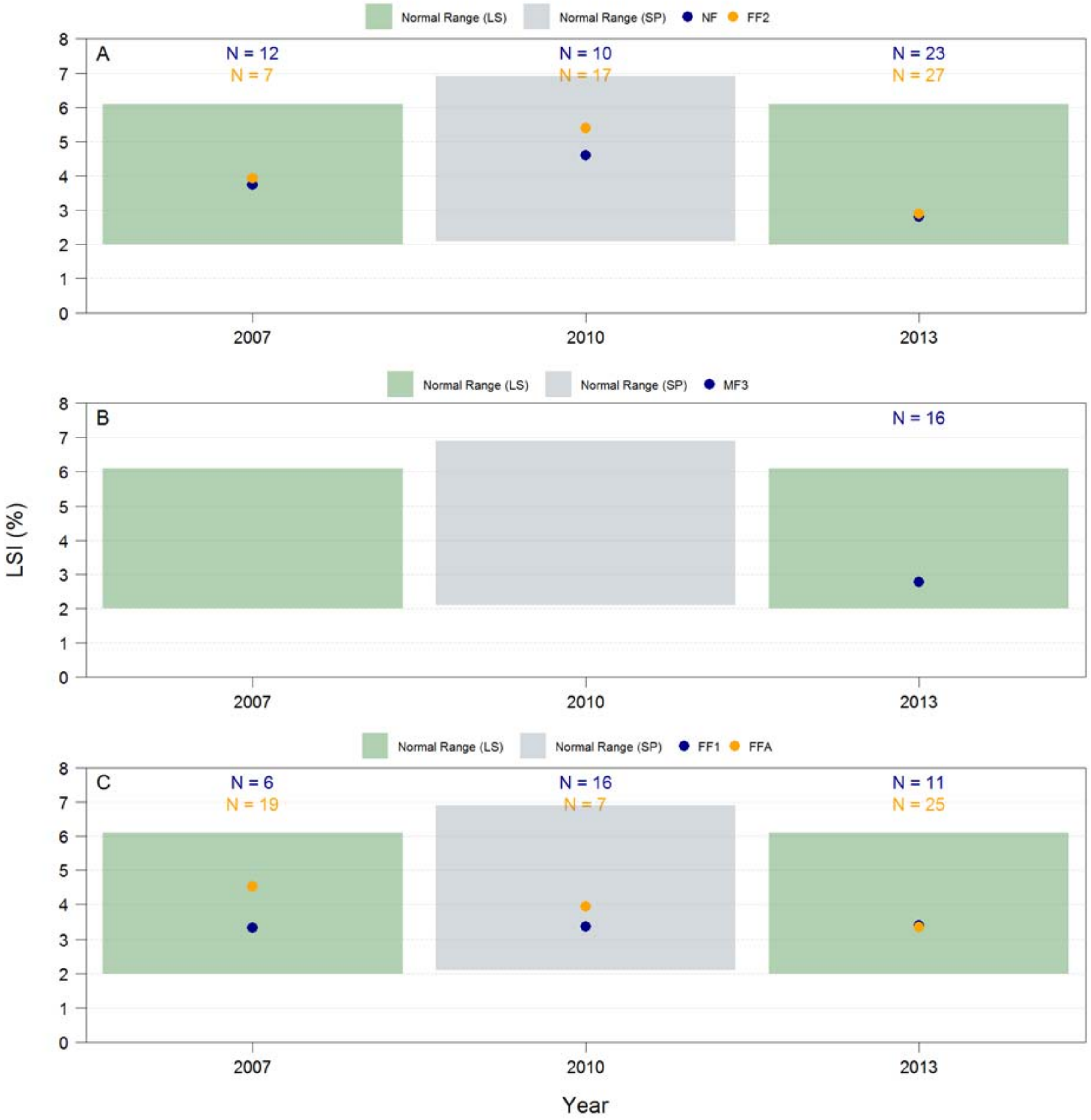
LSI = Liversomatic index; LS = late summer; SP = spring.

Figure 10-14 Mean Liversomatic Index (LSI) of Male Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



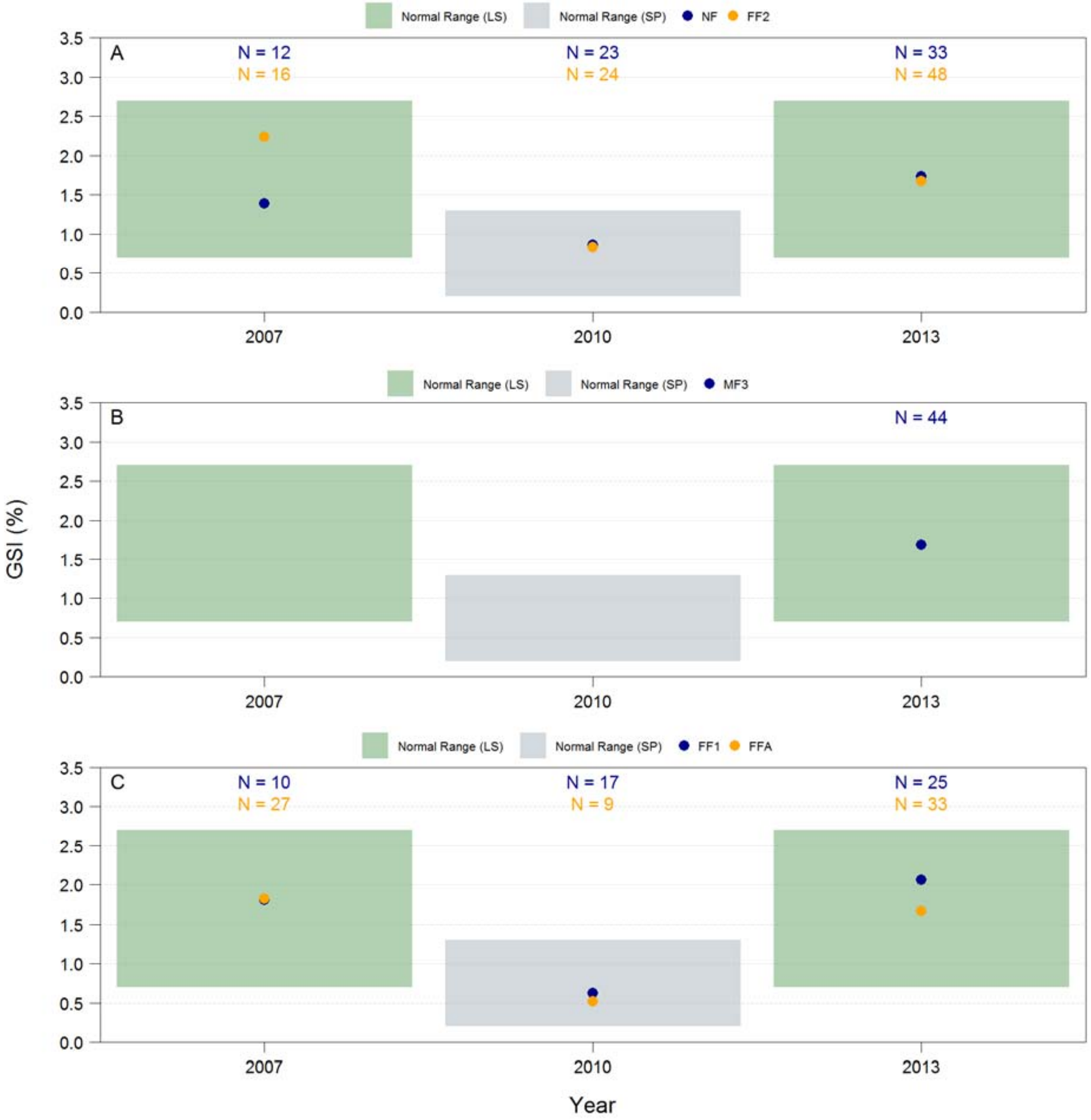
LSI = Liversomatic index; LS = late summer; SP = spring.

Figure 10-15 Mean Liversomatic Index (LSI) of Female Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



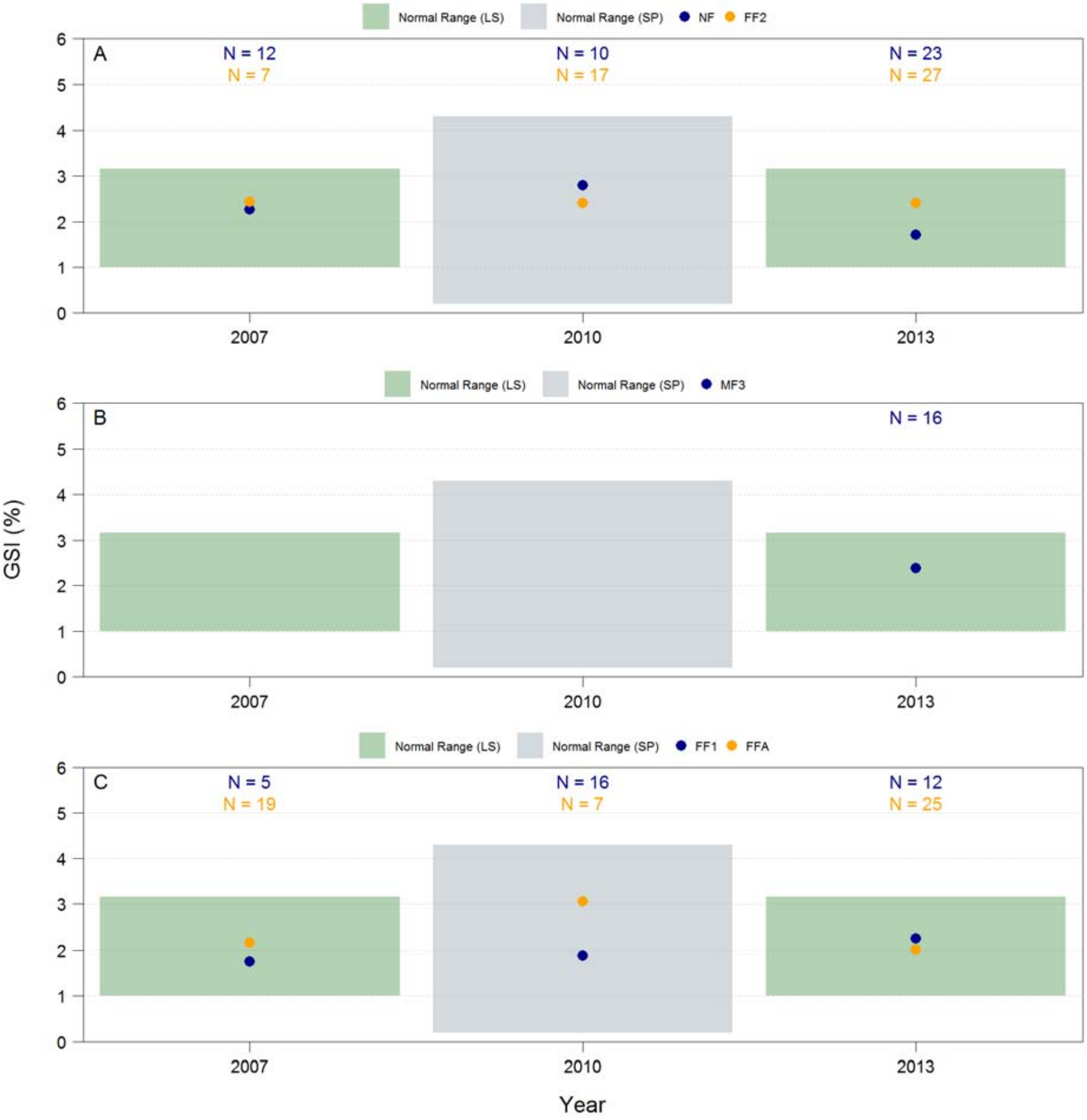
LSI = Liversomatic index; LS = late summer; SP = spring.

Figure 10-16 Mean Gonadosomatic Index (GSI) of Male Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



GSI = Gonadosomatic index; LS = late summer; SP = spring.

Figure 10-17 Mean Gonadosomatic Index (GSI) of Female Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



GSI = Gonadosomatic index; LS = late summer; SP = spring.

Infection by *L. intestinalis*

The percentage of adult Slimy Sculpin infected with the parasite *L. intestinalis* has varied considerably over the years in the exposure areas, without a trend being evident. Infection rates have increased over time for age 1+/juvenile fish in all areas (Figure 10-18).

The incidences of infection in the reference areas have also increased over time for all life stages/sexes. In particular, females from the FFA reference area had a high level of infection in 2010 relative to the other areas and the previous sampling program.

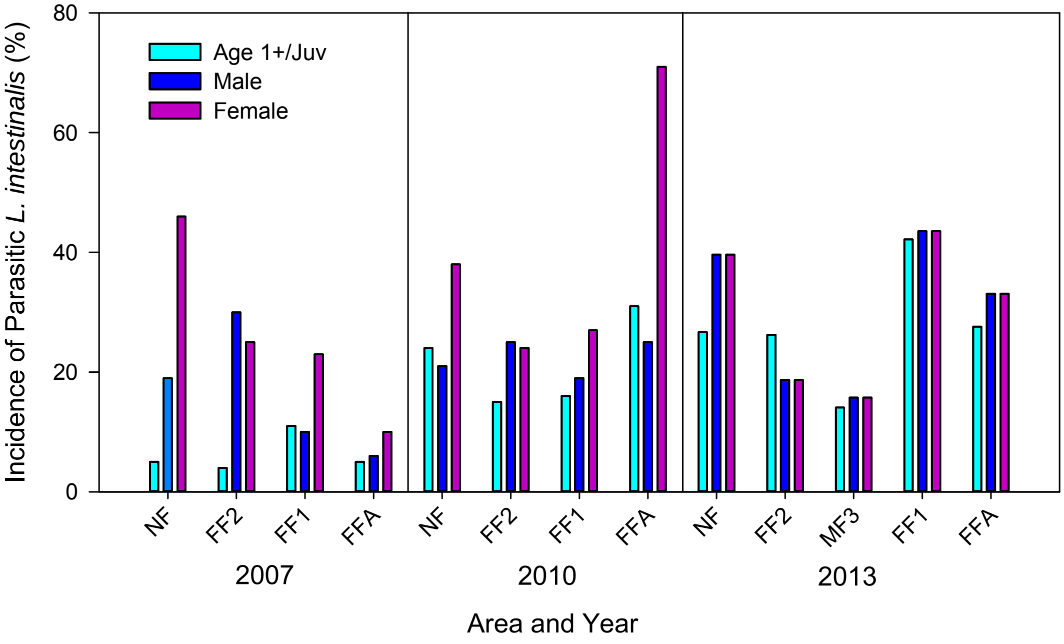
Abnormalities

The incidence of abnormalities in 2007 and 2013 was generally low for all sampling areas. Although the incidence of abnormalities in age 1+/juvenile fish was higher in 2013 compared to 2007, no abnormalities were observed in adult fish from the NF area in 2013. An increased incidence of abnormalities was documented in 2010 relative to 2007 and 2013 (Figure 10-19).

The majority of abnormalities in 2010 were related to pale or fatty livers. Pale gills were the second most frequently occurring pathology. During the 2010 field program, holding times (i.e., the amount of time fish were held in buckets prior to sampling) were longer than in previous years due to the larger number of fish sampled. Since most of the fish reported as having pale gills were held for longer than four hours prior to examination, the pale gill abnormalities may have been due to stress related to length of holding time. This is suspected to be the cause of the inflated overall incidence of pathology in 2010. Holding times were minimized in the 2013 fish survey and pale gills were rarely observed.

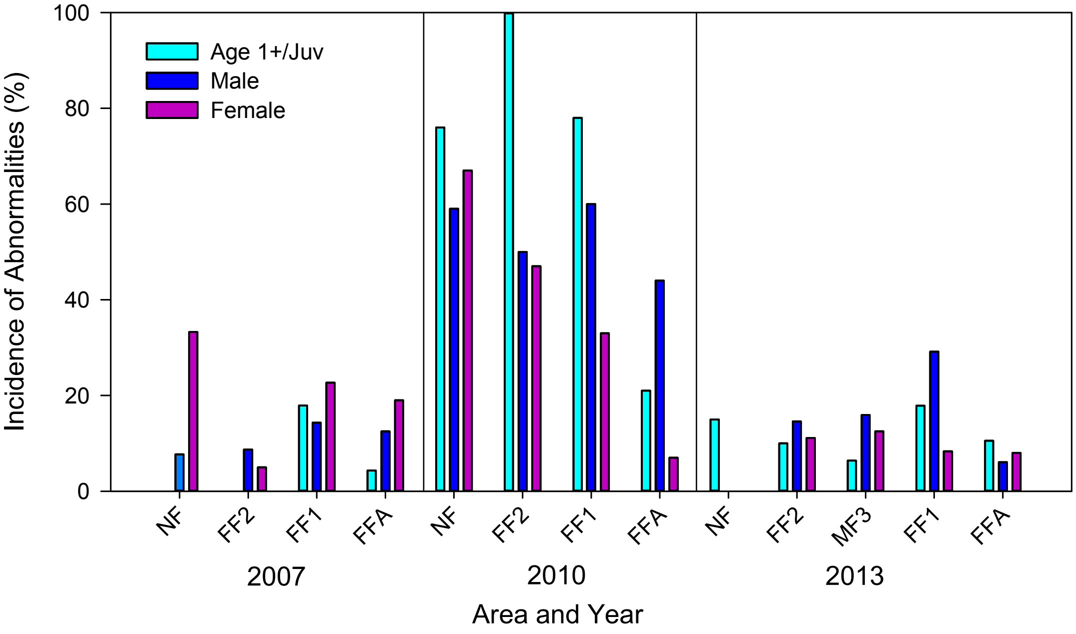
Fatty livers were also frequently observed in 2010 and at greater rates in fish collected from the exposure areas. This could have been a result of a nutrient enrichment response observed in 2010 as Fraikin et al. (2004) showed high incidence of fatty livers in areas of nutrient enrichment.

Figure 10-18 Incidence of Parasitic *Ligula intestinalis* Infection in Slimy Sculpin from Lac de Gras, 2007, 2010 and 2013



NF = near-field; MF = mid-field; FF = far-field; Juv = juvenile.

Figure 10-19 Incidence of Internal and External Abnormalities in Slimy Sculpin from Lac de Gras, 2007, 2010 and 2013



NF = near-field; MF = mid-field; FF = far-field; Juv = juvenile.

10.3 Fish Tissue

10.3.1 Methods

10.3.1.1 Data Sources

10.3.1.1.1 Slimy Sculpin

Three AEMP fish tissue surveys were conducted with Slimy Sculpin in Lac de Gras, as described in Section 10.2.1.1. Eight composite samples of Slimy Sculpin captured at each of the four study areas (NF, FF2, FF1, FFA) were submitted for the analysis of metals in 2007, 2010, and 2013. Eight composite samples of Slimy Sculpin collected from the MF3 area were also analyzed in 2013. The samples consisted of fish carcasses from the Slimy Sculpin fish health assessment. Therefore, gonads and stomachs were not included, as they were required for separate analyses as part of the fish health assessment. The fish making up a composite sample were of the same sex and size class. In each of the sampling years, four male and four female composite samples from each area were submitted for analysis. Samples were composited to meet the minimum sample weight requirement of 5 g wet weight from each area. Samples were analyzed by ALS Canada Ltd. (ALS), Edmonton, Alberta in 2007, and ALS, Burnaby, British Columbia in 2010 and 2013 for metals[1] listed in Table 10-6.

In addition to the three surveys conducted under the AEMP, one other study on Slimy Sculpin in Lac de Gras has been undertaken. A fish tissue assessment of Slimy Sculpin was performed in 2004 by Gray et al. (2005) where Slimy Sculpin were collected from East Island on Lac de Gras. These data are not included in the current summary, because no reference area data were collected in 2005; therefore, a normal range could not be calculated.

10.3.1.1.2 Lake Trout

Mercury concentrations were measured in muscle, liver and kidney tissue from Lake Trout collected in Lac de Gras in 1996, 2002, 2003, 2004, 2005 and 2008 and Lac du Sauvage in 1996, 2008. Additionally, mercury concentrations were measured in muscle in 2011 in both Lac de Gras and Lac du Sauvage. A comparison of all tissue data was conducted up until 2010 in Golder (2011a). As the only new additional data collected since 2010 was muscle in 2011 (Golder 2012b), only a comparison of muscle tissue is provided here.

The 1996 to 2004 concentrations were measured in composite samples or sample sizes were too small; therefore, temporal and spatial comparisons could not be conducted. Mercury bio-accumulates in fish tissue and differences in mercury concentrations can be confounded by differences in fish body size. The 2005 to 2011 concentrations were measured from individual fish and are used here for spatial and temporal comparisons.

The 2005 and 2008 mercury samples were analyzed by ALS with a detection limit of 0.01 µg/g ww. The 2008 mercury samples were also analyzed by Flett (Flett Research Ltd.), Winnipeg, Manitoba, with a detection limit 0.0004 µg/g ww. The 2011 mercury samples were analyzed by Flett.

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[1] The term “metals” includes metalloids such as arsenic, and non-metals such as selenium.

Table 10-6 Variables Analyzed in Slimy Sculpin Tissue Samples from Lac de Gras, 2007 to 2013

Variable	Detection Limit (µg/g ww)		
	2007	2010	2013
% Moisture	0.1	0.1	0.1
Aluminum (Al)	2	0.4	0.4
Antimony (Sb)	0.05	0.002	0.002
Arsenic (As)	0.05	0.004	0.004
Barium (Ba)	0.1	0.01	0.01
Beryllium (Be)	0.2	0.002	0.002
Bismuth (Bi)	0.2	0.002	0.002
Boron (B)	2	0.2	0.2
Cadmium (Cd)	0.01	0.002	0.002
Calcium (Ca)	20	0.5-1.5	5.0(a)
Cesium (Cs)	0.05	0.001	0.001
Chromium (Cr)	0.1	0.01	0.01
Cobalt (Co)	0.1	0.004	0.004
Copper (Cu)	0.05	0.01	0.01
Gallium (Ga)	nt	0.004	0.004
Iron (Fe)	5	0.2	0.2
Lead (Pb)	0.02	0.004	0.004
Lithium (Li)	nt	0.02	0.02
Magnesium (Mg)	5	1-3	10(a)
Manganese (Mn)	0.5	0.004	0.004
Mercury (Hg)	0.01	0.001(b)	0.001
Molybdenum (Mo)	0.05	0.04	0.004
Nickel (Ni)	0.02	0.01	0.01
Phosphorus (P)	20	5-15	50(a)
Potassium (K)	20	20-60	200(a)
Rhenium (Re)	nt	0.002	0.002
Rubidium (Rb)	0.05	0.01	0.01
Selenium (Se)	0.05	0.02	0.02
Silver (Ag)	0.05	0.001	0.001
Sodium (Na)	20	20-60	200
Strontium (Sr)	0.05	0.01	0.01
Tellurium (Te)	0.5	0.04	0.004
Thallium (Tl)	0.05	0.0004	0.0004
Thorium (Th)	nt	0.002	0.002
Tin (Sn)	0.1	0.004	0.02
Titanium (Ti)	0.2	0.01	0.01
Uranium (U)	0.05	0.0004	0.0004
Vanadium (V)	0.1	0.004	0.020(a)
Yttrium (Y)	nt	0.002	0.002
Zinc (Zn)	0.5	0.1	0.1
Zirconium (Zr)	nt	0.04	0.04

a) Laboratory detection limit differed from that originally provided by the lab and listed in the AEMP Study Design Version 3.5 (Golder 2014a).

b) One sample had a detection limit of 0.01 µg/g ww.

ww = wet weight; nt = variable not tested.

10.3.2 Data Handling

Initial screening of the AEMP fish tissue chemistry data set was completed before data analyses to identify unusually high (or low) values in the datasets and decide whether to retain or exclude anomalous data from further analysis. An explanation of the objectives and approach taken to complete initial screening is provided in Section 2.6. Results of the initial screening for anomalous values in the AEMP tissue chemistry datasets did not identify any anomalous values.

Prior to data analyses, non-detect values were substituted by 0.5 times the DL. Substitution with half the DL is a common approach used to deal with censored data (US EPA 2000) and is consistent with the approved methods applied in the calculation of the normal range in the AEMP Reference Conditions Report Version 1.1 (Golder 2015).

10.3.2.1 Data Analysis

10.3.2.1.1 Weight of Evidence Effects Rankings

Slimy Sculpin collected in the AEMP fish surveys (2007, 2010, and 2013) were examined for metal concentrations using composite samples of carcasses. Observed effects were categorized according to the magnitude of the effect (Table 10-7).

Table 10-7 Weight of Evidence Effect Rankings for Slimy Sculpin Fish Tissue Chemistry

Effect Level	Effect Description
Low	Statistically significant increase in the mean NF area concentration relative to the reference areas.
Moderate	Low level effect; **AND** Mean NF area concentration exceeds the upper bound of the normal range.
High	Moderate level effect; **AND** Tissue concentrations in exposure areas at levels known to cause effects in biota.

NF = near-field.

The 2005, 2008 and 2011 concentrations of mercury in Lake Trout were measured from individual fish and are used for spatial and temporal comparisons using body size as a covariate in an analysis of covariance (ANCOVA). Previous regression analyses indicated that fork length explained most of the variation in mercury concentration and, therefore, fork length was used as the covariate. The 1996 data were not included in the weight of evidence analysis as they were measured on composite samples, The 2002 to 2004 data were excluded because the sample sizes were too small (n = 4 or 5). The factor in the ANCOVA was a combination of the sampling area and year so temporal and spatial differences could be assessed. Mercury concentrations and fork length were $\log_{10}$-transformed. Regression slopes were considered parallel at $P > 0.05$, and the ANCOVA was considered significant at $P < 0.1$. Pairwise comparisons were conducted using Tukey's Honestly Significant Differences method using $P < 0.1$. Observed effects were categorized according to the magnitude of the effect (Table 10-8).

Table 10-8 Weight of Evidence Effect Rankings for Mercury in Lake Trout

Effect Level	Effect Description
Low	Statistically significant increase in mercury concentration in Lac de Gras relative to baseline.
Moderate	Early warning/low level change linked to the mine.
High	Human health risk based on the results of human health risk assessment.

10.3.2.1.2 Normal Ranges

Magnitudes of effects on fish tissue chemistry were evaluated by comparing each variable in the exposure areas to background values. Background values for Lac de Gras are those that fall within the range of natural variability, referred to as the normal range. The normal ranges used to evaluate potential effects on fish tissue chemistry were obtained from the AEMP Reference Conditions Report, Version 1.1 (Golder 2015) and are summarized in Table 10-9.

Normal ranges for tissue chemistry were defined using either the LS season data (i.e., 2007 and 2013) or the SP season data (2010). As such, the normal ranges do not account for variation in analytical methods among laboratories.

Table 10-9 Normal Ranges for Fish Tissue Chemistry

Variable	Season	Unit	Normal Range	
			Lower Limit	Upper Limit
Aluminum	LS	µg/g ww	14.8	30.0
	SP	µg/g ww	6.1	14.1
Antimony	n/a	µg/g ww	0	0.002
Arsenic	LS	µg/g ww	0.120	0.150
	SP	µg/g ww	0.060	0.090
Barium	LS	µg/g ww	3.73	4.95
	SP	µg/g ww	4.50	5.57
Beryllium	n/a	µg/g ww	0	0.002
Bismuth	n/a	µg/g ww	0	0.002
Boron	n/a	µg/g ww	0	2
Cadmium	LS	µg/g ww	0.020	0.030
	SP	µg/g ww	0.032	0.053
Calcium	LS	µg/g ww	7,503	10575
	SP	µg/g ww	7,690	9,315
Cesium	LS	µg/g ww	0	0.095
	SP	µg/g ww	0.043	0.058
Chromium	LS	µg/g ww	0.650	2.000
	SP	µg/g ww	0.252	0.625
Cobalt	LS	µg/g ww	0.125	0.300
	SP	µg/g ww	0.065	0.205

Table 10-9 Normal Ranges for Fish Tissue Chemistry

Variable	Season	Unit	Normal Range	
			Lower Limit	Upper Limit
Copper	LS	µg/g ww	0.930	1.113
	SP	µg/g ww	0.757	0.863
Gallium	n/a	µg/g ww	0	0.004
Iron	LS	µg/g ww	30	43
	SP	µg/g ww	22.7	34.8
Lead	LS	µg/g ww	0	0.02
	SP	µg/g ww	0.009	0.015
Lithium	n/a	µg/g ww	0.031	0.056
Magnesium	LS	µg/g ww	349	426
	SP	µg/g ww	314	341
Manganese	LS	µg/g ww	9.23	12.60
	SP	µg/g ww	14.80	17.80
Mercury	LS	µg/g ww	0.033	0.085
	SP	µg/g ww	0.014	0.018
Molybdenum	LS	µg/g ww	0	0.05
	SP	µg/g ww	0.05	0.08
Nickel	LS	µg/g ww	0.913	1.420
	SP	µg/g ww	0.429	0.606
Phosphorus	LS	µg/g ww	5,723	7,338
	SP	µg/g ww	6,110	6,690
Potassium	LS	µg/g ww	3,260	3,365
	SP	µg/g ww	2,825	2,990
Rhenium	n/a	µg/g ww	0	0.002
Rubidium	LS	µg/g ww	5.82	6.83
	SP	µg/g ww	4.18	5.19
Selenium	LS	µg/g ww	0.403	0.453
	SP	µg/g ww	0.372	0.408
Silver	LS	µg/g ww	0	0.001
	SP	µg/g ww	0.002	0.005
Sodium	LS	µg/g ww	1,083	1,198
	SP	µg/g ww	946	1,120
Strontium	LS	µg/g ww	26.4	34.9
	SP	µg/g ww	25.4	29.3
Tellurium	n/a	µg/g ww	0	0.004
Thallium	LS	µg/g ww	0.004	0.005
	SP	µg/g ww	0.009	0.011
Thorium	n/a	µg/g ww	0	0.00255

Table 10-9 Normal Ranges for Fish Tissue Chemistry

Variable	Season	Unit	Normal Range	
			Lower Limit	Upper Limit
Tin	LS	µg/g ww	0.039	0.049
	SP	µg/g ww	0.038	0.082
Titanium	LS	µg/g ww	0	0.400
	SP	µg/g ww	0.180	0.554
Uranium	LS	µg/g ww	0.009	0.0167
	SP	µg/g ww	0.017	0.0217
Vanadium	LS	µg/g ww	0.2	0.2
	SP	µg/g ww	0.037	0.051
Yttrium	LS	µg/g ww	0	0.003
	SP	µg/g ww	0.004	0.007
Zinc	LS	µg/g ww	25.23	29.48
	SP	µg/g ww	36.35	46.73
Zirconium	n/a	µg/g ww	0	0.04

Note:, Normal range applies to all seasons.

n/a = not applicable.

10.3.2.1.3 Temporal Trends – Slimy Sculpin

Time series plots for variables with detected concentrations were generated using data from 2007, 2010, and 2013 for the two exposure areas (NF and FF2), mid-field area (MF3) (2013 only), and the reference areas (FF1 and FFA) of Lac de Gras. The mean values were plotted for each variable and were compared to the normal range.

Trends over time were assessed by comparing the position of the exposure and mid-field area means relative to the normal range. The exposure area and mid-field area means were converted to a percentile rank (PR) relative to the normal range as:

$$PR = \frac{mean - NR_L}{NR_U - NR_L} \times 100$$

where, NR_L is the lower bound of the normal range and NR_U is the upper bound of the normal range.

The concentrations of several metals varied considerably among years, regardless of the sampling area. These variations may have been due to differences in analytical methods among laboratories (ALS Edmonton in 2007, ALS Burnaby in 2010 and 2013).

10.3.2.1.4 Temporal Trends – Lake Trout

The distributions of mercury concentrations in Lake Trout muscle tissue by year and area (Lac de Gras or Lac du Sauvage) were plotted using boxplots for 1996 to 2011. The boxes were defined with the 25th percentile, the median, and the 75th percentile. The whiskers were defined as the 10th and 90th percentiles and concentrations beyond the 10th and 90th percentiles were plotted as individual points. A temporal and spatial analysis for mercury concentrations was conducted using ANCOVA with fork length as a covariate, and a combination of the sampling area and year as a factor, as discussed above. Pairwise comparisons for year and lake were conducted to assess spatial differences between Lac de Gras and Lac du Sauvage.

10.3.3 Results

10.3.3.1 Summary of Effects

10.3.3.1.1 Weight of Evidence Effects Rankings – Slimy Sculpin

Mean bismuth, strontium, thallium and uranium concentrations in Slimy Sculpin collected from the NF area in 2013 were statistically significantly greater than those in reference fish, and exceeded the normal range (Table 10-10). These variables were therefore considered to have moderate level effect rankings. Moderate level effects ranks were also assigned to strontium in 2007 and 2010, and uranium in 2010. Other variables had moderate level effect rankings in 2007 and 2010, but not in 2013 (magnesium, mercury and selenium in 2007; aluminum, lithium, molybdenum, titanium and yttrium in 2010; and barium and lead in both 2007 and 2010).

Low level rankings were assigned to lead in 2013, despite moderate level rankings in 2007 and 2010 (Table 10-10). Thallium was the only metal showing an effect for the first time in 2013. Metals with low level effect rankings previously observed but not observed in 2013 were silver (2010), and thorium (2010).

10.3.3.1.2 Weight of Evidence Effects Rankings – Lake Trout

A low effect ranking was observed for mercury in Lake Trout, as mercury concentrations in Lake Trout muscle tissue increased significantly from baseline. A temporal and spatial analysis for mercury concentrations was conducted using ANCOVA. The factor in the ANCOVA was a combination of the sampling area and year, so temporal and spatial differences could be assessed. Two fish with fork length less than 300 mm were removed from the analysis and one regression outlier and one influential observation were also removed from the analysis (Golder 2012b). Slopes were not significantly different ($P = 0.087$) among groups, and adjusted mercury concentrations (adjusted to a mean length of 625 mm) were significantly different ($P < 0.001$) among groups (Figures 10-20 and 10-21).

Table 10-10 Summary of Weight of Evidence Effect Rankings for Slimy Sculpin Fish Tissue Chemistry, 2007 to 2013

Variable	Year		
	2007	2010	2013
Aluminum (Al)	0	↑↑	0
Antimony (Sb)	0	0	0
Arsenic (As)	0	0	0
Barium (Ba)	↑↑	↑↑	0
Beryllium (Be)	0	0	0
Bismuth (Bi)	0	↑(b)	↑↑
Boron (B)	0	0	0
Cadmium (Cd)	0	0	0
Calcium (Ca)	0	0	0
Cesium (Cs)	0	0	0
Chromium (Cr)	0	0	0
Cobalt (Co)	0	0	0
Copper (Cu)	0	0	0
Gallium (Ga)	n/a	0	0
Iron (Fe)	0	0	0
Lead (Pb)	↑↑	↑↑	↑
Lithium (Li)	n/a	↑↑	0
Magnesium (Mg)	↑↑	0	0
Manganese (Mn)	0	0	0
Mercury (Hg)	↑↑	0	0
Molybdenum (Mo)	0	↑↑	0
Nickel (Ni)	0	0	0
Phosphorus (P)	0	0	0
Potassium (K)	0	0	0
Rhenium (Re)	n/a	0	0
Rubidium (Rb)	0	0	0
Selenium (Se)	↑↑	0	0
Silver (Ag)	0	↑(a)	0
Sodium (Na)	0	0	0
Strontium (Sr)	↑↑	↑↑	↑↑
Tellurium (Te)	0	0	0
Thallium (Tl)	0	0	↑↑
Thorium (Th)	n/a	↑(a)	n/a
Tin (Sn)	0	0	0
Titanium (Ti)	0	↑↑	0
Uranium (U)	↑(b)	↑↑	↑↑
Vanadium (V)	0	0	0
Yttrium (Y)	n/a	↑↑	0
Zinc (Zn)	0	0	0
Zirconium (Zr)	n/a	0	0

Notes: ↑ = increase, 0 = decrease or no change, n/a = not applicable as variable was not measured. ↑ = low level effect; ↑↑ = moderate level effect; ↑↑↑ = high level effect. Statistical analyses are presented in Golder 2008, 2011d, 2014f.

a) Mean concentrations exceeded the normal range of reference area concentrations, but there was no link to the Mine via effluent, water quality or sediment chemistry.

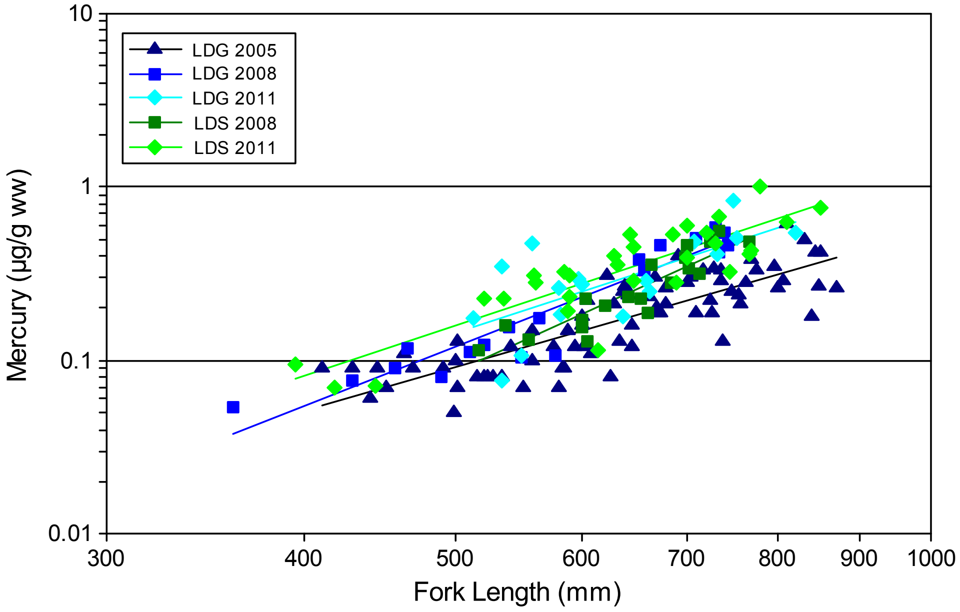
b_ Normal range not determined in the Reference Conditions Report Version 1.1 (Golder 2015).

NF = near-field; FF = far-field

In Lac de Gras, adjusted mercury concentrations increased from baseline (2005) to 2011 (Figure 10-21). Concentrations in 2008 and 2011 were not significantly different from each other ($P = 0.183$) but were significantly greater than in 2005 ($P < 0.001$). In Lac du Sauvage, adjusted mercury concentrations increased significantly from 2008 to 2011 ($P = 0.014$). Mercury concentrations in 2008 and 2011 were not significantly different between Lac de Gras and Lac du Sauvage ($P = 0.917$ and $P = 0.854$ for 2008 and 2011, respectively). Given that the pattern in Lake Trout mercury concentrations are similar between both lakes over time, and that mercury is not detectable in effluent (Golder 2016) , the increase in Lac de Gras cannot be linked to the mine. Hence, a moderate effects ranking was not reached.

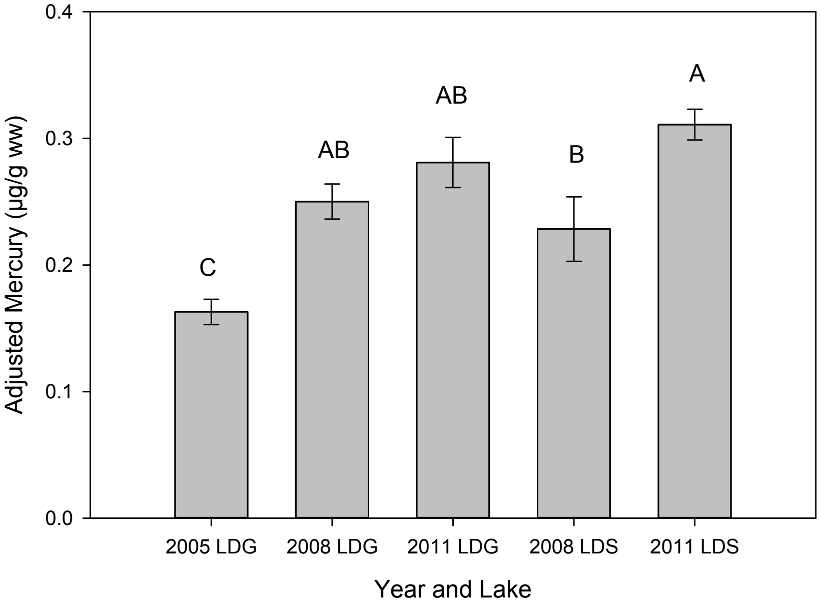
Given that the pattern in Lake Trout mercury concentrations are similar between both lakes over time, and that mercury is not detectable in effluent (Golder 2014) the increase in Lac de Gras cannot be linked to the mine. Hence, a moderate effects ranking was not reached.

Figure 10-20 Linear Regressions of Mercury Concentrations over Fork Length for Lake Trout Collected from Lac de Gras and Lac du Sauvage, 2005 to 2011



Notes: LDG = Lac de Gras; LDS = Lac du Sauvage. Axes are on a logarithmic scale.

Figure 10-21 Mean Mercury Concentrations Adjusted to a Fork Length of 625 mm for Lake Trout Collected from Lac de Gras and Lac du Sauvage, 2005 to 2011



Notes: LDG = Lac de Gras; LDS = Lac du Sauvage. Error bars represent one standard error of the mean. Means that do not share a letter (A, B, or C) are significantly different from each other.

10.3.3.2 Temporal Trends

10.3.3.2.1 Slimy Sculpin

Concentrations of each variable in Slimy Sculpin tissue were plotted by area and year in Figures 10-22 to 10-61. Potassium at the NF area was the only variable that increased relative to the normal range over time (Table 10-11). Of the variables showing effects in 2013 (bismuth, lead, strontium, thallium, uranium Table 10-10), temporal increases relative to the normal range were not observed. Several variables decreased over time relative to the normal range at both the NF and FF2 exposure areas (barium, nickel, vanadium). Other variables that showed a temporal decrease relative to the normal range at the NF area only are cadmium, magnesium, mercury and selenium.

Table 10-11 Summary of Trends for Slimy Sculpin Fish Tissue Concentrations Relative to the Normal Range, 2007 to 2013

Variable	Area	Percentile Rank (%) Relative to the Normal Range			Trend
		2007	2010	2013	
Aluminum (Al)	NF	40	160	-85	0
	FF2	212	63	-81	-
	MF3	n/a	n/a	-80	n/a
Antimony (Sb)	NF	n/a	n/a	50	n/a
	FF2	n/a	n/a	50	n/a
	MF3	n/a	n/a	50	n/a

Table 10-11 Summary of Trends for Slimy Sculpin Fish Tissue Concentrations Relative to the Normal Range, 2007 to 2013

Variable	Area	Percentile Rank (%) Relative to the Normal Range			Trend
		2007	2010	2013	
Arsenic (As)	NF	-67	-24	-235	0
	FF2	75	37	-137	-
	MF3	n/a	n/a	-233	n/a
Barium (Ba)	NF	383	196	41	-
	FF2	146	90	31	-
	MF3	n/a	n/a	156	n/a
Beryllium (Be)	NF	n/a	0	50	n/a
	FF2	n/a	0	50	n/a
	MF3	n/a	n/a	50	n/a
Bismuth (Bi)	NF	n/a	n/a	199	n/a
	FF2	n/a	n/a	102	n/a
	MF3	n/a	n/a	161	n/a
Boron (B)	NF	n/a	n/a	5	n/a
	FF2	n/a	n/a	5	n/a
	MF3	n/a	n/a	5	n/a
Cadmium (Cd)	NF	129	-15	-93	-
	FF2	-50	-38	-63	0
	MF3	n/a	n/a	-77	n/a
Calcium (Ca)	NF	144	55	116	0
	FF2	81	35	110	0
	MF3	n/a	n/a	132	n/a
Cesium (Cs)	NF	26	-23	24	0
	FF2	26	-115	22	0
	MF3	n/a	n/a	25	n/a
Chromium (Cr)	NF	21	122	-46	0
	FF2	28	56	-46	0
	MF3	n/a	n/a	-46	n/a
Cobalt (Co)	NF	-2	6	-57	0
	FF2	43	-4	-47	-
	MF3	n/a	n/a	-52	n/a
Copper (Cu)	NF	3	48	-228	0
	FF2	5	-6	-212	-
	MF3	n/a	n/a	-205	n/a
Gallium (Ga)	NF	n/a	n/a	50	n/a
	FF2	n/a	n/a	50	n/a
	MF3	n/a	n/a	50	n/a
Iron (Fe)	NF	-2	113	-157	0
	FF2	197	55	-118	-
	MF3	n/a	n/a	-125	n/a

Table 10-11 Summary of Trends for Slimy Sculpin Fish Tissue Concentrations Relative to the Normal Range, 2007 to 2013

Variable	Area	Percentile Rank (%) Relative to the Normal Range			Trend
		2007	2010	2013	
Lead (Pb)	NF	193	428	59	0
	FF2	162	71	19	-
	MF3	n/a	n/a	39	n/a
Lithium (Li)	NF	n/a	176	-83	n/a
	FF2	n/a	20	-83	n/a
	MF3	n/a	n/a	-83	n/a
Magnesium (Mg)	NF	172	68	58	-
	FF2	143	5	52	0
	MF3	n/a	n/a	38	n/a
Manganese (Mn)	NF	-38	-222	87	0
	FF2	33	-94	528	0
	MF3	n/a	n/a	-31	n/a
Mercury (Hg)	NF	365	21	-33	-
	FF2	74	-39	-26	0
	MF3	n/a	n/a	-22	n/a
Molybdenum (Mo)	NF	77	169	77	0
	FF2	76	54	100	0
	MF3	n/a	n/a	69	n/a
Nickel (Ni)	NF	18	54	-161	-
	FF2	12	-54	-159	-
	MF3	n/a	n/a	-150	n/a
Phosphorus (P)	NF	129	18	88	0
	FF2	75	13	82	0
	MF3	n/a	n/a	96	n/a
Potassium (K)	**NF**	**-69**	**-20**	**496**	**+**
	FF2	-14	-29	440	0
	MF3	n/a	n/a	323	n/a
Rhenium (Re)	NF	n/a	n/a	50	n/a
	FF2	n/a	n/a	50	n/a
	MF3	n/a	n/a	50	n/a
Rubidium (Rb)	NF	-123	-59	-261	0
	FF2	-159	-82	-212	0
	MF3	n/a	n/a	-200	n/a
Selenium (Se)	NF	406	-189	-295	-
	FF2	75	-352	-304	0
	MF3	n/a	n/a	-314	n/a
Silver (Ag)	NF	n/a	464	117	n/a
	FF2	n/a	29	131	n/a
	MF3	n/a	n/a	56	n/a

Table 10-11 Summary of Trends for Slimy Sculpin Fish Tissue Concentrations Relative to the Normal Range, 2007 to 2013

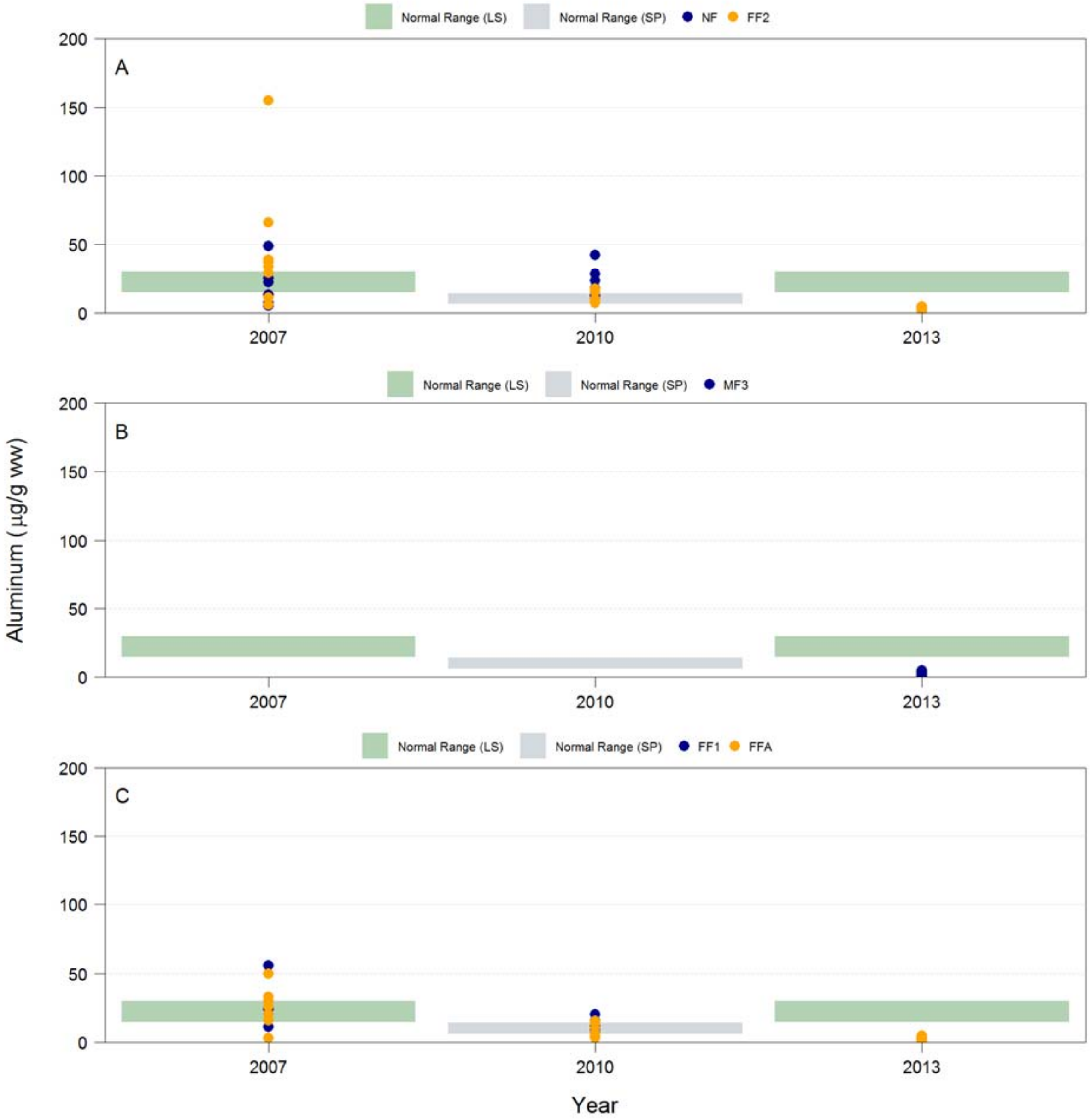
		Percentile Rank (%) Relative to the Normal Range			
Variable	Area	2007	2010	2013	Trend
Sodium (Na)	NF	108	81	159	0
	FF2	162	51	114	0
	MF3	n/a	n/a	220	n/a
Strontium (Sr)	NF	253	254	235	0
	FF2	125	66	164	0
	MF3	n/a	n/a	135	n/a
Tellurium (Te)	NF	n/a	n/a	5	n/a
	FF2	n/a	n/a	5	n/a
	MF3	n/a	n/a	5	n/a
Thallium (Tl)	NF	n/a	-50	122	n/a
	FF2	n/a	-96	78	n/a
	MF3	n/a	n/a	18	n/a
Thorium (Th)	NF	n/a	423	n/a	n/a
	FF2	n/a	166	n/a	n/a
	MF3	n/a	n/a	n/a	n/a
Tin (Sn)	NF	n/a	58	272	n/a
	FF2	n/a	79	436	n/a
	MF3	n/a	n/a	203	n/a
Titanium (Ti)	NF	107	253	28	0
	FF2	319	69	26	-
	MF3	n/a	n/a	28	n/a
Uranium (U)	NF	n/a	2091	1320	n/a
	FF2	n/a	283	271	n/a
	MF3	n/a	n/a	200	n/a
Vanadium (V)	NF	400	207	-775	-
	FF2	300	120	-705	-
	MF3	n/a	n/a	-620	n/a
Yttrium (Y)	NF	n/a	183	81	n/a
	FF2	n/a	83	77	n/a
	MF3	n/a	n/a	96	n/a
Zinc (Zn)	NF	201	9	160	0
	FF2	35	-45	99	0
	MF3	n/a	n/a	167	n/a
Zirconium (Zr)	NF	n/a	n/a	50	n/a
	FF2	n/a	n/a	50	n/a
	MF3	n/a	n/a	75	n/a

Notes: **Bolded and shaded** text indicates an increasing trend for variables showing effects (see Table 10-10).

a); 0 = no trend; + = increase from 2007 to 2010 and from 2010 to 2013; - = decrease from 2007 to 2010 and from 2010 to 2013.

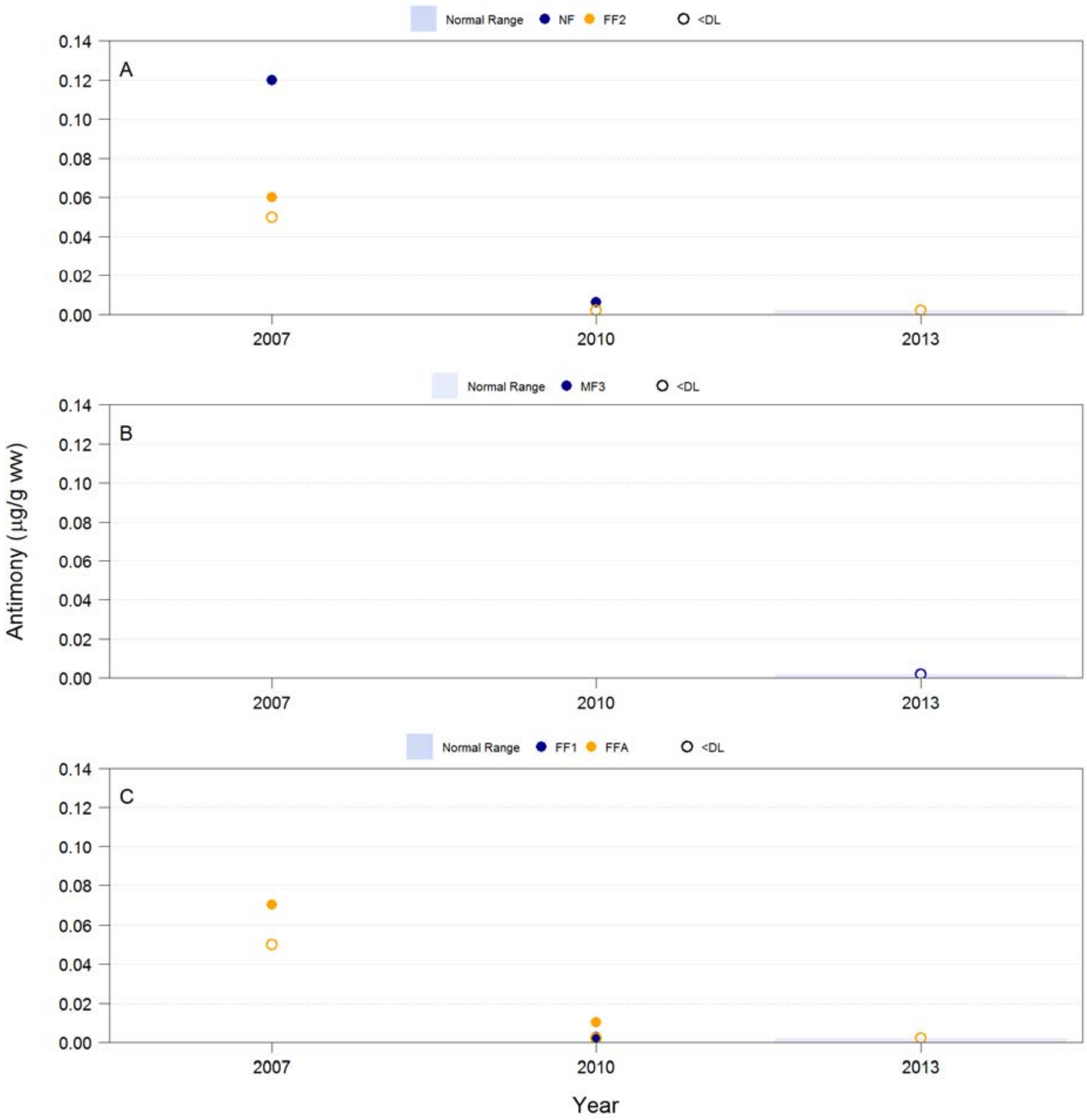
n/a = not applicable

Figure 10-22 Concentrations of Aluminum in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



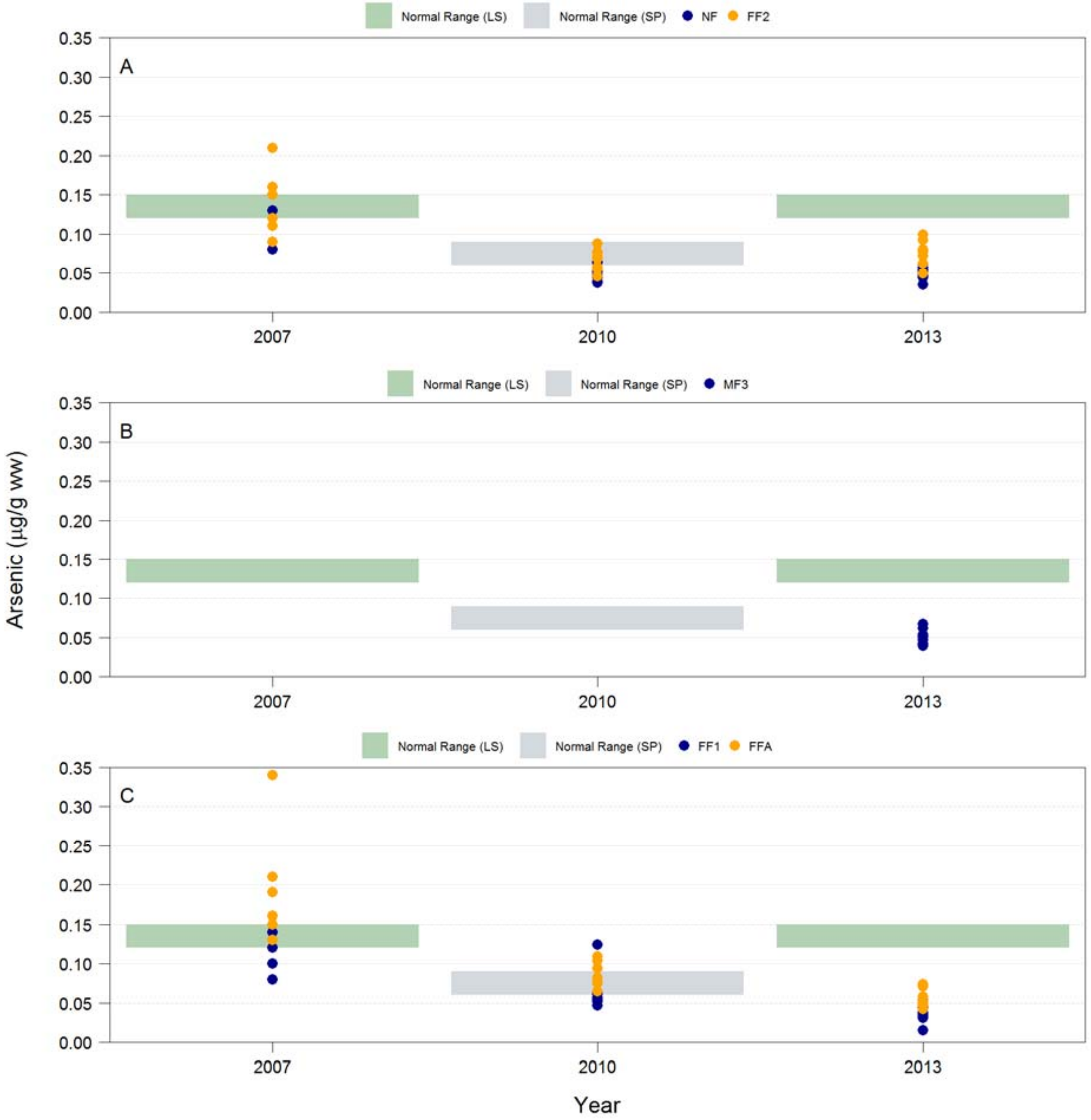
NF = near-field; MF = mid-field; FF = far-field.

Figure 10-23 Concentrations of Antimony in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



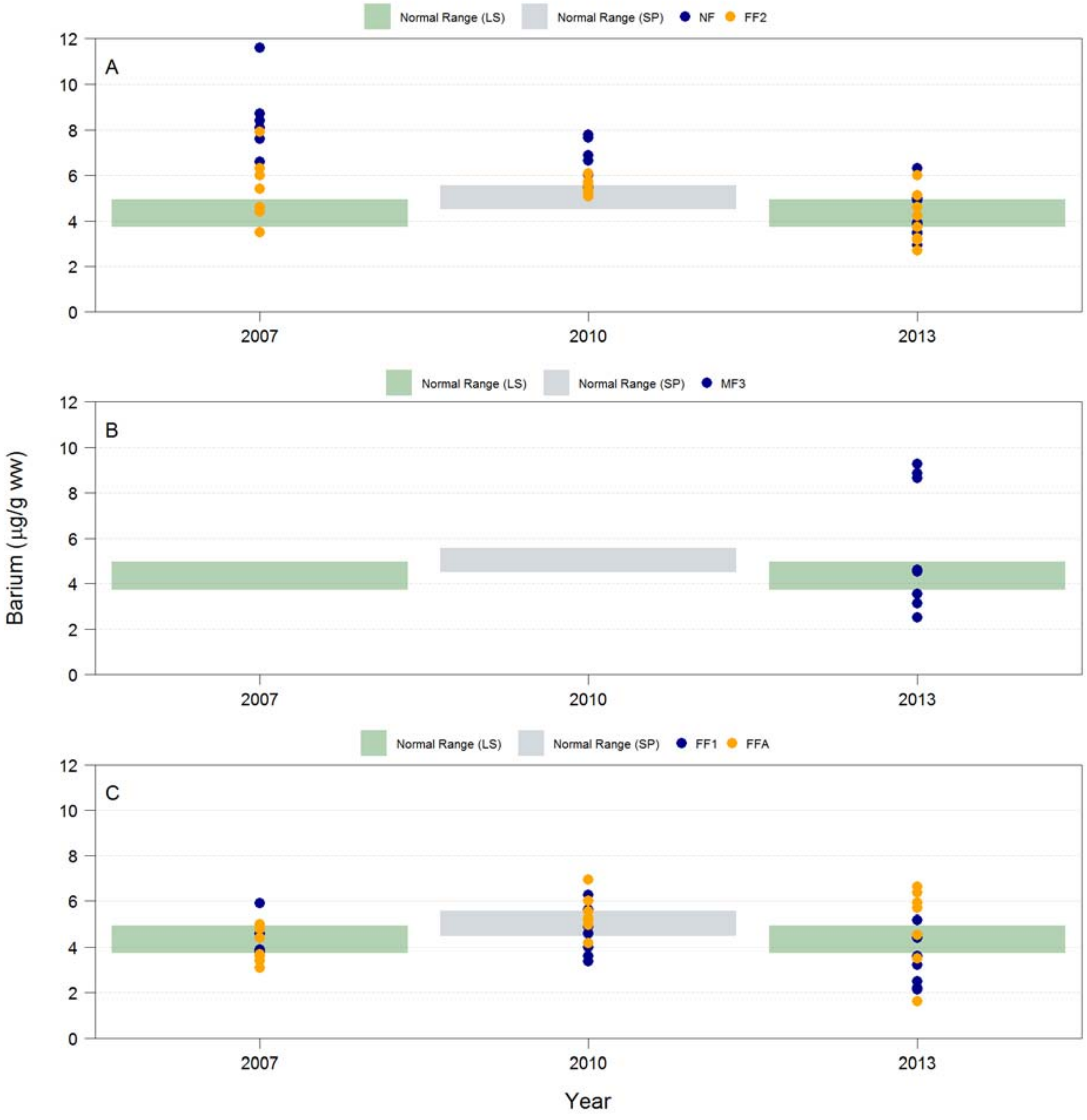
DL = detection limit.

Figure 10-24 Concentrations of Arsenic in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



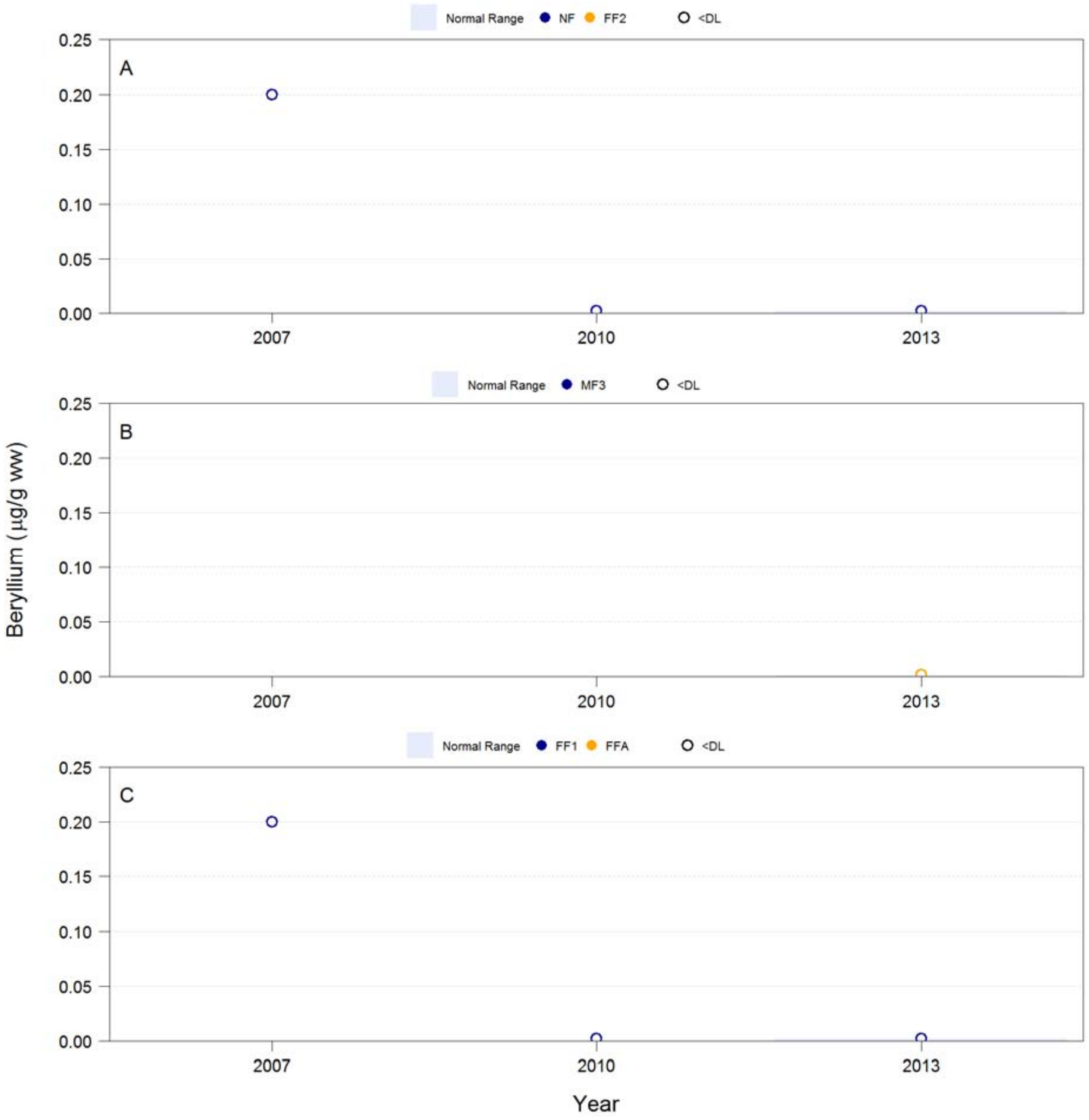
LS = late summer; SP = spring.

Figure 10-25 Concentrations of Barium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



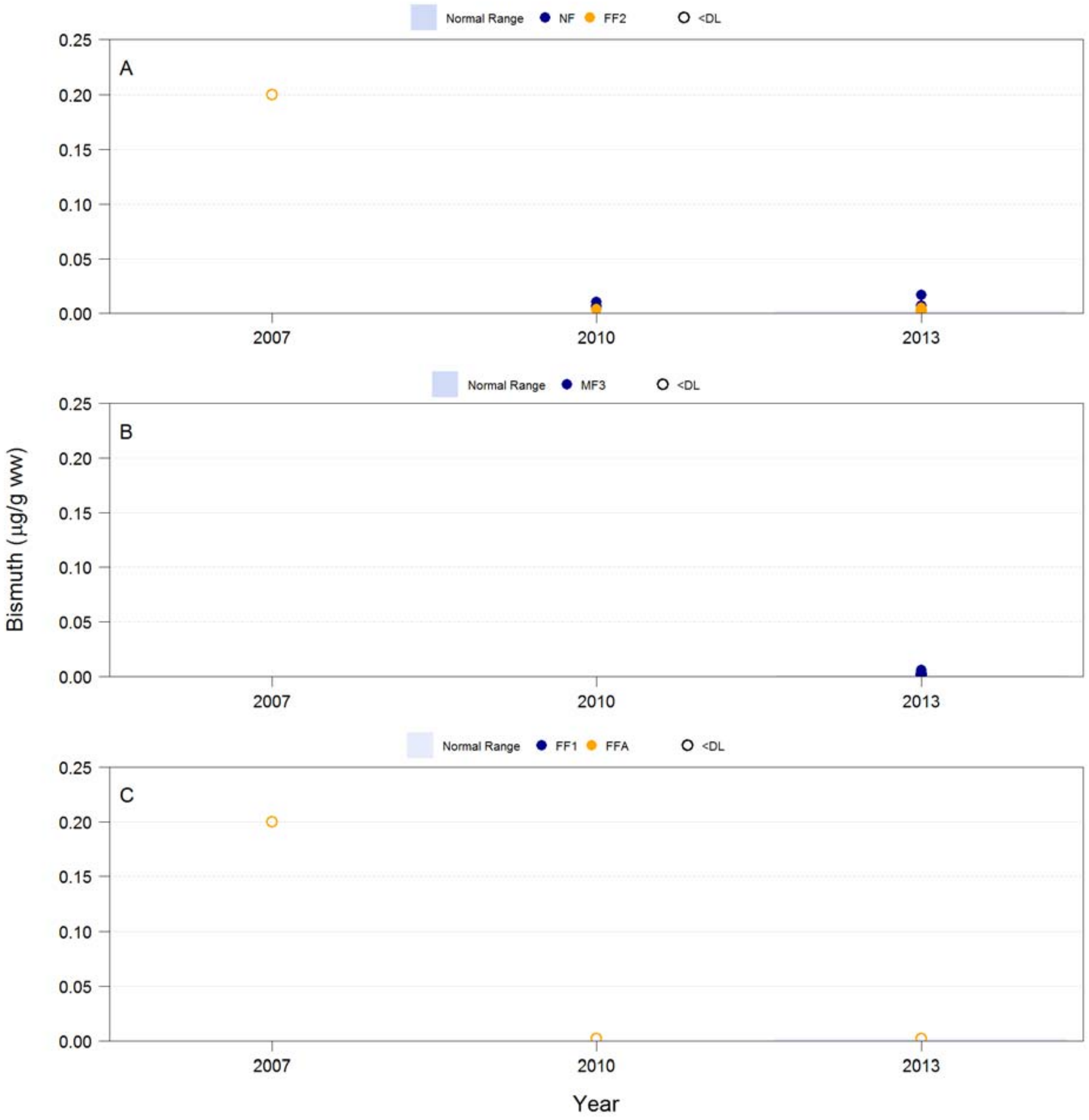
LS = late summer; SP = spring.

Figure 10-26 Concentrations of Beryllium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



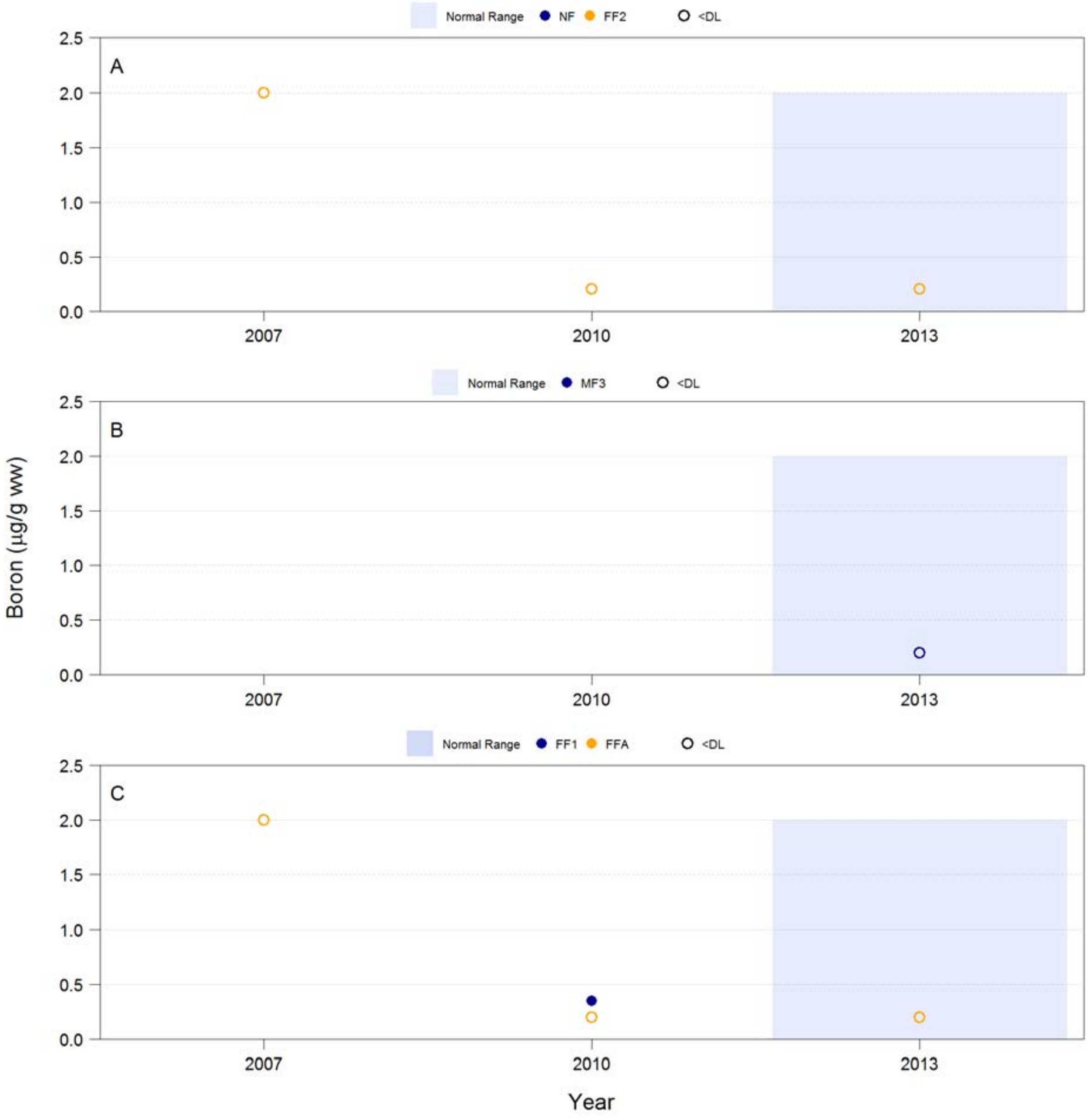
DL = detection limit.

Figure 10-27 Concentrations of Bismuth in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



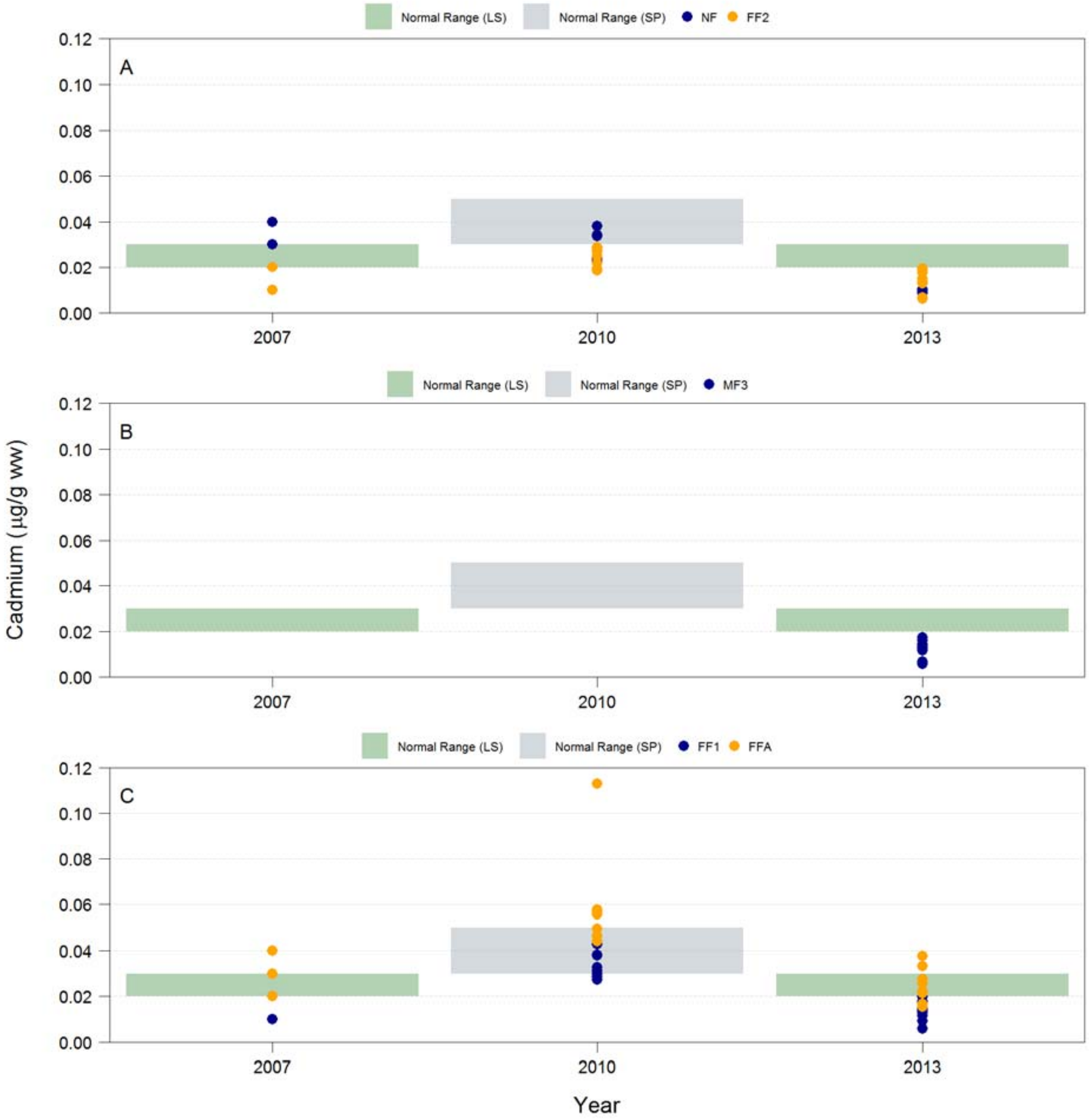
DL = detection limit.

Figure 10-28 Concentrations of Boron in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



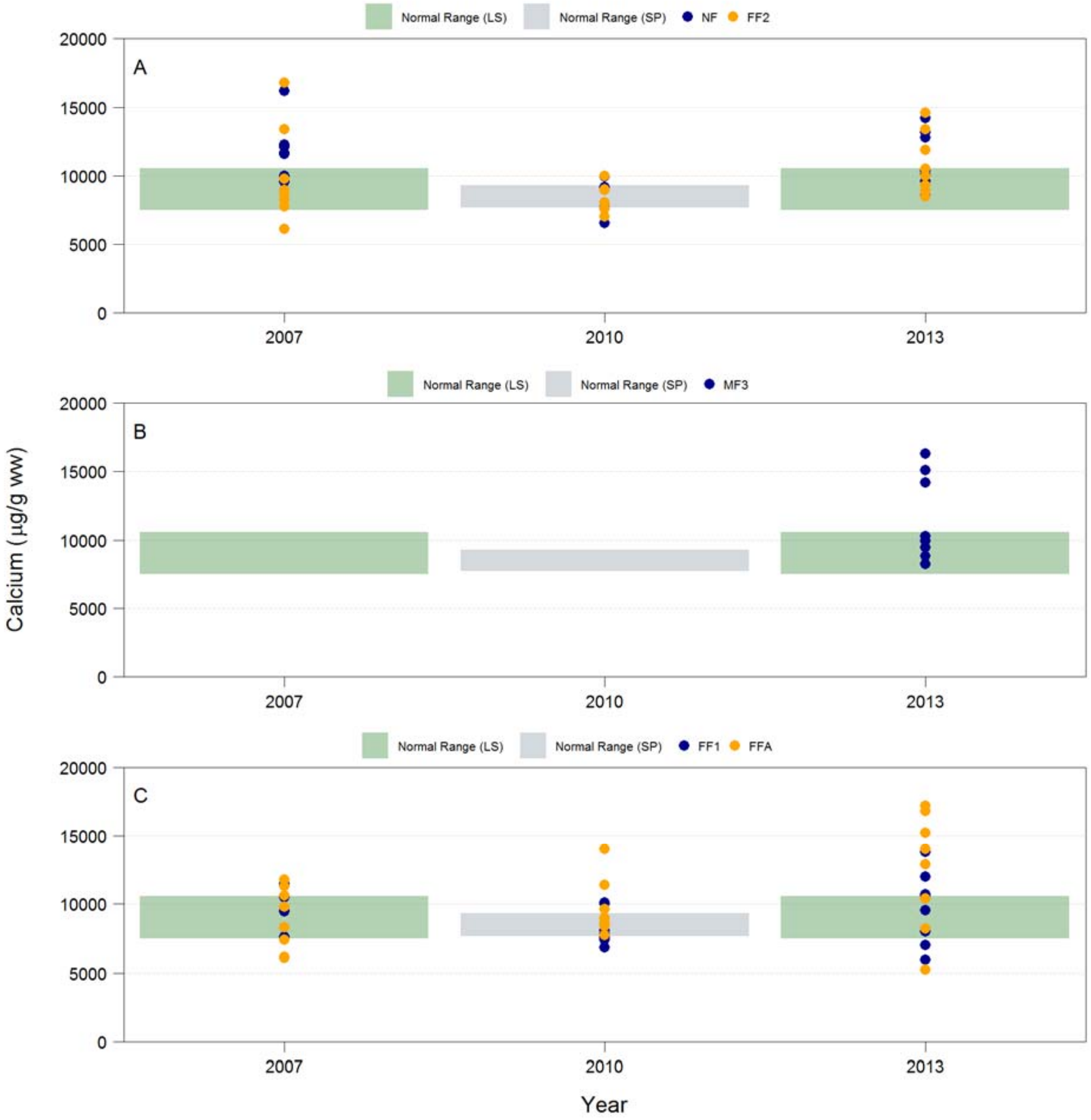
DL = detection limit.

Figure 10-29 Concentrations of Cadmium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



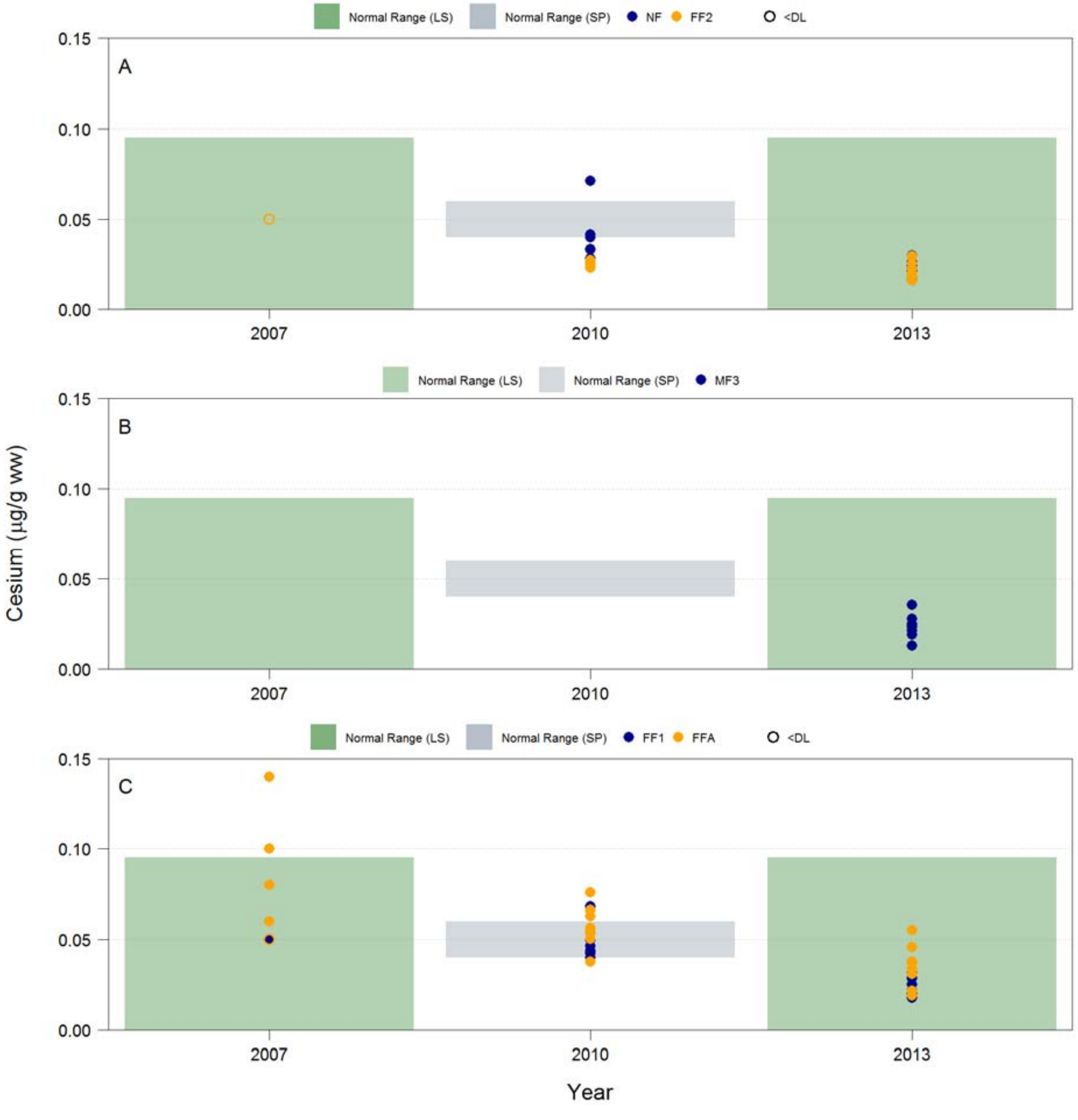
LS = late summer; SP = spring.

Figure 10-30 Concentrations of Calcium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



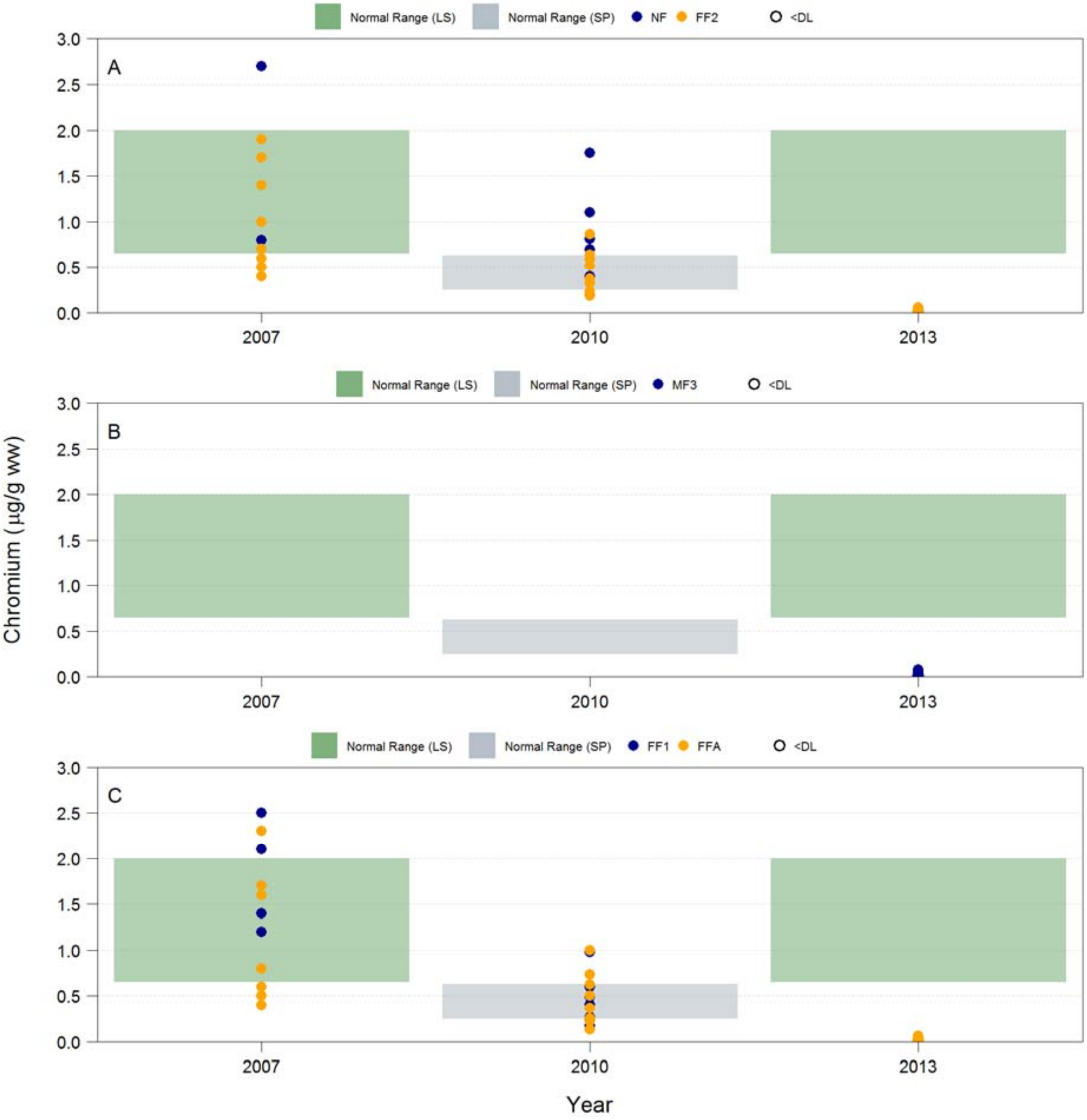
LS = late summer; SP = spring.

Figure 10-31 Concentrations of Cesium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



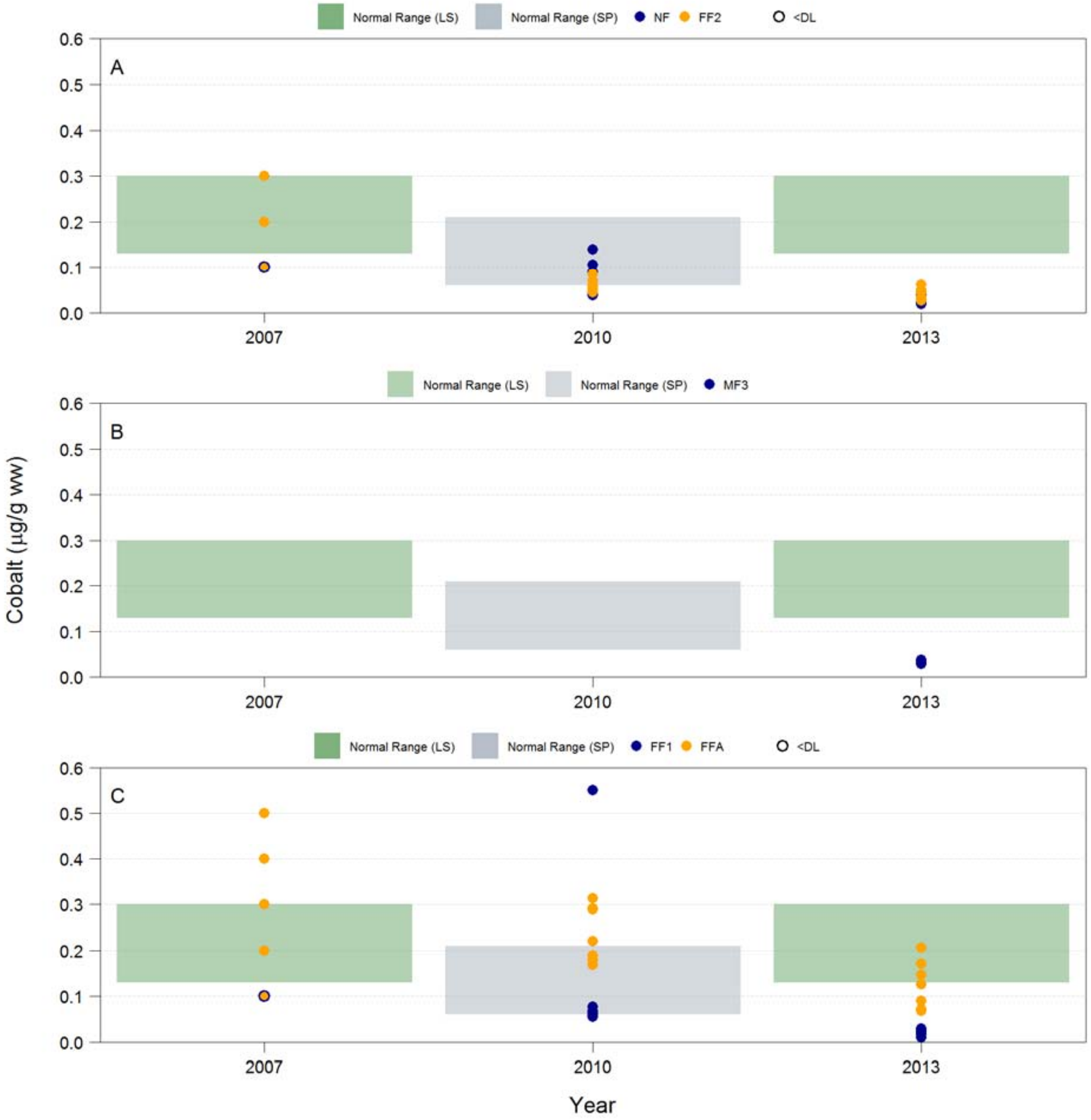
LS = late summer; SP = spring; DL = detection limit.

Figure 10-32 Concentrations of Chromium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



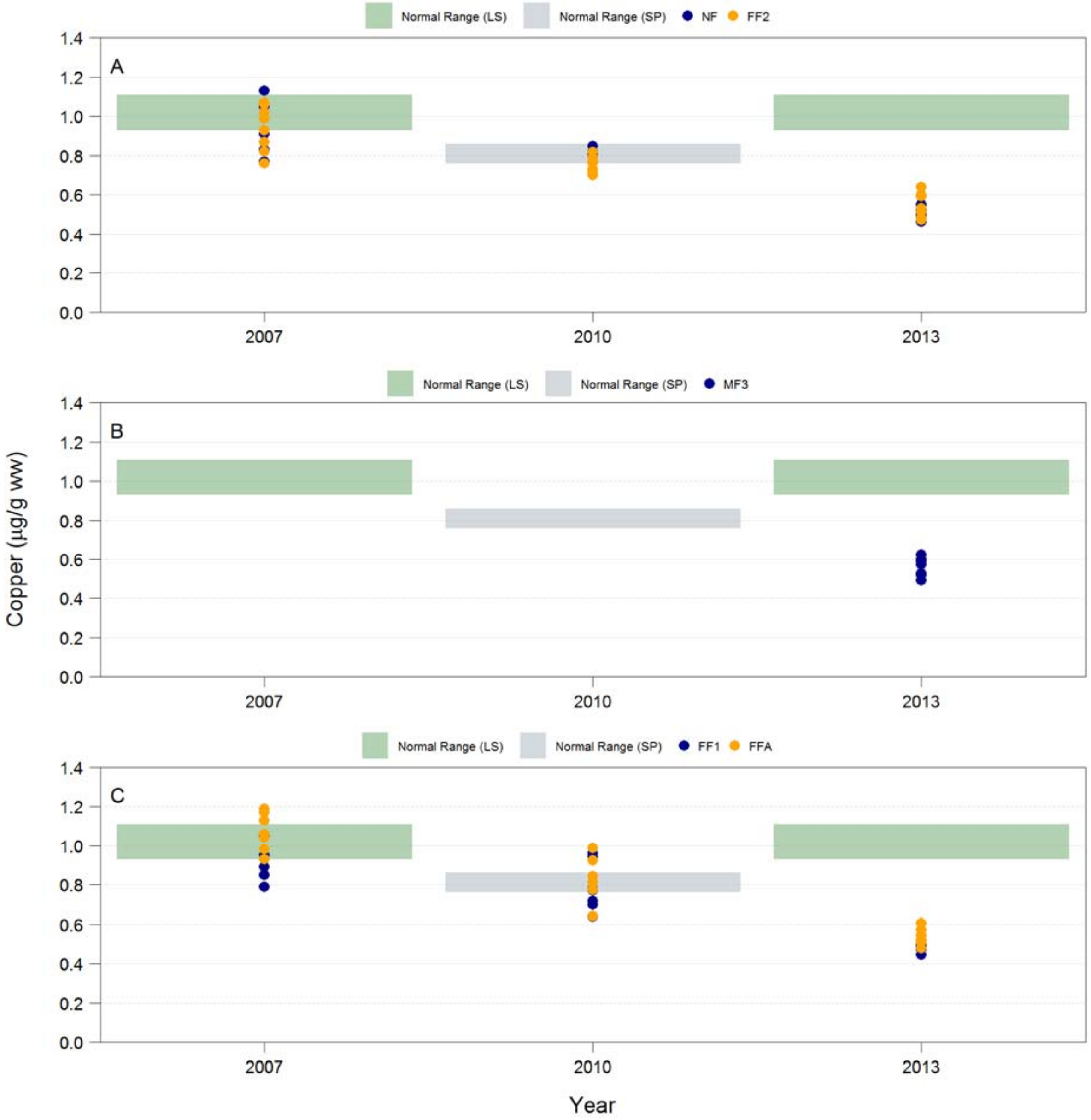
LS = late summer; SP = spring; DL = detection limit.

Figure 10-33 Concentrations of Cobalt in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



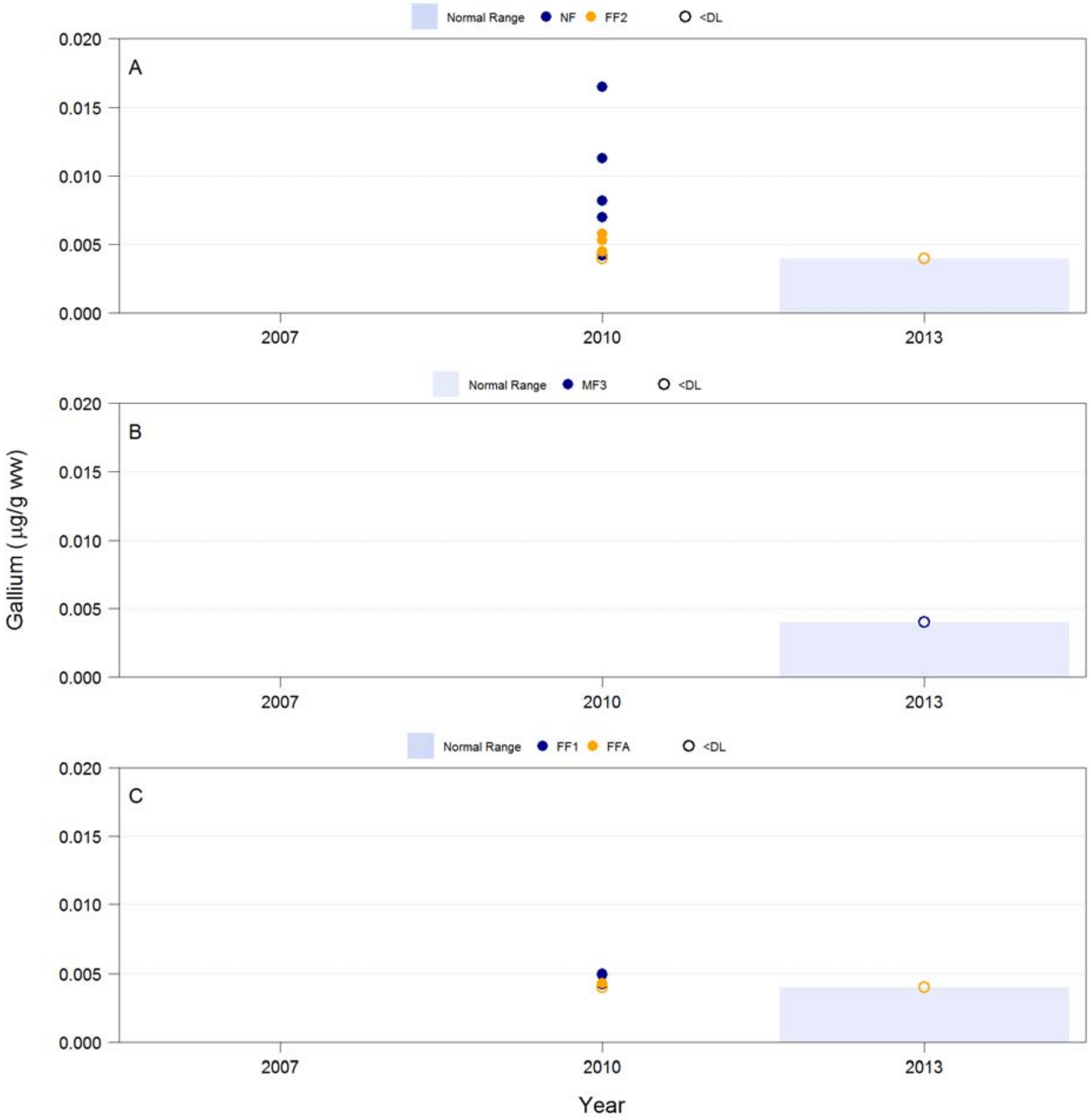
LS = late summer; SP = spring; DL = detection limit.

Figure 10-34 Concentrations of Copper in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



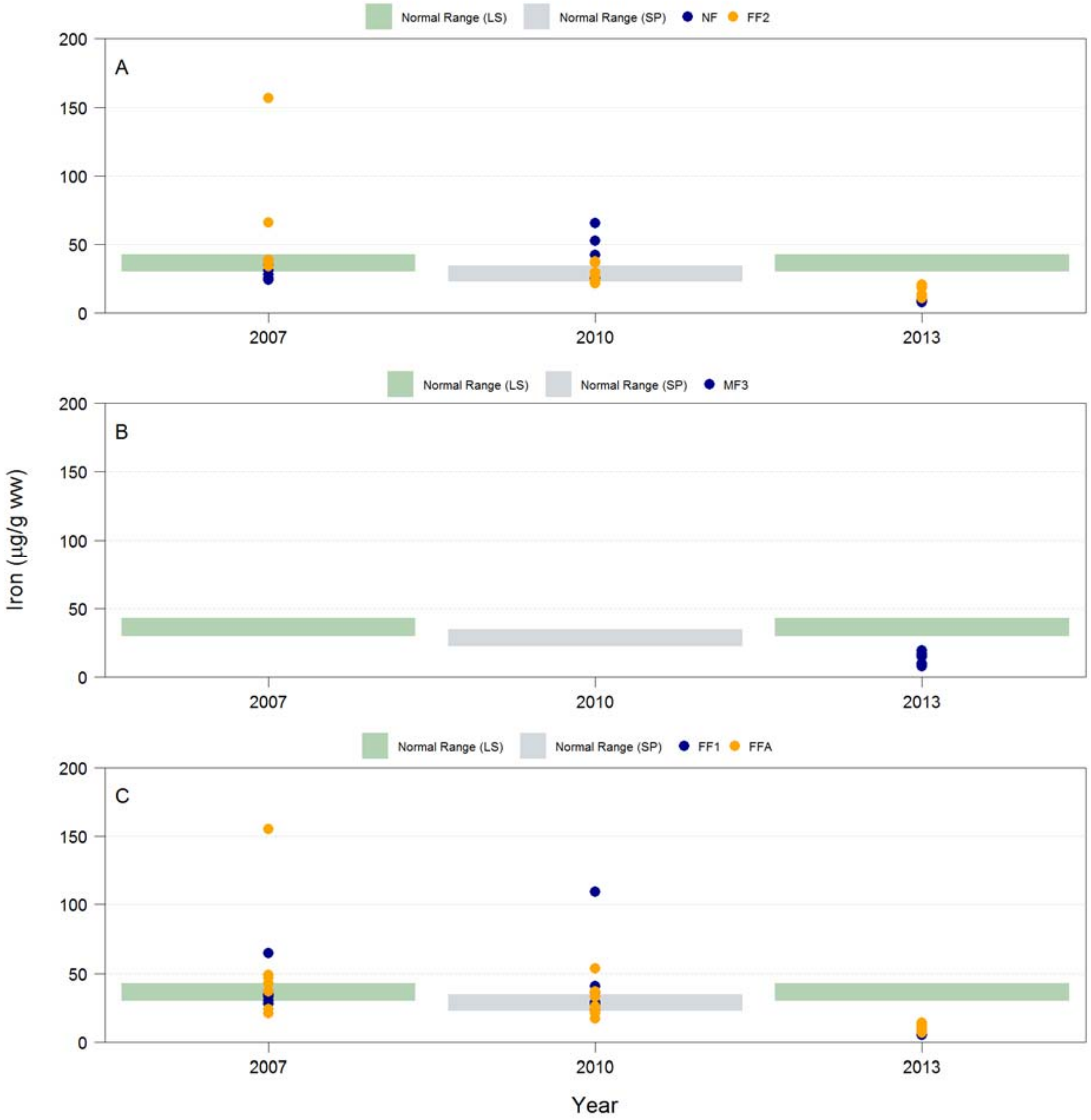
LS = late summer; SP = spring.

Figure 10-35 Concentrations of Gallium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



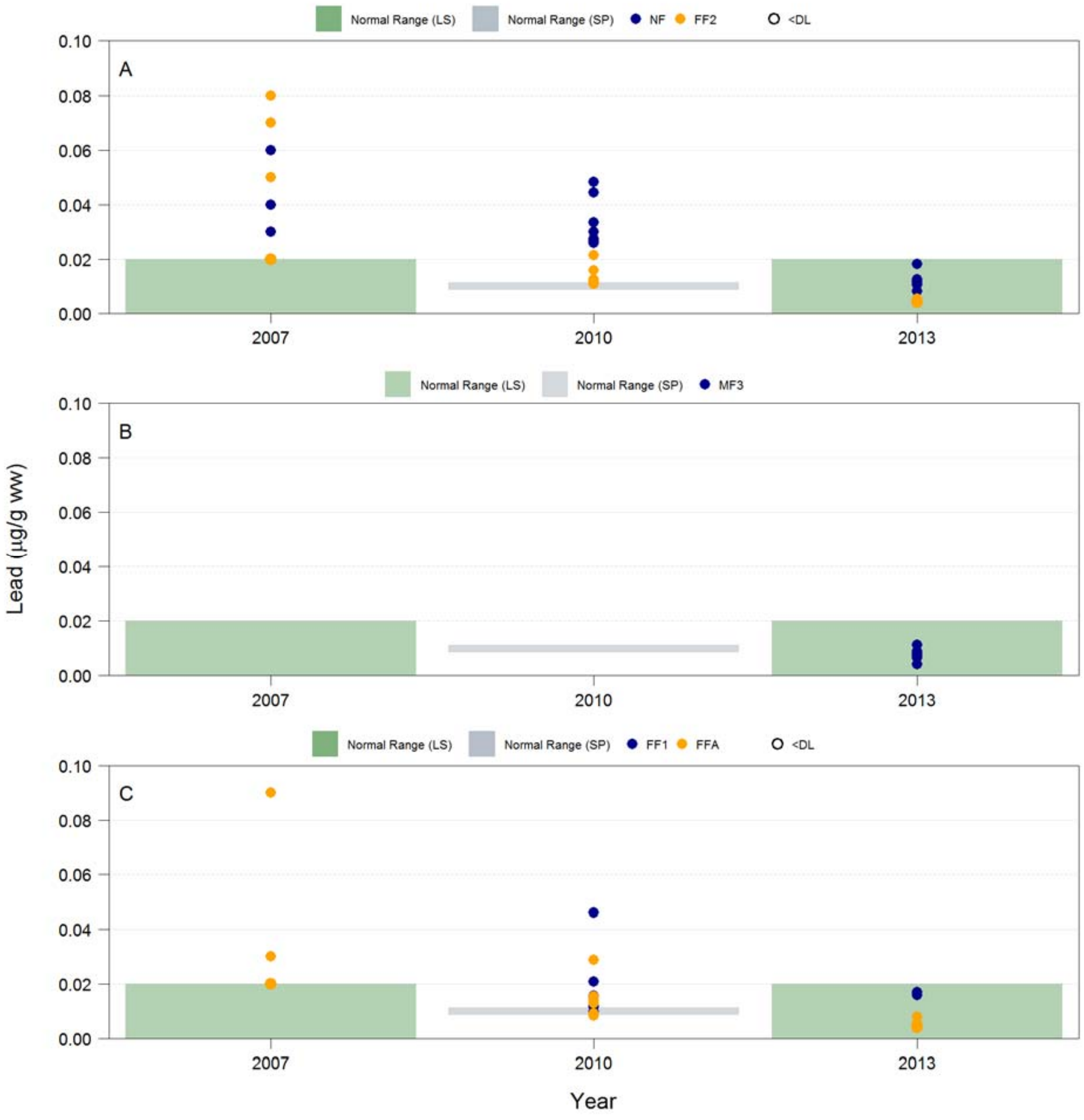
DL = detection limit.

Figure 10-36 Concentrations of Iron in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



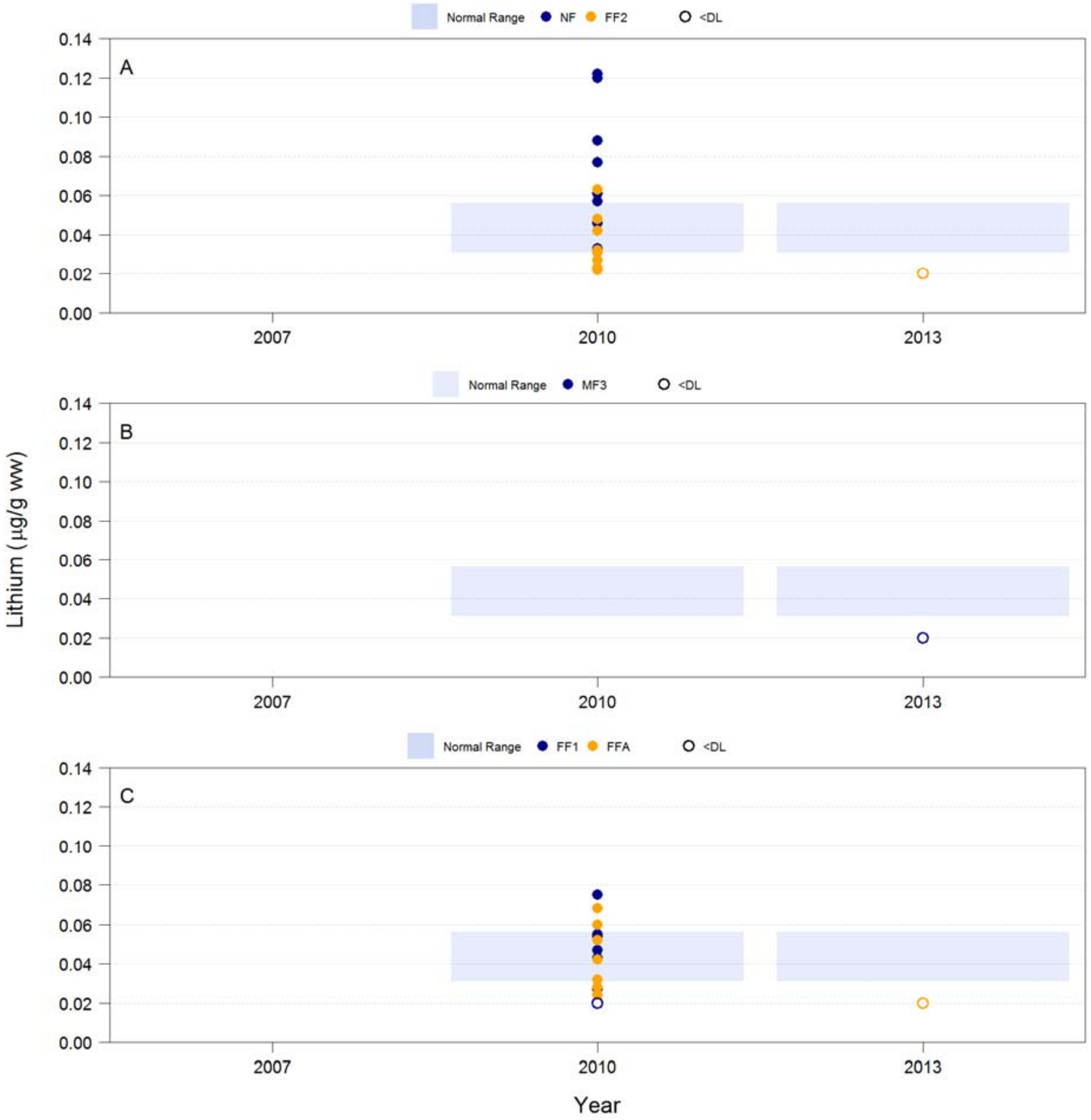
LS = late summer; SP = spring.

Figure 10-37 Concentrations of Lead in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



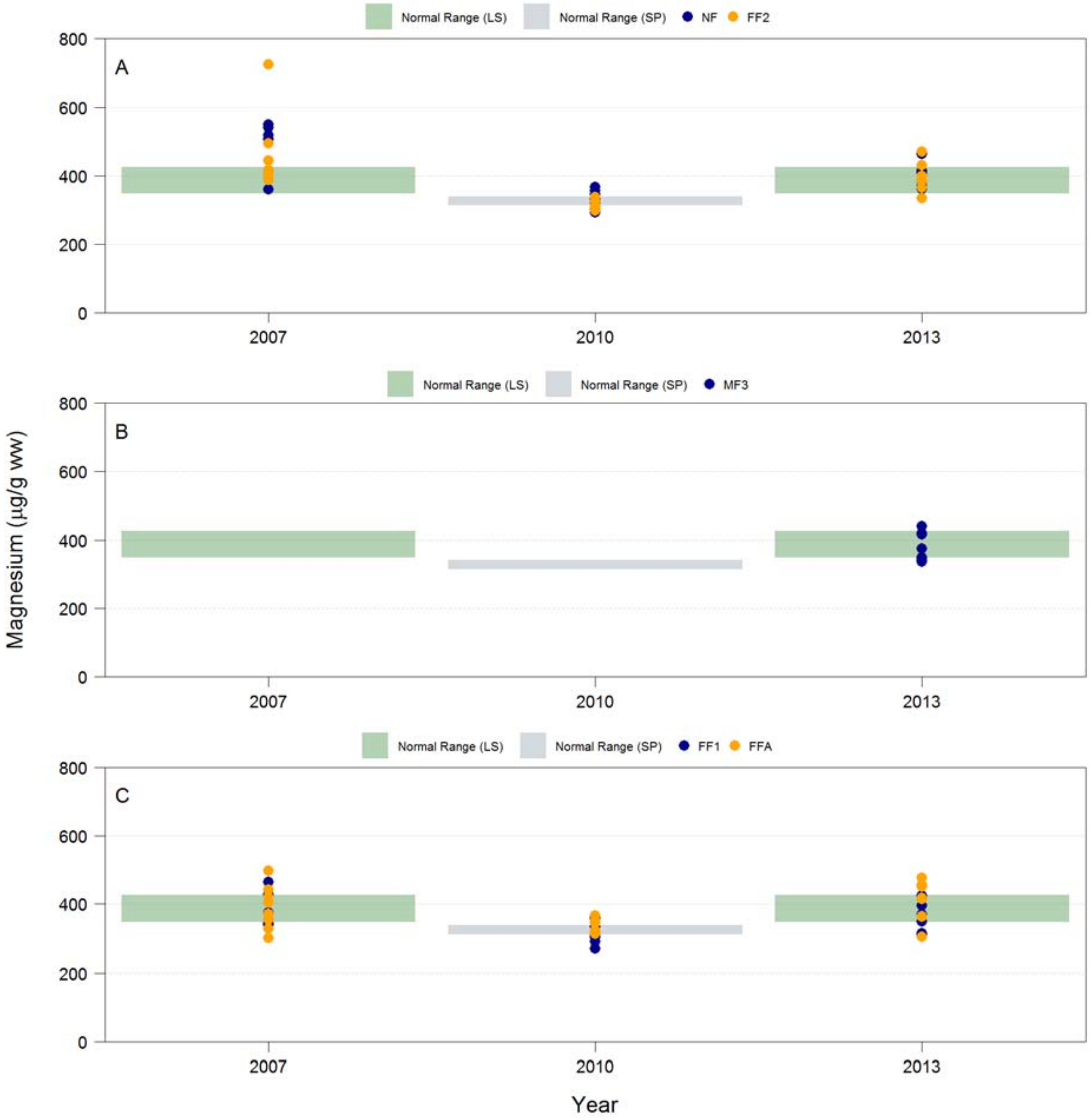
LS = late summer; SP = spring; DL = detection limit.

Figure 10-38 Concentrations of Lithium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



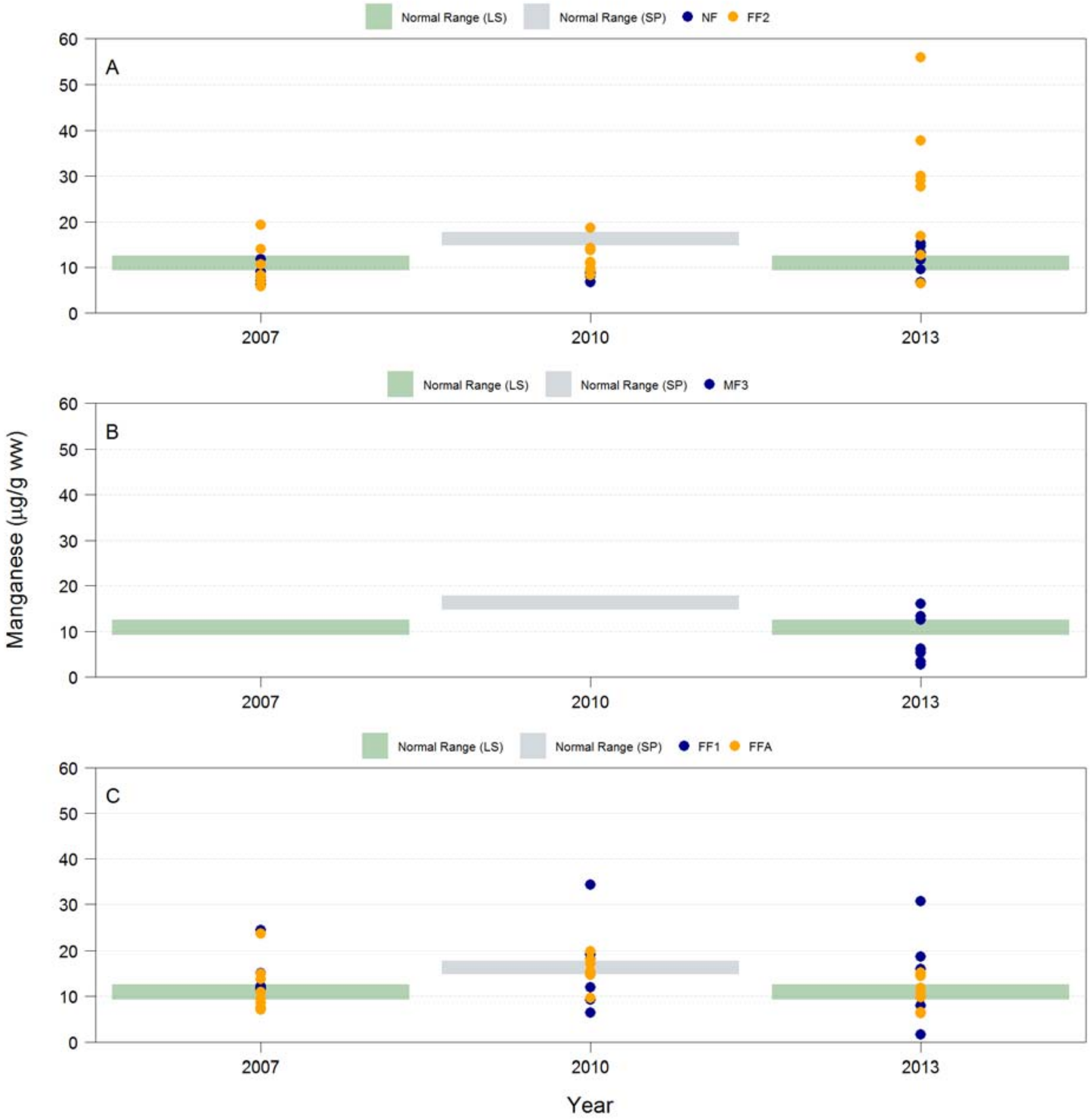
DL = detection limit.

Figure 10-39 Concentrations of Magnesium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



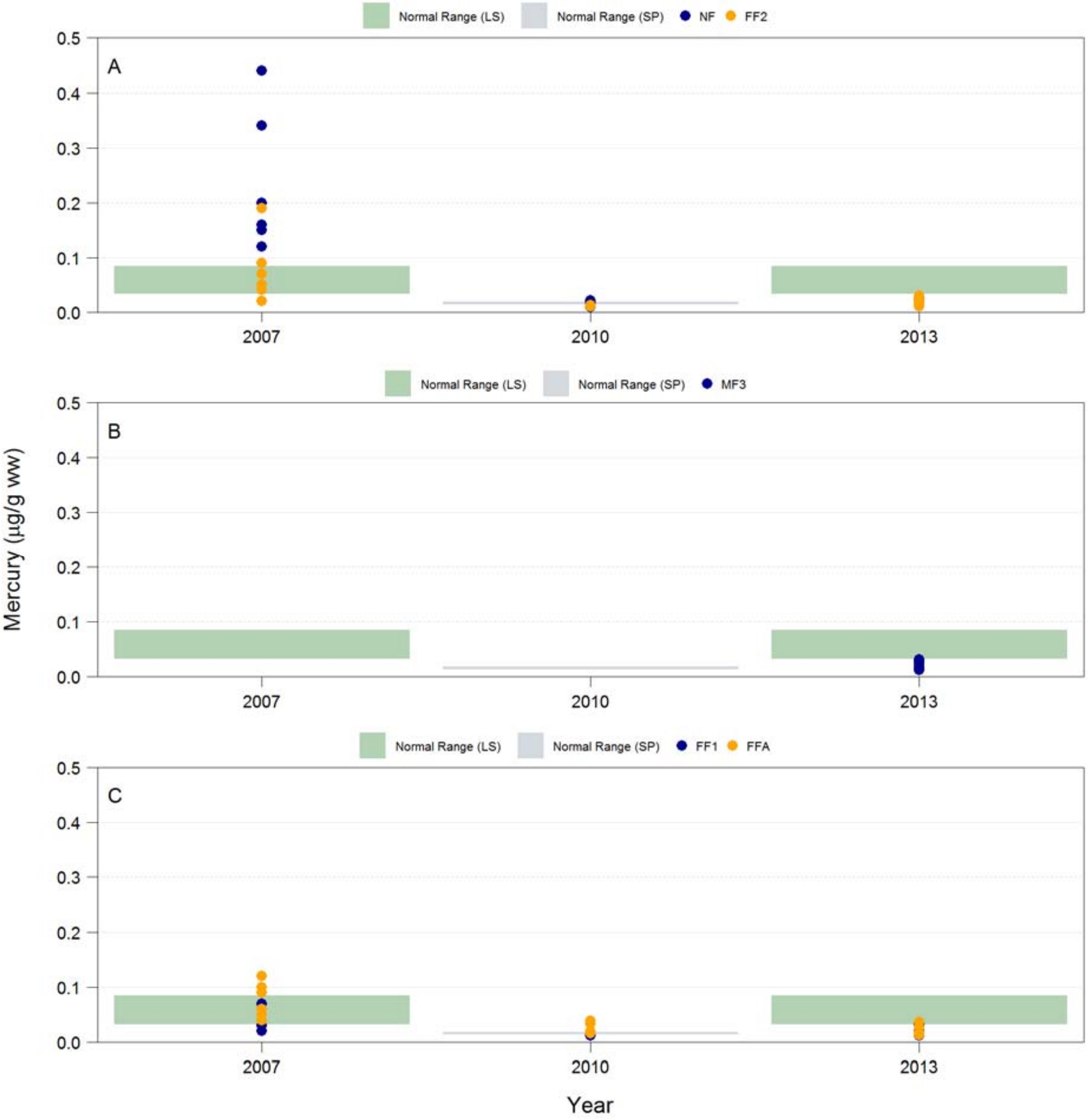
LS = late summer; SP = spring.

Figure 10-40 Concentrations of Manganese in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



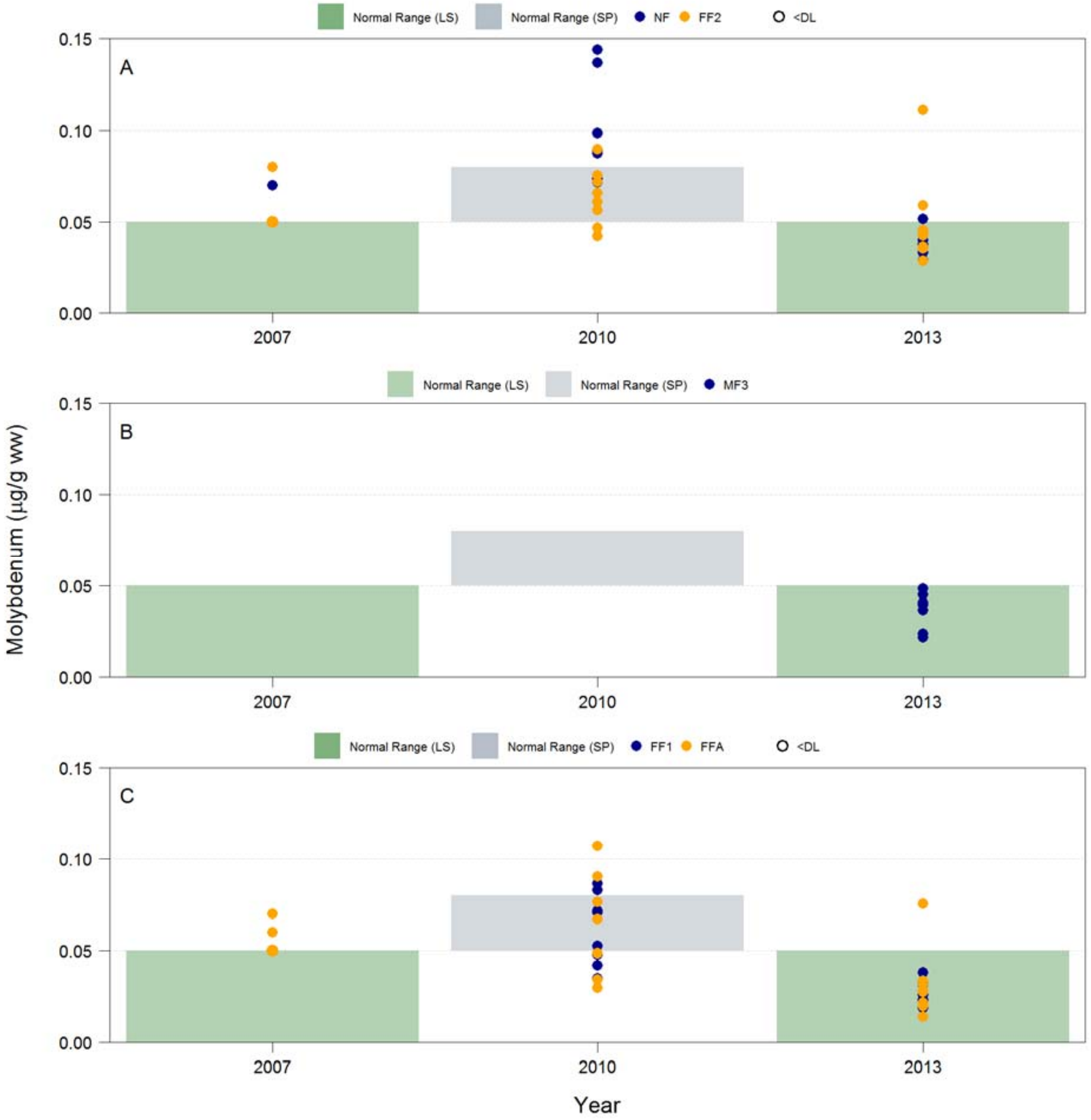
LS = late summer; SP = spring.

Figure 10-41 Concentrations of Mercury in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



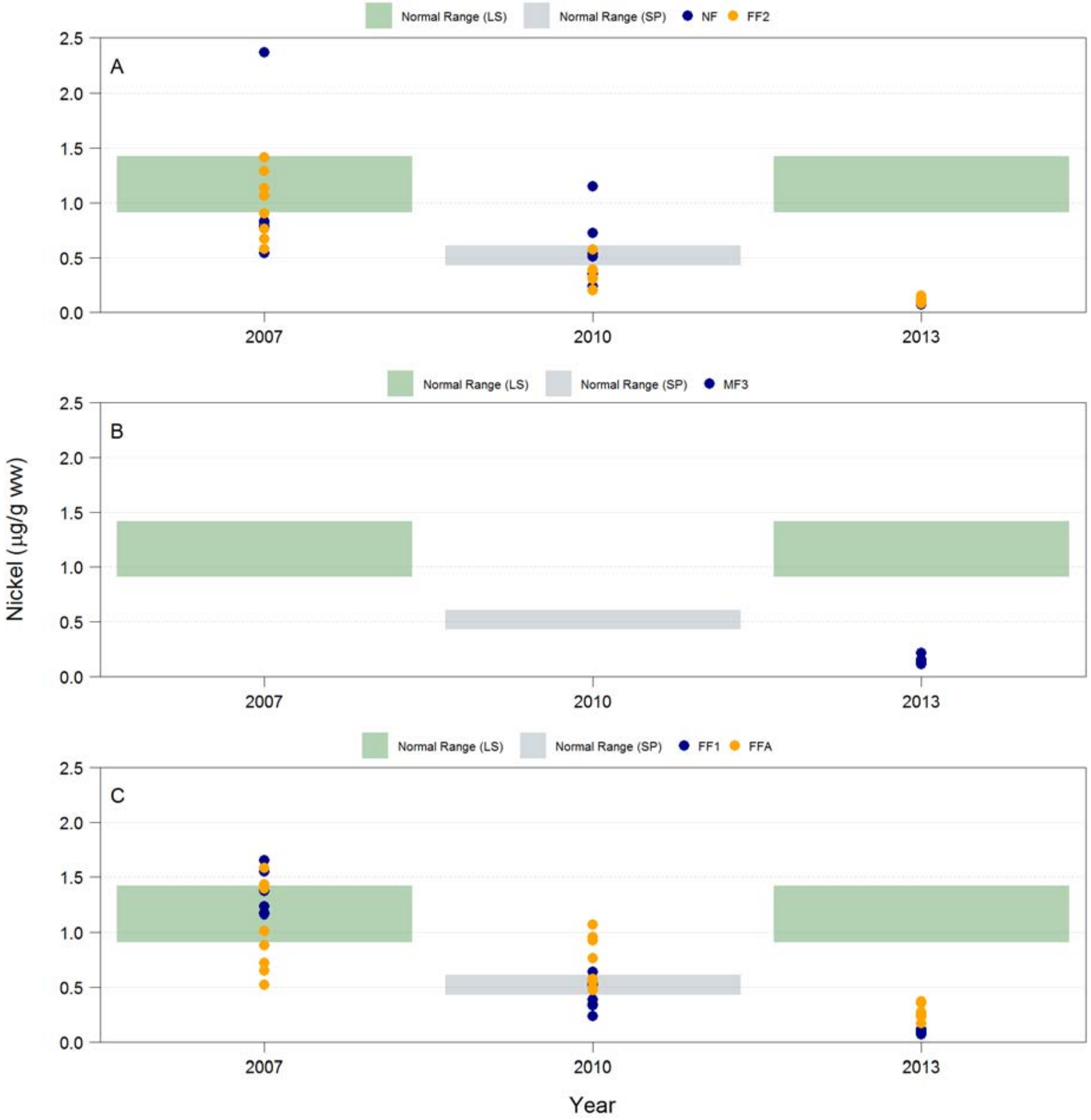
LS = late summer; SP = spring.

Figure 10-42 Concentrations of Molybdenum in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



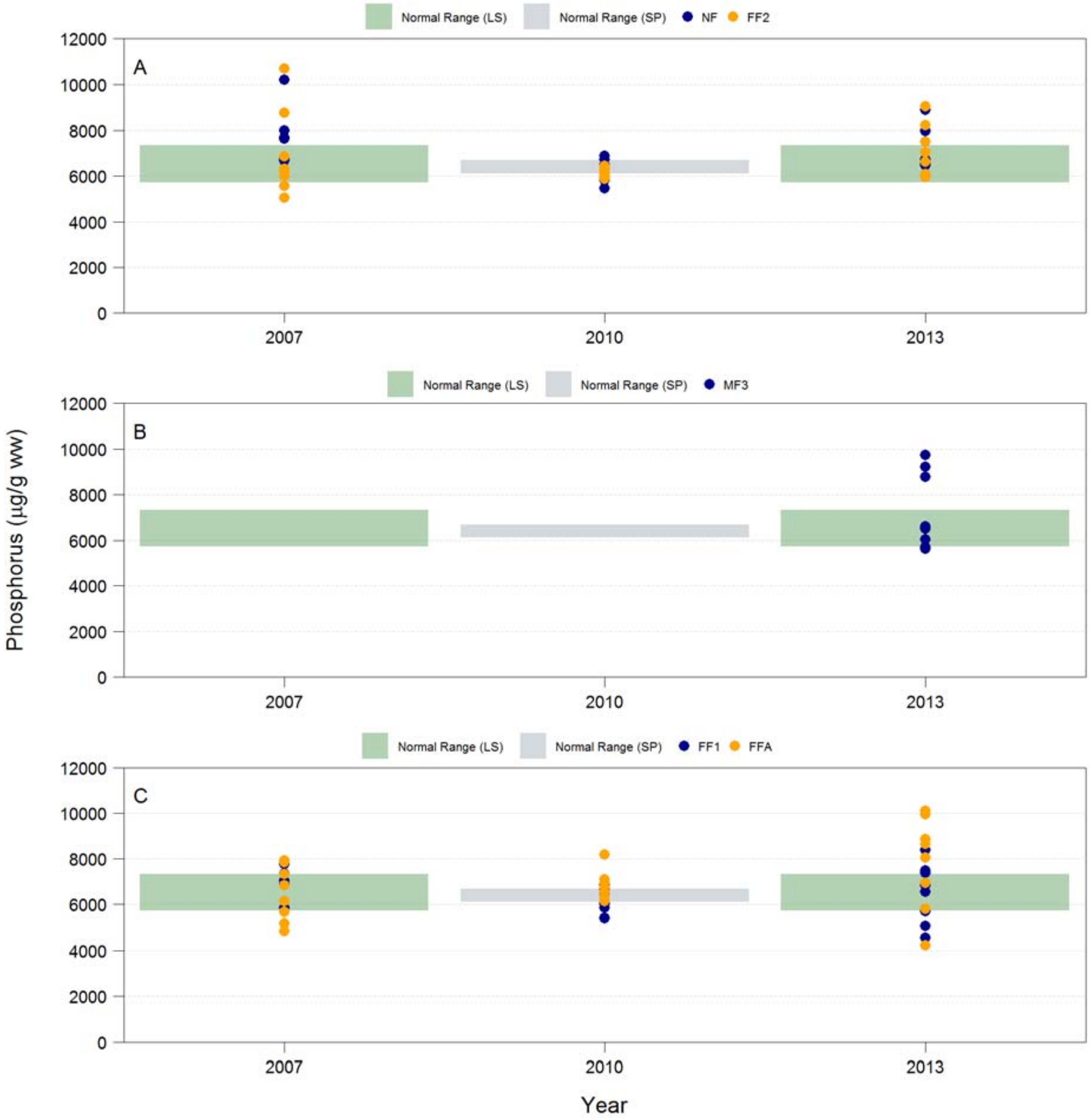
LS = late summer; SP = spring; DL = detection limit.

Figure 10-43 Concentrations of Nickel in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



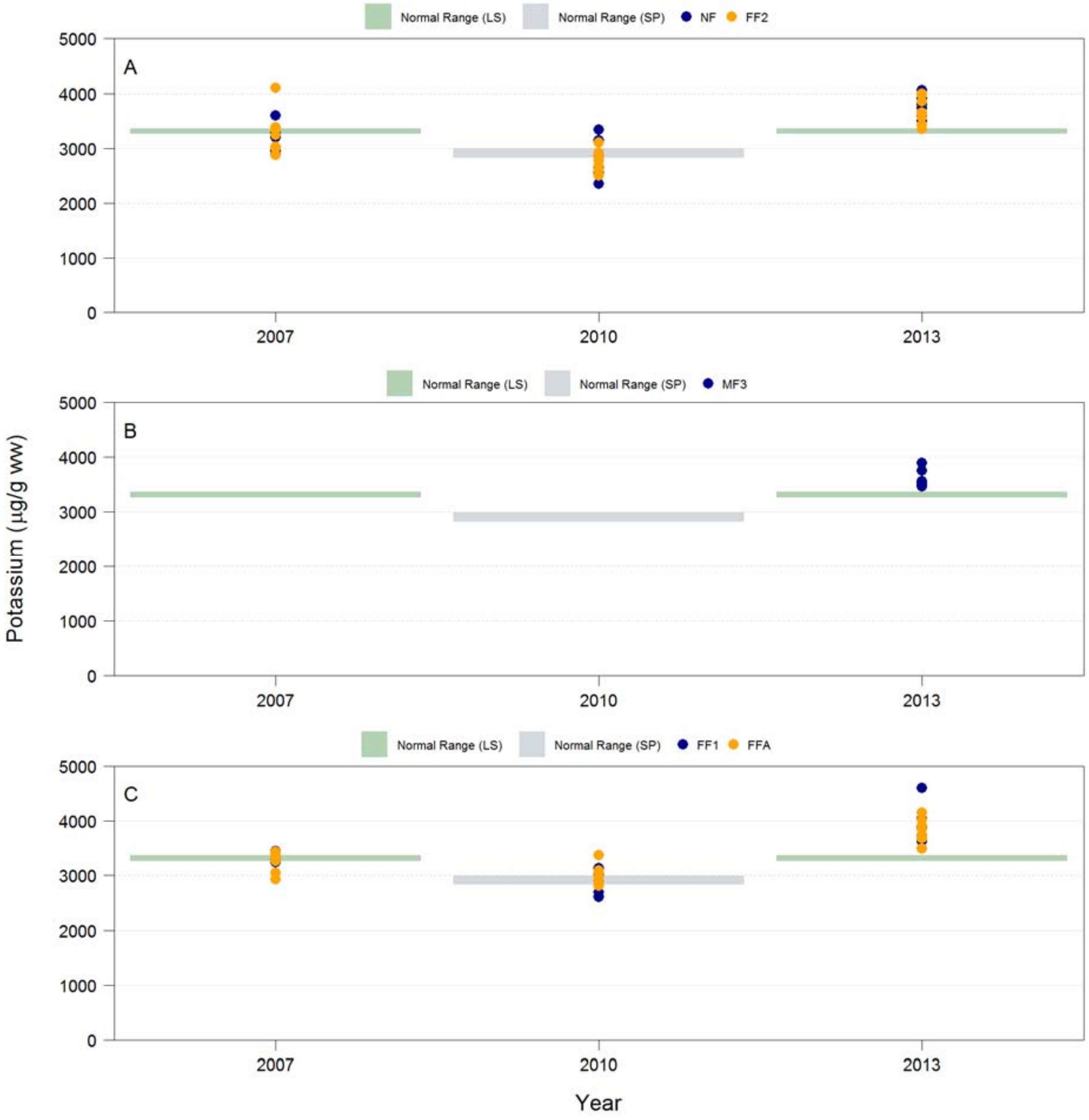
LS = late summer; SP = spring.

Figure 10-44 Concentrations of Phosphorus in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



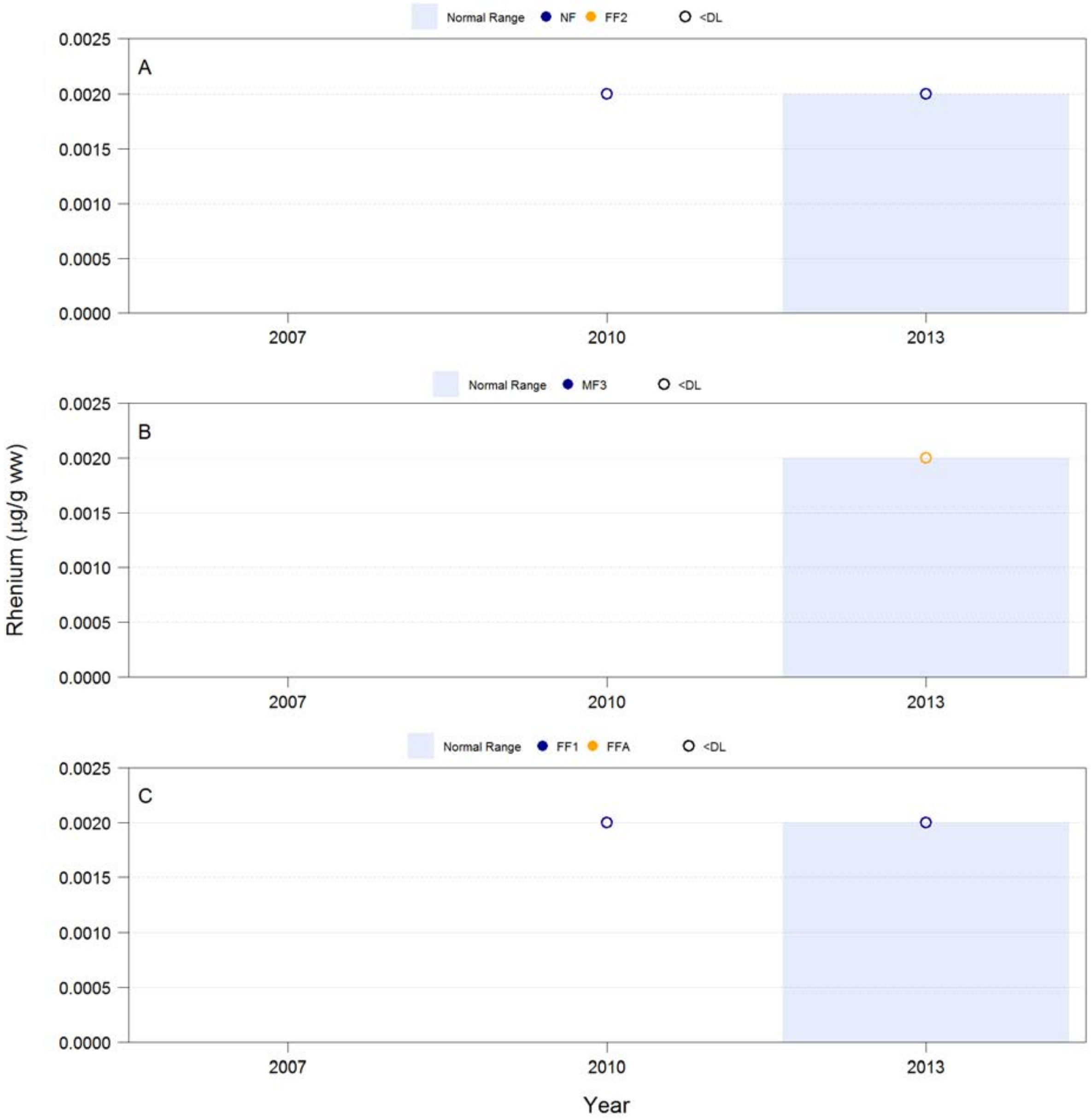
LS = late summer; SP = spring.

Figure 10-45 Concentrations of Potassium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



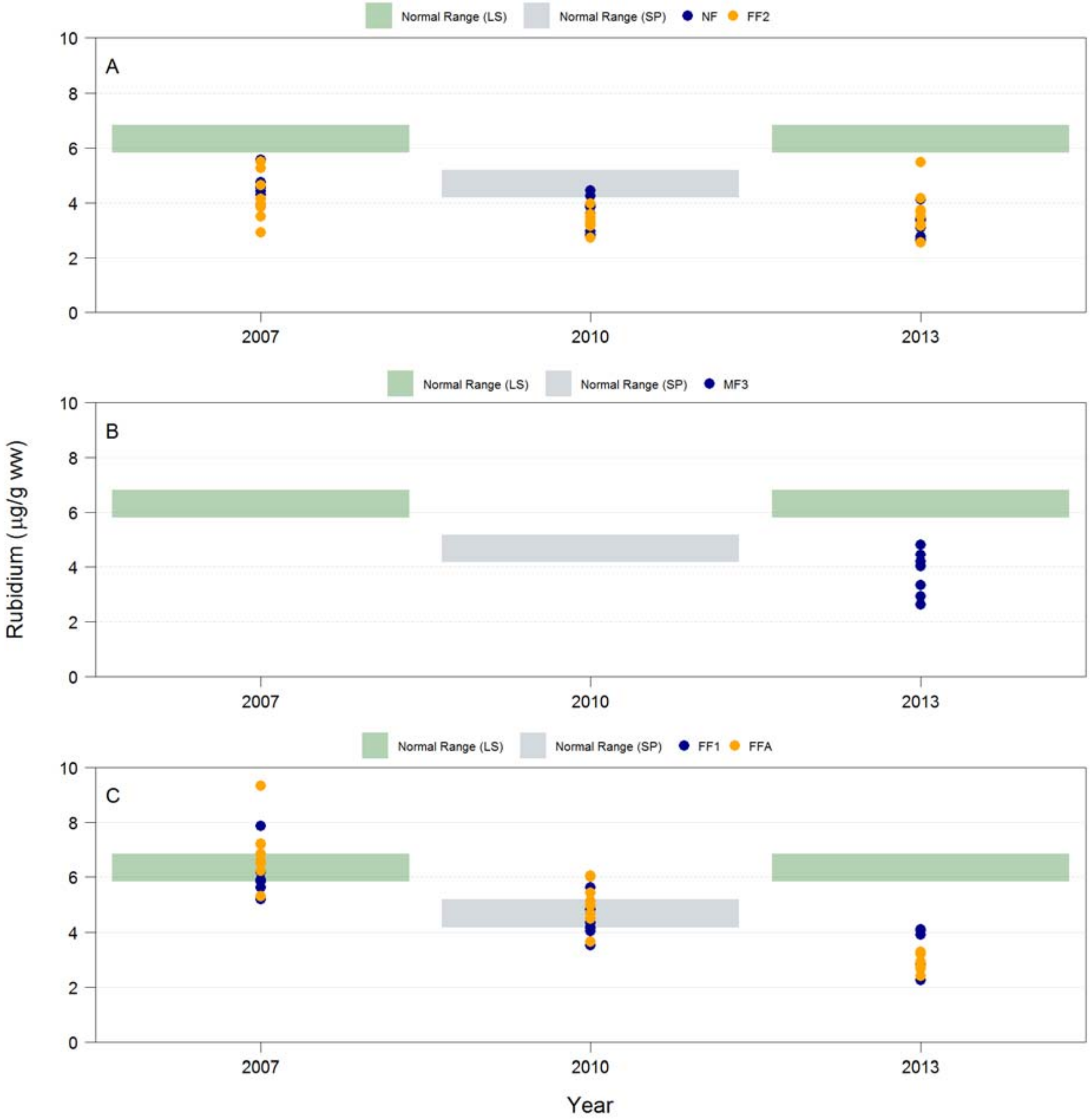
LS = late summer; SP = spring.

Figure 10-46 Concentrations of Rhenium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



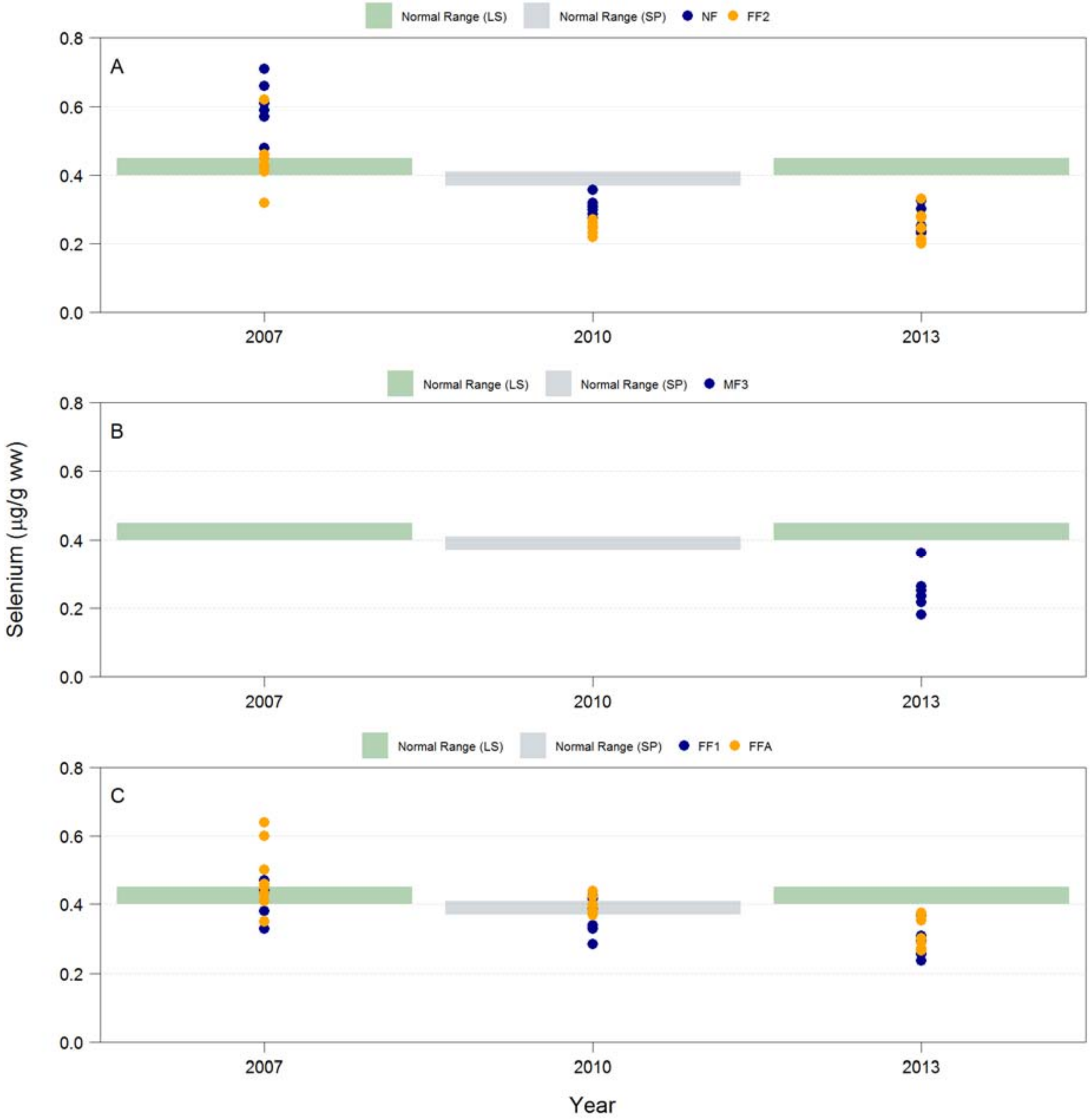
LS = late summer; SP = spring; DL = detection limit.

Figure 10-47 Concentrations of Rubidium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



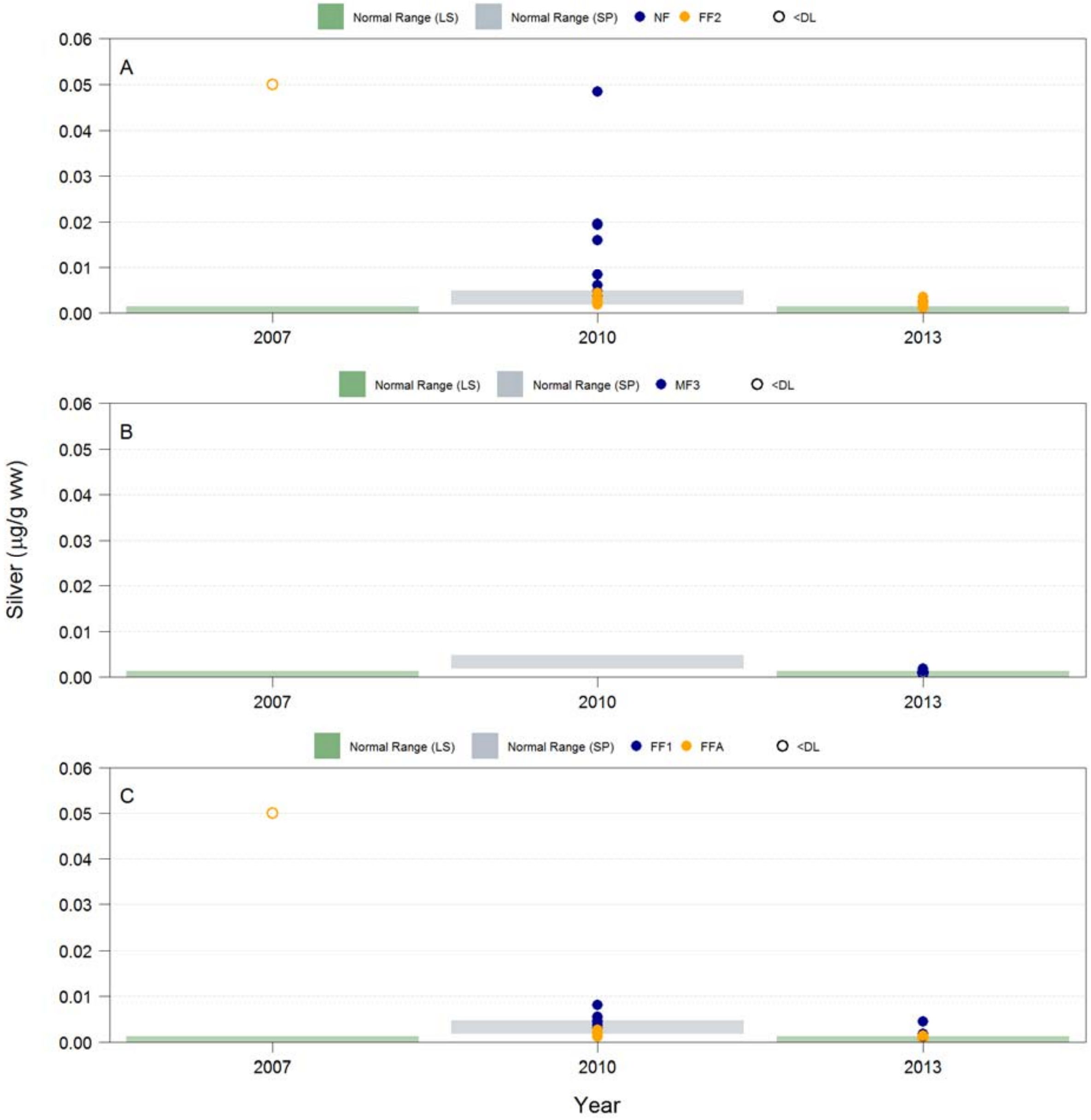
LS = late summer; SP = spring.

Figure 10-48 Concentrations of Selenium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



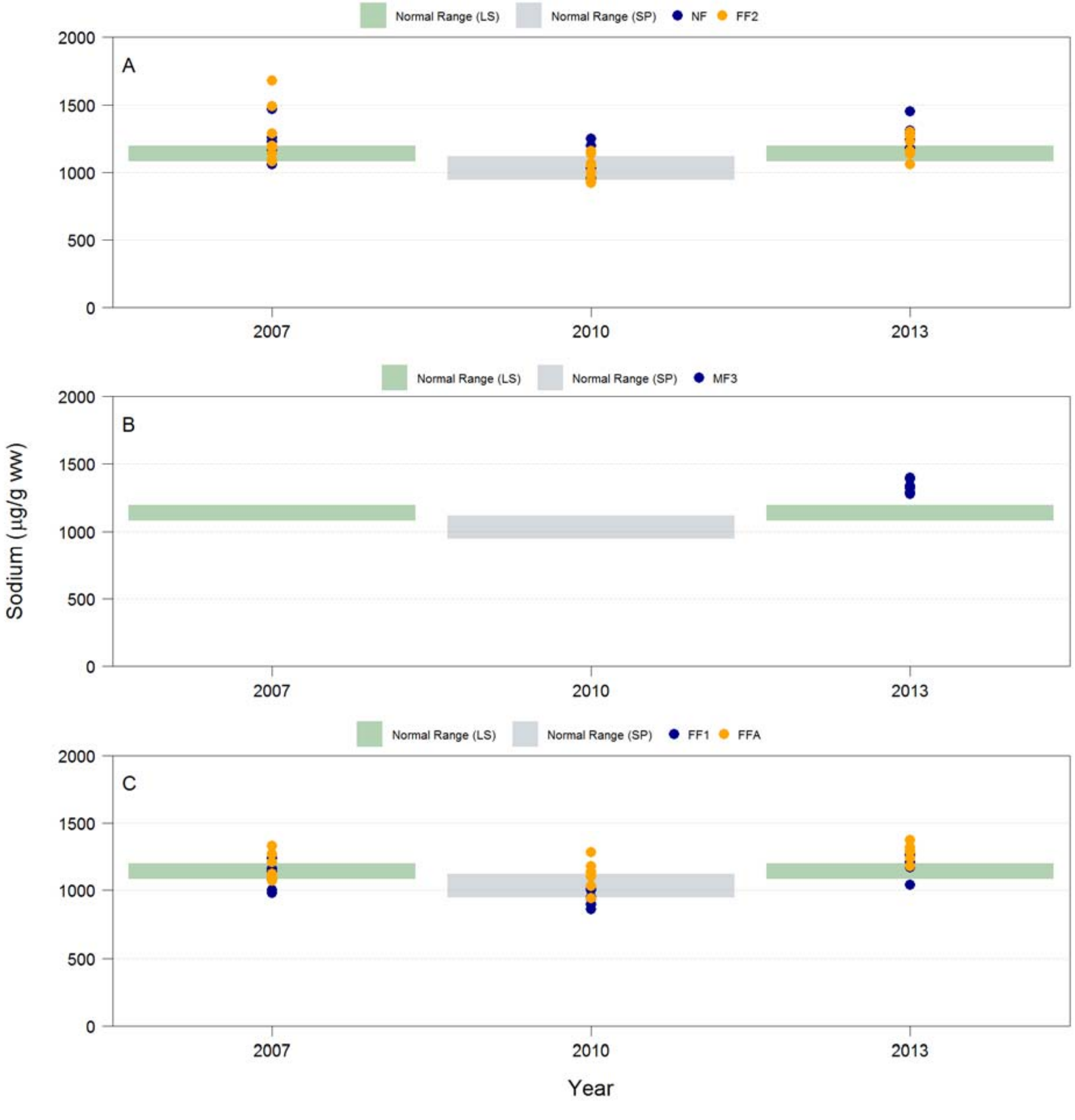
LS = late summer; SP = spring.

Figure 10-49 Concentrations of Silver in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



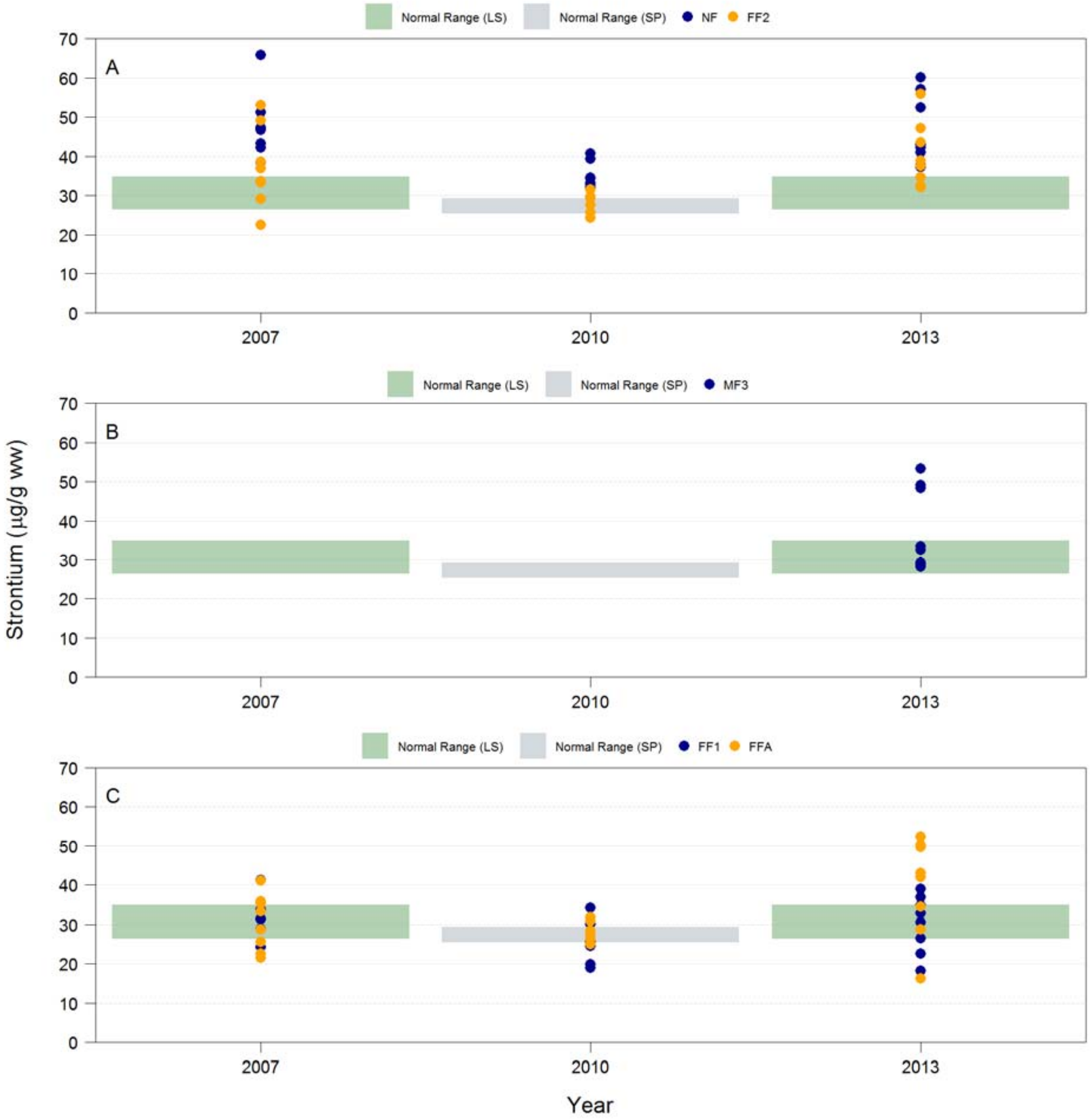
LS = late summer; SP = spring; DL = detection limit.

Figure 10-50 Concentrations of Sodium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



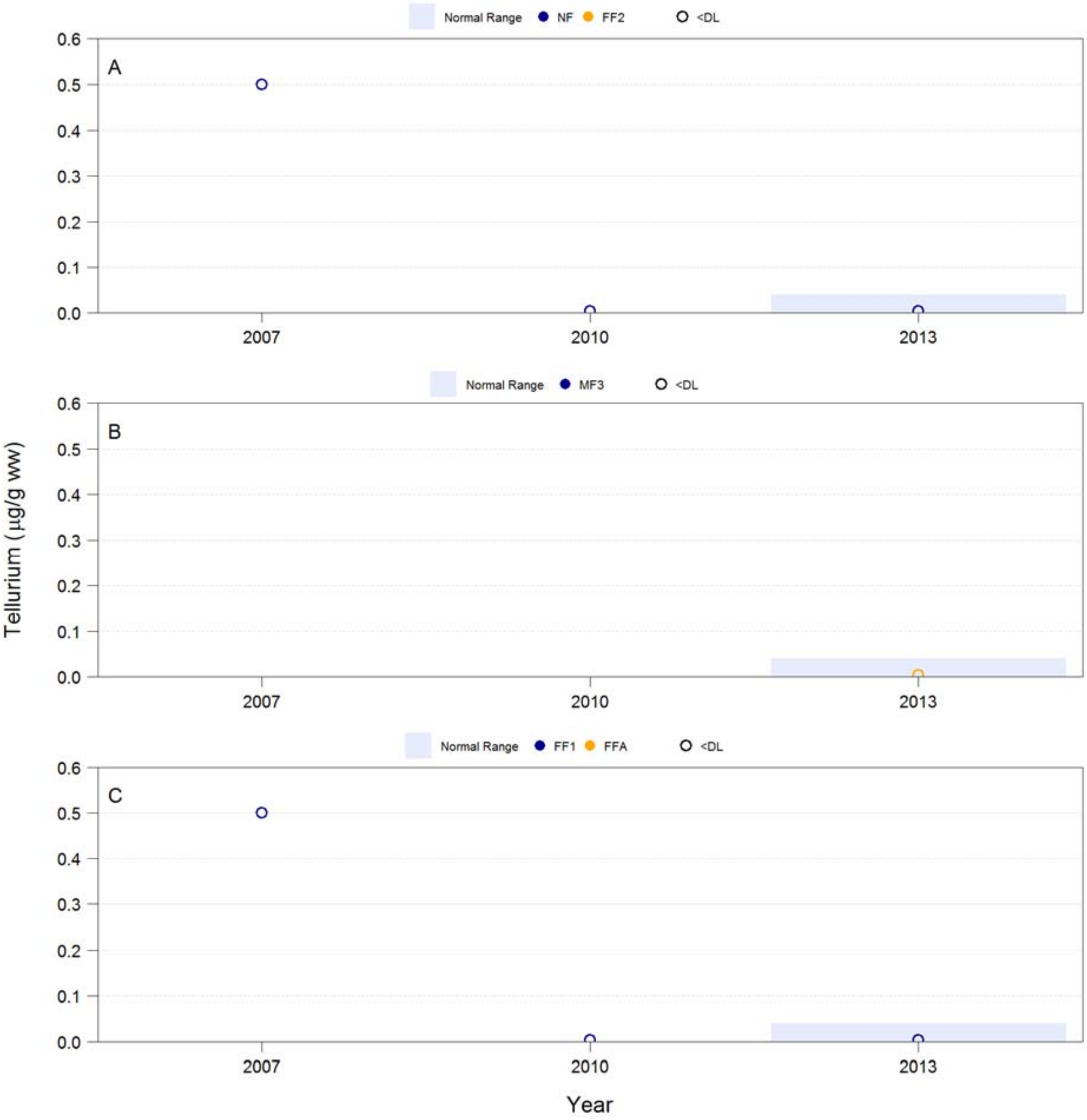
LS = late summer; SP = spring.

Figure 10-51 Concentrations of Strontium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



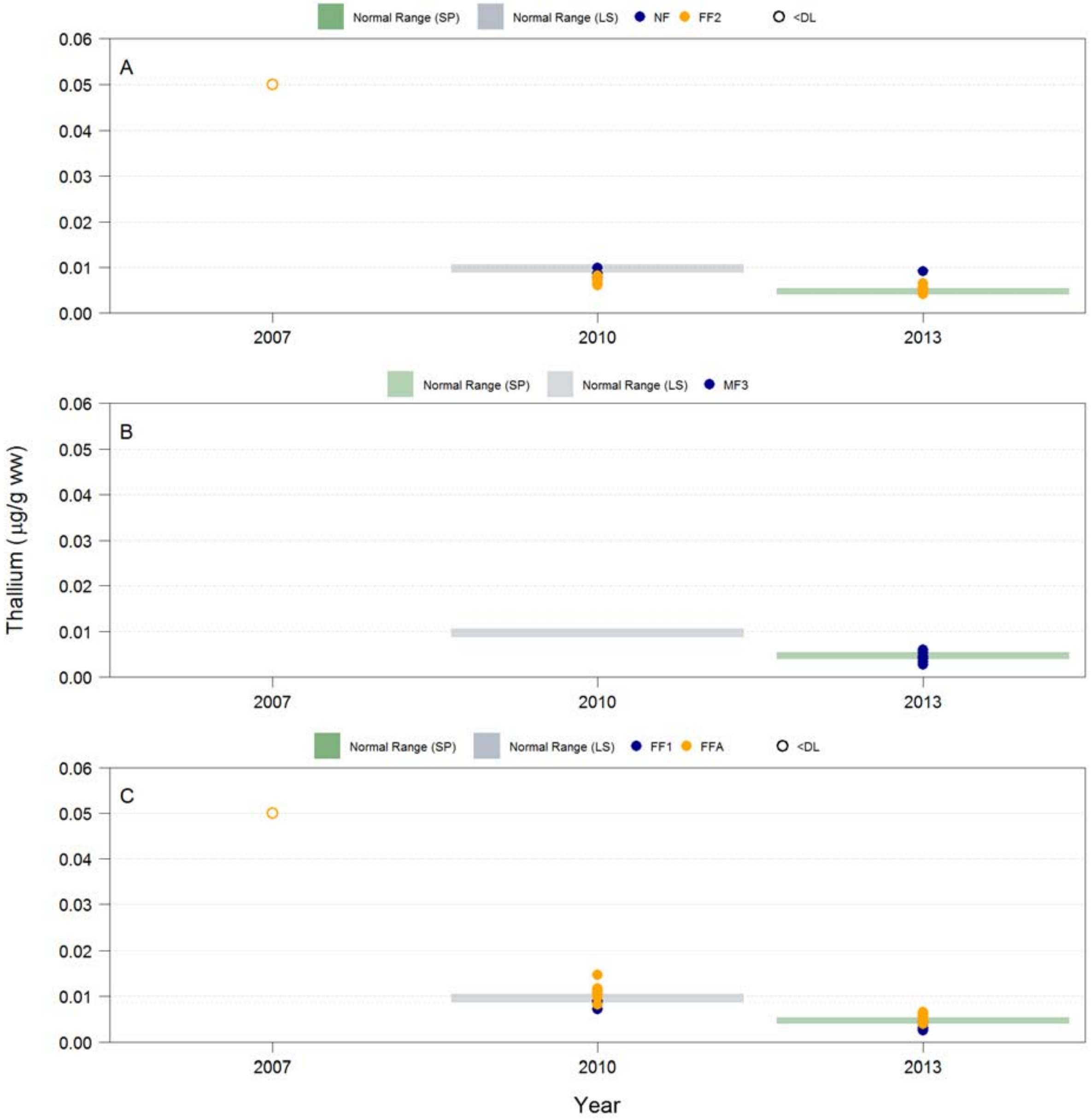
LS = late summer; SP = spring.

Figure 10-52 Concentrations of Tellurium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



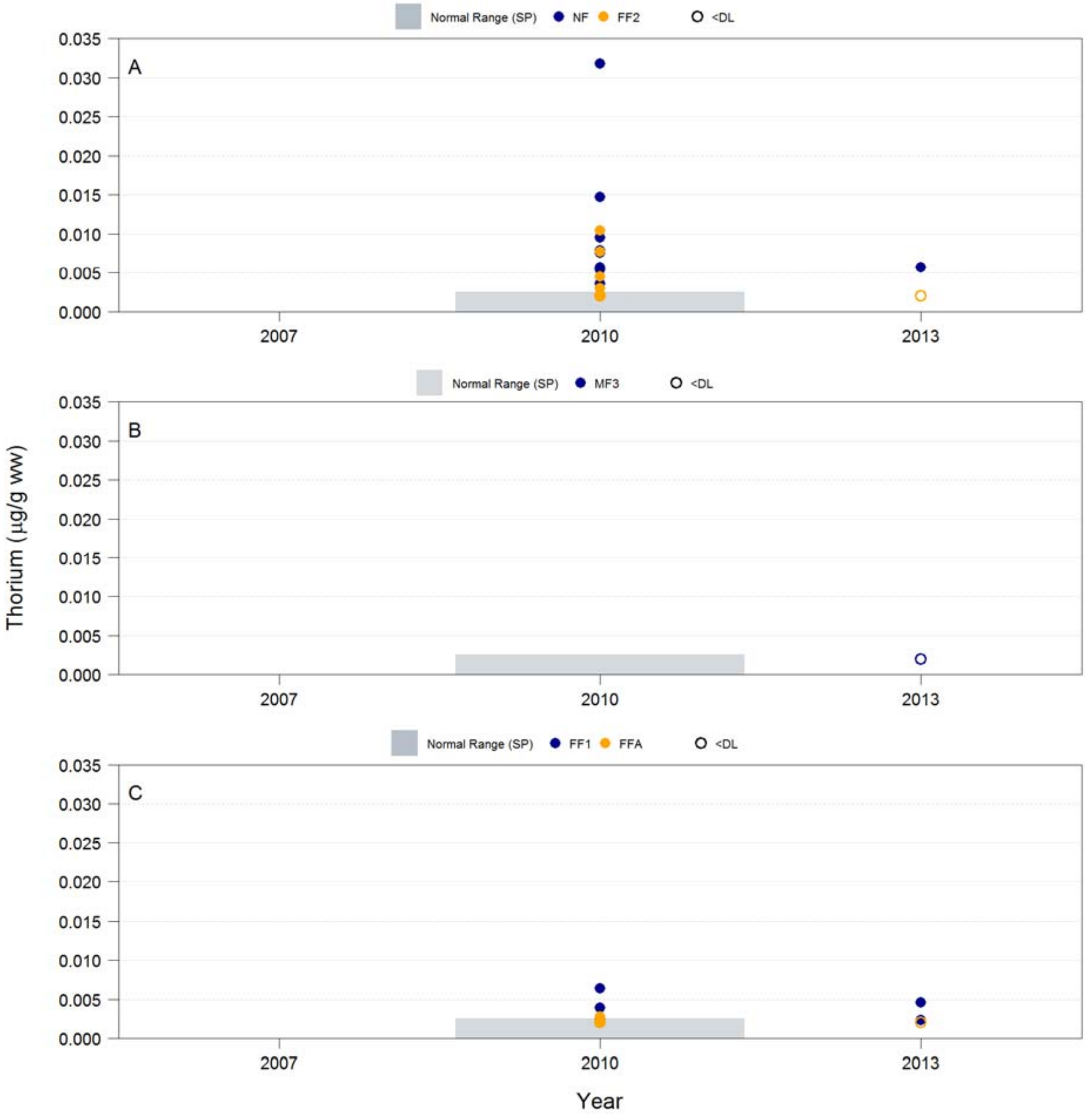
DL = detection limit.

Figure 10-53 Concentrations of Thallium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



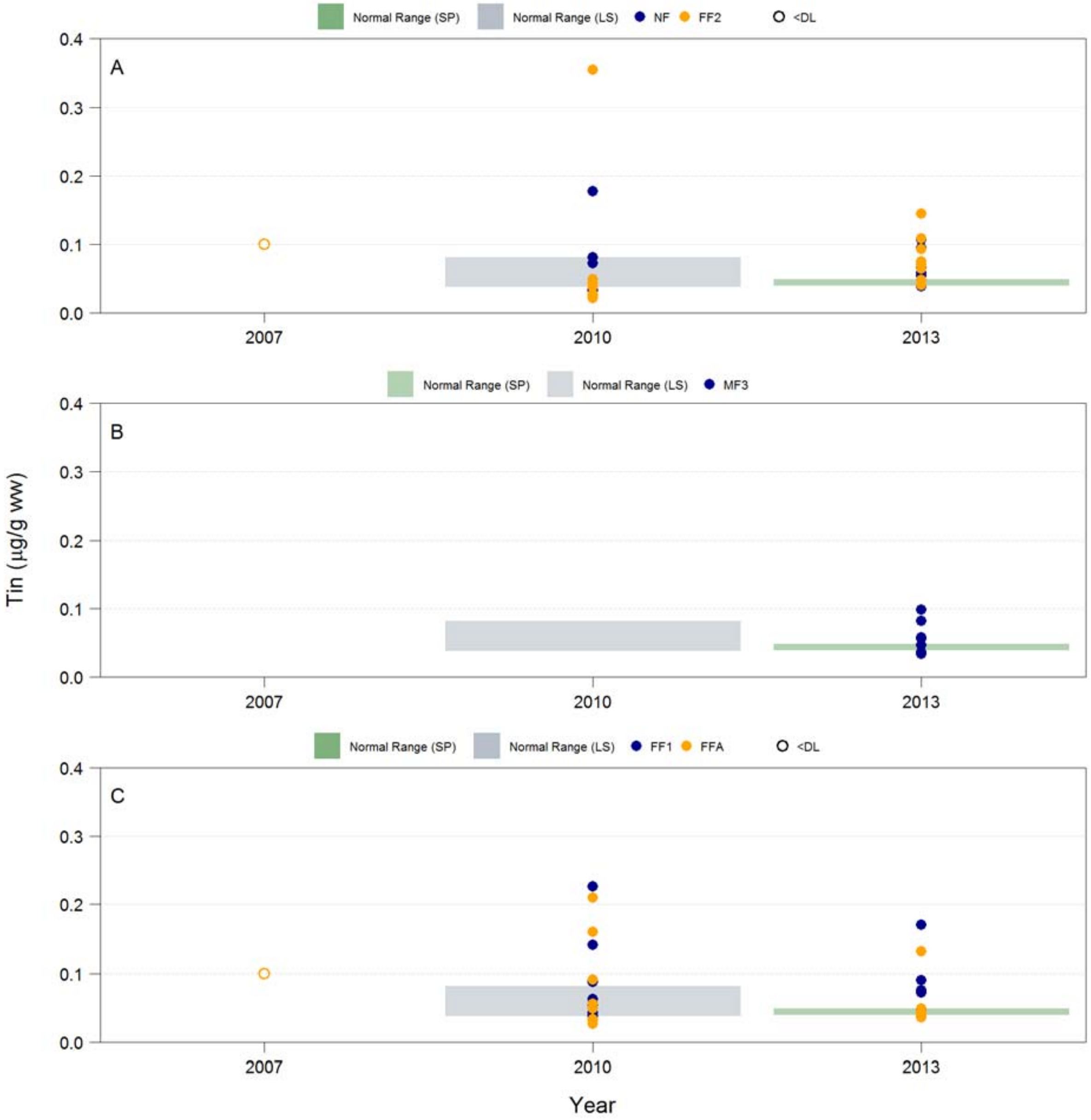
LS = late summer; SP = spring; DL = detection limit.

Figure 10-54 Concentrations of Thorium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



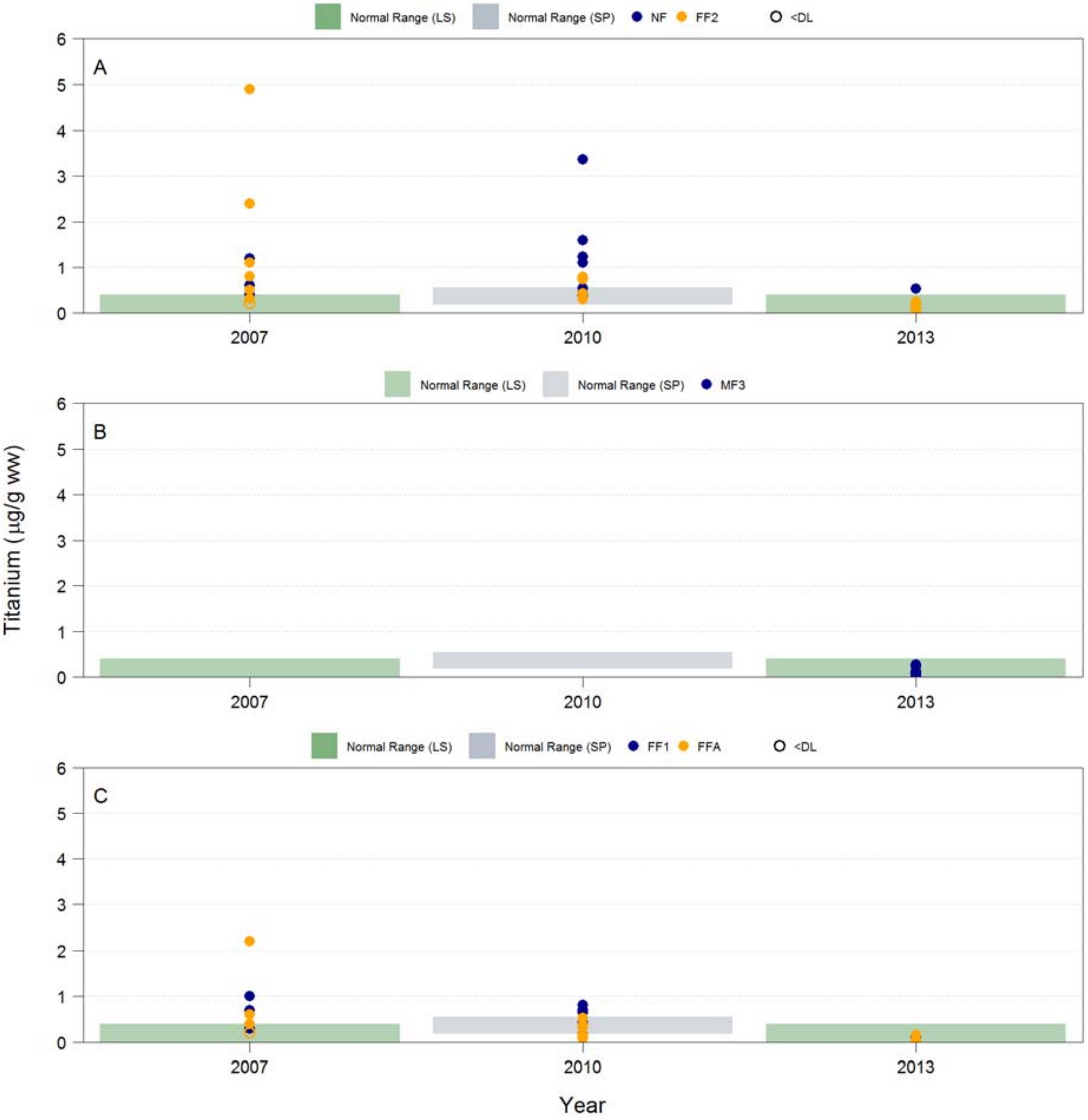
SP = spring; DL = detection limit.

Figure 10-55 Concentrations of Tin in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



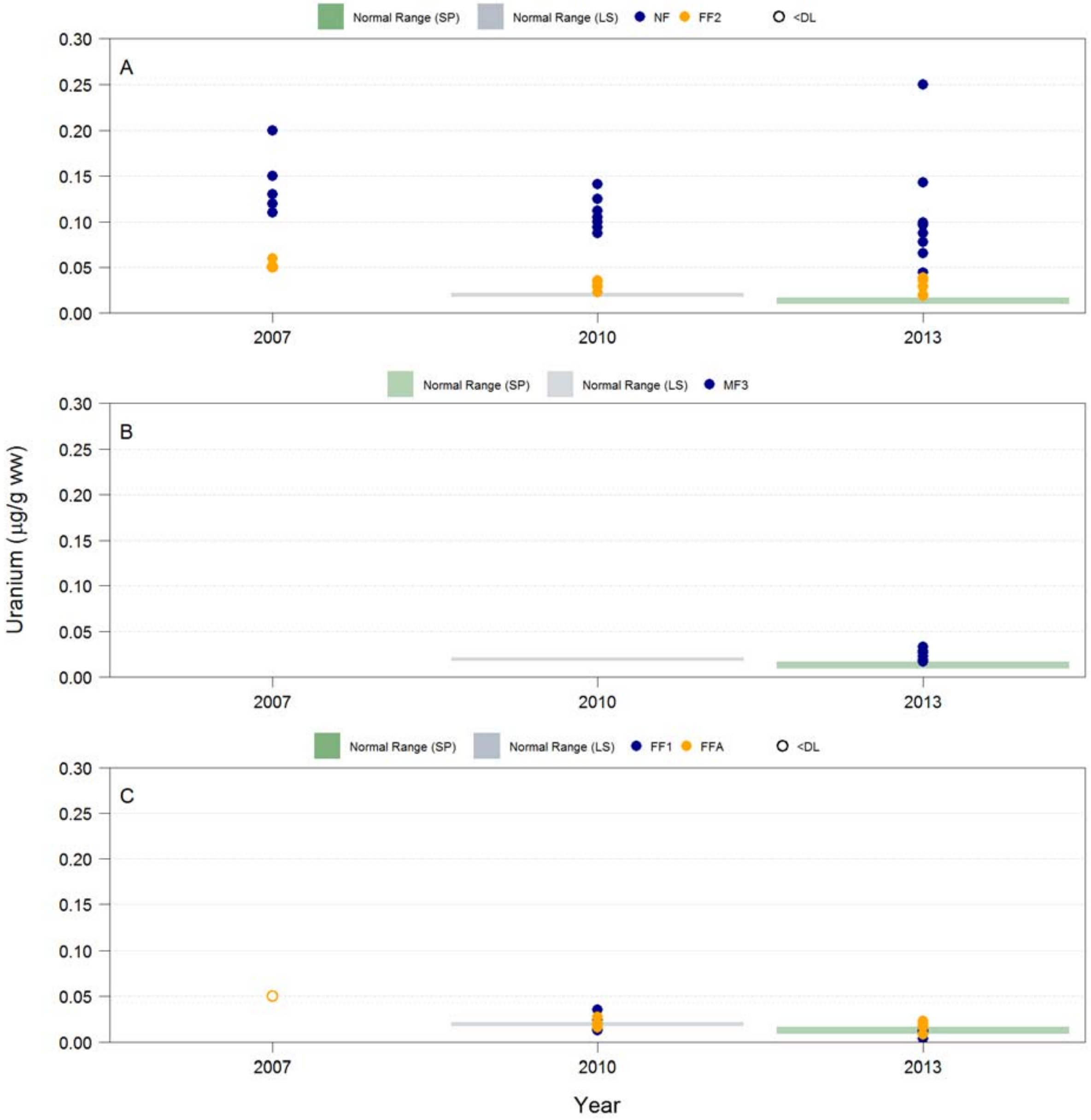
LS = late summer; SP = spring; DL = detection limit.

Figure 10-56 Concentrations of Titanium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



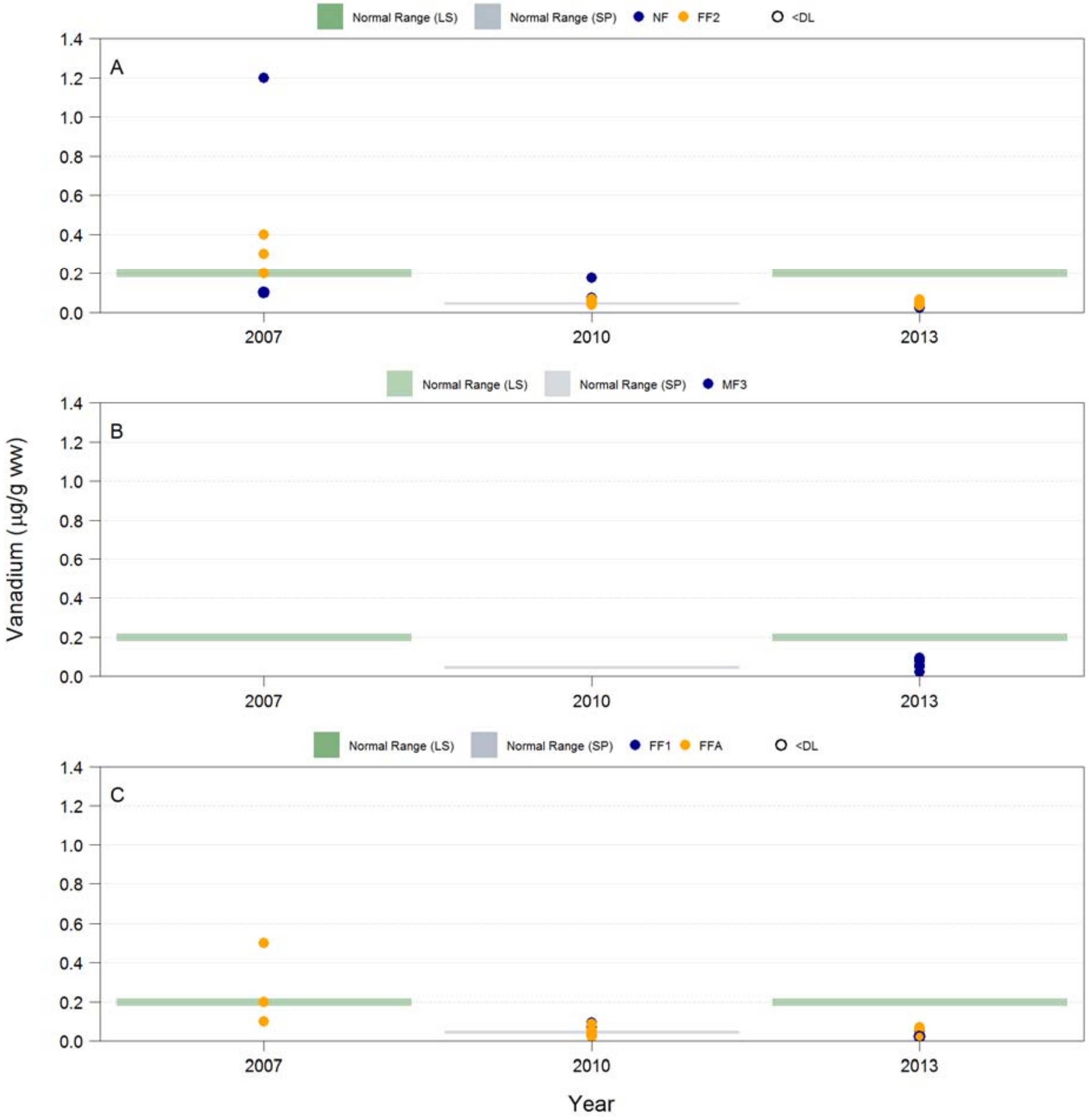
LS = late summer; SP = spring; DL = detection limit.

Figure 10-57 Concentrations of Uranium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid to field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



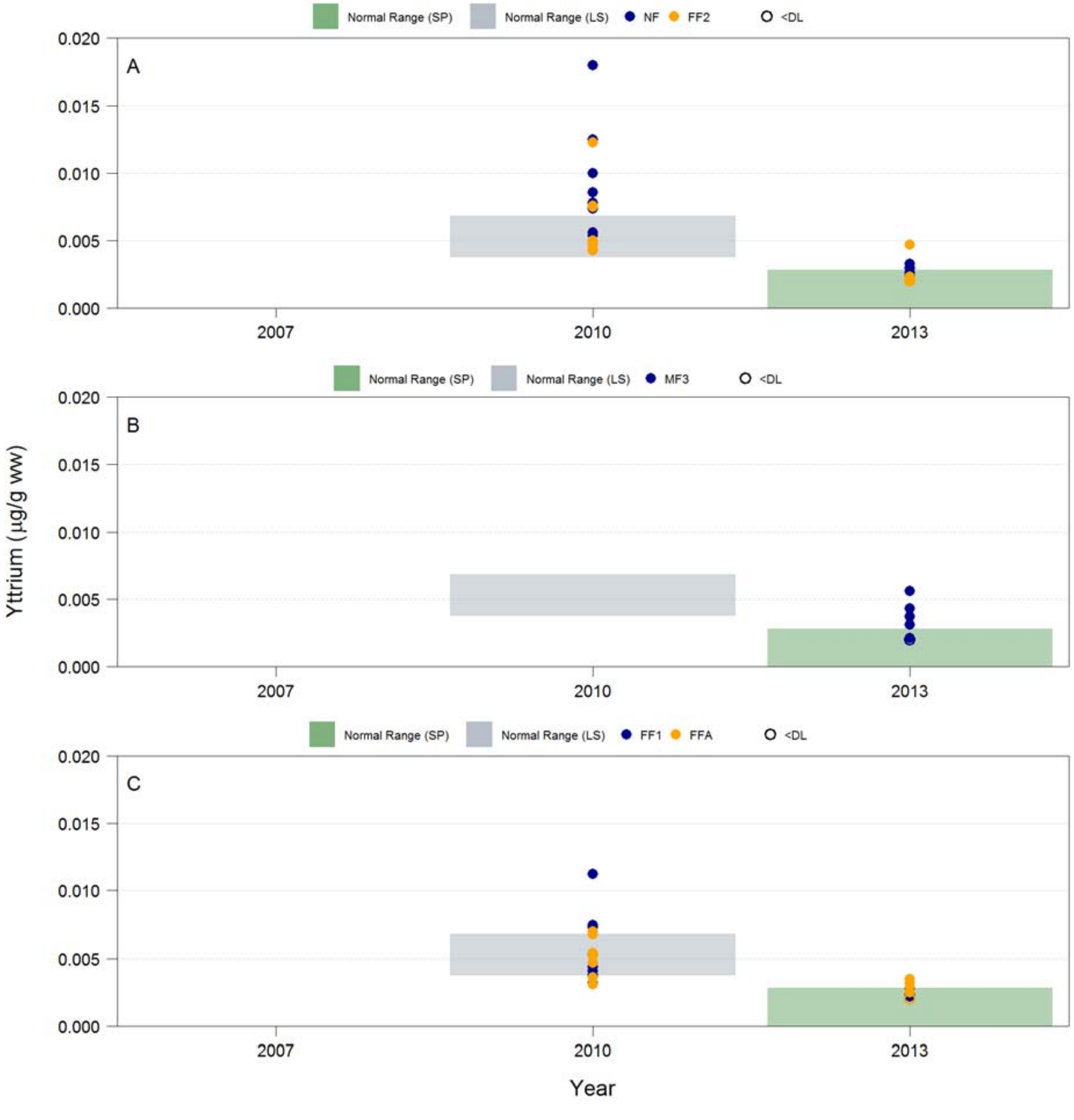
LS = late summer; SP = spring; DL = detection limit.

Figure 10-58 Concentrations of Vanadium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



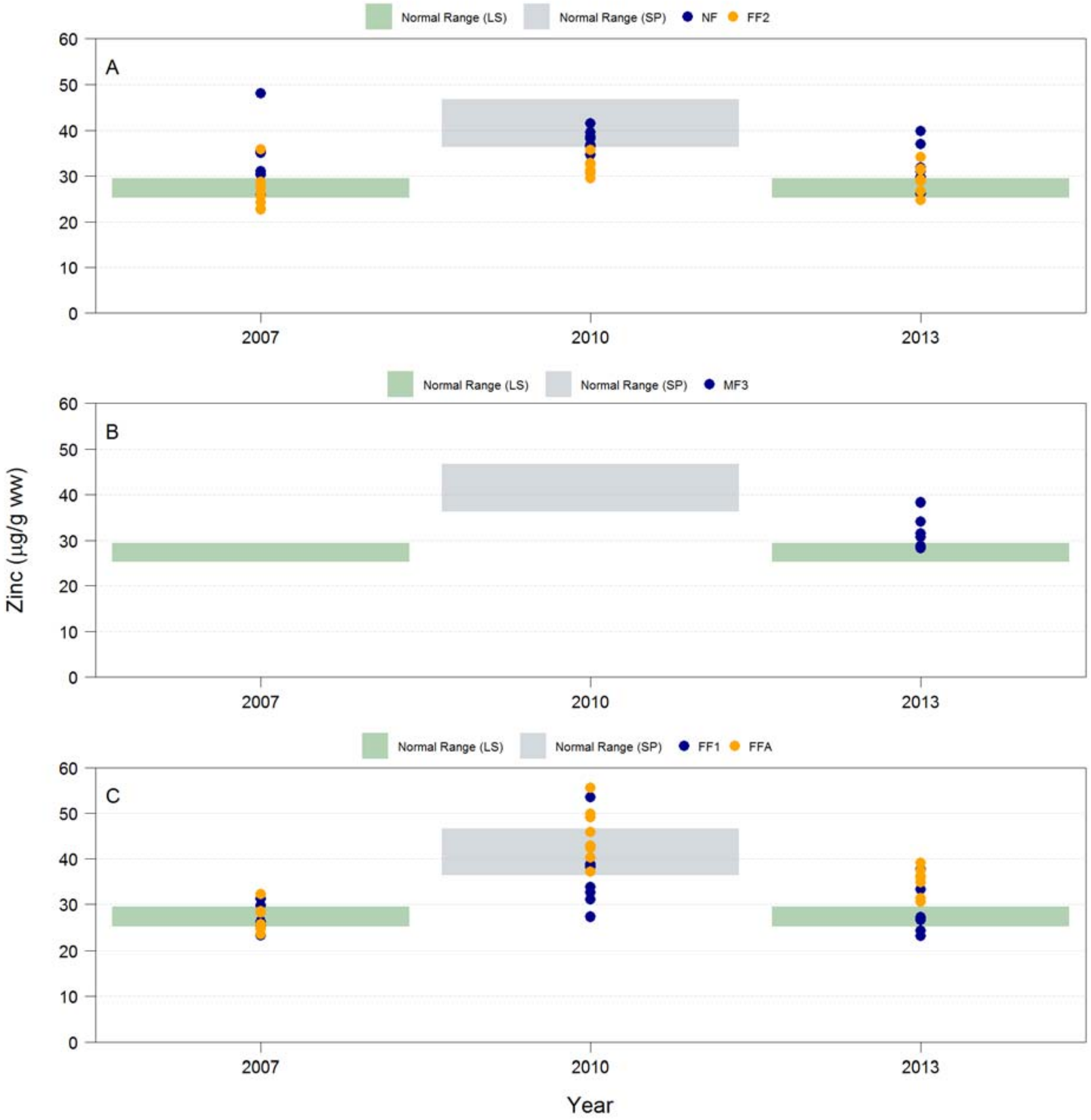
LS = late summer; SP = spring; DL = detection limit.

Figure 10-59 Concentrations of Yttrium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



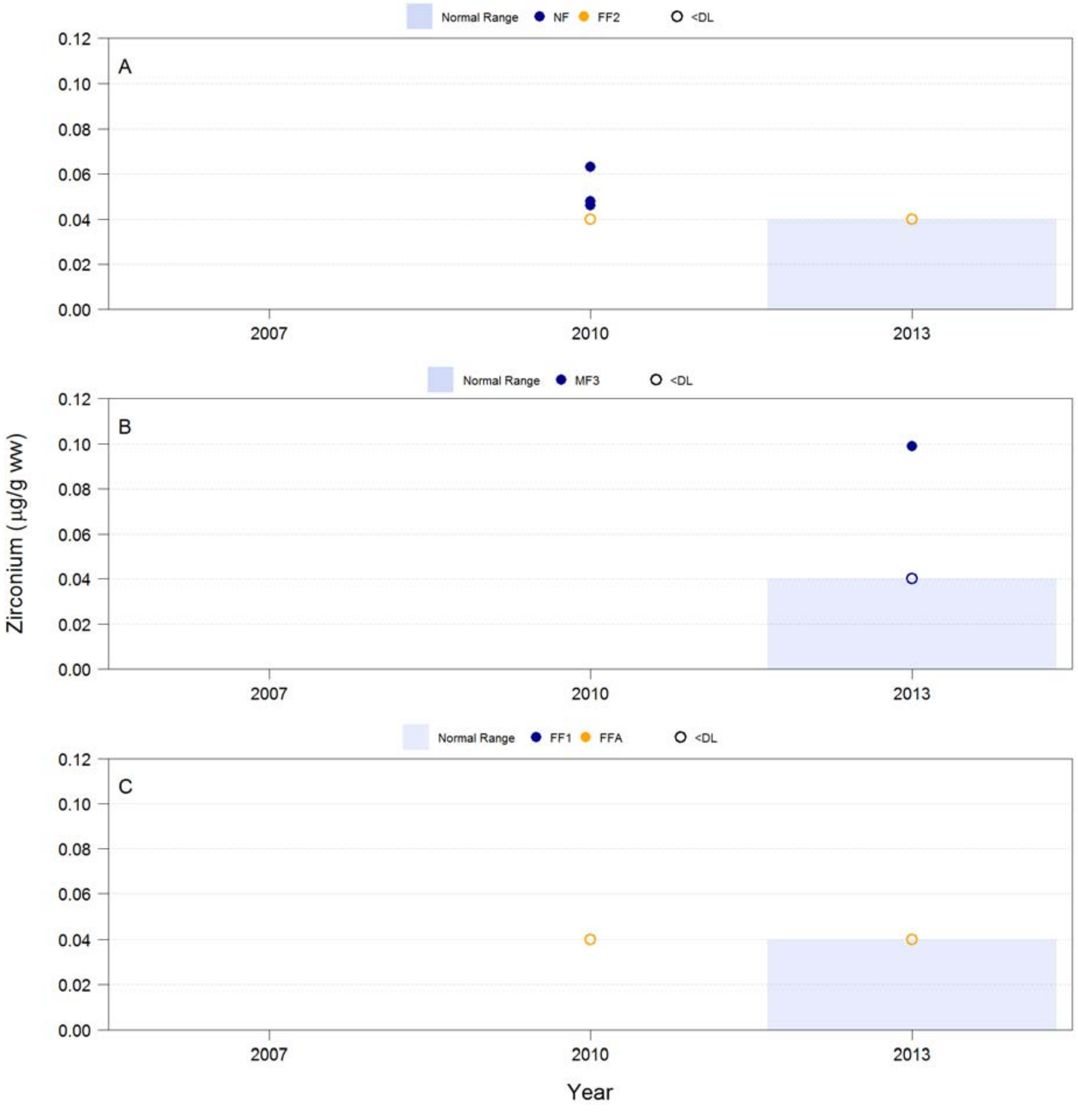
LS = late summer; SP = spring; DL = detection limit.

Figure 10-60 Concentrations of Zinc in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013



LS = late summer; SP = spring.

Figure 10-61 **Concentrations of Zirconium in Composite Samples of Slimy Sculpin Collected from A) the Exposure Sampling Areas; B) the Mid-field Sampling Area; and C) the Reference Sampling Areas of Lac de Gras, 2007 to 2013**

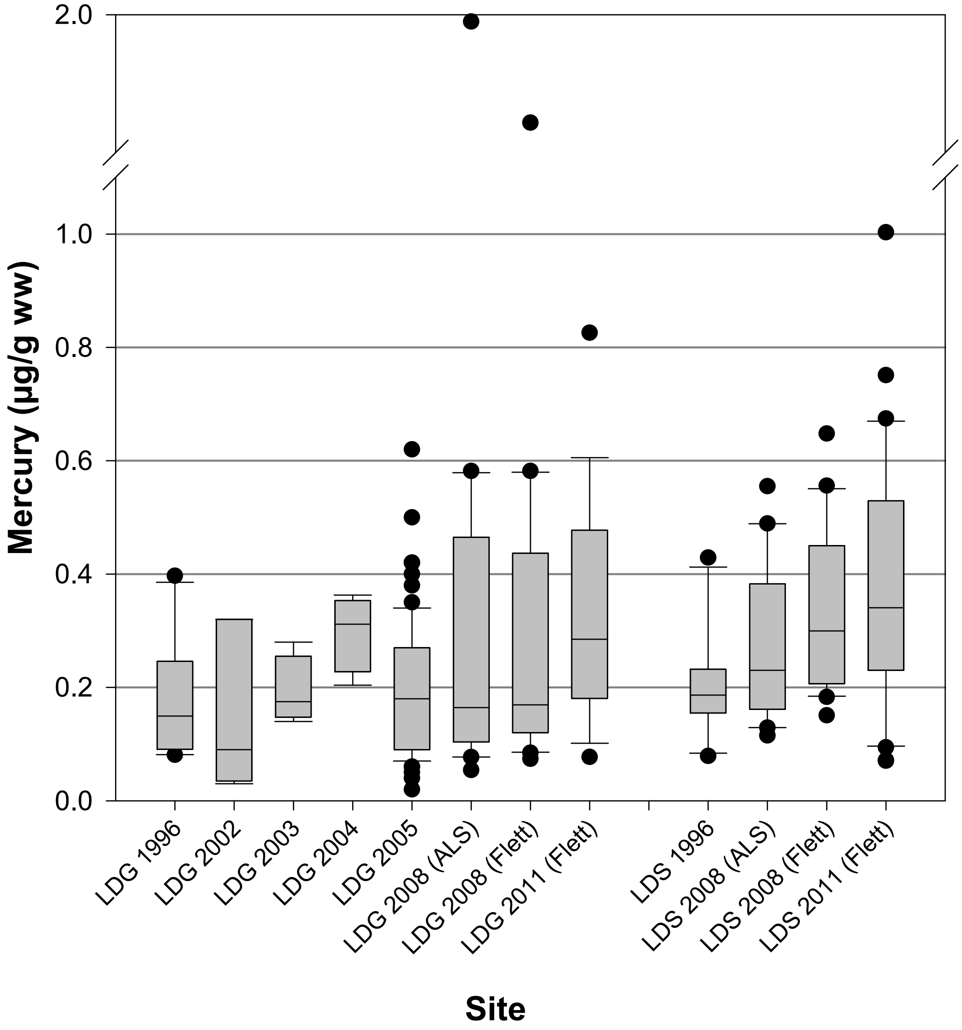


DL = detection limit.

Lake Trout

The distributions of mercury concentrations in Lake Trout muscle tissue by year and area (Lac de Gras or Lac du Sauvage) is shown as boxplots in Figure 10-62. Concentrations of mercury in Lake Trout muscle tissue show a pattern of increasing concentrations in both lakes over time. The median concentrations in 2011 in both lakes were greater than in previous years, with the exception of 2004 in Lac de Gras. The reason that some of the mercury concentrations in 2008 and 2011 were considerably greater than in previous years can be attributed to the much larger and older fish captured in these years, which tend to have the highest mercury concentrations (Figure 10-20). Even taking size into consideration, Lake Trout mercury concentrations are increasing in both lakes; however, concentrations in a given year are the same in both lakes (Section 10.3.2.1).

Figure 10-62 Mercury Concentrations in Lake Trout Muscle Tissue Collected from Lac de Gras and Lac du Sauvage, 1996 to 2011



LDG = Lac de Gras; LDS = Lac du Sauvage; ALS = ALS Canada Ltd; Flett = Flett Research Ltd.

10.3.4 Comparison to EA Predictions

The EA had one prediction regarding fish quality which relates to fish tissue. The EA predicted that mercury concentration in sport and subsistence fisheries would remain below a mean of 0.2 µg/g ww (unadjusted for length). In both 2008 and 2011, this prediction was exceeded in Lac de Gras and Lac du Sauvage.

10.4 Conclusions

The conclusions from this review of the fish surveys are as follows:

- Although significant differences were observed between exposure and reference areas for some fish health endpoints, the responses were generally not consistent among life stage/sex, and among years.
- The findings in 2013 of a potential toxicological response were in contrast to those of the previous survey, which demonstrated population responses more typical of nutrient enriched environments.
- Given the inconsistency in the response patterns from 2007 (little to no response) to 2010 (potential nutrient enrichment response) to 2013 (potential toxicological response), it is difficult to conclude if the Mine is having an impact on the health of the Slimy Sculpin populations of Lac de Gras.
- The effects observed in 2013 were at a magnitude equivalent to Action Level 1.
- Concentrations of lead and strontium have consistently been elevated in Slimy Sculpin in the NF exposure area; however, none of these concentrations are increasing relative to the normal range over time.
- The metals showing a moderate-level WOE effects ranking in 2013 were bismuth, strontium, thallium and uranium. Of these metals, the only metal showing an effect for the first time in 2013 was thallium. These metals in water are not at concentrations known to cause effects in fish and are well below guideline values (Table 5-4).
- Mercury concentration in Lake Trout muscle tissue has been increasing over time in both Lac de Gras and Lac du Sauvage. The mean concentration of mercury detected in 2008 and 2011 in both Lac de Gras and Lac du Sauvage exceeded the EA prediction of 0.2 µg/g ww.

11 WEIGHT-OF-EVIDENCE

11.1 Introduction

The central purpose of the AEMP is “to determine the short and long-term effects in the aquatic environment resulting from the project, test impact predictions, measure the performance of operations and evaluate the effectiveness of impact mitigation” (WLWB 2007). It includes a weight-of-evidence (WOE) integration framework as described in Section 6.10 of the AEMP Study Design Version 3.5 (Golder 2014a) and the 2013 AEMP Annual Report (Golder 2014g). The WOE assessment is conducted each year with the results presented in the annual AEMP technical reports. It considers the following valued ecosystem components:

- Water Quality;
- Sediment Quality;
- Lake Productivity (indicators of eutrophication and plankton);
- Benthic Invertebrate Community Structure; and,
- Fish Population Health and Tissue Chemistry.

WOE analysis provides a systematic and transparent method for integrating complex environmental data. The basis for decision-making within a WOE assessment is a combination of statistical analyses and scoring systems incorporated into a logic system (e.g., Chapman and Anderson 2005; McDonald et al. 2007; Environment Canada and Ontario Ministry of the Environment 2008; Suter and Cormier 2011). Best professional judgment is also a key component of any WOE assessment (Chapman et al. 2002; McDonald et al. 2007) and was incorporated as appropriate. For the AEMP, WOE analyses are conducted separately to address two broad impact[1] hypotheses for Lac de Gras:

- **Toxicological Impairment Hypothesis:** Toxicity to aquatic organisms could occur due to chemical contaminants (primarily metals) released to Lac de Gras.
- **Nutrient Enrichment Hypothesis:** Eutrophication could occur due to the release of nutrients (phosphorus and nitrogen) to Lac de Gras.

For each hypothesis the WOE analysis integrates, semi quantitatively, the results of endpoints for exposure and field effect/response with *a priori*[2] weighting factors, direction weighting factors[3] and *a posteriori*[4] weighting factors to derive Evidence of Impact (EOI) Rankings for the following valued ecosystem components (VECs): lake productivity; benthic invertebrate community; and, fish population

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[1] The term “Impact” is used to indicate a change (positive or negative) in Lac de Gras related to the Mine or Mine activities; however, it is not intended to reflect the ecological significance or level of concern associated with a given change.

[2] Four a priori factors are applied: representativeness; methodological robustness; clarity of interpretation; and, permanence of effects.

[3] Direction-weighting factors reflect the degree of support that an observed biological response contributes to each of the impact hypotheses.

[4] A posteriori factors are applied for coherence of response and evidence of causality.

health. A higher rank represents a higher strength of support for a particular hypothesis. The EOI ranking results for each hypothesis are interpreted to draw conclusions with respect to the nature of impacts that are most likely occurring in Lac de Gras. The various weighting factors are based on professional judgement and are explained in detail in the annual WOE technical reports (e.g., Golder 2014g).

The WOE analysis interprets the results from the annual AEMP technical reports to determine WOE effect rankings as described in the previous chapters. These effects rankings then “feed into” the WOE analysis, where they are scored and weighted, and then compared to a calibrated scale to determine the EOI Ranking. The EOI Ranking indicates the strength of support for each hypothesis (i.e., enrichment or toxicity) determined by the pattern of exposure and biological response in Lac de Gras. It is not intended to determine the severity of observed impacts.

As described in Golder (2014a), ecological significance and the severity of possible effects to an assessment endpoint are categorized according to Action Levels. These classifications were developed to meet the goals of the Response Framework for Aquatic Effects Monitoring that was drafted by the WLWB (Racher et al. 2011). The goal of the Response Framework is to ensure that significant adverse effects never occur. When Action Levels are met for a particular component of the AEMP, then the findings of the WOE analysis serve to inform response planning and environmental stewardship. For example, if the plankton community structure were to shift to a degree that management responses and/or mitigation were considered necessary based on the response framework, then the WOE findings would inform whether adaptive management should focus on the mitigation of nutrient releases or toxicant releases.

11.2 Approach

Figure 11-1 provides a summary of how the WOE framework is implemented. This figure was prepared as part of the 2013 AEMP (Golder 2014g), and is provided here only as an example with the intent to summarize how the WOE framework is implemented. Tables 11-1 and 11-2 summarize the measurement endpoints, Lines of Evidence (LOEs), LOE groups and ecosystem components included in the WOE frameworks for each response hypothesis. Within each ecosystem component, two distinct LOE groups are integrated:

- **Exposure group:** measures of the potential exposure of receptors to Mine-related substances of interest (SOIs), including surface water, sediment and fish tissue chemistry; and
- **Biological Response group:** observationally-based measures of potential ecological changes, including measures of primary productivity, zooplankton biomass, benthic invertebrate community structure and the fish population health.

Since the WOE framework is primarily a scoring and weighting logical system, it is not well-suited to statistical analysis of trends over time. Thus, the 2007 to 2013 summary of the WOE findings followed a different approach to that in the preceding sections and consists of the following three items:

- a summary of WOE conclusions from 2007 to 2013;
- examination of key “driver” endpoints for the WOE conclusions;
- comparison of WOE findings to predicted impacts.

The 2007 to 2013 WOE analyses are described in the individual AEMP reports for each year. The 2013 WOE analysis was carried according to the AEMP Study Design Version 3.5 (Golder 2014a), which updates the WOE approach relative to the AEMP Version 2.0 (e.g., addition of new biological response endpoints such as zooplankton biomass as ash-free dry mass [AFDM] and relative abundance of dominant benthic invertebrate taxa). In addition, the statistical analysis for rating the effects rankings in some of the AEMP components has changed. Changes to the effects rankings system include:

- Benthic gradient analysis (*i.e.*, the gradient of biological response endpoints with distance from the mine[5]) was included in the WOE analysis as part of the Benthic Invertebrate Community component;
- The methods for calculating the normal range of the reference area have changed – the normal range for open-water is based on the August 15 to September 15 period between 2007 to 2010;
- Only those water quality variables that triggered an Action Level of 1 or greater (i.e., SOIs) were analyzed statistically;
- In addition to visual examination of relative density plots (stacked bar graphs) and non-metric multidimensional scaling (nMDS), the relative abundance of the major benthic invertebrate taxa in the near-field and mid-field areas were compared using time series plots to determine if they exceeded the normal range

For consistency, the 2007 to 2012 WOE analyses were re-run using the revised WOE framework. In some cases, the addition of endpoints and changes to the analyses underlying the effects rankings criteria resulted in changes to the EOI Rankings relative to previous years' conclusions. However, it was considered preferable to examine patterns and trends according to the revised WOE approach, rather than attempting to explain differences in conclusions between differing WOE approaches.

The updated WOE analyses are provided in Appendix 11A. Note that field sampling of Lac de Gras fish populations was included in the 2007, 2010, and 2013 AEMPs only; therefore the WOE summary for Fish Population Health is based on these three years only. Also, contaminant parameters in water quality, sediment quality and fish tissue were not monitored in 2012, precluding WOE integration for toxicological impairment for this year.

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[5] Note that previous gradient analysis was based on barium concentration which decreased with distance from the Mine, meaning that a direct relationship between a benthic endpoint and barium concentration meant that the endpoint also decreased with distance from the Mine. The new gradient analysis is based on distance, meaning that an equivalent gradient would involve an inverse relationship – that is, if a benthic endpoint decreased with distance from the Mine, this would be an inverse relationship with distance.

Ecosystem Component	Line of Evidence	Endpoint	Effect Level Rating	Mathematical Representation	*A Priori* Weighting		Direction Weighting			*A Posteriori* Weighting				Final LOE Score	Total WOE Score
					Overall (Product of Factors)	Weighted Endpoint Score	Direction of Observed Effect or Correlation	Support for Nutrient Enrichment Hypothesis	Weighted Endpoint Score	Strength of Linkage	Coherence of Response	Overall (Sum of Factors)	Weighted Endpoint Score		
Lake Productivity	Water Quality (Exposure)	Water Chemistry - total N	↑	0.5	5.6	2.8	n/a	n/a	n/a	0.75	0.75	1.50	4.2	5.6	43.1
		Water Chemistry - Total P	↑	0.5	7.5	3.8	n/a	n/a	n/a	0.75	0.75	1.50	5.6		
	Primary Productivity and Plankton (Biological Response)	Chlorophyll *a* - response	↑↑↑	2	15.0	30.0	Increase	1.0	30.0	0.75	0.50	1.25	37.5	37.5	
		Zooplankton Biomass (AFDM)	↑	0.5	15.0	7.5	Increase	1.0	7.5	0.75	0.50	1.25	9.4		
		Phytoplankton Biomass (enum)	↑	0.5	15.0	7.5	Increase	1.0	7.5	0.75	0.50	1.25	9.4		
		Zooplankton Biomass (enum)	0	0	15.0	0.0									
		Phytoplankton community structure	↑/↓	0.5	11.3	5.6	n/a	0.5	2.81	0.75	0.50	1.25	3.5		
		Zooplankton Community Structure	↑↑/↓↓	1	11.3	11.3	n/a	0.5	5.6	0.75	0.50	1.25	7.0		
Fish Community	Fish Population Health (Biological Response)	Population Structure - survival	0	0	18.8	0.0								0.0	11.3
		Population Structure - size	↓	0.5	18.8	9.4	Decrease	0.0	0.0						
		Energy Stores - K	0	0	25.0	0.0									
		Energy Stores - LSI	↓	0.5	25.0	12.5	Decrease	0.0	0.0						
		Relative reproductive success- Age 1 abundance	0	0	18.8	0.0									
		Reproductive Investment - GSI	↓	0.5	25.0	12.5	Decrease	0.0	0.0						
		Pathology - Occurrence	0	0	25.0	0.0									
	Water Quality (Exposure)	Water Chemistry - Total P	↑	0.5	7.5	3.8	n/a	n/a	n/a	0.75	0.75	1.50	5.6	11.3	
		Water Chemistry - Total N	↑	0.5	5.6	2.8	n/a	n/a	n/a	0.75	0.75	1.50	4.2		
	Primary Productivity (Exposure)	Chlorophyll *a* - exposure	↑↑↑	2	11.3	22.5	n/a	n/a	n/a	0.25	0.25	0.50	11.3		

①

Individual endpoints for each LOE Group were assigned a qualitative rating corresponding to the observed level of effect. Decision criteria are summarized in Tables 2-3 and 2-4 and discussed in Section 3.1.

②

Each qualitative rating was converted to a numerical equivalent to allow mathematical calculation. Numerical equivalents were:

- Negligible (0) = 0
- Early Warning/Low (↑/↓) = 0.5
- Moderate (↑↑/↓↓) = 1
- High (↑↑↑/↓↓↓) = 2

(note that an upward arrow indicates increases while a downward arrow indicates decreases. Both arrows are used for community structure endpoints because changes to community structure are not directional)

③

A priori weighting factors for representativeness, methodological robustness, clarity of interpretation and permanence of effect were applied (Table 2-5). These four individual factors were multiplied to generate an overall *a priori* weighting factor. Qualitative equivalents of the numerical *a priori* factors were:

- Poor = 1
- Satisfactory = 2
- High = 3

The numerical equivalents from Step (2) were multiplied by the overall *a priori* weighting score.

④

Direction weighting factors were applied (Table 2-6) to represent the degree of support for a particular hypothesis (*i.e.*, nutrient enrichment vs. toxicological impairment) indicated by the direction of observed changes in biological response endpoints. Qualitative equivalents of the numerical direction factors were:

- High = 1
- Moderate = 0.75
- Neutral = 0.5
- Low = 0.25
- None = 0

The numerical equivalents for biological/response endpoints from Step (3) were multiplied by the direction weighting factors.

⑤

A posteriori weighting factors for coherence and strength of linkage were developed and applied. Scores of low, medium and high were assigned based the results for exposure and biological response endpoints. Qualitative equivalents of the numerical causality and coherence weighting factors were:

- Low = 0.25
- Medium/Neutral = 0.5
- High = 0.75

The numerical equivalents from Step (2) or (3) were multiplied by the direction weighting factors.

⑥

The final scores for each endpoint were the values from Step (5). The numerical process results in more weight bing assigned to those endpoints with high *a priori* and *a posteriori* weighting scores and a direction of change that supported the hypothesis being examined.

The final score for each Line of Evidence is the maximum endpoint score within the Line of Evidence.

⑦

The final score for each Ecosystem Component is the sum of the Line of Evidence Scores within an Ecosystem Component (i.e., Exposure + Biological Response). This numerical value was converted to an "Evidence of Impact" (EOI) Rank representing the strength of evidence for a particular impact hypothesis.

EOI Ranking Scale:

EOI Rank 3	>40.0
EOI Rank 2	>20.0
EOI Rank 1	>10.0
EOI Rank 0	<10

NOTES

LOE = LINE(S) OF EVIDENCE
WOE = WEIGHT-OF-EVIDENCE
N = NITROGEN
P = PHOSPHORUS
AFDM = ASH-FREE DRY MATTER
ENUM = ENUMERATION
K = CONDITION FACTOR
LSI = LIVER-SOMATIC INDEX
GSI = GONADO-SOMATIC INDEX
EOI = EVIDENCE OF IMPACT

REFERENCE

THE ECOSYSTEM COMPONENTS, LOE GROUPS, ENDPOINTS, RATINGS AND RESULTS ARE PRESENTED FOR ILLUSTRATIVE PURPOSES ONLY (BENTHIC INVERTEBRATES NOT SHOWN). THE WOE ANALYSIS SPREADSHEETS FOR THE 2013 AEMP ARE PROVIDED IN APPENDIX I.

PROJECT
DIAVIK™
DIAMOND MINES INC.

TITLE
EXAMPLE OF WEIGHT-OF-EVIDANCE
FRAMEWORK FOR THE AEMP

Golder Associates

PROJECT No.		14-06208.1000	FILE No.	1406208-1000-HM-0001
DESIGN	RS	2014-09-09	SCALE AS SHOWN	REV.
CADD	VI	2014-09-09	FIGURE: 11-1	
CHECK	TD	2014-09-10		
REVIEW	CF	2014-09-10		

Table 11-1 Endpoints and Lines of Evidence for Each Ecosystem Component Evaluated in the 3-Year AEMP Summary – Toxicological Impairment

Endpoints	Line of Evidence	Ecosystem Component
Water Quality (substances of toxicological concern)	Contaminant Exposure	Lake Productivity
Chlorophyll *a* Zooplankton Biomass (AFDM) Phytoplankton Biomass (enumeration) Zooplankton Biomass (enumeration) Phytoplankton Community Structure/Richness Zooplankton Community Structure/Richness	Biological Productivity (Biological Response)	
Water Quality (substances of toxicological concern) Sediment Quality (substances of toxicological concern)	Contaminant Exposure	Benthic Invertebrate Community Structure
Total Invertebrate Density Dominant Taxa Density Richness Simpson's Diversity Index Evenness Dominance Bray-Curtis Distance Relative Abundance of Dominant Taxa	Benthic Invertebrate Community – Statistical Differences (Biological Response)	
Total Invertebrate Density Dominant Taxa Density Richness Simpson's Diversity Index Evenness Dominance Bray-Curtis Distance	Benthic Invertebrate Community – Gradient with Effluent Exposure (Biological Response)	
Water Quality (substances of toxicological concern) Sculpin Tissue Chemistry	Contaminant Exposure	Fish Population Health
Population Structure - Survival Population Structure – Body Size Energy Stores - K Energy Stores - LSI Relative Reproductive Success - Age 1 Abundance Reproductive Investment - GSI Pathology - Occurrence	Fish Population Health (Biological Response)	

AFDM = ash-free dry mass; GSI - gonadosomatic index; K = condition factor; LSI = liver-somatic index.

Table 11-2 Endpoints and Lines of Evidence for Each Ecosystem Component Evaluated in the 3-Year AEMP Summary – Nutrient Enrichment

Endpoints	Line of Evidence	Ecosystem Component
Water Quality - Total N Water Quality - Total P	Nutrient Exposure	Lake Productivity
Chlorophyll *a* Zooplankton Biomass (AFDM) Phytoplankton Biomass (enumeration) Zooplankton Biomass (enumeration) Phytoplankton Community Structure/Richness Zooplankton Community Structure/Richness	Biological Productivity (Biological Response)	
Water Quality - Total N Water Quality - Total P	Nutrient Exposure	Benthic Invertebrate Community Structure
Chlorophyll *a*	Primary Productivity (Exposure)	
Total Invertebrate Density Dominant Taxa Density Richness Simpson's Diversity Index Evenness Dominance Bray-Curtis Distance Relative Abundance of Dominant Taxa	Benthic Invertebrate Community – Statistical Differences (Biological Response)	
Total Invertebrate Density Dominant Taxa Density Richness Simpson's Diversity Index Evenness Dominance Bray-Curtis Distance	Benthic Invertebrate Community – Gradient with Effluent Exposure (Biological Response)	
Water Quality - Total N Water Quality - Total P	Nutrient Exposure	Fish Population Health
Chlorophyll *a*	Primary Productivity (Exposure)	
Population Structure - Survival Population Structure – Body Size Energy Stores - K Energy Stores - LSI Relative Reproductive Success - Age 1 Abundance Reproductive Investment - GSI Pathology - Occurrence	Fish Population Health (Biological Response)	

AFDM = ash-free dry mass; GSI - gonadosomatic index; K = condition factor; LSI = liver-somatic index; total N = total nitrogen; total P = total phosphorus.

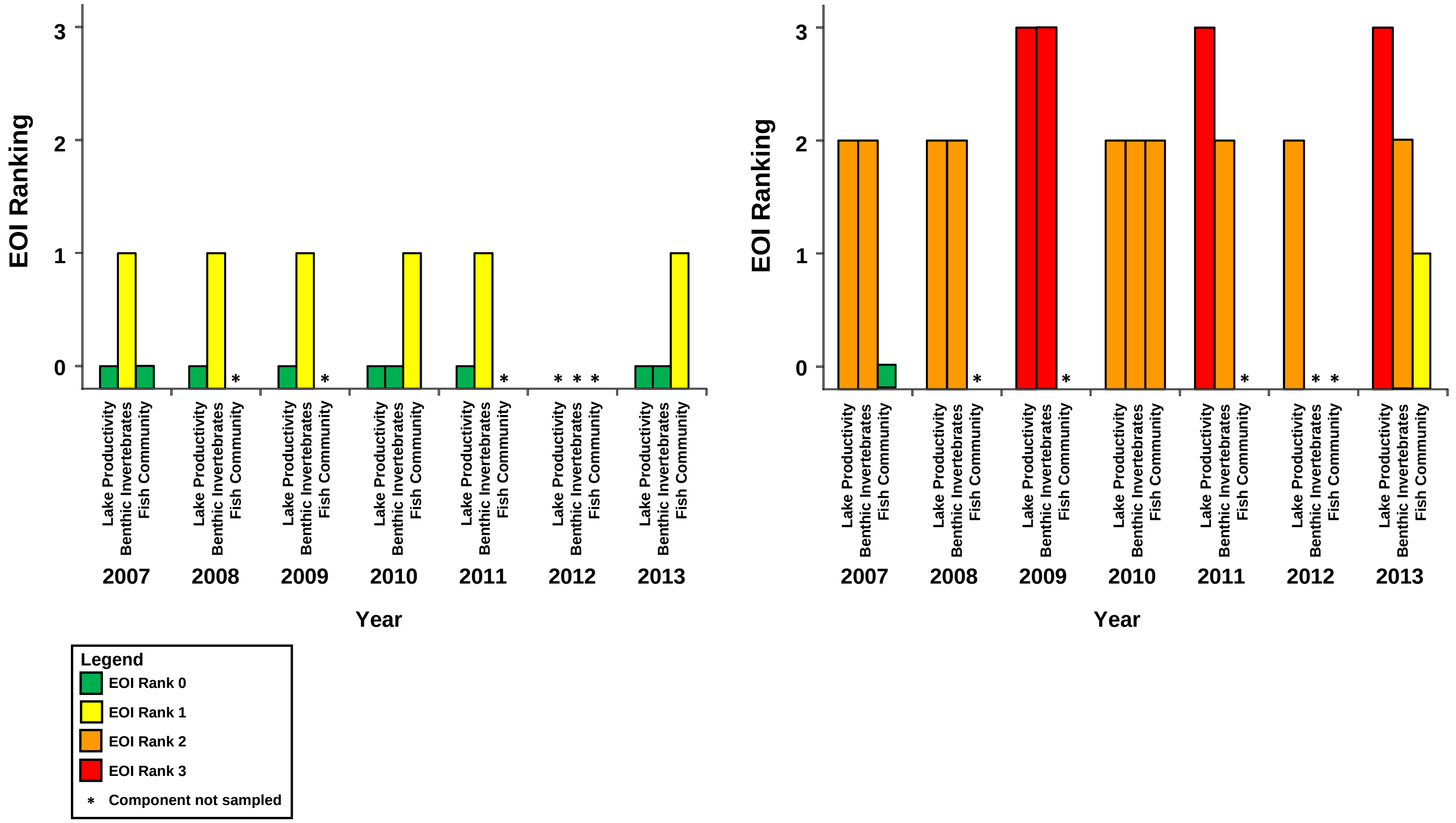
11.3 2007 to 2013 Summary

Figure 11-2 provides a year-by-year summary of the EOI Rankings for the Toxicological Impairment and Nutrient Enrichment WOE analyses. For the toxicological impairment hypothesis, the EOI Rankings have remained consistently weak from 2007 to 2013. The lake productivity component has had an EOI Rank of 0 each year, while the BIC component had an EOI Rank of 0 or 1 from 2007 to 2013. The fish population health component had an EOI Rank of 0 in 2007 due to a lack of biological response for fish health, which increased to an EOI Rank of 1 in 2010 and 2013. The EOI Rank of 1 for fish population health in 2010 is primarily an artefact of the WOE framework (i.e., EOI Rank of 0 may also have been appropriate), because the highest weighted response for fish health was increased pathology, which was attributed to enrichment rather than toxicity, but could not be excluded from the rating and weighting process. For consistency the EOI Rank of 1 was retained for fish population health in 2010.

For the nutrient enrichment hypothesis, the EOI Rankings were moderate to strong from 2007 to 2013. The EOI Rank for the lake productivity component has been variable with an EOI Rank of 2 in four years (2007, 2008, 2010 and 2012) and EOI Rank of 3 in three years (2009, 2011 and 2013). The BIC component had an EOI Rank of 2 for all years except 2009 and 2013, when the EOI Rank was 3. The fish population health component had an EOI Rank of 0 in 2007, which then increased to an EOI Rank of 2 in 2010 and then decreased back to an EOI Rank of 1 in 2013. The EOI Rank of 1 for fish population health in 2013 is considered an artefact of the WOE framework (i.e., EOI Rank of 0 may also have been appropriate), because none of the fish health responses were indicative of enrichment and the final WOE ranking was determine by the high effect rating for exposure (chlorophyll *a*). For consistency the EOI Rank of 1 was retained for fish population health in 2013.

These EOI Ranking results are indicative of much stronger evidence for an enrichment impact on plankton, and to a lesser extent, benthic invertebrates and fish in Lac de Gras, relative to the evidence for toxicological impairment of these ecosystem components. Key driver endpoints that contributed to the WOE Rankings are discussed further in the following sections.

Figure 11-2 Summary of 2007 to 2013 Evidence of Impact Rankings



(a) Toxicological Impairment

(b) Nutrient Enrichment

EOI - Evidence of Impact

11.4 Trend Analysis

11.4.1 Patterns of Response

Figures 11-3 and 11-4 provide summaries of the *Key Driver Endpoints* for the Toxicological Impairment and Nutrient Enrichment WOE analyses from 2007 to 2013 (which, for each year, are summarized in Appendix 11A). The key driver endpoints were those with the highest weighted scores for each ecosystem component within each line of evidence group (i.e., exposure and response groups). The weighted scores for these key driver endpoints resulted in the final WOE scores for each ecosystem component, leading to the EOI Rankings summarized in Figure 11-2. Note that fish population health and tissue chemistry were only measured in the 2007, 2010, and 2013 AEMPs, and, therefore, Figures 11-3 and 11-4 only include a three-year summary for these endpoints. Also, exposure information relevant to toxicological impairment (i.e., water quality, sediment quality and fish tissue chemistry) and benthic community structure information were not collected in 2012, meaning that WOE analysis for toxicological impairment of plankton and benthic invertebrates, and WOE analysis for nutrient enrichment of benthic invertebrates was not conducted.

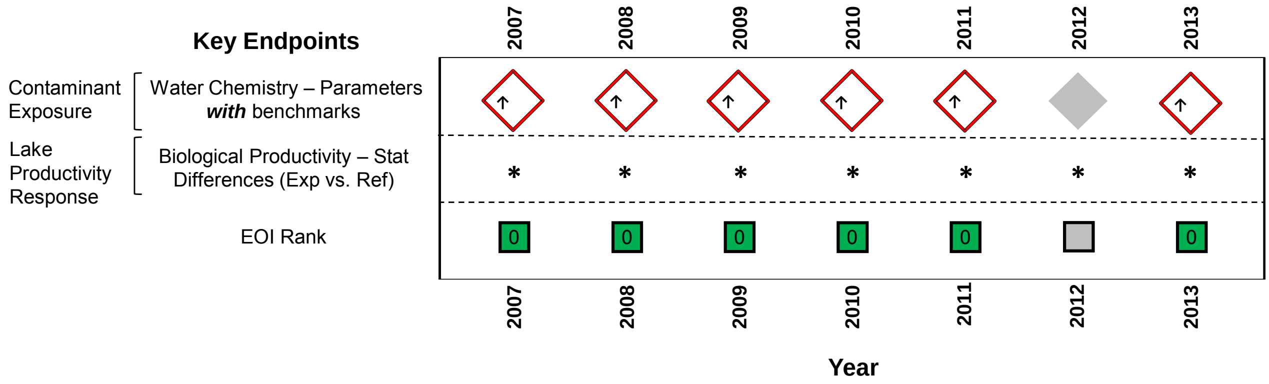
11.4.1.1 Toxicological Impairment

For the Toxicological Impairment Hypothesis, there were no key driver endpoints for the biological response group of the Lake Productivity component, because the direction of effect for these endpoints did not support this hypothesis (weighted scores of 0) even though the exposure endpoint group (i.e., water chemistry) was consistently at a low effect rating each year (Figure 11-3a).

The key driver endpoint for the contaminant exposure group of the benthic invertebrate component was consistently sediment chemistry, while the pattern of key driver endpoints for benthic invertebrate responses was varied. Decreased richness (based on statistical differences, exposed versus reference) was the key driver endpoint in three of the four years resulting in an EOI Rank of 1 (Figure 11-3b). Relative abundance of dominant taxa was the key driver endpoint in 2007, rated as a high level effect, and also resulted in an EOI Rank of 1. These endpoint responses indicate a potential shift in community structure as a result of proximity to the Mine or exposure to Mine effluent. However, these endpoints do not have a high degree of specificity with respect to impact type (e.g., decreased richness and the change to relative abundance could result from either enrichment or toxicity) and based on overall patterns of response the observed changes were most likely related to enrichment rather than toxicological impairment. This was represented in the WOE analyses by the lower *a posteriori* weighting of these endpoints for toxicological impairment relative to those for nutrient enrichment (refer to Appendix 11A). For consistency in treatment of the information, these endpoint results were carried through the toxicological WOE.

Figure 11-3 Key Driver Endpoints for the Toxicological Impairment Weight-of-Evidence

(a) Lake Productivity



(b) Benthic Invertebrate Community

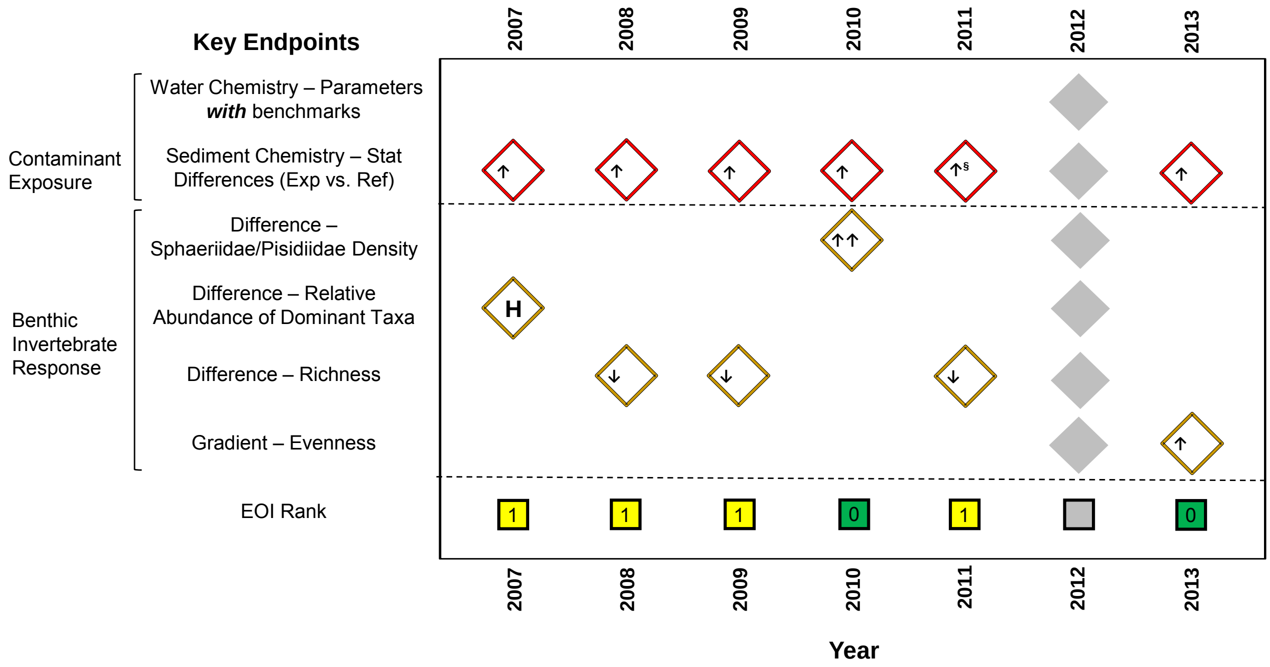
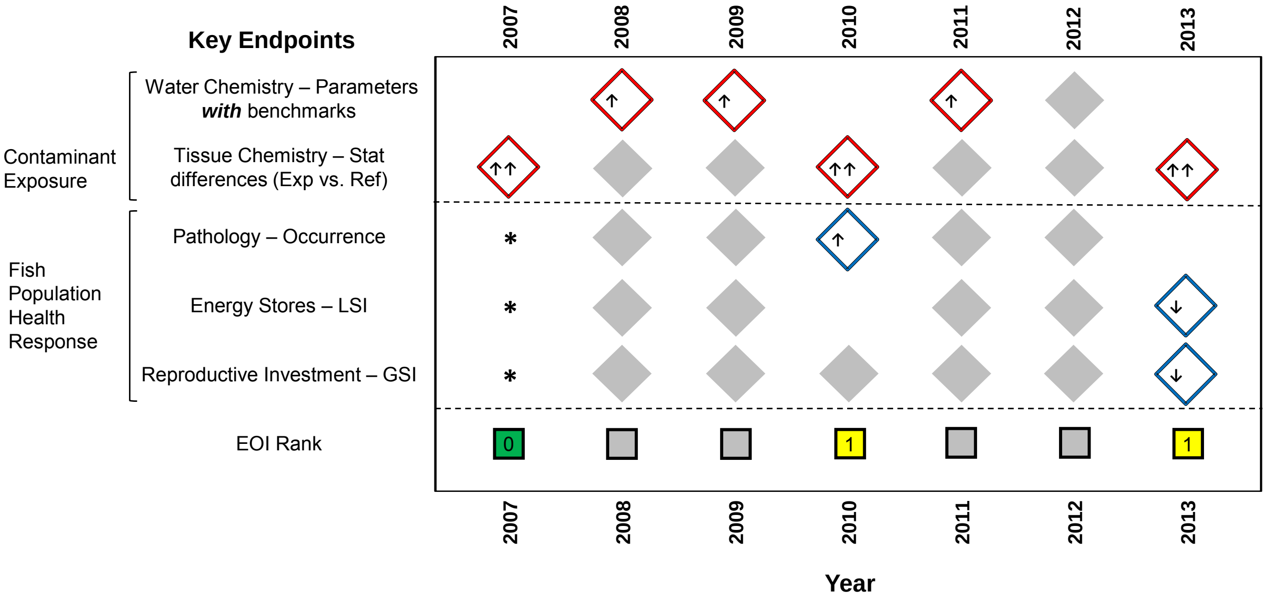


Figure 11-3 (Continued)

(c) Fish Population Health



Notes:

Red diamond = exposure endpoints; brown diamonds = benthic invertebrate community response endpoints; blue diamonds = fish population health response endpoints; grey diamonds = endpoint not measured that year;

↑ or ↓ = early warning/low effect rating and direction; ↑↑ or ↓↓ = moderate effect rating and direction; H = ↑↑↑/↓↓↓ (i.e., high effect rating for non-specific indicator); § = effects rating for 2011 sediment endpoint taken from results of 2010; * = response direction does not indicate toxicity.

EOI = Evidence of Impact; EOI Rank 0 = negligible evidence of impact; EOI Rank 1 = low evidence of impact; EOI Rank 2 = moderate evidence of impact; EOI Rank 3 = strong evidence of impact.

Overall, the EOI Rankings for benthic invertebrates for toxicological impairment are indicative of some contaminant exposure, combined with some BIC responses that could occur in response to toxicity. However, there is no definitive evidence that toxic impacts are occurring. Although sediment exposure remained similar, the EOI Rankings of 0 in 2010 and 2013 resulted from the low support provided for this hypothesis by the increases in Sphaeriidae/Pisidiidae density and the increase in evenness with distance from the Mine.

The key driver endpoint for the contaminant exposure group of the fish population health component has been tissue chemistry, which rated as a moderate effect ranking in each year (Figure 11-3c). In 2007, biological responses associated with the moderate effect ranking in tissue chemistry were not observed, and therefore resulted in an EOI Rank of 0. For 2010, an increase in pathology occurrence was the key driver endpoint for biological response. As discussed in Section 11.3, the increase in pathology occurrence was likely due to an enrichment effect (i.e., enrichment increasing parasite abundance) consistent with the other observed responses for fish population endpoints in 2010 (*i.e.*, an increase in body size, condition factor, and liver somatic index). For consistency in application of the WOE framework the EOI Rank of 1 was retained for fish population health in 2010. For 2013, the key driver endpoints for biological responses included decreased liversomatic index and gonadosomatic index at an effect rating of low combined with a rating of moderate for exposure resulting in an EOI Rank of 1.

11.4.1.2 Nutrient Enrichment

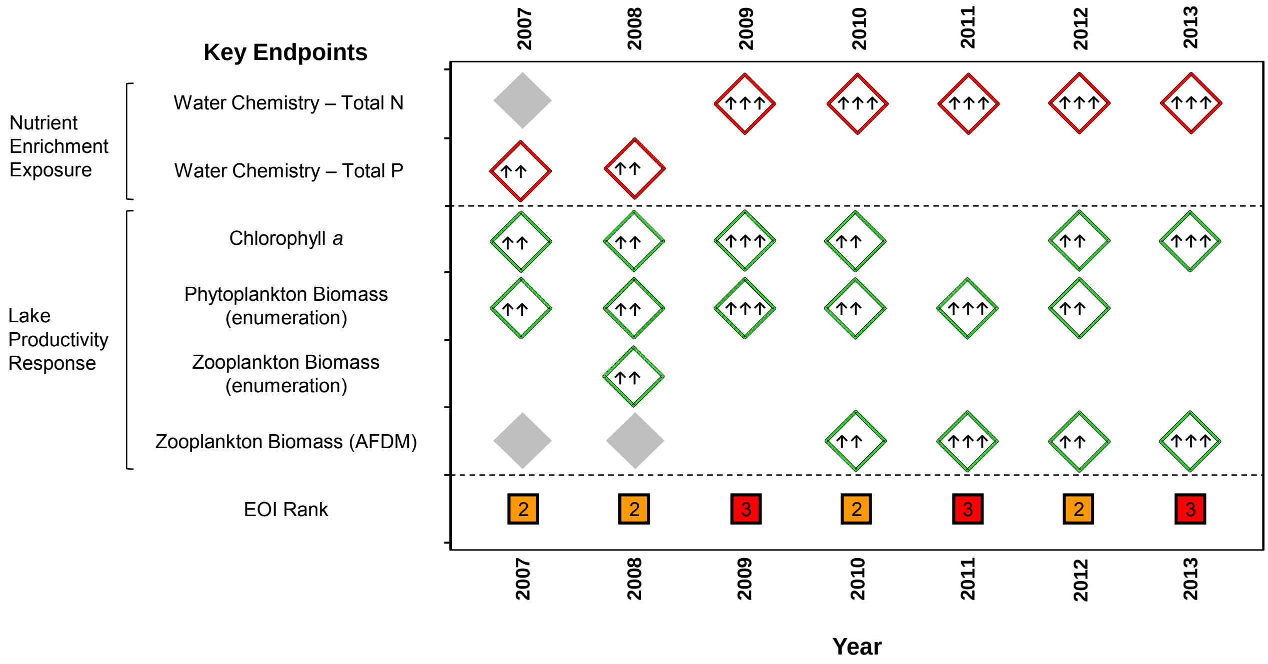
For the Nutrient Enrichment Hypothesis, the key driver endpoint for the exposure group of the Lake Productivity component in 2007 and 2008 was Total P (moderate effect rating) and from 2009 to 2013 was Total N (high effect rating) (Figure 11-4a). The key driver endpoints for the biological response group of lake productivity have varied, but phytoplankton biomass (based on cell enumeration) and chlorophyll *a* featured prominently from 2007 to 2013. In the last four years (*i.e.*, 2010 to 2013), zooplankton biomass (ash-free dry mass) has also been a key driver endpoint. The high effect ratings for both the exposure and biological response groups have resulted in an EOI Rank of 2 or 3 for nutrient enrichment of lake productivity.

The key driver endpoint for the nutrient enrichment exposure group of the benthic invertebrate community component has generally been chlorophyll *a* from 2007 to 2013 at an effect rating ranging from moderate to high. Total N (at a high effect rating) was also a key driver between 2010 and 2012 (Figure 11-4b). For benthic invertebrate biological responses, the key driver endpoints from 2007 to 2013 varied, but were generally total invertebrate density (gradient or statistical differences) or gradients/differences in the densities of dominant taxa (i.e., Heterotrissocladius, Pisidiidae, Procladius). For 2007, a high effect rating for relative abundance was the key driver for biological response of the benthic invertebrate community. An EOI Rank of 2 was determined for the benthic invertebrate community component in all years except 2009 and 2013, which were at an EOI rank of 3, due to a high rating for chlorophyll *a* combined with supporting enrichment-related responses in the benthic invertebrate community.

For fish population health, chlorophyll *a* (rating from moderate to high) has been the key driver endpoint for the enrichment exposure group from 2007 to 2012 (Figure 11-4c). From 2010 to 2013 Total N was also a key driver endpoint for exposure, with a high effect ranking. In 2007 there were no responses observed for any of the biological response endpoints for fish, while in 2013, the direction of response (decrease) were not consistent with a nutrient enrichment effect. Due to the high level effect rating for total N, an EOI Rank of 1 was determined for the Fish Population Health component in 2013 – although this ranking was not supported by the fish health response, it was retained to maintain consistent application of the WOE framework. In 2010, the key driver endpoint for fish health was condition factor, at a low effect rating, contributing to an EOI Rank of 2.

Figure 11-4 Key Driver Endpoints for the Nutrient Enrichment Weight-of-Evidence

(a) Lake Productivity



	Key Endpoints	2007	2008	2009	2010	2011	2012	2013
Nutrient Enrichment Exposure	Water Chemistry – Total N	◆		↑↑↑	↑↑↑	↑↑↑	↑↑↑	↑↑↑
	Water Chemistry – Total P	↑↑	↑↑					
Lake Productivity Response	Chlorophyll *a*	↑↑	↑↑	↑↑↑	↑↑		↑↑	↑↑↑
	Phytoplankton Biomass (enumeration)	↑↑	↑↑	↑↑↑	↑↑	↑↑↑	↑↑	
	Zooplankton Biomass (enumeration)		↑↑					
	Zooplankton Biomass (AFDM)	◆	◆		↑↑	↑↑↑	↑↑	↑↑↑
	EOI Rank	2	2	3	2	3	2	3

Figure 11-4 (Continued)

(b) Benthic Invertebrate Community

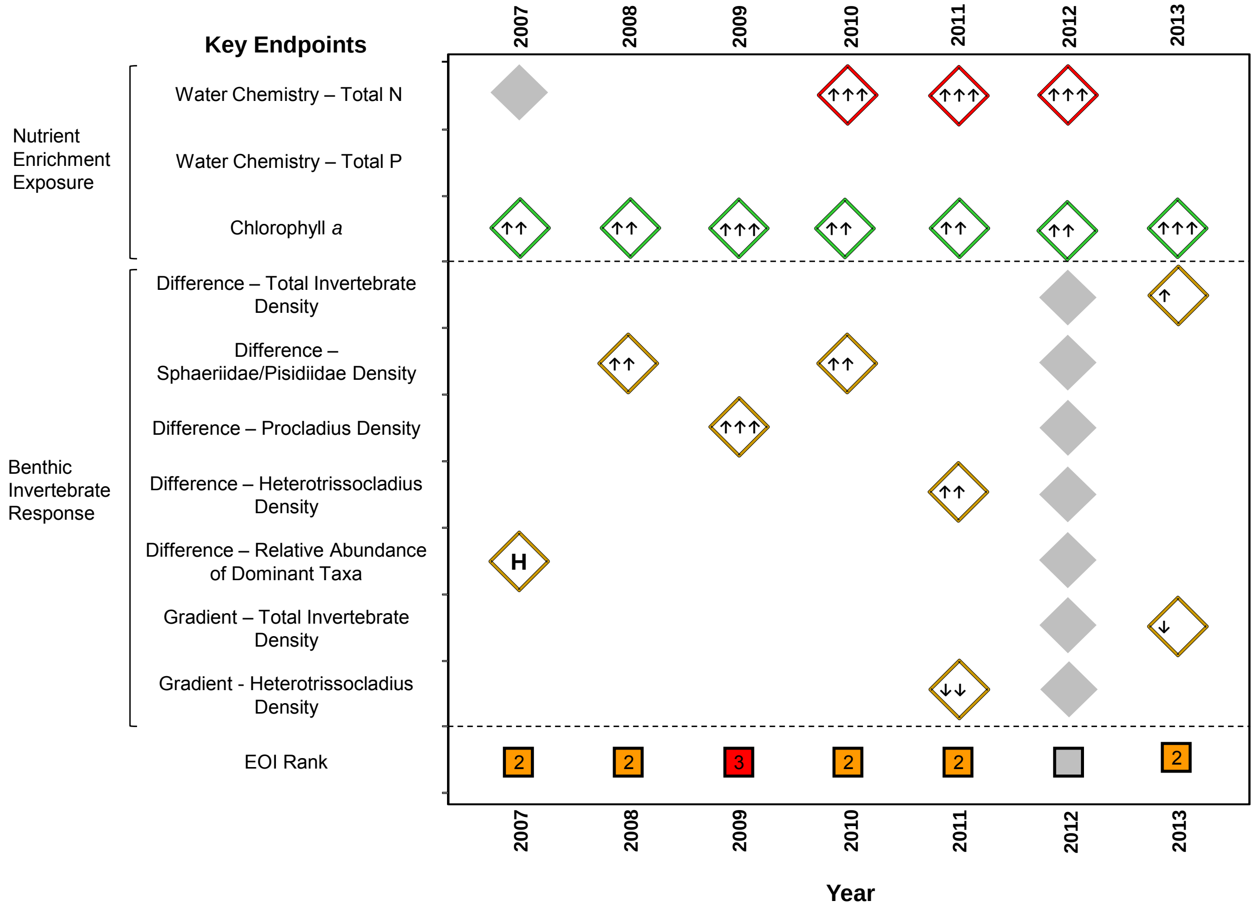
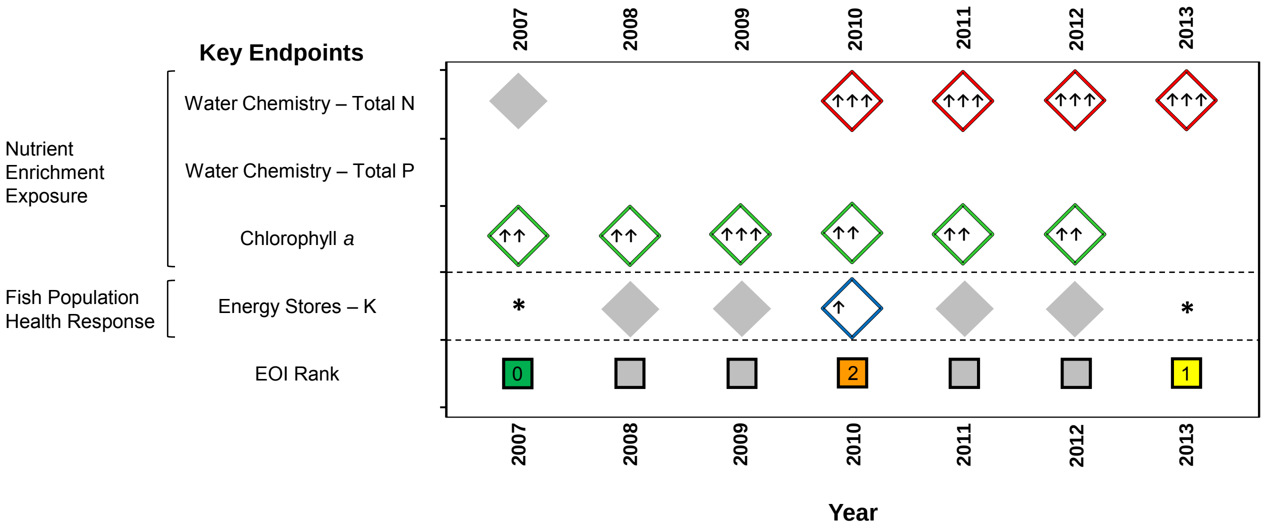


Figure 11-4 (Continued)

(c) Fish Population Health



Notes:

Red diamonds = nutrient enrichment exposure endpoints; green diamonds = nutrient enrichment exposure endpoints and lake productivity response for chlorophyll a; brown diamonds = benthic invertebrate community response endpoints; blue diamonds = fish population health response endpoints; grey diamonds = endpoint not measured that year;

↑ or ↓ = early warning/low effect rating and direction; ↑↑ or ↓↓ = moderate effect rating and direction; ↑↑↑ or ↓↓↓ = high effect rating and direction H = ↑↑↑/↓↓↓ (i.e., high effect rating for non-specific indicator); * = response direction does not indicate enrichment.

EOI = Evidence of Impact; EOI Rank 0 = negligible evidence of impact; EOI Rank 1 = low evidence of impact; EOI Rank 2 = moderate evidence of impact; EOI Rank 3 = strong evidence of impact.

11.4.2 Comparison to Predicted Effects

The EA for the Diavik Project (DDMI 1998b) predicted that, overall, Lac de Gras water would remain at a high quality with regards to drinking water and the protection of aquatic life. The main impact was expected to be the introduction of higher levels of nutrients, particularly phosphorus, with a concomitant increase in primary productivity over a portion of the lake. It was predicted that up to 20% of the surface area of Lac de Gras would be affected by the increase in phosphorus. Based on the predicted effects of phosphorus, the overall effect of the mine water discharge on water quality for the protection of aquatic life was predicted to be of a mid-term, moderate magnitude and regional effect..

The magnitude and type of response that has been observed in Lac de Gras appears to be mild enrichment, resulting in increased lake productivity. The area of effect for total nitrogen slightly exceeds 20% (*i.e.*, a high level rating) in most years, and for some years, this magnitude of effect is also observed for chlorophyll *a*. In 2013, concentrations of chlorophyll *a* exceeded the upper boundary of the normal range of the reference areas over an area representing greater than 20% of the lake, and consequently the magnitude of the eutrophication effect is equivalent to Action Level 2 of the Response Framework. Although there are statistically significant changes to indicators of enrichment in the NF area (and in some cases MF areas), the severity with respect to the ecological integrity of Lac de Gras associated with these changes is considered to be low and consistent with the beginning of a productivity increase on the order of 20% of lake area. .

In contrast, there is little evidence of impairment to lake productivity as a result of contaminant exposure. There is some evidence suggesting potential low-level toxicological impairment of the benthic invertebrate community and the fish community, although these findings have relatively high uncertainty because the link to contaminant exposure is not strong and the responses indicating possible impairment are not consistent over time or with multiple other responses that indicate enrichment. Although fish population health was concluded to be at Action Level 1 of the Response Framework in 2013, this finding contrasted with previous years where a similar degree of exposure to contaminants was occurring. The findings with respect to toxicological impairment are likely due to an inability to definitively rule out the possibility that toxic impacts might be occurring in Lac de Gras as opposed to definitive evidence that toxic impacts are occurring.

11.5 Conclusions

- The WOE EOI in Lac de Gras has remained relatively constant since 2008. For the Toxicological Impairment Hypothesis, the EOI Ranking has remained low (EOI Rank of 0 or 1) for all ecosystem components from 2007 to 2013. For the Nutrient Enrichment Hypothesis, the EOI Ranks for the Lake Productivity and benthic invertebrate community components have varied between 2 and 3 from 2007 to 2013, while the EOI Rank for the Fish Population Health component has varied between 0 and 2 in 2007, 2010, and 2013.
- The general pattern of response is one of nutrient enrichment over 20% of the area of Lac de Gras with a concurrent response in the plankton community. Although nutrient exposure is occurring for the benthic invertebrate community and fish populations in this area, the response in these trophic levels is at a lower degree than in the plankton community.
- The type of impact being observed in Lac de Gras is consistent with that of mild nutrient enrichment over the approximately 20% portion of Lac de Gras that was predicted in the EA for the Mine.
- Exposure to contaminants is also occurring for plankton, benthos, and fish, but biological responses which might indicate toxicity are weak and occur inconsistently, and they could be attributed to natural variability and other ecological factors.

12 TRADITIONAL ECOLOGICAL KNOWLEDGE

12.1 Introduction

This chapter presents a summary of the traditional ecological knowledge (TEK) program prepared under the AEMP Version 3.0. Under the AEMP Version 3.0, a TEK program was proposed that build upon the TEK acquired in previous years of monitoring and was intended to integrate TEK and western scientific information related to the aquatic environment. The development of a methodology by which TEK was incorporated into the AEMP was initiated at community meetings that took place in the winter of 2011 and spring of 2012. The AEMP Version 3.0 included an expanded role of TEK in aquatic monitoring with the aim of identifying potential links between TEK and overall mine operations, planning and management.

In 2012, DDMI, with the assistance of Thorpe Consulting Services, conducted TEK interview sessions with a focus on both documenting and communicating TEK in ways that respect intellectual property rights and are in keeping with standard and accepted protocols specific to the five Aboriginal organizations that assert ties to the Lac de Gras region (DDMI 2013c).

TEK plays an important role in both the fish and water quality components of the AEMP. The objective of the TEK program is as follows:

- Incorporate significant community participation and input into the design and implementation of the AEMP TEK program, including fish palatability and texture studies, and water quality and quantity studies; and
- Provide training and capacity-building opportunities for communities.

12.2 Methods

DDMI, with the assistance of Thorpe Consulting Services, held workshops with communities to jointly develop a mutually agreeable study approach for a TEK program to support the AEMP. Further, agreements around information sharing between knowledge holders and DDMI were discussed during workshops such that community decisions were made prior to data collection. DDMI will continue to work with communities to find a respectful and beneficial approach to sharing information.

The fish palatability and texture studies, and the water quality and quantity studies were conducted from July 30 to August 3, 2012. Details of when the camp was to occur as well as which community members would attend were discussed at the planning meetings held in winter 2011/2012. Table 12-1 presents the TEK component schedule for the meetings, training and field studies.

Table 12-1 Schedule TEK Component Schedule, 2012 to 2013

Timeline	Events[(a)]	Purpose	Outcome
January 2012	Community Scoping / Initial 2012 Planning Meetings	• Present proposed TEK components of the AEMP for discussion. • Request copies of TEK protocols from communities. • Seek guidance on collection, use, access and storage of TEK specific to the AEMP. • Request key contact(s) to advise on AEMP planning (specifically, details of proposed summer 2012 studies).	• AEMP updated according to community input. • Discussion of informed consent was held.
May 2012	2012 Planning Meetings	• Prepare detailed plans and arrange logistics for 2012 studies[(b)]. • Discuss desired outcomes of 2012 studies • Discuss training and capacity building priorities and goals related to 2012-2015 studies. • Initiate process to develop TEK questionnaire for 2012 studies. • Identify participants, Elders and youth for 2012 studies. • Identify what, if any, special 'props' are required by Elders for teaching during 2012 studies. • Introduce concept of environmental 'indicators' as part of monitoring programs. • Submit applications for required research permits to Aurora Research Institute. • Initiate training and capacity building programs.	• Logistics, plans and methods for 2012 studies drafted. • Interview questionnaire and video completed. • List of participants for 2012 studies drafted • Desired outcomes of 2012 studies drafted • Teaching props required for 2012 studies identified • Training and capacity building priorities and goals for 2012 drafted. • Permits obtained.
June 5-6, 2012	2012 Final Planning Meetings	• Finalize logistics, participants and other details for 2012 studies. • Finalize semi-directed interview questionnaire and other proposed methods for documenting and communicating TEK. • Encourage discussion of links between indicators from a TEK perspective and long-term monitoring. • Training and capacity building programs.	• Logistics, plans, methods (including questionnaire) and TK agreements for 2012 studies finalized. • Final participants list for 2012 Studies confirmed. • Indicators from a TEK perspective listed. • Review and signing of informed consent form with participants completed.
July 30 to August 3, 2012	2012 AEMP Studies	• Collection of TK and scientific data on health of fish and water • Elder-youth connection and exchange of knowledge • Intercultural experience and exchange (including drumming, ceremonies, and storytelling)	• Completed Fish Field Forms • Completed Water Field Forms • Completed Fish Palatability Rating Forms • Provided comments and observations as part of Tea Test • Shared stories and cultural experiences

Table 12-1 Schedule TEK Component Schedule, 2012 to 2013

Timeline	Events[(a)]	Purpose	Outcome
February 1 to 4, 2013	Verification & Finalization Meeting in Yellowknife	• Present and seek feedback from communities to support finalization of report with results from 2012 studies. • Gather evaluative feedback on 2012 activities. • Present feature film to communities. • Seek feedback on future AEMP activities through 2015.	• Finalized video and report • Questions, comments and revisions of results from 2012 studies documented. • TEK data verified, corrected and finalized. • 2012 Studies and activities evaluation process completed. • Recommendations for future AEMP activities provided for consideration in 2015 AEMP

a) Events planned are for each of the five Aboriginal parties unless otherwise stated.

b) “2012 studies“ refers to the Fish Palatability and Textures Studies and the Water Quality Studies.

12.3 Results

The TEK program brought together results from traditional knowledge and scientific knowledge shared during a camp held near the Mine at Lac de Gras, NT during the summer of 2012. The results were included as part of the 2012 AEMP (DDMI 2013c). Those involved in the reporting included five Aboriginal parties to their Environmental Agreement: Kitikmeot Inuit Association; Łutsel K'e Dene First Nation; North Slave Métis Alliance; Tłı̨chǫ Government; and Yellowknives Dene First Nation. The companion deliverable to this report is a video-documentary entitled “5 Ways, 2 Days, 1 Camp” which was filmed and produced through a partnership of participating youth and a production crew (Patel 2013).

Elders, youth and scientists collaborated to set nets and inspect overall fish health. Elders tasted a total of four fish that they baked, boiled, fried, and grilled. There were mostly positive descriptions based on the taste test of each fish. The adjectives used repeatedly to describe the fish included good, nice, great, fatty, good flavour and texture, normal, beautiful, fresh, and tasty.

Similarly, camp participants used indicators grounded in TEK to evaluate water quality. From this holistic, interconnected perspective, camp participants deduced that water quality is good by virtue of observing the health of surrounding or submerged vegetation, birds, wildlife, and fish; the shoreline; the presence/absence of surface foam and/or vegetation; clarity; movement; temperature; and taste. A “tea test” was carried out whereby water samples were taken from Lac de Gras, boiled and then made into tea to evaluate the taste. In all cases, the taste of the water was said to be good. Water quality results from scientific results and TK support the same general conclusion that the water is still good in Lac de Gras.

12.3.1 Comparison to EA Predictions

The EA had one prediction regarding fish quality. The EA predicted that no adverse effect on fish quality (i.e., texture, taste) in Lac de Gras would occur as a result of tainting through the introduction of chemicals or fuels at the Mine site. Results of fish palatability and texture studies have indicated that fish quality has not changed since baseline studies.

12.4 Conclusion

In conclusion, results from the fish taste and texture, and water taste and colour tests corroborate observations made by TK holders that there are presently no concerns about fish or water quality. Ongoing monitoring using both ways of knowing will be critical to preserving the future health of the aquatic environment.

13 AEMP SUMMARY OF EFFECTS

A WOE framework was applied annually to AEMP data collected from 2007 to 2013 to provide an integrated assessment of the effects of the Mine on the aquatic environment in Lac de Gras. The assessment focused on two broad impact hypotheses: nutrient enrichment and toxicological impairment. While the annual AEMP reports focus on within-year spatial trends, periodic evaluation of trends over time is also required by DDMI's Water Licence. The preceding technical sections summarize temporal trends from the baseline period (where data were available) through to 2013, and describe the development of Mine related effects and changes relative to what is considered normal for Lac de Gras.

13.1 Nutrient Enrichment

The EA predicted that the discharge of treated water would introduce higher levels of nutrients, particularly phosphorus from natural groundwater, to Lac de Gras. It predicted that water quality in Lac de Gras would remain acceptable for aquatic life. Total phosphorus was the only variable that was predicted to be above its aquatic life threshold (defined in the EA at 5 µg/L) at the mixing zone boundary. Up to 20% of the surface area of Lac de Gras was expected to exceed this threshold during operations. It was predicted that the remainder of the lake would remain below this threshold. Effects associated with the discharge of phosphorus could not be predicted with certainty in the EA, but the EA indicated that effects could include an increase in algal growth, increases in fish growth rates, improvements in fish health and increases in the abundance of some aquatic species, and declines in the abundances of others (DDMI 1998b).

The nutrients with discharge limits in the Water Licence are ammonia and total phosphorus. Neither of these have exceeded their discharge limits to date. When compared to the mass load of phosphorus from the watershed, some of which would be in the dissolved state, our analysis indicated that dust would not be expected to change the background concentration of phosphorus in Lac de Gras. Total phosphorus concentrations in the NF area have remained at similar levels within the normal range during the open-water season since 2008. During the ice-cover season TP concentrations in the NF area increased from within the normal range in 2010 to exceeding the normal range in 2013. Although there was no statistically significant trend over the 2007 to 2013 period, the recent increase in lake concentrations appears to reflect that in the effluent. The spatial extent of the effects on total phosphorus in 2013 (14.1% of the lake) was less than that observed in 2008 (19.6% of the lake), despite the fact that effluent is now being detected in the far-field reference areas (as was predicted).

Chlorophyll *a* concentrations in the NF and MF areas have been consistently greater than the upper bound of the normal range (0.89 µg/L) between 2007 and 2013. In 2009 and 2013, chlorophyll *a* concentrations in the NF and MF areas were greater than the upper bounds of the normal range in over 20% of the lake. There has not been a temporal trend in concentrations, though the greatest mid-field concentrations were encountered in 2013.

Although there has been no temporal trend in phytoplankton taxonomic richness, which has generally remained within the normal range in all areas, phytoplankton biomass increased in the NF exposure area from 2003 to 2010, exceeding the normal range in 2006. From 2011 to 2013 phytoplankton biomass decreased, and by 2013 phytoplankton biomass was within the normal range. Differences continue to be observed in phytoplankton community composition between exposure and reference areas; however, the lake-wide shifts in community structure over the last three-year period (2011 to 2013) compared to the previous summary period (2007 to 2010) are equal to the differences between exposure and reference areas. This indicates that the effluent effects that do exist on community structure are not more pronounced than natural fluctuations over time.

Effects on zooplankton has been less pronounced over the years as evidenced by the lack of temporal trends in total zooplankton biomass, which remained within the normal range in most years. No temporal trends were evident in the biomass of major groups, except for a decrease over time in calanoid copepod biomass in all areas, including the reference areas. This was also evident in their relative biomass. Cladoceran biomass has exceeded the normal range in the NF exposure area in most years from 2008 to 2013, and although their biomass has not increased over the years, their relative biomass appears to be increasing. There continues to be a difference in the zooplankton community assemblage between exposure and the reference areas, though this difference was less pronounced in the 2011 to 2013 period compared to the previous summary period (2007 to 2010).

The effects of nutrient enrichment are also being observed on the benthic invertebrates. Total invertebrate density and densities of most major benthic invertebrate groups have been consistently greater in the NF area compared to the reference areas, since 2008. This effect was confirmed as being Mine-related since total density, and densities of Pisidiidae, *Procladius* sp. and *Heterotrissocladius* sp. were higher at the NF stations relative to stations farther from the effluent discharge. These variables demonstrated significant regressions with distance from the Mine. The relative abundances on major taxonomic groups indicate that there has been a change in community structure over time. Community composition varied between the reference and exposure areas in all years, and the community composition further varied between the AEMP Version 2.0 monitoring period (2007 to 2010) and the AEMP Version 3.0 monitoring period (2011 to 2013). However, this change over the two periods was seen in both exposure and reference areas, so the change over time is not strictly due to the Mine effluent.

The WOE Evidence of Impact (EOI) Rankings in Lac de Gras have remained relatively constant since 2008. For the Nutrient Enrichment Hypothesis, the EOI Ranks for the Lake Productivity and Benthic Invertebrate Community components have varied between 2 and 3 from 2007 to 2013. Evidence of nutrient enrichment in fish population health has been more variable, with the EOI Rank for the Fish Population Health component varying from an EOI of 0 in 2007, to an EOI of 2 in 2010, and an EOI of 1 in 2013.

The type of impact being observed in Lac de Gras is consistent with that of nutrient enrichment over the approximately 20% portion of Lac de Gras, as predicted in the EA. The changes being observed are also consistent with those the EA described as being possible under phosphorus loading from the effluent

13.2 Toxicological Impairment

Characterization of the effluent provides no suggestion that a toxic response would occur in Lac de Gras. Effluent tested from 2002 to 2013 was generally non-toxic to aquatic test organisms, as shown in over 300 acute toxicity tests and over 200 sub-lethal toxicity tests, and Mine effluent continues to meet Effluent Quality Criteria under the Water Licence. Moreover, although effluent loads and/or concentrations of some metals identified as SOIs (molybdenum and strontium) have increased over time, most have either decreased (aluminum, barium, manganese) or have remained at relatively similar levels over time (antimony, chromium, silicon, uranium).

The SOIs that reached Action Levels from 2007 to 2013 were categorized according to the WOE effects rankings. All 25 SOIs satisfied the requirement for a low ranking in one or more years from 2007 to 2013, because concentrations in the NF were significantly greater than in reference areas in one or both sampling seasons (ice-cover or open-water). A moderate ranking was not applied to any of the SOIs because concentrations in all samples were below AEMP Effects Benchmarks. None of the SOIs are at concentrations that, individually, are known to cause toxicity in aquatic biota. Nonetheless, nine SOIs have showed patterns of increasing concentration over time at most exposure and reference areas. These SOIs were specific conductivity, total hardness, calculated TDS, sulphate, calcium, molybdenum, magnesium, sodium and strontium. Correlation analysis found these increases over time to be statistically significant. Chloride also produced significant relationships with time; however, concentrations have not increased since 2011. Although these 10 SOIs in the exposure areas have remained above the normal range throughout 2011 to 2013, they are not near concentrations known to elicit a toxic response.

Similarly, none of the metals that are found in greater concentrations in the exposure area sediments would be expected to cause a toxic response. Fifteen variables satisfied the requirement for a low WOE effects ranking from 2007 to 2013. Concentrations of these variables in the NF area were significantly greater than in reference areas during at least one year of monitoring. Three of these variables (bismuth, lead, and uranium) have exceeded the normal range. A moderate ranking was not applied to any of the sediment variables because concentrations were below guideline levels. The number of sediment variables that have reached a low effect ranking varied among years but has not increased over time, and there were no temporal trends in the concentrations of these SOIs.

Plankton monitoring did not identify any patterns in richness, biomass or community composition that would indicate toxicity resulting from the Mine effluent. Benthic invertebrate monitoring provided evidence of nutrient enrichment, and effects on community composition variables that were non-specific with respect to effect type were attributed to changes associated with enrichment, rather than toxicity.

The responses of fish health endpoints have not been consistent among life stage and sex, nor among years. Fish health endpoints in the exposure areas were all within the normal ranges for the lake. Given the inconsistency in the response patterns from 2007 (little to no response) to 2010 (potential nutrient enrichment response) to 2013 (potential toxicological response), it is difficult to conclude if the Mine is having an impact on the health of the Slimy Sculpin populations. The 2013 responses in fish health were not consistent with those in the chemistry-related and other biological components of the AEMP, which are expected to serve as early warning indicators for effects on fish. Three metals (lead, strontium and uranium) have consistently been elevated in Slimy Sculpin in the NF exposure area; however, only the concentrations of uranium have been increasing relative to the normal range over time. These metals in water are not at concentrations known to cause effects in fish and are well below guideline values.

For the Toxicological Impairment Hypothesis, the EOI Ranking has remained low (EOI Rank of 0 or 1) for all ecosystem components from 2007 to 2013. Based on the biological monitoring results discussed above, the WOE results with respect to toxicological impairment (e.g., EOI Rank of 1) are likely due to an inability to definitively rule out the possibility that toxic effects might be occurring in Lac de Gras, as opposed to definitive evidence that toxic effects are occurring.

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