An investigation of land-use impacts on water quality and phytoplankton communities of the Vermilion River and major tributaries, Sudbury, Ontario, Canada

by

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ABSTRACT

The Vermilion River and major tributaries (VRMT) receive numerous inputs from point and non-point sources along their continuum. In addition to these inputs from the surrounding landscape, a hydroelectric impoundment and control dams/weirs have modified the natural flow regime. Further development in the Vermilion watershed has been proposed and there are concerns that it will push the system beyond a tipping point, leading to a state of permanent impairment. In order to understand how ecosystem health may be impacted by future stressors baseline water quality and phytoplankton data were collected monthly (6 months per year) over a period of two years (2013-2014) for twenty-eight sites. Landscape-scale data were also extracted for these sites using the geographical information software QGIS.

A broad range of quaternary geology types, land-cover types, and road densities were found to exist in the VRMT study area. Impervious land-cover types (i.e. barren and developed land-cover) and road density were positively correlated with many water quality parameters, whereas, forest land-cover was negatively correlated with many water quality parameters. Principal component analyses revealed that sites on the main-stem of the Junction tributary exhibited above average values for the majority of water quality parameters. Notably, sites located downstream of the Sudbury WWTP had above average values for chlorophyll-a, total phosphorus, nitrate, and nitrite, whereas the site upstream had above average values pH and total kjeldahl nitrogen.

Further correspondence analyses and canonical correspondence analyses demonstrated that the abundance and composition of major phytoplankton groups and genera were different between sites and likely influenced by the surrounding landscape (i.e. point and non-point sources) and water quality differences. For all CCAs general biological/chemical parameters and nutrients were slightly better predictors at explaining the variation in phytoplankton biomass compared to metals. Of these general biological/chemical parameters and nutrients, many of parameters were important or moderately important (e.g. Chl-a, CaCO3, DOC, Cond, Cl, TP, TN, TKN, NO3, and NO2). The major phytoplankton group Chlorophyta (i.e. green algae) was abundant at many sites located in Junction tributary in 2013 and in 2014, however, CC-12 which was also located in the Junction tributary was primarily dominated by the major phytoplankton group Bacillariophyta (i.e. diatoms) and had extremely low biomass for all sampling dates. In addition, the major phytoplankton group Cyanophyta (i.e. blue-green algae) was regularly abundant later in the sampling season at ELA-25 for both years and this major phytoplankton group was mainly comprised of *Microcystis*.

Keywords: Land-use, water quality, phytoplankton communities, Vermilion River and major tributaries, Sudbury ON

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List of Abbreviations

Ag	Total silver
Al	Total aluminium
Ba	Total barium
Be	Total beryllium
Bi	Total bismuth
CA	Correspondence analysis
Ca	Total calcium
CaCO3	Calcium carbonate (i.e. hardness)
CCA	Canonical correspondence analysis
Cd	Total cadmium
Chl-a	Chlorophyll-a
Cl	Chloride
Co	Total cobalt
Cond	Conductivity
Cr	Total chromium
Cu	Total copper
DOC	Dissolved organic carbon
E.coli	*Escherichia coli*
Fe	Total iron
K	Total potassium
Li	Total lithium
Mg	Total magnesium
Mn	Total manganese
Mo	Total molybdenum
Na	Total sodium
Ni	Total nickel
NO2	Nitrite
NO3	Nitrate
Pb	Total lead
PCA	Principal component analysis
RDL	Reporting detection limit
Si	Total silicon
Sn	Total tin
Sr	Total strontium
STS	Septic tank system
Ti	Total titanium
TKN	Total kjeldahl nitrogen
TN	Total nitrogen
TP	Total phosphorous
U	Total uranium
UOIT	University of Ontario Institute of Technology
V	Total vanadium
VRMT	Vermilion River and major tributaries
WWTP	Wastewater treatment plant
Zn	Total zinc
Zr	Total zirconium

CHAPTER 1: GENERAL INTRODUCTION

1.1 Introduction

For approximately a century, the Sudbury region in Ontario was subjected to acidification and metal pollution from mining and smelting activities. Consequently, local terrestrial and aquatic systems were significantly impaired and degraded. Upgrades and improvements to mining and smelting facilities in the 1980's have allowed most aquatic ecosystems in the area to recover, both chemically and biologically (Gunn, Keller, & Negusanti, 1995; Havas, Woodfine, & Lutz, 1995). Although most aquatic systems are deemed recovered in the Sudbury region, the ecological health of the Vermilion River and major tributaries (VRMT) remain a concern.

The VRMT receive numerous inputs from point (e.g., smelters, WWTPs, and sewage lagoons) and non-point sources (e.g. runoff from the properties of mining industries, agriculture, roadways, etc.) along their continuum. In addition to these inputs from the surrounding landscape, a hydroelectric impoundment and control dams/weirs have modified the natural flow regime. As a result, it is likely that the VRMT have been impacted by these cumulative factors and from legacy mining activities. Indeed, lakes within the Vermilion watershed are already afflicted by periodic algal blooms and excessive macrophyte growth from legacy phosphorus loadings. Further development in the Vermilion watershed has been proposed, including hydroelectric dams and the expansion of mining activities. There are concerns that further development in the watershed will push the system beyond a tipping point, leading to a state of permanent impairment. Therefore, it is imperative to document and assess current baseline conditions of the VRMT to understand the influence the surrounding landscape (i.e. point and non-point sources) and flow regulation have on the water quality and ecological health of the system.

Assessments of aquatic systems usually rely on water quality parameters; however, this approach only considers the physical and chemical properties of the systems and ignores the biological integrity (i.e., ecological health). Phytoplankton are ideal bioindicators for the biological integrity of aquatic systems as they are sensitive to environmental changes and are the base of aquatic food webs. Thus, incorporating them into assessments may provide valuable insight regarding the state of a system.

1.1.1 Phytoplankton as Ideal Bioindicators

One way to measure and assess the ecological health of aquatic systems, in addition to measuring water quality features, such as turbidity, nutrients, and contaminants, is to study the resident phytoplankton community. Phytoplankton are the floating microalgae that grow in surface waters, and are the main source of energy and elemental nutrient transfer into pelagic foodwebs. Due to their microscopic nature, phytoplankton can respond quickly to physical and chemical changes in their environment. Therefore, information about a particular site can be obtained by documenting the occurrence and/or abundance of phytoplankton species or communities.

Species or communities can prefer or tolerate particular habitats. Furthermore, they can thrive and out-compete other phytoplankton under certain water quality conditions (Longhi & Beisner, 2010; Reynolds, 1984). Since some major phytoplankton groups are restricted to particular habitats and water quality conditions they serve as good bioindicators. Of the ten major phytoplankton groups, four groups are useful bioindicators as they are comprised of species and communities that respond predictably. These include the Bacillariophyta, Chlorophyta, Chrysophyta, and Cyanophyta. This is not to say that the other groups (i.e. Cryptophyta, Dinophyta, Euglenophyta, Xanthophyta, Phaeophyta, and Rhodophyta) are of no use, they are just not ideal for one or more of the following reasons: they are not a prominent group in aquatic systems, they do not provide a diagnostic range for different habitats, they could be difficult to identify, they are not preserved in sediment, and/or most of the members are marine (Bellinger & Sigee, 2010a).

By monitoring the occurrence and/or abundance of phytoplankton species or communities early-warning signals that reflect the ecological health and status of a system can be detected. In addition, both short-term and long-term information can be extracted. For example, if intense phytoplankton blooms form annually this may indicate a system with high nutrients (i.e. eutrophic) possibly from legacy phosphorous loadings or from a constant external source of nutrients such as direct discharge (i.e. point sources) or runoff from the surrounding landscape (i.e. non-point sources). However, if phytoplankton blooms occur sporadically this may indicate a system with inconsistent nutrient levels, possibly from an external source of nutrients that is irregular.

Although biological surveys can offer distinct information compared to physical and chemical monitoring, both are desired as part of a comprehensive water quality monitoring program. By documenting and assessing the baseline conditions of a system (water quality and resident phytoplankton community) one can determine the ecological health and status of a system. If the ecological health is deemed to be impaired, the management practices of that system should be modified to aid in recovery and restoration.

1.2 General Overview: VRMT Study Area

1.2.1 Landscape

The VRMT system is located in northeastern, Ontario, which is a temperate region with a moderate altitude (150m-550m) (Figure 1). This system contained twenty-eight sites. Twenty-five sites were located in the Greater Sudbury municipal boundary, whereas the remaining three sites were outside of this municipal boundary. Furthermore, twenty-seven sites were located within Vermilion watershed and one site was located within the Spanish watershed.

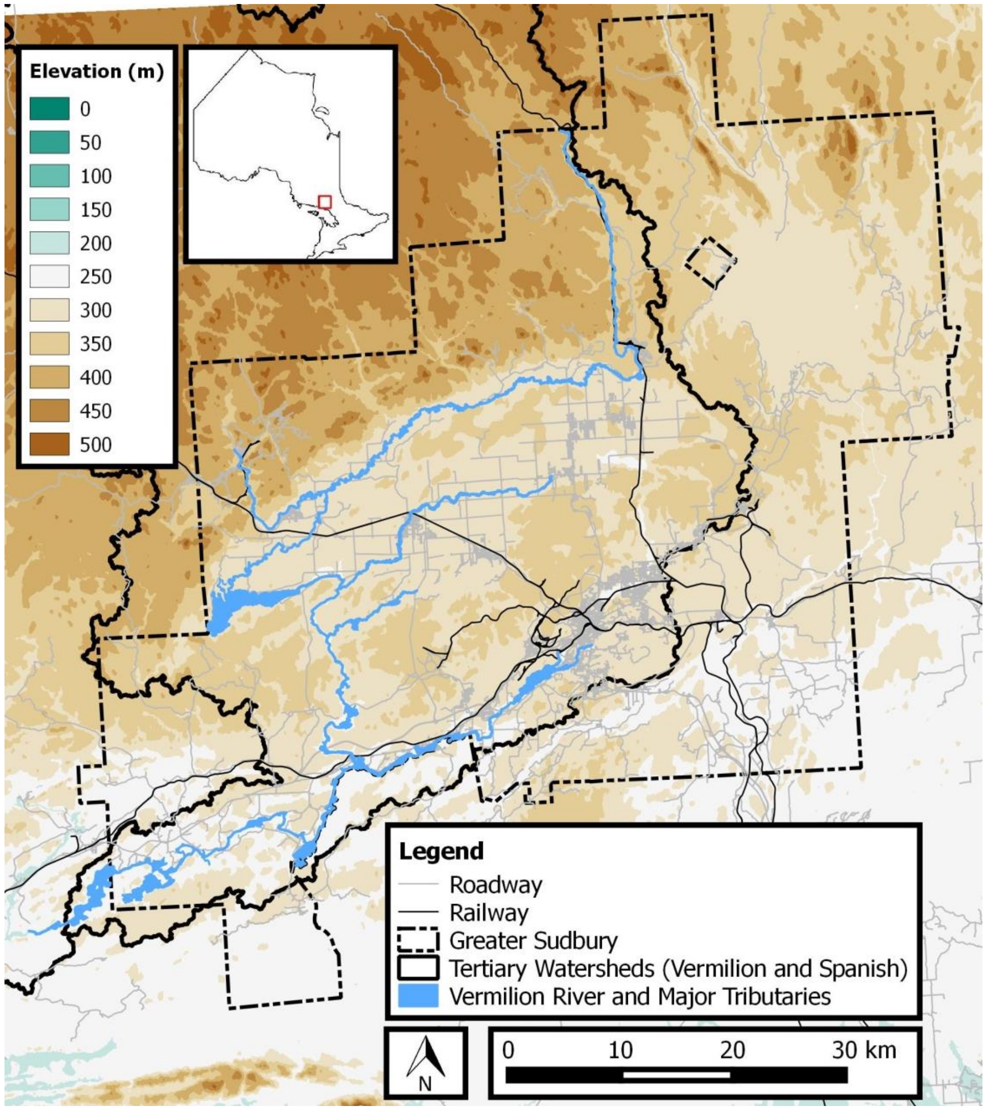

Figure 1 The VRMT system and elevation of the VRMT study area (GC, 2010; GO & GC, 2011; GO, 2013; OMNR, 2006; QGIS Development Team, 2015).

The water quality of a system can depend on the geology of the landscape. Since the majority of the VRMT study area is composed of weathering resistant bedrock covered by shallow soils, the combined effects of acid deposition, development and agriculture have likely increased the leaching rate of ions and mobilized metals (Figure 2 and Figure 3).

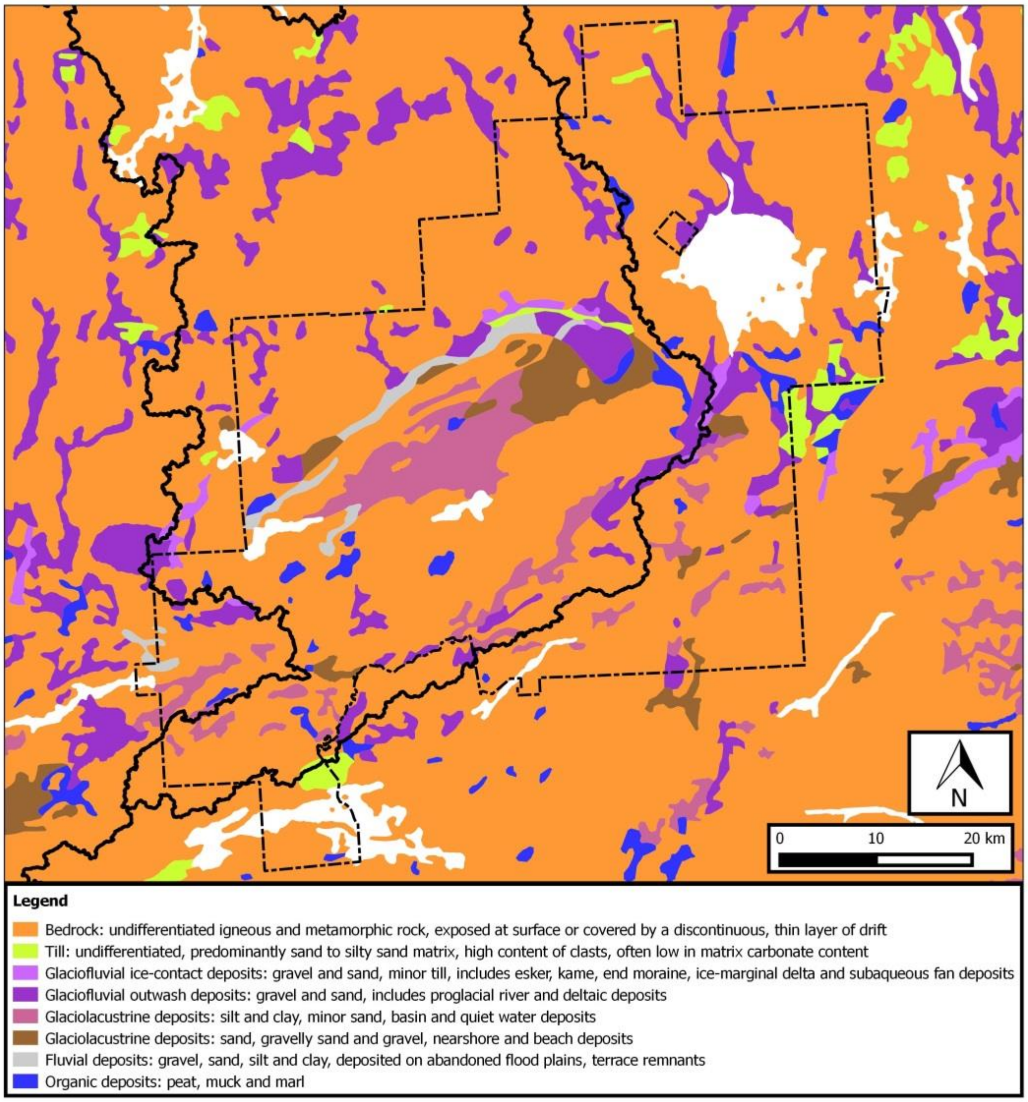

Figure 2 Quaternary geology of the VRMT study area (GC, 2010; GO & GC, 2011; Ontario Geological Survey, 1997; QGIS Development Team, 2015).

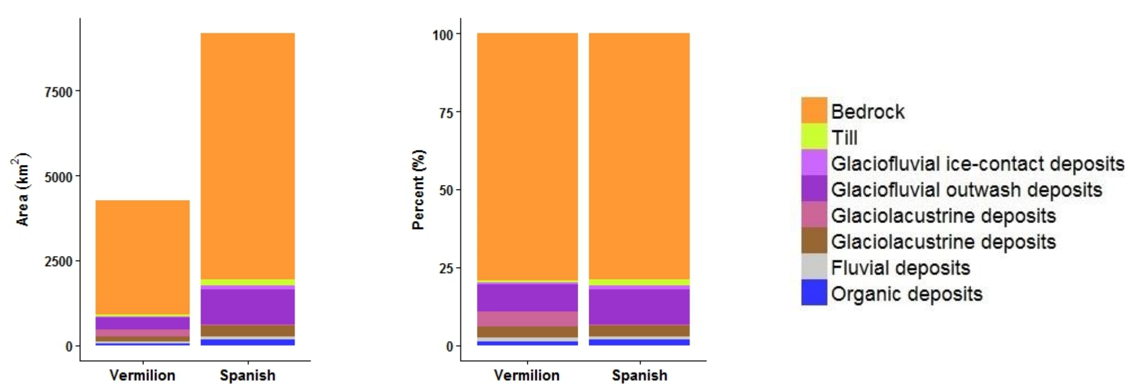

Figure 3 Quaternary geology area and percent of the Vermilion and Spanish watersheds (Ontario Geological Survey, 1997). The Spanish watershed was included since one site (VER-28) falls within this watershed.

Although geology is known to play a role in determining water quality (Sangani, Amiri, Shabani, Sakieh, & Ashrafi, 2015), land-use in the surrounding landscape (i.e., point and non-point sources) seems to be a better determinant for water quality (Carey & Migliaccio, 2009; Maberly et al., 2003).

1.2.2 Past and Current Stressors

Land-use in the surrounding landscape (i.e., point and non-point sources) can significantly influence the water quality of aquatic systems, consequently affecting their structure and functioning (Longhi & Beisner, 2010; Schindler, 2006). Inputs from point sources are relatively easy to monitor and regulate compared to non-point sources since they originate from a single source. Thus, they are often treated before being released into the environment (e.g. smelters, WWTP's, and sewage lagoons). Conversely, inputs from non-point sources are difficult to monitor and regulate compared to point sources since, for the most part, they do not originate from a single source (e.g. runoff from the properties of mining industries, developed and agriculture land, and roadways). Thus, they are often not treated before being released into the environment.

There are many point and non-point sources within the VRMT study area; however focus will be placed on those that may directly or indirectly impact the VRMT. These include: three smelters (Copper Cliff smelter, Coniston smelter, and Falconbridge smelter), two industrial wastewater treatment plants (WWTPs) (Copper Cliff WWTP and Nolin Creek WWTP) as well as tailings ponds and abandoned roast beds, eight municipal wastewater treatment facilities within the Vermilion watershed (Azilda WWTP, Chelmsford WWTP, Dowling WWTP, Levack WWTP, Lively WWTP, Sudbury WWTP, Valley East WWTP, and Walden WWTP), one sewage lagoon that discharges effluent regularly (Capreol lagoon), one sewage lagoon that retains excess flows for a WWTP (Chelmsford lagoon), one sewage lagoon that had been drained back to a stormwater WWTP in 2014 (Garson lagoon), numerous lift stations, septic tank systems, developed and agricultural land, roadways, etc. In addition, the VRMT has one hydroelectric impoundment located on the Vermilion River (Lorne Falls dam) and control dams/weirs located on the

Vermilion River (Stobie dam) and on the Onaping River (Bannerman dam) (Figure 4).

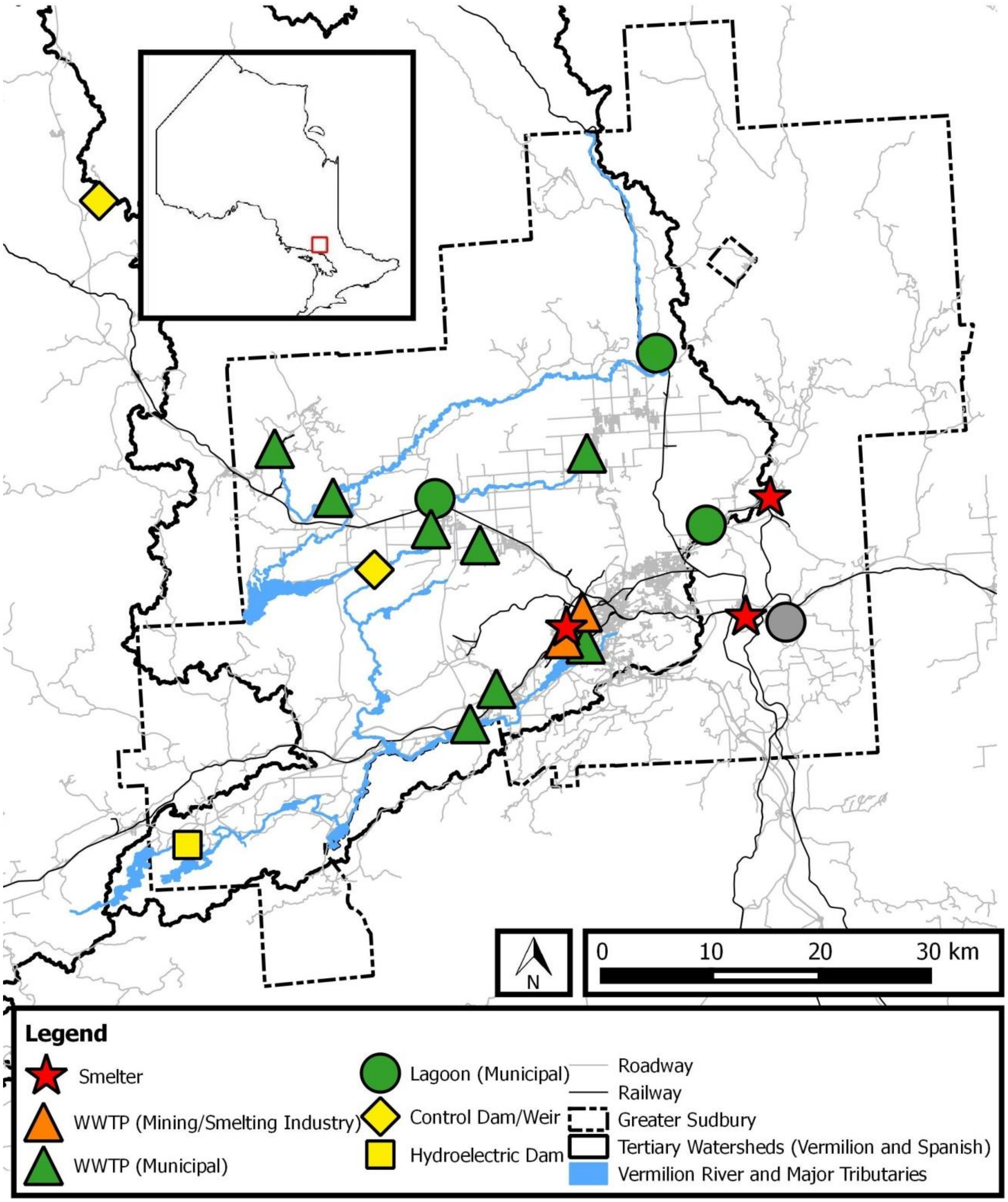

Figure 4 Point and non-point sources in the VRMT study area (GC, 2013; GC, 2010; GO & GC, 2011; GO, 2013; QGIS Development Team, 2015).

Development of the Sudbury region began in the late 1800's when nickel and copper ore deposits were discovered. Open roast beds (1888-1929) and smelters were constructed shortly after the discovery by Nickel Co. (1902), Coniston (1913) and the Falconbridge Limited (1928) (Tropea, Paterson, Keller, & Smol, 2011). Since then it is estimated that one-hundred million tonnes of sulphur dioxide and thousands of tonnes of copper, nickel, and iron have been released (Gunn et al., 1995). Consequently, local terrestrial and aquatic ecosystems were significantly impaired and degraded. Although some aquatic systems remain acidic and heavily contaminated with metals, the majority of lakes and rivers in the Sudbury region have been improving due to decommissioning, and/or upgrades and improvements to smelting facilities (Gunn et al., 1995; Havas et al., 1995).

Aside from emissions released from these smelting facilities, mining and smelting industries also produce wastewater which they treat on site and discharge directly into surface waters. The Vale mines and surface plants, for example, produce waste and wastewater effluent which is disposed of in the large central tailings area at the Clarabelle Mill facility. The Copper Cliff WWTP treats the effluent from this tailings area and discharges it into the environment. Similarly, the Nolin Creek WWTP treats surface water runoff from Vale's property (Vale Canada Limited, 2012, 2013). However, recent allegations reported in a Sudbury Northern Life news article suggests that toxic runoff from this property could have been entering local waterways since at least 1963. In October 2012, water samples were taken from Nolin Creek by Environment Canada. These water samples contained high levels of metals, specifically nickel and copper, which were 68 and 2.6 times higher than the regulated limits, respectively. In addition, when toxicity tests were performed on rainbow trout 100% mortality was observed within 24 hours (Migneault, 2015).

Currently, about 160,000 people reside in Greater Sudbury with the majority of the residents residing in population centres (Statistics Canada, 2012) (Figure A1 and Figure A2). Although, most of the residents reside in population centres, about 13.4% of the Greater Sudbury population lives in rural areas (Figure A3) (Statistics Canada, 2012). Thus, the majority of residents rely on municipal WWTPs and sewage lagoons to dispose of their waste, whereas the remainder of the residents likely rely on septic tank systems.

Municipal sewage effluent is discharged directly into the VRMT causing nutrient enrichment. Nutrient enrichment from WWTPs is believed to be the main factor in increased algal productivity for many aquatic systems. The magnitude of nutrient enrichment is dependent on the level of treatment (i.e. primary, secondary or tertiary) at the facilities and frequency of sewage bypass events which release undertreated or untreated effluent (Carey & Migliaccio, 2009). Since all WWTPs that discharge into the VRMT receive either primary or secondary treatment, the wastewater contains high levels of nutrients, specifically phosphorus and nitrogen. Metals are also released into the VRMT, some metals released from sewage wastewater include: arsenic, cadmium, chromium, cobalt, copper, lead, mercury, molybdenum, nickel, potassium, selenium, and zinc (Greater Sudbury, 2014, 2015).

In 2013 and 2014, approximately 131,000 residents relied on municipal WWTPs and sewage lagoons to dispose of their waste in Greater Sudbury (Figure A4). Consequently, large quantities of nutrients were released into the VRMT. To exemplify the amount of nutrients that can be released into this system annually, the annual nutrient loadings for total phosphorus and total nitrogen (which is the sum of total kjeldahl nitrogen, nitrate, and nitrite) were calculated from the 2013 and 2014 Wastewater Annual Reports for Greater Sudbury (Figure 5 and Figure 6) (Greater Sudbury, 2014, 2015). The Coniston WWTP, Falconbridge WWTP and Wahnapitae lagoon were omitted from these calculations as they are located outside the Vermilion watershed. In addition, total nitrogen loadings from the Capreol lagoon could not be calculated because nitrate and nitrite values were not present within the annual reports and all nitrogen values (total nitrogen, total kjeldahl nitrogen, nitrate, and nitrite) for the Lively WWTP may be lower than the actual amount released in 2014 because October values were absent from the dataset. These results indicate that approximately 14,053kg and 20,892kg of total phosphorus and 451,332kg and 513,626kg of total nitrogen were released into or near the VRMT in 2013 and 2014, respectively. The Sudbury WWTP was also the largest contributor of nutrients into the VRMT for both years as it released 10,037kg and 16,138kg of total phosphorus and 321,485kg and 400,368kg of total nitrogen into Junction Creek in 2013 and 2014, respectively. Thus, the Sudbury WWTP contributed to 71.4% and 77.2% of the total loadings for total phosphorus and 71.2% and 77.9% of the total loadings for total nitrogen when taking into account nutrient loadings that were released into or near the VRMT in 2013 and 2014.

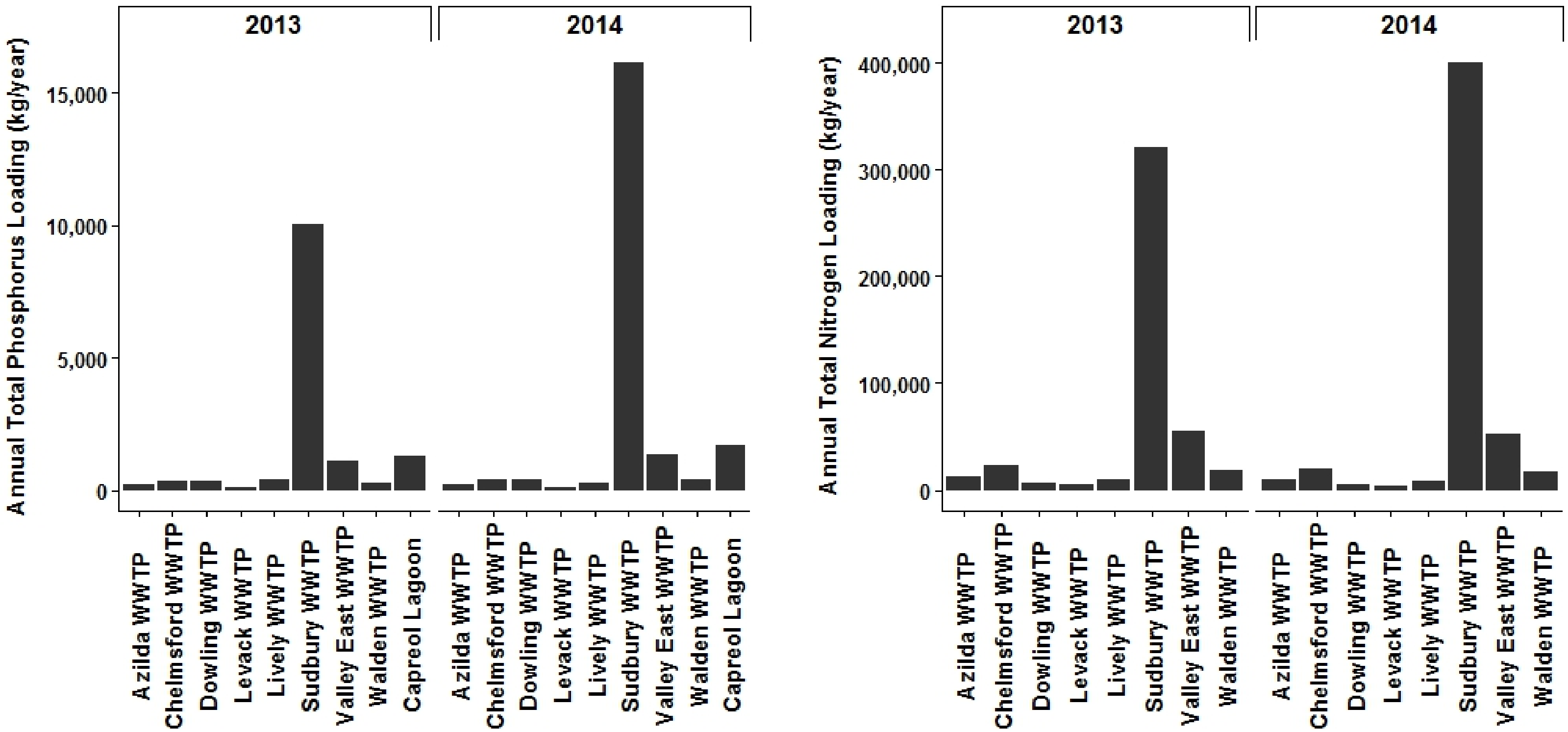

Figure 5 Annual total phosphorus and total nitrogen loadings by WWTPs and a sewage lagoon in the Vermilion watershed (Greater Sudbury, 2014, 2015).

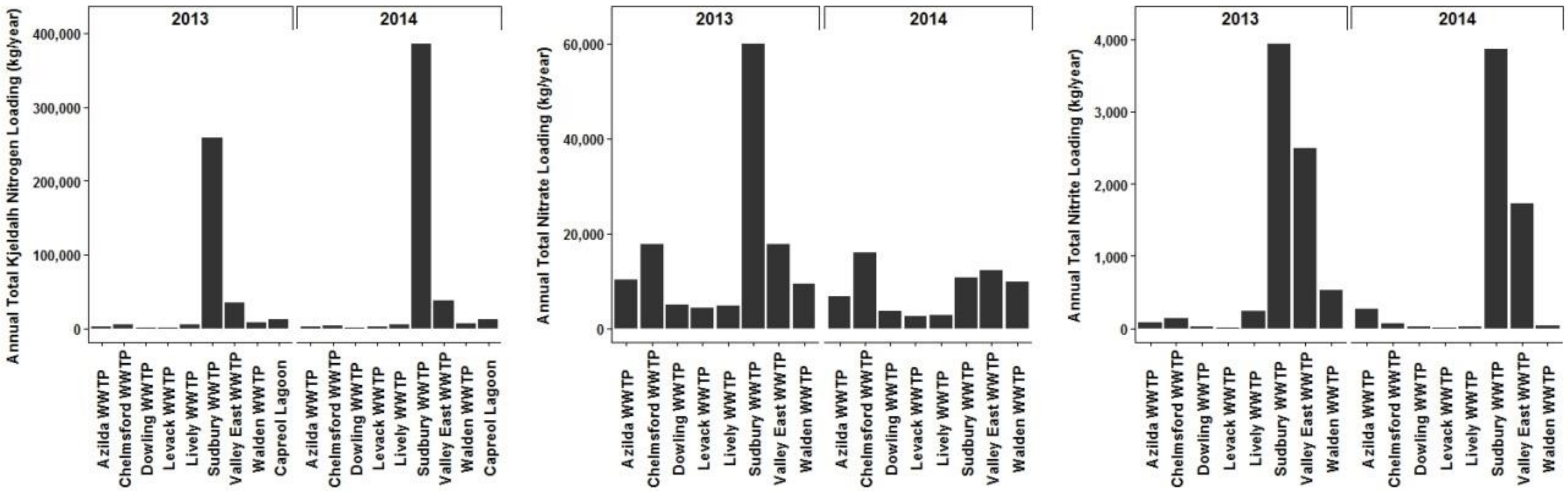

Figure 6 Annual total kjeldahl nitrogen, nitrate, and nitrite loadings by WWTPs and a sewage lagoon in the Vermilion watershed (Greater Sudbury, 2014, 2015).

The remaining 29,000 residents in the Greater Sudbury region likely relied on septic tank systems to dispose of their waste. The amount of nutrients released from septic tank systems is difficult to estimate as few studies have quantified the amount of nutrients released from these systems. Also, studies that have focussed on phosphate removal have not come to a general consensus as removal efficiency range from 8% to 95% (Eveborn, Kong, & Gustafsson, 2012). This large removal efficiency range is expected as the type of system, their reliability and maintenance, and the geology varies considerably from site to site (Withers, Jordan, May, Jarvie, & Deal, 2014). However, the methodology of the studies are likely responsible for the large range as well. For example, a more recent study by Eveborn et al. (2012) reported a phosphorus removal efficiency of 8% to 16% using a mass balance approach; however other studies using an outdated "blackbox" approach (i.e. inflow and outflow measurements) have shown much higher removal of 30%-95% (Eveborn et al., 2012). Although records exist of all the "legal" septic tank systems in the Greater Sudbury area, the impact of these septic tank systems on the VRMT is difficult to quantify as this information is difficult to obtain (i.e. not easily accessible through the Sudbury and District Health Unit, expensive to acquire, and the majority of locations are not mapped out).

The Vermilion and the Spanish watershed are experiencing changes in land-cover due to urban expansion and industrial development. Approximately 74% of Vermillion and 79% of the Spanish land-cover is forest, and 11% and 10% is water, respectively. The remaining 11%-16% contains varying amounts of barren (i.e. rock/rubble and exposed land), developed, wetland (i.e. shrub and treed), herb, or agriculture (i.e. annual crops, and perennial crops and pasture) land-cover (Figure 7 and Figure 8). A figure is provided in Appendix A displaying the original land-cover types of the VRMT study area (Figure A5).

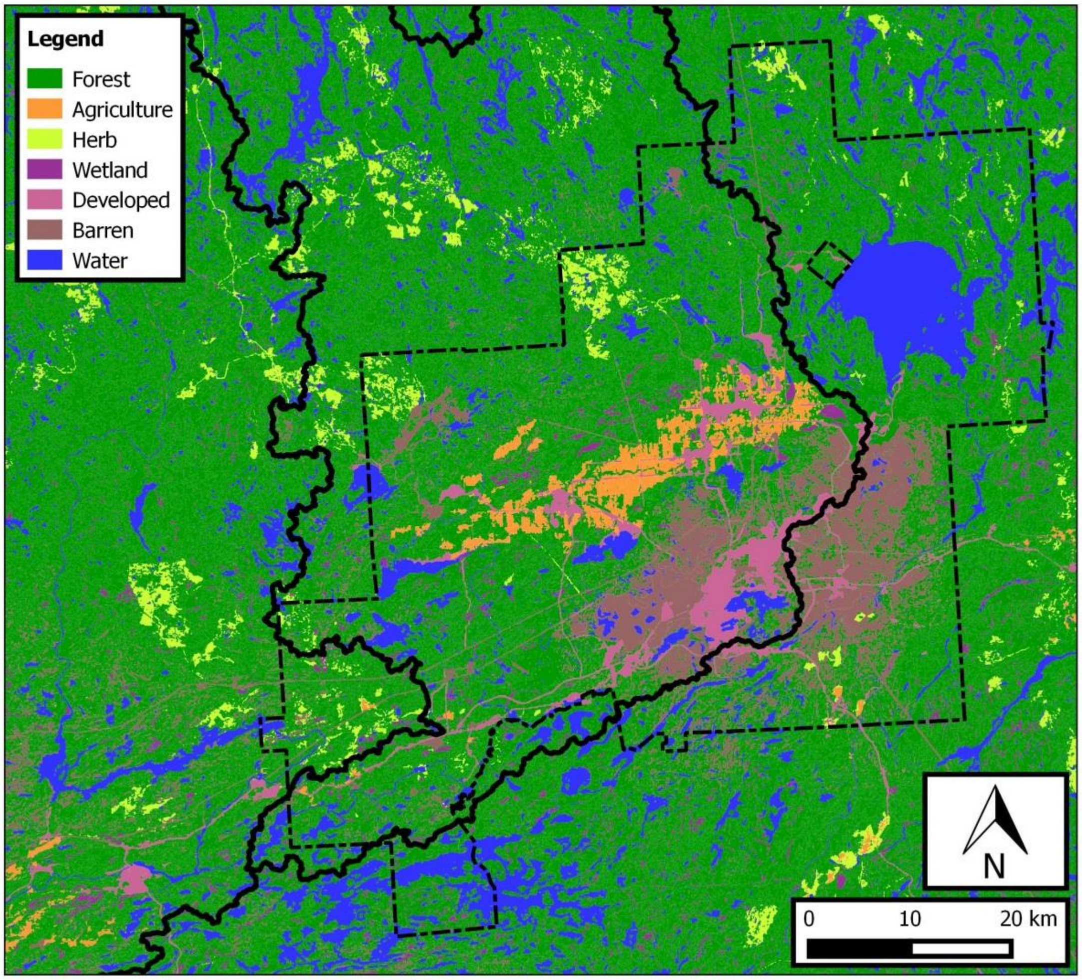

Figure 7 Modified land-cover of the VRMT study area (GC, 2010; GC, 2010; GO & GC, 2011; QGIS Development Team, 2015).

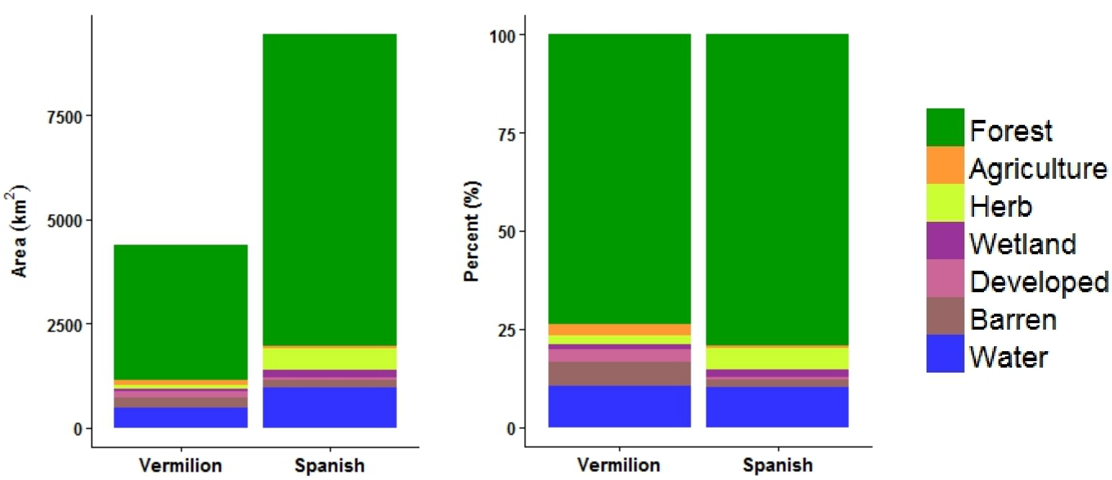

Figure 8 Modified land-cover area and percent of the Vermilion and Spanish watersheds (GC, 2010). The Spanish watershed was included since one site (VER-28) falls within this watershed.

Although these watersheds contain a significant amount of forest, large portions of land-cover surrounding the VRMT has been converted to developed or agricultural land-cover since the late 1800's. These land-cover changes (deforestation, developed, and agriculture) have likely increased the mobilization of nutrient bound sediments causing them to enter aquatic waterways more easily by erosion or surface runoff (Ballantine, Walling, & Leeks, 2009; Hayes, Vanni, Horgan, & Renwick, 2015). Drought, precipitation and snow melt events are known to influence the quantity of sediments and surface runoff that enters aquatic systems, thus they must be taken into consideration when trying to determine how the surrounding landscape affects water quality (Hayes et al., 2015). Therefore, the long-term monthly mean temperature, total precipitation, total rain, total snow, and snow on ground for the last day for 1954 to 2012 is provided in Appendix A (Figure A6) (GC, 2012).

Since sediments can be enriched during transport, sediment recovered from the source may have a significantly lower phosphorus content compared to sediment recovered from the surface runoff (Ballantine et al., 2009). Therefore, land-cover alterations which appear to be insignificant individually may act cumulatively, producing negative impacts on aquatic systems. As developed land increases, roadways also increase. Since the Vermillion watershed has a smaller area and more development (watershed area: 4373km^2; developed area: 142km^2) than the Spanish watershed (watershed area: 9432km^2; developed area: 34km^2), it was expected that its road density would be larger. As predicted, the road density of Vermilion watershed (0.48km/km^2) was larger compared to the Spanish watershed (0.20km/km^2). Thus, roadways within the Vermilion watershed are also a concern, as road salts, nutrients, and metals can be relocated to aquatic systems via surface runoff. The use of road salts is known to increase the chloride concentration of aquatic systems, which can affect the structure by causing anoxia in bottom layers when vertical mixing is obstructed. When oxygen becomes low in the hypolimnion layer, phosphorus detained by the sediment can be released into the overlaying waters (Cañedo-Argüelles et al., 2013). Thus, systems afflicted with legacy phosphorus loadings may be impacted severely by development and roadways.

Legacy phosphorus loadings are indicative of point and non-point sources that have contributed to nutrient enrichment of a system over a substantial amount of time. These loadings can return a significant amount of phosphorus to the overlaying waters, through diffusion or by resuspension. If external loadings from point and non-point sources are reduced, the phosphorus rich sediment layer can be buried by the influx of low-phosphorus sediments. However, this process requires a considerable amount of time before the effects of recovery are observed (Schindler, 2006).

In addition to point and non-point sources, another concern regarding the VRMT system is anthropogenic intervention (i.e. hydroelectric impoundments and control dams/weirs). Hydroelectric impoundments have diverse ecological impacts. Hydroelectric impoundments reduce the natural variation of flow rates in aquatic systems by decreasing the flow rate during the spring and fall (during naturally high periods) and increasing the flow rate in the summer (during naturally low periods) by using previously stored water. Not only do they modify the natural flow regime of rivers (via hydropeaking) and reduce the water renewal rate but they also change the aquatic communities that reside in them and the physical and chemical properties of the water. Similar ecological impacts can be observed for control dams/weirs; however, these impacts are not as severe as hydroelectric impoundments since control dams/weirs maintain more regular flow rates throughout the year. Numerous studies have shown that aquatic organisms such as phytoplankton, zooplankton, macroinvertebrates, and fish are negatively affected by regulated rivers. In addition to these biological changes, the water temperatures may rise in areas which have become more stagnant and the retention time of nutrients above the dams may increase (Ellis & Jones, 2013). Also, nutrient bound sediments can be mixed and resuspended periodically at areas downstream and in close proximity of the hydroelectric impoundments during hydropeaking. Therefore, legacy phosphorus loadings downstream of hydroelectric impoundments may remain an issue since sediments are unable to be buried by low-phosphorus sediments. Thus, both upstream and downstream areas can potentially become more productive (e.g. higher algal biomass) throughout the year due to the increased nutrient availability (Ellis & Jones, 2013).

1.2.3 Future Development

Further development in the Vermilion watershed has been proposed, including four modified peaking hydroelectric dams, as well as two additional mines that will be situated near the VRMT. It is likely that the VRMT are being impacted by cumulative factors (e.g. point sources, non-point sources, and anthropogenic intervention) and there are concerns that further development in the watershed will disrupt the physical, chemical, and biological integrity of this system. The balance between the demands of development and the environment are controversial and can cause great ecological and economic consequences. That said, it is unclear how much development the VRMT can handle before they reach a point of permanent impairment.

Since these cumulative factors are known to alter physical and chemical properties of water, they can cause shifts in the algal community structure. For example, elevated nutrients are known to shift the algal community structure to unfavorable groups (e.g. green algae and blue-green algae) which are unappealing to the public, obstruct recreational activities (e.g. swimming), and can have substantial effects on higher trophic levels as they are a non-preferable food source for zooplankton.

The VRMT are already experiencing periodic blue-green algal (i.e. cyanobacteria) blooms, which are becoming more severe and frequent (Figure 9) (Sudbury District Health Unit, 2015). This is concerning as Greater Sudbury draws drinking water from the Vermilion River and Ramsey Lake (both located in the Vermilion watershed), the Wanapitei River, and numerous municipal wells. Since blue-green algae can bloom and produce many kinds of toxins (i.e. hepatoxins, neurotoxins, etc.) near the intakes of drinking water treatment plants, contamination of drinking water with unsafe levels of toxins may occur (Zamyadi et al., 2012). Thus, source water protection and watershed management should be prioritized for this region.

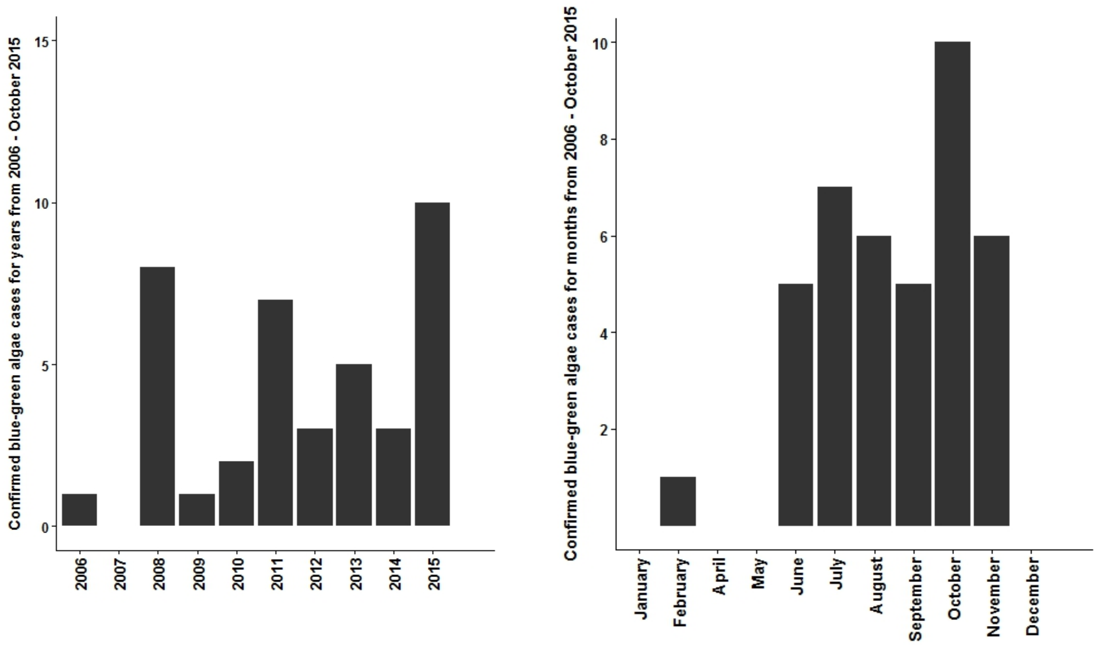

Figure 9 Confirmed cases of blue-green algae in the Sudbury area (2006-October 2015) and confirmed cases of blue-green algae in the Sudbury area for specific months (2006-October 2015). Data presented were calculated based on month presence/absence of blue-green algae (Sudbury District Health Unit, 2015).

Source water protection decisions are made at the municipal or provincial level, as no federal legislation exists. These decisions are usually based on the municipality's legal authority, integration of management plans, social and political support, knowledge and resources (Ivey et al. 2006). Fortunately, watershed associations made up of concerned citizens are becoming more common. Thus, by communicating research findings with these associations, the public and municipalities, educated decisions can be made regarding source water protection.

1.3 Historical Research and Literature Gaps for the VRMT Study Area

A thorough literature search was conducted using the Web of Science database. For inclusion of relevant literature, journal articles had to meet the following criteria: (1) they were performed within or near the VRMT study area, (2) they mentioned phytoplankton in detail or to some extent, and (3) the phytoplankton that were observed or isolated were from aquatic systems. In addition, journal articles were only mentioned if a full text was found using FindIt @ UOIT. From this literature search, it was noted that: extensive research has gone into understanding the impacts of acidification and/or metal pollution on specific phytoplankton species (Gopalapillai, Chakrabarti, & Lean, 2008; Mandal et al., 2002) or communities (Arnott, Yan, Keller, & Nicholls, 2001; Dickman & Fortescue, 1991; A. Dixit, Dixit, & Smol, 1992, 1993, 1996a, 1996c; S. Dixit, Dixit, & Smol, 1991, 2002; S. Dixit, Dixit, & Evans, 1989, 1988; S. Dixit, Dixit, & Smol, 1989; Graham et al., 2007; Havas et al., 1995; Keller, Gunn, & Yan, 1992; Vinebrooke et al., 2002; Yan, 1979), whereas other studies have focused on how phytoplankton communities respond to changes for certain parameters, such as UV-B radiation, dissolved organic carbon, and climate (Arnott et al., 2003; S. Dixit, Keller, Dixit, & Smol, 2001). However, few studies have considered the surrounding landscape and how it structures the phytoplankton species or communities (A. Dixit, Dixit, & Smol, 1996b; Tropea et al., 2011).

To demonstrate the impacts anthropogenic inputs (specifically nutrients) from the surrounding landscape have on water quality, two studies have used paleolimnological techniques to track the long-term changes in diatom assemblages (A. Dixit et al., 1996b; Tropea et al., 2011). The lakes that were analyzed were within or very close to the VRMT study area, Dixit et al. (1996) analyzed core samples from one lake (Ramsey), whereas, Tropea et al. (2011) analyzed core samples from four lakes (Ramsey, Nepahwin, McFarlane, and Richard). These studies concluded that diatom assemblages changed dramatically due to development in the Sudbury region and increased nutrient loadings. However, since paleolimnological techniques only record specific phytoplankton groups (e.g. Bacillariophyta or Chrysophyta) over long time periods, they only provide a small glimpse of the phytoplankton community at certain points in time (generally years). For that reason, further investigations are required to determine which physical and/or chemical changes influence the entire phytoplankton community composition over shorter and more recent time periods in the Sudbury region and how these changes are linked to the surrounding landscape (i.e., point and non-point sources).

1.4 Significance of Research Project

It is likely that the VRMT have been impacted by cumulative factors and may be unable to withstand further stressors. Further development in the Vermilion watershed has been proposed, including hydroelectric dams and the expansion of mining activities. There are concerns that further development in the Vermilion watershed will push the system beyond a tipping point, leading to a state of permanent impairment. By documenting and assessing the baseline conditions of a system (i.e., water quality and resident phytoplankton community) one can determine the ecological health and status of a system. If the ecological health is deemed to be impaired, the management practices of the system should be modified to aid in recovery and restoration.

In March of 2013, the VRS received an Ontario Trillium Foundation grant for the Lower Vermilion Source Water Quality Monitoring Project. The VRS monitored the water quality along the VRMT monthly (6 months per year) over a period of two years (2013-2014). To add a biological component to the study and improve ecological relevance, phytoplankton samples were processed at the Aquatic Ecology and Biotechnology Lab at the University of Ontario Institute of Technology (UOIT).

1.5 Goals and Objectives

The main goal of this study was to document and assess current baseline conditions (i.e. water quality and resident phytoplankton community) of the VRMT to understand the influence the surrounding landscape (i.e. point and non-point sources) and flow regulation have on the water quality and ecological health of the system. To achieve this goal the following short-term objectives were established:

1) Determine when surface runoff was the greatest during the sampling period (2013-2014), using daily temperature, precipitation, and snow cover data (Chapter 2).

2) Characterize the surrounding landscape (quaternary geology, land-cover, and road density) of sites at differing landscape-scales (Chapter 2).

3) Assess spatial and temporal patterns of water quality (Chapter 2).

4) Determine if there are predictive relationships between the surrounding landscape (i.e. point and non-point sources) and water quality (Chapter 2).

5) Assess spatial and temporal patterns of total phytoplankton biomass and major phytoplankton group biomass (Chapter 3).

6) Determine if there are predictive relationships between the water quality and the abundance and composition of phytoplankton communities (i.e. major phytoplankton groups and phytoplankton genera) (Chapter 3).

CHAPTER 2: SPATIAL AND TEMPORAL PATTERNS OF WATER QUALITY PARAMETERS AND HOW THEY RELATE TO LAND-USE IN THE VERMILION RIVER AND MAJOR TRIBUTARIES, SUDBURY, ONTARIO, CANADA

2.1 Introduction

Inputs from the surrounding landscape (i.e., point and non-point sources) can significantly influence the water quality of aquatic systems, consequently affecting their structure and functioning (Longhi & Beisner, 2010; Schindler, 2006). Inputs from point sources are relatively easy to monitor and regulate compared to non-point sources since they originate from a single source (e.g. smelters, WWTP's, and sewage lagoons). Conversely, inputs from non-point sources are difficult to monitor and regulate compared to point sources since, for the most part, they do not originate from a single source (e.g. runoff from the properties of mining industries, developed and agriculture land, and roadways). Due to the vast amount non-point sources in the surrounding landscape monitoring the water quality of aquatic systems has become a challenging task, especially since non-point sources may be more influential at differing landscape-scales.

Since the subsequent chapter will investigate how water quality can affect the structure of phytoplankton (refer to Chapter 3, pg.61-110), the following sections of this chapter will address how inputs from the surrounding landscape of the VRMT study area can affect the water quality, specifically non-point sources. Thus, a general overview of landscape-scales used to monitor aquatic systems will be introduced and the potential impacts of non-point sources at differing landscape-scales will be addressed.

2.1.1 General Overview: Landscape-scales and Non-point Sources

Monitoring the water quality of aquatic systems has become a challenging task. Although some processes within aquatic systems are governed by physical boundaries, others are influenced by the surrounding landscape via cross-boundary subsidies. Boundaries, such as buffers, catchments, and reaches, are advantageous for studying ecosystem processes when dealing with lakes and rivers that are not well-bounded (Post, Doyle, Sabo, & Finlay, 2007).

2.1.1.1 Landscape-scales

For this study, a buffer is defined as a boundary that surrounds a specific point (e.g. study site). A catchment (i.e., subwatershed) is defined as a boundary that is delineated using a specific point on a hydrological network. The delineation process utilizes landscape features (i.e. elevation, slope, etc.) and generates a boundary which encompasses the land area that drains into that point. Finally, a reach utilizes both the buffer and catchment boundaries. Thus, a reach is defined as a boundary where a specific portion of the catchment is extracted using a buffer (e.g. Figure 12, pg.30).

There are ongoing disputes on whether the larger scales (e.g. catchments) or smaller scales (e.g. buffers and reaches) are most influential over water quality. The catchment scale tends to be the most common landscape-scale used to study aquatic systems. However, more studies have started to include or focus on other landscape-scales (e.g. buffers and reaches) (Sliva & Williams, 2001). Regardless, numerous boundaries should be considered when trying to understand ecosystem processes when dealing with lakes and rivers that are not well-bounded, however, this is often not feasible as it is very time consuming and expensive (Post et al., 2007).

2.1.1.2 Impacts of Non-point Sources (i.e., land-cover types)

For this study, sites exhibited a broad range of quaternary geology types and land-cover types at all landscape-scales. The VRMT study area had eight quaternary geology types (e.g. Table B6, pg.131). Although quaternary geology is known to play a role in determining water quality (Sangani et al., 2015), focus was placed on land-cover as they seemed to be better determinants for water quality near our study area (Sliva & Williams, 2001).

Originally the VRMT study area had thirteen land-cover types, however, since many land-cover types were similar they were condensed to form seven land-cover types (e.g. Table B8, pg.140). Of these seven land-cover types, developed, forest, and agriculture are usually the most influential at certain landscape-scales (Hayes et al., 2015; Sliva & Williams, 2001). However, other land-cover types, like wetland and barren, have also been shown to be influential as well (Szkokan-Emilson, Watmough, & Gunn, 2014).

It is well established that developed land-cover increases the quantity and quality of sediments entering aquatic systems. As sediments are transported across the landscape they can become enriched, thus sediment recovered from the source may have a significantly lower nutrient content compared to sediment recovered from the surface runoff (Ballantine et al., 2009). In addition, other contaminants (e.g. metals) are also transported this way. Although barren land-cover is a natural feature of the Sudbury region, it is likely that this land-cover type will act similarly to developed land-cover. That is, it will also increase the amount of nutrients and other contaminants entering aquatic systems (Szkokan-Emilson et al., 2014).

Conversely, forest land-cover is known to have an opposite effect. That is, the quantity of sediment entering aquatic systems is reduced thus the amount of nutrients and other contaminants transported to aquatic systems is also reduced (Sangani et al., 2015; Sliva & Williams, 2001). Wetland land-cover may behave similarly to forest land-cover, that is, wetlands may retain and prevent sediments from entering aquatic systems. However, wetlands are also known to store contaminants (e.g. metals) through ionic exchange with organic matter (Szkokan-Emilson et al., 2014). Thus, these contaminants may be released into aquatic systems under certain conditions (e.g. reductions in pH, presence of road salts, and seasonal increases of dissolved organic carbon) (Szkokan-Emilson et al., 2014). This is a problematic scenario for the Sudbury region as the amount of metals currently being deposited on the landscape (e.g. Co, Cu, Fe, Zn) are above levels reported elsewhere and likely from local smelters. Thus, current and past deposition has caused wetlands to become heavily contaminated with metals.

Agriculture land-cover is known to influence the nutrients entering aquatic systems, thereby changing the ratio of nitrogen to phosphorus. Hayes et al., (2015) reported that lakes surrounded by agricultural land-cover tend to be phosphorus limited but during drought conditions were nitrogen limited, whereas lakes surrounded by forest land-cover were consistently nitrogen limited. Although agriculture land-cover is mainly recognized for influencing the nutrients entering aquatic systems, this land-cover type also influences other contaminants entering aquatic systems.

Up until this point, land-cover types were discussed separately; however, it is important to understand how surficial geology and land-cover types influence the water quality near our study area. A study by Sliva & Williams, (2001) looked at both of these aspects (i.e. surficial geology and land-cover) and their impact on water quality using two landscape-scales (i.e. catchment and 0.1km-radius buffer) near the Greater Toronto Area (i.e. Highland Creek watershed, Rouge River watershed, and Duffins Creek watershed). They determined that the developed land-cover type was important for degrading water quality, the forest land-cover was important for mitigating water quality, the agricultural land-cover type was very variable regarding its influence and was inconsistent with other studies, and the only surficial geology type that had influence on water quality was silt-clay. In addition, they determined that the catchment scale was slightly better than the 0.1km-radius buffer at predicting water quality. However, they also reiterated the notion that there are ongoing disputes on whether the larger scales (e.g. catchments) or smaller scales (e.g. buffers and reaches) are most influential over water quality.

2.1.3 Purpose and Objectives

The purpose of this chapter was to determine how inputs from the surrounding landscape of the VRMT study area can affect water quality. To achieve this, following short-term objectives were established:

1) Determine when surface runoff was the greatest during the sampling period (2013-2014), using daily temperature, precipitation, and snow cover data.

2) Characterize the surrounding landscape (quaternary geology, land-cover, and road density) of sites at differing landscape-scales.

3) Assess spatial and temporal patterns of water quality.

4) Determine if there are predictive relationships between the surrounding landscape (i.e. point and non-point sources) and water quality.

To meet these objectives, data was collected at three spatial scales (i.e. regional-scale, landscape-scale, and local-scale). Precipitation and snow cover data (i.e. regional-scale data) were used to visualize when surface runoff was the greatest during the sampling period since large precipitation and spring snow melt events are known to increase the frequency of sewage bypass events and assist in the transport of nutrients and contaminants to aquatic systems.

To provide a wide-range of boundaries, five landscape-scales (i.e. 5km-radius buffer, catchment, and 1km, 2km, and 3km-radius reaches) were created for each site using the geographical information system QGIS. Quaternary geology, land-cover, and road densities were extracted for each site at these differing landscape-scales (i.e. landscape-scale data).

Initially, water quality (i.e. local-scale data) was investigated independently. Thus, one-way ANOVAs and linear effects models were used to assess spatial and temporal patterns of water quality. In addition, when water quality parameters surpassed the water quality guidelines they were noted. Afterwards, water quality was investigated with the surrounding landscape (i.e. point and non-point sources). Thus, ordinations (PCAs), statistical analyses (i.e. one-way ANOVAs and multiple comparisons), and regression analyses (i.e. Spearman and Pearson correlation analyses) were used to detect predictive relationships between the surrounding landscape and water quality.

2.2 Materials and Methods

2.2.1 Study Area and Sites

The VRMT system is located in northeastern, Ontario (Figure 10). This system contained twenty-eight sites. Twenty-five sites were located in the Greater Sudbury municipal boundary, whereas the remaining three sites were outside of this municipal boundary. Furthermore, twenty-seven sites were located within Vermilion watershed and one site was located within the Spanish watershed. A summary of the area and perimeter, quaternary geology, land-cover, and road length and density for both watersheds is located in Appendix B (Table B1, Table B2, Table B3, and Table B4). In addition, visual representations for quaternary geology and land-cover are located in the previous chapter (Figure 3 and Figure 8).

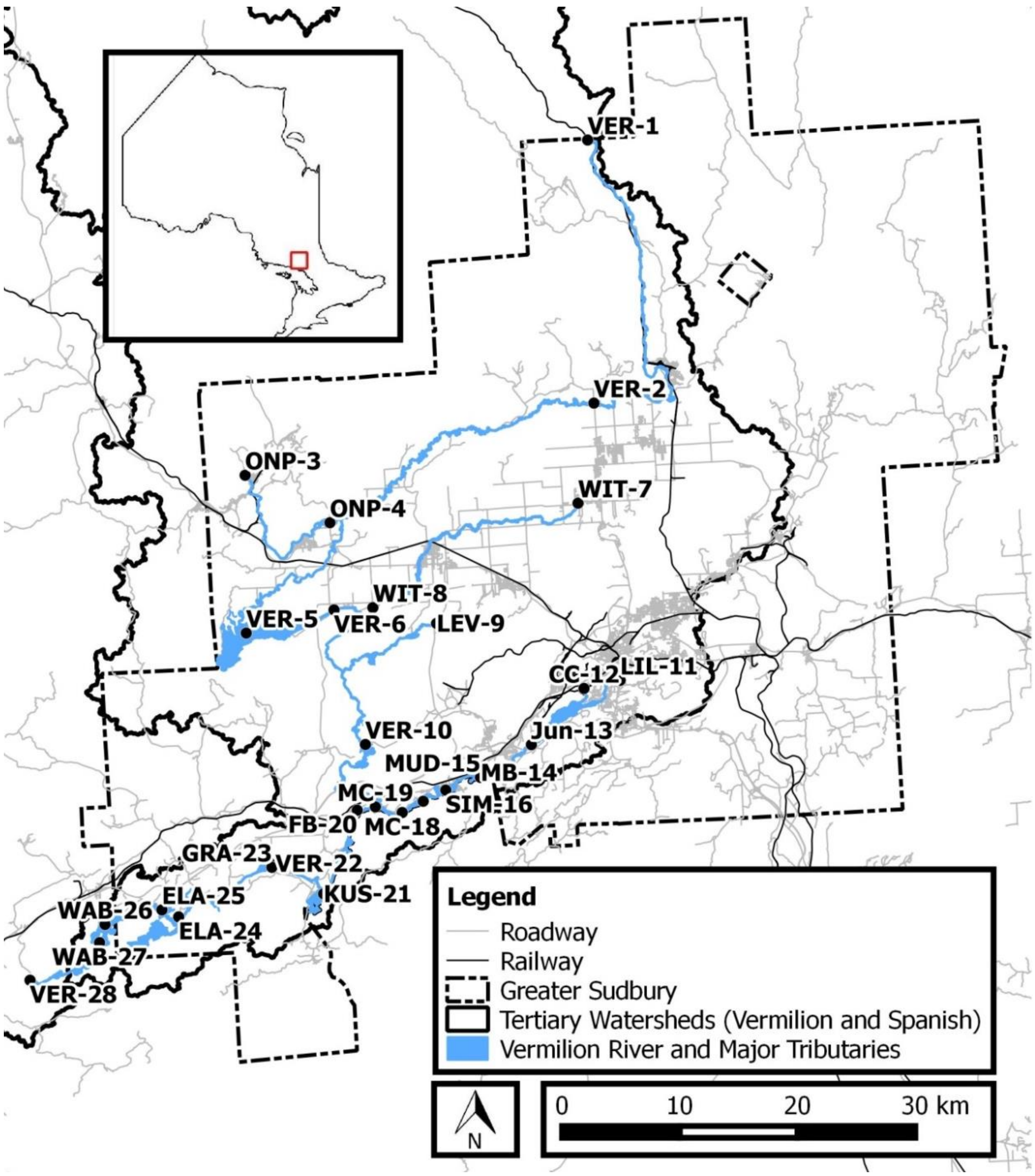

Figure 10 Location of the study sites that were monitored for the 2013-2014 sampling period (GC, 2013; GC, 2010; GO & GC, 2011; GO, 2013; QGIS Development Team, 2015).

For this study, the Vermilion River serves as the main-stem river system, which contains fourteen sites (VER-1, VER-2, VER-5, VER-6, VER-10, MC-19, KUS-21, VER-22, GRA-23, ELA-24, ELA-25, WAB-26, WAB-27, and VER-28).

Numerous tributaries connect to the Vermilion River, of which five tributaries were included in this study. Onaping River contains two sites ONP-3 and ONP-4, Whitson River contains two sites WIT-7 and WIT-8, Levey Creek contains one site LEV-9, the Junction tributary, which includes Junction Creek, Kelly Lake, Mud Lake, Simon Lake, McCharles Lake, Lily Creek, Robinson Lake, Meat Bird Creek representing eight sites LIL-11, CC-12, JUN-13, MB-14, MUD-15, SIM-16, MC-17, and MC-18, and Fairbank Creek which contains one site FB-20. It is also important to note that for this study the main-stem of Junction tributary contains six sites (CC-12, JUN-13, MUD-15, SIM-16, MC-17, and MC-18) and the other two sites (LIL-11 and MB-14) are found in creeks (Lily Creek and Meat Bird Creek) that flow into this main-stem.

To briefly summarize the locations of all sites: thirteen sites were located on eight lakes, nine sites were located on rivers, and six sites were located on creeks. More specifically, one site was located on Vermilion Lake (VER-5), one site was located on Mud Lake (MUD-15), one site was located on Simon Lake (SIM-16), three sites were located on McCharles Lake (MC-17, MC-18, and MC-19), one site was located on Rat Lake commonly known as Kusk Lake (KUS-21), two sites were located on Grassy Lake (VER-22 and GRA-23), two sites were located on Ella Lake (ELA-24 and ELA-25), two sites were located on Wabagishik Lake (WAB-26 and WAB-27), five sites were located on the Vermilion River (VER-1, VER-2, VER-6, VER-10, and VER-28), two sites were located on the Onaping River (ONP-3 and ONP-4), two sites were located on the Whitson River (WIT-7 and WIT-8), one site was located on Levey Creek (LEV-9), one site was located on Lily Creek (LIL-11), two sites were located on Junction Creek (CC-12 and JUN-13), one site was located on Meat Bird Creek (MB-14), and one site was located on Fairbank Creek (FB-20) (Figure 11).

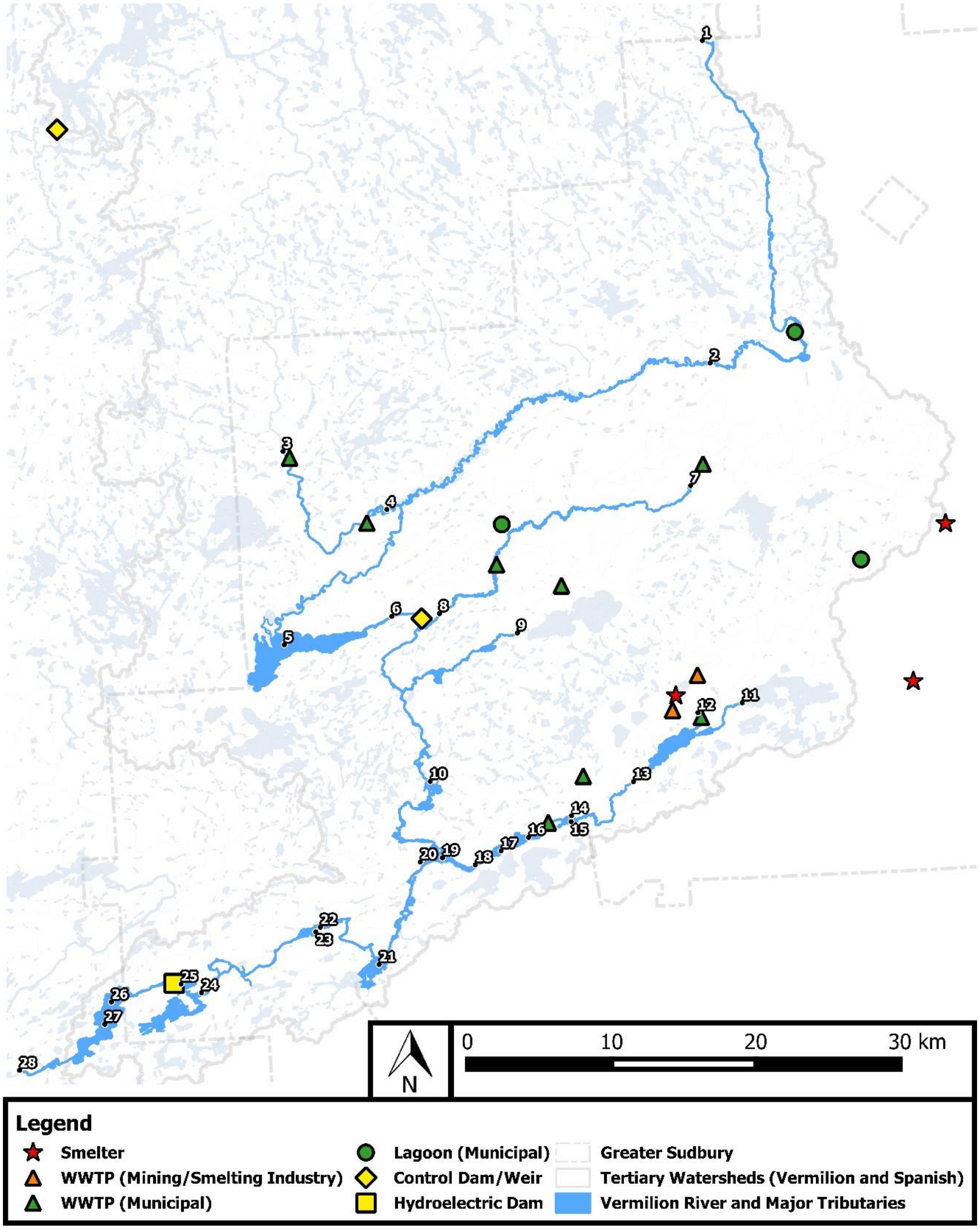

Figure 11 Location of the study sites that were monitored for the 2013-2014 sampling period relative to point sources in the VRMT study area (GC, 2013; GC, 2010; GO & GC, 2011; GO, 2013; QGIS Development Team, 2015).

2.2.2 Spatial Scales

The spatial scales used for this study include: the VRMT study area, buffer (5km-radius), catchment, reaches (1km, 2km, and 3km-radius), and site. Data obtained at these spatial scales were grouped into either regional-scale data (i.e., data representing the VRMT study area), landscape-scale data (i.e., data extracted using QGIS), or local-scale data (i.e., data collected from sites) (Figure 12).

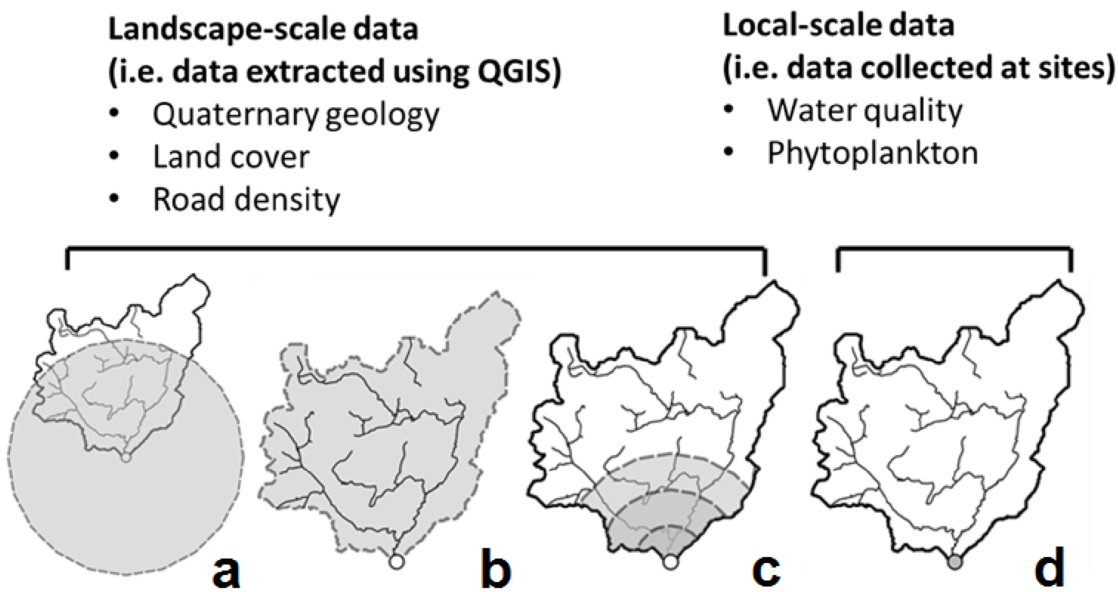

Figure 12 Examples of the landscape-scale and local-scale spatial scales used for this study. The grey shaded area indicates that data was obtained, extracted and/or collected for each site at the following scales: (a) buffer (5km-radius), (b) catchment, (c) reaches (1km, 2km, and 3km-radiuses), and (d) site.

2.2.3 Data Collection

2.2.3.1 Regional-Scale Data (i.e. data representing the VRMT study area)

Daily temperature, precipitation and snow cover data from the Sudbury Climate station (46°37'56.090"N, 80°47'46.080"W) for the 2013 and 2014 sampling period was obtained from the Historical Climate Data provided by Environment Canada at:

http://climate.weather.gc.ca/climateData/dailydata_e.html?timeframe=4&Year=2013&Prov=ON&StationID=49508&txtStationName=SUDBURY&optLimit

=specDate&searchType=stnName&searchMethod=contains&pageName=almanac_results&period=1&Month=1&Day=1&stnSubmit=Go

and http://climate.weather.gc.ca/climateData/dailydata_e.html?timeframe=4&Year=2014&Prov=ON&StationID=49508&txtStationName=SUDBURY&optLimit=specDate&searchType=stnName&searchMethod=contains&pageName=almanac_results&period=1&Month=1&Day=1&stnSubmit=Go (GC, 2013, 2014).

2.2.3.2 Landscape-Scale Data (i.e. data extracted using QGIS)

The landscape-scales were constructed in QGIS (QGIS Development Team, 2015) using 1:50,000 digital elevation models (OMNR, 2006), national hydro network shapefiles (GO & GC, 2011), and site coordinates. A 5km-radius buffer surrounding each site was made using the QGIS buffer tool. A catchment for each site was delineated using the GRASS plugin (GRASS Development Team, 2015). Finally, 1km, 2km, and 3km-radius reaches were made using the QGIS buffer tool on each site catchment.

Data was extracted from quaternary geology (Ontario Geological Survey, 1997), land-cover (GC, 2010), and national road network (GO, 2013) shapefiles. Road density was calculated by taking the road length and dividing by its respective landscape-scale area. A summary of the area and perimeter, quaternary geology, land-cover, and road length and density for sites at different landscape-scales are located in Appendix B (Table B5, Table B7, Table B9, and Table B10). A detailed description of the quaternary geology types and land-cover types are provided in Appendix B as well (Table B6 and Table B8).

2.2.3.3 Local-Scale Data (i.e. data collected from sites)

Sites located on the VRMT were monitored monthly (6 months per year) over a period of two years (2013-2014), from May to October in 2013 and from June to November in 2014. Date ranges for each sampling period are summarized in Table B11. In this table, date ranges were divided further into either Provincial Water Quality Monitoring Network (PWQMN) sites or VRS sites.

Water Quality

Samples were sent to Maxxam Analytics in Mississauga, Ontario for water quality analyses. Due to monitoring differences between sites (specifically between PWQMN sites and VRS sites), water quality parameters monitored for all sites were included and other parameters not monitored for all sites were omitted. Thus, the following water quality parameters were included:

General biological/chemical parameters: chlorophyll-a (Chl-a), *Escherichia coli* (E.coli), pH, calcium carbonate (CaCO3), dissolved organic carbon (DOC), conductivity (Cond), and chloride (Cl).

Nutrients: total phosphorus (TP), total nitrogen (TN), total kjeldahl nitrogen (TKN), nitrate (NO3), and nitrite (NO2).

Metals: aluminium (Al), barium (Ba), beryllium (Be), bismuth (Bi), cadmium (Cd), calcium (Ca), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), lithium (Li), magnesium (Mg), manganese (Mn), molybdenum (Mo), nickel (Ni), potassium (K), silicon (Si), silver (Ag), sodium (Na), strontium (Sr), tin (Sn), titanium (Ti), uranium (U), vanadium (V), zinc (Zn), and zirconium (Zr).

2.2.4 Data Analyses

2.2.4.1 Regional temperature, precipitation, and snow cover for 2013-2014

Line graphs were used to display daily temperature, precipitation, and snow cover of the VRMT study area (package: ggplot2) (Wickham, 2009).

2.2.4.2 Landscape characterization for sites at differing landscape-scales

Bar graphs were constructed to visualize site and landscape-scale differences for quaternary geology (area and percent), land-cover (area and percent), and road length and density (package: ggplot2) (Wickham, 2009).

2.2.4.3 Spatial and temporal patterns of water quality (general biological/chemical parameters and nutrients)

Boxplots were combined using the facet_grid command to visualize spatial (i.e. sites) and temporal (i.e. sampling dates) variations of general biological/chemical parameters and nutrients (package: ggplot2) (Wickham, 2009). To detect if sites and sampling dates differed significantly in 2013 and in 2014 with respect to these water quality parameters, one-way ANOVAs were performed with the aov and anova commands (package: stats) (R Core Team, 2015). Since the dataset was unbalanced (i.e. missing values for sites and sampling dates), linear mixed effects models were also created using the lmer command (package: lme4) to detect relationships between water quality parameters and sampling dates while taking into account site differences (i.e. by-site variability) in 2013 and in 2014 (Bates, Maechler, Bolker, & Walker, 2014). Sampling date was used for the fixed effect term and for the random effects term intercepts were created for each site. P-values were obtained by likelihood ratio tests of the full model (lmer(water.quality.parameter ~ sampling.date + (1|site))) against the reduced model (lmer(water.quality.parameter ~ 1 + (1|site))) using the anova command (package: stats) (R Core Team, 2015). Although results were considered significant if the p-value was <0.05, a p-value <0.10 could also be considered significant if one wants to reduce the type II error, thus the following p-values were provided in tables: 0.10, 0.05, and 0.01.

2.2.4.4 Summary of water quality variations in 2013 and 2014, and water quality guidelines when available

When calculating annual water quality averages and standard deviations for 2013 and 2014, parameters that were below the reporting detection limit (RDL) were set to zero and unspecific values above the RDL were removed from the dataset. Due to monitoring differences between sites (specifically between PWQMN sites and the remaining sites), only water quality parameters monitored at all sites were considered unless specified otherwise. The annual water quality averages and standard deviations for 2013 and 2014 are provided in Appendix B (Table B12, Table B13, Table B14, and Table B15).

Boxplots were constructed to summarize the variability of each water quality parameter. Each boxplot denotes the: minimum, 25% quartile, median, 75% quartile, maximum, and outliers (<Q1-1.5*IQR or >Q3+1.5*IQR) if present (package:ggplot2) (Wickham, 2009). The recreational water quality guideline (RWQG), long-term water quality guideline for the protection of aquatic life (LTWQG), and/or short-term water quality guideline for the protection of aquatic life (STWQG) were also included on these figures when available (CCME, 2007; Health Canada, 2012).

2.2.4.5 Principal component analyses (PCAs) and cluster analyses on water quality

Principal component analyses (PCAs) were performed on normalised (i.e. centre-standardized) annual general biological/chemical parameters and nutrients, to detect correlations between water quality parameters and to determine which sites had above average values for certain water quality parameters. The PCA command (package: FactoMineR) was used, data was extracted from the matrices and plotted (package: ggplot2) (Auguie, 2012; Husson, Josse, Le, & Mazet, 2015; R Core Team, 2015; Wickham, 2009, 2011, 2014). Single-linkage agglomerative cluster analyses were also included, as they are a good complementary analysis for ordination. The Euclidean dissimilarity indices were computed using the vegdist function (package: vegan) on normalised data, then single hierarchical cluster analyses were performed using the hclust command (package: stats) and the results were plotted (package: graphics) (Oksanen et al., 2015; R Core Team, 2015). Similarly, PCAs and single-linkage agglomerative analyses were also performed on normalised annual metals using the same method.

2.2.4.6 One-way ANOVAs and multiple comparisons on nutrient concentrations upstream and downstream of the Sudbury WWTP

Since the preceding PCAs inferred that some sites on the Junction tributary had above average values for nutrients, line graphs were created to show the annual average nutrient concentrations upstream and downstream of the Sudbury WWTP (package: ggplot2) (Wickham, 2009). Distances between sites and the Sudbury WWTP were obtained using the QGIS groupstats tool (QGIS Development Team, 2015). One-way ANOVAs and multiple pairwise comparisons were performed with the aov, anova, and pairwise.t.test commands (package: stats) to determine if the annual average nutrient concentrations of the site upstream of the Sudbury WWTP were significantly different to the sites downstream in 2013 and in 2014 (R Core Team, 2015). Although results were considered significant if the p-value was <0.05, a p-value <0.10 could also be considered significant if one wants to reduce the type II error, thus the following p-values were provided in tables: 0.10, 0.05, and 0.01.

2.2.4.7 Spearman and Pearson correlation analyses on land-cover types and water quality at certain landscape-scales

Spearman and Pearson correlation analyses were used to detect correlations between land-cover types (area and percent) and water quality parameters for all landscape-scales. To determine if the parameters were suitable for linear regression, linear models were created with the lm command (package: stats) and global test procedures to validate the four assumptions of the linear models (linearity, normality, uncorrelatedness, homoscedasticity) were performed using the gvlma function (package: gvlma) (Pena & Slate, 2014; R Core Team, 2015). This method is superior to current graphical techniques, as it eliminates the subjective assessment of the validity of model assumptions. Since the majority of parameters displayed global statistic p-values <0.05, Spearman correlation analyses were performed using the cor.test command (package: stats) for all land-cover types and water quality parameters at all landscape-scales (R Core Team, 2015). However, when the p-value of the global statistic was ≥0.05, Pearson correlation analyses were performed using the cor.test command (package: stats) as well (R Core Team, 2015). Although results were considered significant if the p-value was <0.05, a p-value <0.10 could also be considered significant if one wants to reduce the type II error, thus the following p-values were provided in tables: 0.10, 0.05, and 0.01. Similarly, Spearman and Pearson correlation analyses were also performed on road density and water quality parameters for all landscape-scales using the same method. Parameters displaying significant ($p<0.05$) and strong positive or negative correlations (±0.70) for Pearson correlation analyses were graphed (package: ggplot2) (Wickham, 2009).

2.3 Results

2.3.0.1 Regional temperature, precipitation, and snow cover for 2013-2014

The daily temperature trends were fairly consistent during the sampling period. For both years, temperature reached and dropped to 0°C in early April and late October, respectively. Snow cover also displayed a consistent trend where it diminished by late April and returned in early November for both years; however, snow melt was a bit more variable as the snow began to diminish in early March in 2013 and late March in 2014. Precipitation was also variable in regards to its frequency and amount (Figure 13).

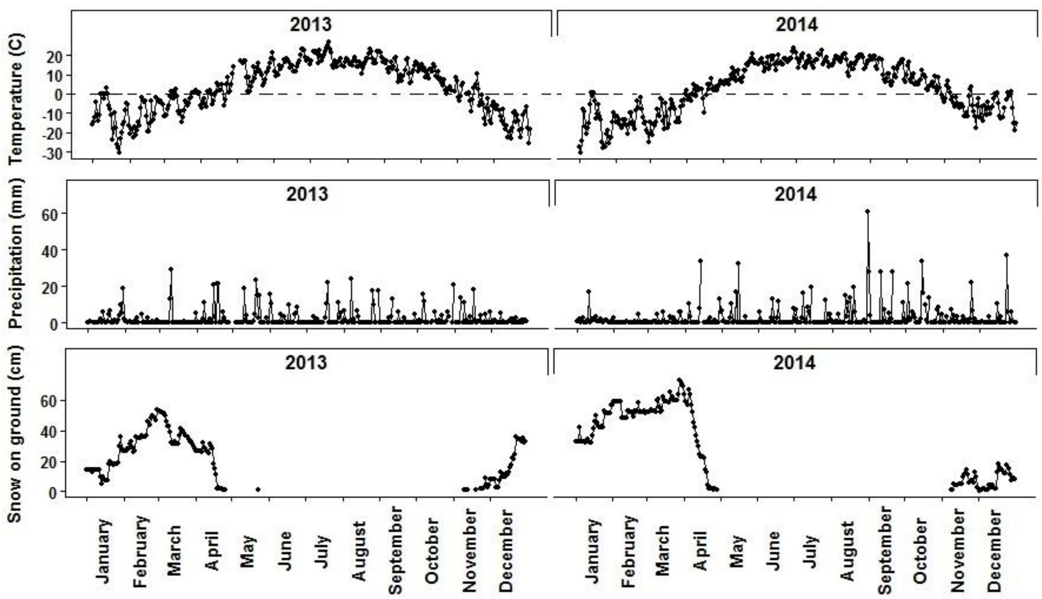

Figure 13 Daily mean temperature, precipitation and snow cover at Sudbury, Ontario for 2013 and 2014 (GC, 2013, 2014).

2.3.0.2 Landscape characterization for sites at differing landscape-scales

The sites exhibited a broad range of quaternary geology types and land-cover types at all landscape-scales. A detailed description of quaternary geology types and land-cover types is provided in Appendix B (Table B6 and Table B8). The majority of sites contained more than 50% bedrock for the buffer (5km-radius) and catchment scales, however, the reaches (1km, 2km, and 3km-radius) were more variable regarding quaternary geology types (Figure B1). The land-cover percent of sites varied considerably for all landscape-scales. The majority of sites were surrounded by more than 50% forest, some sites (VER-2, ONP-4, VER-6, WIT-7, WIT-8, and LEV-9) were surrounded by a considerable amount of agricultural land at certain landscape-scales, whereas other sites (LIL-11, CC-12 & JUN-13, MB-14, MUD-15, SIM-16, MC-17, MC-18, and MC-19) were surrounded by a large percentage of barren (i.e. rock/ruble and exposed land) and developed land (Figure B2). Road length and density also varied considerably for all landscape-scales (Figure B3).

2.3.0.3 Spatial and temporal patterns of water quality (general biological/chemical parameters and nutrients)

Some of the preceding boxplots were combined to show the spatial variations of general biological/chemical parameters and nutrients (Figure 14 and Figure 15). One-way ANOVAs revealed that for the majority of analyses there was at least one site that was significantly different from the others in 2013 and/or 2014 for: Chl-a (2013 and 2014: $p<0.001$), pH (2013 and 2014: $p<0.001$), CaCO3 (2013 and 2014: $p<0.001$), DOC (2013 and 2014: $p<0.001$), Cond (2013 and 2014: $p<0.001$), Cl (2013 and 2014: $p<0.001$), TP (2013: $p<0.001$), TN (2013 and 2014: $p<0.001$), TKN (2013 and 2014: $p<0.001$), NO3 (2013 and 2014: $p<0.001$), and NO2 (2013 and 2014: $p<0.001$). These analyses also revealed that there were no significant differences between sites in 2013 and/or 2014 for: E.coli (2013: $p=0.738$ and 2014: $p=0.313$), and TP (2014: $p=0.148$).

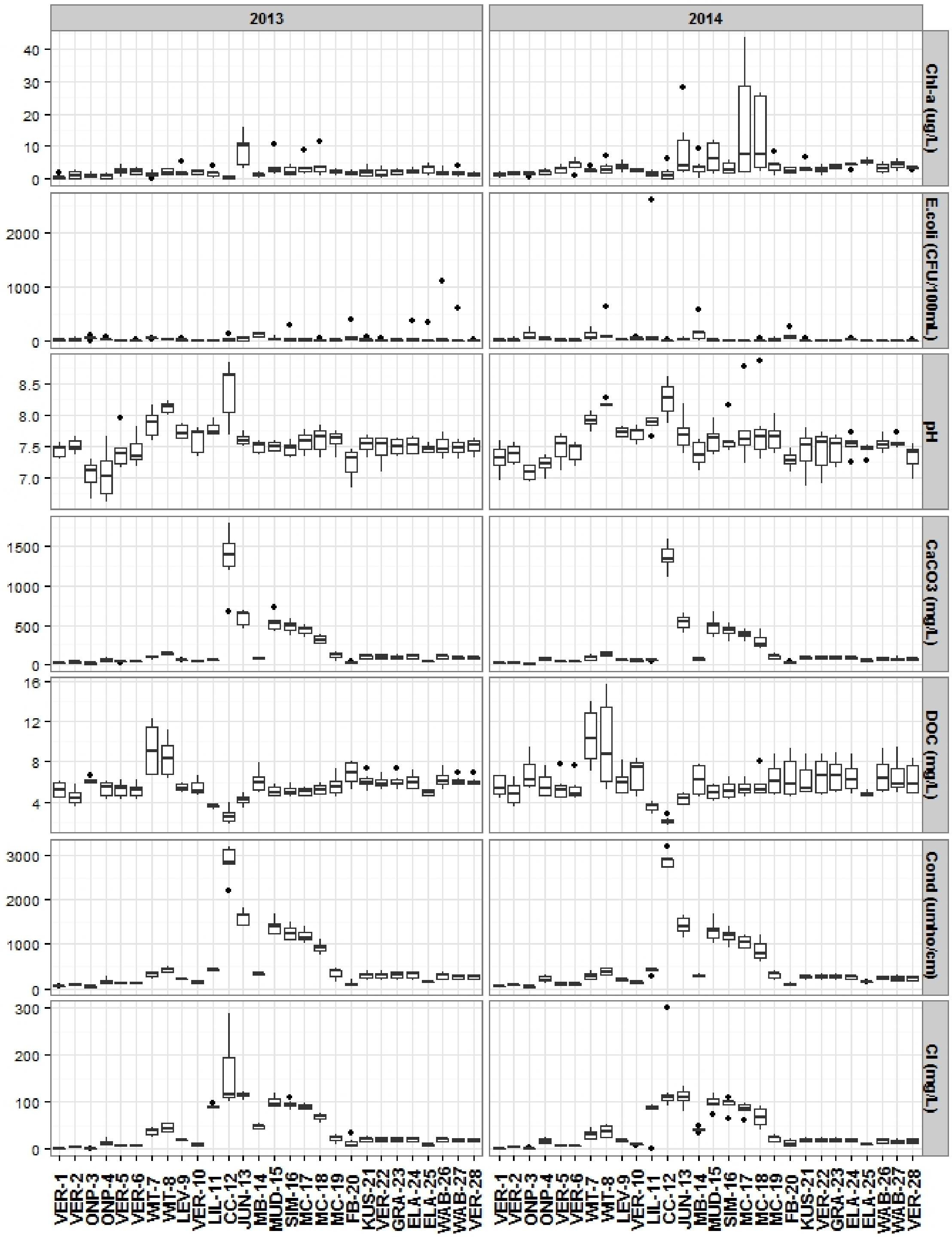

Figure 14 Spatial variations of general biological/chemical parameters for the twenty-eight study sites in 2013 and 2014.

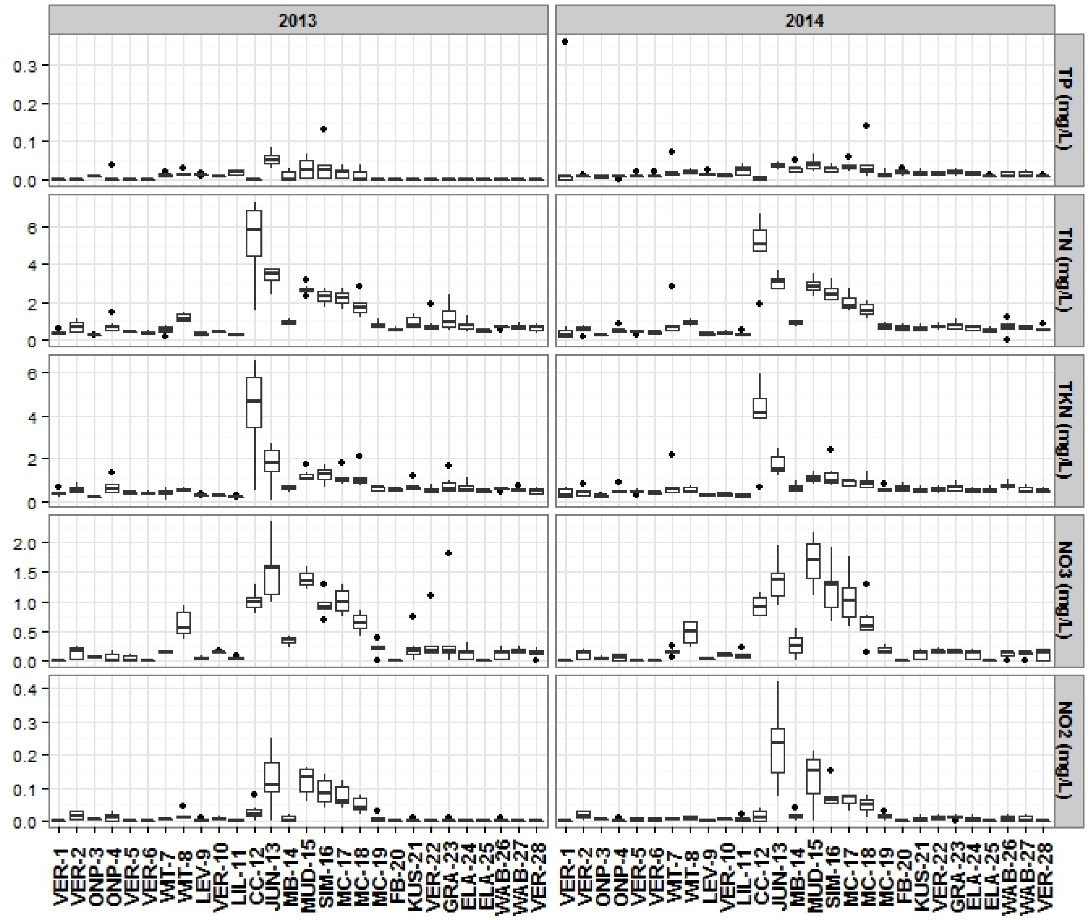

Figure 15 Spatial variations of nutrients for the twenty-eight study sites in 2013 and 2014.

Similarly, some of the preceding boxplots were combined to show the temporal variations of general biological/chemical parameters and nutrients (Figure 16 and Figure 17). One-way ANOVAs also revealed that there was at least one sampling date that was significantly different from the others in 2013 and/or 2014 for: E.coli (2013: $p<0.001$), pH (2013: $p=0.005$), and DOC (2013 and 2014: $p<0.001$). The majority of analyses revealed that there were no significant differences between sampling dates in 2013 and/or 2014 for: Chl-a (2013: $p=0.291$ and 2014: $p=0.059$), E.coli (2014: $p=0.262$), pH (2014: $p=0.086$), CaCO3 (2013: $p=0.938$ and 2014: $p= 0.991$), Cond (2013: $p= 0.959$ and 2014: $p=0.976$), Cl (2013: $p=0.734$ and 2014: $p= 0.756$), TP (2013: $p=0.100$ and 2014: $p=0.297$), TN (2013: $p=0.758$ and 2014: $p=0.867$), TKN (2013: $p=0.798$ and 2014: $p=0.882$), NO3 (2013: $p= 0.639$ and 2014: $p= 0.919$), and NO2 (2013: $p=0.423$ and 2014: $p=0.770$).

However, when linear mixed effects models were used to take into account site differences (i.e. by-site variability), the majority of these water quality parameters appeared to have at least one sampling date that was significantly different from the others in 2013 and/or 2014. These water quality parameters included: Chl-a (2014: $p=0.018$), E.coli (2013: $p<0.001$), pH (2013: $p<0.001$ and 2014: $p<0.001$), CaCO3 (2013: $p=0.019$ and 2014: $p=0.012$), DOC (2013: $p<0.001$ and 2014: $p<0.001$), Cond (2013: $p<0.001$ and 2014: $p<0.001$), Cl (2013: $p<0.001$ and 2014: $p=0.032$), TP, (2013: $p=0.018$), TN (2013: $p=0.032$ and 2014: $p=0.016$), NO3 (2013: $p=0.003$ and 2014: $p=0.040$), and NO2, (2013: $p=0.004$). Linear mixed effects models also revealed that there were no significant differences between sampling dates in 2013 and/or 2014 for: Chl-a (2013: $p=0.085$), E.coli (2014: $p=0.232$), TP (2014: $p=0.271$), TKN (2013: $p=0.312$ and 2014: $p=0.300$), and NO2 (2014: $p=0.142$).

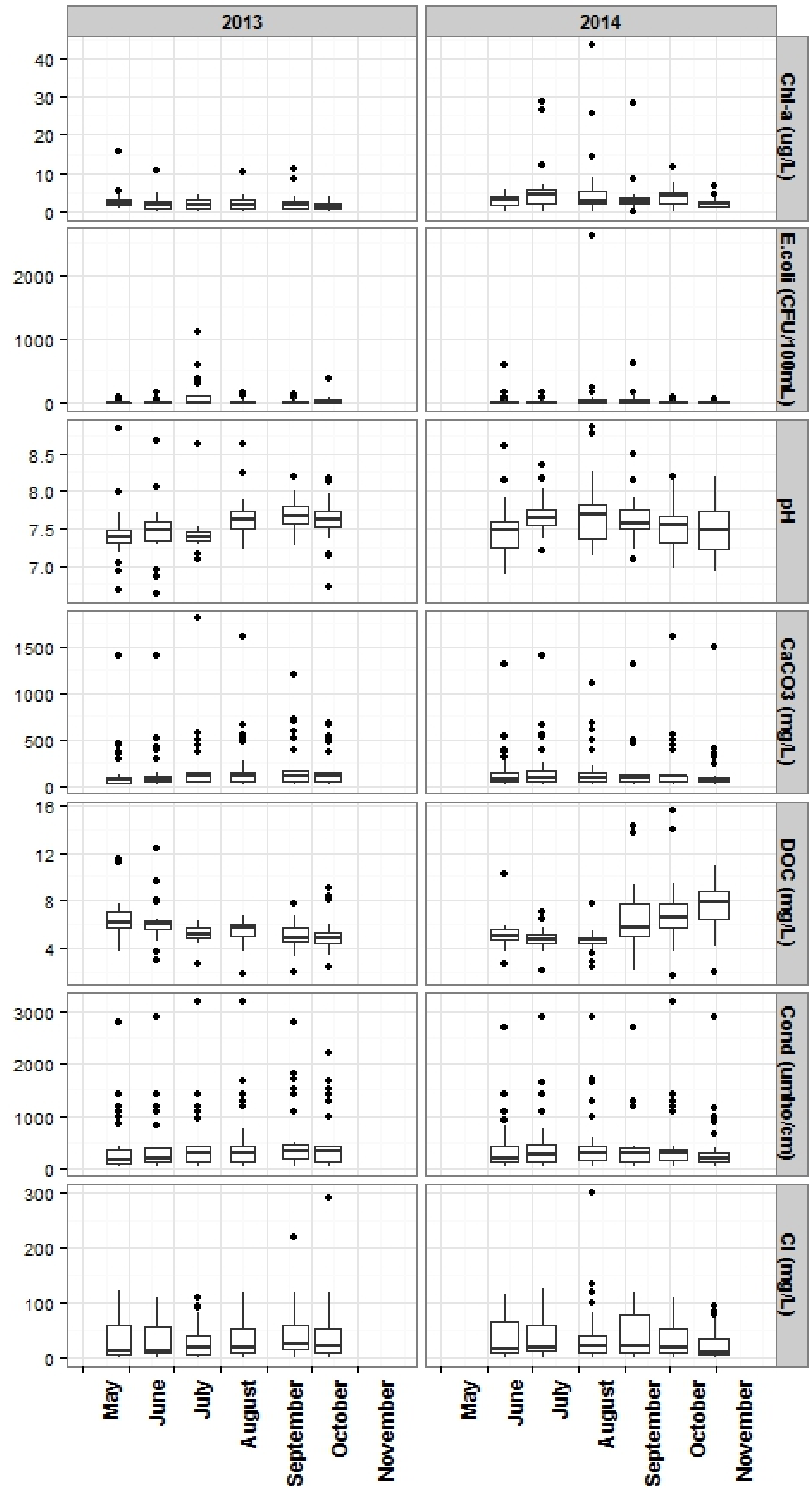

Figure 16 Temporal variations of general biological/chemical parameters for the twelve sampling dates in 2013 and 2014.

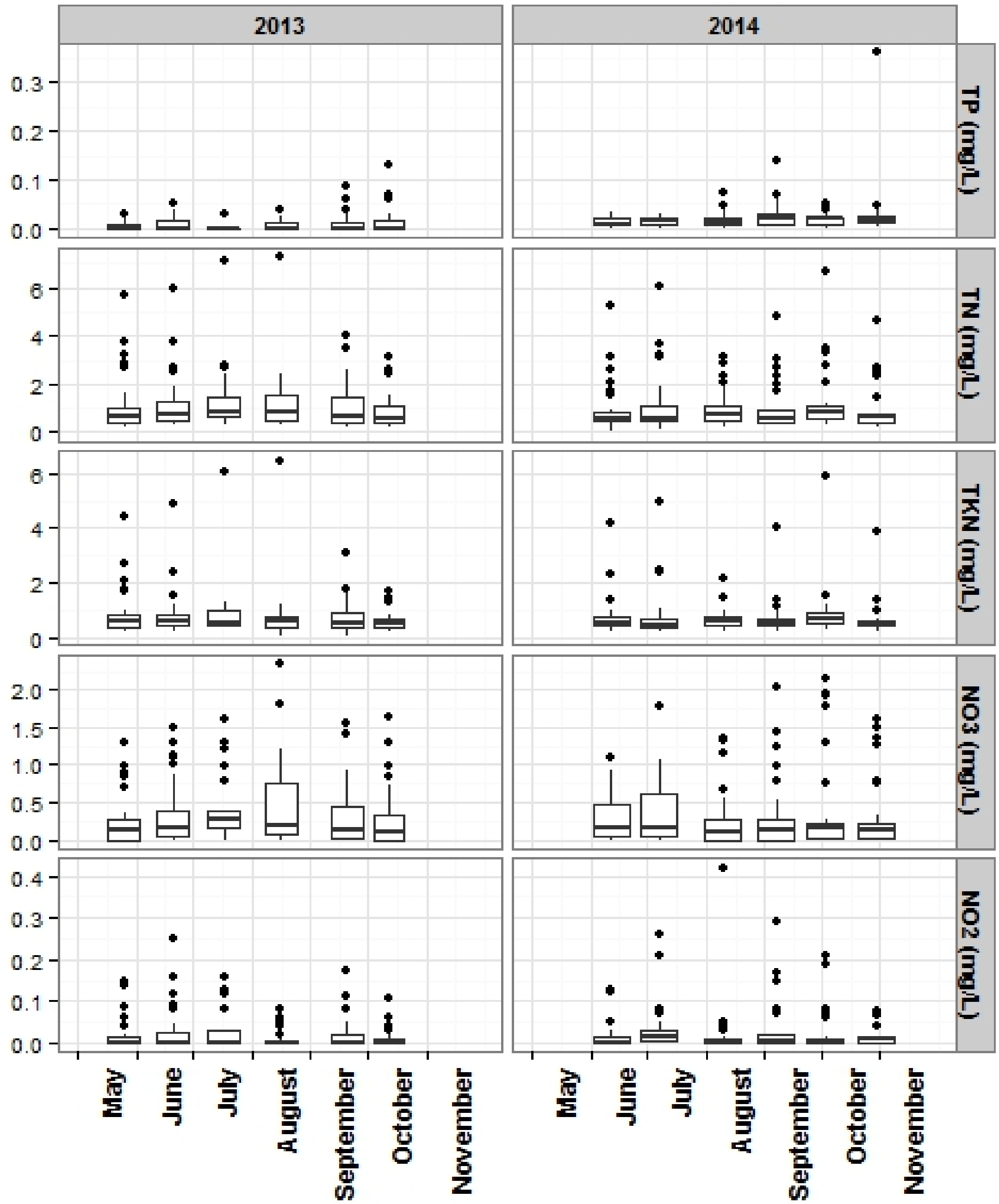

Figure 17 Temporal variations of nutrients for the twelve sampling dates in 2013 and 2014.

2.3.0.4 Summary of water quality variations in 2013 and 2014, and water quality guidelines when available

Boxplots were only constructed for water quality parameters monitored at all sites and the RWQG, LTWQG, and/or STWQG were included on these figures when available (Figure B4-Figure B42). The water quality parameters that surpassed the RWQG, LTWQG, and/or STWQG at one or more sites in 2013-2014 included: E.coli (RWQG), Cl (LTWQG), NO2 (LTWQG), Al (LTWQG), Cd (LTWQG and STWQG), Cu (LTWQG), Fe (LTWQG), Pb (LTWQG), Ni (LTWQG), Ag (LTWQG), and Zn (LTWQG). To quickly summarize these results, E.coli surpassed the RWQG at two sites in 2013 and three sites in 2014, Cl surpassed the LTWQG at three sites in 2013 and in 2014, NO2 surpassed the LTWQG at six sites in 2013 and five sites in 2014, Al surpassed the LTWQG at twelve sites in 2013 and twenty sites in 2014, Cd surpassed the LTWQG at sixteen sites in 2013 and thirteen sites in 2014, Cd also surpassed the STWQG at three sites in 2013 and in 2014, Cu surpassed the LTWQG at twenty-seven sites in 2013 and twenty-six sites in 2014, Fe surpassed the LTWQG at seventeen sites in 2013 and twenty-two sites in 2014, Pb surpassed the LTWQG at one site in 2013 and four sites in 2014, Ni surpassed the LTWQG at twenty-one sites in 2013 and twenty sites in 2014, Ag surpassed the LTWQG at thirteen sites in 2013 and four sites in 2014, and Zn surpassed the LTWQG at seven sites in 2013 and five sites in 2014.

2.3.0.5 Principal component analyses (PCAs) and cluster analyses on water quality

PCAs were performed on normalised annual general biological/chemical parameters and nutrients (Figure 18). When combined, the first and second principle components explained 75.06% and 69.97% of the variance in 2013 and 2014, respectively. The correlation biplots also indicated that the majority of water quality variables represented the two dimensional approximation very well, in addition, the majority of water quality parameters were highly correlated with each other. Sites located on the main-stem of the Junction tributary (i.e. CC-12, JUN-13, MUD-15, SIM-16, MC-17 and MC-18) appeared to exhibit above average values for the majority of water quality parameters. Specifically, sites located downstream of the Sudbury WWTP (i.e. JUN-13, MUD-15, SIM-16, MC-17, and MC-18), had above average values for Chl-a, TP, NO3 and NO2 whereas the site upstream (i.e. CC-12) had above average values pH and TKN. In addition, two sites which are not located on the main-stem of the Junction tributary (i.e. LIL-11 and MB-14) appeared to exhibit average or below average values for the majority of water quality parameters. These findings were further supported by single-linkage agglomerative cluster analyses (Figure B43 and Figure B44).

Similarly additional PCAs were performed on the normalised annual metals (Figure 19). When combined, the first and second principle components explained 59.22% and 54.53% of the variance in 2013 and 2014, respectively. The correlation biplots also indicated that the many of metals represented the two dimensional approximation very well, in addition, the majority of metals were highly correlated with each other. Taking into account all sites, CC-12 and JUN-13 were the most dissimilar and appeared to exhibit above average values for the majority of metals in 2013 and in 2014. These findings were further supported by single-linkage agglomerative cluster analyses (Figure B45 and Figure B46).

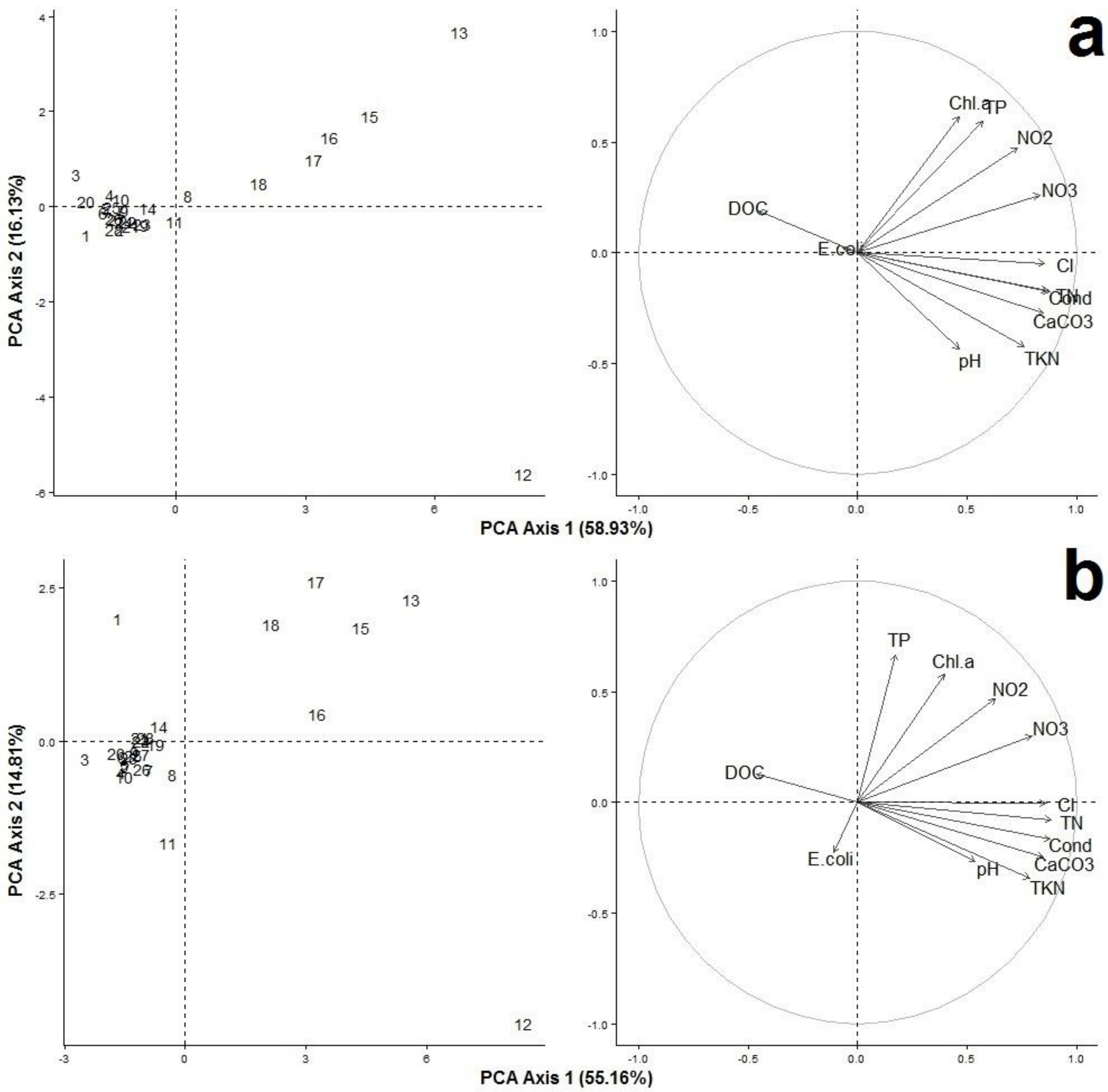

Figure 18 Principal component analysis and correlation biplot performed on the (a) 2013 and (b) 2014 normalised general biological/chemical parameters and nutrient data for twenty-eight sites.

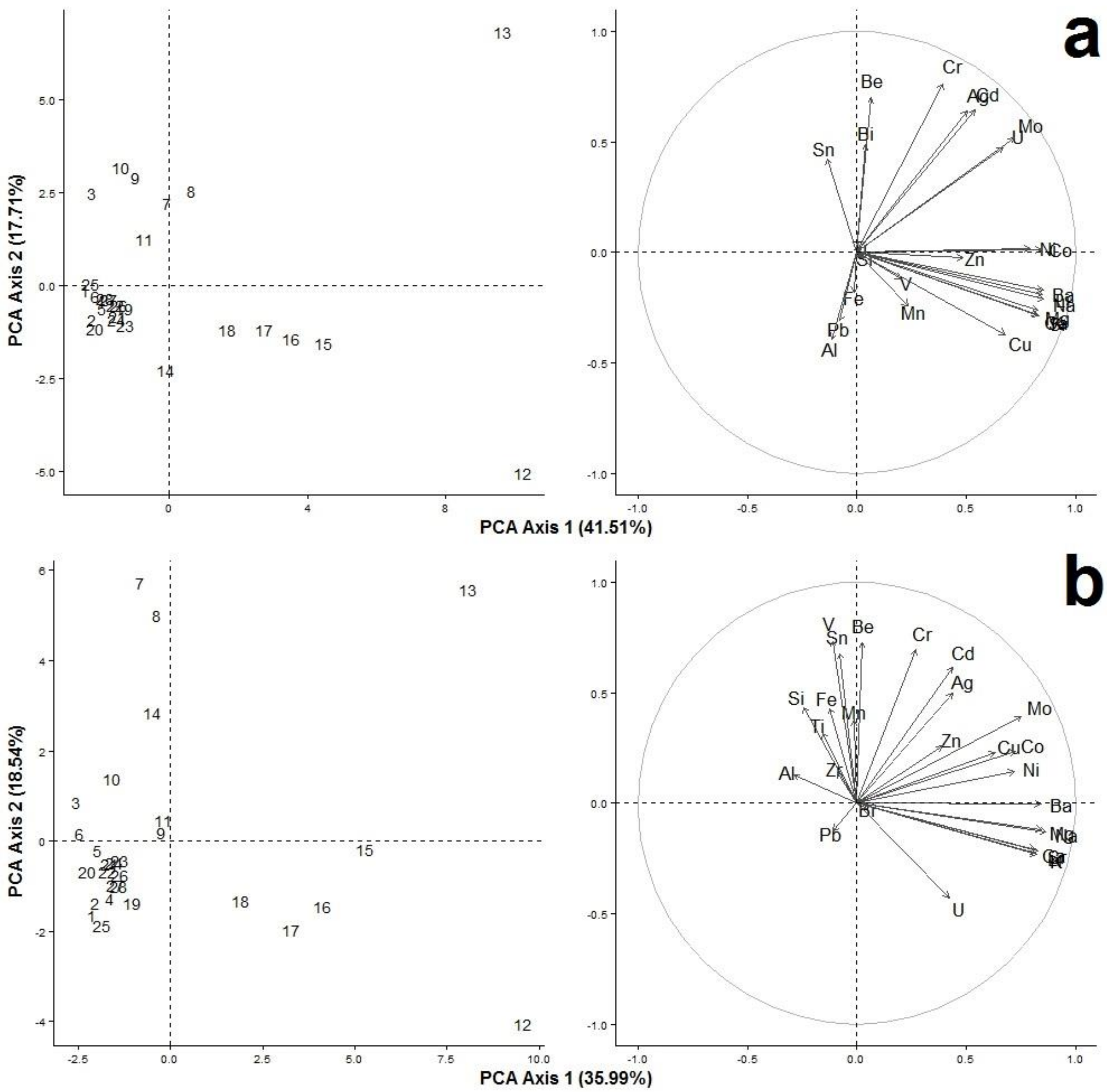

Figure 19 Principal component analysis and correlation biplot performed on the (a) 2013 and (b) 2014 normalised metals data for twenty-eight sites.

2.3.0.6 One-way ANOVAs and multiple comparisons on nutrient concentrations upstream and downstream of the Sudbury WWTP

Since the preceding PCAs inferred that some sites on the Junction tributary had above average values for nutrients, line graphs were created to show the annual average nutrient concentrations upstream and downstream of the Sudbury WWTP (Figure 20). Distances between sites and the Sudbury WWTP are provided in Appendix B (Table B16). The figure below indicates that TP is very low upstream of the Sudbury WWTP, whereas TP is higher downstream of the Sudbury WWTP and progressively declines until MC-18 where it levels off. Conversely, TN is highest upstream of the Sudbury WWTP and progressively declines until MC-18 where it levels off. When TN is broken down into its components (TKN, NO3, and NO2) it appears that TKN, composed of ammonia-nitrogen plus organically bound nitrogen, is highest upstream of the Sudbury WWTP and progressively declines until MC-18 where it levels off, whereas NO3 and NO2, inorganic components, are lower upstream of the Sudbury WWTP compared to the nearest site downstream of the Sudbury WWTP.

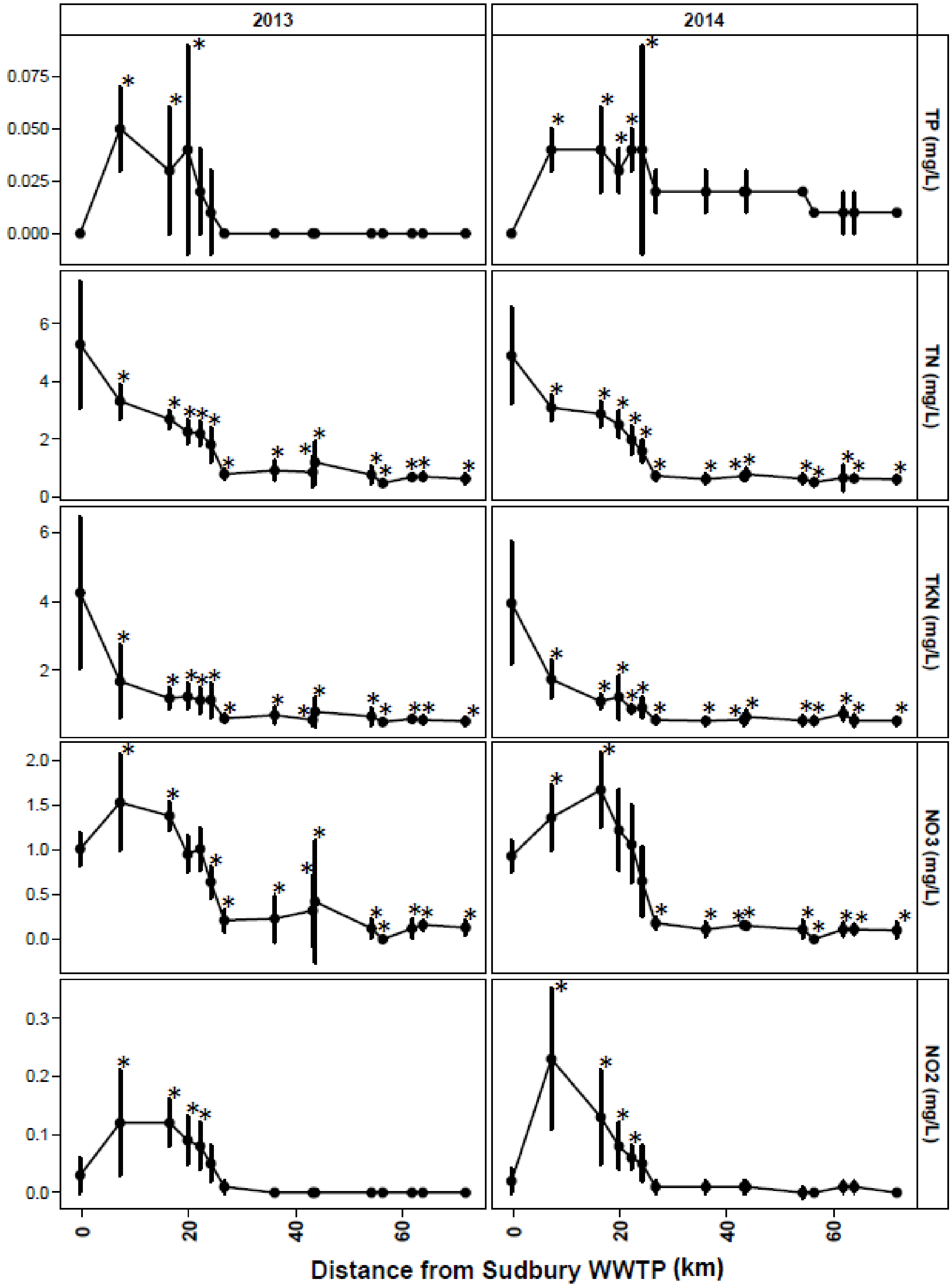

Figure 20 Annual average nutrient concentrations upstream and downstream of the Sudbury WWTP. *Nutrient concentrations were significantly (p<0.05) higher or lower compared to the site upstream of the Sudbury WWTP (CC-12).

One-way ANOVAs revealed that for all nutrients in 2013 and in 2014, there was at least one site that was significantly different from the others since all p-values were <0.001. Further multiple comparison analyses showed that indeed, when sites downstream of the Sudbury WWTP were compared to the site upstream: TP was significantly higher for the first three sites in 2013 and five sites in 2014, TN and TKN were significantly lower for all sites for both years, NO3 was significantly higher for the first two sites for both years but significantly lower for the last ten sites in 2013 and nine sites in 2014, and NO2 was significantly higher for the first four sites for both years (Table B17).

2.3.0.7 Spearman and Pearson correlation analyses on land-cover types and water quality at certain landscape-scales

Spearman and Pearson correlation analyses were used to detect correlations between land-cover types and water quality parameters for all landscape-scales. Since the majority of parameters displayed global statistic p-values <0.05, Spearman correlation analyses were performed for all land-cover types and water quality parameters at all landscape-scales. The results of these Spearman correlation analyses are summarized in Appendix B (Table B18 and Table B19). Some land-cover types and water quality parameters at certain landscape-scales also displayed global statistic p-values ≥0.05, thus Pearson correlation analyses were performed as well. The results of these Pearson correlation analyses are also summarized in Appendix B (Table B20 and Table B21). The subsequent table summarizes the quantity of significant correlations observed (Table 1).

Table 1 Quantity of significant (<0.05) correlations observed for Spearman and Pearson analyses performed on land-cover types and water quality parameters.

Annual biological/chemical parameters and nutrients		Spearman		Pearson	
		2013	2014	2013	2014
Area	5km Buffers	20	21	12	8
	Catchments	45	48	4	2
	1km Reaches	10	17	4	4
	2km Reaches	10	17	2	2
	3km Reaches	12	17	8	6
Percent	5km Buffers	20	21	12	8
	Catchments	58	53	10	12
	1km Reaches	8	14	6	6
	2km Reaches	12	22	5	5
	3km Reaches	13	18	7	4
Annual metals		**Spearman**		**Pearson**	
		2013	**2014**	**2013**	**2014**
Area	5km Buffers	39	40	15	14
	Catchments	71	76	2	7
	1km Reaches	23	18	3	3
	2km Reaches	26	25	4	4
	3km Reaches	31	30	13	11
Percent	5km Buffers	39	40	15	14
	Catchments	94	80	5	12
	1km Reaches	25	18	5	6
	2km Reaches	33	27	7	3
	3km Reaches	30	26	11	12

The following significant trends were observed from the Pearson correlation analyses using annual biological/chemical parameters and nutrients: DOC decreased when the water land-cover type increased, pH, CaCO3, Cond, Cl, TP, TN, TKN, NO3, NO2 increased when the barren land-cover type increased, Cond, Cl, NO3, NO2 increased when the developed land-cover type increased, Cl, TP, NO3, NO2 decreased and DOC increased when the wetland land-cover type increased, pH, Cond, NO3 decreased when the herb land-cover type increased, DOC increased when the agricultural land-cover type increased, and pH, CaCO3, Cond, Cl, TP, TN, NO3, NO2 decreased when the forest land-cover type increased. In addition, the following significant trends were observed from the Pearson correlation analyses using annual metals: Be, Si, V decreased when the water land-cover type increased, Ba, Ca, Co, Li, Mg, Mo, Ni, K, Na, Sr, U, Zn increased when the barren land-cover type increased, Ba, Co, Mn, Ni, Na, U, V, Zn increased when the developed land-cover type increased, Co, Cu, Mo, Ni, U decreased and V increased when the wetland land-cover type increased, Si, V increased when the agricultural land-cover type increased, and Ba, Co, Li, Mg, Mo, Ni, K, Na, Sr, U decreased when the forest land-cover type increased. Parameters displaying significant ($p<0.05$) and strong positive or negative correlations (±0.70) for Pearson correlation analyses were graphed (Figure 21, Figure 22, Figure 23, and Figure 24). Only three land-cover types displayed significant and strong correlations for the water quality parameters tested, they include: barren, developed and forest. When taking into account all these figures, fifty-eight significant and strong positive correlations were detected between water quality parameters (CaCO3, Cond, Cl, TN, TKN, NO3, Ba, Ca, K, Li, Mg, Na, and Sr) and barren land-cover at certain landscape-scales (catchment, 1km reach, 2km reach, and 3km reach), nine significant and strong positive correlations were detected between water quality parameters (Cl, NO3, NO2, Co, and Ni) and developed land-cover at certain landscape-scales (buffer and catchment), and twenty-two significant and strong negative correlations were detected between water quality parameters (pH, Cond, Cl, NO3, Ba, Co, Mo, Na, and Ni) and forest land-cover at certain landscape-scales (buffer, catchment, 2km reach, and 3km reach).

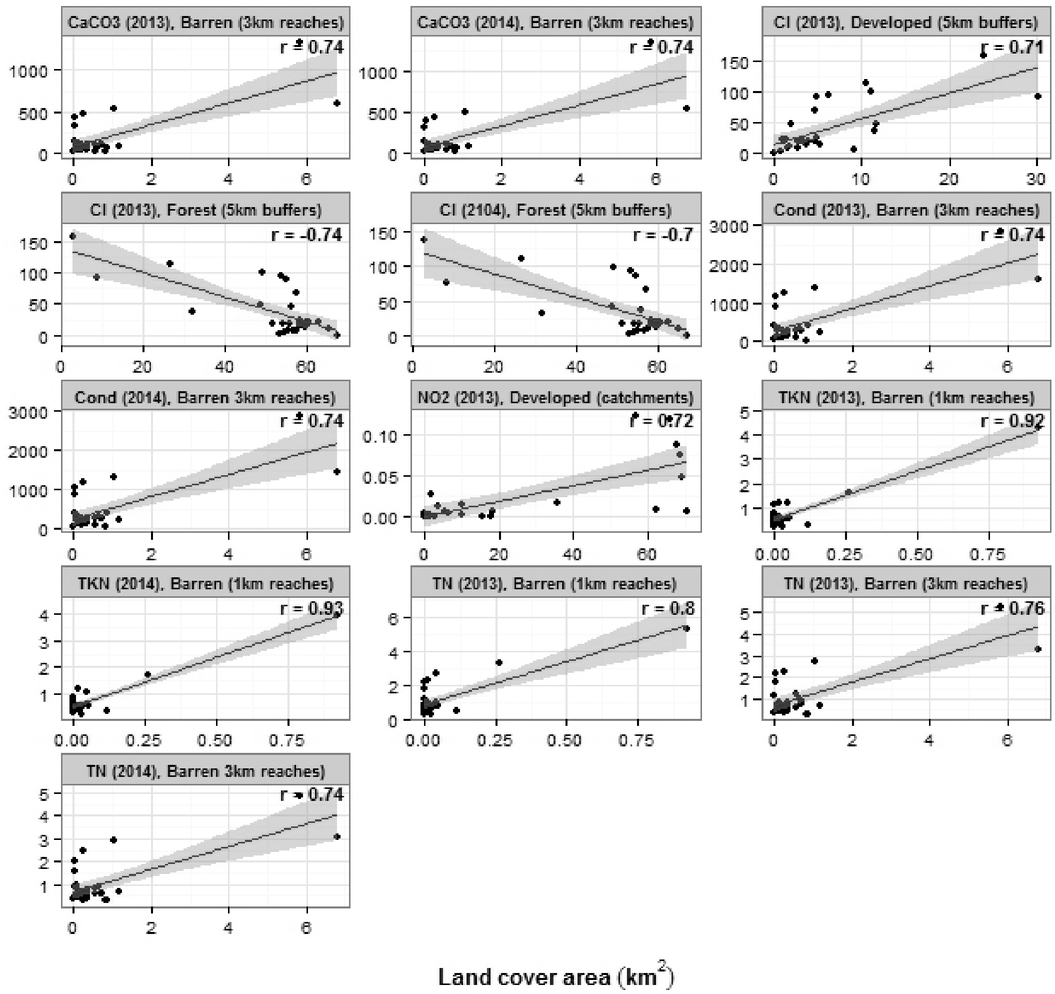

Figure 21 Linear regression analyses performed on land-cover types (area) and general biological/chemical parameters and nutrients at certain landscape-scales.

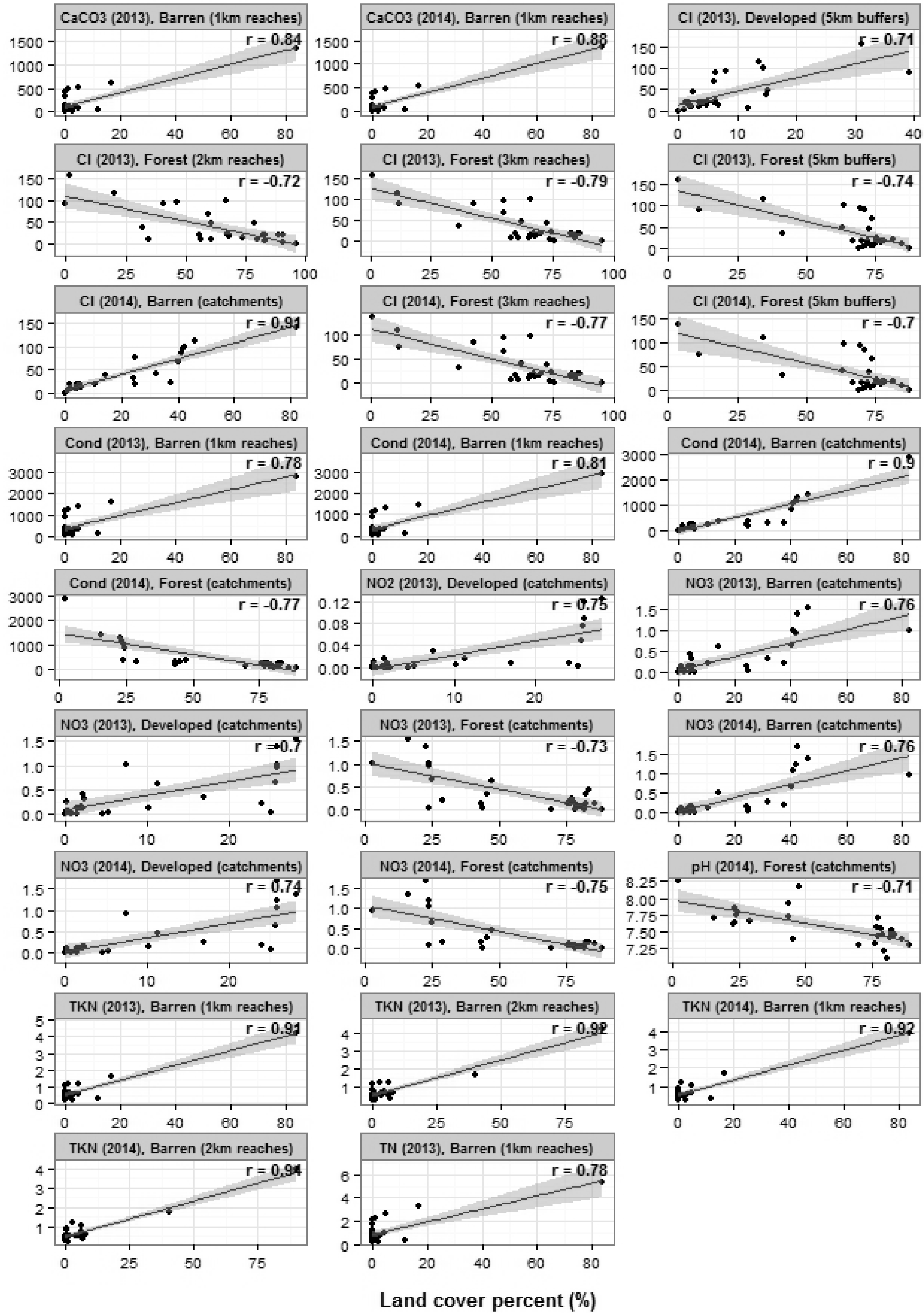

Figure 22 Linear regression analyses performed on land-cover types (percent) and general biological/chemical parameters and nutrients at certain landscape-scales.

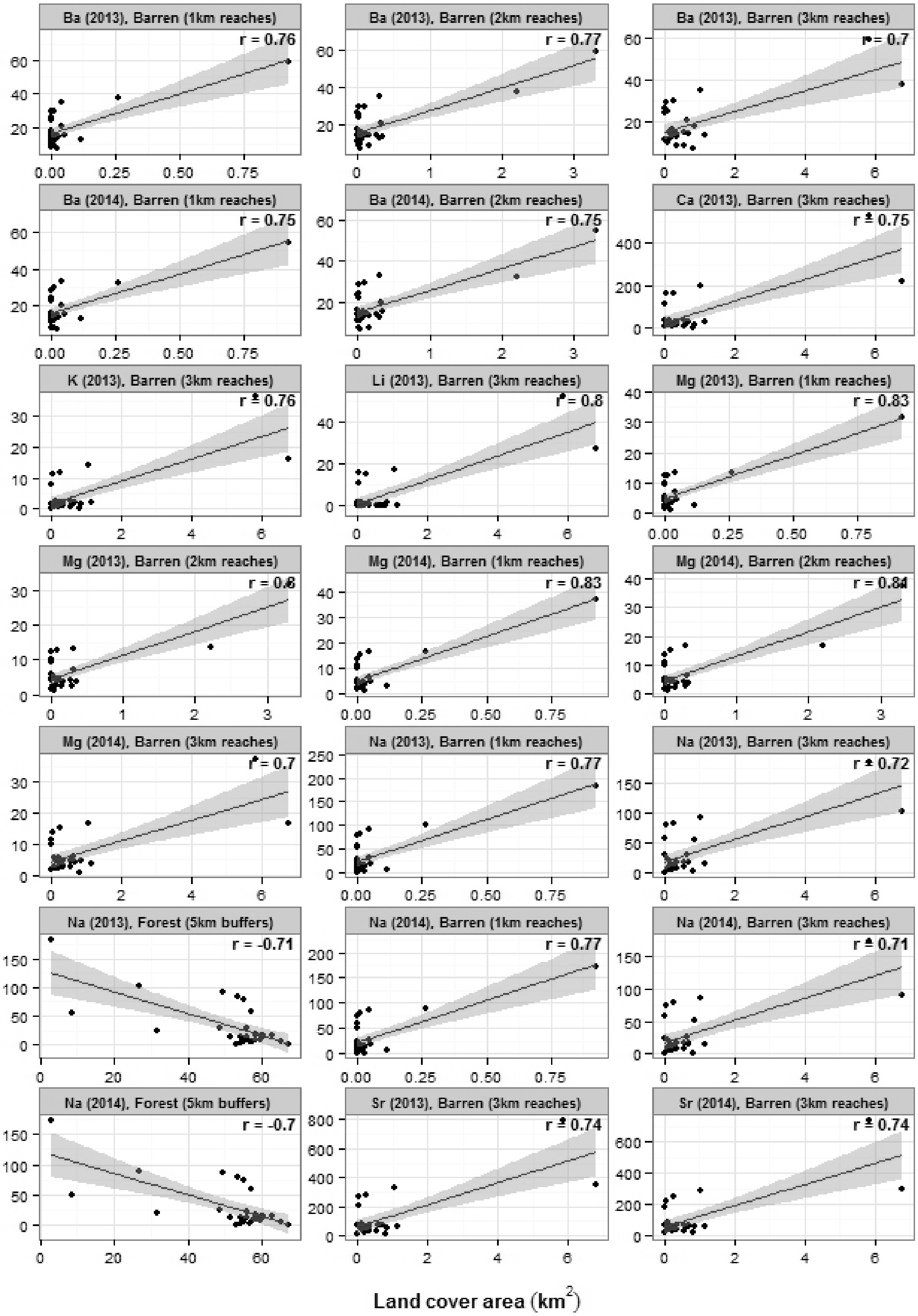

Figure 23 Linear regression analyses performed on land-cover types (area) and metals at certain landscape-scales.

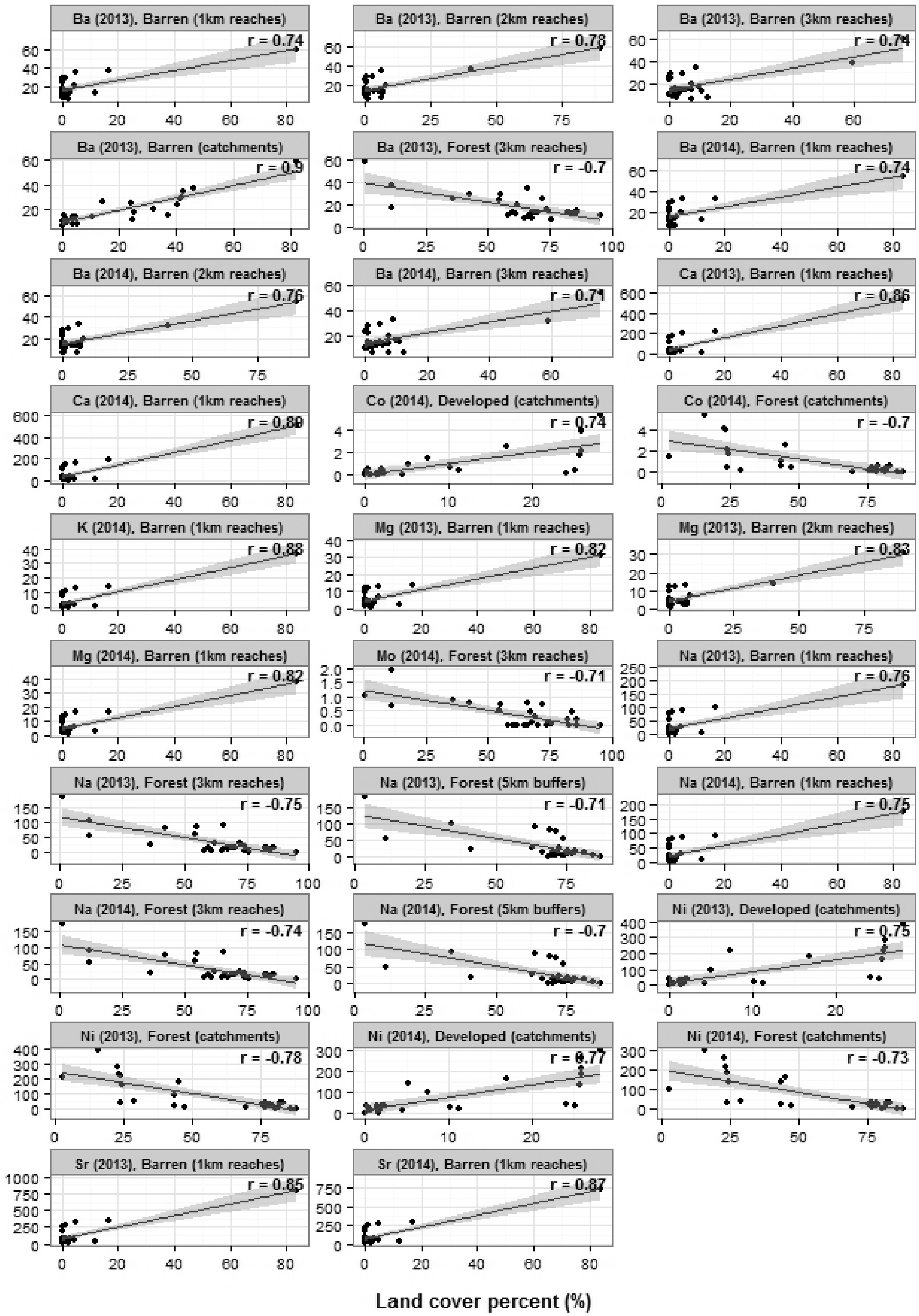

Figure 24 Linear regression analyses performed on land-cover types (percent) and metals at certain landscape-scales.

Similarly, additional Spearman and Pearson correlation analyses were performed on road density and water quality parameters for all landscape-scales. Since the majority of parameters displayed global statistic p-values <0.05, Spearman correlation analyses were performed for all water quality parameters at all landscape-scales. The results of these Spearman correlation analyses are summarized in Appendix B (Table B22). Some water quality parameters at certain landscape-scales also displayed global statistic p-values >0.05, thus Pearson correlation analyses were performed as well. The results of these Pearson correlation analyses are also summarized in Appendix B (Table B23). The table below summarizes the quantity of significant correlations observed (Table 2).

Table 2 Quantity of significant (<0.05) correlations observed for Spearman and Pearson analyses performed on road density and water quality parameters.

Annual biological/chemical parameters and nutrients	**Spearman**		**Pearson**	
	2013	**2014**	**2013**	**2014**
5km Buffers	6	7	2	3
Catchments	10	10	2	1
1km Reaches	8	9	1	2
2km Reaches	7	9	1	2
3km Reaches	8	8	4	4
Annual metals	**Spearman**		**Pearson**	
	2013	**2014**	**2013**	**2014**
5km Buffers	11	11	2	2
Catchments	15	13	2	5
1km Reaches	15	11	2	4
2km Reaches	13	11	2	2
3km Reaches	16	12	3	5

The following significant trends were observed from the Pearson correlation analyses: pH, Cond, Cl, TP, TN, NO3, Ba, Co, Cu, Mg, Mn, Mo, Ni, Si, Na, Ti, U, V, Zn increased when road density increased. Parameters displaying significant ($p<0.05$) and strong positive or negative correlations (±0.70) for Pearson correlation analyses were graphed (Figure 25). Nine significant and strong positive correlations were detected between water quality parameters (Cl, Na, Ni, and NO3) and road density at certain landscape-scales (buffer, catchment, and 3km reach), however, no significant and strong negative correlations were detected.

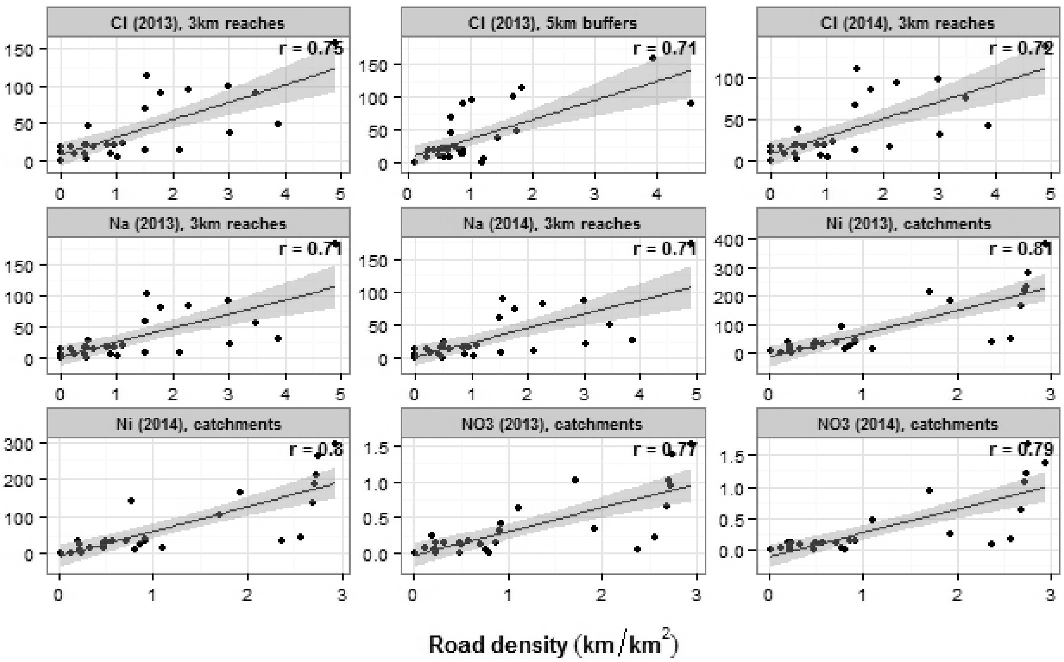

Figure 25 Linear regression analyses of road density and water quality parameters at certain landscape-scales.

2.4 Discussion

This chapter has shown that temperature and snow cover trends were fairly consistent during the sampling period, however, snow melt and precipitation were a bit more variable. Large precipitation and spring snow melt events are known to increase the frequency of sewage bypass events which release undertreated or untreated effluent. Thus, it was expected that more by-pass events would occur in 2014. In 2013 two municipal WWTPs (Azilda WWTP and Lively WWTP) had by-pass events, whereas in 2014 four municipal WWTPs (Azilda WWTP, Chelmsford WWTP, Lively WWTP, and Sudbury WWTP) had by-pass events (Greater Sudbury, 2014, 2015). Drought, precipitation, and snow melt events are also known to influence the quantity and quality of surface runoff that enters aquatic systems, thus these events must be taken into consideration when trying to determine how the surrounding landscape affects water quality (Hayes et al., 2015).

The sites exhibited a broad range of quaternary geology types and land-cover types at all landscape-scales. Although quaternary geology is known to play a role in determining water quality (Sangani et al., 2015), it was omitted from subsequent analyses since sites contained mostly bedrock at certain landscape-scales (i.e. buffer, catchment, and reaches). Instead focus was placed on land-cover and road densities as they seemed to be better determinants for water quality (Maberly et al., 2003).

General biological/chemical parameters, nutrients, and metals were very variable both spatially and temporally. Spatial differences were the most obvious, as certain water quality parameters were elevated at certain sites. When water quality parameters surpassed the RWQG, LTWQG, and/or STWQG at one or more sites in 2013-2014, they were noted. Cl surpassed the LTWQG at CC-12, JUN-13, and MUD-15, which have very high amounts of impervious surfaces (i.e., barren and developed land-cover) for all landscape-scales (i.e. buffer, catchment, and reaches). NO2 surpassed the LTWQG at CC-12, JUN-13, MUD-15, SIM-16, MC-17, and MC-18, which are located on the main-stem of the Junction tributary, however, LIL-11 and MB-14 did not surpass NO2 limits possibly because they flow into the main-stem of the Junction tributary and are uninfluenced by WWTPs (i.e. Sudbury WWTP, Copper Cliff WWTP, and Nolin Creek WWTP) and inputs from the surrounding landscape (i.e. Clarabell Mill property). In addition, over 50% of the sites surpassed the LTWQG in 2013 and/or 2014 for: Al (2014), Cd (2013), Cu (2013 & 2014), Fe (2013 & 2014), and Ni (2013 & 2014). These sites likely surpassed the LTWQG because of past and present atmospheric deposition from smelters (Szkokan-Emilson et al., 2014).

PCAs, cluster analyses, line graphs, one-way ANOVAs and multiple comparisons revealed that the Sudbury WWTP significantly influenced nutrient concentrations at sites directly downstream and in close proximity. As mentioned previously, total phosphorus was significantly higher for the first four sites in 2013, and five sites in 2014 that were downstream of the Sudbury WWTP when compared to the site upstream, TN and TKN were significantly lower for all sites that were downstream of the Sudbury WWTP when compared to the site upstream for both years, and NO3 and NO2 were significantly higher for the first four sites that were downstream of the Sudbury WWTP when compared to the site upstream for both years. Since the Sudbury WWTP was the largest contributor of nutrients into the VRMT for both years it was anticipated that nutrient concentrations would be higher at sites directly downstream and in close proximity, however, TN and TKN were unexpectedly highest upstream. Upon further investigation, it appeared other WWTPs (i.e. Copper Cliff WWTP and Nolin Creek WWTP) and/or surface runoff from the Clarabell Mill property was elevating TN and TKN. A report by Vale indicated that ammonia-nitrogen, which is a component of TKN, and NO3 are released from the property, yet, no reduction strategy was implemented to reduce these nutrients according to Vale's Toxic Reduction Plan Summaries from December 2013 (Vale Canada Limited, 2013).

Spearman and Pearson correlation analyses showed that many water quality parameters were influenced by land-cover types and road density. Notably from Pearson correlation analyses, the impervious land-cover types (i.e. barren and developed) and road density displayed significant and strong positive correlations with numerous water quality parameters, whereas the forest land-cover type displayed significant and strong negative correlations. These analyses also revealed that the landscape-scales (i.e. buffer, catchment, and reaches) varied considerably in detecting significant correlations. Thus from a management perspective, the potential inputs from surrounding landscape at all landscape-scales should be considered before further development occurs.

2.5 Conclusion

Point sources (i.e., WWTPs, sewage lagoons, and smelters) that discharge effluent directly into surface waters or emissions into the atmosphere are generally regulated and monitored; however, their impacts on receiving waters are not usually accessed. Results from PCAs, cluster analyses, scatterplots, one-way ANOVAs and multiple comparisons in this chapter have confirmed that municipal WWTPs significantly influence the water quality of the VRMT. In particular, the Sudbury WWTP is primarily responsible for the elevated nutrient concentrations in the main-stem of the Junction tributary, however, other WWTPs (i.e. Copper Cliff WWTP, and Nolin Creek WWTP) and/or surface runoff from the Clarabell Mill property are likely responsible as well. In addition, smelters are likely responsible for the elevated metal concentrations at many sites in the VRMT system since over 50% of the sites in 2013 and 2014 surpassed the water quality guidelines for Cu, Fe, and Ni, which are common metals released by smelters. Since metals are deposited onto the land they are likely transported into the system via erosion and/or surface runoff (non-point sources).

Non-point sources (e.g. runoff from the properties of mining industries, developed and agricultural land, roadways, etc.) that do not discharge effluent directly into surface waters are often omitted from water quality monitoring since they are difficult to quantify. Results from this chapter have confirmed that the landscape-scale data (i.e. land-cover and road density) significantly influences the water quality of the VRMT.

Although water quality parameters are influenced by both point and non-point sources in the Sudbury region, further investigations are required to determine which water quality parameters influence phytoplankton abundance and composition. Thus, this will be discussed in Chapter 3.

CHAPTER 3: SPATIAL AND TEMPORAL PATTERNS OF PHYTOPLANKTON AND HOW THEY RELATE TO WATER QUALITY IN THE VERMILION RIVER AND MAJOR TRIBUTARIES, SUDBURY, ONTARIO, CANADA

3.1 Introduction

Inputs from the surrounding landscape (i.e., point and non-point sources) can significantly influence the water quality of aquatic systems, consequently affecting their structure and functioning (Longhi & Beisner, 2010; Schindler, 2006). Phytoplankton are important primary producers of aquatic systems, and they are responsible for transporting nutrients and energy to higher trophic levels. Since more species occupy the lower trophic levels, usually multiple species can perform similar ecological functions. For that reason, and due to their microscopic size, the loss of a species may go unnoticed until major alterations occur (i.e., shifts in the entire community composition) and the ecological health begins deteriorating (i.e. harmful algal blooms, fish kills, etc.).

Since the previous chapter (refer to Chapter 2, pg.22-58) discussed how land-use affects water quality, this chapter will discuss how water quality can affect the community structure of phytoplankton in the VRMT. Thus a general overview of phytoplankton will be provided by discussing their general responses to physical, chemical, and biological factors, then the major phytoplankton groups will be introduced and their preference for certain environments. Lastly, predicting phytoplankton community structure will be discussed.

3.1.1 General Overview: Phytoplankton

Aquatic systems, whether they are lentic or lotic, exhibit common phytoplankton successional patterns throughout the year. That being said, the successional patterns in rivers are less understood compared to lakes. Regardless of the system, the successional patterns will be dependent on numerous physical, chemical, and biological factors such as circulation, thermal stratification, light conditions, water temperature, nutrient availability, zooplankton grazing, etc. These factors are influenced by natural and anthropogenic disturbances and the scale of these disturbances will influence the abundance and composition of phytoplankton communities.

3.1.1.1 Responses to Physical, Chemical, and Biological Factors

Numerous studies have been published regarding phytoplankton assemblages in varying aquatic systems and their responses to physical, chemical and biological changes. Although multiple factors alter the abundance and composition of phytoplankton communities, only a small proportion will be covered in the following sections.

Physical Factors

Light is an essential resource for phytoplankton photosynthesis. Since light intensity is unevenly distributed within the water column, some taxonomic groups are favoured over others at certain depths. Taxonomic groups that are more efficient at utilizing low light (e.g. dinoflagellates) are favoured at greater depths, whereas other taxonomic groups that prefer to have more light (e.g. green algae and diatoms) are favoured at shallower depths (Wall & Briand, 1979). Some taxonomic groups also have the ability to swim/float towards or away from light depending on their needs. Another resource that is unevenly distributed within the water column is the light spectrum. Since major taxonomic groups differ in their pigment composition they utilize different wavelengths of light. All taxonomic groups possess the photosynthetic pigment chlorophyll a, however, they usually have additional photosynthetic pigments (e.g. chlorophyll b, c, d, e) and accessory pigments (e.g. carotenoids, xanthophylls, and biliproteins). These pigments allow phytoplankton to absorb certain wavelengths of light, favouring some taxonomic groups over others. For example, red radiation usually increases the proportion of blue-green algae, whereas the proportion of dinoflagellates is usually decreased (Wall & Briand, 1979). Since phytoplankton can utilize different light intensities and wavelengths, potential competition is reduced. Thus, many taxonomic groups can be distributed throughout the water column.

Water temperature also influences photosynthesis. Since the minimal temperature to perform photosynthesis differs between taxonomic groups, some groups have a low minimal temperature (e.g. diatoms), whereas others have a much higher minimal temperature (e.g. blue-green algae) (Robarts & Zohary, 1987). Numerous factors influence water temperature such as light, depth, flow velocity, etc.

Chemical Factors

Inorganic ions (e.g. nutrients and metals) and organic molecules (e.g. hydrocarbons and polychlorinated biphenyls) can change the abundance and composition of phytoplankton communities; however, focus will be placed on the major classes of inorganic contaminants as they are chemical factors relevant to this thesis.

Nutrients are an essential resource for phytoplankton, however, nutrient requirements differ among taxonomic groups. Although many macronutrients and micronutrients are required, only the major ones will be discussed further. The major limiting macronutrients for phytoplankton are phosphorus (i.e., PO^{4-}) and nitrogen (i.e., NH^{4+}, NO^{2-}, and NO^{3-}), though phosphorus is usually the limiting nutrient in freshwater systems. Both are equally important for maintaining cell membranes and constructing proteins. These macronutrients are naturally present in aquatic systems; however, they can be altered by anthropogenic sources. The major limiting micronutrients for some phytoplankton are silica (Si) and iron (Fe). These micronutrients are derived from natural weathering of land, however, they also can be altered by anthropogenic sources (Lund, 1965).

Metals are also naturally present in the environment and needed for enzymatic functions; however they can become elevated from anthropogenic activities. Since metals are non-biodegradable they may accumulate in the environment and pose a threat to organisms.

Biological Factors

Grazing, parasitism and pathogens can also change the abundance and composition of phytoplankton communities. Zooplankton grazing has been studied extensively as it is a main factor for regulating phytoplankton abundance and composition, however parasites and pathogens are just beginning to be studied (Gachon, Sime-Ngando, Strittmatter, Chambouvet, & Kim, 2010). A study by Lampert, Fleckner, Rai, & Taylor (1986) showed that during the spring clear-water phase, zooplankton grazing was a significant factor in reducing phytoplankton biomass and other factors (i.e. nutrients and sedimentation of phytoplankton) were negligible. This study verifies that the clear-water phase and the zooplankton biomass peak are not just a coincidence.

3.1.1.2 Major Groups and Their Preferences for Certain Environments

Phytoplankton can be grouped into ten major divisions (i.e. phyla) based on morphological, biochemical and cytological characteristics. These major divisions are Bacillariophyta (i.e. diatoms), Chlorophyta (i.e. green algae), Chrysophyta (i.e. golden-brown algae), Cryptophyta (i.e. cryptomonads), Cyanophyta (i.e. cyanobacteria, more commonly known as blue-green algae), Dinophyta (i.e. dinoflagellates), Euglenophyta (i.e. euglenoids), Xanthophyta (i.e. yellow-green algae), Phaeophyta (i.e. brown algae) and Rhodophyta (i.e. red algae). Other minor divisions exist; however, they have less of an impact on freshwater environments due to their low densities. Rather than going into detail about the morphological and cytological characteristics of these major divisions, their preferences for certain environments will be briefly described.

Bacillariophyta (Diatoms)

Diatoms are found in both lakes and rivers. They can be either planktonic (i.e. present in surface waters), benthic epiphytic (i.e. attached to filaments or macrophytes) or epizoic (i.e. attached on animals). Planktonic diatoms are usually either meroplanktonic meaning they bloom once and then spend the majority of the year as resistant cells or holoplanktonic meaning they bloom once and are present throughout the year but have a minor abundance. In spring and early summer, diatoms are abundant in many temperate lakes when nutrient levels (i.e., phosphorus, nitrogen, and silica) are high. Some diatoms are also known to bloom in the fall as well when circulation occurs and nutrient levels are high again. In addition to tolerating low light and low water temperatures, diatoms can cope with turbulent conditions (Bellinger & Sigee, 2010a).

Chlorophyta (Green Algae)

Green algae usually become dominant or co-dominant under mesotrophic and eutrophic conditions in the early summer. They can form surface blooms and out-compete blue-green algae if the nutrient levels become high enough in the mid to late summer. Due to their wide range of preferences these algae are found in varying environments. Many desmids (i.e. sub-division of green-algae) are found in oligotrophic lakes and rivers that are slightly acidic, whereas others are found in more eutrophic conditions. This is not to say that they only exist in acidic environments, some live in alkaline environments as well. In addition to their wide range of preferences, they have also adapted advantageous traits like changing their mode of nutrition (e.g. mixotrophy or heterotrophy) (Bellinger & Sigee, 2010a).

Chrysophyta (Golden-Brown Algae)

Golden-brown algae can tolerate adverse conditions such as acidic and low nutrient lakes. They have also developed other modes of nutrition such as mixotrophy. Although they can be important primary producers in freshwater environments, they also act as a nuisance species when they reach high population levels by giving water a fishy smell (Bellinger & Sigee, 2010a).

Cryptophyta (Crytomonads)

Cryptomonads are usually abundant in cold temperate lakes. They usually appear during the early spring and in the early summer. Since they exhibit traits of a r-strategist, they can cope better with the grazing pressure of zooplankton. They also can tolerate low light, thus occupy a large range within the water column. Like many other major phytoplankton groups, crytomonads can be mixotrophic or heterotrophic as well (Bellinger & Sigee, 2010a).

Cyanophyta (Cyanobacteria or Blue-Green Algae)

Blue-green algae have adapted to numerous freshwater environments and are known to out-compete other phytoplankton under nutrient rich conditions. Since many taxa exhibit optimal growth at high temperatures they usually inhabit eutrophic temperate lakes in the mid to late summer. They can tolerate low light, high pH, and low carbon dioxide concentrations which allow them to dominate and continue growth during intense bloom formation. Blue-green algae also have a symbiotic relationship with aerobic bacteria, which is needed for nitrogen fixation when N:P ratios are low. If the epilimnion becomes depleted of nutrients or the algae become photoinhibited they have the ability to regulate their buoyancy and move throughout the water column. Grazing pressure is also reduced as they are a non-preferable food source (Bellinger & Sigee, 2010a).

Dinophyta (Dinoflagellates)

Dinoflagellates are present in the surface waters of lakes and ponds at certain times of the year. They are large-celled organisms that have a long cell cycle and low rate of cell division. Since they exhibit traits of a K-strategist, they dominate environments when algal populations are high and resources are scarce. Dinoflagellates usually have two opportunities to bloom. The first opportunity is in early summer when the germination of cysts occurs. The second opportunity is in the midsummer to autumn when the surface water has very low levels of phosphorus; however, this may be disrupted if blue-green algae bloom instead. Dinoflagellates prefer high calcium levels but low nutrient levels. In addition, some have developed alternate modes of nutrition (e.g. mixotrophy or heterotrophy) (Bellinger & Sigee, 2010a).

Euglenophyta (Euglenoids)

Euglenoids are heterotrophs and prefer environments that are abundant in decaying organic material. Therefore, they are usually abundant in shallow lakes at the sediment-water interface or the air-water interface. Although they may not be regarded as truly planktonic algae, they can tolerate extreme environmental conditions such as very low pH's and metal contamination (Bellinger & Sigee, 2010a).

Xanthophyta (Yellow-Green Algae)

Yellow-green algae do not usually become dominant in freshwater because of their preference towards mud and soil environments. True planktonic forms exist; however, the majority of yellow-green algae are epiphytic and attach to filamentous algae or macrophytes. In addition to their very specific habitat preferences, some have also developed alternative modes of nutrition and ingest other algal species (i.e. holozoic) (Bellinger & Sigee, 2010a).

Phaeophyta (Brown Algae) and Rhodophyta (Red Algae)

Brown algae are mostly marine, but they are all benthic freshwater species. Similarly, red algae are mostly marine; however, freshwater species do exist but mainly in streams and rivers. If their abundance is large they usually can be seen due to their large cell size. They also have a range of morphologies that allow them to cope in moving waters (Bellinger & Sigee, 2010a).

3.1.1.3 Predicting Community Structures

Phytoplankton species or communities can prefer or tolerate particular habitats. Furthermore, they can thrive and out-compete other phytoplankton under certain water quality conditions, therefore they serve as good bioindicators (Longhi & Beisner, 2010; Reynolds, 1984). Although phytoplankton communities cannot be predicted with certainty based on environmental conditions, physical and chemical changes in the environment as well as their duration and intensity can be inferred by monitoring the resident phytoplankton community. By analyzing the abundance and composition of phytoplankton communities over space and time, the impacts of point and non-point sources from the surrounding landscape can be measured.

A disturbance will be defined as any physical and/or chemical change in the environment that alters the phytoplankton composition. Disturbances can be broken down further based on their source, timescale (i.e. duration and frequency), spatial scale, intensity and specificity. Therefore, disturbances can be classified as natural or anthropogenic based on their source, press (i.e. chronic disturbances) or pulse (i.e. acute disturbances) based on their timescale, localized or regional based on their spatial scale, subtle or severe based on their intensity, and non-specific or specific based on their specificity.

The scale of the disturbance (i.e. their severity and frequency) will determine the composition of phytoplankton communities. If the disturbance is sufficiently frequent, the phytoplankton community may become dominate by those that are capable of tolerating or surviving the disturbance (K-strategists). These type of organisms are usually large, colonial, motile, and slower growing phytoplankton. They are generally found later in succession when nutrients are segregated and the water column is stratified. However, if the disturbance is severe and less frequent then the phytoplankton community may be dominated by those that arrive and establish themselves first (i.e. r-strategists). These type of organisms are usually small, unicellular and rapidly growing phytoplankton. They are generally found early in stratification when nutrients are readily available in the upper water column. Continuous disturbance should not change the phytoplankton community, as it represents a form of environmental constancy (Reynolds, 1993).

Numerous studies have tried to develop habitat templates, to separate phytoplankton based on spatial and temporal patterns which they exhibit in aquatic environments. The earliest template was devised by Margalef (1978), using turbulence and nutrients as quantified environmental parameters acting upon phytoplankton over time. This template was revised the following year to accommodate morphological diversity of two major phytoplankton groups, diatoms and dinoflagellates. Reynolds (1980) followed his lead and began devising his own templates to organise ecological information. His first attempt used nutrient availability and column stability as quantified environmental parameters acting upon twelve phytoplankton groups over time. These groups were constructed based on species that regularly co-occur with one another and distinguished by alphanumerics. Later attempts by Reynolds (2003) included grouping phytoplankton with similar ecologies into one of three groups (r-strategists, K-strategists, or w-strategists), changing the quantified environmental parameters, giving ranges to the alphanumeric representatives, adding and revising phytoplankton categories, etc. These types of models could become useful for predicting phytoplankton community composition in fluctuating environments, since environmental changes are known to select species that prefer or tolerate such conditions. By understanding how these communities adapt to environmental fluctuations and linking this to ecosystem functioning, further advancements can be made in ecosystem ecology.

3.1.2 Purpose and Objectives

The purpose of this chapter was to determine how water quality can affect the community structure of phytoplankton in the VRMT. To achieve this, following short-term objectives were established:

1) Assess spatial and temporal patterns of total phytoplankton biomass and major phytoplankton group biomass.

2) Determine if there are predictive relationships between the water quality and the abundance and composition of phytoplankton communities (i.e. major phytoplankton groups and phytoplankton genera).

To meet these objectives, phytoplankton data (i.e. local-scale data) were analyzed and investigated independently. Thus, one-way ANOVAs and linear effects models were used to assess spatial and temporal patterns of total phytoplankton biomass and major phytoplankton group biomass. In addition, figures were used to summarize the abundance and composition of major phytoplankton groups and Chl-a concentrations were used as a reference. Afterwards, phytoplankton data were investigated with water quality. Thus, ordinations (i.e. CAs and CCAs) and statistical analyses (i.e. one-way ANOVAs and multiple comparisons) were used to detect predictive relationships between water quality and phytoplankton structure.

3.2 Methods

3.2.1 Study Area and Sites

Refer to 2.2.1 Study Area and Sites (pg.26).

3.2.2 Data Collection

Local-Scale Data (i.e. sample collection at sites)

Refer to the Local-Scale Data (i.e. sample collection at sites) section in previous chapter (pg.31).

Water Quality

Refer to the Water Quality section in previous chapter (pg.32).

Phytoplankton

Surface water samples were fixed with Lugol's iodine solution and sent to UOIT in Oshawa, Ontario. Samples were stored in the dark at room temperature. The samples were concentrated via sedimentation. An aliquot of 100mL was transferred into a 100mL graduated cylinder and placed in the dark for 24 hours. The top 90mL was carefully siphoned off and the remaining 10mL was resuspended and transferred into a 10mL graduated cylinder. This cylinder was placed in the dark for 24 hours. The top 9mL was carefully siphoned off and the remaining 1mL was resuspended and transferred into a 1.5mL ependorf tube. Using the EVOS xlcore, samples were enumerated and identified using a PhycoTech (ID#615) nanoplankton chamber with a fixed volume of 0.098mL. Using one transect, taxa were identified to genus, and species when possible. Identification resources included: Bellinger & Sigee, 2010b; John, Whitton, & Brook, 2011; Wehr & Sheath, 2003. For solitary cells that were relatively the same size for all sites, about 25 cells were measured for each phytoplankton genus or species to determine the mean cell biovolume. For the majority of filaments, colonies, and solitary cells that were variable in size, they were measured individually to determine the biovolume. These biovolumes assisted in calculating total phytoplankton, major phytoplankton group, and genera biovolumes, which were then converted into biomass (Lund, Kipling, & Le Cren, 1958).

3.2.3 Data Analyses

3.2.3.1 Spatial and temporal patterns of total phytoplankton biomass and major phytoplankton group biomass

Boxplots were constructed to visualize spatial (i.e. sites) and temporal (i.e. sampling dates) variations of total phytoplankton biomass and major phytoplankton group biomass (package: ggplot2) (Wickham, 2009). Each boxplot denotes the: minimum, 25% quartile, median, 75% quartile, maximum, and outliers (<Q1-1.5*IQR or >Q3+1.5*IQR) if present (package:ggplot2) (Wickham, 2009). To detect if sites and sampling dates differed significantly in 2013 and in 2014 with respect to total phytoplankton biomass and major phytoplankton group biomass, one-way ANOVAs were performed with the aov and anova commands (package: stats) (R Core Team, 2015). Since the dataset was unbalanced (i.e. missing values for sites and sampling dates), linear mixed effects models were also created using lmer (package: lme4) to detect relationships between sampling dates while taking into account site differences (i.e. by-site variability) in 2013 and in 2014 (Bates, Maechler, Bolker, & Walker, 2014). Sampling date was used for the fixed effect term, and for the random effects term intercepts were created for each site. P-values were obtained by likelihood ratio tests of the full model (lmer(biomass.group ~ sampling.date + (1|site))) against the reduced model (lmer(biomass.group ~ 1 + (1|site))) using the anova command (package: stats) (R Core Team, 2015). Although results were considered significant if the p-value was <0.05, a p-value <0.10 could also be considered significant if one wants to reduce the type II error, thus the following p-values were provided in tables: 0.10, 0.05, and 0.01.

3.2.3.2 Summary of total phytoplankton biomass and major phytoplankton group biomass in 2013 and 2014, using Chl-a as a reference

Total phytoplankton biomass and major phytoplankton group biomass for each sampling date are provided in Appendix B (Table C1 and Table C2-Table C13). Annual averages for major phytoplankton group biomass were also calculated, however, some sites were omitted from these calculations since they were missing biomass values for one or more sampling dates in that year (Table C14 and Table C 15). Bar graphs were constructed to condense and summarize the biomass and percent composition of major phytoplankton groups for all sites and sampling dates (i.e. all samples analyzed) (package: ggplot2) (Wickham, 2009). Additional bar graphs were also constructed to compare the spatial and temporal trends for Chl-a and total phytoplankton biomass (i.e. the sum of major phytoplankton group biomass) (package: ggplot2) (Wickham, 2009).

3.2.3.3 One-way ANOVAs and multiple comparisons on Chl-a, total phytoplankton biomass, and major phytoplankton group biomass upstream and downstream of the Sudbury WWTP

Since sites located on the main-stem of the Junction tributary appeared to have above average values for nutrients in the previous chapter (refer to 2.3.0.6 One-way ANOVAs and multiple comparisons on nutrient concentrations upstream and downstream of the Sudbury WWTP, pg.47), line graphs were also created to show the annual average Chl-a concentrations, total phytoplankton biomass, and major phytoplankton group biomass upstream and downstream of the Sudbury WWTP (package: ggplot2) (Wickham, 2009). One-way ANOVAs and multiple pairwise comparisons were performed with the aov, anova and pairwise.t.test commands (package: stats) to determine if annual average Chl-a concentrations, total phytoplankton biomass, and major phytoplankton group biomass at the site upstream of the Sudbury WWTP were significantly different to the sites downstream in 2013 and in 2014 (R Core Team, 2015). Although results were considered significant if the p-value was <0.05, a p-value <0.10 could also be considered significant if one wants to reduce the type II error, thus the following p-values were provided in tables: 0.10, 0.05, and 0.01.

3.2.3.4 Correspondence analyses (CAs) on major phytoplankton groups

Correspondence analyses (CAs) were performed on the annual average biomass of major phytoplankton groups, to visualize the relationships between major phytoplankton groups and sites. The ca command (package: ca) was used, data was extracted from the matrices and plotted (package:ggplot2) (Nenadic &

Greenacre, 2007; Wickham, 2009). Since the dataset was unbalanced (i.e. missing values for sites and sampling dates), some sites were omitted. Thus the following sites were omitted from 2013: VER-1, ONP-3, WIT-7, WIT-8, LEV-9, VER-10, LIL-11, and JUN-13. In addition, the following sites were omitted in 2014: VER-1, VER-10, WAB-26, WAB-27, and VER-28.

3.2.3.5 Canonical correspondence analyses (CCAs) on major phytoplankton groups and water quality

Canonical correspondence analyses (CCAs) were performed on the annual average biomass of major phytoplankton groups and general biological/chemical parameters and nutrients, or metals, to detect relationships between major phytoplankton groups, water quality parameters, and sites. The cca command (package: ade4) was used, data was extracted from the matrices and plotted (package:ggplot2) (Dray, Dufour, & Chessel, 2007; Wickham, 2009). As mentioned previously, the dataset was unbalanced (i.e. missing values for sites and sampling dates) so some sites were omitted (refer to 3.2.3.4 Correspondence analyses (CAs) on major phytoplankton groups, pg. 72).

3.2.3.6 Summary of genera observed in 2013-2014

Although annual averages for genera were calculated for subsequent analyses, these values were omitted from the thesis. However, a table of the genera observed in 2013-2014 was provided in Appendix B (Table C18).

3.2.3.7 Canonical correspondence analyses (CCAs) on genera and water quality

CCAs were also performed on the annual average biomass of genera and general biological/chemical parameters and nutrients, or metals using the same method outlined previously (refer to 3.2.3.5 Canonical correspondence analyses (CCAs) on major phytoplankton groups and water quality, pg.73). Since it was difficult to distinguish trends using all genera, CCAs were also performed on the genera of specific major phytoplankton groups that are known to be ideal bioindicators (i.e. Bacillariophyta, Chlorophyta, Chrysophyta, and Cyanophyta).

3.2.3.8 Summary of Anabaena and Microcystis biomass in 2013 and 2014

Line graphs were used to condense and summarize the biomass of *Anabaena* and *Microcystis* for all sites and sampling dates (package: ggplot2) (Wickham, 2009).

3.3 Results

3.3.0.1 Spatial and temporal patterns of total phytoplankton biomass and major phytoplankton group biomass

Boxplots were constructed to show the spatial variations of total phytoplankton biomass and major phytoplankton group biomass (Figure 26 and Figure 27). One-way ANOVAs revealed that there was at least one site that was significantly different from the others in 2013 and/or 2014 for: total phytoplankton biomass (2013: p=0.002 and 2014: p<0.001), Bacillariophyta (2013: p<0.001), Chrysophyta (2013: p<0.001), Cryptophyta (2013: p=0.011 and 2014: p<0.001), Cyanophyta (2013: p<0.001 and 2014: p<0.001), Dinophyta (2013: p=0.012 and 2014: p=0.001), Euglenophyta (2013: p<0.001), and Xanthophyta (2014: p=0.037). However, these analyses revealed that there were no significant differences between sites in 2013 and/or 2014 for: Bacillariophyta (2014: p=0.245), Chlorophyta (2013: p=0.065 and 2014: p=0.100), Chrysophyta (2014: p=0.169), Euglenophyta (2014: p=0.350), and Xanthophyta (2013: p=0.467).

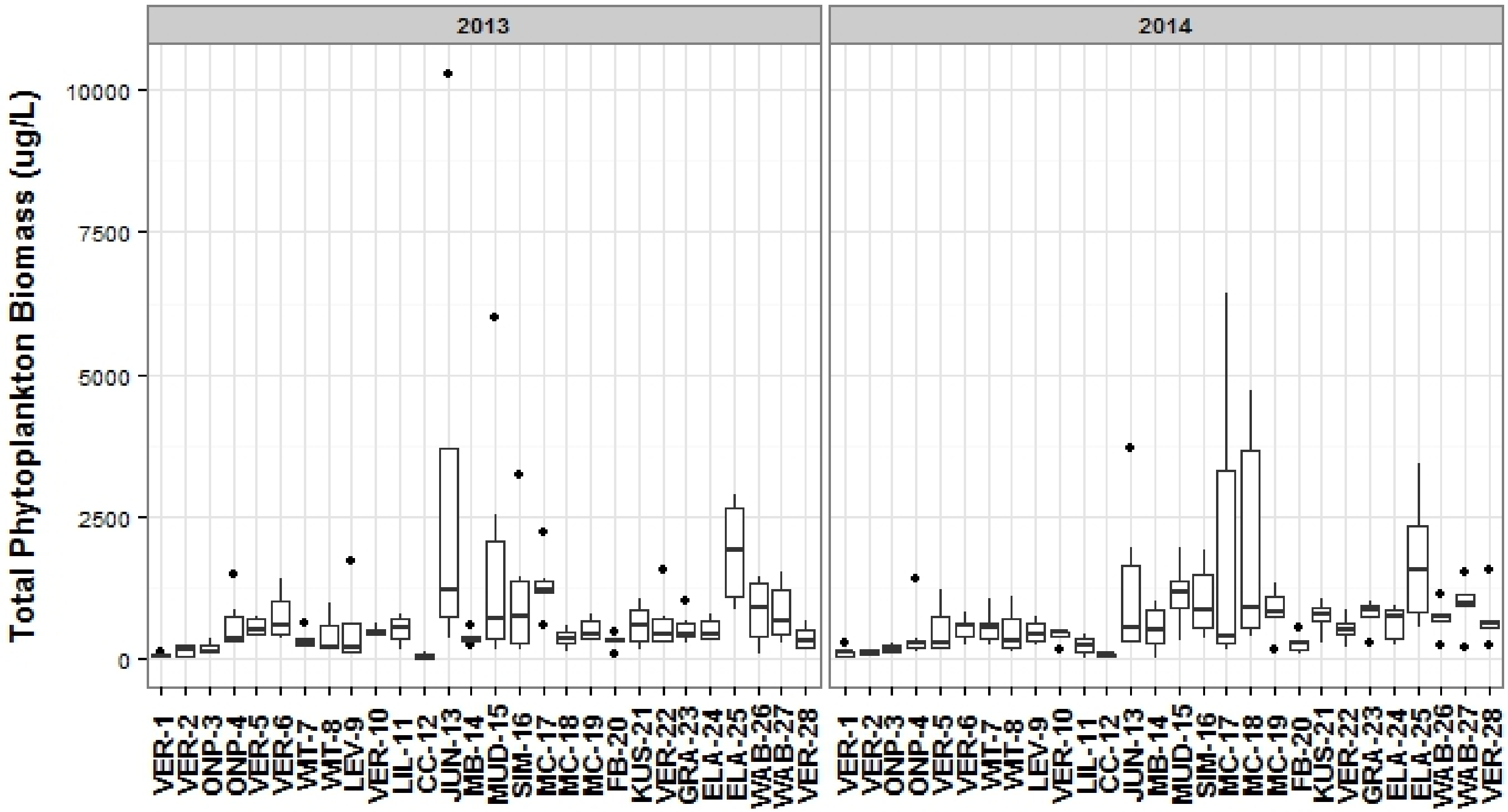

Figure 26 Spatial variations of total phytoplankton biomass for the twenty-eight sites in 2013 and 2014.

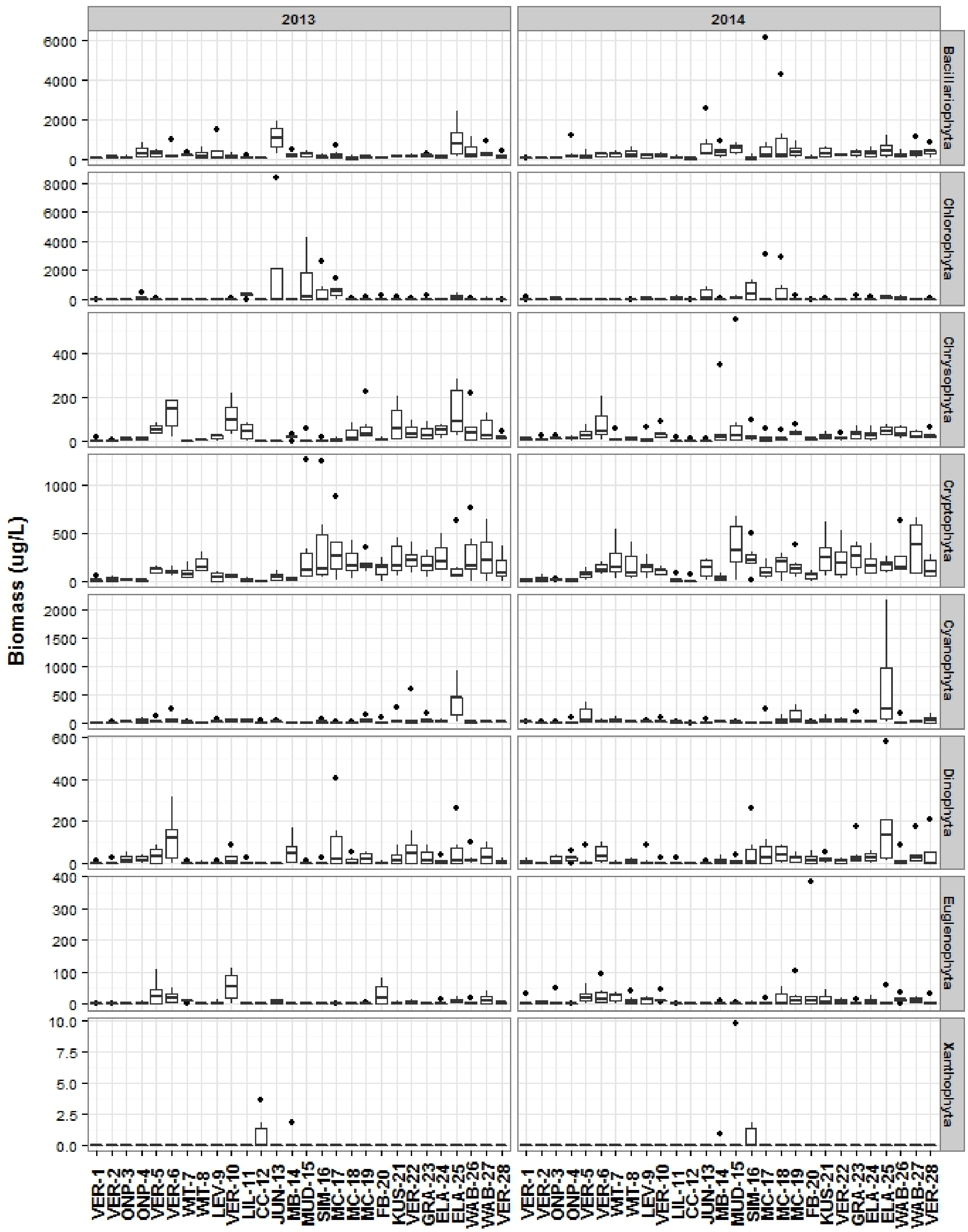

Figure 27 Spatial variations of major phytoplankton groups for the twenty-eight sites in 2013 and 2014.

Similarly, boxplots were constructed to show the temporal variations of total phytoplankton biomass and major phytoplankton group biomass (Figure 28 and Figure 29). One-way ANOVAs revealed that there was at least one sampling date that was significantly different from the others in 2013 and/or 2014 for: total phytoplankton biomass (2014: p=0.027), Chlorophyta (2014: p=0.038), and Cryptophyta (2013 and 2014: p<0.001). These analyses also revealed that there were no significant differences between sampling dates in 2013 and/or 2014 for: total phytoplankton biomass (2013: p=0.359), Bacillariophyta (2013: p=0.562 and 2014: p=0.059), Chlorophyta (2013: p=0.526), Chrysophyta (2013: p=0.101 and 2014: p=0.456), Cyanophyta (2013: p=0.305 and 2014: p=0.206), Dinophyta (2013: p=0.280 and 2014: p=0.211), Euglenophyta (2013: p=0.135 and 2014: p=0.067), and Xanthophyta (2013: p=0.686 and 2014: p=0.573).

However, when linear mixed effects models were used to take into account site differences (i.e. by-site variability), more biomass groups appeared to have at least one sampling date that was significantly different from the others in 2013 and/or 2014. These included: total phytoplankton biomass (2014: p=0.006), Bacillariophyta (2014: p=0.044), Chlorophyta (2014: p=0.022), Chrysophyta (2013: p=0.017), Cryptophyta (2013 and 2014: p<0.001), and Euglenophyta (2013: p=0.046). Linear mixed effects models also revealed that there were no significant differences between sampling dates in 2013 and/or 2014 for: total phytoplankton biomass (2013: p=0.246), Bacillariophyta (2013: p=0.459), Chlorophyta (2013: p=0.481), Chrysophyta (2014: p=0.406), Cyanophyta (2013: p=0.102 and 2014: p=0.081), Dinophyta (2013: p=0.198 and 2014: p=0.110), Euglenophyta (2014: p=0.054), and Xanthophyta (2013: p=0.604 and 2014: p=0.555).

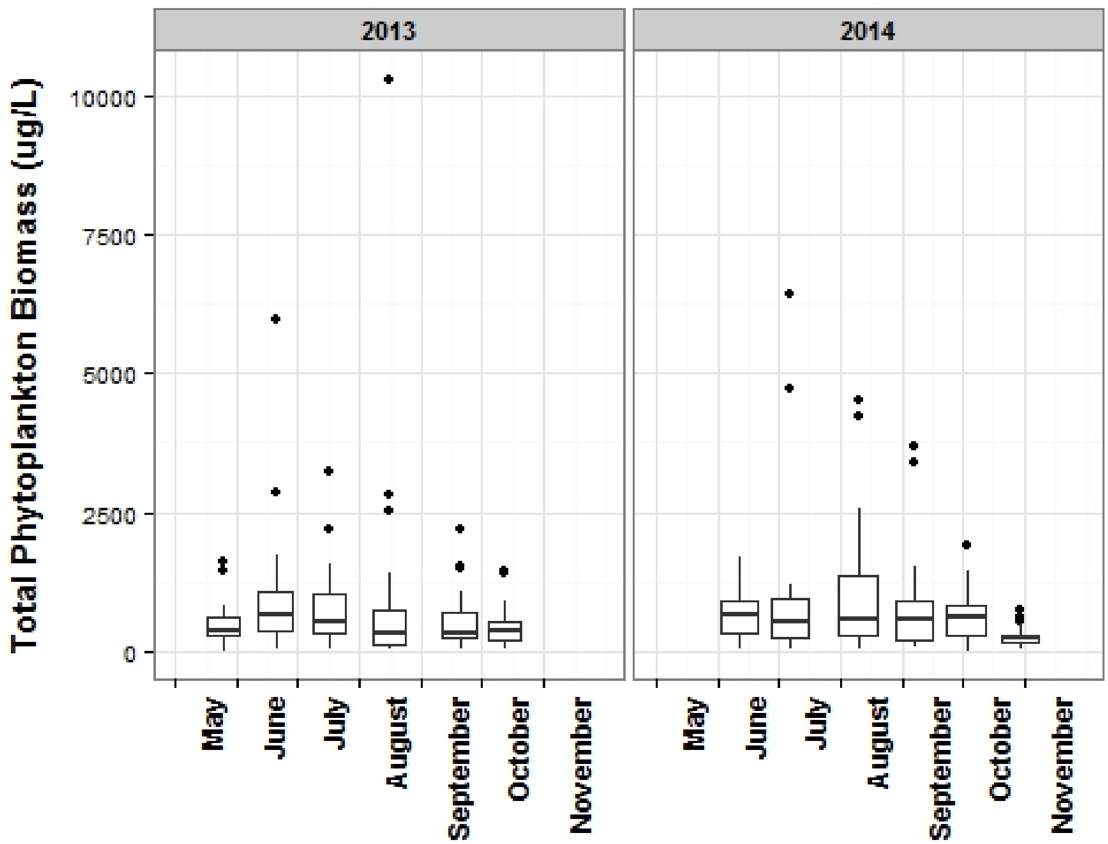

Figure 28 Temporal variations of total phytoplankton biomass for the twenty-eight sites in 2013 and 2014.

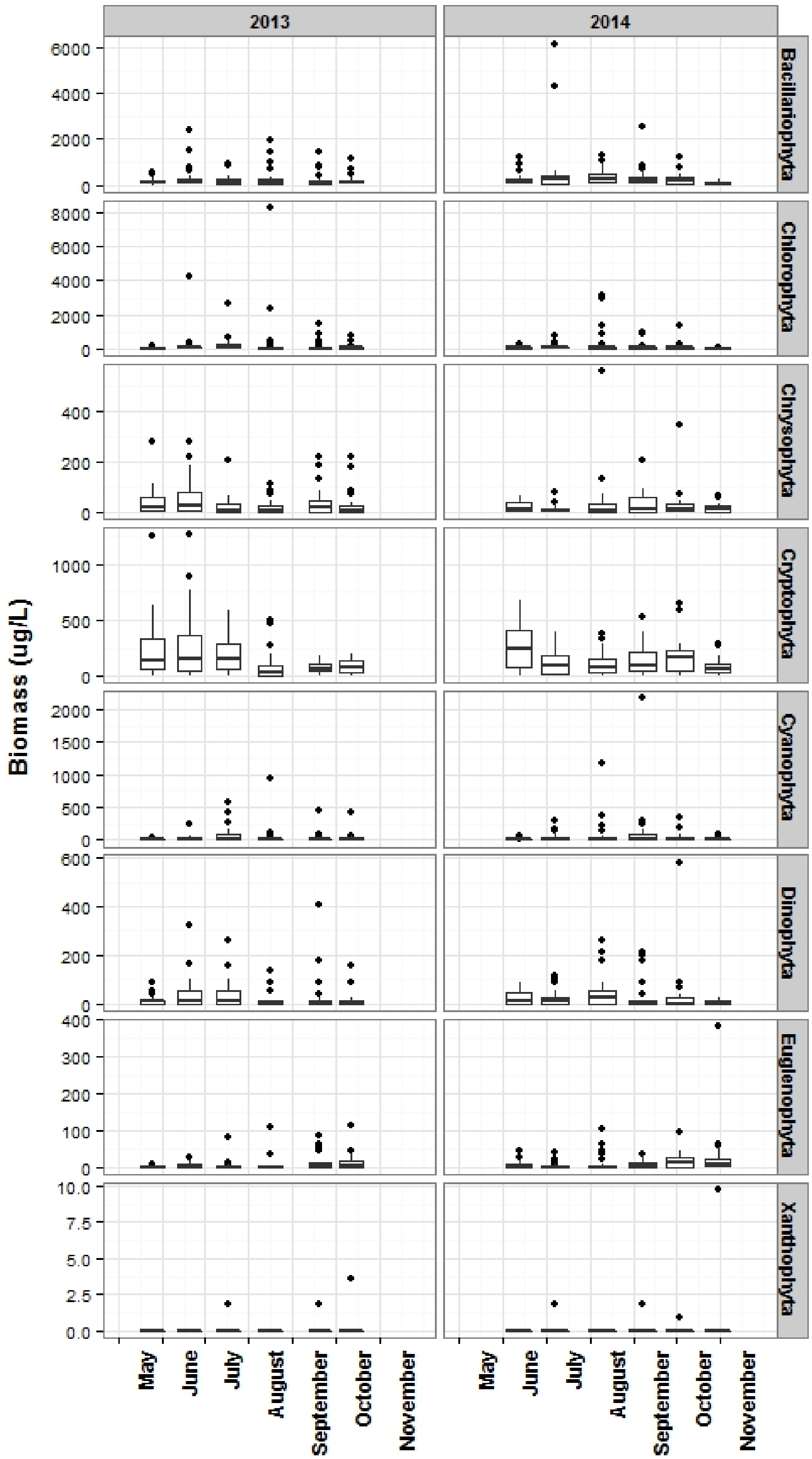

Figure 29 Temporal variations of major phytoplankton groups for the twenty-eight sites in 2013 and 2014.

3.3.0.2 Summary of total phytoplankton biomass and major phytoplankton group biomass in 2013 and 2014, using Chl-a as a reference

The subsequent figures provide a quick overview of the biomass or percent composition of major phytoplankton groups for all samples analyzed (i.e. 314 phytoplankton samples) (Figure 30 and Figure 31). Figure 30 revealed that total phytoplankton biomass varied considerably and ranged from 0ug/L to 10,300ug/L. When taking into account all samples analyzed, Figure 31 revealed that one hundred and seventy-four (55.41%) samples were dominated by Bacillariophyta, ninety-four (29.94%) samples were dominated by Cryptophyta, twenty-nine (9.24%) samples were dominated by Chlorophyta, eight (2.55%) samples were dominated by Cyanophyta, four (1.27%) samples were dominated by Chrysophyta, two (0.64%) samples were dominated by Dinophyta, two (0.64%) samples were dominated by Euglenophyta, and one sample was not dominated by any of the major phytoplankton groups.

Additional bar graphs were also constructed to visualise the spatial and temporal trends for Chl-a and total phytoplankton biomass (i.e. the sum of major phytoplankton group biomass) (Figure C1-Figure C68). Although some figures displayed very similar spatial and temporal trends for Chl-a and total phytoplankton biomass (e.g. Figure C2 and Figure C53), others did not (e.g. Figure C5 and Figure C24).

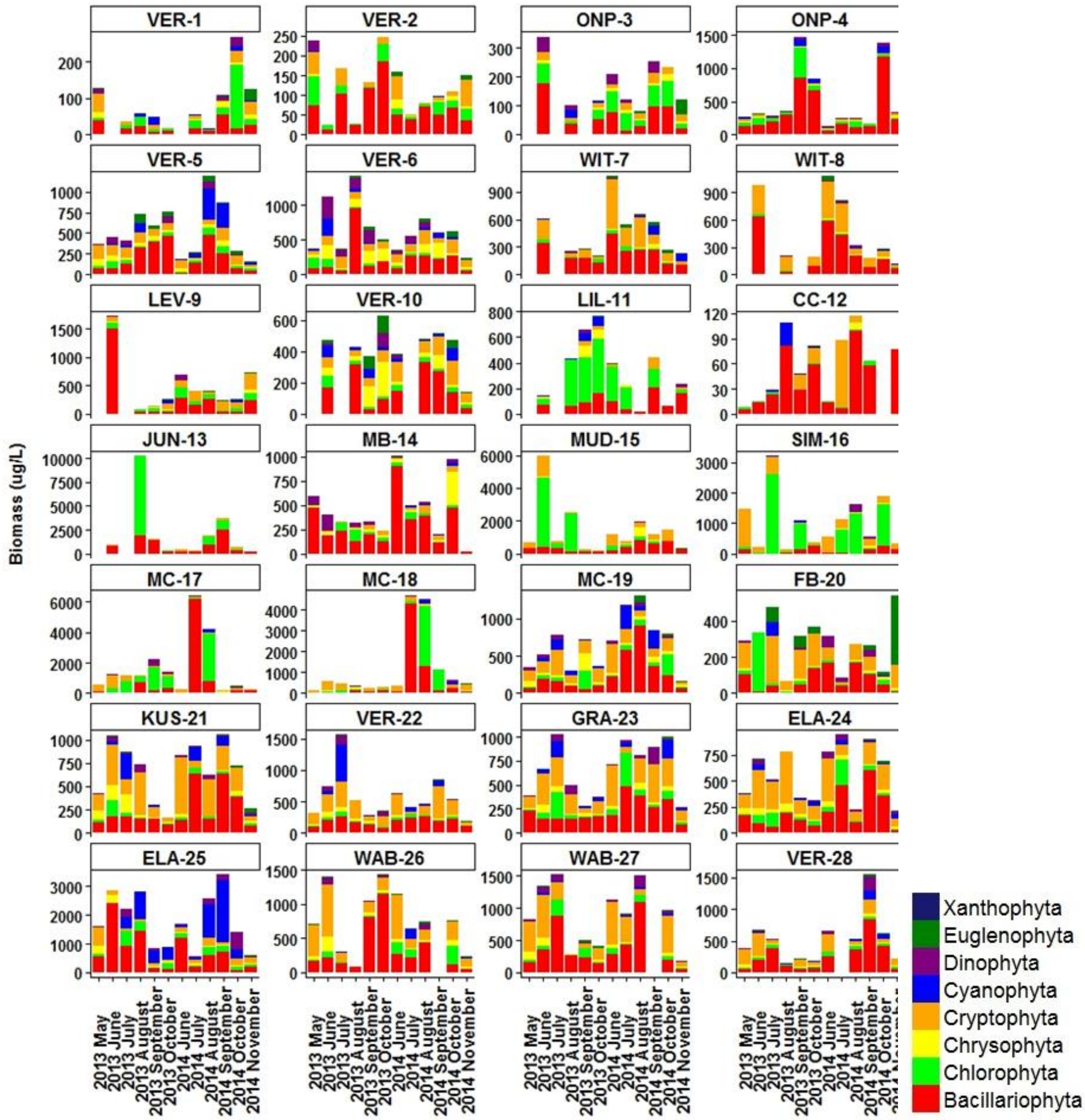

Figure 30 Biomass of major phytoplankton groups for the twenty-eight sites in 2013 and 2014.

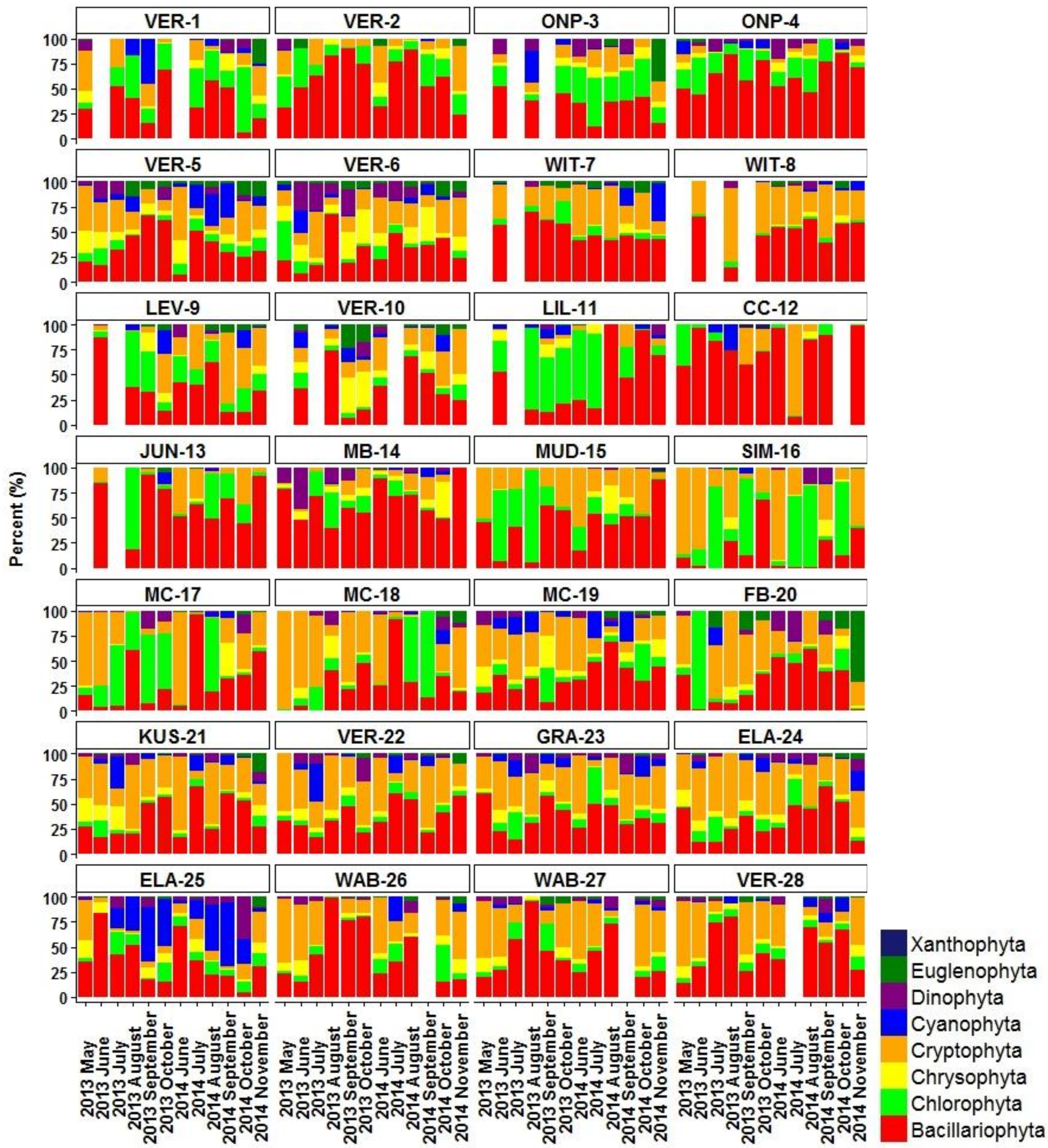

Figure 31 Percent composition of major phytoplankton groups for the twenty-eight sites in 2013 and 2014.

3.3.0.3 One-way ANOVAs and multiple comparisons on Chl-a, total phytoplankton biomass, and major phytoplankton group biomass upstream and downstream of the Sudbury WWTP

Since sites located on the main-stem of the Junction tributary appeared to have above annual average values for nutrients in the previous chapter (refer to 2.3.0.6 One-way ANOVAs and multiple comparisons on nutrient concentrations upstream and downstream of the Sudbury WWTP, pg.47), line graphs were created to show the annual average for Chl-a, total phytoplankton biomass and major phytoplankton group biomass (Figure 32 and Figure 33). The subsequent figures indicate that annual averages for Chl-a and total phytoplankton biomass are lowest upstream of the Sudbury WWTP; whereas annual average for Chl-a and total phytoplankton biomass are higher downstream of the Sudbury WWTP but more variable (Figure 32), in addition, the annual averages for major phytoplankton group biomass are also very variable with Bacillariophyta and Chlorophyta dominating the phytoplankton biomass for many sites (Figure 33). One-way ANOVAs revealed that there was at least one site that was significantly different from the others in 2013 and/or 2014 for: Chl-a (2013: $p<0.001$ and 2014: $p=0.019$), total phytoplankton biomass (2013: $p=0.021$), Bacillariophyta (2013: $p<0.001$), Chrysophyta (2013: $p=0.003$), Cryptophyta (2014: $p=0.040$), Cyanophyta (2013: $p<0.001$ and 2014: $p=0.002$), Dinophyta (2014: $p=0.025$), Euglenophyta (2013: $p=0.006$), and Xanthophyta (2013: $p=0.023$). However, these analyses revealed that there were no significant differences between sites in 2013 and/or 2014 for: total phytoplankton biomass (2014: $p=0.125$), Bacillariophyta (2014: $p=0.565$), Chlorophyta (2013: $p=0.104$ and 2014: $p=0.323$), Chrysophyta (2014: $p=0.307$), Cryptophyta (2013: $p=0.533$), Dinophyta (2013: $p=0.174$), Euglenophyta (2014: $p=0.355$), Xanthophyta (2014: $p=0.478$). Further multiple comparison analyses indicated that some sites downstream of the Sudbury WWTP were indeed significantly different when compared to the site upstream (CC-12) for Chl-a (2013 and 2014), total phytoplankton biomass (2013), and some major phytoplankton groups: Bacillariophyta (2013), Chrysophyta (2013), Cryptophyta (2014), Cyanophyta (2013 and 2014), Dinophyta (2014), Euglenophyta (2013), and Xanthophyta (2013). The results from these multiple comparisons analyses are summarized in Appendix C (Table C16 and Table C17).

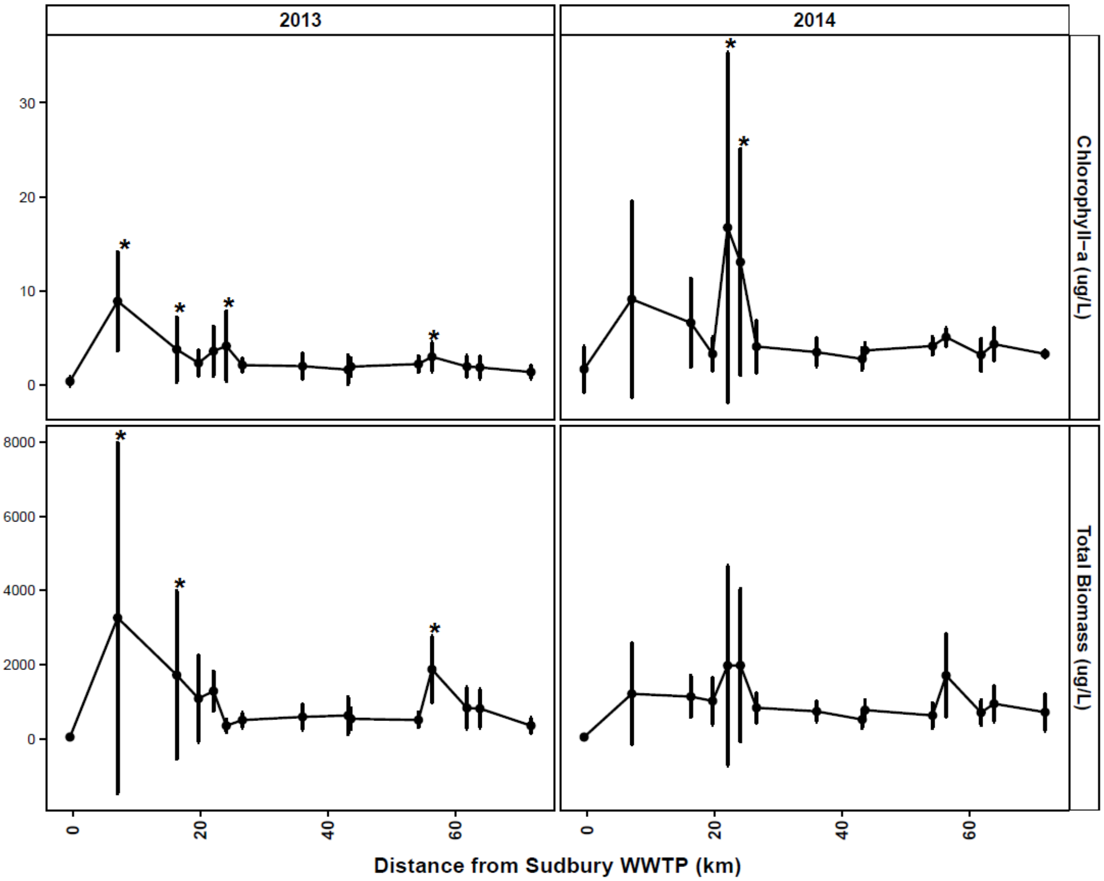

Figure 32 Annual averages for chlorophyll-a concentrations and total phytoplankton biomass upstream and downstream of the Sudbury WWTP. *Chlorophyll-a or total biomass were significantly (p<0.05) higher or lower compared to the site upstream of the Sudbury WWTP (CC-12).

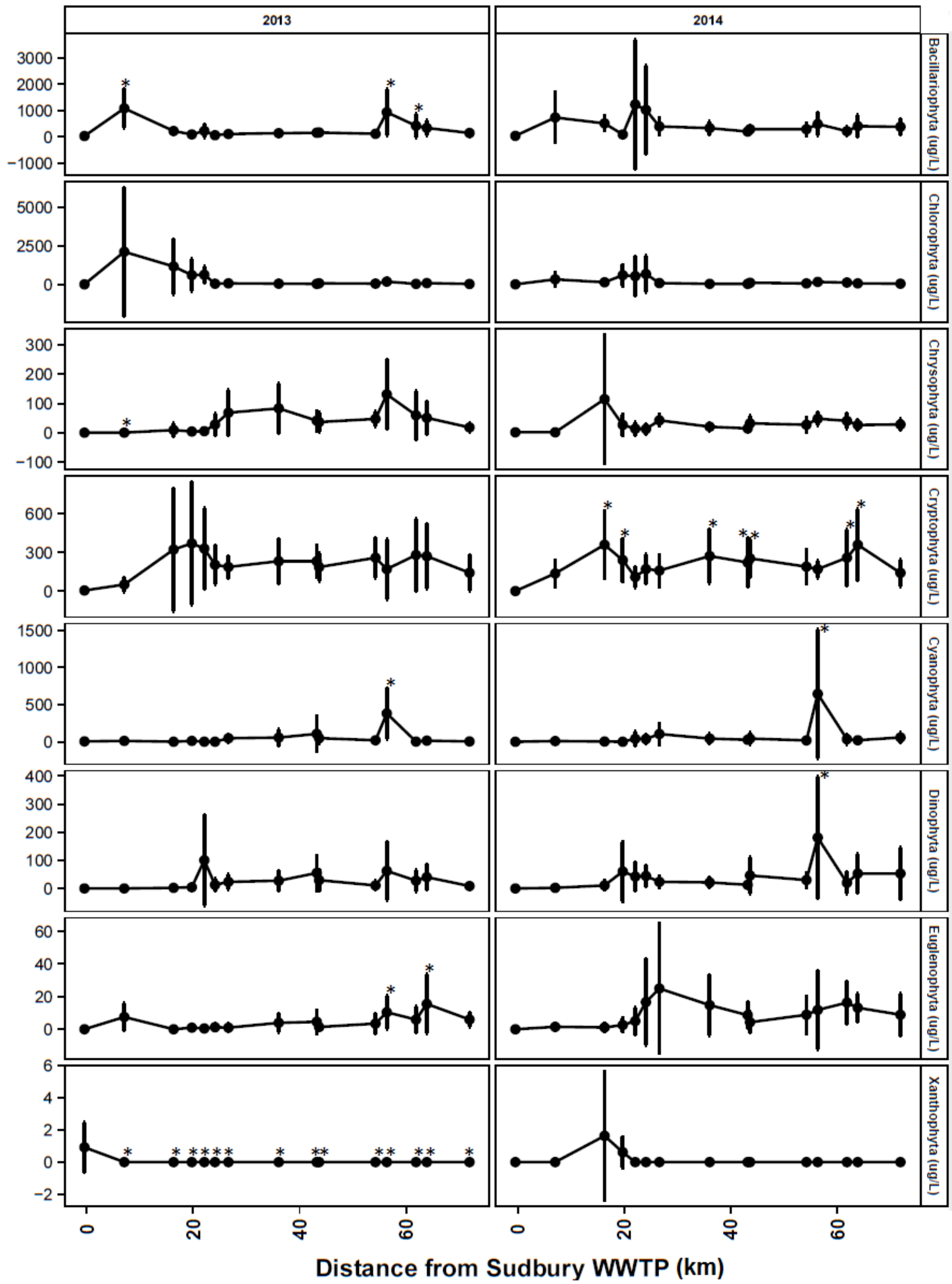

Figure 33 Annual averages for major phytoplankton group biomass upstream and downstream of the Sudbury WWTP. *Major phytoplankton group biomass was significantly ($p<0.05$) higher or lower compared to the site upstream of the Sudbury WWTP (CC-12).

3.2.0.4 Correspondence analyses (CAs) on major phytoplankton groups

CAs were performed on annual major phytoplankton group biomass (Figure 34). When combined, the first and second CA axes explained 74.34% and 66.71% of the variance in 2013 and 2014, respectively. These ordination graphs indicated that certain sites appeared to exhibit above average values of biomass for certain major phytoplankton groups. For example, some sites that exhibited above average values of biomass for both years were: certain sites located on the Junction tributary for Chlorophyta and ELA-25 for Cyanophyta. However, it is important to note that some sites were omitted from these analyses thus direct comparisons between all sites could not be made (refer to 3.2.3.4 Correspondence analyses (CAs) on major phytoplankton groups, pg.72).

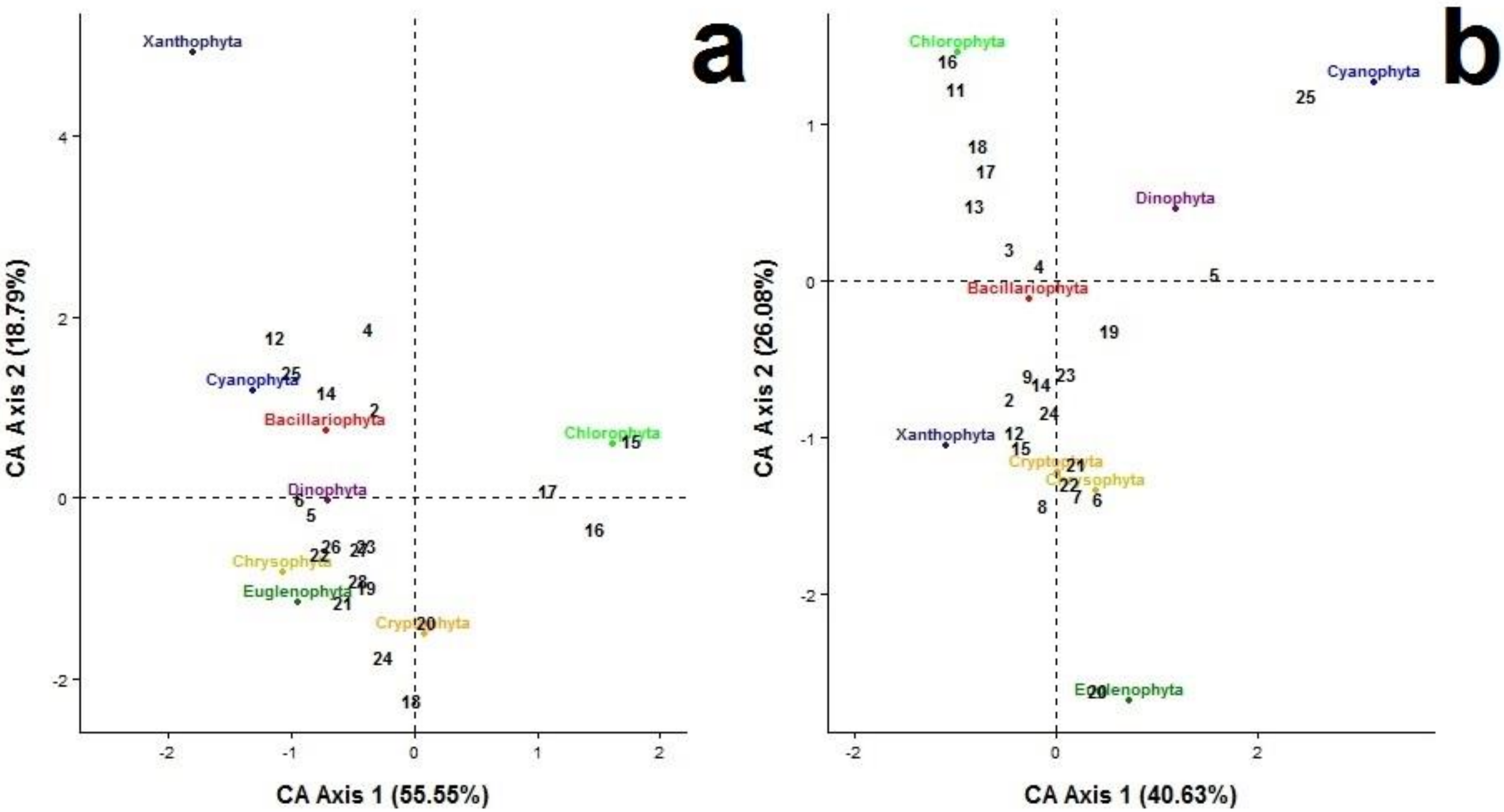

Figure 34 Correspondence analysis performed on annual phytoplankton biomass for (a) 2013 and (b) 2014.

3.3.0.5 Canonical correspondence analyses (CCAs) on major phytoplankton groups and water quality

CCAs were performed on annual major phytoplankton group biomass using annual biological/chemical parameters and nutrients, or metals (Figure 35 and Figure 36). When combined, the first and second CCA axes explained: 80.50% and 79.00% of the variance when using biological and chemical parameters and nutrients, and 74.34% and 66.71% of the variance when using metals in 2013 and 2014, respectively. Thus, biological/chemical parameters and nutrients appeared to be slightly better at explaining the variation when compared to metals.

Sites closest to one another geographically were expected to cluster together; however, many sites did not conform to this assumption. This indicates that although sites are in closer proximity to one another geographically, they are very different based on their water quality and major phytoplankton group composition. It is also important to note that some sites were omitted from these analyses thus direct comparisons between all sites could not be made (refer to 3.2.3.5 Canonical correspondence analyses (CCAs) on major phytoplankton groups and water quality, pg.73).

Based on the lengths of the environmental arrows, it appears that some variables were more important than others when distinguishing sites and community composition. CCAs for general biological/chemical parameters and nutrients revealed that the majority of variables were important or moderately important (e.g. Chl-a, $CaCO_3$, DOC, Cond, Cl, pH, TP, TN, TKN, NO_3, and NO_2). CCAs for metals revealed that variables exhibited a broader range of importance that varied from year to year.

When major phytoplankton groups were projected onto general biological/chemical parameter and nutrient environmental arrows, it appeared that for both years: Chlorophyta had the highest weighted averages for the majority of parameters (i.e. Chl-a, $CaCO_3$, Cond, Cl, TP, TN, TKN, NO_3, and NO_2), whereas, Chrysophyta, Cryptophyta, and Euglenophyta had the highest weighted averages for DOC in 2013 and 2014. Thus, these major phytoplankton groups likely occur when these parameters are elevated above their global average. Other major phytoplankton groups exhibited trends; however, these trends were not consistent from year to year.

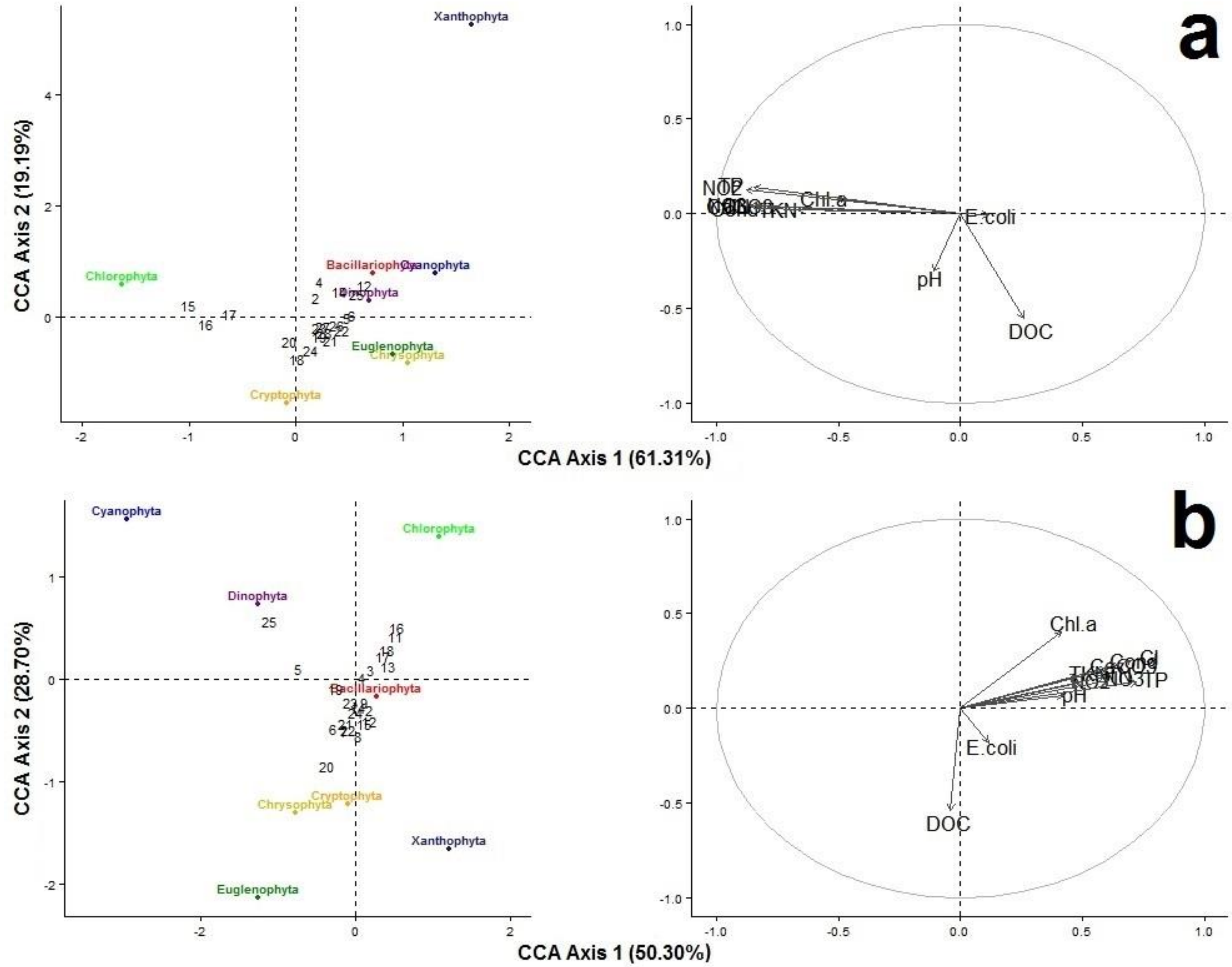

Figure 35 Canonical correspondence analysis performed on annual phytoplankton biomass and chemical/biological parameters and nutrients for (a) 2013 and (b) 2014.

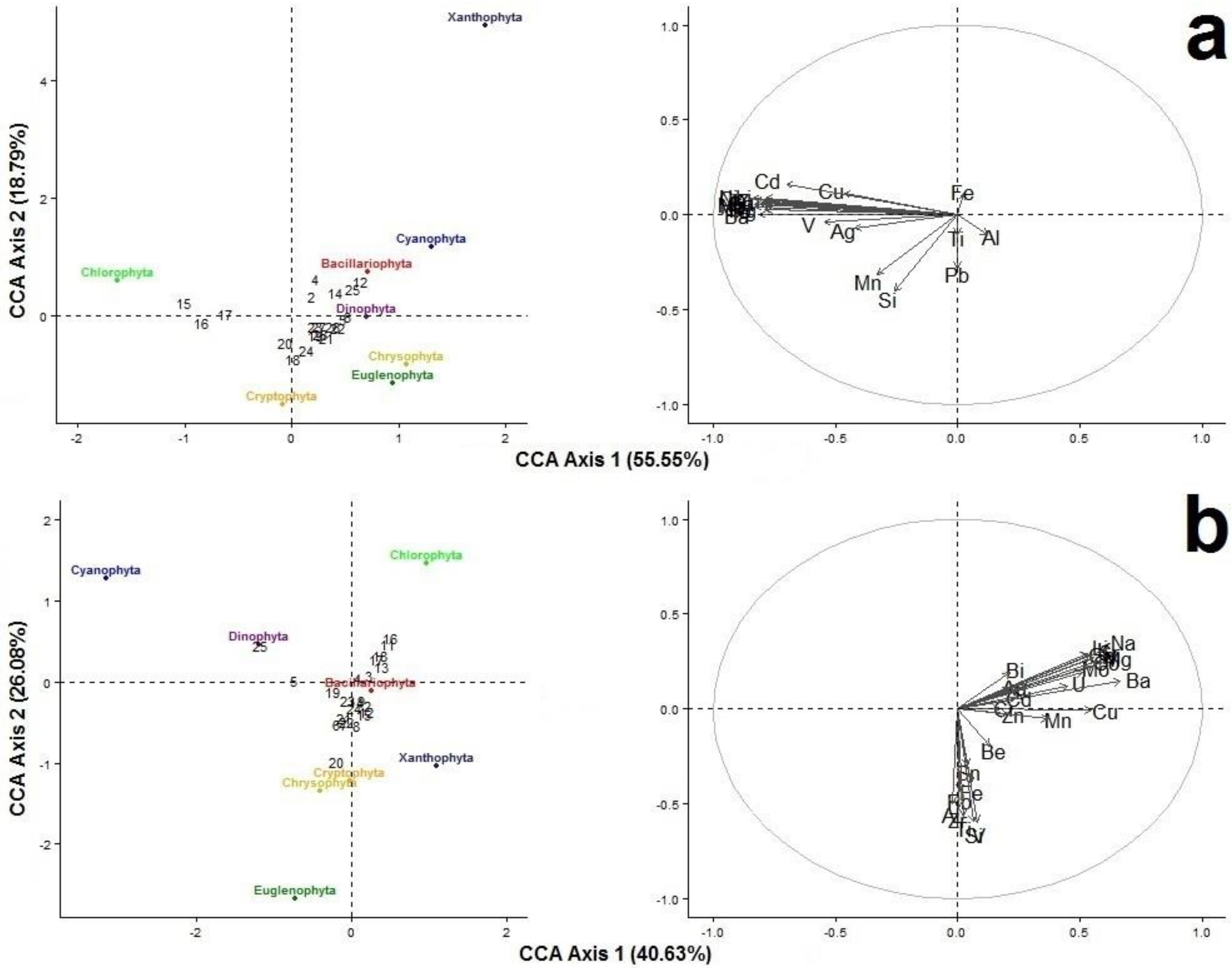

Figure 36 Canonical correspondence analysis performed on annual metals for (a) 2013 and (b) 2014.

3.3.0.6 Summary of genera observed in 2013 and 2014

During the monthly sampling period in 2013 (May-October) and in 2014 (June-November), 132 genera were observed from eight major phytoplankton groups. More specifically, 30 genera represented Bacillariophyta, 59 genera represented Chlorophyta, 8 genera represented Chrysophyta, 3 genera represented Cryptophyta, 21 genera represented Cyanophyta, 5 genera represented Dinophyta, 3 genera represented Euglenophyta, and 3 genera represented Xanthophyta (Table C18).

3.3.0.7 Canonical correspondence analyses (CCAs) on genera and water quality

CCAs were performed on annual genera biomass using annual biological/chemical parameters and nutrients, or metals (Figure 37-Figure 40). When combined, the first and second CCA axes explained: 41.58% and 46.56% of the variance when using biological and chemical parameters and nutrients, and 36.26% and 35.44% of the variance when using metals in 2013 and 2014, respectively. Thus, biological/chemical parameters and nutrients appeared to be slightly better at explaining the variation when compared to metals.

Sites closest to one another geographically were expected to cluster together; however, many sites did not conform to this assumption. This indicates that although sites are in closer proximity to one another geographically, they are very different based on their water quality and genera composition. It is also important to note that some sites were omitted from these analyses thus direct comparisons between all sites could not be made (refer to 3.2.3.7 Canonical correspondence analyses (CCAs) on genera and water quality, pg.73).

Based on the lengths of the environmental arrows, it appears that some variables were more important than others when distinguishing sites and community composition. CCAs for general biological/chemical parameters and nutrients revealed that the majority of variables were important (e.g. Chl-a, $CaCO3$, Cond, Cl, pH, TP, TN, TKN, $NO3$, and $NO2$), whereas, a couple of variables were not (e.g. E.coli and DOC). CCAs for metals revealed that variables exhibited a broader range of importance that varied from year to year.

When sites were projected onto general biological/chemical parameters and nutrient environmental arrows, it appeared that some sites had: above average CaCO3, Cond, Cl, and nutrient concentrations (TP, TN, TKN, NO3, and NO2) in 2013 (e.g. CC-12, MUD-15, SIM-16, and MC-17) and 2014 (e.g. CC-12, JUN-13, MUD-15, SIM-16, MC-17, and MC-18), and above average Chl-a concentrations in 2013 (e.g. MUD-15, SIM-16, MC-17, and MC-18) and 2014 (e.g. MC-17 and MC-18). Interestingly, all of the sites mentioned are located in the Junction tributary. Similarly, when sites were projected onto metal environmental arrows, it appeared that some sites had above average concentrations for the majority of metals in 2013 and 2014 (e.g. CC-12, MB-14, MUD-15, SIM-16, MC-17, and MC-18). These sites were also located on the Junction tributary.

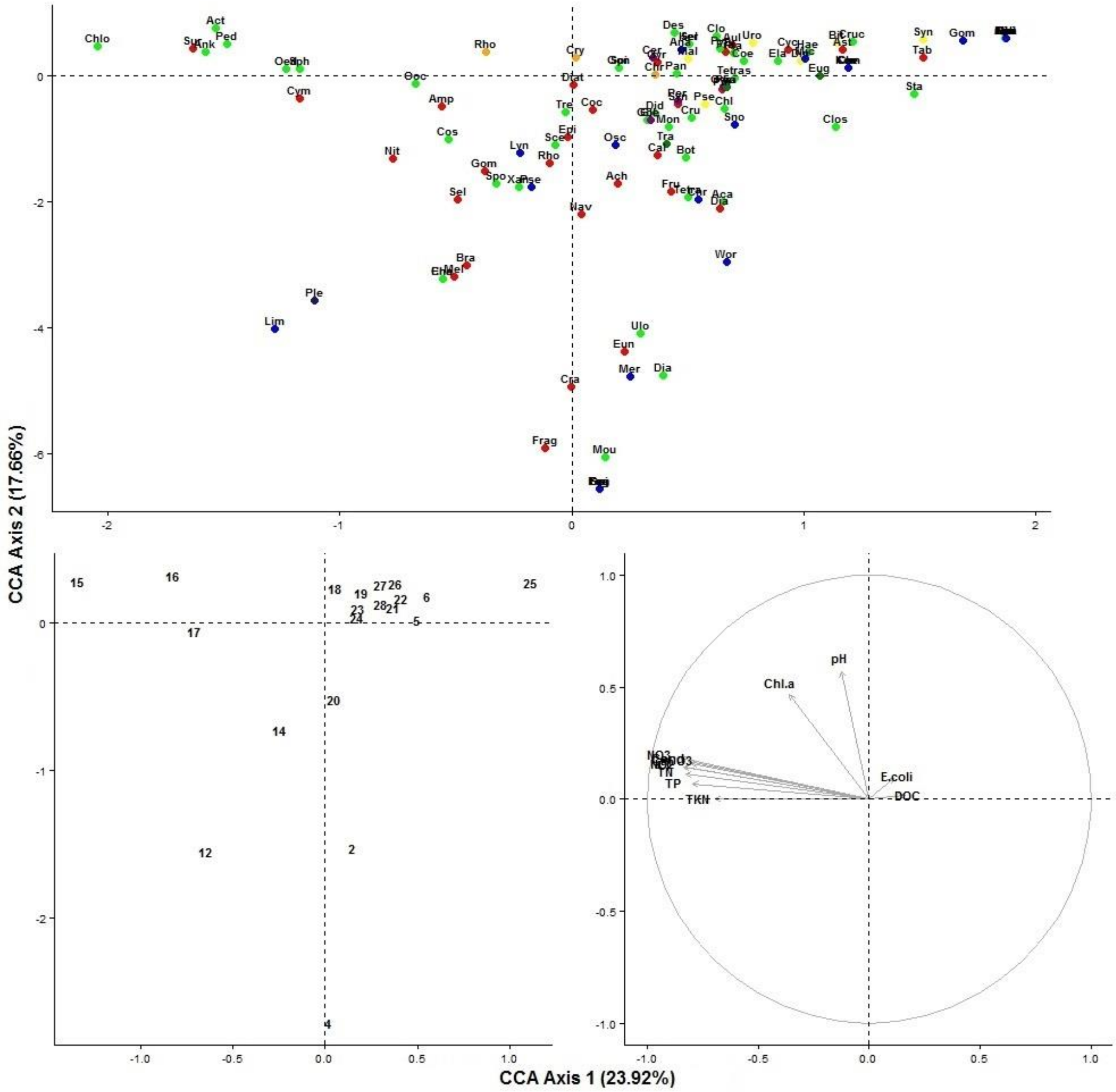

Figure 37 Canonical correspondence analysis performed on annual genera biomass and general biological/chemical parameters and nutrients for 2013.

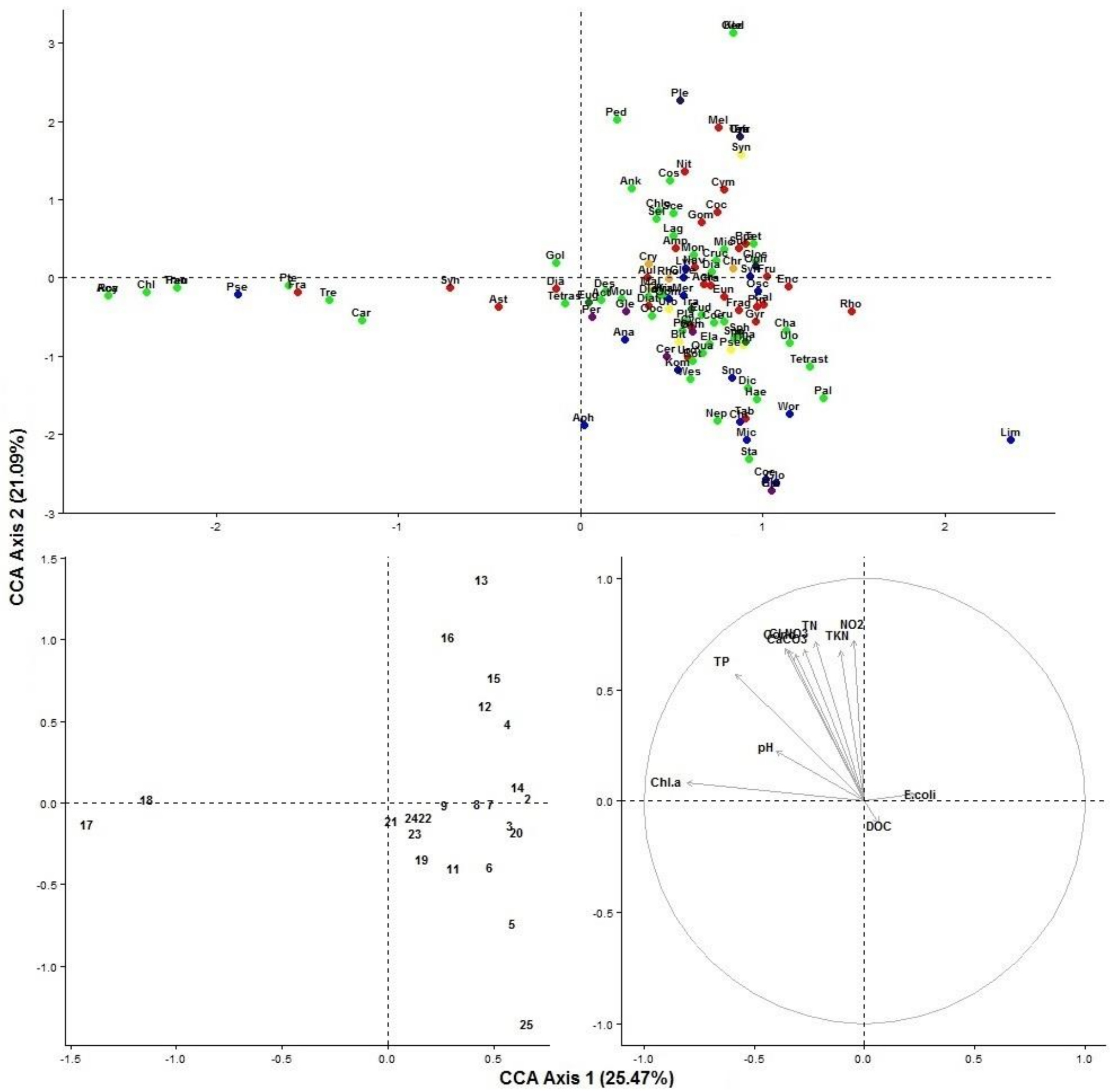

Figure 38 Canonical correspondence analysis performed on annual genera biomass and general biological/chemical parameters and nutrients for 2014.

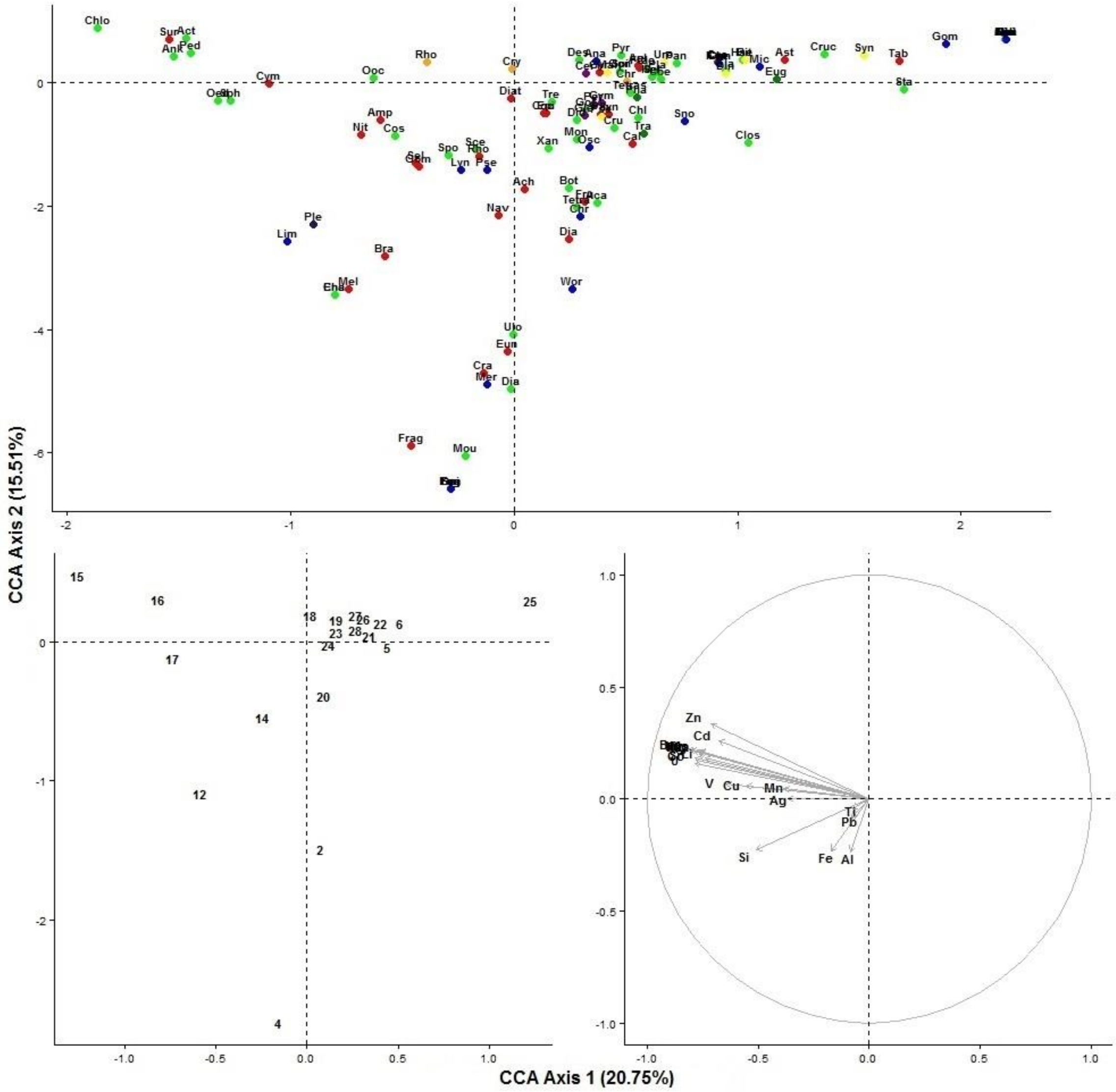

Figure 39 Canonical correspondence analysis performed on annual genera biomass and metals for 2013.

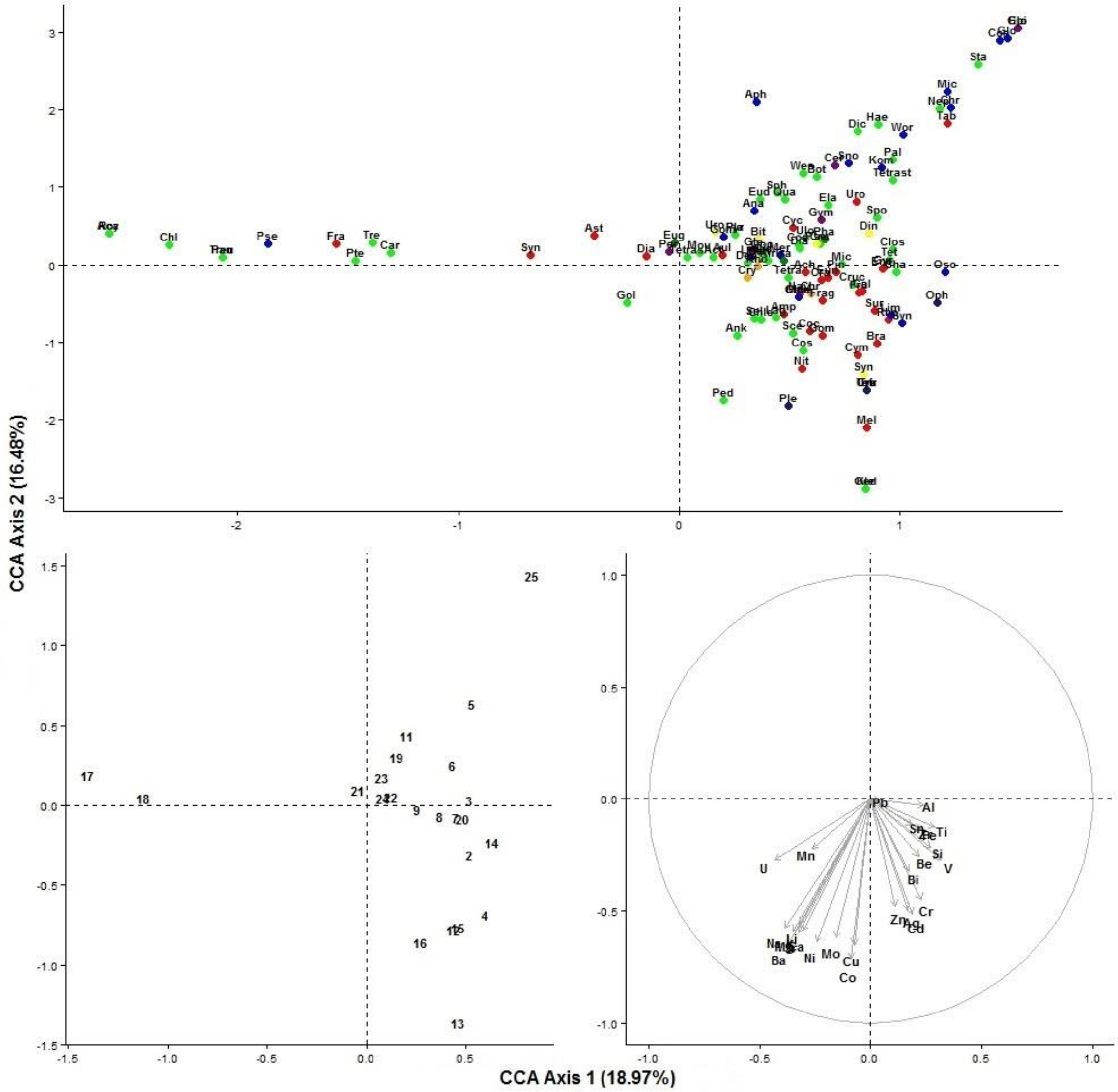

Figure 40 Canonical correspondence analysis performed on annual genera biomass and metals for 2014.

Genera within the same major phytoplankton groups were for the most part randomly distributed within the CCAs. Since it was difficult to project genera on environmental arrows, CCAs were also performed on the genera of specific major phytoplankton groups that are known to be ideal bioindicators (i.e. Bacillariophyta, Chlorophyta, Chrysophyta, and Cyanophyta) (Figure 41-Figure 48). When combined, the first and second CCA axes explained: 53.03% and 58.64% of the variance for Bacillariophyta, 43.50% and 55.97% of the variance for Chlorophyta, 95.38% and 92.76% of the variance for Chrysophyta, and 61.99% and 51.14% of the variance for Cyanophyta when using biological and chemical parameters and nutrients, in 2013 and 2014, respectively. When combined, the first and second CCA axes explained: 47.57% and 47.23% of the variance for Bacillariophyta, 36.39% and 43.76% of the variance for Chlorophyta, 95.17% and 77.07% of the variance for Chrysophyta, and 50.94% and 36.98% of the variance for Cyanophyta when using metals, in 2013 and 2014, respectively. Thus, biological/chemical parameters and nutrients appeared to be slightly better at explaining the variation when compared to metals.

When genera from the specific major phytoplankton groups were projected onto general biological/chemical parameters and nutrient environmental arrows, it appeared that for both years: some Bacillariophyta genera (e.g. *Cymbella, Gomphonema, Melosira,* and *Nitzschia*), Chlorophyta genera (e.g. *Ankyra, Oedogonium,* and *Pediastrum*), and Cyanophyta genera (e.g. *Oscillatoria* and *Pseudanabaena*) had higher biomass when the majority of parameters were above their global average (i.e. CaCO3, Cond, Cl, TP, TN, TKN, NO3, and NO2), whereas some Bacillariophyta genera (e.g. *Aulacoseira, Cyclotella,* and *Tabellaria*), Chlorophyta genera (e.g. *Dictyosphaerium, Eudorina, Staurastrum,* and *Ulothrix*), and Chrysophyta genera (e.g. *Bitrichia* and *Epipyxis*) had higher biomass when the majority of parameters were below their global average (i.e. CaCO3, Cond, Cl, TP, TN, TKN, NO3, and NO2). Other genera from these specific major phytoplankton groups exhibited trends; however, these trends were not consistent from year to year.

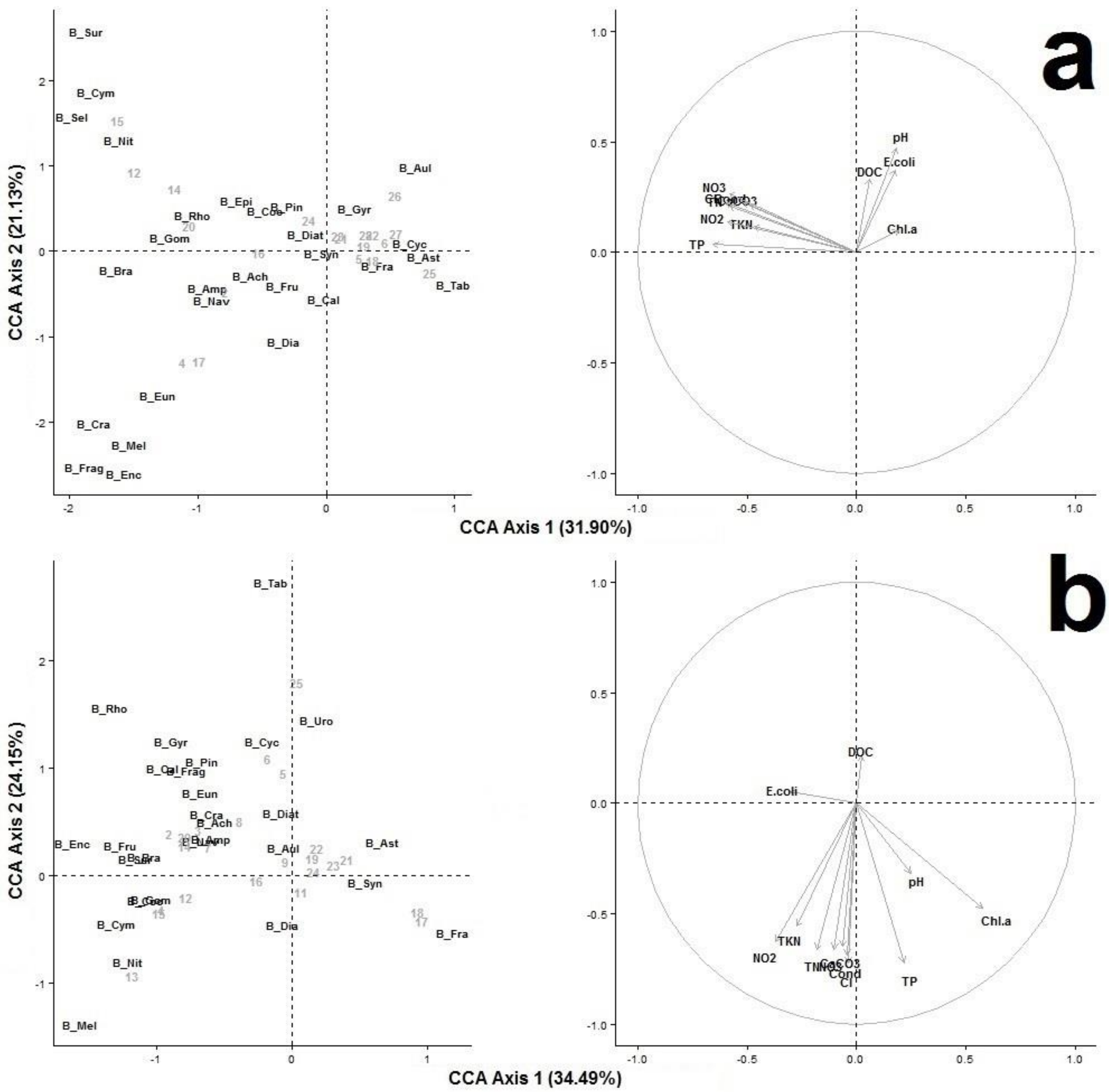

Figure 41 Canonical correspondence analysis performed on annual genera biomass for Bacillariophyta and chemical/biological parameters and nutrients for (a) 2013 and (b) 2014.

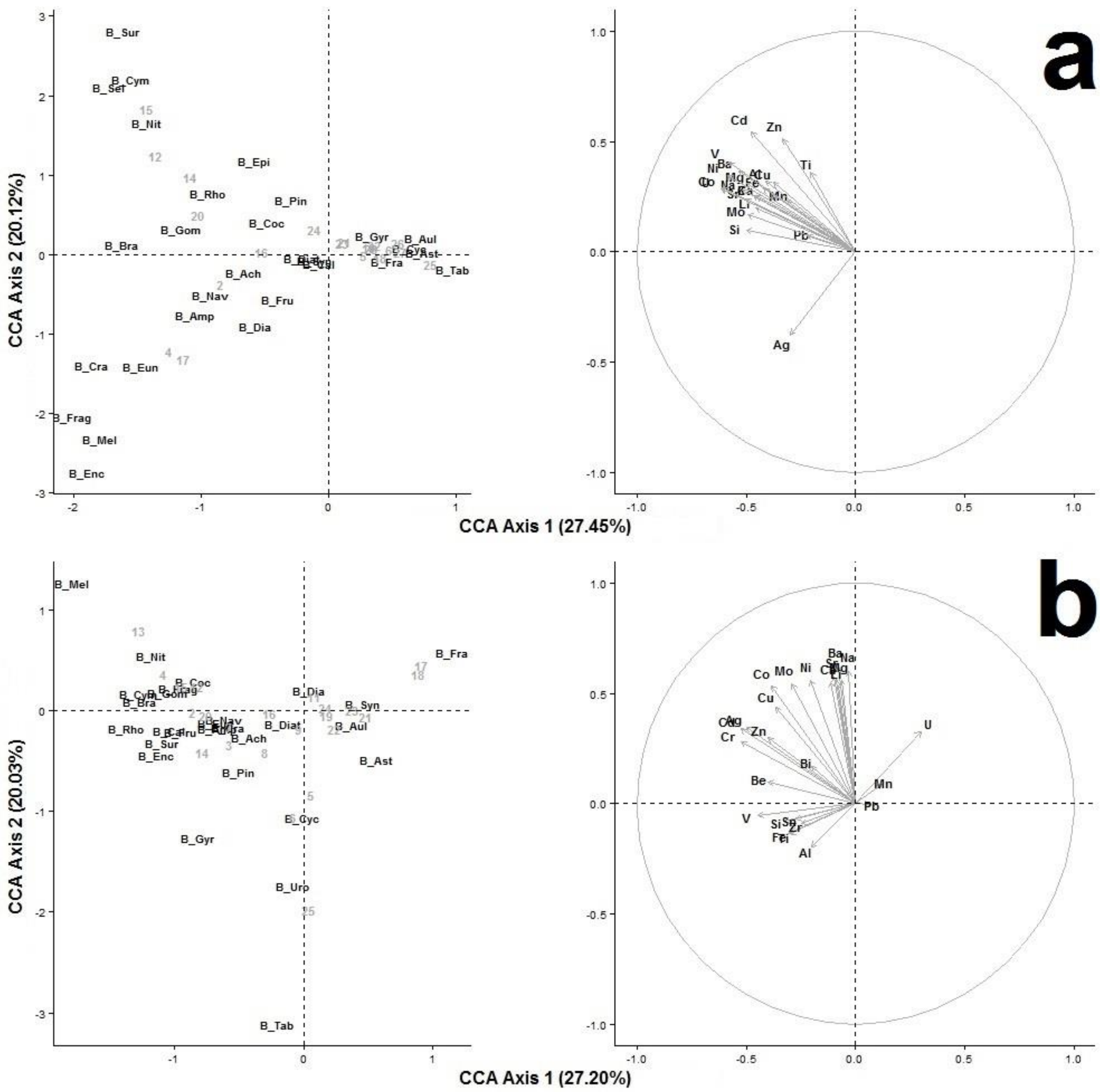

Figure 42 Canonical correspondence analysis performed on annual genera biomass for Bacillariophyta and metals for (a) 2013 and (b) 2014.

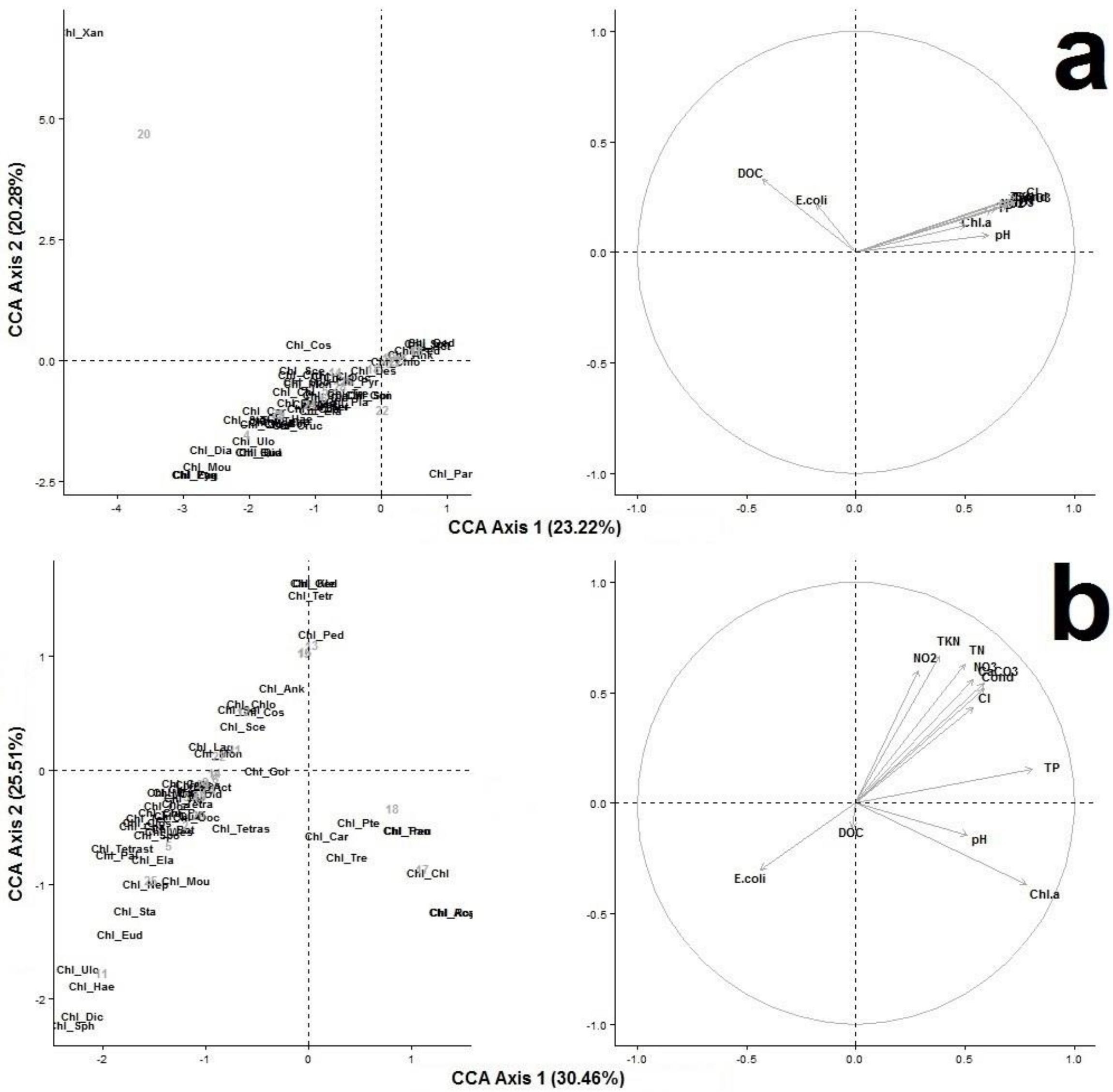

Figure 43 Canonical correspondence analysis performed on annual genera biomass for Chlorophyta and chemical/biological parameters and nutrients for (a) 2013 and (b) 2014.

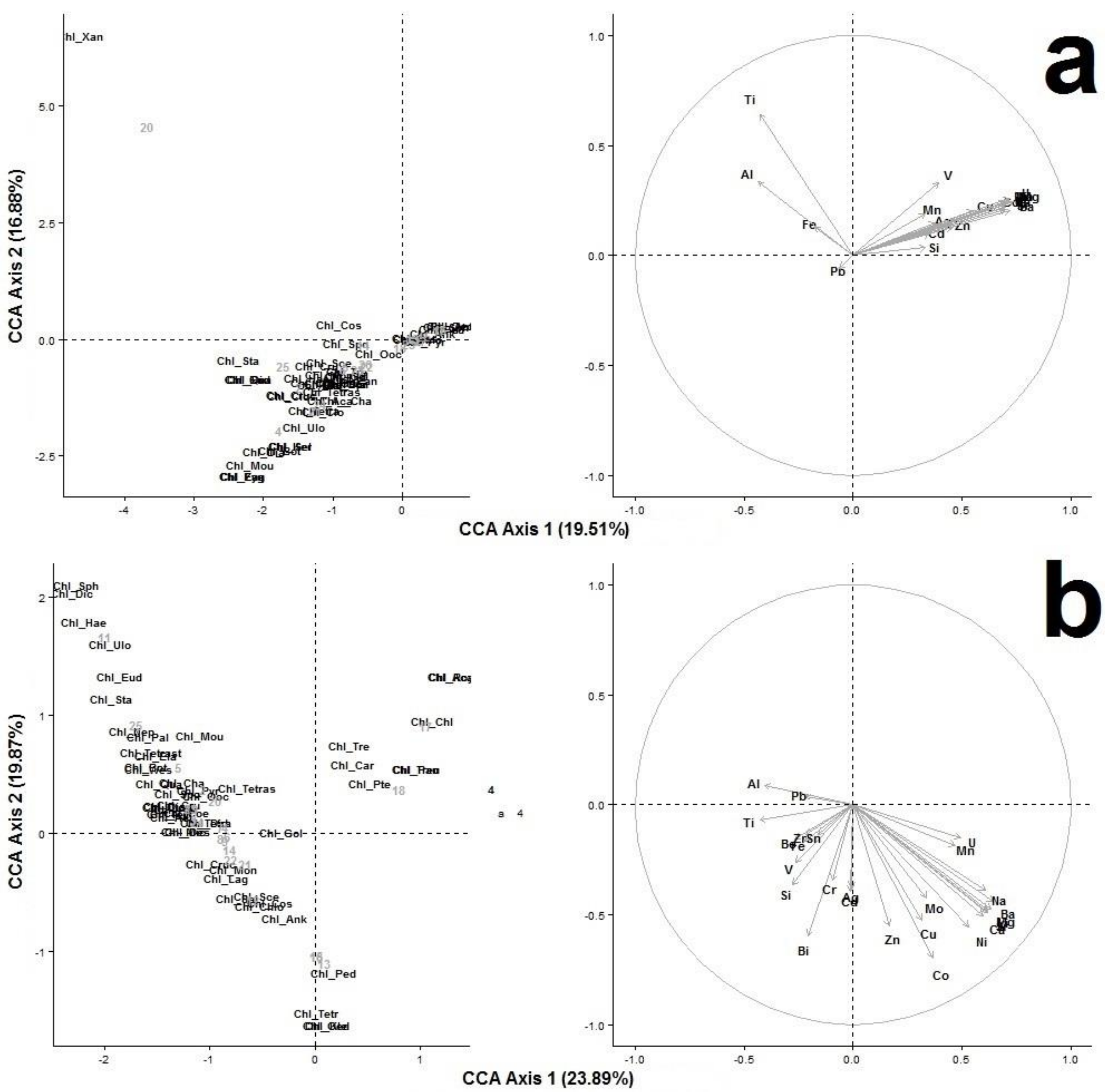

Figure 44 Canonical correspondence analysis performed on annual genera biomass for Chlorophyta and metals for (a) 2013 and (b) 2014.

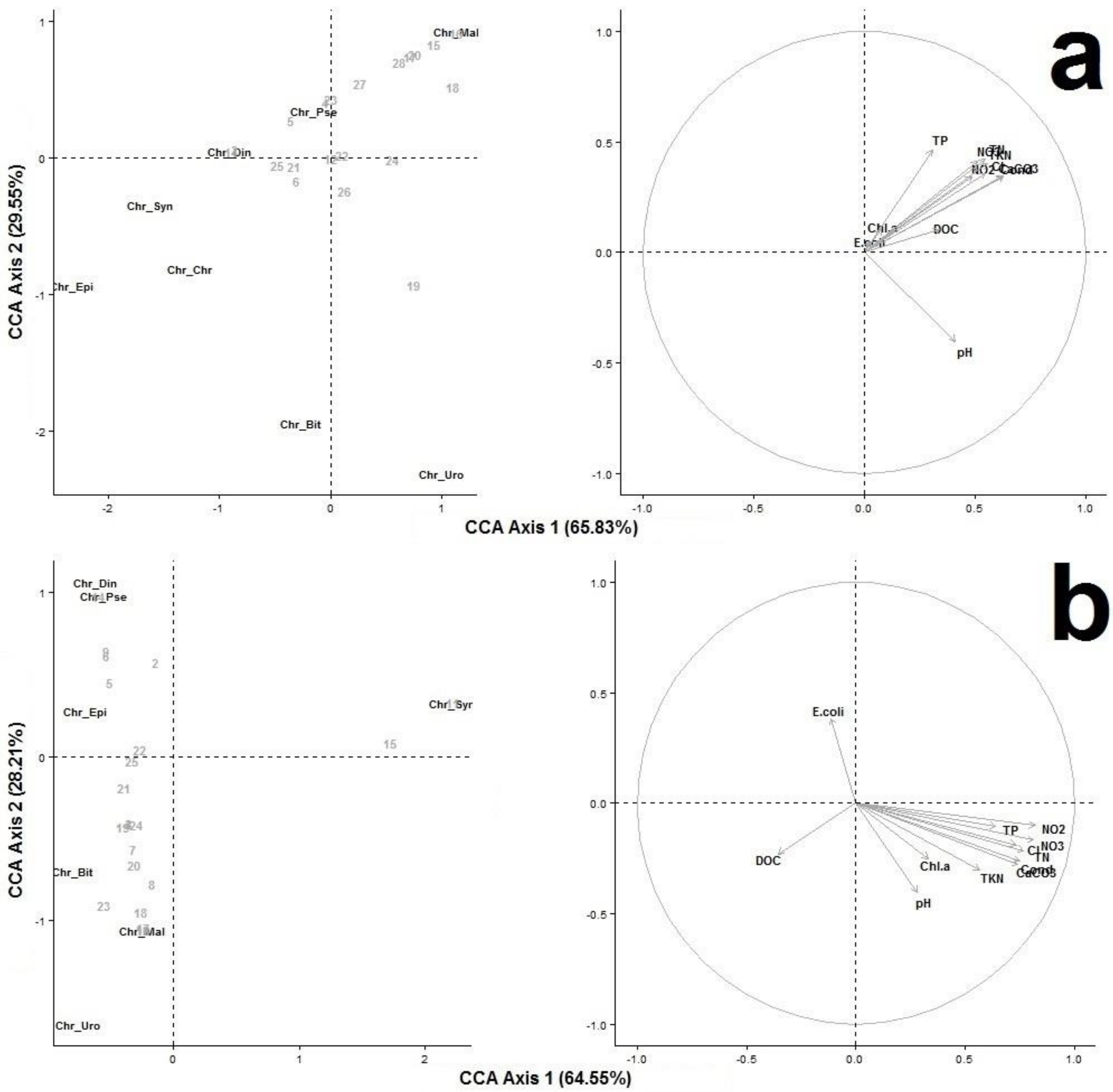

Figure 45 Canonical correspondence analysis performed on annual genera biomass for Chrysophyta and chemical/biological parameters and nutrients for (a) 2013 and (b) 2014.

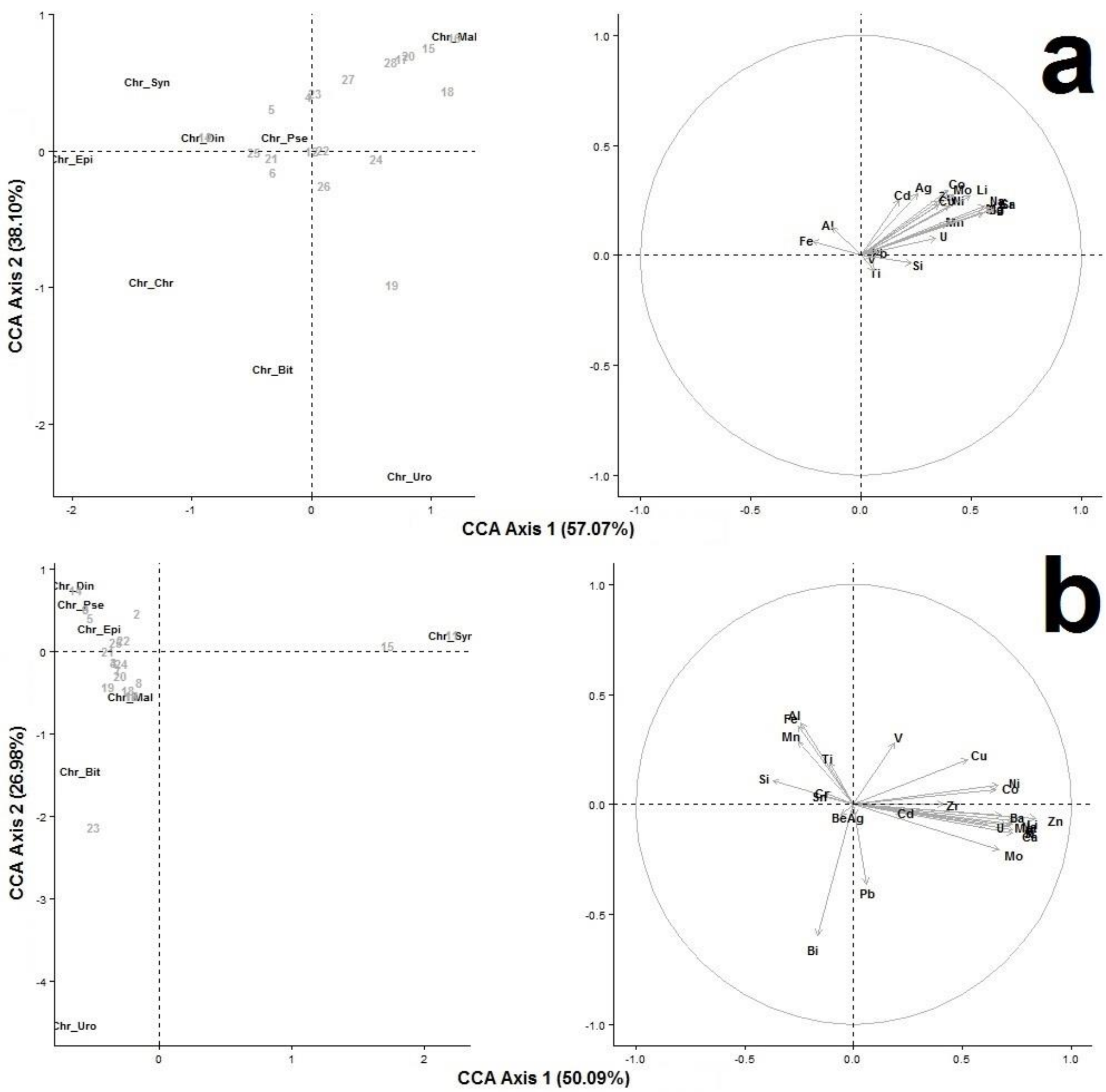

Figure 46 Canonical correspondence analysis performed on annual genera biomass for Chrysophyta and metals for (a) 2013 and (b) 2014.

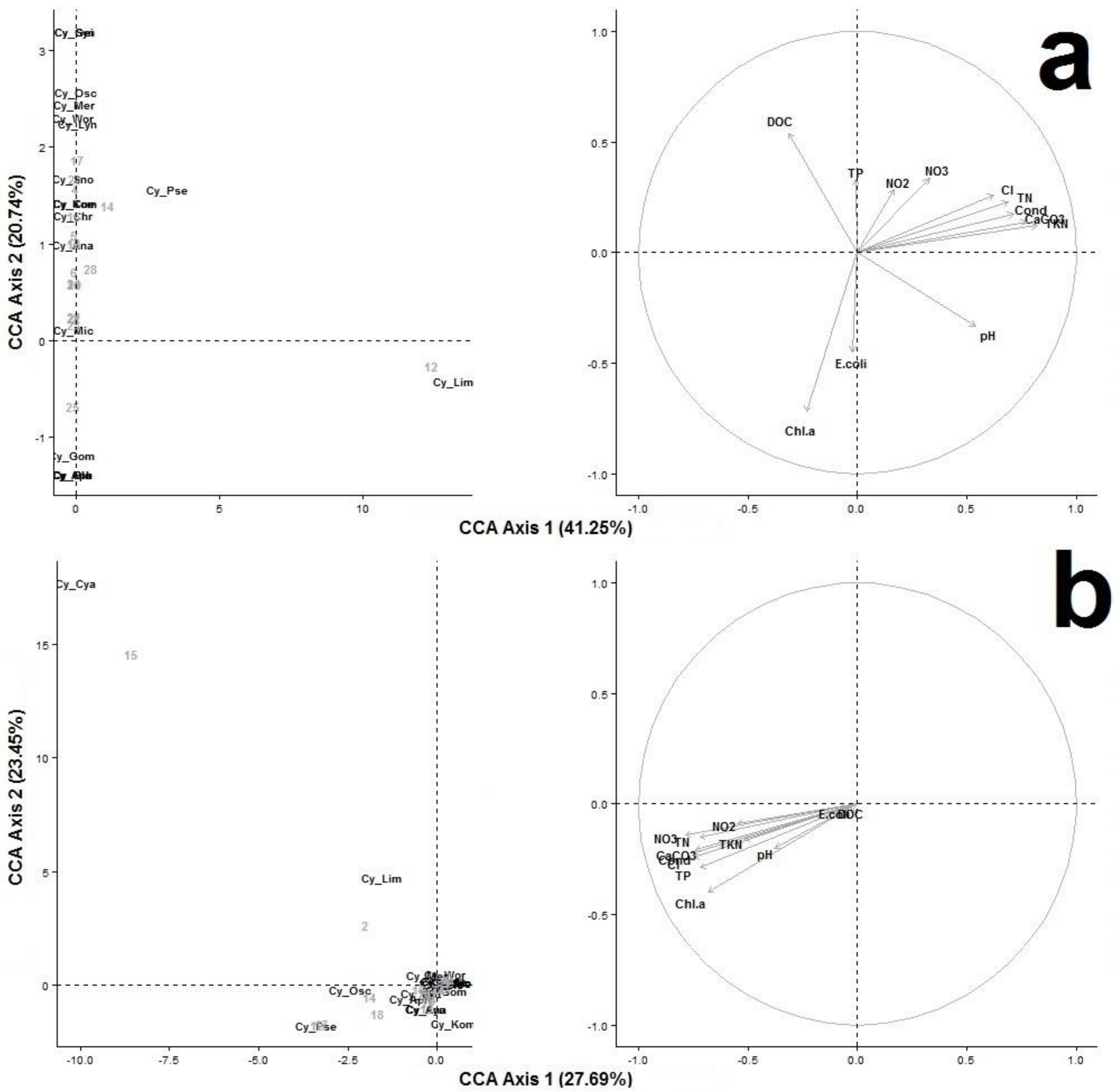

Figure 47 Canonical correspondence analysis performed on annual genera biomass for Cyanophyta and chemical/biological parameters and nutrients for (a) 2013 and (b) 2014.

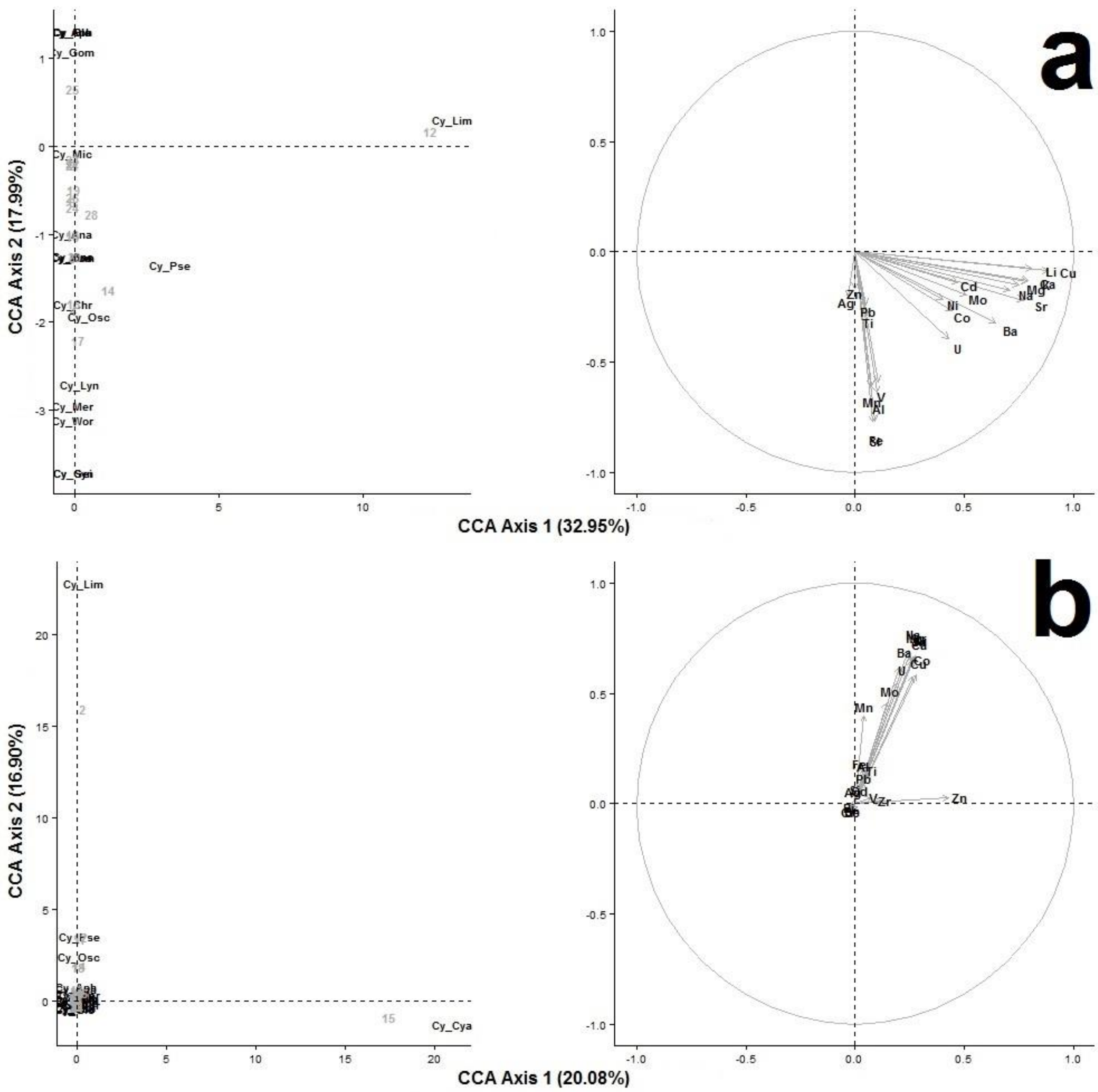

Figure 48 Canonical correspondence analysis performed on annual genera biomass for Cyanophyta and metals for (a) 2013 and (b) 2014.

3.3.0.8 Summary of Anabaena and Microcystis biomass in 2013 and 2014

The subsequent table provides a quick overview of the total biomass of *Anabaena* and *Microcystis* for certain sites in 2013 and 2014 (Table 3). This table revealed that the total biomass of *Microcystis* usually exceeded *Anabaena* in 2013 and in 2014. For example, twenty (83.33%) and eighteen (75.00%) sites had a higher total biomass of *Microcystis* compared to *Anabaena* in 2013 and 2014, respectively.

Table 3 Total biomass of *Anabaena* and *Microcystis* for twenty-four sites in 2013 and 2014.

Site	Anabaena biomass (ug/L)		Microcystis biomass (ug/L)	
	2013	2014	2013	2014
VER-1	0.00	0.00	10.22	2.99
VER-2	0.00	0.00	5.08	0.00
ONP-4	0.00	2.74	45.46	81.24
VER-5	4.39	50.45	78.17	115.75
VER-6	128.32	58.13	164.85	1.52
WIT-7	0.00	0.00	10.01	204.89
WIT-8	0.00	0.00	0.00	21.53
LEV-9	6.17	39.56	60.93	10.88
VER-10	54.84	49.35	77.53	19.19
LIL-11	101.79	10.40	0.00	1.83
JUN-13	0.00	54.84	0.00	0.00
SIM-16	68.55	0.00	0.00	0.00
MC-17	2.44	0.00	0.00	0.00
MC-18	4.55	93.22	0.00	17.97
MC-19	60.32	0.00	173.38	440.74
FB-20	0.00	0.00	0.00	4.87
KUS-21	32.21	10.97	302.18	23.16
VER-22	26.16	0.00	577.29	63.90
GRA-23	43.30	3.05	220.24	40.14
ELA-24	22.77	0.00	69.00	95.96
ELA-25	26.81	114.55	841.02	2686.22
WAB-26	6.56	2.19	8.24	159.75
WAB-27	12.61	53.19	76.78	93.42
VER-28	0.00	41.68	17.16	0.00

The subsequent figure provides a quick overview of the biomass of *Anabaena* and *Microcystis* for certain sites and sampling dates (Figure 49). *Anabaena* biomass varied from 0-118ug/L, whereas *Microcystis* biomass varied from 0-1509ug/L.

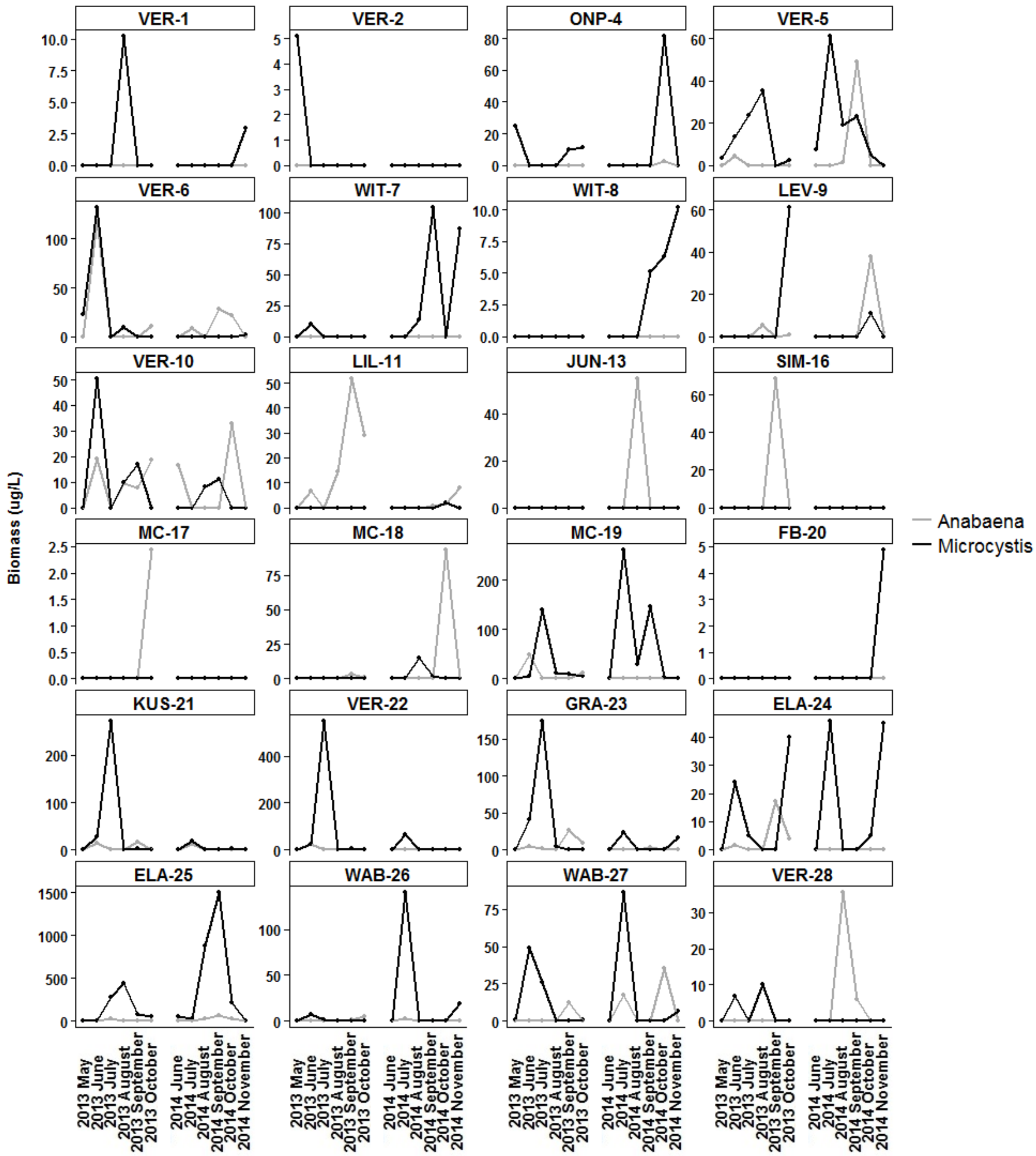

Figure 49 Biomass of Anabaena and Microcystis for twenty-four sites in 2013 and 2014.

3.4 Discussion

This chapter has shown that total phytoplankton biomass and major phytoplankton group biomass were very variable both spatially and temporally. Spatial differences were the most obvious, as total phytoplankton biomass and major phytoplankton group biomass were elevated at certain sites. When visualizing the percent composition of the major phytoplankton groups, it was noted that the majority of samples were dominated by Bacillariophyta (55.41%) or Cryptophyta (29.94%) compared to the other major groups (<10%). Both of these major phytoplankton groups (i.e. Bacillariophyta and Cryptophyta) are r-strategists, thus it is not surprising that they exhibited dominance in the majority of samples analyzed.

In spring when circulation occurs and nutrient availability becomes high, an initial spring bloom of small to medium sized phytoplankton (particularly diatoms, i.e. Bacillariophyta) occurs. Although zooplankton are in their early phase of growth, their grazing pressure remains relatively low until the latter part of the spring. In early/mid-summer, nutrients continue to decline and the phytoplankton biomass declines from diatom sedimentation and the rapid increase of zooplankton grazing. In the latter part of the summer when nutrients are further reduced, the phytoplankton community becomes dominant with other major phytoplankton groups (e.g. Chlorophyta, Chrysophyta, and Cryptophyta) and zooplankton grazing decreases significantly. Nutrient availability is low until the fall when circulation occurs, causing filamentous phytoplankton to become dominant. Phytoplankton biomass continues to decline and zooplankton grazing remains relatively low until the spring (De Senerpont Domis et al., 2013).

Although Bacillariophyta was expected to be abundant in the spring and early summer, their abundance continued throughout the entire sampling season. From May to October in 2013, 28.57%, 48.15%, 47.62%, 53.57%, 50.00%, and 60.71% of samples were dominated by Bacillariophyta, respectively. Whereas from June to November in 2014, 37.04%, 80.77%, 78.57%, 65.38%, 60.71%, and 46.43% of samples were dominated by Bacillariophyta, respectively. Bacillariophyta tend to out-compete other major phytoplankton groups when conditions are favourable (i.e.

high nitrogen, phosphorus, and silica) as they exhibit traits of an r-strategist. When conditions turn unfavourable they sink to the bottom (i.e. sedimentation) until conditions become favourable again (possibly in the fall when fall mixis occurs). Thus, the persistence of Bacillariophyta throughout the year may be explained by the above average nutrient concentrations in the VRMT, specifically in the Junction tributary, since their environment remains favourable throughout the year.

Cryptophyta was also expected to be abundant in the spring and early summer. From May to October in 2013, 66.67%, 44.44%, 33.33%, 28.57%, 15.38%, and 25.00% of samples were dominated by Cryptophyta, respectively. Whereas from June to November in 2014, 59.26%, 3.85%, 7.14%, 19.23%, 17.86%, and 46.43% of samples were dominated by Cryptophyta, respectively. Cryptophyta tend to be abundant in cold temperate lakes. This major phytoplankton group can also cope better with low light and the grazing pressure of zooplankton as they exhibit traits of an r-strategist. Thus, it makes sense that Cryptophyta was abundant at the beginning and at end of the sampling periods in 2013 and 2014.

Although some figures displayed similar spatial and temporal trends for Chl-a and total phytoplankton biomass, others did not. This was expected as phytoplankton differ in their pigment composition. Although all taxonomic groups possess the photosynthetic pigment Chl-a, they usually have additional photosynthetic pigments (e.g. chlorophyll b, c, d, e) and accessory pigments (e.g. carotenoids, xanthophylls, and biliproteins) (Wall & Briand, 1979). Thus, some phytoplankton are known to have a higher Chl-a content than others which may explain the variations observed between Chl-a and total phytoplankton biomass.

Although line graphs, one-way ANOVAs, and multiple comparisons revealed that sites located on the main-stem of the Junction tributary appeared to have above annual average values for nutrients in the previous chapter (refer to 2.3.0.6 One-way ANOVAs and multiple comparisons on nutrient concentrations upstream and downstream of the Sudbury WWTP, pg.47), the annual averages for Chl-a, total phytoplankton biomass, and major phytoplankton group biomass were much more variable, thus less significant differences were detected. However, CAs and supplementary CCAs performed on major phytoplankton groups suggest that certain sites located on the Junction tributary are very similar based on their water quality and major phytoplankton group composition. Specifically, many sites located on the Junction tributary had above average values for the majority of water quality parameters (i.e. Chl-a, CaCO3, Cond, Cl, TP, TN, TKN, NO3, and NO2) and Chlorophyta biomass. The Sudbury WWTP is likely responsible for the elevated abundance of this major phytoplankton group (i.e. Chlorophyta), however, other sources are likely responsible as well since LIL-11 also exhibited above average Chlorophyta biomass in 2014. It is important to note that CC-12 did not exhibit above average values for Chlorophyta. In fact, this site had extremely low biomass for all sampling dates and was primarily dominated by Bacillariophyta. The industrial WWTPs (Copper Cliff WWTP and Nolin Creek WWTP) and/or surface runoff from the Clarabell Mill property are likely responsible for the extremely low phytoplankton biomasses that were observed since this site was very polluted (i.e. elevated TN, TKN, and numerous metals).

These CAs and supplementary CCAs performed on major phytoplankton groups also revealed that ELA-25 have above average values for Cyanophyta biomass. Upon further investigation, it was determined that *Microcystis* biomass was very high at ELA-25 and regularly abundant later in the sampling season. This is concerning as this genera is capable of producing cyanotoxins (e.g. microcystin). Microcystin concentrations are usually negligible or undetectable in many freshwater systems, however the incidences and severity of this toxin is rising in many aquatic systems in Canada (Orihel et al., 2012). Although *Microcystis* is commonly found in eutrophic systems, ELA-25 had average or below average nutrient concentrations compared to other sites in the VRMT system. This finding does not imply that *Microcystis* occurs at sites with low nutrient levels, in fact, this finding may suggest numerous factors are playing a role in its dominance. For example, it is known that heavy metals inhibit and supress Cyanophyta genera. Thus, even with excessive nutrients loadings they may be unable to thrive and out-compete other major phytoplankton groups (e.g. Chlorophyta) when heavy metals are elevated. Since ELA-25 had below average values for the majority of metals, it is plausible that they were dominant because of the lack of suppression or inhibition. Another factor that could be influencing its dominance is the hydroelectric impoundment (i.e. Lorne Falls dam) located directly downstream of ELA-25. Since the natural flow rate and renewal rate have been disrupted, the water temperature at this site is likely higher than it was before this disruption. Therefore, the hydroelectric impoundment may also be responsible for the elevated *Microcystis* biomass at ELA-25.

When CCAs were performed on genera biomass, it appeared that genera within the same major phytoplankton groups were for the most part randomly distributed within the CCAs. This indicates that genera, even if they are in the same phytoplankton group, prefer different water quality conditions. For example, some genera (e.g. *Cymbella, Gomphonema, Melosira, Nitzschia, Ankyra, Oedogonium, Pediastrum, Oscillatoria,* and *Pseudanabaena*) were more common at polluted sites as they exhibited a higher biomass when the majority of parameters were above their global average (i.e. CaCO3, Cond, Cl, TP, TN, TKN, NO3, and NO2). Conversely, some genera (e.g. *Aulacoseira, Cyclotella, Tabellaria, Dictyosphaerium, Eudorina, Staurastrum, Ulothrix, Bitrichia* and *Epipyxis*) were more common at less impacted sites as they exhibited a higher biomass when the majority of parameters were below their global average (i.e. CaCO3, Cond, Cl, TP, TN, TKN, NO3, and NO2). Therefore, it is important that water quality monitoring programs include genera or species if possible as they can serve as ideal bioindicators for specific water quality conditions, however, higher taxonomic levels (i.e. major phytoplankton groups) can still be useful for identifying systems that are severely impacted by the surrounding landscape (i.e., point and non-point sources).

3.5 Conclusion

Results from this chapter have confirmed that water quality parameters which are influenced by the surrounding landscape (i.e. point and non-point sources) can alter the abundance and composition of major phytoplankton groups and genera.

In particular, the major phytoplankton group Chlorophyta (i.e. green algae) was abundant in most sites located in Junction tributary in 2013 and in 2014. The Sudbury WWTP is likely responsible for the elevated abundance of this major phytoplankton group (i.e. Chlorophyta), however, other sources are likely responsible as well since LIL-11 also exhibited above average Chlorophyta biomass in 2014. It is also important to note that CC-12 had extremely low biomass for all sampling dates and was primarily dominated by Bacillariophyta (i.e. diatoms). The industrial WWTPs (Copper Cliff WWTP and Nolin Creek WWTP) and/or surface runoff from the Clarabell Mill property are likely responsible for the extremely low phytoplankton biomasses that were observed since this site was very polluted (i.e. elevated TN, TKN, and numerous metals).

The major phytoplankton group Cyanophyta (i.e. blue-green algae) was regularly abundant later in the sampling season at ELA-25 in 2013 and in 2014. This major phytoplankton group at ELA-25 was mainly comprised of *Microcystis*, which is concerning as this genera is capable of producing cyanotoxins (e.g. microcystin). Microcystin concentrations are usually negligible or undetectable in many freshwater systems, however the incidences and severity of this toxin is rising in many aquatic systems in Canada.

CHAPTER 4: GENERAL CONCLUSION

4.1 Introduction

The previous chapters have shown the VRMT and its watershed are clearly being impacted by point and non-point sources. By analyzing the surrounding landscape, water quality, and phytoplankton communities, it was evident that the point and non-point sources play a key role in determining the water quality (refer to Chapter 2, pg.22-58) and subsequently the abundance and composition of phytoplankton communities (refer to Chapter 3, pg.61-110).

WWTPs significantly increased the amount of nutrients entering the VRMT. Based on the 2013 and 2014 Wastewater Annual Reports for Greater Sudbury, the Sudbury WWTP was the largest contributor of nutrients into the VRMT for both years so it was anticipated that nutrient concentrations would be higher at sites directly downstream and in close proximity. Although this was true for the majority of nutrients (TP, NO3, and NO2), some nutrients (TN and TKN) were unexpectedly highest upstream. Upon further investigation, it appeared other WWTPs (i.e. Copper Cliff WWTP and Nolin Creek WWTP) and/or surface runoff from the Clarabell Mill property was elevating TN and TKN. Clearly, municipal WWTPs, industrial WWTPs, and the surrounding landscape (i.e. surface runoff from the Clarabell Mill property) are primarily responsible for the elevated nutrients. This study has also shown that the above average values of Chlorophyta biomass throughout the year in the Junction tributary were likely caused by these elevated nutrient levels. However, CC-12 which was also located on the Junction tributary but upstream of the Sudbury WWTP had extremely low biomass for all sampling dates and was primarily dominated by Bacillariophyta. The industrial WWTPs (Copper Cliff WWTP and Nolin Creek WWTP) and/or surface runoff from the Clarabell Mill property are likely responsible for the extremely low phytoplankton biomasses that were observed since this site was very polluted (i.e. elevated TN, TKN, and numerous metals).

Smelters are likely responsible for the elevated metal concentrations at many sites in the VRMT system since metals are deposited onto the land and likely transported into the system via erosion and/or surface runoff. However, other sources, like municipal WWTPs, industrial WWTPs, and/or the surrounding landscape (e.g. Clarabell Mill property) may also be contributing to these elevated metal concentrations as well. This study revealed that many sites are surpassing the LTWQG for the protection of aquatic life. This is disconcerting as these guidelines are set based on laboratory based experiments, thus if certain metals are elevated above their respective guidelines the ecological health of that system may begin to deteriorate. This is especially true if many water quality parameters surpass the water quality guidelines. Although parameters may be tolerable individually, when combined they may act synergistically and reduce this tolerance.

4.2 Recommendations

Improvements have been made in reducing the amount of nutrients, biological/chemical parameters, and metals entering aquatic systems through best management practices and upgrades to municipal and industrial facilities, however, this study confirms that these facilities (i.e. municipal and industrial WWTPs) and the surrounding landscape (i.e. Clarabell Mill property, developed and barren land-cover, road density, etc.) remain important drivers for nutrient and metal pollution, as well as some biological/chemical parameters.

Nutrient enrichment, from point and non-point sources, is generally responsible for elevated phytoplankton biomass (i.e. phytoplankton blooms). If long-term costly recoveries are to be avoided, it is clear that nutrient reduction should be the main strategy for preventing eutrophication. Thus, WWTPs that elevate nutrients significantly in the VRMT should be upgraded in the near future to minimize their impact. These include: the Sudbury WWTP, the Copper Cliff WWTP, and the Nolin Creek WWTP. Internal loading usually decreases slowly if external loads are reduced, thus by eliminating or reducing nutrients entering aquatic systems through point and non-point sources these systems can begin to recover slowly (Schindler, 2006).

In addition, metals that are released into the environment should also be reduced as many sites within the VRMT study area are surpassing the LTWQG for the protection of aquatic life. Since smelters are likely responsible for the elevated metal concentrations further upgrades should be considered to reduce metals emissions, however, these upgrades will not mitigate the effect of past atmospheric deposition. In addition, other sources of metals (e.g. municipal WWTPs and industrial WWTPs) should also reduce the amount of metals released into the environment.

Since the surrounding landscape influences the water quality of aquatic systems, the potential inputs from the surrounding landscape should be considered before further development occurs. Since developed land-cover and road density are known to increase the amount of chemical parameters, nutrients, and metals entering aquatic systems and forest land-cover is known to reduce these same parameters, development along the VRMT should be avoided. Barren land-cover is also known to increase the amount of chemical parameters, nutrients, and metals entering aquatic systems, however, this land-cover type is a natural feature of the Sudbury region thus its impact cannot be avoided.

Future water quality monitoring programs in this region should try to incorporate landscape-scale data and hydrological aspects to obtain a better understanding of the system of interest and how it is being impacted. In particular, other point and non-point sources (e.g. tailings areas, abandoned roast beds, and septic tank systems) and hydrological monitoring (e.g. levels, flow rates, etc.) should be included.

4.3 Conclusion

Further development in the Vermilion watershed has been proposed, including hydroelectric dams and the expansion of mining activities. There are concerns that further development in the Vermilion watershed will push the system beyond a tipping point, leading to a state of permanent impairment. In March of 2013, the VRS received an Ontario Trillium Foundation grant for the Lower Vermilion Source Water Quality Monitoring Project. The VRS monitored the water quality along the VRMT monthly (6 months per year) over a period of two years

(2013-2014). To add a biological component to the study and improve ecological relevance, phytoplankton samples were processed at the Aquatic Ecology and Biotechnology Lab at UOIT. The main goal of this study was to document and assess the baseline conditions (water quality and resident phytoplankton community) of the VRMT. To achieve this goal numerous short-term objectives were established (refer to 1.5 Goals and Objectives, pg.20) and carried out within this this thesis.

From this study, it was determined that the surrounding landscape (i.e. point and non-point sources) and flow regulation are likely impacting the water quality and biological integrity (i.e., ecological health) at specific areas of the VRMT study area. Since the ecological health is deemed to be impaired at these specific areas, the management practices of this system should be modified to aid in recovery and restoration.

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APPENDICES

Appendix A

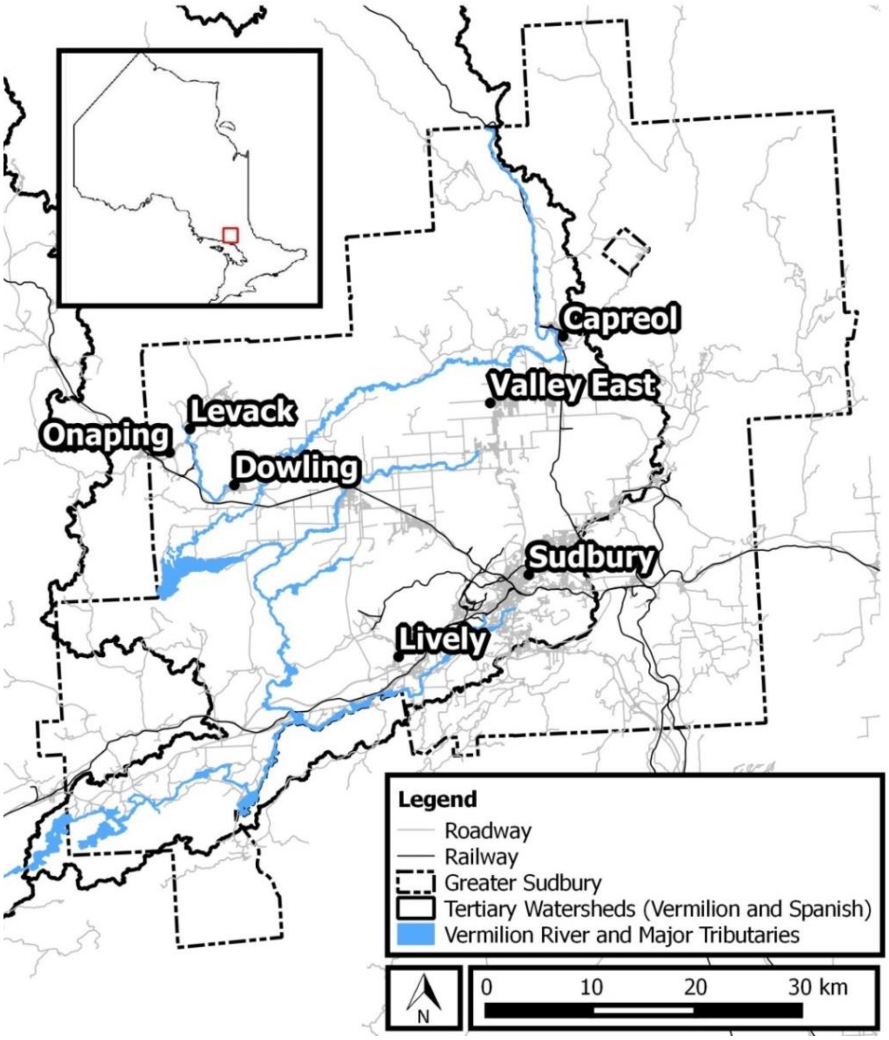

Figure A1 Population centres in Greater Sudbury (GC, 2013; GC, 2010; GO & GC, 2011; GO, 2013; QGIS Development Team, 2015; Statistics Canada, 2012).

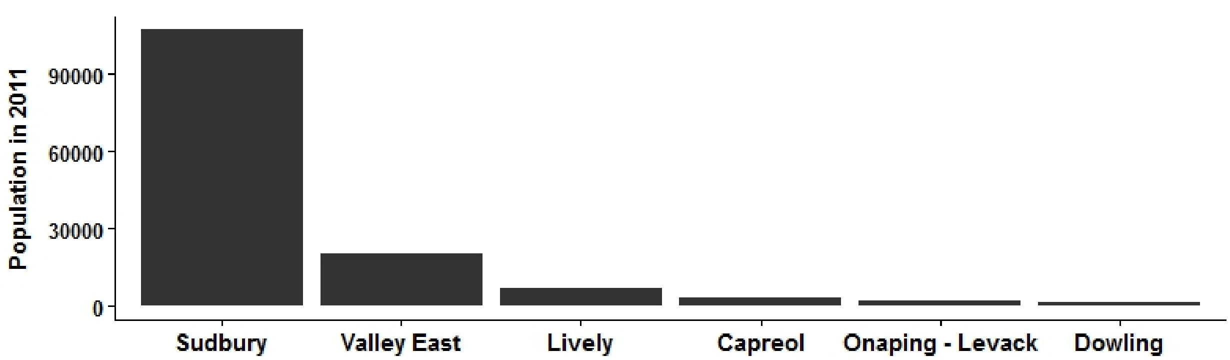

Figure A2 Population in 2011 of the Greater Sudbury population centres (Statistics Canada, 2012).

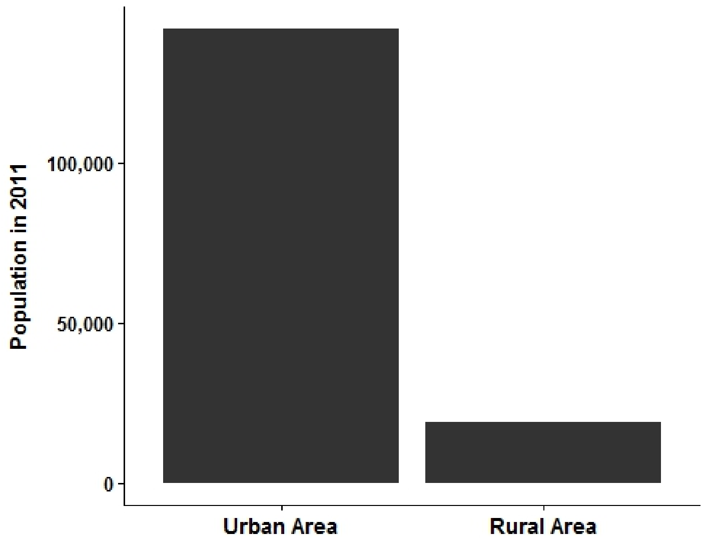

Figure A3 Population in 2011 of the Greater Sudbury urban and rural areas (Statistics Canada, 2012).

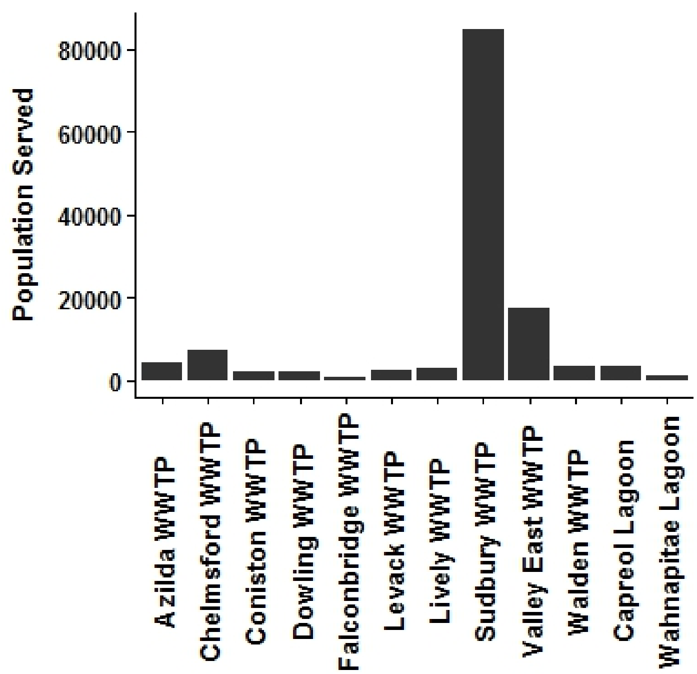

Figure A4 Population served by WWTPs and sewage lagoons in Greater Sudbury in 2013-2014 (Greater Sudbury, 2014, 2015).

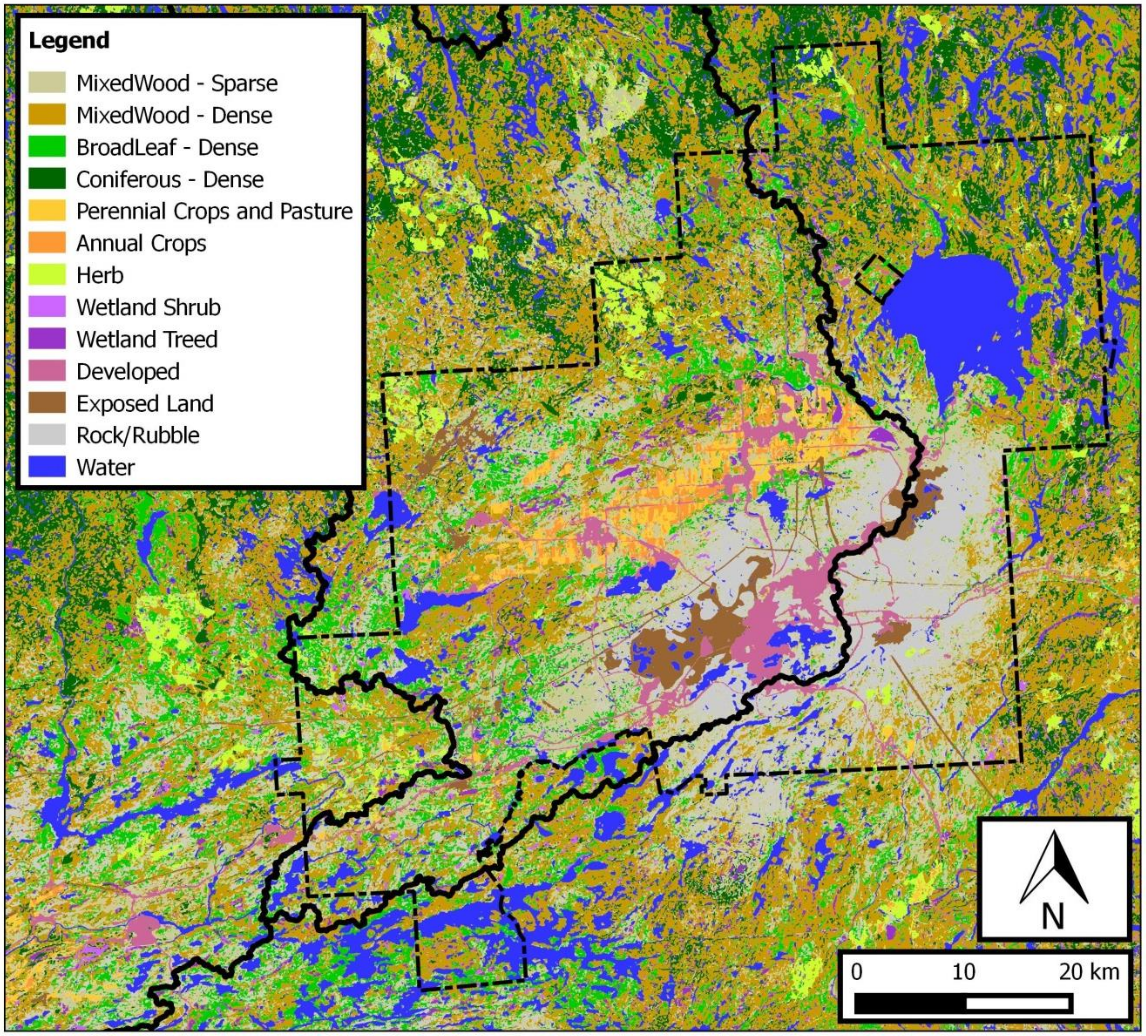

Figure A5 Land-cover of the VRMT study area (GC, 2010; GC, 2010; GO & GC, 2011; QGIS Development Team, 2015).

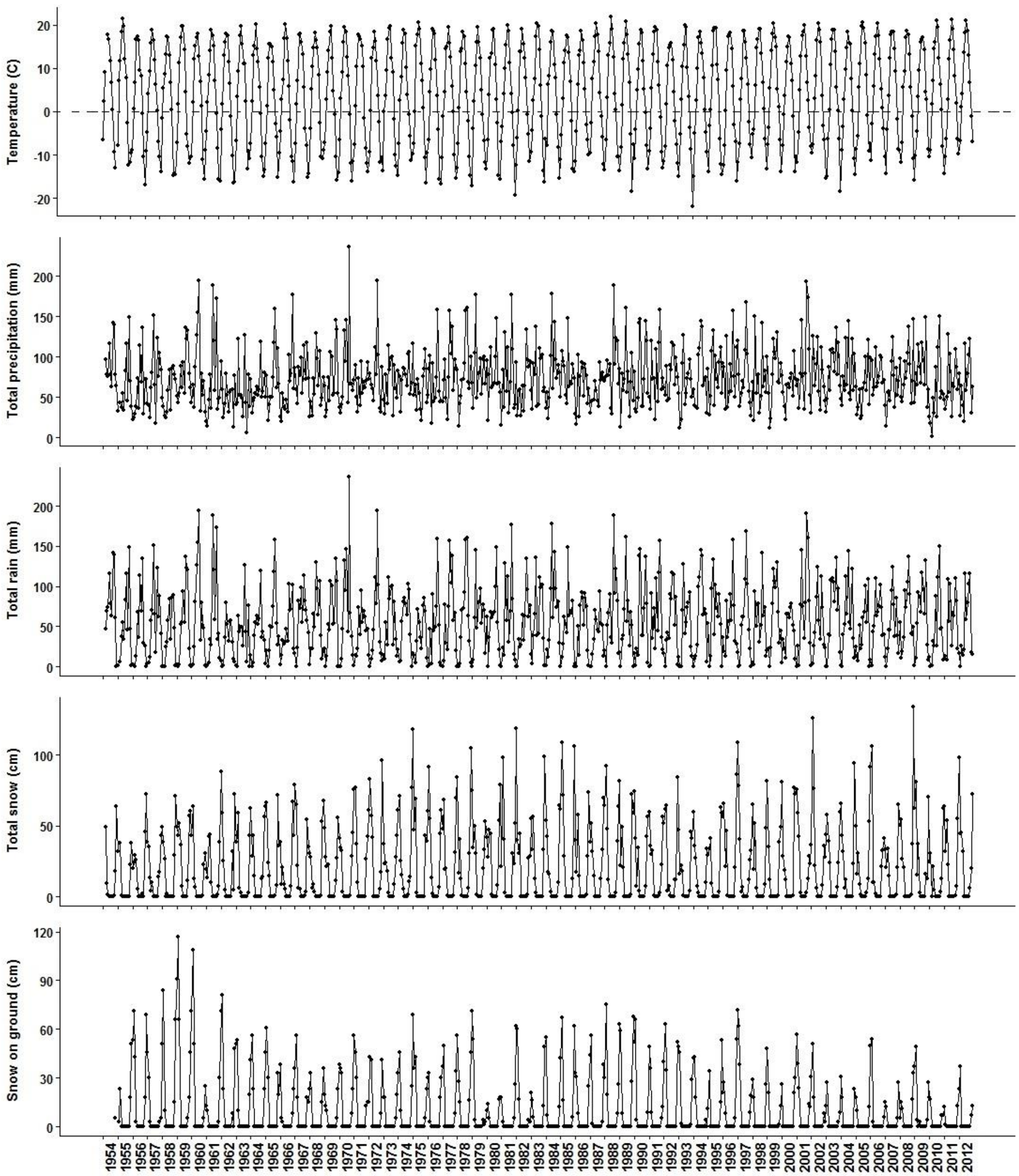

Figure A6 Long-term monthly mean temperature, total precipitation, total rain, total snow, and snow on ground for the last day of the month for 1954 to 2012 (GC, 2012).

Appendix B

Table B1 Area and perimeter of Vermilion and Spanish watersheds.

	Area (km^2)	Perimeter (km)
Vermilion Watershed	4373	684
Spanish Watershed	9432	965

Table B2 Quaternary geology area and percent of Vermilion and Spanish watersheds (Ontario Geological Survey, 1997).

		Area (km^2)	Percent (%)
Vermilion Watershed	Bedrock	3371.23	79.13
	Till	34.80	0.82
	Glaciofluvial ice-contact deposits	27.19	0.64
	Glaciofluvial outwash deposits	366.36	8.60
	Glaciolacustrine deposits	202.56	4.75
	Glaciolacustrine deposits	160.00	3.76
	Fluvial deposits	45.50	1.07
	Organic deposits	52.83	1.24
Spanish Watershed	Bedrock	7244.81	78.90
	Till	171.66	1.87
	Glaciofluvial ice-contact deposits	119.05	1.30
	Glaciofluvial outwash deposits	1028.55	11.20
	Glaciolacustrine deposits	36.30	0.40
	Glaciolacustrine deposits	332.80	3.62
	Fluvial deposits	73.39	0.80
	Organic deposits	175.35	1.91

Table B3 Modified land-cover area and percent of Vermilion and Spanish watersheds (GC, 2010).

		Area (km^2)	Percent (%)
Vermilion Watershed	Water	462.36	10.57
	Barren	256.89	5.87
	Developed	141.86	3.24
	Wetland	61.17	1.40
	Herb	104.88	2.40
	Agriculture	114.31	2.61
	Forest	3231.17	73.90
Spanish Watershed	Water	944.31	10.01
	Barren	210.01	2.23
	Developed	34.31	0.36
	Wetland	203.60	2.16
	Herb	503.54	5.34
	Agriculture	63.99	0.68
	Forest	7472.08	79.22

Table B4 Road length and density of Vermilion and Spanish watersheds (GO, 2013).

	Road Length (km)	Road Density (km/km^2)
Vermilion Watershed	2093.29	0.48
Spanish Watershed	1927.05	0.20

Table B5 Area and perimeter of buffer (5km-radius), catchment, and reaches (1km, 2km, and 3km-radius) for each site.

	5km Buffer		Catchment		1km Reach		2km Reach		3km Reach	
	Area (km^2)	Perimeter (km)	Area (km^2)	Perimeter (km)	Area (km^2)	Perimeter (km)	Area (km^2)	Perimeter (km)	Area (km^2)	Perimeter (km)
VER-1	77.5	31.4	336	178	1.2	4.7	4.3	9.4	9.7	14.5
VER-2	77.5	31.4	683	250	1.1	4.5	5.0	11.7	11.4	16.1
ONP-3	77.5	31.4	1213	375	1.2	4.8	4.6	10.1	10.8	16.7
ONP-4	77.5	31.4	1381	440	1.5	5.0	4.6	8.5	8.4	12.9
VER-5	77.5	31.4	2794	576	1.0	4.6	5.7	13.9	16.4	23.5
VER-6	77.5	31.4	2829	575	1.9	6.7	6.4	11.6	12.7	18.2
WIT-7	77.5	31.4	179	93	1.2	4.6	4.2	9.6	10.0	14.8
WIT-8	77.5	31.4	319	162	1.9	7.7	6.8	13.6	11.7	18.0
LEV-9	77.5	31.4	125	74	1.8	6.5	5.5	12.0	11.6	19.0
VER-10	77.5	31.4	3413	621	1.0	4.8	4.3	10.0	9.3	14.0
LIL-11	77.5	31.4	40	40	1.6	5.7	4.0	9.3	8.5	16.2
CC-12	77.5	31.4	26	31	1.1	4.8	3.7	9.1	7.7	13.5
JUN-13	77.5	31.4	203	104	1.6	5.5	5.5	10.0	11.5	14.3
MB-14	77.5	31.4	33	34	1.0	4.4	4.1	9.3	8.7	13.4
MUD-15	77.5	31.4	256	126	0.9	5.0	4.9	11.2	11.9	17.3
SIM-16	77.5	31.4	262	132	1.3	5.1	3.4	8.5	5.7	13.3
MC-17	77.5	31.4	266	136	0.8	4.0	2.5	7.1	4.7	10.3
MC-18	77.5	31.4	270	141	0.8	4.0	2.5	7.1	4.1	10.2
MC-19	77.5	31.4	294	151	1.7	6.7	6.8	13.1	13.7	20.2
FB-20	77.5	31.4	64	79	1.1	4.6	2.7	9.2	4.5	12.2
KUS-21	77.5	31.4	27	32	1.6	6.0	5.5	12.0	9.4	16.2
VER-22	77.5	31.4	19	30	1.0	5.0	4.1	10.0	10.0	17.4
GRA-23	77.5	31.4	21	36	1.1	7.0	5.7	16.7	12.2	24.3
ELA-24	77.5	31.4	70	60	1.2	4.6	3.8	11.8	9.7	18.1
ELA-25	77.5	31.4	104	77	1.5	6.2	6.4	11.9	14.4	17.4
WAB-26	77.5	31.4	111	86	0.2	2.6	1.5	6.2	3.7	15.4
WAB-27	77.5	31.4	140	90	0.9	6.0	5.0	12.3	10.6	20.3
VER-28	77.5	31.4	166	97	1.3	5.2	4.6	8.8	8.1	12.3

Table B6 Quaternary geology units, material and age from the Ontario Geological Survey dataset 14 (Ontario Geological Survey, 1997).

	Unit name: material	**Age**
	Bedrock: undifferentiated igneous and metamorphic rock, exposed at surface or covered by a discontinuous, thin layer of drift.	Precambrian
	Till: undifferentiated, predominantly sand to silty sand matrix, high content of clasts, often low in matrix carbonate content.	Pleistocene
	Glaciofluvial ice-contact deposits: gravel and sand, minor till, includes esker, kame, end moraine, ice-marginal delta and subaqueous fan deposits.	Pleistocene
	Glaciofluvial outwash deposits: gravel and sand, includes proglacial river and deltaic deposits.	Pleistocene
	Glaciolacustrine deposits: silt and clay, minor sand, basin and quiet water deposits.	Pleistocene
	Glaciolacustrine deposits: sand, gravelly sand and gravel, nearshore and beach deposits.	Pleistocene
	Fluvial deposits: gravel, sand, silt and clay, deposited on abandoned flood plains, terrace remnants.	Pleistocene
	Organic deposits: peat, muck and marl.	Recent

Table B7 Quaternary geology area and percent of buffer (5km-radius), catchment, and reaches (1km, 2km, and 3km-radius) for each site (Ontario Geological Survey, 1997).

		5km Buffer		Catchment		1km Reach		2km Reach		3km Reach	
		Area (km²)	Percent (%)	Area (km²)	Percent (%)	Area (km²)	Percent (%)	Area (km²)	Percent (%)	Area (km²)	Percent (%)
VER-1	Bedrock	75.06	97.16	309.36	92.98	1.20	100.00	4.32	100.00	9.61	100.00
	Till	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	0.32	0.10	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	0.42	0.55	23.05	6.93	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	1.77	2.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VER-2	Bedrock	16.47	21.33	569.50	84.17	0.02	1.84	0.02	0.41	0.10	0.89
	Till	4.76	6.17	4.50	0.67	0.00	0.00	0.00	0.00	1.08	9.54
	Glaciofluvial ice-contact deposits	7.25	9.38	4.37	0.65	0.00	0.00	0.00	0.00	0.25	2.16
	Glaciofluvial outwash deposits	18.35	23.75	91.98	13.59	0.22	20.11	2.31	46.52	5.48	48.26
	Glaciolacustrine deposits	0.04	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	21.75	28.15	3.29	0.49	0.24	21.13	1.06	21.33	2.23	19.66
	Fluvial deposits	8.63	11.18	2.50	0.37	0.63	56.92	1.57	31.74	2.21	19.49
	Organic deposits	0.00	0.00	0.50	0.07	0.00	0.00	0.00	0.00	0.00	0.00
ONP-3	Bedrock	65.06	84.27	944.65	82.59	1.12	97.14	3.91	85.06	8.59	79.73
	Till	0.00	0.00	20.91	1.83	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	2.21	2.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	9.60	12.43	119.49	10.45	0.03	2.86	0.69	14.94	2.18	20.27
	Glaciolacustrine deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	0.34	0.44	54.13	4.73	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	0.00	0.00	4.63	0.41	0.00	0.00	0.00	0.00	0.00	0.00
ONP-4	Bedrock	60.33	78.10	1077.57	82.93	0.85	58.03	2.42	53.22	4.58	54.76
	Till	0.00	0.00	22.07	1.70	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	2.82	0.22	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	0.22	0.29	129.14	9.94	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	2.83	3.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	7.83	10.14	62.99	4.85	0.44	30.42	1.96	43.07	3.61	43.23
	Fluvial deposits	6.04	7.81	0.17	0.01	0.17	11.56	0.17	3.71	0.17	2.02
	Organic deposits	0.00	0.00	4.63	0.36	0.00	0.00	0.00	0.00	0.00	0.00

Table B7 (cont.)

		5km Buffer		Catchment		1km Reach		2km Reach		3km Reach	
		Area (km²)	Percent (%)	Area (km²)	Percent (%)	Area (km²)	Percent (%)	Area (km²)	Percent (%)	Area (km²)	Percent (%)
VER-5	Bedrock	53.65	81.75	2226.65	82.55	0.70	93.96	1.03	26.48	5.73	43.99
	Till	0.00	0.00	31.82	1.18	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	25.14	0.93	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	1.54	2.35	288.46	10.69	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	0.57	0.87	1.26	0.05	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	0.00	0.00	75.15	2.79	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	5.93	9.04	38.51	1.43	0.05	6.04	1.88	48.58	3.48	26.75
	Organic deposits	3.92	5.98	10.32	0.38	0.00	0.00	0.97	24.94	3.81	29.26
VER-6	Bedrock	42.79	56.70	2250.26	82.53	0.14	7.53	3.08	48.28	8.35	67.12
	Till	0.00	0.00	31.82	1.17	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	25.14	0.92	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	0.14	0.19	288.46	10.58	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	20.60	27.30	5.84	0.21	1.76	92.47	3.30	51.72	4.09	32.88
	Glaciolacustrine deposits	0.99	1.31	75.15	2.76	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	9.04	11.98	39.45	1.45	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	1.89	2.51	10.32	0.38	0.00	0.00	0.00	0.00	0.00	0.00
WIT-7	Bedrock	30.36	39.30	109.00	61.40	0.14	11.32	1.67	39.46	5.47	54.77
	Till	0.00	0.00	0.28	0.16	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	1.52	0.85	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	0.00	0.00	22.37	12.60	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	16.26	21.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	30.64	39.66	30.46	17.16	1.07	88.68	2.56	60.54	4.52	45.23
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	0.00	0.00	13.89	7.83	0.00	0.00	0.00	0.00	0.00	0.00
WIT-8	Bedrock	38.99	50.47	137.90	43.56	0.46	24.54	3.04	44.91	5.12	44.08
	Till	0.00	0.00	0.28	0.09	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	1.52	0.48	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	0.00	0.00	22.37	7.07	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	33.81	43.76	72.39	22.87	1.42	75.46	3.73	55.09	6.49	55.92
	Glaciolacustrine deposits	0.00	0.00	66.44	20.99	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	3.17	4.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	1.29	1.67	15.64	4.94	0.00	0.00	0.00	0.00	0.00	0.00

Table B7 (cont.)

		5km Buffer		Catchment		1km Reach		2km Reach		3km Reach	
		Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)
LEV-9	Bedrock	51.61	71.24	80.49	69.70	1.68	100.00	4.58	100.00	9.12	100.00
	Till	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	20.20	27.89	30.40	26.33	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	0.63	0.87	4.59	3.97	0.00	0.00	0.00	0.00	0.00	0.00
VER-10	Bedrock	67.31	87.12	2559.58	77.61	0.79	80.85	1.89	44.23	6.30	68.11
	Till	0.00	0.00	32.10	0.97	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	26.66	0.81	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	9.00	11.65	313.81	9.51	0.19	19.15	2.38	55.77	2.95	31.89
	Glaciolacustrine deposits	0.00	0.00	137.79	4.18	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	0.00	0.00	141.61	4.29	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	0.00	0.00	45.50	1.38	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	0.95	1.23	41.15	1.25	0.00	0.00	0.00	0.00	0.00	0.00
LIL-11	Bedrock	55.65	72.03	34.50	86.65	1.41	89.29	3.60	90.18	7.14	83.98
	Till	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	4.39	5.69	5.02	12.60	0.00	0.00	0.22	5.58	1.19	14.03
	Glaciolacustrine deposits	17.21	22.28	0.30	0.75	0.17	10.71	0.17	4.24	0.17	1.99
	Glaciolacustrine deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CC-12	Bedrock	56.84	73.58	21.04	80.39	0.81	73.19	2.12	57.53	4.33	56.11
	Till	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	1.54	1.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	18.88	24.43	5.13	19.61	0.30	26.81	1.56	42.47	3.38	43.89
	Glaciolacustrine deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B7 (cont.)

		5km Buffer		Catchment		1km Reach		2km Reach		3km Reach	
		Area (km²)	Percent (%)	Area (km²)	Percent (%)	Area (km²)	Percent (%)	Area (km²)	Percent (%)	Area (km²)	Percent (%)
JUN-13	Bedrock	50.93	65.93	145.41	72.26	0.36	22.88	2.78	50.81	7.06	61.66
	Till	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	6.61	8.56	26.07	12.95	0.83	53.16	1.31	23.88	1.80	15.75
	Glaciolacustrine deposits	19.71	25.51	29.76	14.79	0.38	23.96	1.39	25.32	2.59	22.59
	Glaciolacustrine deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MB-14	Bedrock	55.18	71.43	28.46	86.16	0.18	18.57	1.60	39.56	4.99	57.38
	Till	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	9.17	11.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	12.78	16.54	4.54	13.75	0.78	81.43	2.45	60.44	3.71	42.62
	Glaciolacustrine deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	0.13	0.17	0.03	0.09	0.00	0.00	0.00	0.00	0.00	0.00
MUD-15	Bedrock	55.46	71.79	183.67	72.30	0.27	29.11	2.47	50.51	5.79	49.07
	Till	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	9.04	11.70	29.53	11.63	0.00	0.00	0.03	0.63	0.78	6.62
	Glaciolacustrine deposits	12.36	15.99	40.81	16.07	0.66	70.89	2.39	48.86	5.23	44.32
	Glaciolacustrine deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	0.40	0.52	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00
SIM-16	Bedrock	63.86	82.67	187.62	72.15	0.89	71.16	2.95	86.65	4.33	76.00
	Till	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	7.70	9.97	29.90	11.50	0.36	28.84	0.36	10.65	0.36	6.37
	Glaciolacustrine deposits	5.69	7.37	42.50	16.34	0.00	0.00	0.09	2.70	1.00	17.63
	Glaciolacustrine deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	0.00	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Table B7 (cont.)

		5km Buffer		Catchment		1km Reach		2km Reach		3km Reach	
		Area (km²)	Percent (%)	Area (km²)	Percent (%)	Area (km²)	Percent (%)	Area (km²)	Percent (%)	Area (km²)	Percent (%)
MC-17	Bedrock	69.61	90.10	190.14	71.98	0.19	24.13	1.12	44.85	2.69	57.70
	Till	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	6.85	8.87	31.51	11.93	0.58	75.87	1.38	55.15	1.97	42.30
	Glaciolacustrine deposits	0.80	1.03	42.50	16.09	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	0.00	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00
MC-18	Bedrock	69.71	90.24	193.08	72.04	0.75	91.90	1.77	71.76	2.64	63.89
	Till	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	6.52	8.44	32.43	12.10	0.07	8.10	0.70	28.24	1.49	36.11
	Glaciolacustrine deposits	0.00	0.00	42.50	15.86	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	1.02	1.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	0.00	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00
MC-19	Bedrock	63.08	81.65	214.76	73.67	0.88	52.03	5.11	75.46	11.78	86.50
	Till	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	9.88	12.78	34.25	11.75	0.81	47.97	1.66	24.54	1.84	13.50
	Glaciolacustrine deposits	0.08	0.10	42.50	14.58	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	4.22	5.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	0.00	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00
MC-20	Bedrock	60.37	78.14	56.53	89.11	1.07	99.58	2.47	93.45	3.26	73.13
	Till	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	0.42	0.66	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	8.36	10.83	0.09	0.14	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	1.56	2.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	6.77	8.77	4.81	7.58	0.00	0.42	0.17	6.55	1.20	26.87
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	0.19	0.25	1.59	2.51	0.00	0.00	0.00	0.00	0.00	0.00

Table B7 (cont.)

		5km Buffer		Catchment		1km Reach		2km Reach		3km Reach	
		Area (km²)	Percent (%)	Area (km²)	Percent (%)	Area (km²)	Percent (%)	Area (km²)	Percent (%)	Area (km²)	Percent (%)
KUS-21	Bedrock	43.34	56.10	21.24	80.98	0.76	46.70	3.03	55.51	5.80	62.35
	Till	10.97	14.20	2.33	8.89	0.00	0.00	0.00	0.00	0.85	9.10
	Glaciofluvial ice-contact deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	10.09	13.06	0.95	3.62	0.48	29.59	0.95	17.44	0.95	10.22
	Glaciolacustrine deposits	5.80	7.51	1.20	4.59	0.39	23.71	1.19	21.90	1.20	12.94
	Glaciolacustrine deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	7.04	9.12	0.50	1.91	0.00	0.00	0.28	5.15	0.50	5.40
VER-22	Bedrock	59.80	77.40	12.84	69.43	0.39	39.48	2.25	55.13	7.04	70.43
	Till	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	12.06	15.61	3.02	16.31	0.00	0.00	0.00	0.00	0.36	3.60
	Glaciolacustrine deposits	1.22	1.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	4.18	5.41	2.64	14.27	0.60	60.52	1.83	44.87	2.59	25.97
GRA-23	Bedrock	61.58	79.72	14.85	71.80	0.59	54.53	3.72	65.04	9.30	76.39
	Till	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	11.56	14.96	3.03	14.65	0.00	0.00	0.01	0.14	0.11	0.92
	Glaciolacustrine deposits	0.25	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	3.86	5.00	2.80	13.55	0.49	45.47	1.99	34.81	2.76	22.70
ELA-24	Bedrock	66.32	85.85	60.14	85.91	1.20	100.00	3.58	94.22	8.54	88.47
	Till	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	10.89	14.09	6.79	9.69	0.00	0.00	0.22	5.78	1.11	11.53
	Glaciolacustrine deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	0.04	0.05	3.08	4.40	0.00	0.00	0.00	0.00	0.00	0.00

Table B7 (cont.)

		5km Buffer		Catchment		1km Reach		2km Reach		3km Reach	
		Area (km²)	Percent (%)	Area (km²)	Percent (%)	Area (km²)	Percent (%)	Area (km²)	Percent (%)	Area (km²)	Percent (%)
ELA-25	Bedrock	64.05	82.90	93.31	90.44	1.44	100.00	6.32	99.81	13.47	94.17
	Till	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	12.82	16.60	6.79	6.58	0.00	0.00	0.01	0.19	0.83	5.83
	Glaciolacustrine deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	0.39	0.50	3.08	2.98	0.00	0.00	0.00	0.00	0.00	0.00
WAB-26	Bedrock	62.84	81.35	98.36	89.60	0.20	100.00	1.50	100.00	3.03	82.58
	Till	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	7.10	9.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	7.31	9.46	8.34	7.60	0.00	0.00	0.00	0.00	0.64	17.42
	Glaciolacustrine deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	0.00	0.00	3.08	2.80	0.00	0.00	0.00	0.00	0.00	0.00
WAB-27	Bedrock	69.99	90.60	121.07	87.28	0.87	100.00	4.93	100.00	10.60	100.00
	Till	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	4.97	6.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	2.29	2.97	14.56	10.50	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	0.00	0.00	3.08	2.22	0.00	0.00	0.00	0.00	0.00	0.00
VER-28	Bedrock	60.15	77.86	146.52	89.09	1.11	86.04	4.27	93.28	7.75	96.18
	Till	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial ice-contact deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciofluvial outwash deposits	4.01	5.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	0.00	0.00	14.56	8.85	0.00	0.00	0.00	0.00	0.00	0.00
	Glaciolacustrine deposits	3.11	4.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Fluvial deposits	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Organic deposits	9.98	12.92	3.39	2.06	0.18	13.96	0.31	6.72	0.31	3.82

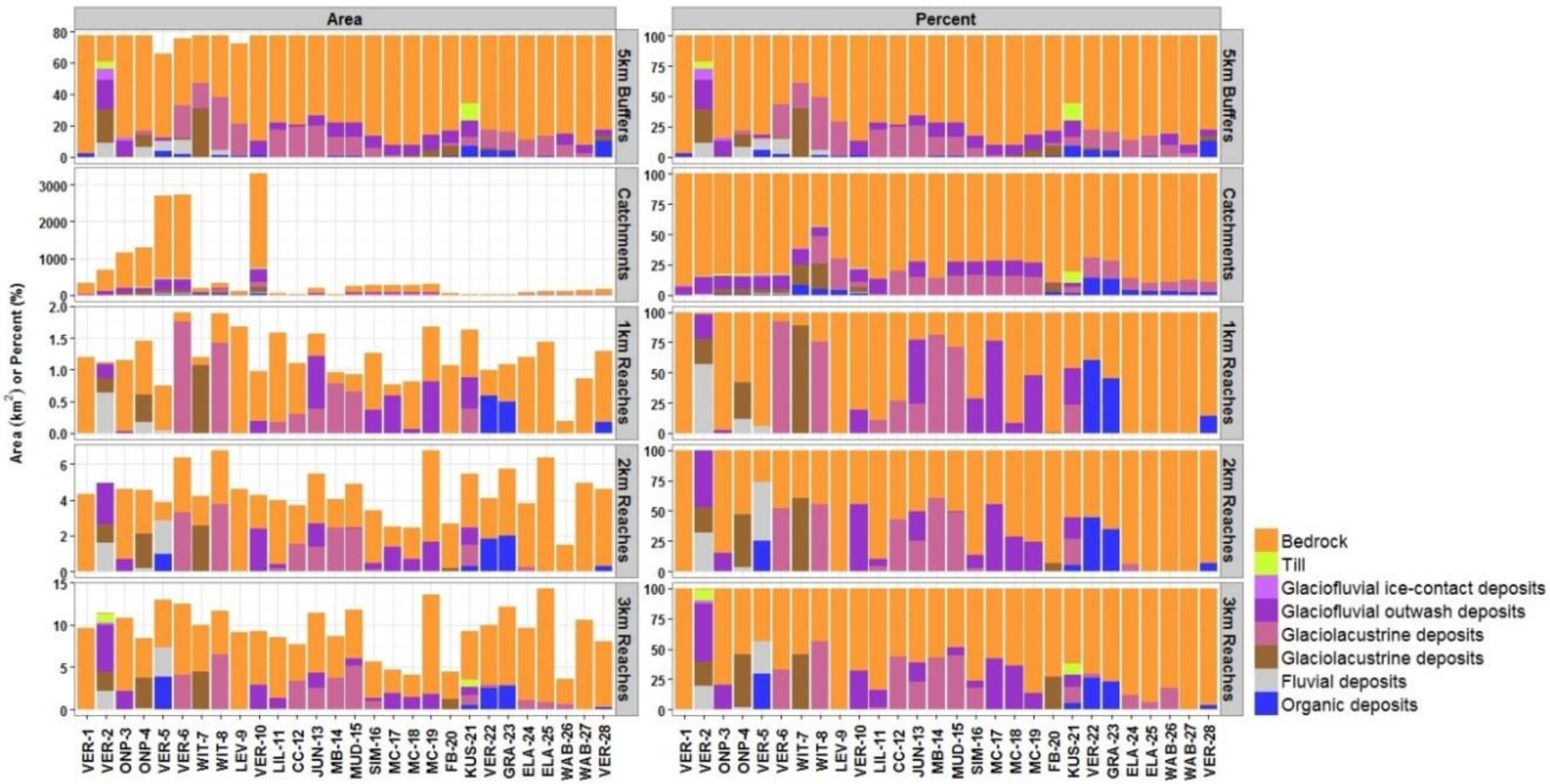

Figure B1 Quaternary geology area and percent of buffers (5km-radius), catchments, and reaches (1km, 2km, and 3km-radius) (Ontario Geological Survey, 1997).

Table B8 Modified land-cover types, original land-cover types and descriptions from the land-cover, circa 2000-Vector (LCC2000-V) dataset (GC, 2010).

	Modified land-cover type	Land-cover type: descriptions
	Forest	**Coniferous – dense:** greater than 60% crown closure; coniferous trees are 75% or more of total basal area. **Broadleaf – dense:** greater than 60% crown closure; broadleaf trees are 75% or more of total basal area. **Mixedwood – dense:** greater than 60% crown closure; neither coniferous nor broadleaf tree account for 75% or more of total basal area **Mixedwood – sparse:** 10-25% crown closure; neither coniferous nor broadleaf tree account for 75% or more of total basal area.
	Agriculture	**Annual crops:** annually cultivated cropland and woody perennial crops. Includes annual field crops, vegetables, summer fallow, orchards and vineyards. Comments: Classification process primarily detects and delineates lands that change from bare cover to green/vegetated cover during the growing season. **Perennial crops and pasture:** periodically cultivated cropland. Includes tame grasses and other perennial crops such as alfalfa and clover grown alone or as mixtures for hay, pasture or seed. Comments: Fall seeded crops such as winter wheat may be erroneously identified in this class. Grassland and shrubland may be delineated within in this class.
	Herb	**Herb:** vascular plant without woody stem (grasses, crops, forbs, graminoids); minimum of 20% ground cover or one-third of total vegetation must be herb.
	Wetland	**Wetland treed:** land with a water table near/at/above soil surface for enough time to promote wetland or aquatic processes; the majority of vegetation is coniferous, broadleaf, or mixed wood. **Wetland shrub:** land with a water table near/at/above soil surface for enough time to promote wetland or aquatic processes; the majority of vegetation is tall, low, or a mixture of tall and low shrub.
	Developed	**Developed:** land that is predominantly built-up or developed and vegetation associated with these land-covers. This includes road surfaces, railway surfaces, buildings and paved surfaces, urban areas, industrial sites, mine structures and farmsteads.
	Barren	**Rock/rubble:** bedrock, rubble, talus, blockfield, rubbley mine spoils, or lava beds. **Exposed land:** river sediments, exposed soils, pond or lake sediments, reservoir margins, beaches, landings, burned areas, road surfaces, mudflat sediments, cutbanks, moraines, gravel pits, tailings, railway surfaces, buildings and parking, or other non-vegetated surfaces.
	Water	**Water:** lakes, reservoirs, rivers, streams, or salt water.

Table B9 Modified land-cover area and percent of buffer (5km-radius), catchment, and reaches (1km, 2km, and 3km-radius) for each site (GC, 2010).

		5km Buffer		**Catchment**		**1km Reach**		**2km Reach**		**3km Reach**	
		Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)
VER-1	Water	5.95	7.70	33.89	10.11	0.08	6.65	0.17	3.85	0.45	4.70
	Barren	2.09	2.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Developed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Wetland	1.90	2.45	3.00	0.89	0.00	0.00	0.00	0.00	0.00	0.00
	Herb	0.00	0.00	1.63	0.49	0.00	0.00	0.00	0.00	0.00	0.00
	Agriculture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	67.31	87.13	296.55	88.50	1.12	93.35	4.15	96.15	9.16	95.30
VER-2	Water	2.45	3.17	60.65	8.92	0.00	0.00	0.00	0.00	0.08	0.75
	Barren	1.13	1.46	6.43	0.95	0.00	0.00	0.06	1.13	0.22	1.90
	Developed	9.05	11.71	10.18	1.50	0.08	7.44	0.08	1.67	0.08	0.73
	Wetland	2.77	3.58	4.15	0.61	0.00	0.00	0.08	1.62	0.42	3.73
	Herb	0.26	0.33	7.46	1.10	0.03	2.57	0.05	1.03	0.17	1.45
	Agriculture	7.27	9.41	7.13	1.05	0.25	22.26	0.55	11.04	2.00	17.57
	Forest	54.34	70.34	584.22	85.89	0.75	67.72	4.14	83.50	8.39	73.86
ONP-3	Water	4.87	6.30	169.48	14.02	0.04	3.74	0.14	3.15	0.19	1.76
	Barren	11.82	15.31	1.66	0.14	0.03	2.22	0.04	0.91	0.81	7.55
	Developed	0.68	0.89	0.24	0.02	0.00	0.00	0.00	0.00	0.00	0.00
	Wetland	0.22	0.29	5.94	0.49	0.00	0.00	0.00	0.00	0.00	0.00
	Herb	6.42	8.30	57.48	4.76	0.00	0.12	0.22	4.87	1.60	14.86
	Agriculture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	53.24	68.92	973.88	80.57	1.08	93.92	4.19	91.06	8.17	75.83
ONP-4	Water	3.02	3.91	189.78	13.79	0.00	0.00	0.00	0.00	0.02	0.26
	Barren	2.53	3.28	21.38	1.55	0.00	0.00	0.03	0.76	0.08	0.97
	Developed	3.61	4.68	3.62	0.26	0.00	0.00	0.16	3.48	1.50	17.97
	Wetland	2.26	2.92	6.36	0.46	0.00	0.00	0.00	0.00	0.00	0.00
	Herb	0.08	0.10	62.84	4.57	0.00	0.00	0.00	0.00	0.00	0.00
	Agriculture	7.38	9.56	1.24	0.09	0.77	52.51	1.24	27.37	1.24	14.89
	Forest	58.37	75.55	1090.53	79.27	0.69	47.48	3.11	68.39	5.51	65.90

Table B9 (cont.)

		5km Buffer		Catchment		1km Reach		2km Reach		3km Reach	
		Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)
VER-5	Water	13.84	17.91	300.01	10.78	0.89	86.33	3.25	57.52	5.56	34.05
	Barren	2.22	2.87	46.51	1.67	0.01	1.27	0.07	1.16	0.16	1.00
	Developed	1.50	1.94	15.71	0.56	0.00	0.00	0.00	0.00	0.00	0.00
	Wetland	2.36	3.06	25.59	0.92	0.00	0.00	0.37	6.60	0.65	3.95
	Herb	0.03	0.04	99.97	3.59	0.00	0.00	0.00	0.00	0.00	0.00
	Agriculture	2.13	2.75	18.41	0.66	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	55.18	71.43	2277.13	81.81	0.13	12.40	1.96	34.72	9.95	61.00
VER-6	Water	4.52	5.86	306.50	10.87	0.13	6.60	0.25	3.98	0.63	4.98
	Barren	0.38	0.50	46.69	1.66	0.00	0.00	0.05	0.73	0.12	0.93
	Developed	2.68	3.47	17.81	0.63	0.05	2.39	0.35	5.53	0.81	6.38
	Wetland	2.13	2.76	26.94	0.96	0.03	1.62	0.41	6.39	0.55	4.36
	Herb	0.44	0.57	100.02	3.55	0.00	0.00	0.03	0.53	0.05	0.39
	Agriculture	10.38	13.44	21.69	0.77	0.97	50.67	1.70	26.65	3.16	24.85
	Forest	56.71	73.40	2298.85	81.56	0.74	38.72	3.58	56.19	7.38	58.11
WIT-7	Water	3.33	4.31	8.55	4.79	0.00	0.00	0.00	0.00	0.25	2.48
	Barren	4.69	6.07	43.22	24.22	0.00	0.00	0.01	0.23	0.08	0.77
	Developed	11.55	14.95	18.19	10.19	0.99	82.25	2.36	56.03	4.39	43.92
	Wetland	0.71	0.91	6.66	3.73	0.00	0.00	0.00	0.00	0.00	0.00
	Herb	0.06	0.08	0.42	0.24	0.00	0.00	0.00	0.00	0.01	0.13
	Agriculture	25.12	32.52	23.85	13.36	0.14	11.95	0.49	11.64	1.64	16.39
	Forest	31.79	41.16	77.58	43.47	0.07	5.80	1.36	32.10	3.63	36.31
WIT-8	Water	2.38	3.08	9.06	2.86	0.00	0.00	0.01	0.14	0.06	0.49
	Barren	0.13	0.17	44.73	14.09	0.00	0.00	0.00	0.00	0.00	0.02
	Developed	1.79	2.31	35.88	11.30	0.04	1.91	0.06	0.93	0.06	0.54
	Wetland	2.09	2.70	11.05	3.48	0.10	5.14	0.52	7.62	0.66	5.72
	Herb	0.58	0.75	0.56	0.18	0.00	0.00	0.00	0.00	0.05	0.45
	Agriculture	14.28	18.48	65.73	20.70	0.26	14.05	0.86	12.68	2.38	20.51
	Forest	56.01	72.50	150.47	47.39	1.48	78.89	5.33	78.63	8.39	72.26

Table B9 (cont.)

		5km Buffer		Catchment		1km Reach		2km Reach		3km Reach	
		Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)
LEV-9	Water	6.45	8.35	14.46	11.61	0.12	6.73	0.92	16.82	2.38	20.59
	Barren	2.63	3.41	31.04	24.91	0.00	0.00	0.03	0.51	0.24	2.11
	Developed	3.84	4.98	6.41	5.15	0.22	12.48	0.34	6.27	0.59	5.13
	Wetland	2.16	2.80	1.88	1.51	0.08	4.49	0.21	3.84	0.26	2.24
	Herb	0.49	0.64	0.19	0.15	0.00	0.00	0.00	0.01	0.10	0.86
	Agriculture	6.01	7.77	16.16	12.97	0.11	6.53	0.23	4.18	0.23	1.99
	Forest	55.66	72.05	54.48	43.71	1.23	69.77	3.75	68.37	7.74	67.08
VER-10	Water	4.76	6.16	337.61	9.93	0.14	14.11	0.45	10.52	0.85	9.23
	Barren	3.73	4.83	124.51	3.66	0.12	11.94	0.30	6.99	0.34	3.67
	Developed	1.59	2.05	62.10	1.83	0.00	0.00	0.00	0.00	0.00	0.00
	Wetland	1.94	2.51	46.51	1.37	0.11	11.35	0.11	2.58	0.27	2.90
	Herb	0.01	0.01	101.38	2.98	0.00	0.00	0.00	0.00	0.00	0.00
	Agriculture	0.00	0.00	112.22	3.30	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	65.24	84.44	2616.03	76.93	0.61	62.60	3.42	79.91	7.78	84.20
LIL-11	Water	12.08	15.64	10.39	25.97	0.49	31.05	1.78	44.56	3.23	37.98
	Barren	26.51	34.31	9.99	24.97	0.00	0.00	0.00	0.00	0.85	10.03
	Developed	30.19	39.08	10.09	25.23	1.09	68.95	2.22	55.44	3.44	40.46
	Wetland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Herb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Agriculture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	8.47	10.96	9.53	23.84	0.00	0.00	0.00	0.00	0.98	11.54
CC-12	Water	8.63	11.17	2.03	7.75	0.00	0.00	0.01	0.35	0.01	0.17
	Barren	41.60	53.85	21.51	82.19	0.92	83.80	3.31	89.91	5.86	75.99
	Developed	24.10	31.19	1.94	7.43	0.14	13.15	0.30	8.18	1.78	23.08
	Wetland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Herb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Agriculture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	2.93	3.79	0.69	2.63	0.03	3.05	0.06	1.56	0.06	0.76

Table B9 (cont.)

		5km Buffer		Catchment		1km Reach		2km Reach		3km Reach	
		Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)
JUN-13	Water	5.83	7.55	19.87	9.82	0.15	9.60	0.61	11.17	1.42	12.38
	Barren	34.21	44.28	93.11	46.03	0.26	16.73	2.21	40.38	6.79	59.34
	Developed	10.50	13.59	57.02	28.19	0.66	42.19	1.55	28.39	1.93	16.83
	Wetland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Herb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Agriculture	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	26.69	34.55	32.27	15.95	0.49	31.48	1.10	20.06	1.31	11.45
MB-14	Water	9.17	11.87	1.90	5.76	0.00	0.00	0.00	0.00	0.01	0.10
	Barren	7.13	9.23	10.57	32.00	0.04	4.51	0.32	7.93	0.65	7.50
	Developed	11.74	15.19	5.59	16.93	0.37	38.82	1.28	31.53	2.66	30.54
	Wetland	0.42	0.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Herb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Agriculture	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	48.77	63.13	14.97	45.31	0.54	56.66	2.45	60.54	5.38	61.86
MUD-15	Water	10.27	13.30	21.92	8.59	0.03	3.11	0.03	0.59	0.03	0.25
	Barren	6.03	7.81	108.61	42.56	0.04	4.74	0.31	6.26	1.05	8.91
	Developed	11.14	14.42	66.14	25.92	0.31	33.97	1.28	26.16	2.94	24.93
	Wetland	0.50	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Herb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Agriculture	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	49.28	63.79	58.53	22.93	0.54	58.19	3.28	66.99	7.78	65.90
SIM-16	Water	14.12	18.28	22.97	8.79	0.44	34.68	0.50	14.58	0.81	14.15
	Barren	2.34	3.03	108.86	41.68	0.01	1.01	0.09	2.73	0.26	4.60
	Developed	6.23	8.07	67.66	25.90	0.44	35.35	1.22	35.98	1.50	26.32
	Wetland	0.76	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Herb	0.27	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Agriculture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	53.53	69.29	61.70	23.62	0.36	28.95	1.59	46.72	3.13	54.93

Table B9 (cont.)

		5km Buffer		Catchment		1km Reach		2km Reach		3km Reach	
		Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)
MC-17	Water	14.19	18.37	23.88	9.00	0.29	37.15	0.82	32.86	1.28	27.48
	Barren	1.32	1.70	108.94	41.06	0.00	0.00	0.01	0.27	0.04	0.81
	Developed	4.78	6.19	68.61	25.86	0.29	37.14	0.64	25.74	1.37	29.34
	Wetland	1.74	2.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Herb	0.30	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Agriculture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	54.92	71.09	63.89	24.08	0.20	25.71	1.03	41.12	1.97	42.37
MC-18	Water	12.50	16.19	24.61	9.14	0.23	28.33	0.64	25.87	1.00	24.23
	Barren	0.41	0.53	108.96	40.48	0.00	0.00	0.01	0.23	0.02	0.37
	Developed	4.52	5.85	69.03	25.64	0.00	0.00	0.24	9.62	0.74	17.93
	Wetland	2.16	2.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Herb	0.43	0.56	0.12	0.05	0.03	4.25	0.12	4.98	0.12	2.97
	Agriculture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	57.23	74.08	66.47	24.69	0.55	67.43	1.46	59.29	2.25	54.50
MC-19	Water	10.11	13.09	26.26	8.97	0.60	35.86	1.15	17.00	1.69	12.44
	Barren	1.40	1.81	109.37	37.37	0.05	3.00	0.08	1.21	0.13	0.93
	Developed	4.73	6.12	70.60	24.12	0.13	7.65	0.43	6.37	0.70	5.13
	Wetland	1.99	2.58	1.02	0.35	0.03	1.67	0.47	6.91	0.64	4.71
	Herb	0.57	0.74	0.34	0.12	0.01	0.73	0.05	0.69	0.34	2.52
	Agriculture	0.17	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	58.28	75.44	85.10	29.07	0.86	51.08	4.59	67.81	10.11	74.27
FB-20	Water	7.37	9.54	11.19	17.64	0.00	0.00	0.00	0.00	0.02	0.36
	Barren	1.32	1.71	3.55	5.59	0.00	0.00	0.16	6.00	0.56	12.51
	Developed	5.17	6.69	2.81	4.43	0.38	35.25	0.54	20.30	0.87	19.54
	Wetland	2.38	3.08	0.91	1.44	0.00	0.00	0.00	0.00	0.00	0.00
	Herb	0.74	0.95	0.27	0.42	0.00	0.00	0.00	0.00	0.00	0.00
	Agriculture	0.65	0.84	0.60	0.94	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	59.63	77.18	44.12	69.54	0.70	64.75	1.95	73.70	3.01	67.59

Table B9 (cont.)

		5km Buffer		Catchment		1km Reach		2km Reach		3km Reach	
		Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)
KUS-21	Water	6.76	8.75	1.69	6.30	0.55	33.88	1.02	18.57	1.23	13.12
	Barren	3.05	3.94	2.78	10.37	0.01	0.61	0.27	4.85	0.71	7.56
	Developed	0.86	1.12	0.02	0.08	0.00	0.00	0.00	0.00	0.01	0.06
	Wetland	2.87	3.71	1.62	6.05	0.15	9.30	0.50	9.09	0.79	8.45
	Herb	0.88	1.14	0.05	0.19	0.00	0.00	0.00	0.00	0.05	0.53
	Agriculture	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	62.82	81.31	20.64	77.02	0.92	56.22	3.70	67.48	6.56	70.28
VER-22	Water	4.69	6.07	1.37	7.41	0.13	13.13	0.44	10.84	0.86	8.64
	Barren	4.90	6.35	0.80	4.33	0.00	0.00	0.00	0.00	0.35	3.49
	Developed	3.27	4.24	0.42	2.26	0.00	0.00	0.00	0.00	0.00	0.00
	Wetland	3.15	4.08	0.17	0.89	0.00	0.00	0.00	0.00	0.15	1.49
	Herb	1.23	1.59	0.55	2.98	0.00	0.00	0.00	0.00	0.09	0.87
	Agriculture	0.07	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	59.94	77.59	15.19	82.13	0.86	86.87	3.63	89.16	8.54	85.51
GRA-23	Water	4.61	5.97	1.44	6.94	0.15	14.10	0.42	7.43	0.91	7.48
	Barren	5.19	6.72	0.80	3.87	0.00	0.00	0.01	0.16	0.57	4.68
	Developed	2.60	3.37	0.42	2.02	0.00	0.00	0.00	0.00	0.00	0.00
	Wetland	3.16	4.09	0.20	0.95	0.00	0.00	0.05	0.83	0.18	1.48
	Herb	1.20	1.55	0.60	2.92	0.05	4.91	0.05	0.93	0.06	0.50
	Agriculture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	60.50	78.31	17.22	83.29	0.87	80.99	5.18	90.66	10.45	85.86
ELA-24	Water	10.37	13.42	5.26	7.50	0.22	18.43	0.49	12.97	0.76	7.84
	Barren	3.49	4.52	3.02	4.31	0.02	1.47	0.14	3.59	0.69	7.17
	Developed	1.27	1.64	1.45	2.08	0.00	0.00	0.00	0.00	0.00	0.00
	Wetland	1.70	2.21	1.65	2.36	0.00	0.00	0.02	0.55	0.21	2.17
	Herb	0.80	1.03	1.07	1.53	0.00	0.00	0.00	0.00	0.00	0.00
	Agriculture	1.31	1.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	58.32	75.49	57.60	82.23	0.96	80.11	3.15	82.89	7.99	82.81

Table B9 (cont.)

		5km Buffer		Catchment		1km Reach		2km Reach		3km Reach	
		Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)
ELA-25	Water	10.29	13.32	13.29	12.78	0.61	42.53	2.23	35.23	4.20	29.36
	Barren	3.59	4.65	4.04	3.89	0.02	1.04	0.02	0.39	0.35	2.42
	Developed	1.42	1.84	1.45	1.40	0.00	0.00	0.00	0.00	0.00	0.00
	Wetland	1.93	2.49	2.43	2.33	0.00	0.00	0.22	3.51	0.39	2.70
	Herb	1.10	1.42	1.14	1.10	0.00	0.00	0.00	0.00	0.06	0.44
	Agriculture	1.31	1.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	57.62	74.58	81.62	78.50	0.81	56.43	3.86	60.87	9.31	65.07
WAB-26	Water	14.29	18.49	14.51	13.12	0.18	90.17	0.58	38.50	0.93	25.28
	Barren	5.27	6.83	4.26	3.85	0.00	0.00	0.09	5.98	0.20	5.52
	Developed	4.55	5.88	1.47	1.33	0.00	0.00	0.00	0.00	0.00	0.00
	Wetland	0.85	1.10	2.54	2.29	0.00	0.00	0.00	0.00	0.00	0.00
	Herb	0.05	0.07	1.14	1.03	0.00	0.00	0.00	0.00	0.00	0.00
	Agriculture	0.77	1.00	0.14	0.13	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	51.47	66.63	86.52	78.25	0.02	9.83	0.83	55.53	2.54	69.20
WAB-27	Water	13.02	16.85	17.74	12.72	0.53	60.95	1.82	36.90	3.11	29.31
	Barren	5.06	6.56	6.68	4.79	0.03	3.00	0.35	7.04	1.15	10.87
	Developed	3.00	3.89	2.72	1.95	0.00	0.00	0.00	0.00	0.00	0.00
	Wetland	1.63	2.10	2.93	2.10	0.00	0.00	0.00	0.00	0.00	0.00
	Herb	0.02	0.03	1.52	1.09	0.00	0.00	0.00	0.00	0.00	0.00
	Agriculture	0.31	0.40	1.31	0.94	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	54.21	70.17	106.61	76.42	0.31	36.05	2.76	56.07	6.34	59.83
VER-28	Water	10.01	12.96	22.83	13.80	0.13	10.10	0.30	6.58	0.67	8.26
	Barren	3.40	4.40	8.10	4.90	0.03	2.15	0.16	3.58	0.32	4.00
	Developed	1.01	1.31	2.72	1.64	0.00	0.00	0.00	0.00	0.00	0.00
	Wetland	2.32	3.00	3.82	2.31	0.00	0.00	0.29	6.40	0.43	5.36
	Herb	0.00	0.00	1.52	0.92	0.00	0.00	0.00	0.00	0.00	0.00
	Agriculture	0.02	0.03	1.31	0.79	0.00	0.00	0.00	0.00	0.00	0.00
	Forest	60.49	78.31	125.17	75.65	1.14	87.75	3.82	83.44	6.64	82.38

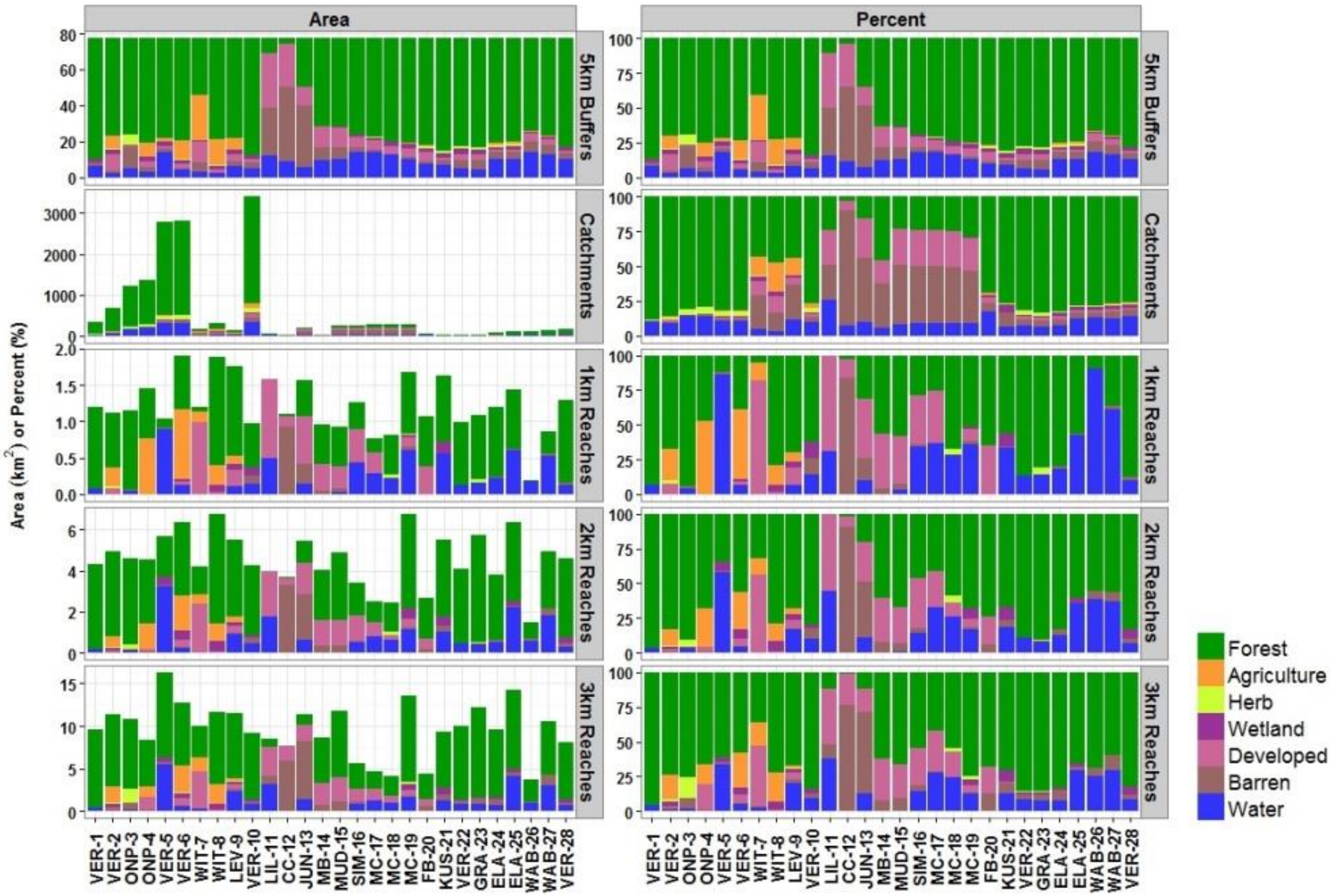

Figure B2 Land-cover area and percent of buffers (5km-radius), catchments, reaches (1km, 2km, and 3km-radius) (GC, 2010).

Table B10 Road length and road density of buffer (5km-radius), catchment, and reaches (1km, 2km, and 3km-radius) for each site (GO, 2013).

	5km Buffer		**Catchment**		**1km Reach**		**2km Reach**		**3km Reach**	
	Road Length (km)	Road Density (km/km^2)	Road Length (km)	Road Density (km/km^2)	Road Length (km)	Road Density (km/km^2)	Road Length (km)	Road Density (km/km^2)	Road Length (km)	Road Density (km/km^2)
VER-1	8.25	0.11	4.96	0.01	0.00	0.00	0.00	0.00	0.00	0.00
VER-2	95.03	1.23	161.73	0.24	1.21	1.08	4.21	0.85	11.74	1.03
ONP-3	92.72	1.20	152.23	0.13	1.06	0.92	2.75	0.60	5.23	0.48
ONP-4	67.60	0.87	306.34	0.22	2.41	1.65	4.42	0.97	17.79	2.12
VER-5	22.70	0.29	609.88	0.22	0.00	0.00	0.00	0.00	7.00	0.43
VER-6	51.92	0.67	626.88	0.22	2.96	1.55	6.80	1.06	11.41	0.90
WIT-7	112.42	1.45	155.55	0.87	5.46	4.51	17.32	4.09	30.44	3.04
WIT-8	52.87	0.68	351.38	1.10	1.90	1.00	2.97	0.44	5.93	0.51
LEV-9	47.90	0.62	96.00	0.77	1.68	0.95	4.73	0.86	6.97	0.60
VER-10	38.05	0.49	1123.34	0.33	0.00	0.00	0.00	0.00	0.00	0.00
LIL-11	353.43	4.56	95.23	2.37	6.19	3.89	17.02	4.24	29.70	3.48
CC-12	305.21	3.94	45.00	1.71	4.84	4.36	14.55	3.94	37.99	4.91
JUN-13	142.66	1.84	597.11	2.94	2.93	1.86	10.17	1.85	17.89	1.56
MB-14	134.47	1.74	63.85	1.93	4.68	4.87	15.44	3.80	33.83	3.87
MUD-15	130.95	1.69	703.18	2.75	2.54	2.73	11.62	2.37	35.58	3.00
SIM-16	79.06	1.02	716.01	2.73	3.13	2.49	9.85	2.89	12.97	2.27
MC-17	68.08	0.88	721.61	2.71	1.46	1.90	3.59	1.43	8.31	1.78
MC-18	54.03	0.70	726.04	2.69	1.00	1.22	3.09	1.25	6.23	1.51
MC-19	56.44	0.73	753.09	2.56	2.49	1.47	7.89	1.16	15.09	1.10
FB-20	66.43	0.86	51.20	0.80	2.14	1.99	3.96	1.50	6.82	1.53
KUS-21	49.26	0.64	5.37	0.20	0.67	0.41	3.08	0.56	4.24	0.45
VER-22	67.58	0.87	17.00	0.92	0.33	0.33	3.08	0.75	9.54	0.95
GRA-23	63.45	0.82	19.16	0.92	1.98	1.84	4.47	0.78	10.31	0.84
ELA-24	42.80	0.55	49.97	0.71	1.64	1.37	3.38	0.89	4.60	0.48
ELA-25	44.05	0.57	50.43	0.48	0.00	0.00	3.28	0.52	3.84	0.27
WAB-26	37.73	0.49	55.16	0.50	0.00	0.00	0.48	0.32	0.76	0.20
WAB-27	25.12	0.32	80.50	0.58	0.00	0.00	0.00	0.00	0.03	0.00
VER-28	32.10	0.41	80.50	0.48	0.00	0.00	0.00	0.00	0.00	0.00

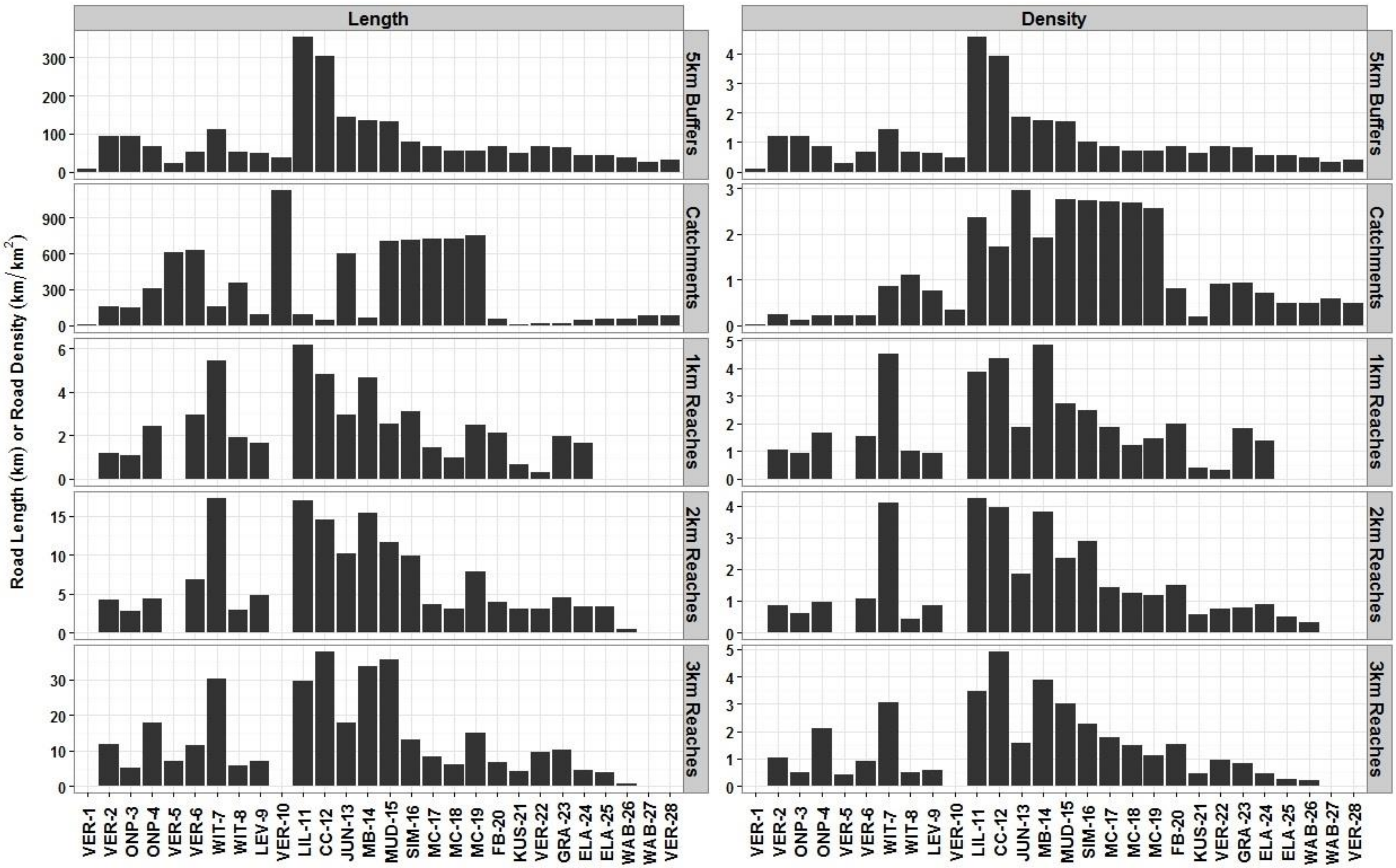

Figure B3 Road length and density of buffers (5km-radius), catchments, and reaches (1km, 2km, and 3km-radius) (GO, 2013).

Table B11 Date ranges when the VRMT were monitored monthly in 2013-2014.

2013	**May**	**May 13th - May 31st** PWQMN sites (May 13th - May 14th) VRS sites (May 28th – May 31st)
	June	**June 17th – June 25th** PWQMN sites (June 17th – June 18th) VRS sites (June 17th – June 25th)
	July	**July 15th – July 24th** VRS sites (July 15th – July 24th)
	August	**August 12th – August 20th** PWQMN sites (August 19th – August 20th) VRS sites (August 12th – August 20th)
	September	**September 16th – September 25th** PWQMN sites (September 24th – September 25th) VRS sites (September 16th – September 25th)
	October	**October 7th – October 24th** PWQMN sites (October 23rd – October 24th) VRS sites (October 7th – October 11th)
2014	**June**	**June 9th – June 18th** PWQMN sites (June 17th – June 18th) VRS sites (June 9th – June 13th)
	July	**July 2nd – July 11th** PWQMN sites (July 2nd) VRS sites (July 3rd – July 11th)
	August	**August 5th – August 21st** PWQMN sites (August 20th – August 21st) VRS sites (August 5th – August 11th)
	September	**September 2nd – September 11th** PWQMN sites (September 10th – September 11th) VRS sites (September 2nd – September 9th)
	October	**September 30th – October 9th** PWQMN sites (October 6th – October 7th) VRS sites (September 30th – October 9th)
	November	**October 24th – November 6th** PWQMN sites (November 5th – November 6th) VRS sites (October 24th – November 3rd)

Table B12 Means (± standard deviations) of general biological/chemical parameters and nutrients for 2013.

	Chl-a (ug/L)		E.coli (CFU/100mL)		pH		CaCO3 (mg/L)		DOC (mg/L)		Cond (umho/cm)		Cl (mg/L)	
VER-1	0.59	(±0.76)	8.00	(±8.37)	7.44	(±0.12)	22.80	(±2.86)	5.28	(±0.70)	51.60	(±6.02)	0.00	(±0.00)
VER-2	1.15	(±1.15)	23.33	(±30.11)	7.51	(±0.11)	32.50	(±8.87)	4.53	(±0.86)	89.67	(±25.96)	5.20	(±2.71)
ONP-3	1.07	(±0.87)	40.00	(±36.74)	7.05	(±0.26)	13.06	(±2.54)	6.14	(±0.28)	36.60	(±6.66)	1.40	(±0.42)
ONP-4	0.85	(±0.84)	25.00	(±18.71)	7.06	(±0.39)	54.17	(±24.73)	5.35	(±0.79)	161.67	(±70.26)	14.18	(±6.61)
VER-5	2.48	(±1.35)	3.33	(±5.16)	7.43	(±0.29)	42.17	(±9.00)	5.25	(±0.74)	113.67	(±28.15)	7.98	(±2.60)
VER-6	2.32	(±0.96)	1.67	(±4.08)	7.44	(±0.24)	42.67	(±9.79)	5.17	(±0.71)	115.67	(±29.24)	7.75	(±2.44)
WIT-7	1.32	(±0.99)	32.00	(±10.95)	7.86	(±0.23)	95.02	(±19.06)	9.28	(±2.59)	313.60	(±67.73)	36.66	(±8.81)
WIT-8	2.11	(±0.89)	30.00	(±18.71)	8.12	(±0.10)	143.00	(±16.05)	8.48	(±1.99)	425.60	(±60.07)	45.56	(±8.64)
LEV-9	2.33	(±1.60)	14.00	(±20.74)	7.73	(±0.12)	61.20	(±2.62)	5.50	(±0.40)	203.40	(±12.42)	18.96	(±1.29)
VER-10	2.01	(±0.61)	6.00	(±8.94)	7.61	(±0.21)	44.58	(±9.90)	5.48	(±0.79)	136.00	(±34.44)	9.98	(±2.57)
LIL-11	1.66	(±1.52)	6.00	(±8.94)	7.79	(±0.11)	60.24	(±2.35)	3.60	(±0.20)	426.40	(±15.21)	90.96	(±3.55)
CC-12	0.43	(±0.47)	31.67	(±51.93)	8.38	(±0.49)	1345.00	(±388.52)	2.68	(±0.78)	2850.00	(±367.42)	158.33	(±78.34)
JUN-13	8.93	(±5.22)	34.00	(±31.30)	7.61	(±0.10)	600.20	(±103.51)	4.24	(±0.61)	1600.00	(±173.49)	114.60	(±6.88)
MB-14	1.20	(±0.80)	105.00	(±53.20)	7.50	(±0.10)	80.50	(±7.58)	6.08	(±1.11)	323.33	(±12.11)	48.00	(±5.29)
MUD-15	3.81	(±3.42)	33.33	(±36.70)	7.50	(±0.08)	535.00	(±107.66)	5.13	(±0.48)	1400.00	(±189.74)	99.83	(±12.43)
SIM-16	2.37	(±1.41)	61.67	(±113.74)	7.46	(±0.11)	483.33	(±81.89)	5.10	(±0.55)	1266.67	(±163.30)	95.33	(±9.09)
MC-17	3.63	(±2.59)	18.33	(±24.83)	7.57	(±0.17)	440.00	(±65.42)	5.05	(±0.37)	1183.33	(±147.20)	90.33	(±6.41)
MC-18	4.17	(±3.67)	6.67	(±12.11)	7.61	(±0.21)	323.33	(±52.41)	5.30	(±0.54)	918.33	(±126.40)	68.50	(±8.46)
MC-19	2.15	(±0.76)	8.33	(±7.53)	7.60	(±0.16)	117.67	(±44.67)	5.67	(±0.98)	341.67	(±122.22)	23.55	(±8.73)
FB-20	1.66	(±0.66)	95.00	(±141.24)	7.24	(±0.24)	31.50	(±7.66)	6.90	(±1.22)	109.83	(±51.06)	13.27	(±11.37)
KUS-21	2.03	(±1.41)	16.67	(±26.58)	7.53	(±0.14)	97.83	(±29.18)	6.08	(±0.75)	291.67	(±82.08)	20.33	(±5.68)
VER-22	1.66	(±1.48)	6.67	(±12.11)	7.46	(±0.22)	98.00	(±29.73)	5.97	(±0.63)	291.67	(±83.77)	19.67	(±5.68)
GRA-23	1.98	(±0.93)	13.33	(±12.11)	7.49	(±0.13)	96.67	(±27.33)	6.08	(±0.73)	293.33	(±82.38)	19.67	(±5.68)
ELA-24	2.26	(±0.84)	70.00	(±147.78)	7.52	(±0.14)	104.67	(±32.83)	6.03	(±0.78)	300.00	(±86.72)	20.17	(±5.67)
ELA-25	3.03	(±1.55)	56.67	(±138.80)	7.47	(±0.07)	46.67	(±2.42)	4.90	(±0.31)	138.33	(±7.53)	8.55	(±0.34)
WAB-26	1.99	(±1.15)	188.33	(±446.65)	7.50	(±0.16)	95.33	(±26.94)	6.28	(±0.84)	278.33	(±76.00)	19.17	(±4.96)
WAB-27	1.90	(±1.21)	98.33	(±240.87)	7.48	(±0.12)	87.00	(±21.26)	6.10	(±0.49)	258.33	(±61.78)	17.83	(±3.82)
VER-28	1.41	(±0.71)	5.00	(±8.37)	7.51	(±0.12)	88.33	(±21.25)	6.07	(±0.50)	253.33	(±57.85)	17.67	(±4.08)

Note: Water quality parameter means (± standard deviations) calculated using n=6, with the exception of VER-6 for Chl-a (n=5, May was missing) and VER-1 for all water quality parameters (n=5, June was missing).

Table B12 (cont.)

	TP (mg/L)		TN (mg/L)		TKN (mg/L)		NO3 (mg/L)		NO2 (mg/L)	
VER-1	0.00	(±0.00)	0.38	(±0.16)	0.38	(±0.16)	0.00	(±0.00)	0.00	(±0.00)
VER-2	0.00	(±0.00)	0.71	(±0.31)	0.56	(±0.20)	0.14	(±0.12)	0.02	(±0.01)
ONP-3	0.01	(±0.00)	0.29	(±0.03)	0.23	(±0.03)	0.06	(±0.02)	0.00	(±0.00)
ONP-4	0.01	(±0.02)	0.76	(±0.39)	0.69	(±0.34)	0.05	(±0.08)	0.01	(±0.01)
VER-5	0.00	(±0.00)	0.44	(±0.04)	0.40	(±0.04)	0.04	(±0.05)	0.00	(±0.00)
VER-6	0.00	(±0.00)	0.41	(±0.07)	0.41	(±0.07)	0.00	(±0.00)	0.00	(±0.00)
WIT-7	0.01	(±0.00)	0.53	(±0.23)	0.39	(±0.22)	0.14	(±0.03)	0.01	(±0.00)
WIT-8	0.02	(±0.01)	1.18	(±0.22)	0.53	(±0.09)	0.63	(±0.24)	0.02	(±0.02)
LEV-9	0.01	(±0.00)	0.34	(±0.04)	0.30	(±0.03)	0.04	(±0.03)	0.00	(±0.00)
VER-10	0.01	(±0.00)	0.43	(±0.03)	0.29	(±0.02)	0.13	(±0.02)	0.01	(±0.01)
LIL-11	0.02	(±0.01)	0.29	(±0.04)	0.25	(±0.03)	0.04	(±0.02)	0.00	(±0.00)
CC-12	0.00	(±0.00)	5.28	(±2.18)	4.25	(±2.20)	1.01	(±0.18)	0.03	(±0.03)
JUN-13	0.05	(±0.02)	3.32	(±0.58)	1.67	(±1.04)	1.53	(±0.53)	0.12	(±0.09)
MB-14	0.01	(±0.02)	0.96	(±0.10)	0.61	(±0.12)	0.34	(±0.07)	0.01	(±0.01)
MUD-15	0.03	(±0.03)	2.70	(±0.30)	1.18	(±0.28)	1.38	(±0.15)	0.12	(±0.04)
SIM-16	0.04	(±0.05)	2.26	(±0.39)	1.23	(±0.36)	0.95	(±0.20)	0.09	(±0.04)
MC-17	0.02	(±0.02)	2.20	(±0.41)	1.12	(±0.35)	1.01	(±0.23)	0.08	(±0.04)
MC-18	0.01	(±0.02)	1.82	(±0.58)	1.13	(±0.49)	0.64	(±0.17)	0.05	(±0.03)
MC-19	0.00	(±0.00)	0.80	(±0.18)	0.59	(±0.11)	0.21	(±0.12)	0.01	(±0.01)
FB-20	0.00	(±0.00)	0.56	(±0.08)	0.56	(±0.08)	0.00	(±0.00)	0.00	(±0.00)
KUS-21	0.00	(±0.00)	0.93	(±0.33)	0.69	(±0.25)	0.23	(±0.26)	0.00	(±0.00)
VER-22	0.00	(±0.00)	0.87	(±0.51)	0.55	(±0.14)	0.32	(±0.39)	0.00	(±0.00)
GRA-23	0.00	(±0.00)	1.21	(±0.72)	0.79	(±0.43)	0.42	(±0.68)	0.00	(±0.00)
ELA-24	0.00	(±0.00)	0.78	(±0.29)	0.65	(±0.25)	0.12	(±0.11)	0.00	(±0.00)
ELA-25	0.00	(±0.00)	0.49	(±0.07)	0.49	(±0.07)	0.00	(±0.00)	0.00	(±0.00)
WAB-26	0.00	(±0.00)	0.70	(±0.08)	0.58	(±0.08)	0.12	(±0.10)	0.00	(±0.00)
WAB-27	0.00	(±0.00)	0.71	(±0.13)	0.55	(±0.10)	0.16	(±0.05)	0.00	(±0.00)
VER-28	0.00	(±0.00)	0.64	(±0.18)	0.51	(±0.13)	0.13	(±0.08)	0.00	(±0.00)

Note: Water quality parameter means (± standard deviations) calculated using a n=6, with the exception of VER-6 for Chl-a (n=5, May was missing) and VER-1 for all water quality parameters (n=5, June was missing).

Table B13 Means (± standard deviations) of general biological/chemical parameters and nutrients for 2014.

	Chl-a (ug/L)		E.coli (CFU/100mL)		pH		CaCO3 (mg/L)		DOC (mg/L)		Cond (mg/L)		Cl (mg/L)	
VER-1	1.29	(±0.91)	6.20	(±5.22)	7.31	(±0.24)	22.60	(±1.95)	5.56	(±1.01)	50.20	(±4.92)	0.00	(±0.00)
VER-2	1.72	(±0.55)	20.00	(±22.80)	7.39	(±0.15)	30.33	(±6.28)	4.90	(±1.17)	82.83	(±19.57)	4.55	(±1.71)
ONP-3	1.56	(±0.51)	96.67	(±93.31)	7.09	(±0.13)	12.52	(±1.64)	6.88	(±1.64)	34.83	(±4.75)	1.68	(±0.71)
ONP-4	1.93	(±0.73)	36.67	(±20.66)	7.22	(±0.14)	71.50	(±23.79)	5.68	(±1.25)	213.33	(±69.47)	17.00	(±5.66)
VER-5	3.03	(±1.27)	6.67	(±8.16)	7.48	(±0.23)	41.83	(±8.04)	5.50	(±1.24)	117.00	(±24.62)	7.20	(±1.84)
VER-6	4.16	(±2.22)	5.00	(±5.48)	7.42	(±0.16)	39.33	(±5.85)	5.33	(±1.24)	110.33	(±19.61)	6.68	(±1.28)
WIT-7	2.64	(±0.69)	93.33	(±88.92)	7.92	(±0.11)	89.87	(±32.59)	10.53	(±2.88)	279.17	(±92.33)	31.78	(±10.89)
WIT-8	3.24	(±2.15)	158.33	(±227.28)	8.18	(±0.04)	136.00	(±30.80)	9.75	(±4.49)	378.33	(±95.71)	36.55	(±14.07)
LEV-9	3.69	(±1.33)	20.00	(±18.97)	7.73	(±0.08)	61.78	(±3.14)	6.05	(±1.29)	196.00	(±6.69)	17.60	(±1.70)
VER-10	2.69	(±0.48)	34.00	(±20.74)	7.70	(±0.13)	48.64	(±8.87)	6.72	(±1.66)	136.40	(±25.34)	9.40	(±1.72)
LIL-11	1.53	(±0.81)	455.00	(±1051.11)	7.86	(±0.12)	58.13	(±9.81)	3.58	(±0.45)	398.67	(±57.64)	75.45	(±36.52)
CC-12	1.71	(±2.44)	3.33	(±8.16)	8.25	(±0.28)	1366.67	(±175.12)	2.22	(±0.37)	2883.33	(±183.48)	138.83	(±79.50)
JUN-13	9.14	(±10.46)	31.67	(±24.01)	7.71	(±0.27)	536.33	(±93.84)	4.37	(±0.51)	1426.67	(±206.56)	110.50	(±19.07)
MB-14	3.65	(±3.09)	173.33	(±210.78)	7.39	(±0.20)	69.17	(±12.48)	6.20	(±1.59)	288.33	(±27.87)	41.00	(±5.55)
MUD-15	6.64	(±4.67)	11.67	(±16.02)	7.61	(±0.22)	488.33	(±121.39)	4.97	(±0.72)	1300.00	(±244.95)	98.17	(±16.03)
SIM-16	3.32	(±1.77)	3.33	(±5.16)	7.63	(±0.27)	431.67	(±81.83)	5.23	(±0.87)	1186.67	(±165.73)	94.83	(±15.05)
MC-17	16.75	(±18.58)	0.00	(±0.00)	7.76	(±0.53)	385.00	(±56.83)	5.37	(±0.73)	1051.67	(±135.71)	85.50	(±12.47)
MC-18	13.09	(±12.03)	5.00	(±12.25)	7.78	(±0.56)	298.33	(±95.17)	5.70	(±1.25)	855.00	(±241.72)	67.50	(±21.19)
MC-19	4.12	(±2.79)	20.00	(±24.49)	7.66	(±0.23)	102.83	(±28.81)	6.32	(±1.67)	301.67	(±86.12)	22.00	(±7.01)
FB-20	2.48	(±0.99)	86.67	(±79.92)	7.29	(±0.14)	30.67	(±8.24)	6.48	(±2.05)	103.33	(±39.66)	11.80	(±7.68)
KUS-21	3.52	(±1.53)	6.67	(±16.33)	7.44	(±0.34)	84.50	(±16.62)	6.20	(±1.60)	256.67	(±45.90)	18.83	(±4.22)
VER-22	2.80	(±1.11)	3.33	(±5.16)	7.43	(±0.34)	89.17	(±20.67)	6.58	(±1.78)	268.33	(±58.45)	19.17	(±4.54)
GRA-23	3.70	(±0.82)	3.33	(±5.16)	7.46	(±0.24)	91.83	(±21.95)	6.67	(±1.69)	268.33	(±56.36)	19.00	(±4.38)
ELA-24	4.17	(±0.93)	13.33	(±10.33)	7.53	(±0.16)	87.33	(±17.50)	6.48	(±1.53)	258.33	(±47.08)	18.83	(±4.07)
ELA-25	5.12	(±0.98)	0.00	(±0.00)	7.46	(±0.09)	49.33	(±1.86)	4.87	(±0.22)	141.67	(±4.08)	8.93	(±0.24)
WAB-26	3.24	(±1.71)	0.00	(±0.00)	7.55	(±0.15)	80.50	(±18.36)	6.73	(±1.97)	245.00	(±46.55)	17.25	(±4.50)
WAB-27	4.37	(±1.76)	0.00	(±0.00)	7.56	(±0.10)	76.00	(±21.37)	6.60	(±1.78)	228.00	(±50.70)	16.60	(±4.10)
VER-28	3.33	(±0.41)	2.00	(±4.47)	7.33	(±0.22)	75.60	(±15.44)	6.34	(±1.57)	234.00	(±51.77)	16.60	(±4.56)

Note: Water quality parameter means (± standard deviations) calculated using n=6, with the exception of ONP-4, VER-5, VER-6, MC-17, MC-18, MC-19 for Chl-a (n=5, June was missing), ELA-24, ELA-25 for Chl-a (n=5, August was missing), WAB-26, WAB-27 for Chl-a (n=4, August and September were missing), WAB-26 for pH, CaCO3, DOC, Cond, Cl, TKN, NO3, NO2 (n=4, June and September were missing), VER-10 for TKN (n=4, June and July missing or incorrect value), VER-1 for all other water quality parameters not previously mentioned (n=5, June was missing), VER-10 and VER-28 for all other water quality parameters not previously mentioned (n=5, July was missing), and WAB-26 and WAB-27 for all other water quality parameters not previously mentioned (n=5, September was missing).

Table B13 (cont.)

	TP (mg/L)		TN (mg/L)		TKN (mg/L)		NO3 (mg/L)		NO2 (mg/L)	
VER-1	0.08	(±0.16)	0.38	(±0.23)	0.38	(±0.23)	0.00	(±0.00)	0.00	(±0.00)
VER-2	0.01	(±0.00)	0.56	(±0.20)	0.44	(±0.20)	0.11	(±0.09)	0.02	(±0.01)
ONP-3	0.01	(±0.00)	0.29	(±0.03)	0.25	(±0.03)	0.05	(±0.03)	0.00	(±0.00)
ONP-4	0.01	(±0.00)	0.55	(±0.15)	0.50	(±0.18)	0.05	(±0.06)	0.00	(±0.00)
VER-5	0.01	(±0.00)	0.45	(±0.11)	0.45	(±0.11)	0.00	(±0.00)	0.01	(±0.01)
VER-6	0.01	(±0.00)	0.43	(±0.07)	0.43	(±0.07)	0.00	(±0.00)	0.00	(±0.01)
WIT-7	0.02	(±0.02)	1.00	(±0.91)	0.81	(±0.69)	0.15	(±0.06)	0.01	(±0.00)
WIT-8	0.02	(±0.01)	0.94	(±0.13)	0.51	(±0.16)	0.47	(±0.22)	0.01	(±0.00)
LEV-9	0.02	(±0.01)	0.33	(±0.05)	0.31	(±0.04)	0.03	(±0.01)	0.00	(±0.00)
VER-10	0.01	(±0.00)	0.40	(±0.06)	0.34	(±0.06)	0.10	(±0.02)	0.00	(±0.00)
LIL-11	0.02	(±0.01)	0.34	(±0.10)	0.28	(±0.06)	0.09	(±0.07)	0.00	(±0.01)
CC-12	0.00	(±0.00)	4.89	(±1.66)	3.95	(±1.77)	0.93	(±0.18)	0.02	(±0.02)
JUN-13	0.04	(±0.01)	3.10	(±0.41)	1.73	(±0.54)	1.36	(±0.36)	0.23	(±0.12)
MB-14	0.03	(±0.01)	0.92	(±0.13)	0.64	(±0.20)	0.26	(±0.21)	0.02	(±0.01)
MUD-15	0.04	(±0.02)	2.88	(±0.43)	1.09	(±0.20)	1.67	(±0.41)	0.13	(±0.08)
SIM-16	0.03	(±0.01)	2.51	(±0.45)	1.22	(±0.63)	1.22	(±0.45)	0.08	(±0.04)
MC-17	0.04	(±0.01)	1.99	(±0.47)	0.87	(±0.13)	1.06	(±0.43)	0.06	(±0.02)
MC-18	0.04	(±0.05)	1.60	(±0.39)	0.91	(±0.28)	0.65	(±0.39)	0.05	(±0.03)
MC-19	0.02	(±0.01)	0.74	(±0.14)	0.55	(±0.12)	0.18	(±0.06)	0.01	(±0.01)
FB-20	0.02	(±0.01)	0.63	(±0.18)	0.63	(±0.18)	0.00	(±0.00)	0.00	(±0.00)
KUS-21	0.02	(±0.01)	0.63	(±0.17)	0.52	(±0.11)	0.11	(±0.08)	0.01	(±0.01)
VER-22	0.02	(±0.00)	0.73	(±0.15)	0.56	(±0.15)	0.16	(±0.03)	0.01	(±0.01)
GRA-23	0.02	(±0.01)	0.80	(±0.20)	0.64	(±0.19)	0.15	(±0.03)	0.01	(±0.01)
ELA-24	0.02	(±0.00)	0.64	(±0.14)	0.53	(±0.12)	0.11	(±0.09)	0.00	(±0.01)
ELA-25	0.01	(±0.00)	0.52	(±0.14)	0.52	(±0.14)	0.00	(±0.00)	0.00	(±0.00)
WAB-26	0.01	(±0.01)	0.67	(±0.43)	0.73	(±0.21)	0.11	(±0.07)	0.01	(±0.01)
WAB-27	0.01	(±0.01)	0.65	(±0.13)	0.53	(±0.17)	0.11	(±0.06)	0.01	(±0.01)
VER-28	0.01	(±0.00)	0.62	(±0.14)	0.52	(±0.11)	0.10	(±0.09)	0.00	(±0.00)

Note: Water quality parameter means (± standard deviations) calculated using n=6, with the exception of ONP-4, VER-5, VER-6, MC-17, MC-18, MC-19 for Chl-a (n=5, June was missing), ELA-24, ELA-25 for Chl-a (n=5, August was missing), WAB-26, WAB-27 for Chl-a (n=4, August and September were missing), WAB-26 for pH, CaCO3, DOC, Cond, Cl, TKN, NO3, NO2 (n=4, June and September were missing), VER-10 for TKN (n=4, June and July missing or incorrect value), VER-1 for all other water quality parameters not previously mentioned (n=5, June was missing), VER-10 and VER-28 for all other water quality parameters not previously mentioned (n=5, July was missing), and WAB-26 and WAB-27 for all other water quality parameters not previously mentioned (n=5, September was missing).

Table B14 Means (± standard deviations) of metals for 2013.

	Al (ug/L)		Ba (ug/L)		Be (ug/L)		Bi (ug/L)		Cd (ug/L)		Ca (mg/L)		Cr (ug/L)	
VER-1	45.80	(±24.65)	11.20	(±1.90)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	6.84	(±0.64)	0.00	(±0.00)
VER-2	39.33	(±31.38)	16.00	(±4.00)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	9.38	(±2.31)	0.00	(±0.00)
ONP-3	56.54	(±26.09)	6.90	(±0.84)	0.03	(±0.05)	0.00	(±0.00)	0.11	(±0.06)	3.65	(±0.76)	0.31	(±0.24)
ONP-4	57.33	(±19.94)	9.50	(±1.81)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	17.83	(±8.80)	0.00	(±0.00)
VER-5	67.00	(±30.10)	11.83	(±0.75)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	13.35	(±3.35)	0.00	(±0.00)
VER-6	51.17	(±29.80)	11.17	(±0.75)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	13.00	(±3.22)	0.00	(±0.00)
WIT-7	25.18	(±16.84)	25.10	(±5.33)	0.03	(±0.04)	0.08	(±0.18)	0.84	(±0.35)	28.50	(±6.06)	0.65	(±0.18)
WIT-8	28.34	(±15.24)	26.14	(±2.14)	0.03	(±0.04)	0.00	(±0.00)	1.18	(±0.10)	40.44	(±4.29)	0.89	(±0.35)
LEV-9	12.41	(±11.41)	12.46	(±1.09)	0.02	(±0.05)	0.31	(±0.35)	0.59	(±0.11)	15.80	(±0.96)	0.28	(±0.22)
VER-10	34.32	(±35.87)	12.34	(±0.77)	0.03	(±0.04)	0.13	(±0.18)	0.33	(±0.11)	13.47	(±3.07)	0.50	(±0.38)
LIL-11	9.60	(±11.81)	17.46	(±0.55)	0.01	(±0.01)	0.02	(±0.04)	0.54	(±0.18)	16.66	(±0.76)	0.37	(±0.22)
CC-12	74.00	(±64.22)	59.17	(±11.74)	0.00	(±0.00)	0.00	(±0.00)	0.24	(±0.24)	528.33	(±168.93)	0.00	(±0.00)
JUN-13	17.61	(±17.07)	37.70	(±6.56)	0.02	(±0.04)	0.08	(±0.11)	4.61	(±0.62)	218.00	(±41.02)	1.70	(±0.76)
MB-14	193.33	(±55.74)	20.50	(±1.64)	0.00	(±0.00)	0.00	(±0.00)	0.04	(±0.06)	20.83	(±2.14)	0.00	(±0.00)
MUD-15	47.83	(±14.91)	35.00	(±5.40)	0.00	(±0.00)	0.00	(±0.00)	0.44	(±0.29)	198.33	(±34.88)	0.00	(±0.00)
SIM-16	26.82	(±19.17)	29.67	(±3.14)	0.00	(±0.00)	0.00	(±0.00)	0.08	(±0.09)	166.67	(±25.82)	0.00	(±0.00)
MC-17	30.12	(±20.23)	29.17	(±2.93)	0.00	(±0.00)	0.00	(±0.00)	0.08	(±0.09)	161.67	(±24.83)	0.00	(±0.00)
MC-18	17.20	(±9.82)	24.17	(±1.83)	0.00	(±0.00)	0.00	(±0.00)	0.08	(±0.06)	111.83	(±17.96)	0.00	(±0.00)
MC-19	40.67	(±41.14)	15.00	(±1.79)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	40.50	(±15.16)	0.00	(±0.00)
FB-20	169.67	(±98.73)	8.23	(±2.36)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	8.87	(±1.97)	0.00	(±0.00)
KUS-21	58.83	(±31.77)	14.17	(±1.33)	0.00	(±0.00)	0.00	(±0.00)	0.10	(±0.08)	33.00	(±9.96)	0.00	(±0.00)
VER-22	57.83	(±28.29)	14.33	(±1.75)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	33.33	(±10.19)	0.00	(±0.00)
GRA-23	75.50	(±24.49)	14.67	(±1.37)	0.00	(±0.00)	0.00	(±0.00)	0.05	(±0.07)	34.33	(±10.29)	0.00	(±0.00)
ELA-24	60.00	(±34.33)	14.33	(±1.75)	0.00	(±0.00)	0.00	(±0.00)	0.02	(±0.04)	33.50	(±10.78)	0.00	(±0.00)
ELA-25	17.00	(±9.88)	8.40	(±0.89)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	14.50	(±0.84)	0.00	(±0.00)
WAB-26	51.33	(±31.35)	14.17	(±1.72)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	30.00	(±9.47)	0.00	(±0.00)
WAB-27	44.67	(±30.16)	13.67	(±1.37)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	27.83	(±7.17)	0.00	(±0.00)
VER-28	45.33	(±25.22)	14.33	(±2.34)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	27.83	(±7.70)	0.00	(±0.00)

Note: Water quality parameter means (± standard deviations) calculated using n=6, with the exception of VER-1 for all water quality parameters (n=5, June was missing). Zr was omitted from the table as all values were below the detection limit.

Table B14 (cont.)

	Co (ug/L)		Cu (ug/L)		Fe (ug/L)		Pb (ug/L)		Li (ug/L)		Mg (mg/L)		Mn (ug/L)	
VER-1	0.00	(±0.00)	1.22	(±0.74)	154.00	(±41.59)	0.00	(±0.00)	0.00	(±0.00)	1.66	(±0.21)	19.80	(±8.56)
VER-2	0.00	(±0.00)	1.88	(±1.04)	246.67	(±60.22)	0.85	(±2.08)	0.00	(±0.00)	2.27	(±0.58)	35.50	(±9.87)
ONP-3	0.24	(±0.18)	1.17	(±0.31)	283.60	(±60.11)	0.00	(±0.00)	0.00	(±0.00)	0.96	(±0.15)	20.96	(±9.70)
ONP-4	0.65	(±0.17)	4.37	(±0.83)	411.67	(±135.86)	0.00	(±0.00)	0.00	(±0.00)	2.45	(±0.80)	38.50	(±11.31)
VER-5	0.00	(±0.00)	3.32	(±0.54)	380.00	(±84.62)	0.16	(±0.39)	0.00	(±0.00)	2.48	(±0.53)	46.17	(±15.98)
VER-6	0.00	(±0.00)	3.03	(±0.37)	240.00	(±35.21)	0.00	(±0.00)	0.00	(±0.00)	2.43	(±0.54)	35.33	(±5.99)
WIT-7	0.78	(±0.24)	4.92	(±2.94)	812.20	(±374.40)	0.00	(±0.00)	1.27	(±1.04)	5.76	(±0.93)	79.30	(±24.06)
WIT-8	0.50	(±0.20)	4.64	(±2.32)	507.60	(±237.69)	0.00	(±0.00)	1.35	(±1.12)	10.19	(±1.52)	52.84	(±39.54)
LEV-9	0.47	(±0.27)	7.84	(±2.73)	69.70	(±46.39)	0.00	(±0.00)	0.56	(±0.58)	5.28	(±0.23)	28.49	(±18.73)
VER-10	0.26	(±0.10)	3.05	(±0.44)	182.60	(±38.23)	0.00	(±0.00)	0.29	(±0.49)	2.65	(±0.55)	30.50	(±7.55)
LIL-11	0.29	(±0.14)	8.92	(±0.62)	54.98	(±47.43)	0.00	(±0.00)	1.08	(±0.61)	4.53	(±0.16)	15.55	(±7.84)
CC-12	5.45	(±3.18)	149.17	(±109.76)	321.67	(±338.67)	0.20	(±0.49)	52.00	(±14.41)	31.50	(±10.25)	49.03	(±57.44)
JUN-13	7.80	(±1.57)	27.64	(±15.69)	136.06	(±50.63)	0.00	(±0.00)	27.26	(±4.79)	13.58	(±0.98)	48.72	(±10.67)
MB-14	2.45	(±1.30)	19.33	(±8.69)	2583.33	(±376.39)	0.12	(±0.29)	0.00	(±0.00)	7.20	(±0.77)	143.33	(±30.77)
MUD-15	4.60	(±1.62)	22.67	(±11.78)	293.33	(±101.52)	0.09	(±0.23)	16.85	(±4.63)	13.33	(±1.51)	50.50	(±12.10)
SIM-16	5.77	(±1.60)	14.33	(±7.30)	236.67	(±188.11)	0.00	(±0.00)	15.17	(±3.19)	12.50	(±1.38)	130.17	(±55.57)
MC-17	3.22	(±1.89)	14.85	(±6.14)	126.67	(±104.24)	0.14	(±0.35)	15.50	(±3.73)	12.17	(±0.75)	60.33	(±28.09)
MC-18	2.89	(±2.47)	10.90	(±4.72)	105.00	(±123.09)	0.10	(±0.24)	10.38	(±2.54)	9.48	(±1.25)	201.33	(±321.44)
MC-19	0.28	(±0.43)	5.63	(±1.28)	191.67	(±124.49)	0.15	(±0.38)	0.85	(±2.08)	4.72	(±1.29)	50.17	(±19.24)
FB-20	0.18	(±0.28)	6.03	(±3.19)	768.33	(±216.93)	0.11	(±0.28)	0.00	(±0.00)	2.57	(±0.82)	60.50	(±14.82)
KUS-21	0.13	(±0.32)	6.03	(±1.23)	256.67	(±92.66)	0.41	(±0.32)	0.00	(±0.00)	4.18	(±0.86)	42.83	(±12.12)
VER-22	0.21	(±0.34)	5.72	(±1.19)	213.33	(±103.09)	0.00	(±0.00)	0.00	(±0.00)	4.28	(±0.91)	38.33	(±15.54)
GRA-23	0.53	(±0.28)	6.47	(±1.39)	288.33	(±93.68)	0.49	(±0.39)	0.00	(±0.00)	4.40	(±0.91)	46.00	(±14.42)
ELA-24	0.24	(±0.37)	6.47	(±1.97)	191.67	(±120.40)	0.39	(±0.45)	0.00	(±0.00)	4.23	(±0.95)	37.33	(±16.26)
ELA-25	0.00	(±0.00)	2.28	(±0.69)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	2.62	(±0.16)	18.23	(±8.55)
WAB-26	0.20	(±0.31)	5.70	(±1.25)	171.67	(±111.79)	0.00	(±0.00)	0.00	(±0.00)	3.92	(±0.82)	72.83	(±57.16)
WAB-27	0.08	(±0.20)	5.60	(±1.18)	110.00	(±130.23)	0.00	(±0.00)	0.00	(±0.00)	3.80	(±0.61)	42.33	(±14.92)
VER-28	0.00	(±0.00)	5.93	(±0.70)	98.33	(±118.39)	0.00	(±0.00)	0.00	(±0.00)	3.82	(±0.72)	33.17	(±8.68)

Note: Water quality parameter means (± standard deviations) calculated using n=6, with the exception of VER-1 for all water quality parameters (n=5, June was missing). Zr was omitted from the table as all values were below the detection limit.

Table B14 (cont.)

	Mo (ug/L)		Ni (ug/L)		K (mg/L)		Si (mg/L)		Ag (ug/L)		Na (mg/L)		Sr (ug/L)	
VER-1	0.00	(±0.00)	5.96	(±10.67)	0.31	(±0.03)	2.58	(±0.16)	0.00	(±0.00)	1.12	(±0.08)	17.40	(±1.67)
VER-2	0.00	(±0.00)	2.62	(±0.97)	0.85	(±0.25)	2.90	(±0.28)	0.02	(±0.06)	4.35	(±1.74)	26.17	(±4.49)
ONP-3	0.34	(±0.19)	1.32	(±1.31)	0.39	(±0.06)	2.10	(±0.25)	0.30	(±0.48)	1.48	(±0.37)	15.30	(±2.61)
ONP-4	0.00	(±0.00)	23.50	(±9.61)	1.49	(±0.70)	2.28	(±0.25)	0.00	(±0.00)	8.45	(±3.44)	71.33	(±35.37)
VER-5	0.00	(±0.00)	10.72	(±1.86)	1.07	(±0.26)	2.62	(±0.22)	0.00	(±0.00)	5.10	(±1.34)	47.00	(±10.60)
VER-6	0.08	(±0.20)	9.65	(±1.12)	1.03	(±0.25)	2.48	(±0.26)	0.00	(±0.00)	4.87	(±1.31)	46.17	(±11.30)
WIT-7	0.68	(±0.16)	23.44	(±13.81)	0.80	(±0.10)	4.42	(±1.29)	0.49	(±0.44)	23.36	(±4.87)	57.14	(±11.97)
WIT-8	0.88	(±0.18)	15.82	(±9.11)	1.43	(±0.25)	4.04	(±0.52)	0.57	(±0.43)	28.78	(±5.27)	74.26	(±9.51)
LEV-9	0.68	(±0.12)	93.06	(±45.58)	1.02	(±0.21)	0.40	(±0.39)	0.44	(±0.62)	13.36	(±1.53)	40.68	(±2.37)
VER-10	0.63	(±0.21)	10.35	(±2.11)	0.97	(±0.21)	2.43	(±0.18)	0.35	(±0.58)	6.43	(±1.82)	43.98	(±11.80)
LIL-11	0.77	(±0.24)	38.46	(±3.96)	1.54	(±0.03)	0.80	(±0.15)	0.38	(±0.48)	54.54	(±1.42)	56.82	(±2.34)
CC-12	0.84	(±0.71)	214.83	(±127.61)	36.33	(±11.41)	2.35	(±1.45)	0.00	(±0.00)	183.33	(±25.82)	795.00	(±202.85)
JUN-13	2.67	(±0.90)	385.00	(±17.48)	16.04	(±3.10)	1.91	(±0.82)	5.29	(±2.61)	101.66	(±7.74)	355.60	(±65.75)
MB-14	0.09	(±0.21)	183.33	(±57.15)	1.88	(±0.27)	2.78	(±0.57)	0.00	(±0.00)	30.33	(±3.08)	71.00	(±5.83)
MUD-15	0.79	(±0.13)	280.00	(±40.00)	14.33	(±2.34)	2.08	(±0.68)	0.00	(±0.00)	91.50	(±11.10)	330.00	(±55.86)
SIM-16	0.69	(±0.07)	233.33	(±40.82)	12.02	(±2.07)	2.32	(±0.43)	0.08	(±0.19)	82.67	(±8.02)	281.67	(±44.01)
MC-17	0.80	(±0.08)	221.67	(±52.31)	11.53	(±1.82)	2.05	(±0.39)	0.18	(±0.35)	79.83	(±6.52)	271.67	(±44.01)
MC-18	0.63	(±0.07)	165.00	(±54.68)	8.10	(±1.36)	2.02	(±0.26)	0.03	(±0.07)	57.67	(±8.45)	203.33	(±28.75)
MC-19	0.00	(±0.00)	49.00	(±16.44)	2.83	(±1.07)	2.30	(±0.13)	0.00	(±0.00)	19.60	(±7.19)	87.00	(±27.38)
FB-20	0.00	(±0.00)	14.70	(±4.88)	0.71	(±0.48)	1.98	(±0.90)	0.00	(±0.00)	9.38	(±7.47)	34.17	(±7.05)
KUS-21	0.00	(±0.00)	39.33	(±5.65)	2.32	(±0.70)	2.17	(±0.21)	0.00	(±0.00)	16.40	(±4.33)	74.33	(±20.19)
VER-22	0.00	(±0.00)	38.00	(±4.38)	2.35	(±0.73)	2.20	(±0.14)	0.04	(±0.09)	16.65	(±4.62)	76.33	(±19.82)
GRA-23	0.00	(±0.00)	40.50	(±4.14)	2.38	(±0.74)	2.28	(±0.15)	0.04	(±0.11)	17.15	(±4.74)	78.17	(±19.36)
ELA-24	0.00	(±0.00)	38.50	(±5.89)	2.35	(±0.68)	2.15	(±0.21)	0.00	(±0.00)	16.67	(±4.93)	73.67	(±19.21)
ELA-25	0.00	(±0.00)	20.00	(±1.67)	1.12	(±0.08)	0.46	(±0.35)	0.00	(±0.00)	6.95	(±0.64)	36.17	(±1.47)
WAB-26	0.09	(±0.21)	35.50	(±3.73)	2.10	(±0.59)	1.98	(±0.25)	0.00	(±0.00)	14.98	(±4.31)	68.67	(±17.91)
WAB-27	0.00	(±0.00)	33.50	(±4.93)	1.93	(±0.41)	2.00	(±0.24)	0.00	(±0.00)	14.00	(±3.22)	64.33	(±13.34)
VER-28	0.00	(±0.00)	33.67	(±3.56)	1.90	(±0.49)	1.98	(±0.23)	0.00	(±0.00)	14.23	(±3.81)	64.83	(±16.34)

Note: Water quality parameter means (± standard deviations) calculated using n=6, with the exception of VER-1 for all water quality parameters (n=5, June was missing). Zr was omitted from the table as all values were below the detection limit.

Table B14 (cont.)

	Sn (ug/L)		Ti (ug/L)		U (ug/L)		V (ug/L)		Zn (ug/L)	
VER-1	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	0.29	(±0.41)	0.00	(±0.00)
VER-2	0.00	(±0.00)	0.00	(±0.00)	0.02	(±0.05)	0.21	(±0.33)	2.32	(±3.60)
ONP-3	3.30	(±3.37)	0.93	(±0.19)	0.10	(±0.22)	0.29	(±0.07)	2.80	(±1.42)
ONP-4	0.00	(±0.00)	0.00	(±0.00)	0.02	(±0.05)	0.26	(±0.41)	2.32	(±3.74)
VER-5	0.00	(±0.00)	1.10	(±2.69)	0.06	(±0.09)	0.50	(±0.42)	10.45	(±1.54)
VER-6	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	0.32	(±0.35)	2.33	(±5.72)
WIT-7	0.91	(±0.89)	0.97	(±0.15)	0.08	(±0.14)	0.89	(±0.18)	6.16	(±0.91)
WIT-8	0.98	(±1.75)	1.62	(±0.42)	0.24	(±0.21)	0.92	(±0.23)	11.71	(±5.52)
LEV-9	0.40	(±0.89)	0.63	(±0.26)	0.02	(±0.05)	0.13	(±0.09)	3.78	(±0.97)
VER-10	2.42	(±3.78)	1.23	(±0.85)	0.14	(±0.19)	0.32	(±0.10)	4.15	(±0.94)
LIL-11	0.00	(±0.00)	0.84	(±0.72)	0.00	(±0.00)	0.11	(±0.05)	4.84	(±0.91)
CC-12	0.00	(±0.00)	0.88	(±2.16)	0.28	(±0.43)	0.52	(±1.04)	6.67	(±16.33)
JUN-13	0.00	(±0.00)	1.83	(±0.61)	1.41	(±2.12)	0.28	(±0.17)	30.66	(±3.59)
MB-14	0.00	(±0.00)	3.57	(±4.14)	0.14	(±0.08)	0.83	(±0.46)	5.63	(±4.70)
MUD-15	0.00	(±0.00)	0.92	(±2.25)	0.19	(±0.04)	0.65	(±0.58)	64.67	(±28.85)
SIM-16	0.00	(±0.00)	0.00	(±0.00)	0.17	(±0.02)	0.50	(±0.58)	33.67	(±33.45)
MC-17	0.00	(±0.00)	0.00	(±0.00)	0.17	(±0.04)	0.45	(±0.35)	17.00	(±5.93)
MC-18	0.00	(±0.00)	0.00	(±0.00)	0.14	(±0.08)	0.20	(±0.31)	16.73	(±8.87)
MC-19	0.00	(±0.00)	0.88	(±2.16)	0.08	(±0.09)	0.37	(±0.29)	7.33	(±4.03)
FB-20	0.00	(±0.00)	7.78	(±5.29)	0.03	(±0.07)	0.57	(±0.45)	2.48	(±3.93)
KUS-21	0.00	(±0.00)	0.00	(±0.00)	0.06	(±0.06)	0.31	(±0.35)	14.67	(±4.03)
VER-22	0.00	(±0.00)	0.00	(±0.00)	0.06	(±0.07)	0.50	(±0.27)	0.85	(±2.08)
GRA-23	0.00	(±0.00)	0.00	(±0.00)	0.08	(±0.09)	0.54	(±0.30)	18.70	(±10.82)
ELA-24	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	0.47	(±0.39)	13.53	(±4.57)
ELA-25	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	0.12	(±0.29)	4.93	(±4.07)
WAB-26	0.00	(±0.00)	2.33	(±5.72)	0.00	(±0.00)	0.18	(±0.45)	17.88	(±12.88)
WAB-27	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	0.09	(±0.22)	10.22	(±3.07)
VER-28	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	0.09	(±0.21)	2.67	(±6.53)

Note: Water quality parameter means (± standard deviations) calculated using n=6, with the exception of VER-1 for all water quality parameters (n=5, June was missing). Zr was omitted from the table as all values were below the detection limit.

Table B15 Means (± standard deviations) of metals for 2014.

	Al (ug/L)		Ba (ug/L)		Be (ug/L)		Bi (ug/L)		Cd (ug/L)		Ca (mg/L)		Cr (ug/L)	
VER-1	63.00	(±29.39)	11.20	(±1.30)	0.00	(±0.00)	0.30	(±0.67)	0.00	(±0.00)	6.66	(±1.04)	0.00	(±0.00)
VER-2	52.50	(±34.36)	14.33	(±1.86)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	8.90	(±2.21)	0.00	(±0.00)
ONP-3	74.68	(±34.56)	6.75	(±0.54)	0.03	(±0.02)	0.04	(±0.09)	0.19	(±0.15)	3.42	(±0.45)	0.69	(±0.09)
ONP-4	67.50	(±34.42)	11.22	(±1.52)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	24.00	(±8.60)	0.00	(±0.00)
VER-5	79.50	(±49.87)	12.00	(±0.89)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	12.83	(±3.37)	0.83	(±2.04)
VER-6	128.00	(±59.68)	12.33	(±1.21)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	12.00	(±2.28)	0.00	(±0.00)
WIT-7	44.82	(±23.38)	22.08	(±6.02)	0.06	(±0.04)	0.00	(±0.00)	0.84	(±0.25)	27.07	(±10.28)	1.26	(±0.27)
WIT-8	54.53	(±33.45)	23.72	(±4.37)	0.05	(±0.03)	0.02	(±0.04)	1.10	(±0.16)	38.18	(±8.59)	1.16	(±0.30)
LEV-9	37.35	(±29.53)	12.50	(±1.10)	0.02	(±0.03)	0.05	(±0.12)	0.50	(±0.05)	15.87	(±0.86)	1.00	(±0.40)
VER-10	58.66	(±31.00)	12.78	(±0.91)	0.03	(±0.02)	0.14	(±0.32)	0.40	(±0.16)	14.56	(±2.67)	1.01	(±0.45)
LIL-11	78.80	(±157.06)	16.25	(±0.42)	0.03	(±0.05)	0.09	(±0.22)	0.60	(±0.11)	15.92	(±2.62)	0.78	(±0.56)
CC-12	40.17	(±32.37)	54.67	(±12.80)	0.00	(±0.00)	0.00	(±0.00)	0.12	(±0.17)	505.00	(±63.48)	0.00	(±0.00)
JUN-13	18.41	(±10.32)	32.53	(±4.36)	0.03	(±0.03)	0.11	(±0.26)	4.09	(±0.88)	187.50	(±34.51)	3.04	(±1.31)
MB-14	281.67	(±187.87)	20.17	(±1.72)	0.00	(±0.00)	0.00	(±0.00)	0.02	(±0.05)	18.00	(±2.97)	0.00	(±0.00)
MUD-15	76.83	(±53.76)	33.00	(±4.15)	0.00	(±0.00)	0.00	(±0.00)	0.22	(±0.06)	168.33	(±46.65)	0.00	(±0.00)
SIM-16	33.67	(±28.12)	29.67	(±3.08)	0.00	(±0.00)	0.22	(±0.53)	0.06	(±0.07)	143.33	(±26.58)	0.00	(±0.00)
MC-17	32.83	(±32.31)	28.50	(±2.59)	0.00	(±0.00)	0.00	(±0.00)	0.04	(±0.07)	128.17	(±20.69)	0.00	(±0.00)
MC-18	34.50	(±41.97)	24.50	(±4.37)	0.00	(±0.00)	0.00	(±0.00)	0.04	(±0.06)	101.00	(±31.11)	0.00	(±0.00)
MC-19	69.33	(±67.32)	15.33	(±1.51)	0.00	(±0.00)	0.18	(±0.45)	0.00	(±0.00)	32.83	(±9.43)	0.00	(±0.00)
FB-20	123.67	(±58.16)	7.53	(±1.63)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	8.53	(±2.12)	0.00	(±0.00)
KUS-21	109.33	(±87.37)	14.50	(±0.84)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	27.83	(±5.98)	0.00	(±0.00)
VER-22	77.67	(±43.43)	14.50	(±1.76)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	28.67	(±7.87)	0.00	(±0.00)
GRA-23	107.67	(±50.09)	15.00	(±1.55)	0.00	(±0.00)	0.17	(±0.41)	0.00	(±0.00)	28.17	(±6.91)	0.00	(±0.00)
ELA-24	94.33	(±56.66)	14.33	(±1.21)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	27.00	(±5.44)	0.00	(±0.00)
ELA-25	25.33	(±27.90)	7.55	(±0.60)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	14.33	(±0.52)	0.00	(±0.00)
WAB-26	70.60	(±57.91)	13.60	(±1.14)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	24.80	(±4.87)	0.00	(±0.00)
WAB-27	62.00	(±56.86)	15.40	(±2.88)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	25.00	(±5.79)	0.00	(±0.00)
VER-28	64.20	(±40.18)	13.60	(±1.95)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	24.80	(±6.30)	0.00	(±0.00)

Note: Water quality parameter means (± standard deviations) calculated using n=6, with the exception of FB-20, VER-22 and GRA-23 for Zn (n=5, June was missing), VER-1 for all water quality parameters (n=5, June was missing), VER-10 and VER-28 for all water quality parameters (n=5, July was missing), and WAB-26 and WAB-27 for all water quality parameters (n=5, September was missing).

Table B15 (cont.)

	Co (ug/L)		Cu (ug/L)		Fe (ug/L)		Pb (ug/L)		Li (ug/L)		Mg (mg/L)		Mn (ug/L)	
VER-1	0.00	(±0.00)	1.52	(±0.24)	142.00	(±98.84)	0.00	(±0.00)	0.00	(±0.00)	1.66	(±0.48)	19.20	(±5.97)
VER-2	0.00	(±0.00)	2.13	(±0.46)	296.67	(±90.92)	0.00	(±0.00)	0.00	(±0.00)	2.03	(±0.53)	39.00	(±7.01)
ONP-3	0.14	(±0.06)	1.33	(±0.18)	354.67	(±76.11)	0.00	(±0.00)	0.16	(±0.27)	0.97	(±0.13)	24.93	(±7.34)
ONP-4	0.63	(±0.34)	3.98	(±0.50)	390.00	(±30.98)	0.00	(±0.00)	0.00	(±0.00)	2.67	(±0.52)	40.33	(±7.06)
VER-5	0.00	(±0.00)	3.08	(±0.65)	338.33	(±58.79)	0.00	(±0.00)	0.00	(±0.00)	2.27	(±0.59)	49.33	(±16.88)
VER-6	0.00	(±0.00)	3.63	(±0.47)	323.33	(±92.66)	0.00	(±0.00)	0.00	(±0.00)	2.45	(±0.61)	55.33	(±21.20)
WIT-7	0.65	(±0.21)	6.21	(±3.32)	1108.17	(±418.37)	0.00	(±0.00)	0.44	(±1.08)	5.44	(±1.74)	96.92	(±52.94)
WIT-8	0.43	(±0.22)	6.42	(±3.69)	649.17	(±374.67)	0.00	(±0.00)	0.55	(±0.76)	9.87	(±2.34)	59.80	(±20.40)
LEV-9	0.96	(±0.42)	10.28	(±3.67)	151.68	(±86.32)	0.00	(±0.00)	1.34	(±0.87)	5.38	(±0.28)	53.33	(±24.87)
VER-10	0.24	(±0.10)	4.09	(±0.96)	299.40	(±112.25)	0.00	(±0.00)	0.60	(±0.97)	2.98	(±0.54)	46.06	(±14.03)
LIL-11	0.40	(±0.62)	10.78	(±4.06)	118.88	(±174.58)	0.01	(±0.03)	0.39	(±0.68)	4.47	(±0.80)	16.93	(±8.27)
CC-12	1.50	(±1.07)	11.77	(±4.76)	213.33	(±156.55)	0.16	(±0.27)	49.33	(±5.57)	37.50	(±13.28)	21.22	(±27.06)
JUN-13	5.35	(±3.34)	17.16	(±12.76)	132.18	(±41.33)	0.00	(±0.00)	16.83	(±4.59)	16.63	(±2.23)	39.48	(±6.93)
MB-14	2.62	(±1.57)	21.65	(±11.78)	2400.00	(±189.74)	0.39	(±0.43)	0.00	(±0.00)	6.28	(±0.78)	126.67	(±10.33)
MUD-15	4.10	(±3.60)	20.05	(±17.16)	256.67	(±113.61)	0.27	(±0.30)	16.67	(±4.32)	16.50	(±3.51)	48.17	(±17.05)
SIM-16	3.92	(±3.16)	12.83	(±6.62)	233.33	(±177.95)	0.00	(±0.00)	14.00	(±3.46)	15.17	(±2.93)	76.67	(±62.14)
MC-17	2.14	(±1.51)	11.28	(±5.32)	100.00	(±114.02)	0.09	(±0.21)	12.50	(±1.87)	13.67	(±1.86)	50.83	(±25.53)
MC-18	1.73	(±1.16)	8.10	(±3.35)	111.67	(±107.78)	0.00	(±0.00)	9.05	(±2.06)	11.23	(±2.73)	87.67	(±103.10)
MC-19	0.11	(±0.27)	5.10	(±1.42)	255.00	(±155.92)	0.10	(±0.25)	0.00	(±0.00)	4.78	(±1.22)	49.50	(±18.96)
FB-20	0.00	(±0.00)	5.57	(±2.93)	678.33	(±107.78)	0.14	(±0.25)	0.00	(±0.00)	2.47	(±0.86)	59.67	(±34.50)
KUS-21	0.41	(±0.73)	5.75	(±1.71)	336.67	(±230.62)	0.80	(±0.91)	0.00	(±0.00)	4.33	(±0.82)	46.83	(±13.73)
VER-22	0.19	(±0.29)	5.63	(±1.62)	240.00	(±144.64)	0.36	(±0.29)	0.00	(±0.00)	4.50	(±1.05)	42.17	(±15.79)
GRA-23	0.56	(±0.52)	6.48	(±2.16)	338.33	(±145.66)	0.85	(±0.71)	0.00	(±0.00)	4.52	(±1.02)	49.50	(±16.85)
ELA-24	0.45	(±0.54)	5.63	(±1.40)	313.33	(±221.24)	0.51	(±0.44)	0.00	(±0.00)	4.30	(±0.82)	46.83	(±18.63)
ELA-25	0.00	(±0.00)	2.08	(±0.44)	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	2.85	(±0.23)	28.33	(±22.39)
WAB-26	0.13	(±0.29)	5.54	(±1.46)	212.00	(±157.86)	0.12	(±0.26)	0.00	(±0.00)	4.16	(±0.81)	47.00	(±14.68)
WAB-27	0.13	(±0.28)	5.54	(±1.76)	182.00	(±159.91)	0.82	(±1.52)	0.00	(±0.00)	3.78	(±0.79)	37.20	(±22.15)
VER-28	0.11	(±0.25)	5.38	(±1.69)	154.00	(±146.90)	0.12	(±0.27)	0.00	(±0.00)	3.98	(±1.03)	46.40	(±22.03)

Note: Water quality parameter means (± standard deviations) calculated using n=6, with the exception of FB-20, VER-22 and GRA-23 for Zn (n=5, June was missing), VER-1 for all water quality parameters (n=5, June was missing), VER-10 and VER-28 for all water quality parameters (n=5, July was missing), and WAB-26 and WAB-27 for all water quality parameters (n=5, September was missing).

Table B15 (cont.)

	Mo (ug/L)		Ni (ug/L)		K (mg/L)		Si (mg/L)		Ag (ug/L)		Na (mg/L)		Sr (ug/L)	
VER-1	0.00	(±0.00)	1.90	(±0.42)	0.05	(±0.11)	2.94	(±0.13)	0.00	(±0.00)	0.99	(±0.01)	16.40	(±1.82)
VER-2	0.00	(±0.00)	3.10	(±1.07)	0.88	(±0.19)	2.93	(±0.16)	0.00	(±0.00)	4.08	(±1.45)	24.17	(±5.34)
ONP-3	0.02	(±0.04)	0.70	(±0.41)	0.37	(±0.05)	2.23	(±0.34)	0.00	(±0.01)	1.39	(±0.28)	14.17	(±1.45)
ONP-4	0.00	(±0.00)	24.50	(±8.87)	2.12	(±0.78)	2.32	(±0.49)	0.00	(±0.00)	10.12	(±2.62)	87.83	(±31.04)
VER-5	0.00	(±0.00)	10.78	(±3.64)	1.16	(±0.41)	3.00	(±0.00)	0.00	(±0.00)	4.92	(±1.36)	42.50	(±11.04)
VER-6	0.00	(±0.00)	12.28	(±2.13)	0.99	(±0.02)	2.98	(±0.04)	0.00	(±0.00)	4.58	(±0.92)	40.17	(±7.44)
WIT-7	0.85	(±0.20)	25.82	(±13.06)	0.83	(±0.09)	4.59	(±0.75)	0.26	(±0.31)	20.28	(±5.91)	51.52	(±17.52)
WIT-8	0.72	(±0.22)	17.48	(±9.87)	1.48	(±0.21)	4.09	(±0.51)	0.11	(±0.13)	23.08	(±7.69)	68.40	(±18.01)
LEV-9	0.47	(±0.22)	138.77	(±89.45)	1.13	(±0.12)	0.69	(±0.34)	0.00	(±0.00)	12.37	(±1.21)	38.58	(±2.78)
VER-10	0.43	(±0.18)	14.57	(±4.60)	1.00	(±0.16)	2.73	(±0.26)	0.00	(±0.00)	6.27	(±1.16)	40.74	(±6.20)
LIL-11	0.64	(±0.24)	33.38	(±4.89)	1.47	(±0.12)	1.16	(±0.18)	0.38	(±0.39)	51.10	(±7.37)	53.78	(±7.18)
CC-12	1.01	(±0.51)	101.33	(±103.84)	36.67	(±6.22)	2.33	(±0.82)	0.00	(±0.00)	173.33	(±40.33)	736.67	(±70.05)
JUN-13	1.94	(±1.58)	295.33	(±73.38)	14.07	(±2.46)	1.87	(±0.67)	2.52	(±1.81)	90.38	(±14.10)	294.33	(±48.11)
MB-14	0.00	(±0.00)	165.33	(±49.91)	1.90	(±0.15)	3.13	(±1.19)	0.00	(±0.00)	26.83	(±3.97)	59.67	(±8.69)
MUD-15	0.78	(±0.15)	263.33	(±93.95)	13.10	(±3.67)	1.72	(±1.07)	0.00	(±0.00)	86.50	(±18.11)	283.33	(±69.47)
SIM-16	0.71	(±0.16)	211.67	(±41.19)	11.20	(±2.16)	1.93	(±0.65)	0.00	(±0.00)	80.17	(±15.32)	248.33	(±49.56)
MC-17	0.77	(±0.04)	185.00	(±52.44)	10.12	(±1.65)	1.20	(±1.23)	0.00	(±0.00)	74.50	(±11.95)	223.33	(±37.24)
MC-18	0.52	(±0.26)	136.67	(±45.46)	8.07	(±2.47)	1.52	(±1.08)	0.00	(±0.00)	59.33	(±18.46)	178.33	(±46.22)
MC-19	0.10	(±0.23)	41.33	(±7.34)	2.63	(±0.57)	2.68	(±0.53)	0.00	(±0.00)	18.33	(±5.92)	70.67	(±17.27)
FB-20	0.10	(±0.23)	12.98	(±5.19)	0.96	(±0.09)	2.13	(±0.71)	0.00	(±0.00)	8.22	(±4.94)	32.67	(±9.18)
KUS-21	0.00	(±0.00)	35.50	(±7.79)	1.95	(±0.12)	2.48	(±0.53)	0.00	(±0.00)	15.57	(±3.91)	61.17	(±10.68)
VER-22	0.00	(±0.00)	35.83	(±5.19)	2.28	(±0.57)	2.50	(±0.55)	0.00	(±0.00)	15.70	(±4.40)	65.17	(±16.40)
GRA-23	0.20	(±0.30)	37.50	(±6.16)	2.28	(±0.57)	2.52	(±0.57)	0.00	(±0.00)	15.38	(±4.09)	63.50	(±12.53)
ELA-24	0.00	(±0.00)	34.17	(±7.39)	1.92	(±0.13)	2.35	(±0.50)	0.00	(±0.00)	15.15	(±3.28)	62.67	(±11.79)
ELA-25	0.00	(±0.00)	17.50	(±1.76)	1.05	(±0.08)	0.82	(±0.40)	0.00	(±0.00)	7.52	(±0.53)	35.50	(±1.52)
WAB-26	0.30	(±0.67)	33.20	(±7.46)	1.92	(±0.18)	2.52	(±0.56)	0.00	(±0.00)	13.80	(±2.59)	58.40	(±10.67)
WAB-27	0.00	(±0.00)	33.40	(±8.88)	2.12	(±0.54)	2.40	(±0.96)	0.00	(±0.00)	13.60	(±2.88)	57.40	(±11.26)
VER-28	0.18	(±0.41)	30.00	(±8.28)	1.98	(±0.63)	2.20	(±0.76)	0.00	(±0.00)	13.40	(±3.64)	56.20	(±10.64)

Note: Water quality parameter means (± standard deviations) calculated using n=6, with the exception of FB-20, VER-22 and GRA-23 for Zn (n=5, June was missing), VER-1 for all water quality parameters (n=5, June was missing), VER-10 and VER-28 for all water quality parameters (n=5, July was missing), and WAB-26 and WAB-27 for all water quality parameters (n=5, September was missing).

Table B15 (cont.)

	Sn (ug/L)		Ti (ug/L)		U (ug/L)		V (ug/L)		Zn (ug/L)		Zr (ug/L)	
VER-1	0.00	(±0.00)	0.00	(±0.00)	0.13	(±0.12)	0.28	(±0.38)	2.28	(±3.16)	0.00	(±0.00)
VER-2	0.00	(±0.00)	0.00	(±0.00)	0.11	(±0.09)	0.26	(±0.41)	1.10	(±2.69)	0.00	(±0.00)
ONP-3	0.68	(±1.67)	1.10	(±0.33)	0.00	(±0.00)	0.29	(±0.11)	3.41	(±1.60)	0.04	(±0.01)
ONP-4	0.00	(±0.00)	0.00	(±0.00)	0.04	(±0.06)	0.09	(±0.23)	6.62	(±6.07)	0.20	(±0.49)
VER-5	0.00	(±0.00)	0.00	(±0.00)	0.02	(±0.05)	0.32	(±0.37)	11.62	(±3.13)	0.00	(±0.00)
VER-6	0.00	(±0.00)	2.53	(±3.95)	0.02	(±0.05)	0.53	(±0.28)	6.87	(±9.27)	0.40	(±0.98)
WIT-7	1.01	(±1.15)	1.24	(±0.43)	0.00	(±0.00)	1.00	(±0.37)	6.04	(±1.57)	0.17	(±0.05)
WIT-8	1.10	(±1.85)	1.97	(±0.88)	0.00	(±0.00)	0.96	(±0.24)	18.92	(±11.61)	0.20	(±0.11)
LEV-9	0.00	(±0.00)	1.16	(±1.11)	0.00	(±0.00)	0.20	(±0.14)	5.41	(±3.47)	0.00	(±0.00)
VER-10	0.32	(±0.71)	1.53	(±0.38)	0.00	(±0.00)	0.41	(±0.14)	5.20	(±1.80)	0.04	(±0.03)
LIL-11	0.00	(±0.00)	1.62	(±2.34)	0.00	(±0.00)	0.29	(±0.38)	6.05	(±3.85)	0.02	(±0.05)
CC-12	0.00	(±0.00)	0.00	(±0.00)	0.15	(±0.29)	0.08	(±0.20)	0.00	(±0.00)	0.00	(±0.00)
JUN-13	0.17	(±0.42)	0.79	(±0.47)	0.00	(±0.00)	0.45	(±0.17)	30.80	(±4.54)	0.00	(±0.00)
MB-14	0.22	(±0.53)	7.67	(±9.16)	0.12	(±0.07)	0.60	(±0.54)	9.10	(±6.51)	0.00	(±0.00)
MUD-15	0.00	(±0.00)	2.25	(±3.53)	0.19	(±0.13)	0.52	(±0.26)	40.50	(±20.01)	0.33	(±0.82)
SIM-16	0.00	(±0.00)	0.00	(±0.00)	0.17	(±0.12)	0.11	(±0.26)	15.50	(±5.32)	0.00	(±0.00)
MC-17	0.00	(±0.00)	0.00	(±0.00)	0.15	(±0.10)	0.10	(±0.24)	13.18	(±4.16)	0.00	(±0.00)
MC-18	0.00	(±0.00)	0.00	(±0.00)	0.10	(±0.07)	0.19	(±0.30)	12.32	(±3.64)	0.00	(±0.00)
MC-19	0.00	(±0.00)	1.22	(±2.98)	0.12	(±0.09)	0.13	(±0.31)	10.87	(±4.72)	0.00	(±0.00)
FB-20	0.00	(±0.00)	3.60	(±4.05)	0.05	(±0.07)	0.12	(±0.29)	4.66	(±4.39)	0.00	(±0.00)
KUS-21	0.00	(±0.00)	2.67	(±6.53)	0.02	(±0.04)	0.38	(±0.45)	16.17	(±5.78)	0.00	(±0.00)
VER-22	0.00	(±0.00)	0.85	(±2.08)	0.05	(±0.08)	0.42	(±0.50)	3.94	(±3.66)	0.53	(±1.31)
GRA-23	0.00	(±0.00)	4.30	(±3.65)	0.08	(±0.11)	0.34	(±0.55)	13.68	(±5.04)	0.25	(±0.61)
ELA-24	0.00	(±0.00)	2.40	(±3.78)	0.05	(±0.07)	0.49	(±0.43)	13.53	(±5.18)	0.00	(±0.00)
ELA-25	0.00	(±0.00)	0.00	(±0.00)	0.00	(±0.00)	0.11	(±0.27)	11.97	(±7.61)	0.00	(±0.00)
WAB-26	0.00	(±0.00)	0.00	(±0.00)	0.02	(±0.05)	0.32	(±0.46)	11.10	(±2.66)	0.00	(±0.00)
WAB-27	0.00	(±0.00)	1.04	(±2.33)	0.02	(±0.05)	0.31	(±0.44)	19.22	(±21.13)	0.00	(±0.00)
VER-28	0.00	(±0.00)	0.00	(±0.00)	0.05	(±0.07)	0.35	(±0.33)	9.20	(±17.41)	0.00	(±0.00)

Note: Water quality parameter means (± standard deviations) calculated using n=6, with the exception of FB-20, VER-22 and GRA-23 for Zn (n=5, June was missing), VER-1 for all water quality parameters (n=5, June was missing), VER-10 and VER-28 for all water quality parameters (n=5, July was missing), and WAB-26 and WAB-27 for all water quality parameters (n=5, September was missing).

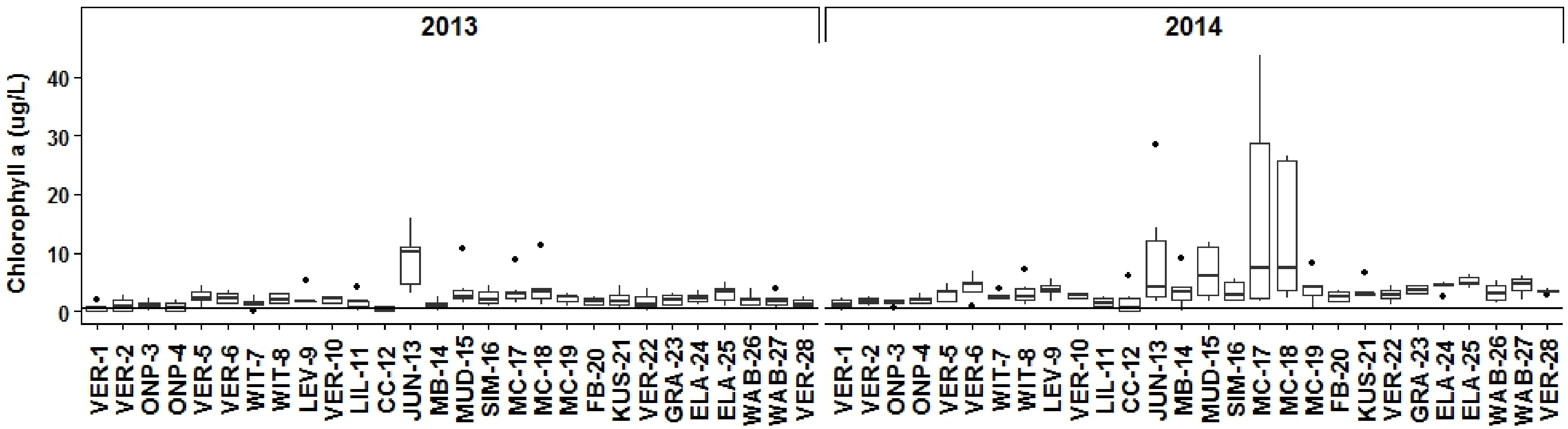

Figure B4 Chlorophyll a concentrations for sites in 2013 and 2014.

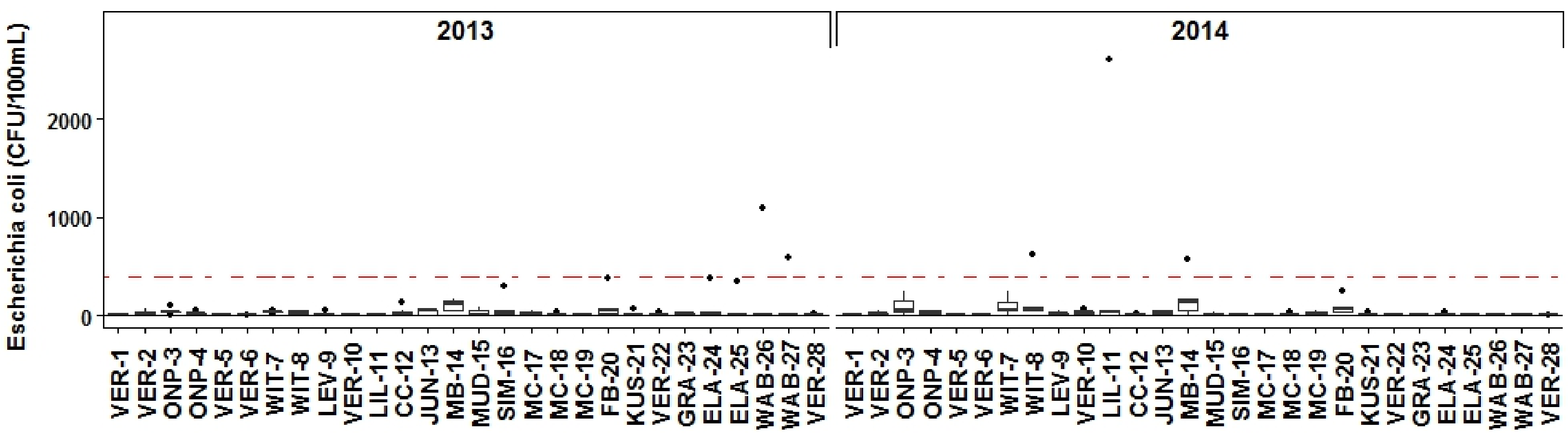

Figure B5 *Escherichia coli* concentrations for sites in 2013 and 2014.

Note: The recreation water quality guideline (400 CFU/100mL, indicated by the red dotted line) was equal or surpassed by WIT-8 on September 11th, 2014, LIL-11 on August 20th, 2014, MB-14 on June 11th, 2014, WAB-26 on July 18th 2013 and WAB-27 on July 18th, 2013.

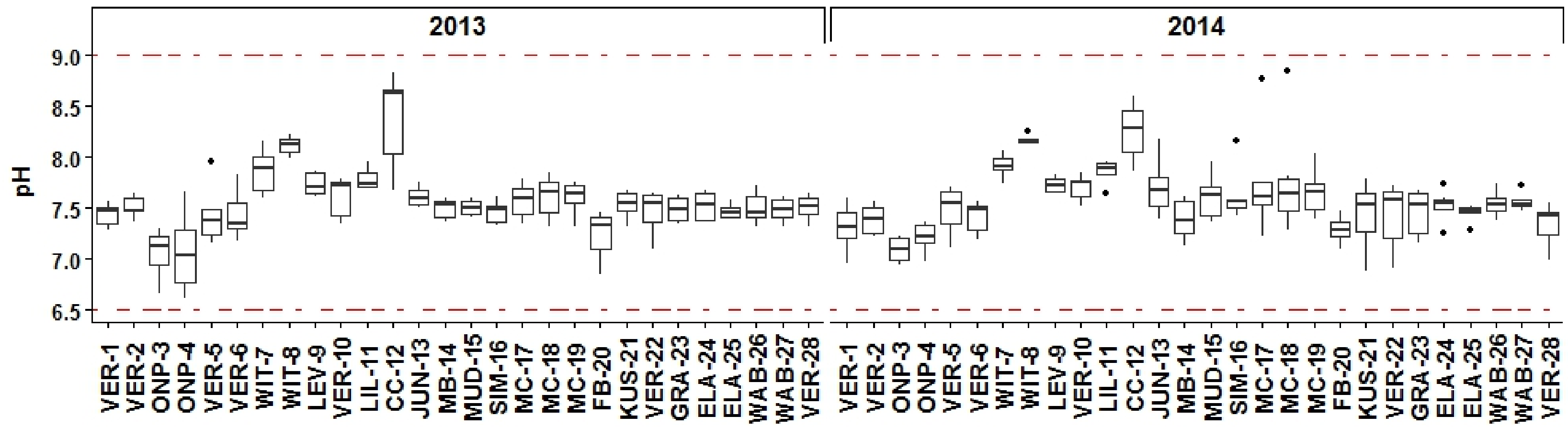

Figure B6 pH for sites in 2013 and 2014.

Note: The long-term water quality guideline for the protection of aquatic life (6.5-9, indicated by the red dotted line) is provided.

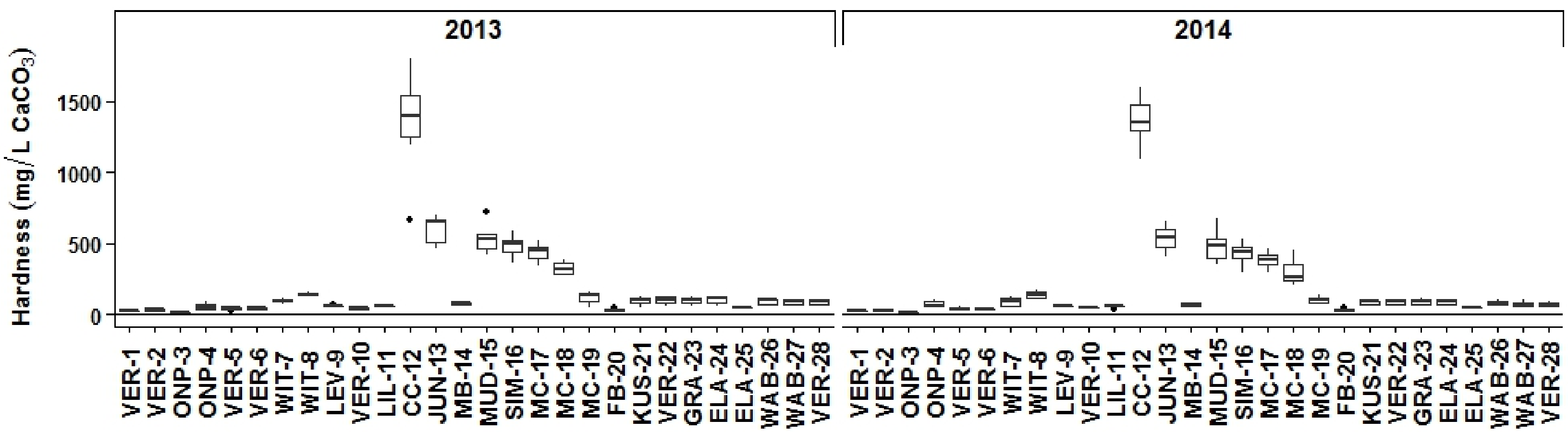

Figure B7 Hardness concentrations for sites in 2013 and 2014.

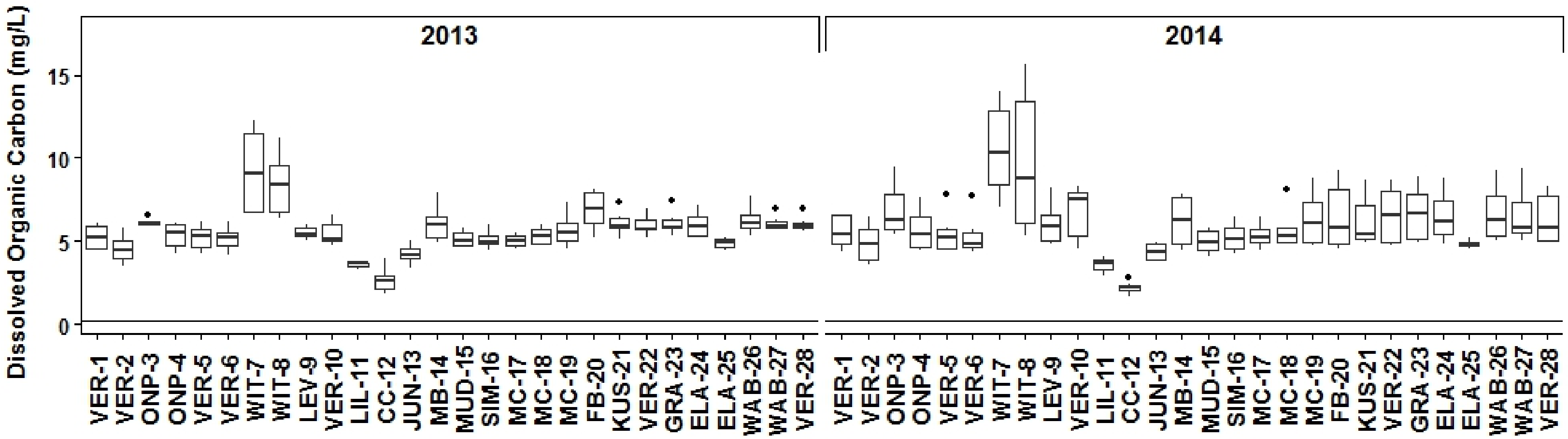

Figure B8 Dissolved organic carbon concentrations for sites in 2013 and 2014.

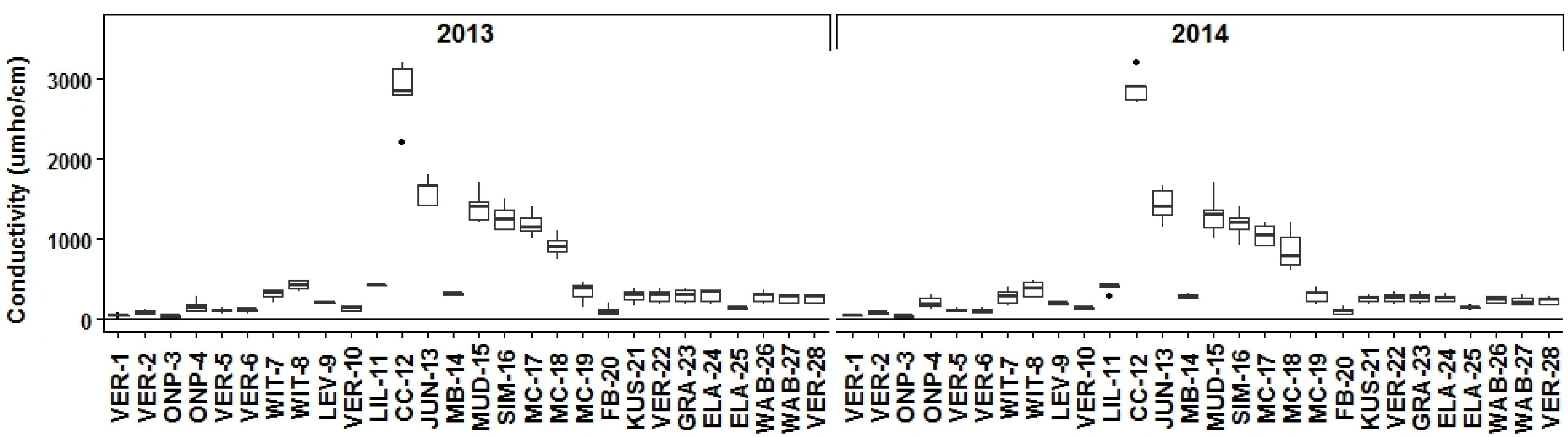

Figure B9 Conductivity for sites in 2013 and 2014.

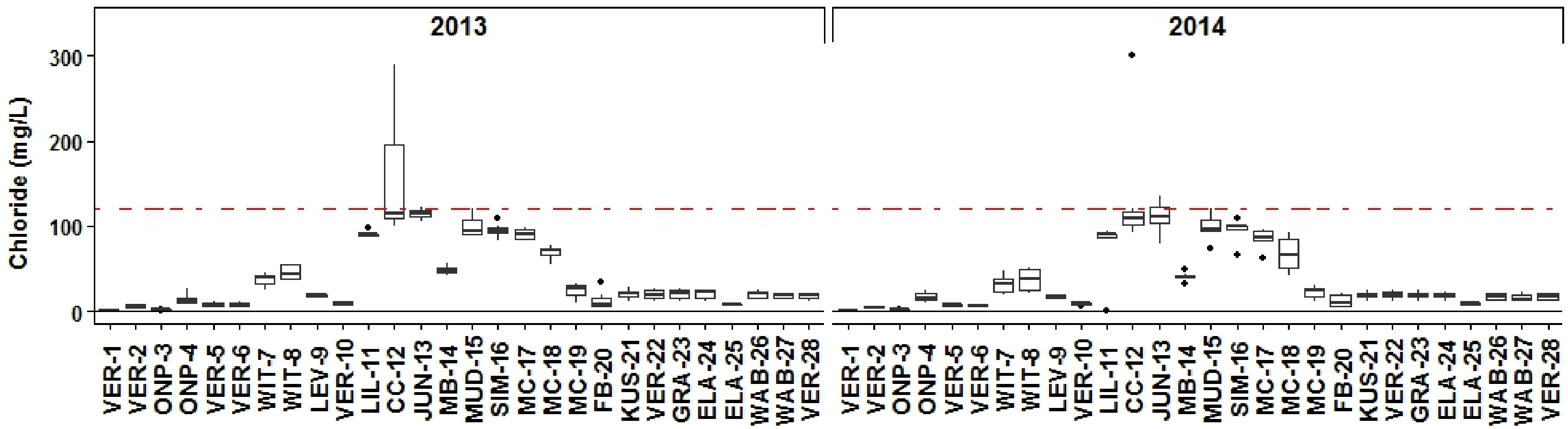

Figure B10 Chloride concentrations for sites in 2013 and 2014.

Note: The long-term water quality guideline for the protection of aquatic life (120mg/L, indicated by the red dotted line) was equal to or surpassed by CC-12 on August 20th, 2013, September 25th, 2013, October 8th, 2013, August 6th, 2014, September 2nd, 2014, JUN-13 on May 13th, 2013, July 2nd, 2014, August 21st, 2014, and MUD-15 on September 18th, 2013 and August 8th, 2014. All sites were below the short-term water quality guideline for the protection of aquatic life (640mg/L).

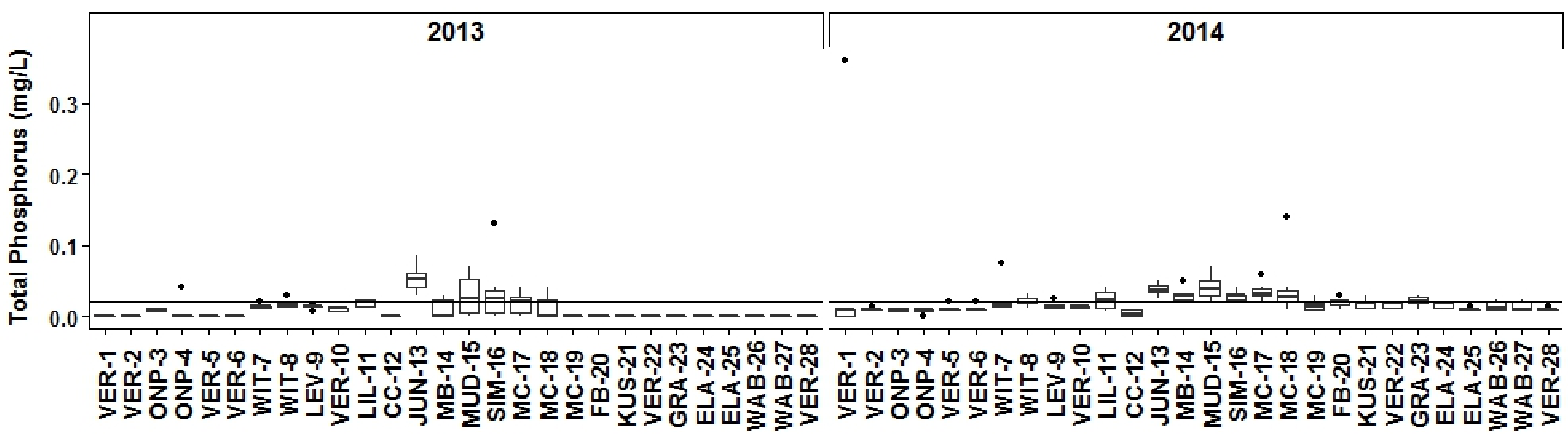

Figure B11 Total phosphorus concentrations for sites in 2013 and 2014.

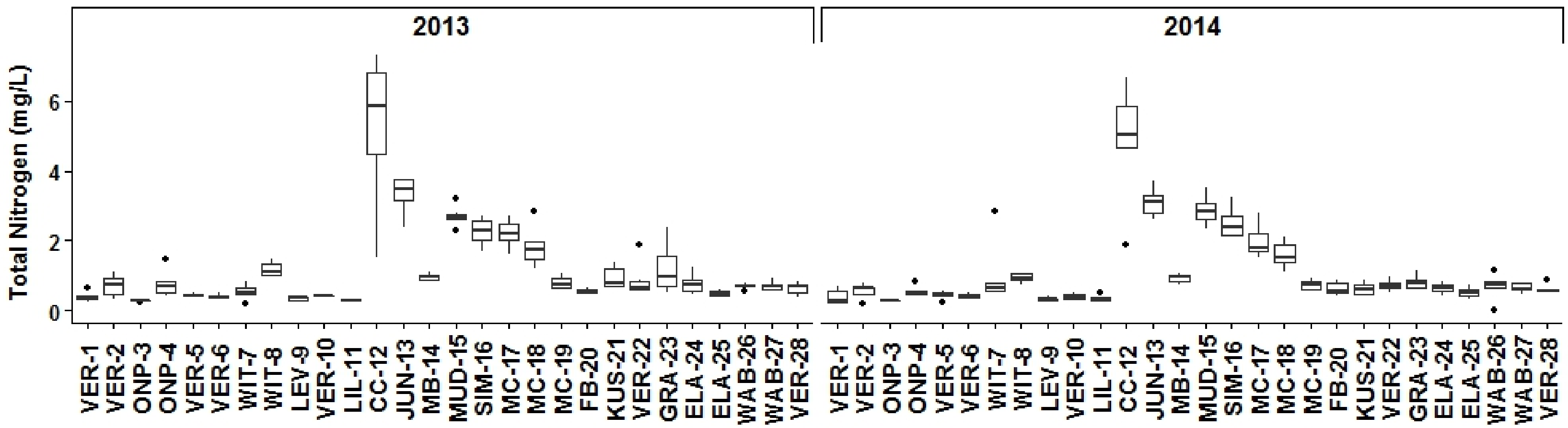

Figure B12 Total nitrogen concentrations for sites in 2013 and 2014.

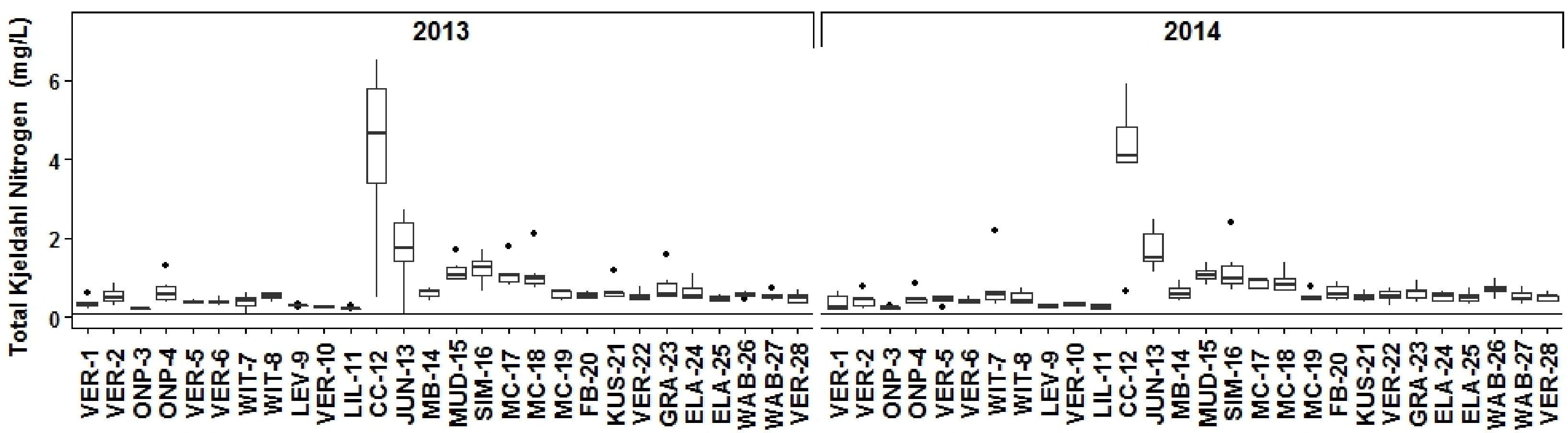

Figure B13 Total kjeldahl nitrogen concentrations for sites in 2013 and 2014.

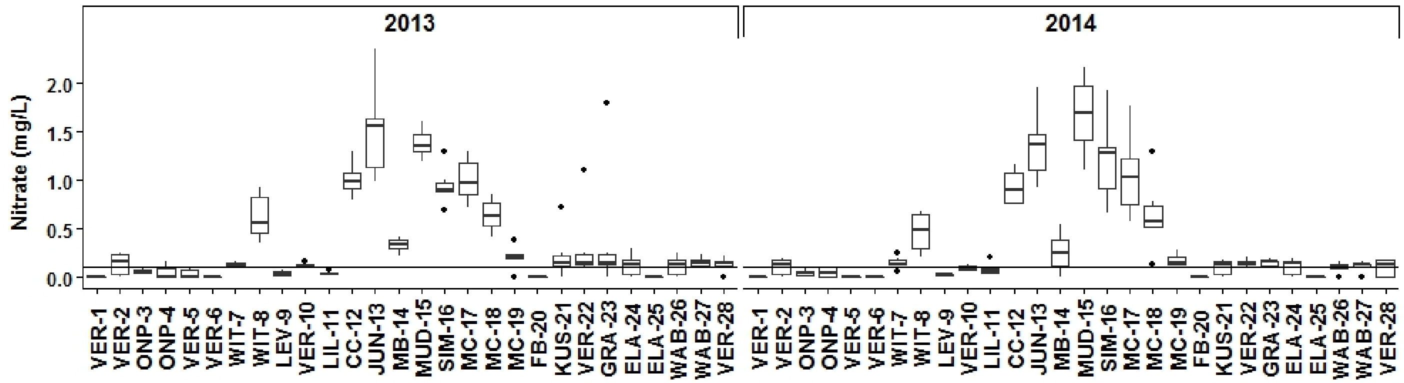

Figure B14 Nitrate concentrations for sites in 2013 and 2014.
Note: All sites were below the long and short-term water quality guidelines for the protection of aquatic life (13mg/L & 550mg/L, respectively).

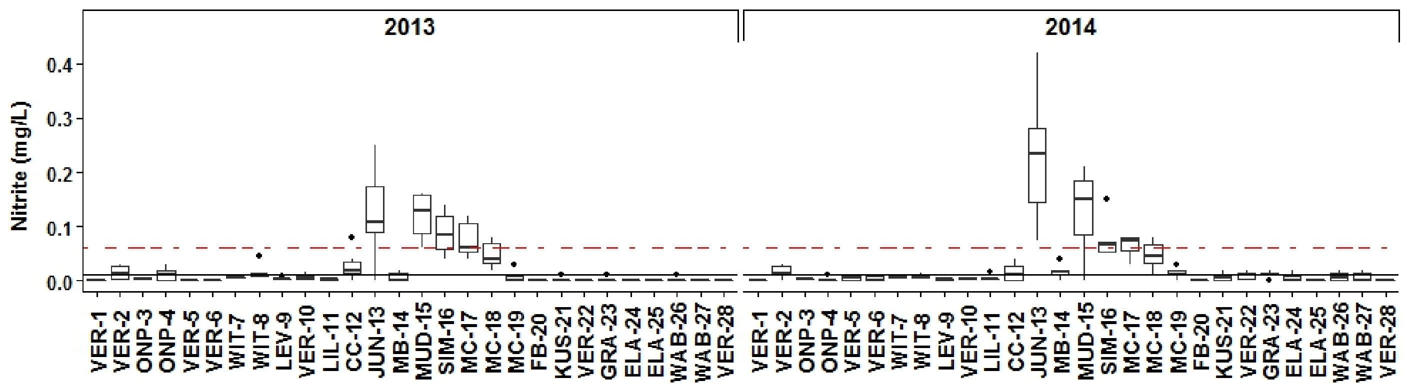

Figure B15 Nitrite concentrations for sites in 2013 and 2014.
Note: The long-term water quality guideline for the protection of aquatic life (0.06mg/L, indicated by the red dotted line) was equal to or surpassed by CC-12 on September 25th, 2013, JUN-13 on May 13th, 2013, June 17th, 2013, September 24th, 2013, October 23rd, 2013, June 17th, 2014, July 2nd, 2014, August 21st, 2014, September 11th, 2014, October 7th, 2014, November 5th, 2014, MUD-15 on May 30th, 2013, June 21st, 2013, July 17th, 2013, August 14th, 2013, September 18th, 2013, October 9th, 2013, June 11th, 2014, July 11th, 2014, September 9th, 2014, October 1st, 2014, October 28th, 2014, SIM-16 on May 28th, 2013, June 19th, 2013, July 17th, 2013, September 18th, 2013, July 10th, 2014, September 3rd, 2014, October 2nd, 2014, October 28th, 2014, MC-17 on May 28th, 2013, June 21st, 2013, July 16th, 2013, August 13th, 2013, July 10th, 2014, September 3rd, 2014, October 1st, 2014, October 24th, 2014, and MC-18 on June 21st, 2013, July 16th, 2013, September 3rd, 2014 and October 1st, 2014.

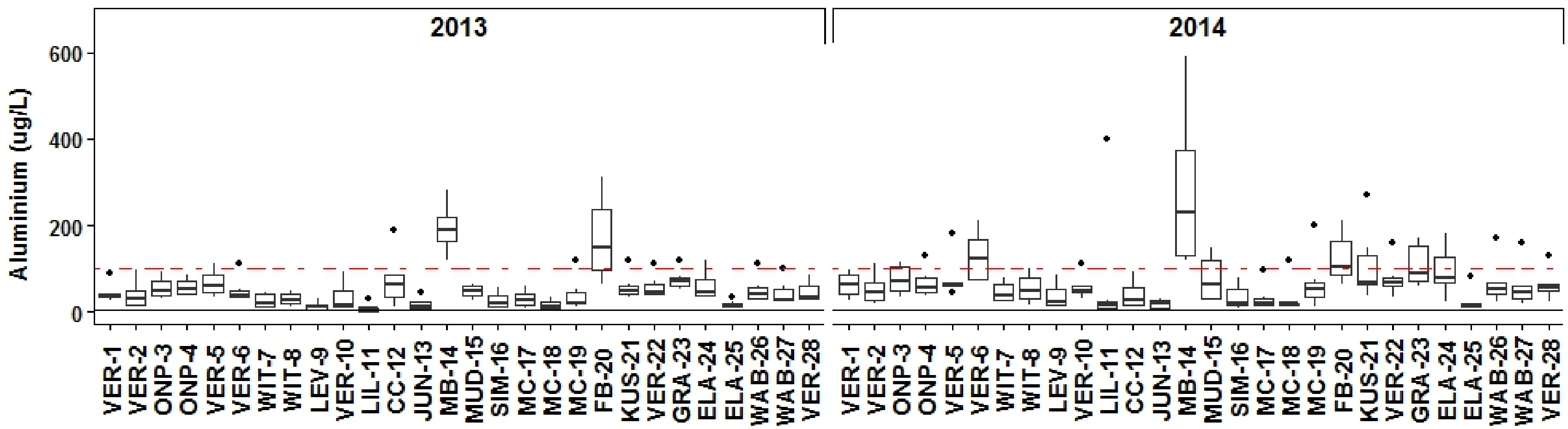

Figure B16 Total aluminium concentrations for sites in 2013 and 2014.

Note: The long-term water quality guideline for the protection of aquatic life (100ug/L when pH≥6.5, indicated by the red dotted line) that should not be exceeded was equal to or surpassed by VER-2 on November 3rd, 2014, ONP-3 on October 6th, 2014, November 5th, 2014, ONP-4 on October 27th, 2014, VER-5 on May 30th, 2013, October 27th, 2014, VER-6 on May 30th, 2013, July 8th, 2014, August 5th, 2014, October 27th, 2014, WIT-8 on November 5th, 2014, VER-10 on November 5th, 2014, LIL-11 on August 20th, 2014, CC-12 on October 8th, 2013, MB-14 on May 31st, 2013, June 19th, 2013, July 15th, 2013, August 19th, 2013, September 18th, 2013, October 9th, 2013, June 11th, 2014, July 11th, 2014, August 8th, 2014, September 2nd, 2014, October 2nd, 2014, October 28th, 2014, MUD-15 on September 9th, 2014, October 28th, 2014, MC-18 on October 24th, 2014, MC-19 on May 28th, 2013, October 24th, 2014, FB-20 on May 31st, 2013, June 25th, 2013, October 8th,2013, September 2nd, 2014, October 1st, 2014, October 24th, 2014, KUS-21 on May 29th, 2013, July 8th, 2014, October 28th, 2014, VER-22 on May 28th, 2013, October 27th, 2014, GRA-23 on May 28th, 2013, September 9th, 2014, October 27th, 2014, ELA-24 on May 29th, 2013, July 9th, 2014, October 27th, 2014, WAB-26 on May 29th, 2013, October 29th, 2014, WAB-27 on May 29th, 2013, October 29th, 2014, and VER-28 on November 3rd, 2014.

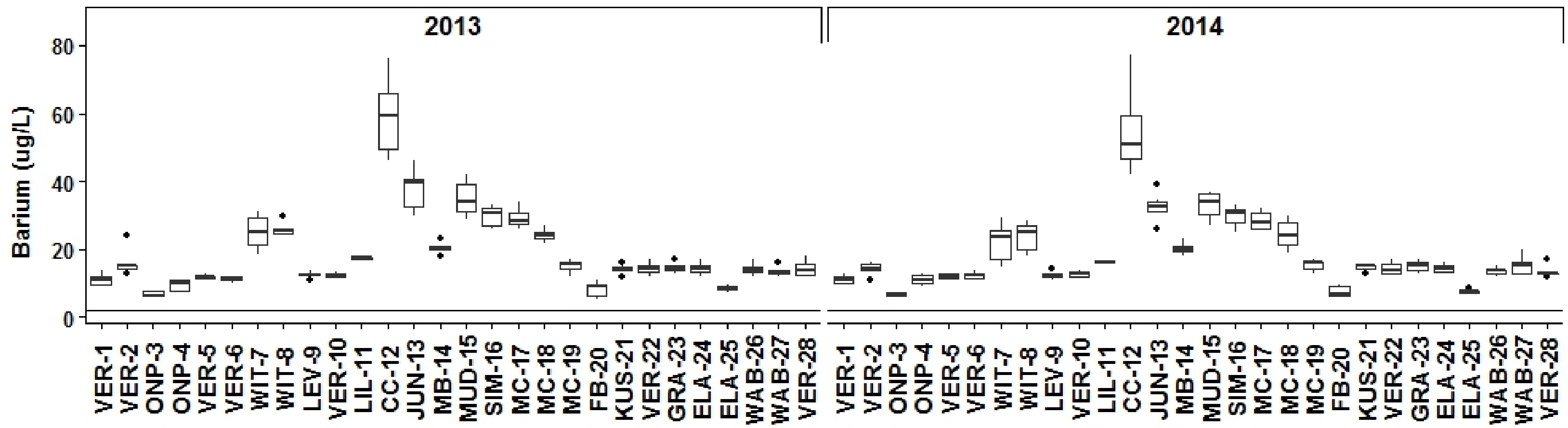

Figure B17 Total barium concentrations for sites in 2013 and 2014.

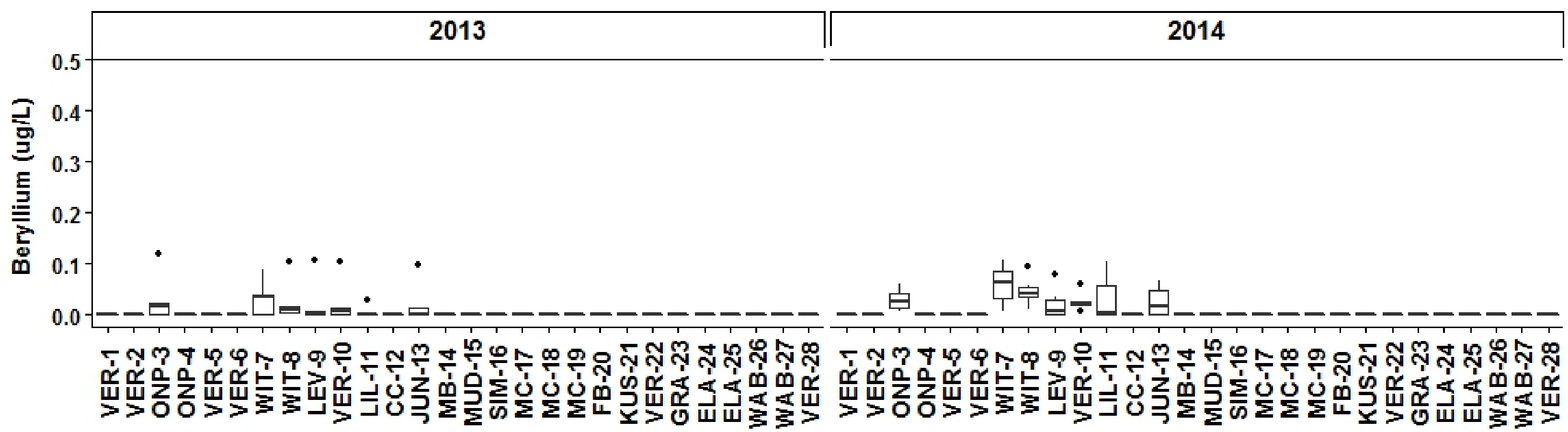

Figure B18 Total beryllium concentrations for sites in 2013 and 2014.
Note: The RDL for the majority of sites was not surpassed (0.5ug/L, indicated by the black solid line), however PWQMN sites (ONP-3, WIT-7, WIT-8, LEV-9, VER-10, LIL-11, and JUN-13) had a lower RDL.

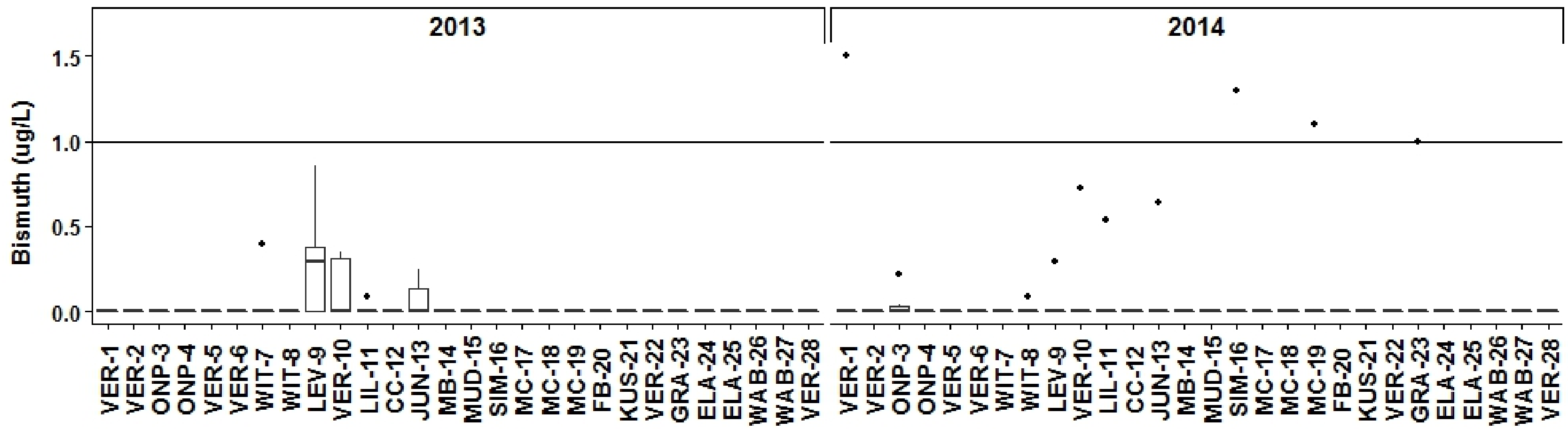

Figure B19 Total bismuth concentrations for sites in 2013 and 2014.
Note: The RDL for the majority of sites was not surpassed (1ug/L, indicated by the black solid line), however PWQMN sites (ONP-3, WIT-7, WIT-8, LEV-9, VER-10, LIL-11, and JUN-13) had a lower RDL.

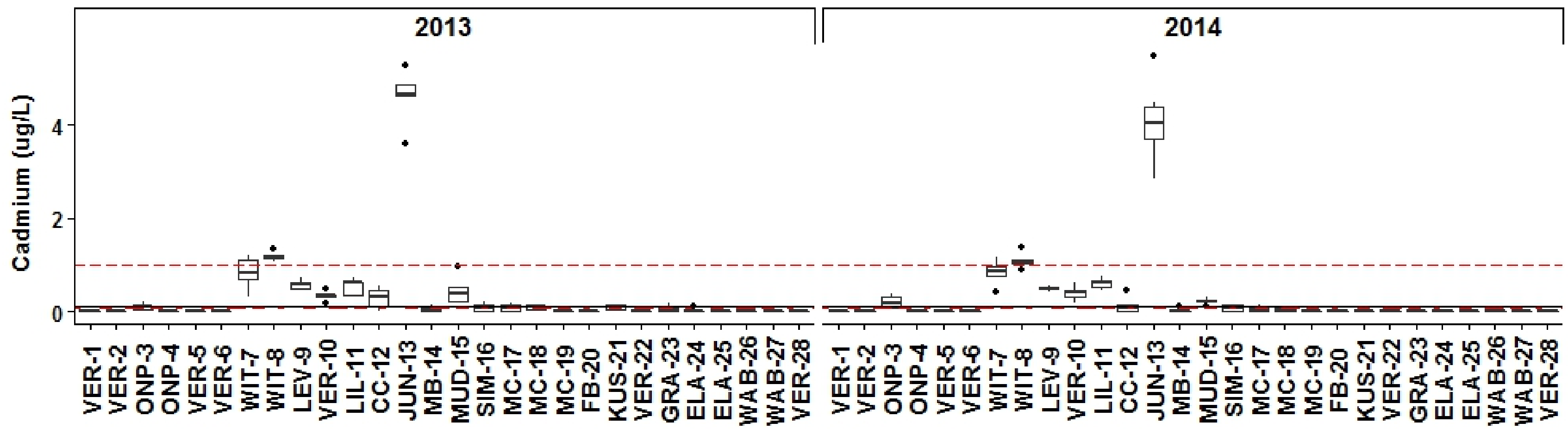

Figure B20 Total cadmium concentrations for sites in 2013 and 2014.

Note: The long-term water quality guideline for the protection of aquatic life (0.09ug/L, indicated by the red dotted line) was equal to or surpassed by ONP-3 on May 13th, 2013, August 19th, 2013, September 25th, 2013, July 2nd, 2014 , August 21st, 2014, September 11th, 2014, November 5th, 2014, WIT-7 on May 14th, 2013, September 24th, 2013, October 24th, 2013, July 2nd 2014, August 20th, 2014, September 10th, 2014, October 6th 2014, November 5th 2014, WIT-8 on November 5th, 2014, LEV-9 on May 13th, 2013, June 17th, 2013, August 19th, 2013, September 25th, 2013, October 23rd, 2013, June 17th, 2014, July 2nd, 2014, August 21st, 2014, September 11th, 2014, October 6th, 2014, November 5th, 2014, VER-10 on May 13th, 2013, June 17th, 2013, August 19th, 2013, September 25th, 2013, October 23rd, 2013, June 17th, 2014, August 21st, 2014, September 11th, 2014, October 6th, 2014, November 5th, 2014, LIL-11 on May 13th, 2013, June 18th, 2013, August 20th, 2013, September 25th, 2013, October 24th, 2013, June 18th, 2014, July 2nd, 2014, August 20th, 2014, September 10th, 2014, October 6th, 2014, November 6th, 2014, CC-12 on June 25th, 2013, August 20th, 2013, September 25th, 2013, October 8th, 2013, June 9th, 2014, August 6th, 2014, October 24th,2014, MB-14 on May 31st, 2013, July 15th, 2013, October 28th, 2014, MUD-15 on May 20th, 2013, June 21st, 2013, July 17th, 2013, August 14th, 2013, September 18th, 2013, October 9th, 2013, June 11th, 2014, July 11th, 2014, August 8th, 2014, September 9th, 2014, October 1st, 2014, October 28th, 2014, SIM-16 on May 28th, 2013, June 19th, 2013, July 17th, 2013, June 11th, 2014, July 10th, 2014, October 28th, 2014, MC-17 on May 28th, 2013, June 21st, 2013, July 16th, 2013, June 10th, 2014, October 24th, 2014, MC-18 on May 28th, 2013, June 21st, 2013, July 16th, 2013, September 16th, 2013, June 10th, 2014, October 24th, 2014, KUS-21 on June 21st, 2013, August 12th, 2013, September 17th, 2013, October 8th, 2013, GRA-23 on August 12th, 2013, October 8th, 2013, and ELA-24 on June 19th, 2013.The short-term water quality guideline for the protection of aquatic life (1ug/L, indicated by the red dotted line) was equal to or surpassed by WIT-7 on June 18th, 2013, August 20th, 2013, June 18th, 2014, WIT-8 on May 13th, 2013, June 17th, 2013, August 19th, 2013, September 25th, 2013, October 23rd, 2013, June 17th, 2014, July 2nd, 2014, August 21st, 2014, September 11th, 2014, October 6th, 2014, and JUN-13 on May 13th, 2013, June 17th, 2013, August 20th,2013, September 24th, 2013, October 23rd, 2013, June 17th, 2014, July 2nd, 2014, August 21st, 2014, September 11th, 2014, October 7th, 2014, and November 5th, 2014.

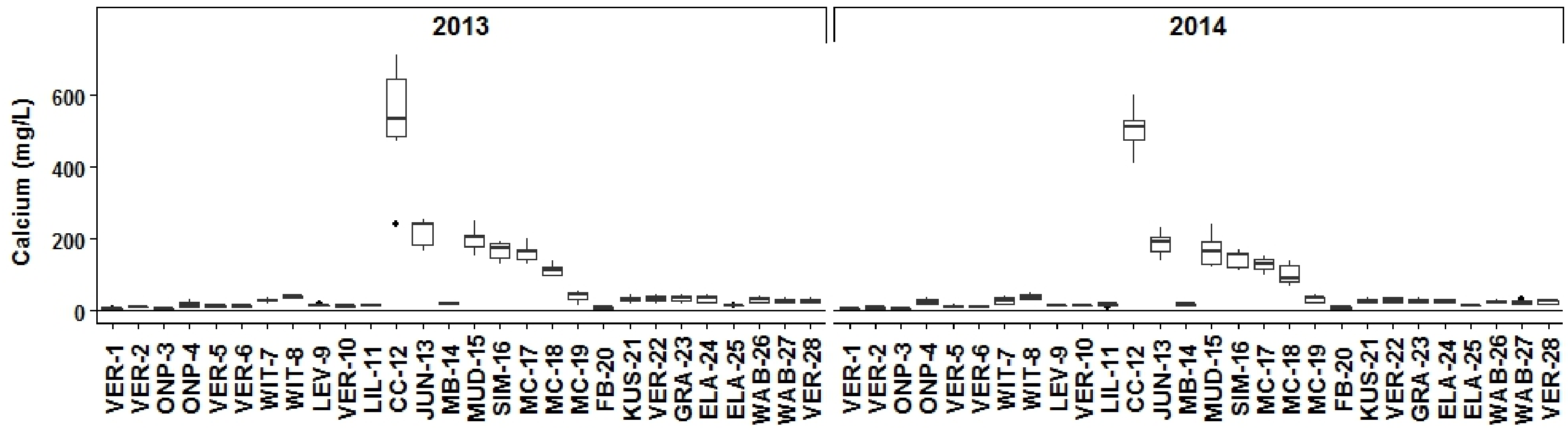

Figure B21 Total calcium concentrations for sites in 2013 and 2014.

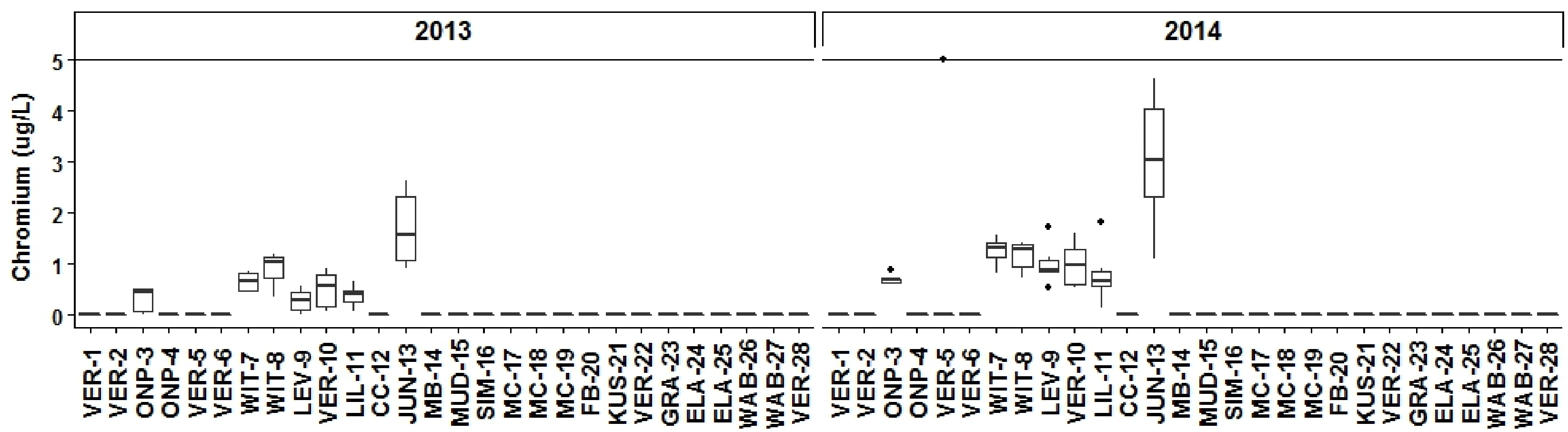

Figure B22 Total chromium concentrations for sites in 2013 and 2014.
Note: The RDL for the majority of sites was not surpassed (5ug/L, indicated by the black solid line), however PWQMN sites (ONP-3, WIT-7, WIT-8, LEV-9, VER-10, LIL-11, and JUN-13) had a lower RDL.

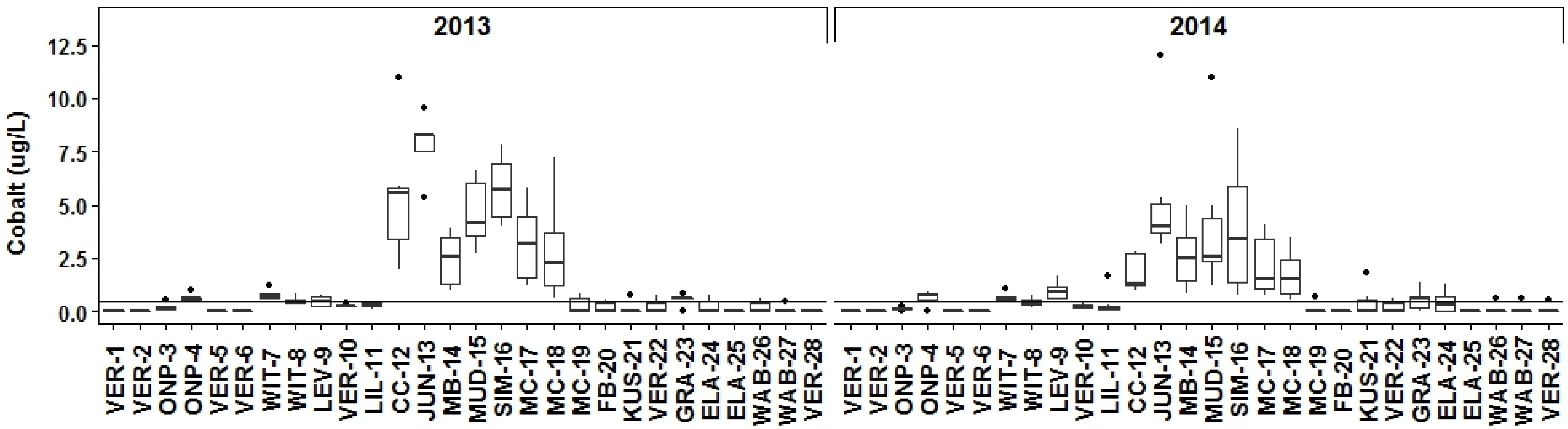

Figure B23 Total cobalt concentrations for sites in 2013 and 2014.

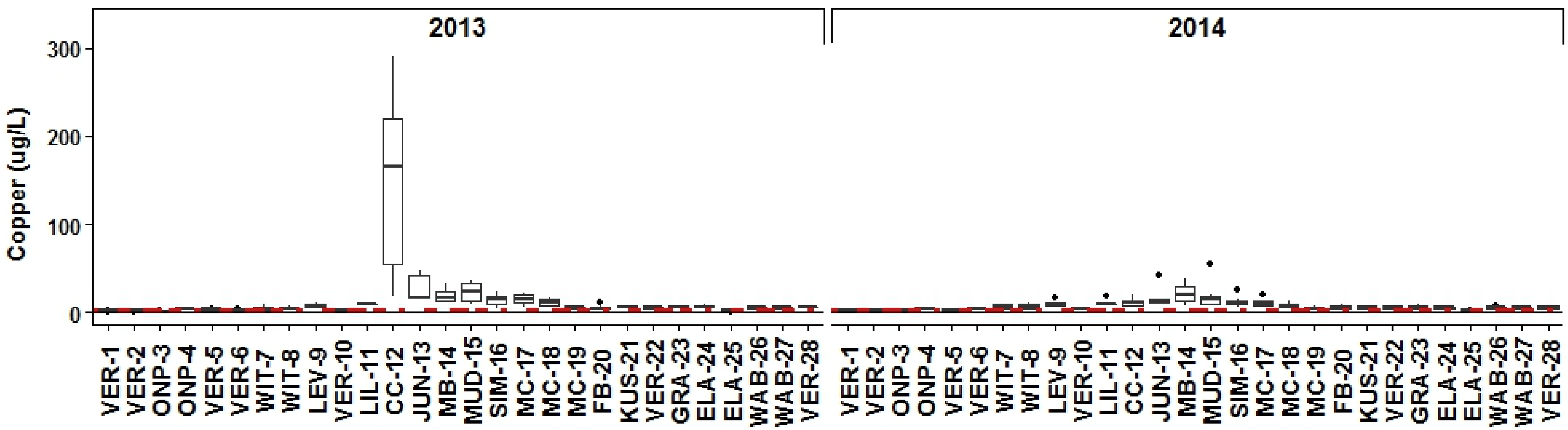

Figure B24 Total copper concentrations for sites in 2013 and 2014.

Note: The long-term water quality guideline for the protection of aquatic life (4ug/L if hardness >180mg/L or 2-4ug/L if hardness ≤ 180mg/L, indicated by the red dotted line) was equal to or surpassed by VER-1 on May 31st, 2013, VER-2 on May 31st, 2013, June 25th, 2013, July 19th, 2013, June 13th, 2014, September 5th, 2014, October 9th, 2014, November 3rd, 2014, ONP-4 on May 30th, 2013, June 17th, 2013, July 16th, 2013, August 13th, 2013, September 16th, 2013, October 7th, 2013, June 10th, 2014, July 8th, 2014, August 5th, 2014, September 9th, 2014, October 3rd, 2014, October 27th, 2014, VER-5 on May 30th, 2013, June 20th, 2013, July 16th, 2013, August 13th, 2013, September 16th, 2013, October 7th, 2013, June 10th, 2014, July 8th, 2014, August 5th, 2014, September 9th, 2014, October 3rd, 2014, October 27th, 2014, VER-6 on May 30th, 2013, June 20th, 2013, July 16th, 2013, August 13th, 2013, September 16th, 2013, October 7th, 2013, June 10th, 2014, July 8th, 2014, August 5th, 2014, September 9th 2014, October 3rd, 2014, October 27th, 2014, WIT-7 on May 14th, 2013, June 18th, 2013, August 20th, 2013, September 24th, 2013, October 24th,2013, June 18th, 2014, July 2nd, 2014, August 20th, 2014, September 10th, 2014, October 6th, 2014, November 5th, 2014, WIT-8 on May 13th, 2013, June 17th, 2013, August 19th, 2013, September 25th, 2013, October 23rd, 2013, June 17th, 2014, July 2nd, 2014, August 21st, 2014, September 11th, 2014, October 6th, 2014, November 5th, 2014, LEV-9 on May 13th, 2013, June 17th, 2013, August 19th, 2013, September 25th, 2013, October 23rd, 2013, June 17th, 2014, July 2nd, 2014, August 21st, 2014, September 11th, 2014, October 6th, 2014, November 5th, 2014, VER-10 on May 13th, 2013, June 17th, 2013, August 19th, 2013, September 25th, 2013, October 23rd, 2013, June 17th, 2014, August 21st, 2014, September 11th, 2014, October 6th, 2014, November 5th, 2014, LIL-11 on May 13th, 2013, June 18th, 2013, August 20th, 2013, September 25th, 2013, October 24th, 2013, June 18th, 2014, July 2nd, 2014, August 20th, 2014, September 10th, 2014, October 6th, 2014, November 6th, 2014, CC-12 on May 31st, 2013, June 25th, 2013, July 15th, 2013, August 20th, 2013, September 25th, 2013, October 8th, 2013, June 9th, 2014, July 10th, 2014, August 6th, 2014, September 2nd, 2014, October 2nd, 2014, October 24th, 2014, JUN-13 on May 13th, 2013, June 17th, 2013, August 20th, 2013, September 24th, 2013, October 23rd, 2013, June 17th, 2014, July 2nd, 2014, August 21st, 2014, September 11th, 2014, October 7th, 2014, November 5th, 2014, MB-14 on May 31st, 2013, June 19th, 2013, July 15th, 2013, August 19th, 2013, September 18th, 2013, October 9th, 2013, June 11th, 2014, July 11th, 2014, August 8th, 2014, September 2nd, 2014, October 2nd, 2014, October 28th, 2014, MUD-15 on May 30th, 2013, June 21st, 2013, July 17th, 2013, August 14th, 2013, September 18th, 2013, October 9th, 2013, June 11th, 2014, July 11th, 2014, August 8th, 2014, September 9th, 2014, October 1st, 2014, October 28th, 2014, SIM-16 on May 28th, 2013, June 19th, 2013, July 17th, 2014, August 14th, 2013, September 18th, 2013, October 9th, 2013, June 11th, 2014, July 10th, 2014, August 6th, 2014, September 3rd, 2014, October 2nd, 2014, October 28th, 2014, MC-17 on May 28th, 2013, June 21st, 2013, July 16th, 2013, August 13th, 2013, September16th, 2013, October 7th, 2013, June 10th, 2014, July 10th, 2014, August

6th, 2014, September 3rd, 2014, October 1st, 2014, October 24th, 2014, MC-18 on May 28th, 2013, June 21st, 2013, July 16th, 2013, August 13th, 2013, September 16th, 2013, October 7th, 2013, June 10th, 2014, July 10th, 2014, August 6th, 2014, September 3rd, 2014, October 1st, 2014, October 24th, 2014, MC-19 on May 28th, 2013, June 21st, 2013, July 16th, 2013, August 13th, 2013, September 16th, 2013, October 7th, 2013, June 10th, 2014, July 10th, 2014, August 6th, 2014, September 3rd, 2014, October 1st, 2014, October 24th, 2014, FB-20 on May 31st, 2013, June 25th, 2013, July 15th, 2013, August 19th, 2013, September 24th, 2013, October 8th, 2013, June 9th, 2014, July 10th, 2014, August 6th, 2014, September 2nd, 2014, October 1st, 2014, October 24th, 2014, KUS-21 on May 29th, 2013, June 21st, 2013, July 15th, 2013, August 12th, 2013, September 17th, 2013, October 8th, 2013, June 9th, 2014, July 8th, 2014, August 5th, 2014, September 2nd, 2014, October 2nd, 2014, October 28th, 2014, VER-22 on May 28th, 2013, June 21st, 2013, July 15th, 2013, August 12th, 2013, September 17th, 2013, October 8th, 2013, June 9th, 2014, July 8th, 2014, August 5th, 2014, September 9th, 2014, September 29th, 2014, October 27th, 2014, GRA-23 on May 28th, 2013, June 21st, 2013, July 15th, 2013, August 12th, 2013, September 17th, 2013, October 8th, 2013, June 9th, 2014, July 8th, 2014, August 5th, 2014, September 9th, 2014, September 30th, 2014, October 27th, 2014, ELA-24 on May 29th, 2013, June 19th, 2013, July 24th, 2013, August 14th, 2013, September 18th, 2013, October 10th, 2013, June 11th, 2014, July 9th, 2014, August 7th, 2014, September 3rd, 2014, September 30th, 2014, October 27th, 2014, ELA-25 on May 29th, 2013, June 19th, 2013, July 24th, 2013, August 14th, 2013, October 10th, 2013, August 7th, 2014, September 3rd, 2014, September 30th, 2014, WAB-26 on May 29th, 2013, June 20th, 2013, July 18th, 2013, August 15th, 2013, September 19th, 2013, October 10th, 2013, June 12th, 2014, July 9th, 2014, August 7th, 2014, September 30th, 2014, October 29th, 2014, WAB-27 on May 29th, 2013, June 20th, 2013, July 18th, 2013, August 15th, 2013, September 19th, 2013, October 10th, 2013, June 12th, 2014, July 9th, 2014, August 7th, 2014, September 30th, 2014, October 29th, 2014, and VER-28 on May 30th, 2013, June 20th, 2013, July 18th, 2013, August 15th, 2013, September 19th, 2013, October 10th, 2013, June 12th, 2014, August 11th, 2014, September 5th, 2014, October 9th, 2014, and November 3rd, 2014, when taking into account the mean annual hardness for sites in 2013 and 2014 (mean annual hardness was >180mg/L for CC-12, JUN-13, MUD-15, SIM-16, MC-17, MC-18).

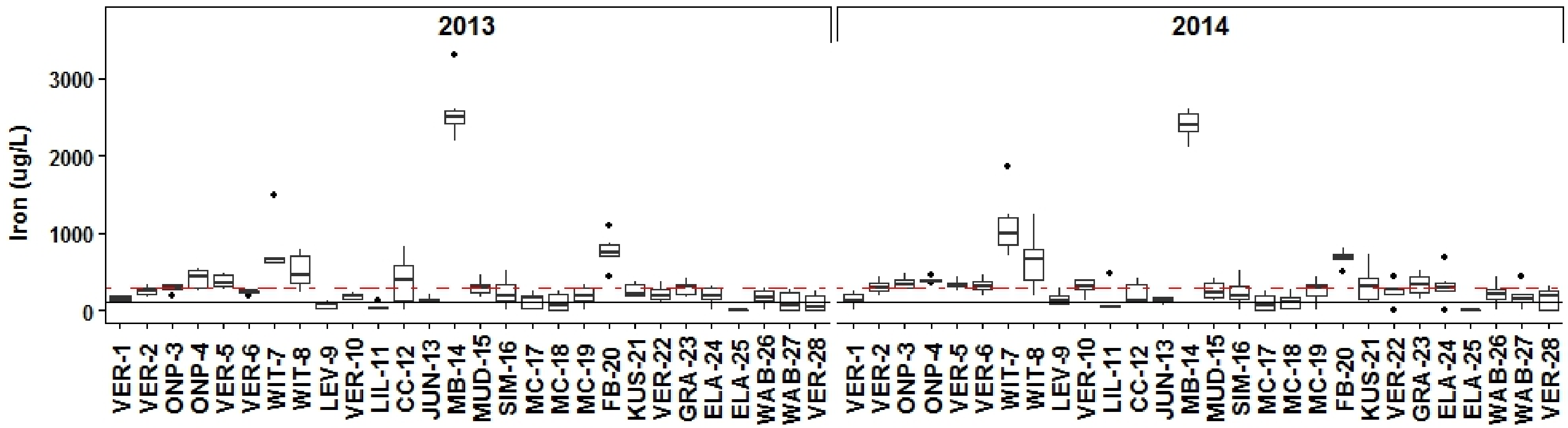

Figure B25 Total iron concentrations for sites in 2013 and 2014.

Note: The long-term water quality guideline for the protection of aquatic life (300ug/L, indicated by the red dotted line) was equal to or surpassed by VER-2 on July 19th, 2013, September 5th, 2014, October 9th, 2014, November 3rd, 2014, ONP-3 on June 17th, 2013, September 25th, 2013, June 17th, 2014, September 11th, 2014, October 6th, 2014, November 5th, 2014, ONP-4 on June 17th, 2013, July 16th, 2014, August 13th, 2014, September 16th, 2014, June 10th, 2014, July 8th, 2014, August 5th, 2014, September 9th, 2014, October 3rd, 2014, October 27th, 2014, VER-5 on June 20th, 2013, July 16th, 2013, August 13th, 2013, September 16th, 2013, October 7th, 2013, June 10th, 2014, July 8th, 2014, September 9th, 2014, October 3rd, 2014, November 27th, 2014, VER-6 on June 10th, 2014, July 8th, 2014, August 5th, 2014, October 27th, 2014, WIT-7 on May 14th, 2013, June 18th, 2013, August 20th, 2013, September 24th, 2013, October 24th, 2013, June 18th, 2014, August, 20th, 2014, September 10th, 2014, October 6th, 2014, November 5th, 2014, WIT-8 on May 13th, 2013, June 17th, 2013, September 25th, 2013, October 23rd, 2013, June 17th, 2014, July 2nd, 2014, September 11th, 2014, October 6th, 2014, November 5th, 2014, VER-10 on September 11th, 2014, October 6th, 2014, November 5th, 2014, LIL-11 on August 20th, 2014, CC-12 on June 25th, 2013, September 25th, 2013, October 8th, 2013, August 6th, 2014, October 24th, 2014, MB-14 on May 31st, 2013, June 19th, 2013, July 15th, 2013, August 19th, 2013, September 18th, 2013, October 9th, 2013, June 11th, 2014, July 11th, 2014, August 8th, 2014, September 2nd, 2014, October 2nd, 2014, October 28th, 2014, MUD-15 on May 30th, 2013, June 21st, 2013, July 17th, 2013, October 9th, 2013, September 9th, 2014, October 28th, 2014, SIM-16 on July 17th, 2013, October 9th, 2013, July 10th, 2014, October 28th, 2014, MC-19 on May 28th, 2013, June 21st, 2013, June 10th, 2014, September 3rd, 2014, October 1st, 2014, October 24th, 2014, FB-20 on May 31st, 2013, June 25th, 2013, July 15th, 2013, August 19th, 2013, September 24th, 2013, October 8th, 2013, June 9th, 2014, July 10th, 2014, August 6th, 2014, September 2nd, 2014, October 1st, 2014, October 24th, 2014, KUS-21 on May 29th, 2013, June 21st, 2013, July 8th, 2014, October 2nd, 2014, October 28th, 2014, VER-22 on May 28th, 2013, June 21st, 2013, October 27th, 2014, GRA-23 on May 28th, 2013, June 21st, 2013, October 8th, 2013, June 9th, 2014, September 9th, 2014, September 30th, 2014, October 27th, 2014, ELA-24 on May 29th, 2013, June 19th, 2013, June 11th, 2014, July 9th, 2014, October 27th, 2014, WAB-26 on May 29th, 2013, October 29th, 2014, WAB-27 on October 29th, 2014, and VER-28 on November 3rd, 2014.

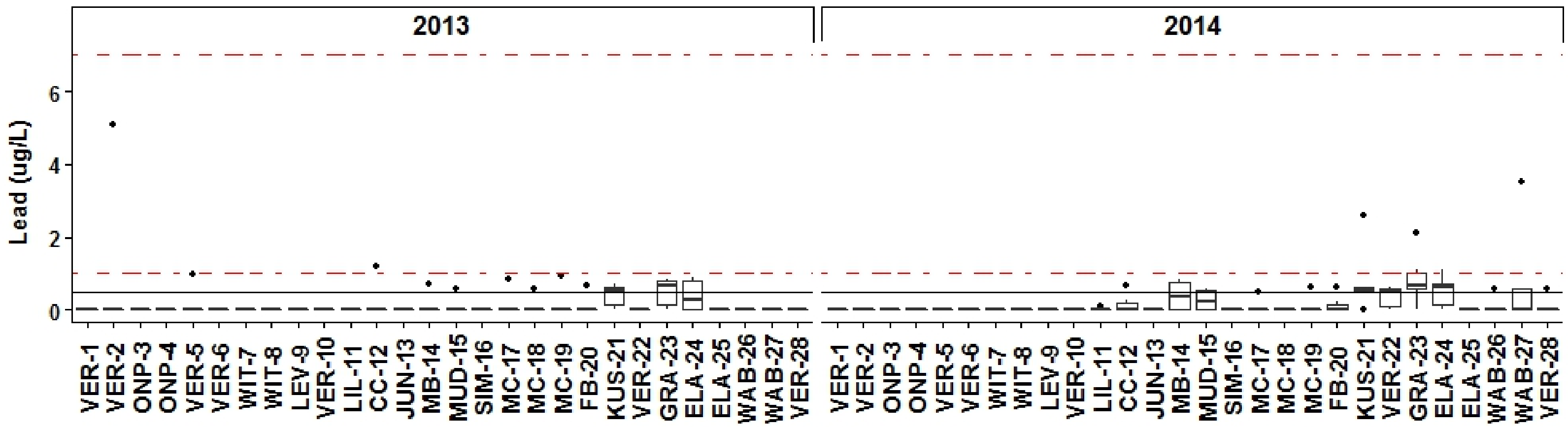

Figure B26 Total lead concentrations for sites in 2013 and 2014.

Note: The long-term water quality guideline for the protection of aquatic life (7ug/L if hardness >180mg/L or 1-7ug/L if hardness ≤ 180mg/L, indicated by the red dotted line) was equal to or surpassed by VER-2 on July 19th, 2013, KUS-21 on July 8th, 2014, GRA-23 on September 9th, 2014, September 30th, 2014, ELA-24 on July 9th, 2014, and WAB-27 on September 30th, 2014, when taking into account the mean annual hardness for sites in 2013 and 2014 (mean annual hardness was >180mg/L for CC-12, JUN-13, MUD-15, SIM-16, MC-17, MC-18).

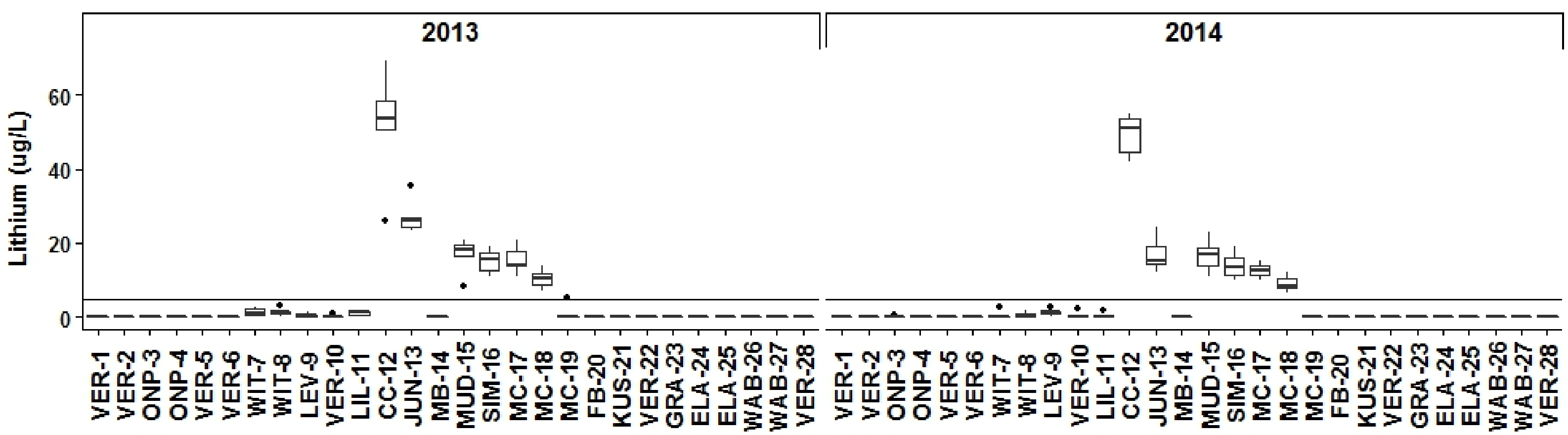

Figure B27 Total lithium concentrations for sites in 2013 and 2014.

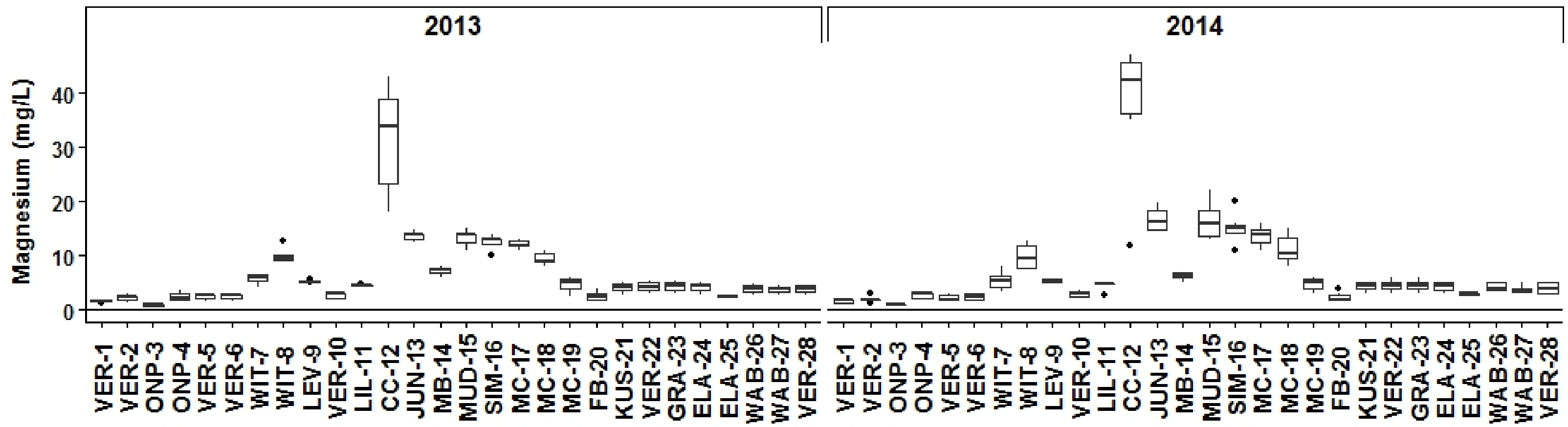

Figure B28 Total magnesium concentrations for sites in 2013 and 2014.

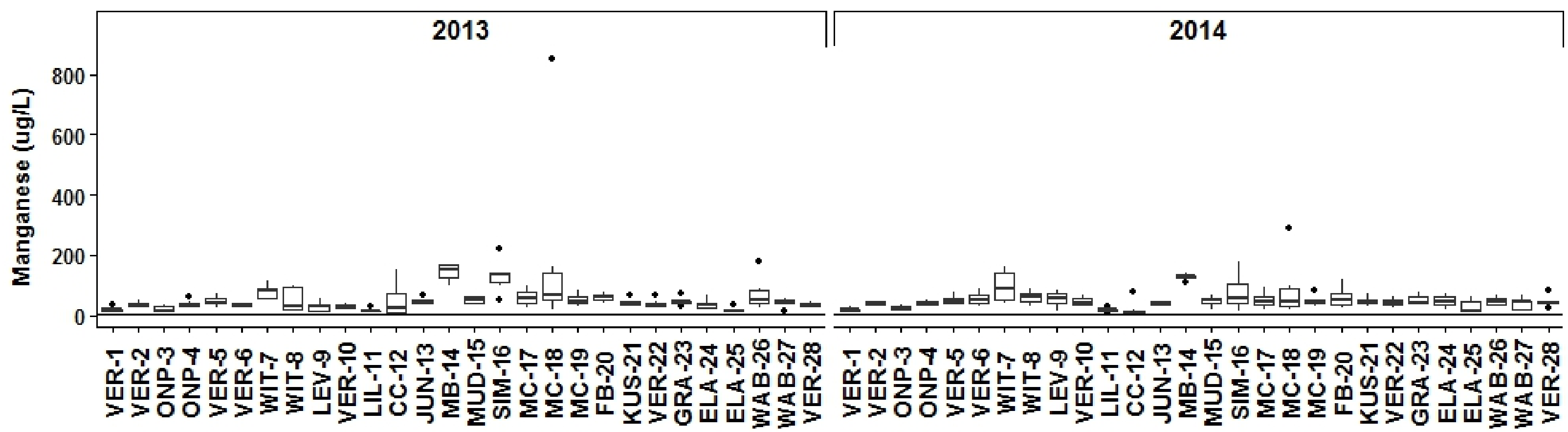

Figure B29 Total manganese concentrations for sites in 2013 and 2014.

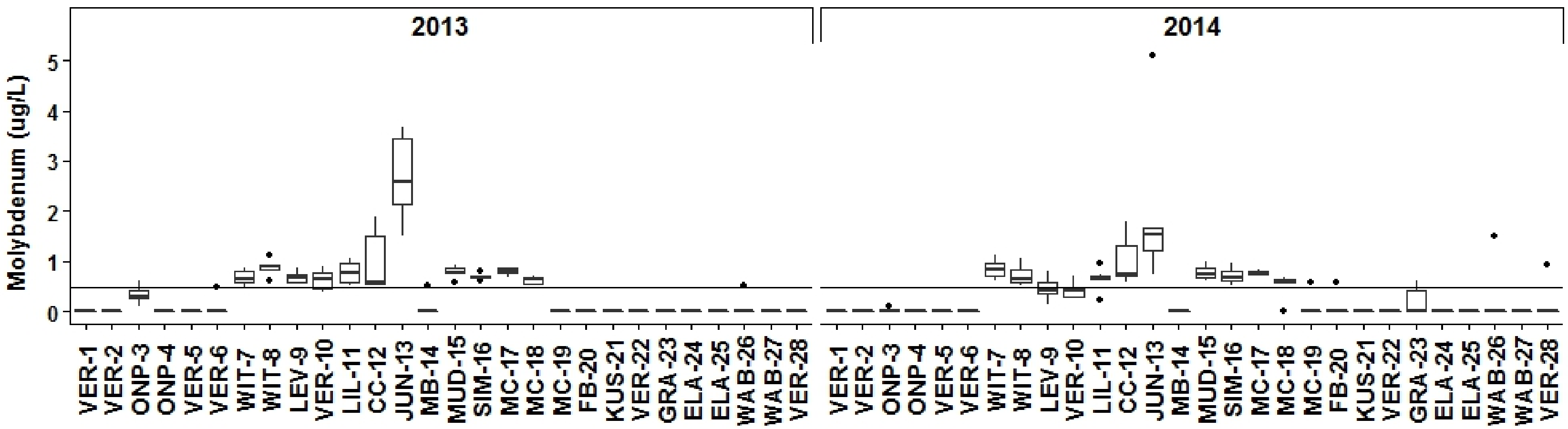

Figure B30 Total molybdenum concentrations for sites in 2013 and 2014.
Note: All sites were well below the long-term water quality guideline for the protection of aquatic life (73ug/L).

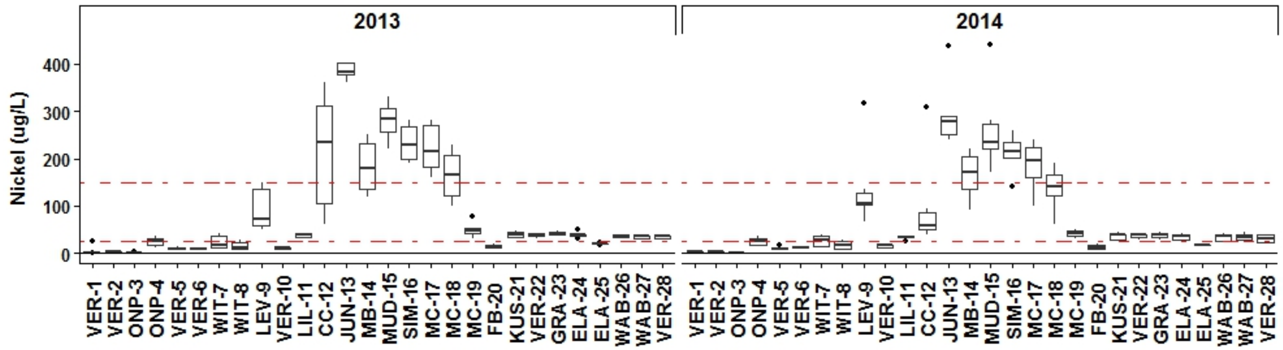

Figure B31 Total nickel concentrations for sites in 2013 and 2014.

Note: The long-term water quality guideline for the protection of aquatic life (150ug/L if hardness >180mg/L or 25-150ug/L if hardness ≤ 180mg/L, indicated by the red dotted line) was equal to or surpassed by VER-1 on May 31st, 2013, ONP-4 on July 16th, 2013, August 13th, 2013, September 16th, 2013, July 8th, 2014, August 5th, 2014, September 9th, 2014, WIT-7 on May 14th, 2013, June 18th, 2013, September 10th, 2014, October 6th, 2014, November 5th, 2014, WIT-8 on May 13th, 2013, September 11th, 2014, October 6th, 2014, LEV-9 on May 13th, 2013, June 17th, 2013, August 19th, 2013, September 25th, 2013, October 23rd, 2013, June 17th, 2014, July 2nd, 2014, August 21st, 2014, September 11th, 2014, October 6th, 2014, November 5th, 2014, LIL-11 on May 13th, 2013, June 18th, 2013, August 20th, 2013, September 25, 2013, October 24th, 2013, June 18th, 2014, July 2nd, 2014, September 10th, 2014, October 6th, 2014, November 6th, 2014, CC-12 in June 25th, 2013, July 15th, 2013, September 25th, 2013, October 8th, 2013, August 6th, 2014, JUN-13 on May 13th, 2013, June 17th, 2013, August 20th, 2013, September 24th, 2013, October 23rd, 2013, June 17th, 2014, July 2nd, 2014, August 21st, 2014, September 11th, 2014, October 7th, 2014, November 5th, 2014, MB-14 on May 31st, 2013, June 19th, 2013, July 15th, 2013, August 19th, 2013, September 18th, 2013, October 9th, 2013, June 11th, 2014, July 11th, 2014, August 8th, 2014, September 2nd, 2014, October 2nd, 2014, October 28th, 2014, MUD-15 on May 30th, 2013, June 21st, 2013, July 17th, 2013, August 14th, 2013, September 18th, 2013, October 9th, 2013, June 11th, 2014, July 11th, 2014, August 8th, 2014, September 9th, 2014, October 1st, 2014, October 28th, 2014, SIM-16 on May 28th, 2013, June 19th, 2013, July 17th, 2013, August 14th, 2013, September 18th, 2013, October 9th, 2013, June 11th, 2014, July 10th, 2014, September 3rd, 2014, October 2nd, 2014, October 28th, 2014, MC-17 on May 28th, 2013, June 21st, 2013, July 16th, 2013, August 13th, 2013, September 16th, 2013, October 7th, 2013, June 10th, 2014, July 10th, 2014, September 3rd, 2014, October 1st, 2014, October 24th, 2014, MC-18 on May 28th, 2013, June 21st, 2013, July 16th, 2013, June 10th, 2014, October 1st, 2014, October 24th, 2014, MC-19 on May 28th, 2013, June 21st, 2013, July 16th, 2013, August 13th, 2013, September 16th, 2013, October 7th, 2013, June 10th, 2014, July 10th, 2014, August 6th, 2014, September 3rd, 2014, October 1st, 2014, October 24th, 2014, KUS-21 on May 29th, 2013, June 21st, 2013, July 15th, 2013, August 12th, 2013, September 17th, 2013, October 8th, 2013, June 9th, 2014, July 8th, 2014, August 5th, 2014, September 2nd, 2014, October 2nd, 2014, October 28th, 2014, VER-22 on May 28th, 2013, June 21st, 2013, July 15th, 2013, August 12th, 2013, September 17th, 2013, October 8th, 2013, June 9th, 2014, July 8th, 2014, August 5th, 2014, September 9th, 2014, September 20th, 2014, October 27th, 2014, GRA-23 on May 28th, 2013, June 21st, 2013, July 15th, 2013, August 12th, 2013, September 17th, 2013, October 8th, 2013, June 9th, 2014, July 8th, 2014, August 5th, 2014, September 9th, 2014, September 30th, 2014, October 27th, 2014, ELA-24 on May 29th, 2013, June 19th, 2013, July 24th, 2013, August 14th, 2013, September 18th, 2013, October 10th, 2013, June 11th, 2014, July 9th, 2014, August 7th, 2014, September 3rd, 2014, September 30th, 2014, October 27th, 2014, WAB-26 on May 29th, 2013, June 20th, 2013, July 18th, 2013, August 15th, 2013, September 19th, 2013, October 10th, 2013, June 12th, 2014, July 9th, 2014, August 7th, 2014, September 30th, 2014, October 29th, 2014, WAB-27 on May 29th, 2013, June 20th, 2013, July 18th, 2013, August 15, 2013, September 19th, 2013, October 10th, 2013, June 12th, 2014, July 9th, 2014, September 30th, 2014, October 29th, 2014, and VER-28 on May 30th, 2013, June 20th, 2013, July 18th, 2013, August 15th, 2013, September 19th, 2013, October 10th, 2013, June 12th, 2014, October 9th, 2014, and November 3rd 2014, when taking into account the mean annual hardness for sites in 2013 and 2014 (mean annual hardness was >180mg/L for CC-12, JUN-13, MUD-15, SIM-16, MC-17, MC-18).

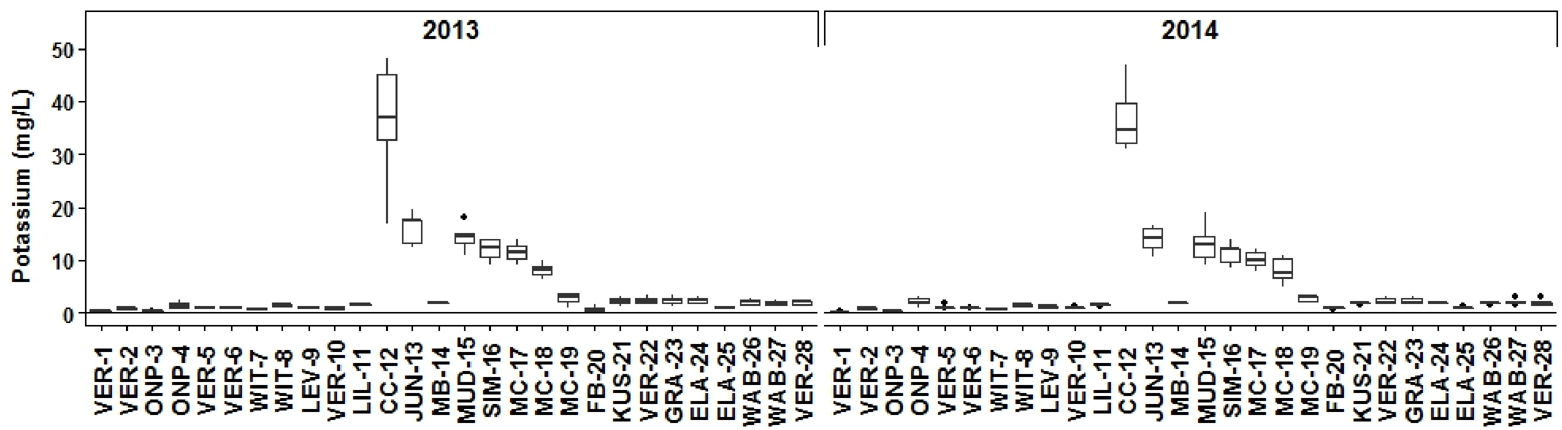

Figure B32 Total potassium concentrations for sites in 2013 and 2014.

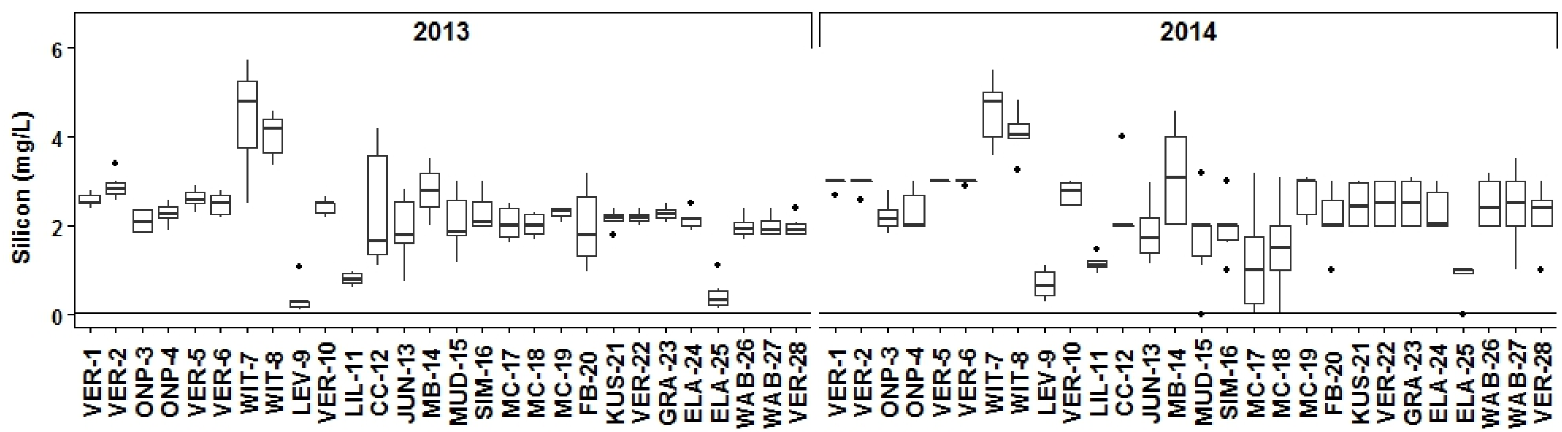

Figure B33 Total silicon concentrations for sites in 2013 and 2014.

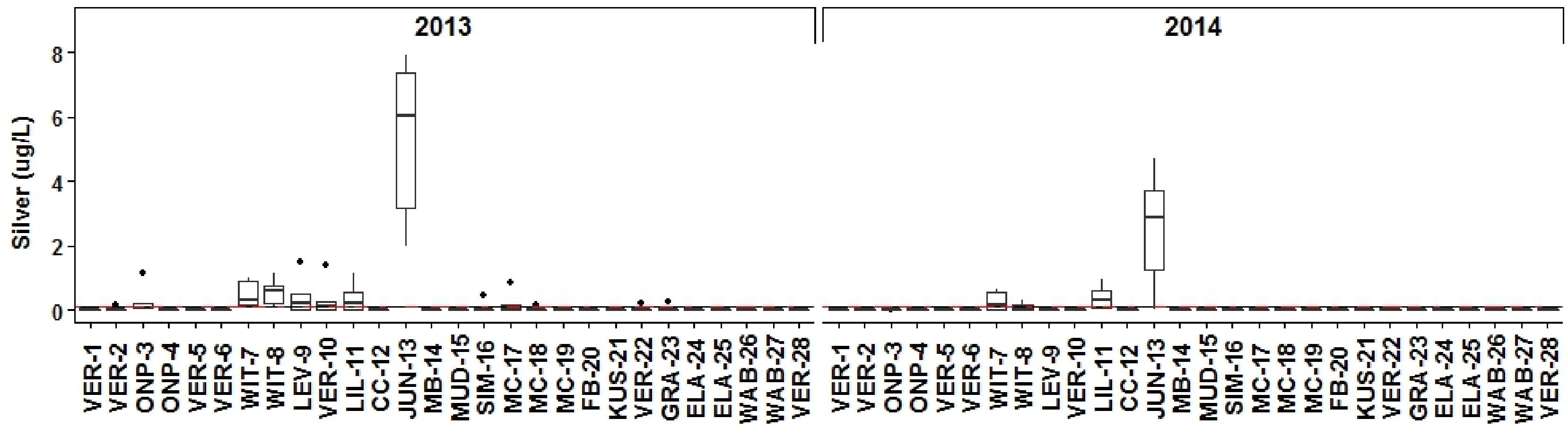

Figure B34 Total silver concentrations for sites in 2013 and 2014.

Note: The long-term water quality guideline for the protection of aquatic life (0.1ug/L, indicated by the red dotted line) was equal to or surpassed by VER-2 on July 19th, 2013, ONP-3 on May 13th, 2013, September 25th, 2013, WIT-7 on May 14th, 2013, August 20th, 2013, September 24th, 2013, October 24th, 2013, June 18th, 2014, August 20th, 2014, September 10th, 2014, WIT-8 on May 13th, 2013, August 19th, 2013, September 25th, 2013, October 23rd, 2013, June 17th, 2014, September 11th, 2014, LEV-9 on May 13th, 2013, September 25th, 2013, October 23rd, 2013, VER-10 on May 13th, 2013, September 25th, 2013, October 23rd, 2013, LIL-11 on May 13th, 2013, June 18th, 2013, September 25th, 2013, June 18th, 2014, August 20th, 2014, September 10th, 2014, October 6th, 2014, JUN-13 on May 13th, 2013, June 17th, 2013, August 20th, 2013, September 24th, 2013, October 23rd, 2013, June 17th, 2014, July 2nd, 2014, August 21st, 2014, September 11th, 2014, October 7th, 2014, SIM-16 on May 28th, 2013, MC-17 on May 29th, 2013, August 13th, 2013, MC-18 on May 28th, 2013, VER-22 on May 28th, 2013, and GRA-23 on May 28th, 2013.

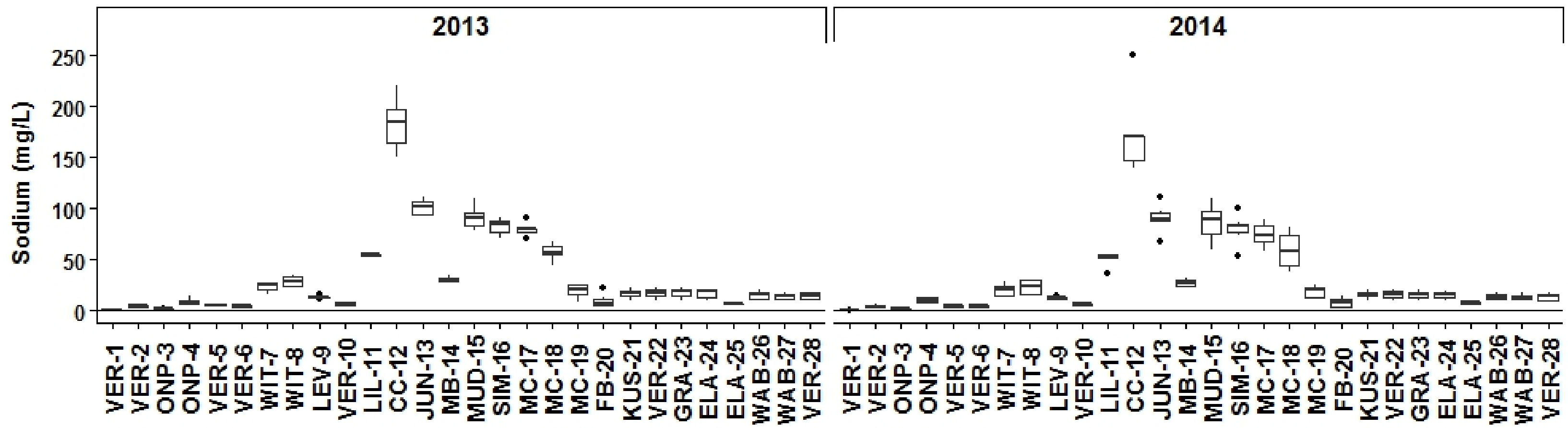

Figure B35 Total sodium concentrations for sites in 2013 and 2014.

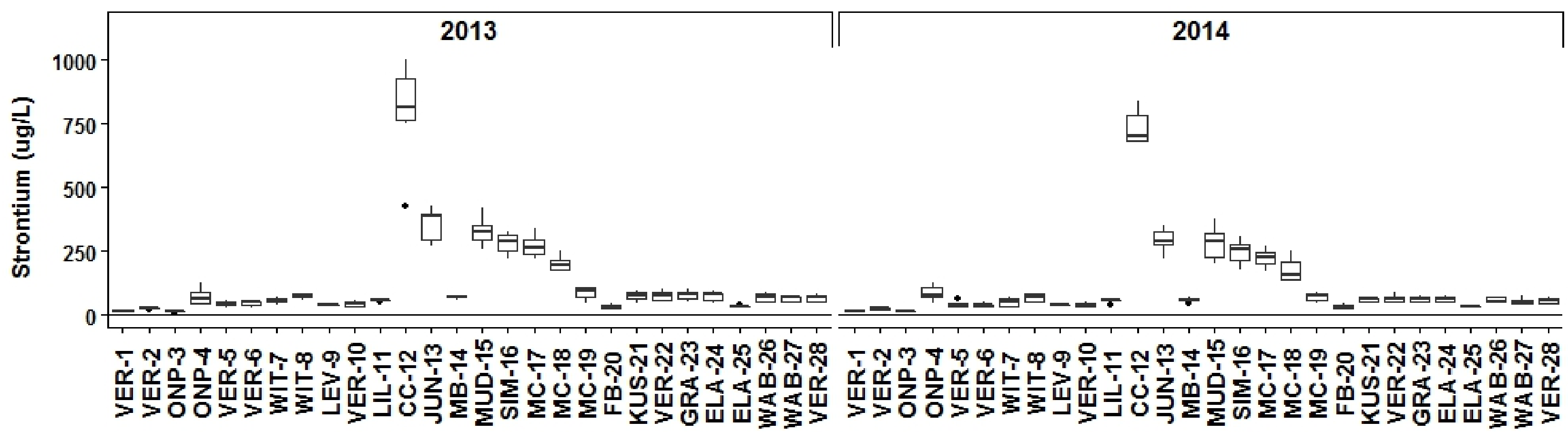

Figure B36 Total strontium concentrations for sites in 2013 and 2014.

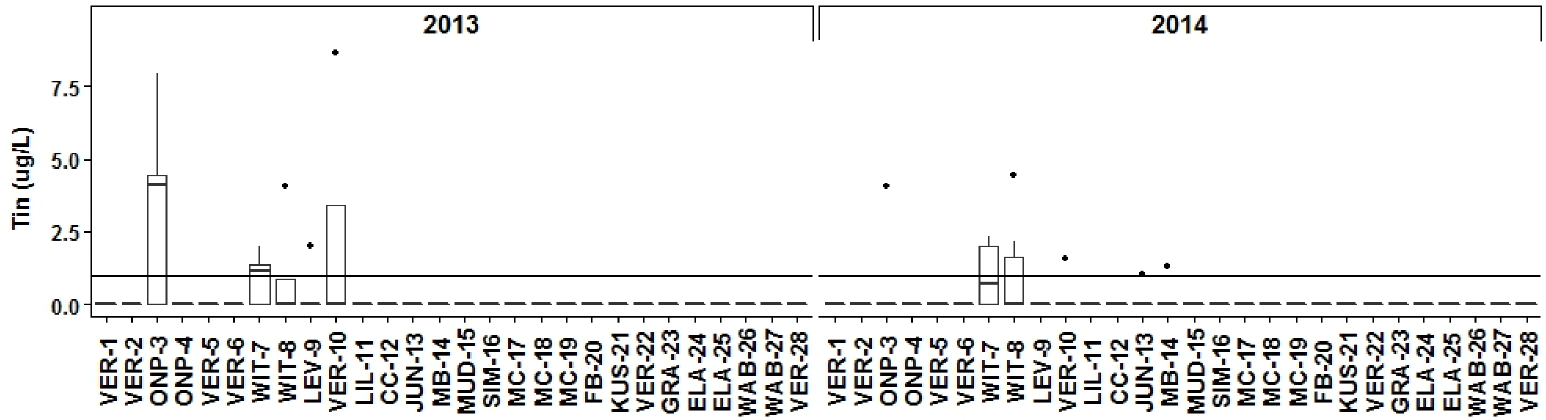

Figure B37 Total tin concentrations for sites in 2013 and 2014.

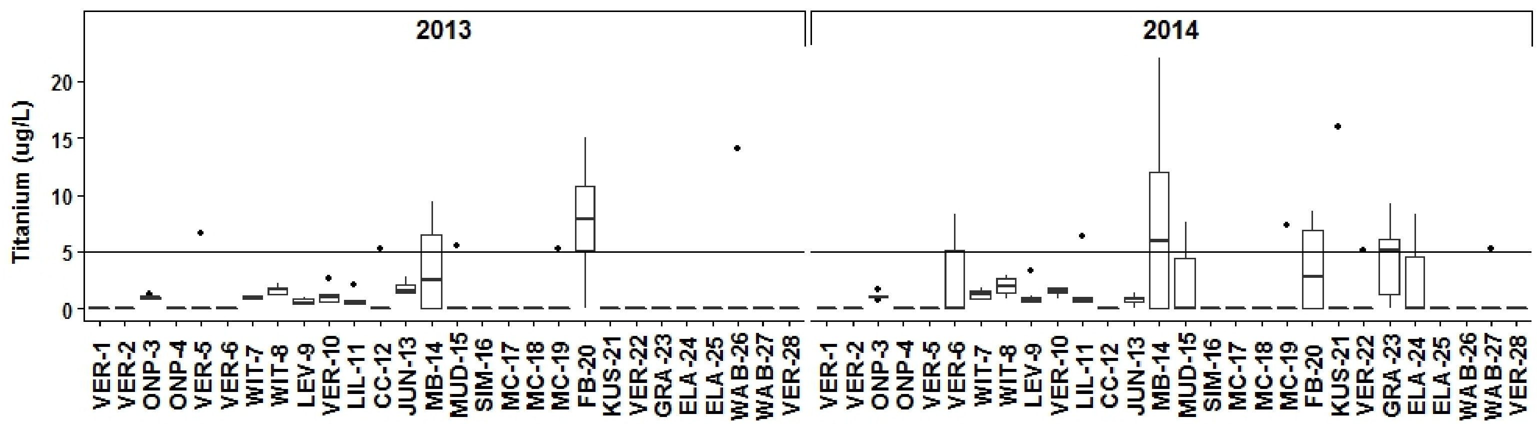

Figure B38 Total titanium concentrations for sites in 2013 and 2014.

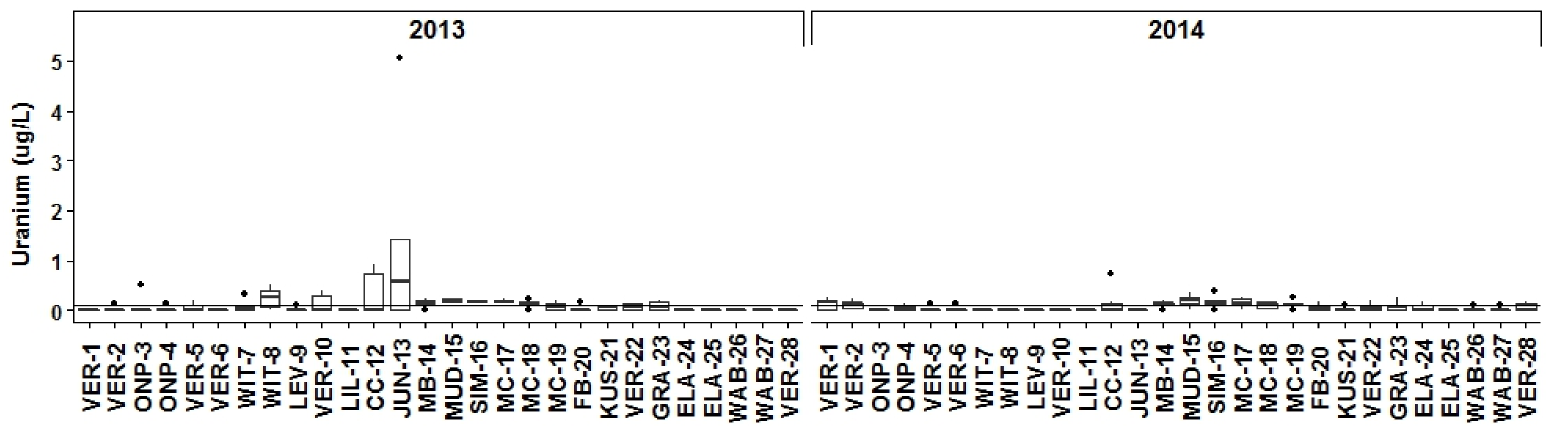

Figure B39 Total uranium concentrations for sites in 2013 and 2014.
Note: All sites were well below the long and short-term water quality guidelines for the protection of aquatic life (15ug/L and 33ug/L, respectively).

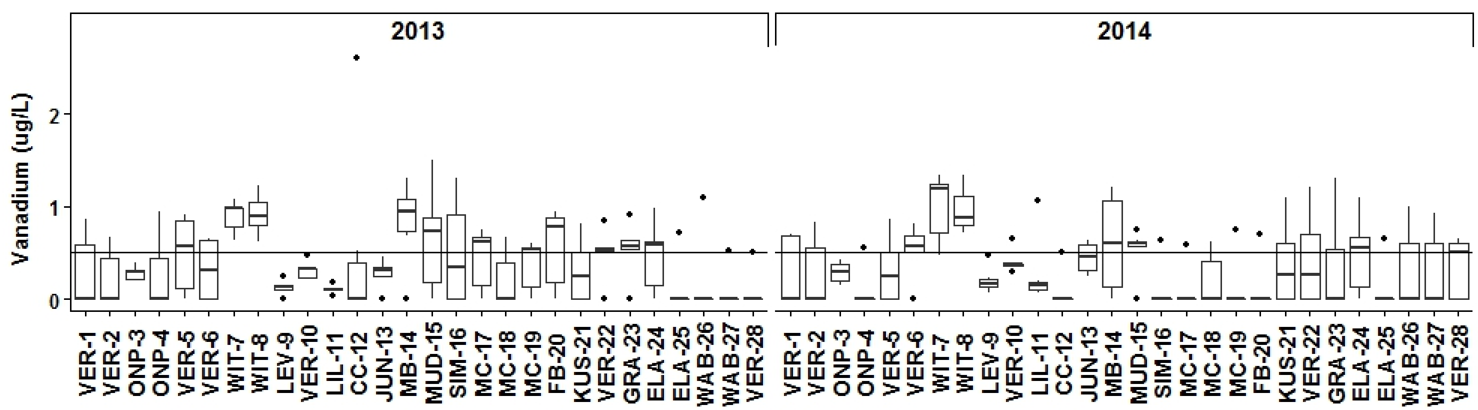

Figure B40 Total vanadium concentrations for sites in 2013 and 2014.

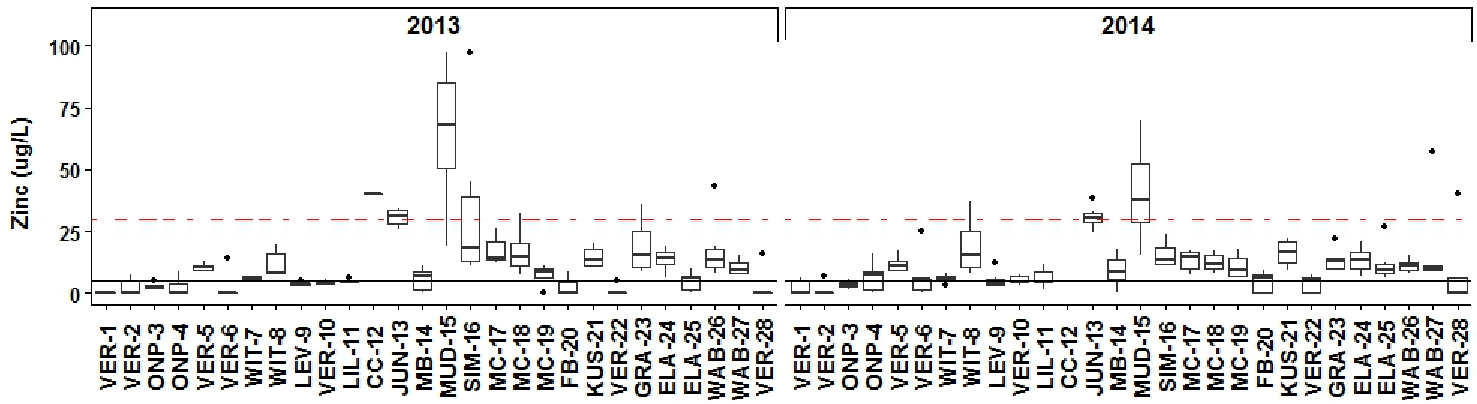

Figure B41 Total zinc concentrations for sites in 2013 and 2014.

Note: The long-term water quality guideline for the protection of aquatic life (30ug/L, indicated by the red dotted line) was equal to or surpassed by WIT-8 on September 11th, 2014, CC-12 on October 8th, 2013, JUN-13 on August 20th, 2013, September 24th, 2013, October 23rd, 2013, July 2nd, 2014, August 21st, 2014, November 5th, 2014, MUD-15 on May 30th, 2013, June 21st, 2013, August 14th, 2013, September 18th, 2013, October 9th, 2013, June 11th, 2014, August 8th, 2014, September 9th, 2014, October 1st, 2014, SIM-16 on May 28th, 2013, June 19th, 2013, MC-18 on August 13th, 2013, GRA-23 on June 21st, 2013, WAB-26 on May 29th, 2013, WAB-27 on June 12th, 2014, and VER-28 on October 9th, 2014.

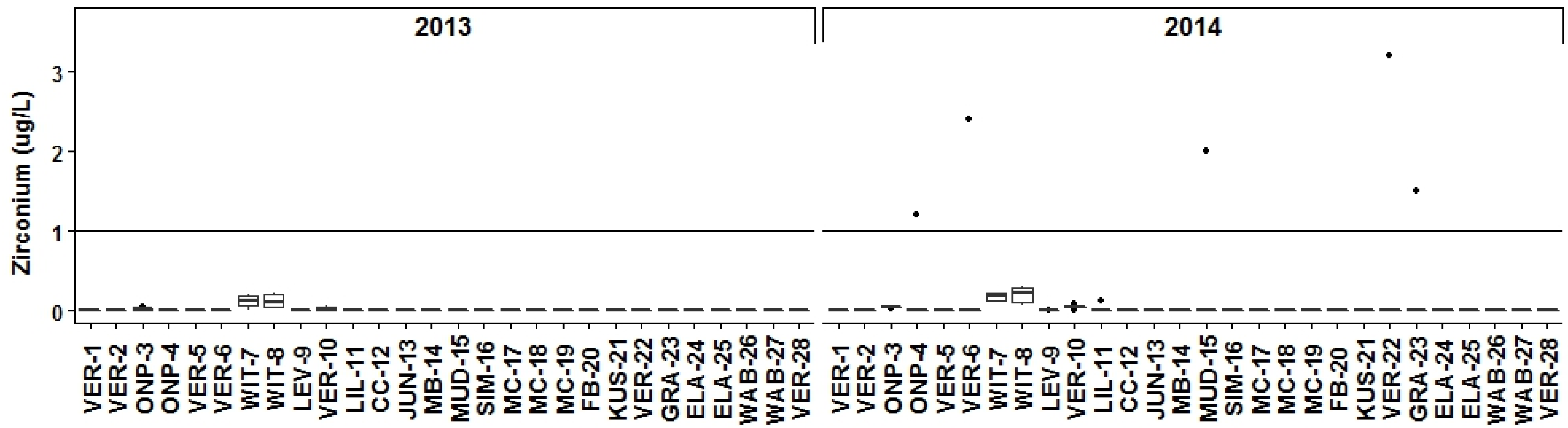

Figure B42 Total zirconium concentrations for sites in 2013 and 2014.
Note: The RDL for the majority of sites was not surpassed (1ug/L, indicated by the black solid line), however PWQMN sites (ONP-3, WIT-7, WIT-8, LEV-9, VER-10, LIL-11, and JUN-13) had a lower RDL.

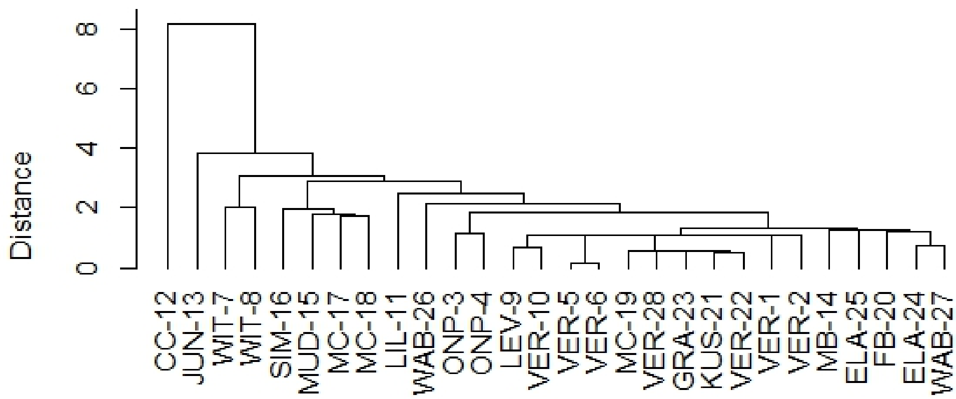

Figure B43 Single-linkage agglomerative cluster analyses performed on the Euclidean distance matrix of the 2013 normalised general biological/chemical parameters and nutrients.

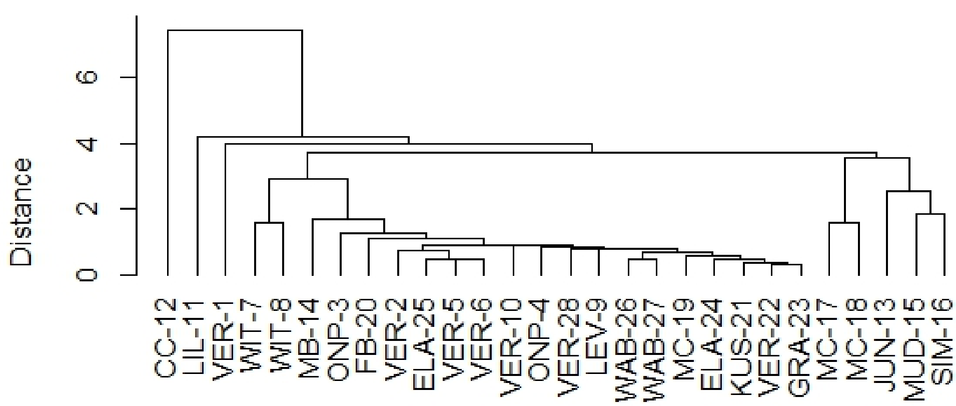

Figure B44 Single-linkage agglomerative cluster analyses performed on the Euclidean distance matrix of the 2014 normalised general biological/chemical parameters and nutrients.

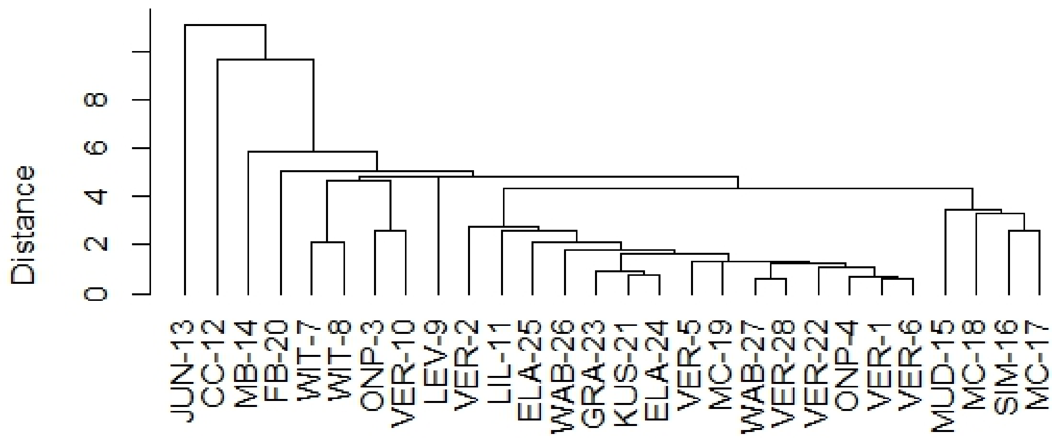

Figure B45 Single-linkage agglomerative cluster analyses performed on the Euclidean distance matrix of the 2013 normalised metals.

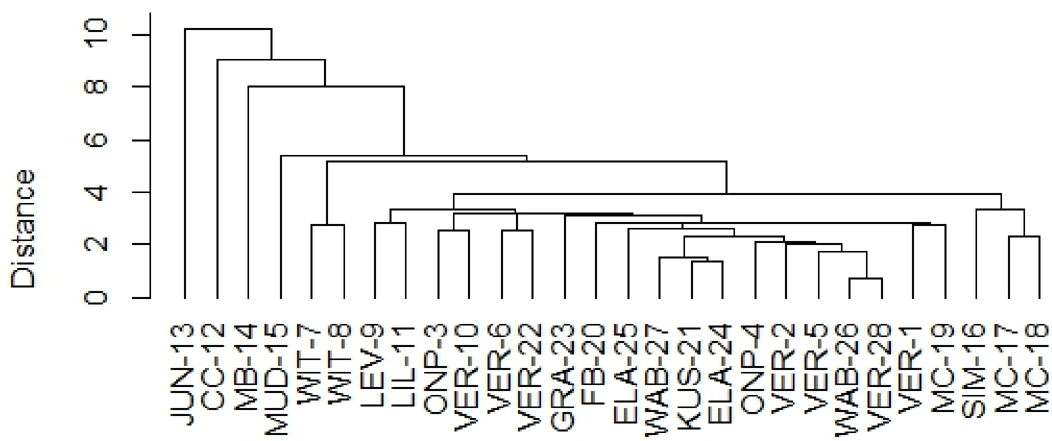

Figure B46 Single-linkage agglomerative cluster analyses performed on the Euclidean distance matrix of the 2013 normalised metals.

Table B16 Site distances from the Sudbury WWTP.

	Distance from Sudbury WWTP (km)
CC-12	-0.42
JUN-13	7.06
MUD-15	16.33
SIM-16	19.75
MC-17	22.10
MC-18	24.11
MC-19	26.63
KUS-21	36.08
VER-22	43.22
GRA-23	43.66
ELA-24	54.26
ELA-25	56.38
WAB-26	61.87
WAB-27	63.90
VER-28	71.92

Note: Distances were calculated for a site located upstream of the WWTP (CC-12), sites located on the main-stem on the Junction tributary (JUN-13, MUD-15, SIM-16, MC-17, MC-18), and lower Vermilion River (MC-19, KUS-21, VER-22, GRA-23, ELA-24, ELA-25, WAB-26, WAB-27, VER-28).

Table B17 Multiple pairwise comparisons to determine if nutrient concentrations at the site upstream of the Sudbury WWTP (CC-12) was significantly different compared to the sites downstream.

	TP		TN		TKN		NO3		NO2	
	2013	**2014**	**2013**	**2014**	**2013**	**2014**	**2013**	**2014**	**2013**	**2014**
JUN-13	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	0.003***	0.004***	<0.001***	<0.001***
MUD-15	0.003***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	0.022**	<0.001***	<0.001***	<0.001***
SIM-16	<0.001***	0.007***	<0.001***	<0.001***	<0.001***	<0.001***	0.693	0.053*	<0.001***	0.015**
MC-17	0.063*	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	0.975	0.388	0.009***	0.046**
MC-18	0.233	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	0.024**	0.055*	0.255	0.189
MC-19	1.000	0.173	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	0.218	0.951
KUS-21	1.000	0.117	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	0.130	0.743
VER-22	1.000	0.179	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	0.108	0.811
GRA-23	1.000	0.053*	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	0.130	0.870
ELA-24	1.000	0.173	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	0.108	0.671
ELA-25	1.000	0.447	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	0.108	0.538
WAB-26	1.000	0.248	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	0.130	0.804
WAB-27	1.000	0.248	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	0.108	0.742
VER-28	1.000	0.457	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	0.108	0.557

*p<0.1, **p<0.05, ***p<0.01

Note: Previous one-way ANOVA analyses revealed that for all nutrients (TP, TN, TKN, NO3, & NO2) in 2013 and in 2014, there was at least one site that was significantly different from the others since all p-values were <0.001. Water quality parameter means calculated using n=6 for both years, with the exception of JUN-13 (n=5 in 2013, July was missing), WAB-26 (n=5 for TP & TN in 2014, June was missing, & n=4 for TKN NO3 & NO2 in 2014, June & September were missing), WAB-27 (n=5 in 2014, September was missing), and VER-28 (n=5 in 2014, July was missing).

Table B18 Spearman correlation analyses performed on land-cover types (area or percent) and annual general biological/chemical parameters and nutrients (2013 or 2014) for buffer (5km-radius), catchment, and reaches (1km, 2km, and 3km-radius) landscape-scales.

5km buffer

		Water		Barren		Developed		Wetland		Herb		Agriculture		Forest	
		2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Area	Chl-a	0.43**	0.38**	-0.24	-0.11	0.01	0.00	0.01	0.00	0.15	0.13	0.04	0.03	-0.04	-0.01
	E.coli	0.22	-0.47**	0.34*	0.06	0.26	0.23	-0.45**	-0.19	0.05	-0.07	0.13	0.19	-0.41**	-0.18
	pH	-0.02	0.23	0.12	0.10	0.40**	0.46**	-0.28	-0.40**	-0.25	-0.22	-0.06	-0.09	-0.31	-0.45**
	CaCO3	0.27	0.22	0.18	0.18	0.39**	0.42**	-0.27	-0.26	-0.09	-0.10	-0.22	-0.20	-0.29	-0.30
	DOC	-0.20	-0.24	-0.04	-0.02	-0.31	-0.38**	0.23	0.22	0.36*	0.38**	0.27	0.17	0.25	0.32
	Cond	0.31	0.29	0.28	0.29	0.60***	0.60***	-0.46**	-0.43**	-0.26	-0.26	-0.29	-0.30	-0.48***	-0.47**
	Cl	0.30	0.25	0.32*	0.31	0.65***	0.67***	-0.47**	-0.43**	-0.27	-0.24	-0.29	-0.28	-0.52***	-0.50***
	TP	0.02	0.21	0.13	-0.06	0.46**	0.28	-0.51***	-0.22	-0.27	-0.18	-0.17	-0.32*	-0.49***	-0.07
	TN	0.12	0.18	0.08	0.13	0.38**	0.54***	-0.09	-0.27	-0.06	-0.16	-0.23	-0.14	-0.19	-0.37**
	TKN	0.24	0.33*	0.07	0.22	0.39**	0.54***	-0.08	-0.27	-0.07	-0.17	-0.23	-0.19	-0.16	-0.35*
	NO3	0.07	0.12	0.22	0.19	0.43**	0.54***	-0.24	-0.34*	-0.16	-0.18	-0.36*	-0.27	-0.33*	-0.41**
	NO2	-0.05	0.17	0.06	0.13	0.57***	0.60***	-0.39**	-0.28	-0.27	-0.18	-0.24	-0.23	-0.47**	-0.50***
Percent	Chl-a	0.43**	0.38**	-0.24	-0.11	0.01	0.00	0.01	0.00	0.15	0.13	0.04	0.03	-0.04	-0.01
	E.coli	0.22	-0.47**	0.34*	0.06	0.26	0.23	-0.45**	-0.19	0.05	-0.07	0.13	0.19	-0.41**	-0.18
	pH	-0.02	0.23	0.12	0.10	0.40**	0.46**	-0.28	-0.40**	-0.25	-0.22	-0.06	-0.09	-0.31	-0.45**
	CaCO3	0.27	0.22	0.18	0.18	0.39**	0.42**	-0.27	-0.26	-0.09	-0.10	-0.22	-0.20	-0.29	-0.30
	DOC	-0.20	-0.24	-0.04	-0.02	-0.31	-0.38**	0.23	0.22	0.36*	0.38**	0.27	0.17	0.25	0.32
	Cond	0.31	0.29	0.28	0.29	0.60***	0.60***	-0.46**	-0.43**	-0.26	-0.26	-0.29	-0.30	-0.48***	-0.47**
	Cl	0.30	0.25	0.32*	0.31	0.65***	0.67***	-0.47**	-0.43**	-0.27	-0.24	-0.29	-0.28	-0.52***	-0.50***
	TP	0.02	0.21	0.13	-0.06	0.46**	0.28	-0.51***	-0.22	-0.27	-0.18	-0.17	-0.32*	-0.49***	-0.07
	TN	0.12	0.18	0.08	0.13	0.38**	0.54***	-0.09	-0.27	-0.06	-0.16	-0.23	-0.14	-0.19	-0.37**
	TKN	0.24	0.33*	0.07	0.22	0.39**	0.54***	-0.08	-0.27	-0.07	-0.17	-0.23	-0.19	-0.16	-0.35*
	NO3	0.07	0.12	0.22	0.19	0.43**	0.54***	-0.24	-0.34*	-0.16	-0.18	-0.36*	-0.27	-0.33*	-0.41**
	NO2	-0.05	0.17	0.06	0.13	0.57***	0.60***	-0.39**	-0.28	-0.27	-0.18	-0.24	-0.23	-0.47**	-0.50***

*p<0.1, **p<0.05, ***p<0.01

Note: All spearman correlation analyses performed using n=28.

Table B18 (cont.)

Catchments		**Water**		**Barren**		**Developed**		**Wetland**		**Herb**		**Agriculture**		**Forest**	
		2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Area	Chl-a	0.13	-0.06	0.54***	0.38**	0.54***	0.37*	-0.25	-0.34*	-0.27	-0.29	-0.09	-0.21	-0.03	-0.14
	E.coli	-0.34*	0.02	-0.21	0.10	-0.16	0.18	-0.25	0.15	-0.28	-0.06	-0.22	0.20	-0.25	-0.01
	pH	-0.32*	-0.21	0.41**	0.59***	0.39**	0.55***	-0.24	-0.30	-0.49***	-0.51***	0.06	0.04	-0.35*	-0.30
	CaCO3	-0.40**	-0.38**	0.40**	0.42**	0.37*	0.40**	-0.63***	-0.59***	-0.69***	-0.67***	-0.40**	-0.35*	-0.52***	-0.49***
	DOC	-0.30	-0.18	-0.33*	-0.24	-0.29	-0.22	0.35*	0.44**	0.22	0.35*	0.30	0.35*	0.10	0.22
	Cond	-0.41**	-0.41**	0.47**	0.46**	0.46**	0.46**	-0.72***	-0.72***	-0.82***	-0.82***	-0.43**	-0.44**	-0.61***	-0.61***
	Cl	-0.47**	-0.46**	0.43**	0.44**	0.43**	0.45**	-0.75***	-0.76***	-0.88***	-0.87***	-0.43**	-0.43**	-0.69***	-0.69***
	TP	0.06	-0.23	0.57***	0.20	0.61***	0.33*	-0.32*	-0.54***	-0.52***	-0.60***	-0.05	-0.38**	-0.16	-0.40**
	TN	-0.33*	-0.37*	0.28	0.36*	0.29	0.40**	-0.62***	-0.59***	-0.60***	-0.65***	-0.43**	-0.32*	-0.45**	-0.46**
	TKN	-0.25	-0.37**	0.22	0.27	0.22	0.29	-0.66***	-0.65***	-0.58***	-0.65***	-0.50***	-0.40**	-0.46**	-0.51***
	NO3	-0.29	-0.29	0.38**	0.43**	0.39**	0.48***	-0.59***	-0.61***	-0.63***	-0.67***	-0.36*	-0.37*	-0.43**	-0.43**
	NO2	0.14	-0.16	0.64***	0.46**	0.65***	0.53***	-0.40**	-0.59***	-0.52***	-0.62***	-0.16	-0.34*	-0.13	-0.38**
Percent	Chl-a	-0.07	-0.19	0.40**	0.43**	0.45**	0.43**	-0.07	-0.04	-0.26	-0.26	-0.14	-0.23	-0.33*	-0.27
	E.coli	-0.08	-0.06	0.19	0.00	0.17	0.13	0.06	-0.09	-0.21	-0.07	-0.08	0.22	-0.18	-0.12
	pH	-0.39**	-0.34*	0.61***	0.68***	0.56***	0.67***	0.00	-0.14	-0.60***	-0.59***	0.12	0.05	-0.58***	-0.68***
	CaCO3	-0.55***	-0.55***	0.80***	0.79***	0.72***	0.72***	-0.28	-0.29	-0.64***	-0.61***	-0.37*	-0.33*	-0.64***	-0.65***
	DOC	-0.14	-0.15	-0.24	-0.32	-0.24	-0.24	0.62***	0.58***	0.29	0.41**	0.39**	0.41**	0.26	0.32
	Cond	-0.49***	-0.48***	0.89***	0.88***	0.84***	0.84***	-0.44**	-0.46**	-0.78***	-0.77***	-0.41**	-0.42**	-0.78***	-0.77***
	Cl	-0.47**	-0.47**	0.92***	0.91***	0.85***	0.87***	-0.44**	-0.48***	-0.82***	-0.80***	-0.39**	-0.39**	-0.82***	-0.80***
	TP	-0.13	-0.37*	0.56***	0.50***	0.68***	0.60***	-0.43**	-0.29	-0.56***	-0.63***	-0.03	-0.32*	-0.67***	-0.37*
	TN	-0.61***	-0.61***	0.65***	0.74***	0.59***	0.71***	-0.40**	-0.34*	-0.53***	-0.61***	-0.40**	-0.27	-0.45**	-0.59***
	TKN	-0.42**	-0.45**	0.58***	0.70***	0.48***	0.63***	-0.42**	-0.33*	-0.48***	-0.57***	-0.47**	-0.34*	-0.41**	-0.56***
	NO3	-0.64***	-0.65***	0.70***	0.74***	0.68***	0.78***	-0.45**	-0.47**	-0.59***	-0.64***	-0.33*	-0.33*	-0.56***	-0.60***
	NO2	-0.33*	-0.60***	0.59***	0.64***	0.64***	0.70***	-0.61***	-0.57***	-0.59***	-0.60***	-0.15	-0.34*	-0.66***	-0.51***

*p<0.1, **p<0.05, ***p<0.01

Note: All spearman correlation analyses performed using n=28.

Table B18 (cont.)

1km reaches

		Water		Barren		Developed		Wetland		Herb		Agriculture		Forest	
		2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Area	Chl-a	0.56***	0.44**	0.05	0.18	0.12	0.00	0.27	0.05	-0.04	0.05	-0.15	-0.17	-0.09	0.00
	E.coli	-0.19	-0.47**	0.20	0.02	0.20	0.41**	-0.44**	0.21	-0.16	0.04	-0.15	0.32*	-0.19	0.11
	pH	-0.03	0.18	0.08	0.04	0.39**	0.42**	0.22	0.18	-0.01	-0.10	0.08	0.00	-0.14	-0.41**
	CaCO3	0.14	0.10	0.26	0.23	0.27	0.29	-0.10	-0.13	-0.05	-0.02	-0.22	-0.18	-0.23	-0.27
	DOC	-0.21	-0.15	-0.19	-0.17	-0.26	-0.36*	0.14	0.18	0.04	0.12	0.08	0.05	0.32*	0.32
	Cond	0.11	0.10	0.24	0.23	0.50***	0.49***	-0.17	-0.19	-0.08	-0.08	-0.22	-0.23	-0.40**	-0.41**
	Cl	0.05	0.01	0.22	0.19	0.57***	0.57***	-0.16	-0.19	-0.13	-0.11	-0.23	-0.20	-0.43**	-0.41**
	TP	-0.14	0.07	0.03	-0.21	0.61***	0.42**	-0.04	-0.15	-0.15	-0.02	0.11	-0.27	-0.26	-0.12
	TN	-0.04	-0.09	0.27	0.21	0.20	0.38**	-0.22	-0.30	0.10	0.02	-0.20	-0.18	-0.19	-0.37*
	TKN	0.03	-0.01	0.25	0.21	0.18	0.34*	-0.30	-0.42**	0.10	-0.03	-0.23	-0.33*	-0.25	-0.46**
	NO3	-0.04	-0.07	0.31	0.26	0.28	0.39**	-0.15	-0.22	0.17	0.13	-0.22	-0.17	-0.23	-0.28
	NO2	-0.24	0.03	0.22	0.16	0.49***	0.42**	-0.05	-0.15	0.19	0.25	0.11	-0.15	-0.29	-0.41**
Percent	Chl-a	0.51***	0.41**	0.05	0.17	0.10	0.03	0.26	0.04	-0.04	0.05	-0.17	-0.19	-0.17	-0.05
	E.coli	-0.09	-0.58***	0.23	0.04	0.20	0.40**	-0.44**	0.22	-0.16	0.04	-0.14	0.33*	-0.13	0.08
	pH	-0.06	0.17	0.06	0.04	0.41**	0.44**	0.24	0.20	-0.01	-0.10	0.07	-0.02	-0.26	-0.50***
	CaCO3	0.13	0.10	0.24	0.22	0.29	0.31	-0.09	-0.13	-0.05	-0.02	-0.23	-0.19	-0.27	-0.30
	DOC	-0.12	-0.03	-0.18	-0.16	-0.26	-0.36*	0.14	0.19	0.04	0.12	0.06	0.04	0.33*	0.38**
	Cond	0.07	0.06	0.23	0.23	0.52***	0.51***	-0.16	-0.18	-0.08	-0.08	-0.24	-0.24	-0.42**	-0.41**
	Cl	0.01	-0.03	0.22	0.19	0.59***	0.59***	-0.16	-0.18	-0.13	-0.11	-0.24	-0.21	-0.44**	-0.41**
	TP	-0.17	0.04	0.06	-0.20	0.61***	0.42**	-0.03	-0.15	-0.15	-0.02	0.10	-0.28	-0.23	-0.01
	TN	-0.06	-0.07	0.27	0.21	0.23	0.41**	-0.22	-0.30	0.10	0.02	-0.20	-0.19	-0.14	-0.30
	TKN	0.01	0.03	0.25	0.21	0.19	0.36*	-0.30	-0.42**	0.10	-0.03	-0.22	-0.33*	-0.22	-0.35*
	NO3	-0.05	-0.07	0.32*	0.27	0.31	0.42**	-0.14	-0.21	0.17	0.13	-0.22	-0.17	-0.13	-0.19
	NO2	-0.25	0.03	0.23	0.18	0.51***	0.45**	-0.04	-0.15	0.19	0.25	0.12	-0.15	-0.26	-0.31

*p<0.1, **p<0.05, ***p<0.01

Note: All spearman correlation analyses performed using n=28.

Table B18 (cont.)

2km reaches		Water		Barren		Developed		Wetland		Herb		Agriculture		Forest	
		2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Area	Chl-a	0.58***	0.44**	0.03	0.18	0.19	0.12	0.25	0.16	0.04	0.09	-0.15	-0.17	-0.13	-0.04
	E.coli	-0.21	-0.42**	0.40**	-0.05	0.13	0.42**	-0.44**	-0.01	-0.26	0.07	-0.15	0.32*	-0.23	0.06
	pH	0.11	0.30	0.02	-0.05	0.36*	0.42**	0.13	-0.02	-0.06	-0.12	0.08	0.00	-0.23	-0.42**
	CaCO3	0.14	0.09	0.20	0.17	0.33*	0.36*	-0.14	-0.18	-0.19	-0.18	-0.22	-0.18	-0.31	-0.32*
	DOC	-0.25	-0.20	-0.03	-0.12	-0.29	-0.39**	0.09	0.10	0.02	0.08	0.08	0.05	0.28	0.31
	Cond	0.11	0.10	0.16	0.13	0.56***	0.55***	-0.26	-0.27	-0.22	-0.24	-0.22	-0.23	-0.46**	-0.46**
	Cl	0.07	0.04	0.19	0.14	0.61***	0.63***	-0.31	-0.33*	-0.26	-0.24	-0.23	-0.20	-0.52***	-0.50***
	TP	-0.06	0.04	-0.09	-0.19	0.67***	0.47**	-0.33*	-0.33*	-0.12	-0.13	0.11	-0.27	-0.33*	-0.21
	TN	-0.12	-0.16	0.31	0.27	0.26	0.43**	-0.19	-0.32*	-0.13	-0.20	-0.20	-0.18	-0.21	-0.37*
	TKN	-0.07	-0.09	0.39**	0.35*	0.27	0.40**	-0.26	-0.44**	-0.10	-0.23	-0.23	-0.33*	-0.32*	-0.50***
	NO3	-0.07	-0.11	0.27	0.21	0.32*	0.44**	-0.23	-0.30	-0.04	-0.07	-0.22	-0.17	-0.20	-0.26
	NO2	-0.21	-0.01	0.14	0.19	0.58***	0.46**	-0.27	-0.25	0.09	0.07	0.11	-0.15	-0.26	-0.31
Percent	Chl-a	0.55***	0.39**	0.04	0.17	0.16	0.09	0.24	0.15	0.05	0.10	-0.16	-0.18	-0.34*	-0.23
	E.coli	-0.17	-0.48***	0.46**	-0.04	0.16	0.39**	-0.44**	-0.01	-0.27	0.07	-0.14	0.34*	-0.13	0.09
	pH	0.08	0.31	0.01	-0.05	0.37*	0.45**	0.14	-0.02	-0.04	-0.11	0.08	0.01	-0.36*	-0.61***
	CaCO3	0.15	0.10	0.19	0.15	0.36*	0.39**	-0.13	-0.18	-0.18	-0.18	-0.21	-0.16	-0.39**	-0.41**
	DOC	-0.22	-0.15	-0.02	-0.11	-0.29	-0.39**	0.10	0.11	0.00	0.06	0.10	0.07	0.37*	0.44**
	Cond	0.13	0.12	0.15	0.12	0.60***	0.59***	-0.26	-0.27	-0.22	-0.23	-0.21	-0.22	-0.56***	-0.55***
	Cl	0.09	0.06	0.19	0.14	0.66***	0.67***	-0.30	-0.33*	-0.25	-0.23	-0.22	-0.18	-0.57***	-0.54***
	TP	-0.06	0.06	-0.07	-0.18	0.69***	0.49***	-0.33*	-0.33*	-0.11	-0.13	0.13	-0.26	-0.37*	-0.16
	TN	-0.11	-0.13	0.30	0.27	0.31	0.48***	-0.19	-0.33*	-0.12	-0.19	-0.20	-0.17	-0.21	-0.40**
	TKN	-0.05	-0.04	0.40**	0.37*	0.32	0.45**	-0.26	-0.43**	-0.08	-0.23	-0.23	-0.31	-0.26	-0.44**
	NO3	-0.07	-0.09	0.25	0.21	0.36*	0.48***	-0.22	-0.30	-0.04	-0.06	-0.22	-0.16	-0.24	-0.29
	NO2	-0.21	0.03	0.17	0.20	0.62***	0.50***	-0.27	-0.25	0.10	0.08	0.11	-0.16	-0.31	-0.39**

*p<0.1, **p<0.05, ***p<0.01

Note: All spearman correlation analyses performed using n=28.

Table B18 (cont.)

3km reaches		Water		Barren		Developed		Wetland		Herb		Agriculture		Forest	
		2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Area	Chl-a	0.55***	0.40**	-0.05	0.06	0.11	0.09	0.20	0.11	0.04	0.05	-0.14	-0.16	-0.02	-0.03
	E.coli	-0.27	-0.36*	0.35*	0.04	0.19	0.41**	-0.48***	-0.04	-0.21	0.08	-0.15	0.33*	-0.27	-0.04
	pH	0.13	0.30	0.04	-0.02	0.37*	0.39**	0.08	-0.08	0.06	-0.05	0.13	0.04	-0.34*	-0.38**
	CaCO3	0.05	0.03	0.17	0.13	0.36*	0.39**	-0.14	-0.19	-0.11	-0.12	-0.21	-0.17	-0.35*	-0.35*
	DOC	-0.21	-0.13	-0.12	-0.18	-0.34*	-0.47**	0.08	0.11	0.16	0.20	0.09	0.07	0.17	0.26
	Cond	0.04	0.03	0.23	0.21	0.59***	0.58***	-0.29	-0.29	-0.20	-0.20	-0.21	-0.22	-0.50***	-0.49***
	Cl	0.00	-0.02	0.28	0.25	0.65***	0.65***	-0.34*	-0.35*	-0.23	-0.20	-0.22	-0.19	-0.57***	-0.54***
	TP	-0.03	0.05	0.00	-0.12	0.61***	0.36*	-0.39**	-0.36*	-0.14	-0.18	0.12	-0.24	-0.44**	-0.22
	TN	-0.21	-0.20	0.18	0.11	0.34*	0.45**	-0.17	-0.32*	-0.12	-0.18	-0.20	-0.16	-0.27	-0.38**
	TKN	-0.17	-0.14	0.21	0.18	0.37**	0.41**	-0.26	-0.43**	-0.21	-0.26	-0.26	-0.32*	-0.36*	-0.46**
	NO3	-0.13	-0.16	0.24	0.16	0.32*	0.43**	-0.21	-0.28	-0.03	-0.06	-0.20	-0.15	-0.29	-0.32*
	NO2	-0.23	-0.03	-0.01	0.13	0.59***	0.42**	-0.32*	-0.22	-0.01	0.01	0.11	-0.12	-0.40**	-0.27
Percent	Chl-a	0.52***	0.33*	-0.10	-0.02	0.11	0.08	0.17	0.10	0.04	0.05	-0.14	-0.16	-0.29	-0.23
	E.coli	-0.22	-0.43**	0.46**	0.04	0.19	0.36*	-0.49***	-0.04	-0.24	0.09	-0.15	0.33*	-0.16	0.00
	pH	0.09	0.30	-0.01	-0.05	0.35*	0.40**	0.11	-0.09	0.07	-0.05	0.13	0.04	-0.31	-0.53***
	CaCO3	0.04	0.00	0.16	0.12	0.34*	0.37*	-0.12	-0.18	-0.08	-0.08	-0.21	-0.17	-0.34*	-0.37*
	DOC	-0.21	-0.12	-0.04	-0.15	-0.30	-0.43**	0.10	0.14	0.19	0.23	0.09	0.07	0.43**	0.53***
	Cond	0.04	0.03	0.21	0.20	0.57***	0.56***	-0.28	-0.28	-0.18	-0.17	-0.21	-0.22	-0.53***	-0.51***
	Cl	0.00	-0.02	0.30	0.25	0.64***	0.64***	-0.33*	-0.34*	-0.20	-0.17	-0.22	-0.19	-0.55***	-0.53***
	TP	0.01	0.06	-0.01	-0.10	0.60***	0.39**	-0.39**	-0.36*	-0.13	-0.13	0.12	-0.24	-0.47**	-0.16
	TN	-0.23	-0.20	0.19	0.15	0.32*	0.44**	-0.17	-0.31	-0.08	-0.15	-0.20	-0.16	-0.25	-0.40**
	TKN	-0.18	-0.11	0.28	0.26	0.36*	0.41**	-0.26	-0.43**	-0.17	-0.23	-0.26	-0.32*	-0.29	-0.43**
	NO3	-0.16	-0.17	0.20	0.13	0.31	0.42**	-0.19	-0.26	0.01	-0.02	-0.20	-0.15	-0.26	-0.30
	NO2	-0.22	-0.05	0.00	0.11	0.57***	0.41**	-0.32	-0.24	0.01	0.04	0.11	-0.12	-0.42**	-0.39**

*p<0.1, **p<0.05, ***p<0.01

Note: All spearman correlation analyses performed using n=28.

Table B19 Spearman correlation analyses performed on land-cover types (area or percent) and annual metals (2013 or 2014) for buffer (5km-radius), catchment, and reaches (1km, 2km, and 3km-radius) landscape-scales.

5km buffers

		Water		**Barren**		**Developed**		**Wetland**		**Herb**		**Agriculture**		**Forest**	
		2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Area	Al	-0.08	-0.09	0.15	0.08	-0.17	-0.17	0.24	0.26	0.12	0.16	-0.03	0.07	0.22	0.24
	Ba	0.14	0.20	0.19	0.23	0.65***	0.63***	-0.40**	-0.43**	-0.37*	-0.35*	-0.23	-0.27	-0.53***	-0.53***
	Be	-0.40**	-0.38**	0.22	0.23	0.03	0.10	-0.34*	-0.36*	0.01	-0.05	0.07	0.08	-0.27	-0.31
	Bi	-0.21	-0.14	0.28	0.05	0.27	-0.09	-0.26	-0.16	-0.27	-0.02	0.04	-0.41**	-0.22	0.12
	Cd	-0.16	-0.12	0.33*	0.29	0.32*	0.44**	-0.47**	-0.59***	-0.14	-0.28	-0.22	-0.17	-0.44**	-0.56***
	Ca	0.27	0.21	0.19	0.18	0.40**	0.40**	-0.26	-0.23	-0.10	-0.11	-0.24	-0.24	-0.28	-0.28
	Cr	-0.39**	-0.29	0.24	0.17	0.11	0.05	-0.36*	-0.25	-0.09	-0.13	0.07	0.18	-0.30	-0.29
	Co	0.06	0.10	0.30	0.34*	0.62***	0.50***	-0.49***	-0.43**	-0.20	-0.21	-0.31	-0.29	-0.49***	-0.43**
	Cu	0.40**	0.23	0.35*	0.32*	0.60***	0.66***	-0.33*	-0.37**	-0.28	-0.27	-0.38**	-0.28	-0.40**	-0.48**
	Fe	-0.43**	-0.51***	-0.02	-0.06	0.19	-0.04	0.08	0.20	0.07	0.23	0.28	0.38**	-0.11	0.08
	Pb	0.11	0.26	-0.13	0.38**	0.11	0.06	0.29	0.08	0.16	0.06	-0.12	-0.23	0.08	0.09
	Li	0.15	0.09	0.10	0.20	0.58***	0.46**	-0.51***	-0.54***	-0.33*	-0.29	-0.27	-0.35*	-0.51***	-0.51***
	Mg	0.24	0.21	0.25	0.24	0.60***	0.59***	-0.41**	-0.38**	-0.23	-0.20	-0.23	-0.24	-0.47**	-0.44**
	Mn	0.25	0.04	-0.11	-0.43**	0.50***	0.22	-0.12	0.19	-0.08	0.19	0.02	0.25	-0.32	-0.01
	Mo	0.05	0.09	0.24	0.23	0.53***	0.54***	-0.64***	-0.48**	-0.34*	-0.31	-0.22	-0.27	-0.65***	-0.50***
	Ni	0.43**	0.38**	0.31	0.30	0.52***	0.51***	-0.31	-0.29	-0.20	-0.16	-0.35*	-0.32*	-0.35*	-0.33*
	K	0.43**	0.38**	0.27	0.23	0.36*	0.36*	-0.22	-0.15	-0.12	-0.16	-0.37*	-0.35*	-0.25	-0.21
	Si	-0.46**	-0.43**	-0.27	-0.18	0.00	-0.15	0.10	0.17	-0.08	-0.05	0.19	0.35*	0.04	0.13
	Ag	-0.31	-0.29	0.08	0.30	0.21	0.22	-0.18	-0.48***	0.10	-0.09	-0.11	0.06	-0.25	-0.48***
	Na	0.31	0.30	0.31	0.31	0.64***	0.64***	-0.45**	-0.44**	-0.25	-0.25	-0.31	-0.30	-0.50***	-0.50***
	Sr	0.24	0.23	0.18	0.16	0.39**	0.41**	-0.19	-0.22	-0.12	-0.17	-0.29	-0.24	-0.23	-0.25
	Sn	-0.44**	-0.45**	0.03	0.21	-0.19	0.03	-0.13	-0.37*	0.19	-0.06	0.13	0.09	-0.04	-0.25
	Ti	-0.03	-0.29	0.30	0.13	0.35*	0.04	-0.38**	0.05	-0.27	0.24	0.13	0.09	-0.42**	0.10
	U	-0.09	0.30	0.13	-0.14	0.39**	0.27	-0.28	0.02	-0.07	-0.21	-0.32	-0.37*	-0.33*	0.03
	V	-0.24	-0.33*	-0.04	0.19	0.24	-0.10	-0.02	-0.06	0.12	-0.07	0.07	0.29	-0.07	-0.04
	Zn	0.50***	0.37*	0.19	-0.01	0.22	-0.05	-0.30	-0.08	-0.05	0.03	-0.23	0.01	-0.34*	-0.07
	Zr		-0.59***		0.09		-0.02		0.14		0.22		0.20		0.08

*p<0.1, **p<0.05, ***p<0.01

Note: All spearman correlation analyses performed using n=28.

Table B19 (cont.)

5km buffers		Water		Barren		Developed		Wetland		Herb		Agriculture		Forest	
		2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Percent	Al	-0.08	-0.09	0.15	0.08	-0.17	-0.17	0.24	0.26	0.12	0.16	-0.03	0.07	0.22	0.24
	Ba	0.14	0.20	0.19	0.23	0.65***	0.63***	-0.40**	-0.43**	-0.37*	-0.35*	-0.23	-0.27	-0.53***	-0.53***
	Be	-0.40**	-0.38**	0.22	0.23	0.03	0.10	-0.34*	-0.36*	0.01	-0.05	0.07	0.08	-0.27	-0.31
	Bi	-0.21	-0.14	0.28	0.05	0.27	-0.09	-0.26	-0.16	-0.27	-0.02	0.04	-0.41**	-0.22	0.12
	Cd	-0.16	-0.12	0.33*	0.29	0.32*	0.44**	-0.47**	-0.59***	-0.14	-0.28	-0.22	-0.17	-0.44**	-0.56***
	Ca	0.27	0.21	0.19	0.18	0.40**	0.40**	-0.26	-0.23	-0.10	-0.11	-0.24	-0.24	-0.28	-0.28
	Cr	-0.39**	-0.29	0.24	0.17	0.11	0.05	-0.36*	-0.25	-0.09	-0.13	0.07	0.18	-0.30	-0.29
	Co	0.06	0.10	0.30	0.34*	0.62***	0.50***	-0.49***	-0.43**	-0.20	-0.21	-0.31	-0.29	-0.49***	-0.43**
	Cu	0.40**	0.23	0.35*	0.32*	0.60***	0.66***	-0.33*	-0.37**	-0.28	-0.27	-0.38**	-0.28	-0.40**	-0.48**
	Fe	-0.43**	-0.51***	-0.02	-0.06	0.19	-0.04	0.08	0.20	0.07	0.23	0.28	0.38**	-0.11	0.08
	Pb	0.11	0.26	-0.13	0.38**	0.11	0.06	0.29	0.08	0.16	0.06	-0.12	-0.23	0.08	0.09
	Li	0.15	0.09	0.10	0.20	0.58***	0.46**	-0.51***	-0.54***	-0.33*	-0.29	-0.27	-0.35*	-0.51***	-0.51***
	Mg	0.24	0.21	0.25	0.24	0.60***	0.59***	-0.41**	-0.38**	-0.23	-0.20	-0.23	-0.24	-0.47**	-0.44**
	Mn	0.25	0.04	-0.11	-0.43**	0.50***	0.22	-0.12	0.19	-0.08	0.19	0.02	0.25	-0.32	-0.01
	Mo	0.05	0.09	0.24	0.23	0.53***	0.54***	-0.64***	-0.48**	-0.34*	-0.31	-0.22	-0.27	-0.65***	-0.50***
	Ni	0.43**	0.38**	0.31	0.30	0.52***	0.51***	-0.31	-0.29	-0.20	-0.16	-0.35*	-0.32*	-0.35*	-0.33*
	K	0.43**	0.38**	0.27	0.23	0.36*	0.36*	-0.22	-0.15	-0.12	-0.16	-0.37*	-0.35*	-0.25	-0.21
	Si	-0.46**	-0.43**	-0.27	-0.18	0.00	-0.15	0.10	0.17	-0.08	-0.05	0.19	0.35*	0.04	0.13
	Ag	-0.31	-0.29	0.08	0.30	0.21	0.22	-0.18	-0.48***	0.10	-0.09	-0.11	0.06	-0.25	-0.48***
	Na	0.31	0.30	0.31	0.31	0.64***	0.64***	-0.45**	-0.44**	-0.25	-0.25	-0.31	-0.30	-0.50***	-0.50***
	Sr	0.24	0.23	0.18	0.16	0.39**	0.41**	-0.19	-0.22	-0.12	-0.17	-0.29	-0.24	-0.23	-0.25
	Sn	-0.44**	-0.45**	0.03	0.21	-0.19	0.03	-0.13	-0.37*	0.19	-0.06	0.13	0.09	-0.04	-0.25
	Ti	-0.03	-0.29	0.30	0.13	0.35*	0.04	-0.38**	0.05	-0.27	0.24	0.13	0.09	-0.42**	0.10
	U	-0.09	0.30	0.13	-0.14	0.39**	0.27	-0.28	0.02	-0.07	-0.21	-0.32	-0.37*	-0.33*	0.03
	V	-0.24	-0.33*	-0.04	0.19	0.24	-0.10	-0.02	-0.06	0.12	-0.07	0.07	0.29	-0.07	-0.04
	Zn	0.50***	0.37*	0.19	-0.01	0.22	-0.05	-0.30	-0.08	-0.05	0.03	-0.23	0.01	-0.34*	-0.07
	Zr		-0.59***		0.09		-0.02		0.14		0.22		0.20		0.08

*p<0.1, **p<0.05, ***p<0.01

Note: All spearman correlation analyses performed using n=28.

Table B19 (cont.)

Catchments		Water		Barren		Developed		Wetland		Herb		Agriculture		Forest	
		2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Area	Al	-0.23	-0.20	-0.45**	-0.41**	-0.50***	-0.38**	0.02	0.10	0.16	0.18	-0.13	-0.02	-0.13	-0.10
	Ba	-0.32*	-0.34*	0.45**	0.48***	0.51***	0.51***	-0.60***	-0.63***	-0.73***	-0.75***	-0.28	-0.30	-0.49***	-0.51***
	Be	0.03	-0.02	0.17	0.18	0.16	0.19	0.29	0.25	0.02	-0.03	0.34*	0.33*	0.11	0.06
	Bi	0.00	0.16	0.30	0.11	0.27	0.12	0.08	-0.05	-0.13	-0.06	0.32*	-0.15	-0.10	0.02
	Cd	-0.25	-0.06	0.35*	0.49***	0.32	0.47**	-0.25	-0.20	-0.53***	-0.47**	-0.03	0.07	-0.35*	-0.20
	Ca	-0.38**	-0.37*	0.40**	0.42**	0.37*	0.39**	-0.63***	-0.60***	-0.68***	-0.67***	-0.42**	-0.37*	-0.50***	-0.49***
	Cr	0.00	0.09	0.23	0.29	0.23	0.27	0.21	0.32	-0.06	0.04	0.32*	0.44**	0.05	0.14
	Co	-0.21	-0.30	0.50***	0.40**	0.49***	0.37*	-0.61***	-0.60***	-0.71***	-0.71***	-0.34*	-0.34*	-0.48**	-0.52***
	Cu	-0.48**	-0.53***	0.29	0.34*	0.28	0.36*	-0.86***	-0.77***	-0.88***	-0.89***	-0.48***	-0.34*	-0.80***	-0.76***
	Fe	-0.15	-0.11	-0.05	-0.14	-0.01	-0.10	0.17	0.39**	0.01	0.24	0.19	0.35*	-0.01	0.14
	Pb	-0.21	-0.64***	-0.08	-0.40**	-0.02	-0.39**	-0.29	-0.43**	-0.21	-0.31	-0.28	-0.39**	-0.30	-0.58***
	Li	-0.02	0.04	0.70***	0.60***	0.68***	0.54***	-0.48***	-0.40**	-0.66***	-0.56***	-0.16	-0.12	-0.30	-0.24
	Mg	-0.45**	-0.45**	0.49***	0.49***	0.48***	0.47**	-0.69***	-0.69***	-0.85***	-0.84***	-0.33*	-0.34*	-0.64***	-0.63***
	Mn	-0.21	-0.11	0.40**	0.43**	0.47**	0.50***	-0.39**	-0.07	-0.50***	-0.26	-0.08	0.23	-0.26	-0.07
	Mo	-0.04	-0.12	0.57***	0.53***	0.53***	0.53***	-0.34*	-0.39**	-0.56***	-0.59***	-0.03	-0.04	-0.24	-0.31
	Ni	-0.40**	-0.39**	0.36*	0.38**	0.33*	0.36*	-0.84***	-0.81***	-0.85***	-0.82***	-0.56***	-0.51***	-0.71***	-0.68***
	K	-0.30	-0.22	0.32*	0.36*	0.27	0.30	-0.73***	-0.68***	-0.63***	-0.59***	-0.57***	-0.48***	-0.53***	-0.46**
	Si	0.14	0.03	0.13	-0.08	0.14	-0.07	0.40**	0.56***	0.27	0.44**	0.31	0.44**	0.32*	0.36*
	Ag	-0.06	-0.12	0.26	0.06	0.34*	0.14	-0.04	0.04	-0.22	-0.19	0.15	0.06	-0.10	-0.08
	Na	-0.47**	-0.47**	0.42**	0.42**	0.43**	0.43**	-0.77***	-0.76***	-0.87***	-0.87***	-0.44**	-0.44**	-0.68***	-0.68***
	Sr	-0.32*	-0.25	0.40**	0.44**	0.36*	0.40**	-0.65***	-0.60***	-0.65***	-0.61***	-0.46**	-0.40**	-0.50***	-0.43**
	Sn	0.11	-0.02	0.14	0.18	0.09	0.17	0.50***	0.29	0.24	0.04	0.48***	0.28	0.32	0.16
	Ti	-0.06	-0.42**	0.23	-0.13	0.22	-0.07	0.03	-0.04	-0.16	-0.16	0.23	0.03	-0.07	-0.32*
	U	-0.08	0.02	0.52***	0.09	0.50***	0.14	-0.41**	-0.51***	-0.53***	-0.32*	-0.21	-0.45**	-0.27	-0.21
	V	-0.32*	-0.26	0.13	-0.04	0.18	-0.02	-0.11	0.26	-0.27	0.10	-0.01	0.27	-0.24	0.02
	Zn	-0.22	-0.15	0.36*	0.26	0.35*	0.28	-0.47**	-0.26	-0.52***	-0.30	-0.32	-0.17	-0.31	-0.12
	Zr		-0.03		0.01		0.02		0.27		0.20		0.26		0.10

*p<0.1, **p<0.05, ***p<0.01

Note: All spearman correlation analyses performed using n=28.

Table B19 (cont.)

Catchments		**Water**		**Barren**		**Developed**		**Wetland**		**Herb**		**Agriculture**		**Forest**	
		2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Percent	Al	-0.17	-0.01	-0.27	-0.33*	-0.38**	-0.34*	0.05	0.16	0.33*	0.33*	-0.16	-0.07	0.40**	0.42**
	Ba	-0.60***	-0.59***	0.79***	0.83***	0.81***	0.81***	-0.45**	-0.45**	-0.77***	-0.77***	-0.24	-0.27	-0.68***	-0.72***
	Be	0.03	0.02	0.03	0.08	0.13	0.19	0.15	0.13	-0.01	-0.07	0.37*	0.36*	-0.22	-0.26
	Bi	0.09	0.02	0.19	0.03	0.27	0.15	0.05	-0.21	-0.18	-0.15	0.33*	-0.15	-0.33*	-0.09
	Cd	-0.34*	-0.18	0.55***	0.54***	0.54***	0.60***	-0.15	-0.28	-0.51***	-0.52***	0.00	0.09	-0.61***	-0.68***
	Ca	-0.54***	-0.56***	0.78***	0.79***	0.71***	0.71***	-0.32	-0.31	-0.61***	-0.61***	-0.40**	-0.35*	-0.62***	-0.64***
	Cr	0.00	0.01	0.12	0.06	0.23	0.16	0.10	0.13	-0.11	-0.01	0.34*	0.41**	-0.29	-0.22
	Co	-0.39**	-0.45**	0.75***	0.72***	0.77***	0.70***	-0.58***	-0.46**	-0.64***	-0.62***	-0.31	-0.32	-0.74***	-0.66***
	Cu	-0.29	-0.45**	0.87***	0.87***	0.77***	0.83***	-0.48***	-0.42**	-0.78***	-0.81***	-0.41**	-0.27	-0.72***	-0.75***
	Fe	-0.46**	-0.33*	-0.06	-0.27	-0.06	-0.23	0.01	0.26	0.11	0.35*	0.17	0.33*	0.08	0.28
	Pb	-0.43**	-0.26	0.13	0.21	0.06	0.09	-0.13	0.08	-0.12	-0.14	-0.27	-0.32	0.10	0.01
	Li	-0.28	-0.17	0.81***	0.68***	0.81***	0.67***	-0.49***	-0.47**	-0.75***	-0.61***	-0.14	-0.10	-0.86***	-0.77***
	Mg	-0.53***	-0.55***	0.93***	0.92***	0.88***	0.86***	-0.38**	-0.39**	-0.82***	-0.80***	-0.27	-0.29	-0.81***	-0.80***
	Mn	-0.47**	-0.42**	0.56***	0.33*	0.54***	0.40**	-0.23	0.07	-0.48***	-0.25	-0.03	0.25	-0.47**	-0.24
	Mo	-0.18	-0.16	0.64***	0.71***	0.66***	0.72***	-0.41**	-0.31	-0.63***	-0.65***	-0.02	0.02	-0.76***	-0.80***
	Ni	-0.35*	-0.38**	0.86***	0.84***	0.76***	0.77***	-0.49***	-0.46**	-0.75***	-0.72***	-0.52***	-0.46**	-0.70***	-0.68***
	K	-0.36*	-0.28	0.71***	0.69***	0.61***	0.59***	-0.45**	-0.49***	-0.54***	-0.50***	-0.58***	-0.49***	-0.53***	-0.56***
	Si	-0.60***	-0.45**	-0.23	-0.41**	-0.15	-0.34*	0.02	0.32	0.17	0.34*	0.21	0.36*	0.26	0.44**
	Ag	-0.16	0.00	0.23	0.18	0.42**	0.27	-0.11	-0.02	-0.20	-0.19	0.18	0.08	-0.29	-0.31
	Na	-0.47**	-0.48**	0.92***	0.92***	0.87***	0.85***	-0.45**	-0.46**	-0.81***	-0.81***	-0.40**	-0.40**	-0.80***	-0.81***
	Sr	-0.52***	-0.45**	0.74***	0.71***	0.65***	0.64***	-0.42**	-0.46**	-0.56***	-0.53***	-0.47**	-0.42**	-0.57***	-0.59***
	Sn	-0.06	-0.28	-0.15	0.03	-0.07	0.13	0.32*	0.11	0.19	-0.01	0.50***	0.28	-0.03	-0.15
	Ti	0.02	-0.31	0.21	0.08	0.24	0.13	-0.05	0.23	-0.21	-0.03	0.26	0.05	-0.34*	0.02
	U	-0.52***	-0.28	0.62***	0.28	0.62***	0.27	-0.51***	-0.52***	-0.49***	-0.36*	-0.22	-0.43**	-0.59***	-0.12
	V	-0.69***	-0.44**	0.25	-0.06	0.31	0.03	-0.07	0.36*	-0.17	0.11	-0.02	0.22	-0.12	0.14
	Zn	-0.37**	-0.26	0.58***	0.39**	0.53***	0.37*	-0.15	0.07	-0.48**	-0.28	-0.32	-0.19	-0.48***	-0.27
	Zr		-0.13		-0.20		-0.03		0.05		0.33*		0.19		0.15

*p<0.1, **p<0.05, ***p<0.01

Note: All spearman correlation analyses performed using n=28.

Table B19 (cont.)

1km reaches

		Water		Barren		Developed		Wetland		Herb		Agriculture		Forest	
		2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Area	Al	-0.24	-0.07	0.16	-0.08	-0.30	-0.16	-0.08	0.14	0.00	0.00	-0.20	-0.08	0.07	0.13
	Ba	-0.08	0.01	0.16	0.21	0.56***	0.51***	-0.20	-0.16	0.03	0.00	-0.09	-0.14	-0.37*	-0.44**
	Be	-0.25	-0.22	-0.01	-0.05	0.27	0.33*	0.27	0.25	-0.04	-0.08	0.27	0.28	0.09	0.01
	Bi	-0.06	0.14	0.02	0.06	0.41**	0.15	0.24	0.20	-0.21	0.23	0.17	-0.13	-0.17	0.24
	Cd	-0.18	-0.26	0.12	0.13	0.50***	0.59***	0.18	0.09	-0.10	-0.15	0.06	0.11	-0.11	-0.23
	Ca	0.16	0.12	0.27	0.25	0.25	0.27	-0.13	-0.11	0.00	-0.02	-0.24	-0.20	-0.26	-0.26
	Cr	-0.21	-0.10	0.02	0.03	0.34*	0.28	0.26	0.36*	-0.11	-0.16	0.25	0.24	0.01	-0.06
	Co	-0.21	-0.15	0.21	0.21	0.55***	0.44**	-0.21	-0.18	0.03	-0.09	-0.06	-0.07	-0.36*	-0.27
	Cu	0.04	-0.09	0.22	0.11	0.52***	0.62***	-0.25	-0.16	-0.15	-0.19	-0.37*	-0.18	-0.36*	-0.35*
	Fe	-0.58***	-0.49***	0.03	-0.01	0.18	0.02	0.06	0.23	0.01	0.05	0.29	0.35*	-0.06	0.15
	Pb	0.08	0.12	0.08	0.18	-0.02	-0.11	0.02	-0.20	0.42**	-0.03	-0.20	-0.48***	0.00	-0.03
	Li	-0.04	-0.14	0.20	0.20	0.61***	0.52***	0.01	-0.02	-0.06	-0.09	-0.04	-0.04	-0.38**	-0.32*
	Mg	0.00	-0.01	0.20	0.20	0.56***	0.53***	-0.08	-0.08	-0.12	-0.09	-0.18	-0.15	-0.32*	-0.30
	Mn	-0.12	-0.11	-0.02	-0.27	0.35*	0.31	-0.14	0.24	0.05	0.05	-0.08	0.23	-0.42**	-0.01
	Mo	-0.22	-0.15	0.10	0.08	0.61***	0.59***	0.03	-0.08	-0.21	-0.05	0.08	-0.05	-0.37*	-0.36*
	Ni	0.20	0.19	0.29	0.27	0.42**	0.41**	-0.19	-0.16	-0.07	-0.05	-0.36*	-0.32*	-0.29	-0.26
	K	0.33*	0.26	0.36*	0.37*	0.14	0.12	-0.21	-0.20	0.04	0.02	-0.41**	-0.36*	-0.31	-0.30
	Si	-0.37*	-0.27	-0.03	-0.07	0.00	-0.17	0.24	0.31	0.10	0.04	0.38**	0.32	0.02	0.07
	Ag	-0.12	-0.16	-0.24	-0.04	0.38**	0.42**	0.10	-0.05	0.12	-0.04	0.21	0.18	-0.01	-0.12
	Na	0.05	0.05	0.21	0.21	0.55***	0.54***	-0.23	-0.21	-0.08	-0.11	-0.26	-0.25	-0.42**	-0.43**
	Sr	0.15	0.09	0.29	0.30	0.22	0.22	-0.12	-0.14	0.00	-0.05	-0.25	-0.18	-0.28	-0.31
	Sn	-0.34*	-0.40**	-0.03	0.20	0.02	0.20	0.40**	0.17	0.02	-0.04	0.34*	0.19	0.27	0.05
	Ti	-0.31	-0.17	0.23	-0.01	0.40**	0.23	0.15	0.32*	-0.18	-0.01	-0.08	0.05	-0.28	0.22
	U	-0.22	-0.09	0.33*	0.09	0.39**	0.09	0.07	-0.40**	0.13	0.19	-0.13	-0.29	-0.17	-0.11
	V	-0.39**	-0.19	0.01	0.04	0.33*	0.01	0.09	0.24	-0.07	-0.19	0.05	0.16	-0.06	0.14
	Zn	0.41**	0.48***	0.22	0.19	0.17	0.00	-0.03	0.08	0.06	-0.09	-0.37*	-0.19	-0.35*	-0.07
	Zr		-0.37*		-0.26		0.00		0.18		0.00		0.46**		0.15

*p<0.1, **p<0.05, ***p<0.01

Note: All spearman correlation analyses performed using n=28.

Table B19 (cont.)

1km reaches															
		Water		**Barren**		**Developed**		**Wetland**		**Herb**		**Agriculture**		**Forest**	
		2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Percent	Al	-0.21	-0.10	0.18	-0.06	-0.28	-0.18	-0.09	0.13	0.00	0.00	-0.20	-0.09	0.18	0.17
	Ba	-0.11	-0.02	0.16	0.22	0.59***	0.54***	-0.20	-0.16	0.03	0.00	-0.09	-0.15	-0.33*	-0.40**
	Be	-0.27	-0.26	0.01	-0.04	0.26	0.33*	0.29	0.26	-0.04	-0.08	0.26	0.26	0.04	-0.05
	Bi	-0.09	0.08	0.02	0.04	0.40**	0.11	0.25	0.23	-0.21	0.23	0.17	-0.14	-0.22	0.17
	Cd	-0.25	-0.29	0.15	0.15	0.50***	0.60***	0.18	0.10	-0.10	-0.15	0.05	0.10	-0.16	-0.21
	Ca	0.15	0.11	0.26	0.24	0.28	0.29	-0.13	-0.10	0.00	-0.02	-0.25	-0.21	-0.28	-0.29
	Cr	-0.25	-0.14	0.03	0.05	0.34*	0.27	0.27	0.37*	-0.11	-0.16	0.24	0.22	-0.05	-0.13
	Co	-0.22	-0.17	0.22	0.24	0.57***	0.46**	-0.20	-0.18	0.03	-0.09	-0.06	-0.07	-0.30	-0.22
	Cu	0.01	-0.11	0.23	0.12	0.52***	0.64***	-0.25	-0.16	-0.15	-0.19	-0.37*	-0.19	-0.30	-0.31
	Fe	-0.60***	-0.53***	0.06	0.02	0.19	0.02	0.06	0.22	0.01	0.05	0.29	0.35*	-0.03	0.13
	Pb	0.00	0.14	0.08	0.19	0.01	-0.09	0.02	-0.20	0.42**	-0.03	-0.19	-0.48***	0.01	0.06
	Li	-0.08	-0.15	0.19	0.22	0.62***	0.52***	0.02	-0.01	-0.06	-0.09	-0.05	-0.05	-0.41**	-0.28
	Mg	-0.02	-0.03	0.20	0.20	0.58***	0.55***	-0.07	-0.08	-0.12	-0.09	-0.19	-0.16	-0.34*	-0.32
	Mn	-0.05	-0.10	0.00	-0.26	0.37**	0.32*	-0.14	0.24	0.05	0.05	-0.09	0.21	-0.34*	-0.05
	Mo	-0.20	-0.13	0.13	0.08	0.63***	0.59***	0.04	-0.07	-0.21	-0.05	0.06	-0.07	-0.37*	-0.34*
	Ni	0.17	0.17	0.28	0.27	0.43**	0.43**	-0.19	-0.16	-0.07	-0.05	-0.36*	-0.32*	-0.30	-0.25
	K	0.31	0.25	0.35*	0.36*	0.16	0.14	-0.21	-0.20	0.04	0.02	-0.42**	-0.36*	-0.30	-0.28
	Si	-0.39**	-0.24	-0.01	-0.06	0.04	-0.13	0.25	0.31	0.10	0.04	0.38**	0.30	0.01	0.04
	Ag	-0.13	-0.24	-0.24	-0.03	0.38**	0.42**	0.11	-0.05	0.12	-0.04	0.20	0.16	0.01	-0.17
	Na	0.01	0.02	0.21	0.21	0.57***	0.56***	-0.23	-0.21	-0.08	-0.11	-0.27	-0.26	-0.40**	-0.42**
	Sr	0.12	0.08	0.29	0.30	0.24	0.24	-0.12	-0.14	0.00	-0.05	-0.26	-0.18	-0.30	-0.32*
	Sn	-0.30	-0.41**	-0.01	0.22	0.02	0.23	0.42**	0.18	0.02	-0.04	0.32*	0.17	0.24	0.08
	Ti	-0.25	-0.27	0.26	0.01	0.39**	0.21	0.17	0.31	-0.18	-0.01	-0.09	0.03	-0.23	0.17
	U	-0.26	-0.05	0.35*	0.09	0.42**	0.11	0.08	-0.39**	0.13	0.19	-0.14	-0.27	-0.11	0.06
	V	-0.41**	-0.20	0.04	0.06	0.35*	0.03	0.09	0.22	-0.07	-0.19	0.03	0.13	-0.01	0.17
	Zn	0.42**	0.44**	0.24	0.19	0.18	-0.01	-0.03	0.07	0.06	-0.09	-0.38**	-0.21	-0.36*	-0.16
	Zr		-0.37*		-0.24		-0.02		0.18		0.00		0.45**		0.19

*p<0.1, **p<0.05, ***p<0.01

Note: All spearman correlation analyses performed using n=28.

Table B19 (cont.)

2km Reaches															
		Water		**Barren**		**Developed**		**Wetland**		**Herb**		**Agriculture**		**Forest**	
		2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Area	Al	-0.37*	-0.18	0.34*	0.10	-0.32*	-0.17	-0.04	0.14	-0.08	0.04	-0.20	-0.08	0.08	0.15
	Ba	-0.09	0.01	0.14	0.20	0.57***	0.55***	-0.23	-0.27	-0.14	-0.16	-0.09	-0.14	-0.37*	-0.42**
	Be	-0.09	-0.08	-0.18	-0.22	0.20	0.26	0.02	0.01	0.08	0.02	0.27	0.28	0.05	-0.01
	Bi	0.12	0.15	-0.01	-0.19	0.36*	0.07	-0.04	0.06	-0.07	0.22	0.17	-0.13	-0.24	0.30
	Cd	-0.05	-0.10	0.03	-0.02	0.46**	0.57***	-0.11	-0.23	-0.05	-0.08	0.06	0.11	-0.20	-0.29
	Ca	0.13	0.11	0.20	0.18	0.32*	0.33*	-0.16	-0.17	-0.17	-0.19	-0.24	-0.20	-0.31	-0.30
	Cr	-0.05	0.07	-0.14	-0.12	0.28	0.21	0.02	0.12	-0.02	-0.06	0.25	0.24	-0.03	-0.07
	Co	-0.17	-0.11	0.12	0.18	0.64***	0.53***	-0.47**	-0.42**	-0.05	-0.13	-0.06	-0.07	-0.43**	-0.41**
	Cu	0.08	-0.03	0.34*	0.21	0.54***	0.63***	-0.36*	-0.35*	-0.21	-0.23	-0.37*	-0.18	-0.55***	-0.49***
	Fe	-0.69***	-0.61***	0.17	0.14	0.18	0.01	-0.04	0.15	-0.07	0.04	0.29	0.35*	0.04	0.22
	Pb	-0.03	0.04	0.22	0.36*	-0.04	-0.17	0.20	-0.10	0.23	-0.20	-0.20	-0.48***	0.04	-0.05
	Li	0.05	-0.01	0.06	0.09	0.66***	0.53***	-0.23	-0.32	-0.09	-0.05	-0.04	-0.04	-0.42**	-0.41**
	Mg	0.07	0.04	0.16	0.16	0.58***	0.57***	-0.22	-0.23	-0.20	-0.17	-0.18	-0.15	-0.41**	-0.39**
	Mn	-0.21	-0.17	0.21	-0.05	0.43**	0.39**	-0.29	0.14	-0.11	0.13	-0.08	0.23	-0.43**	-0.08
	Mo	-0.08	-0.06	0.04	0.05	0.61***	0.58***	-0.28	-0.27	-0.11	-0.09	0.08	-0.05	-0.44**	-0.42**
	Ni	0.23	0.23	0.29	0.27	0.48***	0.47**	-0.28	-0.28	-0.14	-0.11	-0.36*	-0.32*	-0.42**	-0.37*
	K	0.28	0.24	0.31	0.31	0.22	0.22	-0.19	-0.22	-0.13	-0.14	-0.41**	-0.36*	-0.35*	-0.33*
	Si	-0.49***	-0.38**	-0.07	-0.01	0.01	-0.20	0.19	0.28	0.03	-0.01	0.38**	0.32	0.22	0.26
	Ag	0.00	-0.09	-0.38**	-0.21	0.32*	0.38**	-0.10	-0.15	0.16	-0.04	0.21	0.18	-0.05	-0.14
	Na	0.05	0.06	0.18	0.17	0.59***	0.59***	-0.33*	-0.33*	-0.24	-0.26	-0.26	-0.25	-0.50***	-0.51***
	Sr	0.10	0.05	0.23	0.22	0.32*	0.34*	-0.18	-0.23	-0.17	-0.22	-0.25	-0.18	-0.32*	-0.36*
	Sn	-0.21	-0.37*	-0.18	0.04	-0.04	0.17	0.16	-0.02	0.17	-0.05	0.34*	0.19	0.27	0.08
	Ti	-0.23	-0.20	0.31	0.14	0.32*	0.19	-0.12	0.20	-0.20	0.08	-0.08	0.05	-0.26	0.20
	U	-0.20	-0.22	0.19	0.15	0.43**	0.15	-0.18	-0.30	0.02	0.02	-0.13	-0.29	-0.15	-0.07
	V	-0.48***	-0.21	0.04	0.10	0.29	0.00	-0.04	0.21	-0.17	-0.13	0.05	0.16	0.00	0.16
	Zn	0.35*	0.41**	0.27	0.20	0.20	0.06	-0.06	0.15	-0.10	-0.19	-0.37*	-0.19	-0.31	-0.05
	Zr		-0.33*		-0.38**		0.07		0.03		0.17		0.46**		0.26

*p<0.1, **p<0.05, ***p<0.01

Note: All spearman correlation analyses performed using n=28.

Table B19 (cont.)

2km reaches															
		Water		**Barren**		**Developed**		**Wetland**		**Herb**		**Agriculture**		**Forest**	
		2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Percent	Al	-0.33*	-0.14	0.35*	0.08	-0.32*	-0.21	-0.03	0.14	-0.10	0.02	-0.20	-0.09	0.29	0.26
	Ba	-0.06	0.03	0.12	0.17	0.61***	0.59***	-0.23	-0.27	-0.13	-0.15	-0.09	-0.13	-0.45**	-0.52***
	Be	-0.14	-0.12	-0.18	-0.23	0.17	0.24	0.02	0.00	0.07	0.00	0.29	0.29	-0.03	-0.10
	Bi	0.06	0.08	-0.02	-0.21	0.33*	0.06	-0.03	0.07	-0.07	0.20	0.19	-0.13	-0.26	0.19
	Cd	-0.09	-0.13	0.01	-0.01	0.47**	0.58***	-0.10	-0.23	-0.06	-0.08	0.08	0.13	-0.30	-0.37*
	Ca	0.15	0.11	0.19	0.16	0.35*	0.37*	-0.15	-0.16	-0.16	-0.18	-0.23	-0.18	-0.39**	-0.39**
	Cr	-0.10	0.01	-0.14	-0.12	0.24	0.17	0.01	0.13	-0.03	-0.07	0.27	0.26	-0.12	-0.21
	Co	-0.16	-0.10	0.14	0.18	0.69***	0.58**	-0.47**	-0.40**	-0.06	-0.13	-0.04	-0.05	-0.40**	-0.36*
	Cu	0.11	0.00	0.34*	0.21	0.58***	0.67***	-0.34*	-0.33*	-0.21	-0.23	-0.36*	-0.17	-0.47**	-0.48***
	Fe	-0.68***	-0.62***	0.16	0.11	0.18	-0.01	-0.05	0.15	-0.08	0.02	0.31	0.37*	0.07	0.26
	Pb	-0.05	0.07	0.21	0.33*	-0.01	-0.17	0.22	-0.08	0.24	-0.21	-0.22	-0.48***	0.06	0.08
	Li	0.03	-0.02	0.07	0.11	0.68***	0.57***	-0.23	-0.32	-0.08	-0.05	-0.03	-0.03	-0.54***	-0.44**
	Mg	0.06	0.04	0.15	0.15	0.62***	0.61***	-0.21	-0.22	-0.20	-0.16	-0.16	-0.14	-0.51***	-0.48***
	Mn	-0.13	-0.15	0.25	-0.05	0.50***	0.41**	-0.29	0.13	-0.10	0.13	-0.06	0.24	-0.40**	-0.14
	Mo	-0.05	-0.03	0.07	0.06	0.63***	0.60***	-0.30	-0.27	-0.11	-0.09	0.08	-0.04	-0.52***	-0.46**
	Ni	0.22	0.21	0.28	0.27	0.51***	0.50***	-0.26	-0.26	-0.14	-0.11	-0.35*	-0.31	-0.45**	-0.41**
	K	0.30	0.25	0.30	0.31	0.25	0.25	-0.18	-0.21	-0.12	-0.14	-0.41**	-0.35*	-0.39**	-0.36*
	Si	-0.50***	-0.36*	-0.11	-0.03	0.02	-0.22	0.17	0.27	0.04	-0.01	0.38**	0.31	0.13	0.18
	Ag	-0.02	-0.10	-0.37**	-0.22	0.33*	0.35*	-0.10	-0.16	0.16	-0.06	0.22	0.19	-0.08	-0.26
	Na	0.07	0.09	0.17	0.17	0.64***	0.64***	-0.32*	-0.33*	-0.23	-0.25	-0.25	-0.24	-0.55***	-0.56***
	Sr	0.11	0.08	0.22	0.22	0.35*	0.38**	-0.17	-0.22	-0.16	-0.21	-0.24	-0.16	-0.38**	-0.39**
	Sn	-0.25	-0.41**	-0.18	0.05	-0.05	0.16	0.16	-0.04	0.15	-0.06	0.35*	0.21	0.22	0.03
	Ti	-0.21	-0.26	0.38**	0.09	0.29	0.12	-0.11	0.19	-0.21	0.05	-0.07	0.05	-0.25	0.16
	U	-0.25	-0.17	0.21	0.15	0.46**	0.20	-0.18	-0.29	0.02	0.03	-0.12	-0.30	-0.21	0.07
	V	-0.49***	-0.21	0.03	0.03	0.30	-0.07	-0.05	0.20	-0.18	-0.14	0.06	0.15	0.00	0.10
	Zn	0.39**	0.40**	0.28	0.17	0.23	0.05	-0.05	0.15	-0.11	-0.19	-0.36*	-0.19	-0.46**	-0.28
	Zr		-0.33*		-0.42**		0.01		0.01		0.14		0.47**		0.24

*p<0.1, **p<0.05, ***p<0.01

Note: All spearman correlation analyses performed using n=28.

Table B19 (cont.)

3km reaches

		Water		**Barren**		**Developed**		**Wetland**		**Herb**		**Agriculture**		**Forest**	
		2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Area	Al	-0.46**	-0.23	0.25	0.21	-0.23	-0.14	0.02	0.19	-0.21	-0.08	-0.23	-0.09	0.17	0.23
	Ba	-0.11	-0.04	0.12	0.20	0.56***	0.55***	-0.23	-0.28	-0.14	-0.17	-0.05	-0.11	-0.41**	-0.46**
	Be	0.02	0.04	0.03	0.03	0.11	0.19	-0.03	-0.04	0.20	0.15	0.30	0.31	-0.07	-0.13
	Bi	0.26	0.19	0.10	-0.04	0.27	-0.09	-0.09	-0.01	-0.05	0.11	0.19	-0.12	-0.25	0.23
	Cd	-0.04	-0.08	0.24	0.13	0.46**	0.52***	-0.18	-0.30	0.00	-0.05	0.10	0.15	-0.35*	-0.41**
	Ca	0.05	0.04	0.17	0.16	0.36*	0.37*	-0.17	-0.17	-0.13	-0.11	-0.24	-0.19	-0.34*	-0.34*
	Cr	0.07	0.19	0.07	-0.01	0.19	0.11	-0.03	0.09	0.10	0.05	0.28	0.27	-0.15	-0.04
	Co	-0.20	-0.15	0.15	0.22	0.66***	0.58***	-0.53***	-0.46**	-0.15	-0.20	-0.08	-0.09	-0.51***	-0.51***
	Cu	-0.01	-0.08	0.42**	0.32*	0.55***	0.63***	-0.39**	-0.38**	-0.35*	-0.28	-0.37*	-0.17	-0.60***	-0.57***
	Fe	-0.69***	-0.58***	-0.02	-0.03	0.26	0.06	-0.02	0.17	-0.05	0.05	0.29	0.35*	0.08	0.23
	Pb	-0.09	-0.05	0.14	0.54***	0.05	-0.11	0.23	-0.05	0.10	-0.21	-0.19	-0.48***	0.15	-0.04
	Li	0.02	-0.05	0.03	0.13	0.62***	0.51***	-0.30	-0.38**	-0.11	-0.12	-0.01	-0.02	-0.48***	-0.50***
	Mg	0.01	-0.01	0.19	0.17	0.57***	0.57***	-0.26	-0.26	-0.15	-0.11	-0.15	-0.13	-0.46**	-0.46**
	Mn	-0.25	-0.15	-0.17	-0.42**	0.41**	0.29	-0.31	0.09	-0.16	0.10	-0.06	0.26	-0.40**	-0.09
	Mo	-0.11	-0.04	0.09	0.07	0.57***	0.50***	-0.36*	-0.36*	-0.17	-0.16	0.11	-0.02	-0.56***	-0.53***
	Ni	0.14	0.16	0.32*	0.32	0.49***	0.46**	-0.31	-0.30	-0.21	-0.15	-0.37*	-0.33*	-0.45**	-0.41**
	K	0.16	0.13	0.33*	0.29	0.27	0.26	-0.17	-0.21	-0.19	-0.21	-0.43**	-0.39**	-0.33*	-0.34*
	Si	-0.47**	-0.32*	-0.39**	-0.33*	0.03	-0.22	0.23	0.33*	0.06	0.05	0.41**	0.35*	0.31	0.38**
	Ag	0.15	0.02	-0.07	0.14	0.19	0.33*	-0.11	-0.19	0.26	0.07	0.25	0.21	-0.15	-0.24
	Na	-0.02	-0.01	0.26	0.26	0.62***	0.62***	-0.35*	-0.35*	-0.23	-0.21	-0.25	-0.24	-0.54***	-0.56***
	Sr	0.00	-0.04	0.19	0.15	0.38**	0.42**	-0.17	-0.22	-0.18	-0.23	-0.26	-0.21	-0.34*	-0.38**
	Sn	-0.14	-0.30	-0.15	0.00	-0.11	0.12	0.11	-0.06	0.32*	0.08	0.37*	0.23	0.15	-0.03
	Ti	-0.22	-0.21	0.16	0.33*	0.23	0.17	-0.17	0.17	-0.21	0.07	-0.05	0.07	-0.21	0.12
	U	-0.25	-0.34*	0.11	-0.08	0.40**	0.15	-0.19	-0.27	0.03	-0.21	-0.11	-0.30	-0.21	-0.04
	V	-0.51***	-0.15	-0.05	0.11	0.29	-0.05	-0.02	0.24	-0.08	-0.02	0.07	0.20	0.11	0.18
	Zn	0.27	0.35*	0.21	0.15	0.19	0.07	-0.13	0.10	-0.19	-0.17	-0.35*	-0.19	-0.24	-0.04
	Zr		-0.23		-0.06		0.07		0.06		0.24		0.45**		0.24

*p<0.1, **p<0.05, ***p<0.01

Note: All spearman correlation analyses performed using n=28.

Table B19 (cont.)

3km reaches															
		Water		**Barren**		**Developed**		**Wetland**		**Herb**		**Agriculture**		**Forest**	
		2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Percent	Al	-0.49***	-0.26	0.32*	0.24	-0.23	-0.15	0.01	0.18	-0.17	-0.04	-0.23	-0.09	0.34*	0.36*
	Ba	-0.10	-0.04	0.10	0.17	0.54***	0.54***	-0.21	-0.27	-0.12	-0.13	-0.05	-0.11	-0.45**	-0.52***
	Be	-0.03	0.00	-0.03	-0.03	0.07	0.14	-0.02	-0.03	0.19	0.14	0.30	0.31	-0.07	-0.13
	Bi	0.20	0.12	0.05	-0.08	0.22	-0.12	-0.07	-0.01	-0.06	0.09	0.19	-0.12	-0.23	0.25
	Cd	-0.08	-0.08	0.18	0.09	0.43**	0.49***	-0.17	-0.29	0.03	-0.05	0.10	0.15	-0.35*	-0.45**
	Ca	0.03	0.02	0.16	0.14	0.33*	0.35*	-0.15	-0.15	-0.09	-0.07	-0.24	-0.19	-0.33*	-0.35*
	Cr	0.01	0.12	0.01	-0.06	0.12	0.05	-0.02	0.07	0.09	0.04	0.28	0.27	-0.15	-0.19
	Co	-0.21	-0.15	0.17	0.20	0.65***	0.58***	-0.53***	-0.45**	-0.13	-0.16	-0.08	-0.09	-0.48**	-0.43**
	Cu	0.00	-0.07	0.47**	0.35*	0.56***	0.64***	-0.38**	-0.37*	-0.31	-0.24	-0.37*	-0.17	-0.47**	-0.50***
	Fe	-0.73***	-0.63***	0.04	0.01	0.24	0.05	-0.05	0.15	-0.02	0.08	0.29	0.35*	0.03	0.24
	Pb	-0.16	-0.09	0.13	0.56***	0.09	-0.10	0.19	-0.04	0.13	-0.17	-0.19	-0.48***	0.08	0.20
	Li	0.02	-0.02	0.02	0.12	0.60***	0.50***	-0.29	-0.37*	-0.11	-0.11	-0.01	-0.02	-0.58***	-0.53***
	Mg	0.00	-0.03	0.18	0.16	0.57***	0.56***	-0.25	-0.25	-0.12	-0.09	-0.15	-0.13	-0.50***	-0.48***
	Mn	-0.17	-0.11	-0.02	-0.34*	0.46**	0.39**	-0.32*	0.08	-0.11	0.12	-0.06	0.26	-0.38**	-0.15
	Mo	-0.06	-0.02	0.10	0.12	0.55***	0.49***	-0.35*	-0.34*	-0.16	-0.15	0.11	-0.02	-0.58***	-0.47**
	Ni	0.11	0.12	0.33*	0.30	0.49***	0.46**	-0.30	-0.29	-0.18	-0.12	-0.37*	-0.33*	-0.42**	-0.39**
	K	0.14	0.11	0.32*	0.29	0.24	0.23	-0.17	-0.20	-0.15	-0.18	-0.43**	-0.39**	-0.32*	-0.32*
	Si	-0.48***	-0.36*	-0.44**	-0.34*	0.04	-0.24	0.21	0.31	0.08	0.06	0.41**	0.35*	0.14	0.30
	Ag	0.13	-0.02	-0.14	0.09	0.19	0.25	-0.10	-0.19	0.26	0.07	0.25	0.21	-0.15	-0.30
	Na	-0.01	0.00	0.28	0.27	0.61***	0.61***	-0.34*	-0.34*	-0.20	-0.18	-0.25	-0.24	-0.53***	-0.55***
	Sr	-0.02	-0.05	0.18	0.15	0.35*	0.38**	-0.16	-0.22	-0.13	-0.19	-0.26	-0.21	-0.33*	-0.36*
	Sn	-0.16	-0.34*	-0.21	-0.05	-0.10	0.08	0.12	-0.05	0.31	0.08	0.37*	0.23	0.17	-0.02
	Ti	-0.24	-0.32*	0.28	0.29	0.17	0.15	-0.18	0.17	-0.22	0.10	-0.05	0.07	-0.16	0.18
	U	-0.30	-0.28	0.08	-0.03	0.38**	0.21	-0.20	-0.26	0.06	-0.19	-0.11	-0.30	-0.29	0.04
	V	-0.55***	-0.23	-0.05	0.01	0.31	-0.12	-0.05	0.26	-0.07	0.01	0.07	0.20	0.01	0.18
	Zn	0.28	0.32*	0.24	0.12	0.19	0.04	-0.16	0.07	-0.16	-0.15	-0.35*	-0.19	-0.34*	-0.20
	Zr		-0.31		-0.17		0.01		0.07		0.25		0.45**		0.18

*p<0.1, **p<0.05, ***p<0.01

Note: All spearman correlation analyses performed using n=28.

Table B20 Pearson correlation analyses performed on land-cover types (area or percent) and annual general biological/chemical parameters and nutrients (2013 or 2014) for buffer (5km-radius), catchment, and reaches (1km, 2km, and 3km-radius) landscape-scales.

Land-cover area and 2013 annual general biological/chemical parameters and nutrients								
		Water	**Barren**	**Developed**	**Wetland**	**Herb**	**Agriculture**	**Forest**
5km Buffers	CaCO3							-0.62***
	DOC	-0.30					0.60***	
	Cond			0.55***				-0.64***
	Cl			0.71***	-0.64***			-0.74***
	TP		0.36*		-0.56***	-0.11		
	TN							-0.56***
	NO3		0.45**		-0.42**	-0.18		-0.37*
	NO2				-0.43**			
Catchments	Cl	-0.35*				-0.36*	-0.18	
	NO3	-0.30	0.59***	0.62***		-0.32*		
	NO2		0.68***	0.72***				
1km Reaches	Cl		0.64***		-0.19	-0.09	-0.23	-0.49***
	TN		0.80***					
	TKN		0.92***					
	NO3				-0.11		-0.22	-0.23
2km Reaches	Cl	-0.13	0.68***		-0.31	-0.17	-0.22	-0.64***
	NO3						-0.21	-0.32*
3km Reaches	pH		0.40**					
	CaCO3		0.74***					
	DOC						0.30	
	Cond		0.74***					
	Cl	-0.13	0.66***		-0.40**		-0.20	
	TP		0.43**					
	TN		0.76***					
	NO3				-0.29		-0.17	-0.42**

*p<0.1, **p<0.05, ***p<0.01

Note: All Pearson correlation analyses performed using n=28.

Table B20 (cont.)

Land-cover area and 2014 annual general biological/chemical parameters		Water	Barren	Developed	Wetland	Herb	Agriculture	Forest
5km Buffers	pH	0.11			-0.34*	-0.39**	0.29	
	DOC	-0.35*					0.62***	
	Cond							-0.65***
	Cl	0.32*		0.66***	-0.62***	-0.27	-0.18	-0.70***
	TN							-0.59***
	NO3				-0.48***			
Catchments	pH				0.00		0.32*	
	Cl	-0.34*			-0.35*	-0.35*	-0.20	-0.37*
	NO3		0.64***	0.68***				
1km Reaches	pH	-0.01	0.51***		0.21	-0.05		
	Cl	-0.08	0.61***		-0.20	-0.07	-0.23	-0.48***
	TKN		0.93***					
2km Reaches	pH	0.02			0.08	-0.29		
	Cl	-0.13	0.66***		-0.33*	-0.16	-0.22	-0.63***
3km Reaches	pH	0.03	0.36*		-0.01	-0.34*	0.11	
	CaCO3		0.74***					
	DOC						0.32*	
	Cond		0.74***					
	Cl	-0.14	0.65***		-0.42**	-0.22	-0.22	-0.69***
	TN		0.74***					

*p<0.1, **p<0.05, ***p<0.01

Note: All Pearson correlation analyses performed using n=28.

Table B20 (cont.)

Land-cover percent and 2013 annual biological/chemical parameters and nutrients

		Water	Barren	Developed	Wetland	Herb	Agriculture	Forest
5km Buffers	CaCO3							-0.62***
	DOC	-0.30					0.60***	
	Cond			0.55***				-0.64***
	Cl			0.71***	-0.64***			-0.74***
	TP		0.36*		-0.56***			
	TN							-0.56***
	NO3		0.45**		-0.42**	-0.18		-0.37*
	NO2				-0.43**			
Catchments	pH		0.61***					-0.58***
	DOC	-0.37*			0.60***		0.62***	
	NO3		0.76***	0.70***		-0.43**		-0.73***
	NO2			0.75***				-0.67***
1km Reaches	CaCO3		0.84***					
	Cond		0.78***					
	Cl	-0.12	0.62***		-0.20		-0.24	-0.51***
	TN		0.78***					
	TKN		0.91***					
	NO3				-0.13		-0.24	-0.20
2km Reaches	DOC	-0.24						
	Cond							-0.60***
	Cl		0.67***		-0.34*		-0.23	-0.72***
	TN							-0.50***
	TKN		0.92***					
	NO3				-0.26		-0.22	-0.37*
3km Reaches	DOC						0.32*	
	Cond							-0.69***
	Cl		0.69***		-0.39**	-0.20	-0.20	-0.79***
	TP		0.30					-0.48***
	TN							-0.61***
	NO3				-0.27	-0.14	-0.17	-0.48***

*p<0.1, **p<0.05, ***p<0.01

Note: All Pearson correlation analyses performed using n=28.

Table B20 (cont.)

Land-cover percent and general biological/chemical parameters and nutrients								
		Water	**Barren**	**Developed**	**Wetland**	**Herb**	**Agriculture**	**Forest**
5km Buffers	pH	0.11			-0.34*	-0.39**	0.29	
	DOC	-0.35*					0.62***	
	Cond							-0.65***
	Cl	0.32*		0.66***	-0.62***	-0.27	-0.18	-0.70***
	TN							-0.59***
	NO3				-0.48***			
Catchments	pH				0.02	-0.54***		-0.71***
	DOC	-0.40**			0.57***		0.66***	
	Cond	-0.19	0.90***	0.51***	-0.37*	-0.42**	-0.13	-0.77***
	Cl		0.91***				-0.10	
	NO3		0.76***	0.74***				-0.75***
1km Reaches	pH	-0.01	0.51***		0.18	-0.02		
	CaCO3		0.88***					
	Cond		0.81***					
	Cl	-0.11	0.59***		-0.21	-0.04	-0.24	-0.48***
	TKN		0.92***					
2km Reaches	pH	0.09	0.48**		0.04	-0.18		
	Cl	-0.02	0.64***		-0.35*		-0.23	-0.69***
	TN							-0.54***
	TKN		0.94***					
3km Reaches	pH				-0.03	-0.32*	0.11	
	DOC						0.35*	
	Cl	0.04	0.67***		-0.40**	-0.20	-0.22	-0.77***
	TN							-0.64***

*p<0.1, **p<0.05, ***p<0.01

Note: All Pearson correlation analyses performed using n=28.

Table B21 Pearson correlation analyses performed on land-cover types (area or percent) and annual metals (2013 or 2014) for buffer (5km-radius), catchment, and reaches (1km, 2km, and 3km-radius) landscape-scales.

Land-cover area and 2013 annual metals								
		Water	**Barren**	**Developed**	**Wetland**	**Herb**	**Agriculture**	**Forest**
5km Buffers	Ba			0.59***				-0.68***
	Be	-0.48***						
	Co				-0.58***			
	Li							-0.65***
	Mg							-0.64***
	Mo		0.61***					
	Ni		0.49***		-0.54***			-0.41**
	K							-0.62***
	Si		-0.18		0.03	-0.09		0.04
	Na			0.65***				-0.71***
	Sr							-0.62***
	V	-0.24	-0.06	0.10	-0.13	-0.06	0.43**	-0.09
Catchments	Ni		0.56***	0.57***				
	Si	0.12	0.11			0.12		
	V	-0.12	0.14	0.15	0.01	-0.09	0.22	-0.09
1km Reaches	Ba		0.76***					
	Mg		0.83***					
	Si		0.01	0.04	0.07	0.06		-0.01
	Na		0.77***					
	V	-0.32*	0.08	0.24	0.03	-0.05	-0.02	-0.03
2km Reaches	Ba		0.77***					
	Co							-0.50***
	Mg		0.80***					
	Ni				-0.34*			-0.47**
	Si		-0.01	0.11		0.00	0.33*	0.12
	V		0.05	0.33*	0.02	-0.16	0.10	0.03
3km Reaches	Ba		0.70***					
	Ca		0.75***					
	Co							-0.58***
	Li		0.80***					
	Mg		0.69***					
	Mo		0.69***					
	Ni				-0.41**			-0.53***
	K		0.76***					
	Si		-0.10	0.17		-0.03	0.52***	0.07
	Na		0.72***					
	Sr		0.74***					
	V		-0.02	0.40**	-0.02	-0.11	0.24	0.02

*p<0.1, **p<0.05, ***p<0.01

Note: All Pearson correlation analyses performed using n=28.

Table B21 (cont.)

Land-cover area and 2014 annual metals

		Water	Barren	Developed	Wetland	Herb	Agriculture	Forest
5km Buffers	Ba			0.57***				-0.64***
	Co				-0.54***			
	Cu				-0.57***		-0.19	
	Mg							-0.63***
	Mo		0.63***		-0.58***			
	Ni		0.33*		-0.47**		-0.25	
	Si	-0.46**	-0.18	-0.13	0.09	-0.07	0.61***	0.07
	Na			0.64***				-0.70***
	U	0.31	-0.01	0.18	-0.11	-0.23	-0.33*	0.00
	V	-0.41**					0.66***	
Catchments	Co		0.57***	0.58***				
	Cu						-0.19	
	Ni	-0.30	0.59***	0.60***		-0.33*		
	Si	0.19	-0.12		0.33*	0.21	0.37**	0.24
	U	-0.29	0.34*		-0.37*	-0.33*	-0.36*	-0.29
	Zn		0.43**	0.49***				
1km Reaches	Ba		0.75***					
	Cu	-0.18			-0.12	-0.12	-0.24	
	Mg		0.83***					
	Ni				-0.15		-0.23	
	Si	-0.26	-0.03	-0.02	0.13	0.00	0.24	0.05
	Na		0.77***					
	U	-0.13	0.24		-0.34*	0.21	-0.19	-0.15
2km Reaches	Ba		0.75***					
	Cu	-0.19			-0.31	-0.27	-0.24	
	Mg		0.81***					
	Mo		0.60***					
	Ni				-0.31		-0.25	-0.38**
	Si		-0.06	0.03	0.23	-0.05	0.36*	0.23
	U	-0.30	0.15		-0.28	-0.05	-0.23	-0.10
3km Reaches	Ba		0.66***					
	Cu	-0.18			-0.40**		-0.25	
	Mg		0.70***					
	Mn			0.37*				
	Mo		0.69***					
	Ni		0.47**		-0.39**		-0.29	-0.44**
	Si		-0.14	0.06	0.25	-0.03	0.53***	0.23
	Na		0.71***					
	Sr		0.74***					
	U	-0.35*	0.04	0.19	-0.27	-0.16	-0.22	-0.11
	V						0.49***	

*p<0.1, **p<0.05, ***p<0.01

Note: All Pearson correlation analyses performed using n=28.

Table B21 (cont.)

Land-cover percent and 2013 annual metals								
		Water	**Barren**	**Developed**	**Wetland**	**Herb**	**Agriculture**	**Forest**
5km Buffers	Ba			0.59***				-0.68***
	Be	-0.48***						
	Co				-0.58***			
	Li							-0.65***
	Mg							-0.64***
	Mo		0.61***					
	Ni		0.49***		-0.54***			-0.41**
	K							-0.62***
	Si		-0.18		0.03	-0.09		0.04
	Na			0.65***				-0.71***
	Sr							-0.62***
	V	-0.24	-0.06	0.10	-0.13	-0.06	0.43**	-0.09
Catchments	Ba		0.90***					
	Ni			0.75***				-0.78***
	Si	-0.63***	-0.02		0.22	0.05		0.05
	V		0.25		0.08	-0.14	0.43**	-0.24
1km Reaches	Ba		0.74***					
	Ca		0.86***					
	Mg		0.82***					
	Si		0.02	0.13	0.06	0.05		-0.02
	Na		0.76***					
	Sr		0.85***					
	V	-0.33*	0.10	0.37*	-0.01	-0.06	-0.03	-0.04
2km Reaches	Ba		0.78***					-0.60***
	Co							-0.52***
	Mg		0.83***					
	Ni				-0.35*			-0.47**
	Si		0.00	0.10		-0.02		0.11
	Na							-0.66***
	V	-0.43**	0.07	0.34*	-0.04	-0.19	0.08	-0.02
3km Reaches	Ba		0.74***					-0.70***
	Co							-0.62***
	Mo		0.59***					
	Ni		0.57***		-0.40**			-0.56***
	Si	-0.55***	-0.08	0.12	0.12	-0.03	0.54***	0.09
	Na							-0.75***
	V	-0.51***	0.02	0.37*	-0.06	-0.13	0.25	-0.03

*p<0.1, **p<0.05, ***p<0.01

Note: All Pearson correlation analyses performed using n=28.

Table B21 (cont.)

Land-cover percent and 2014 annual metals

		Water	Barren	Developed	Wetland	Herb	Agriculture	Forest
5km Buffers	Ba			0.57***				-0.64***
	Co				-0.54***			
	Cu				-0.57***		-0.19	
	Mg							-0.63***
	Mo		0.63***		-0.58***			
	Ni		0.33*		-0.47**		-0.25	
	Si	-0.46**	-0.18	-0.13	0.09	-0.07	0.61***	0.07
	Na			0.64***				-0.70***
	U	0.31	-0.01	0.18	-0.11	-0.23	-0.33*	0.00
	V	-0.41**					0.66***	
Catchments	Co			0.74***				-0.70***
	Cu						-0.04	
	Ni			0.77***				-0.73***
	Si	-0.52***	-0.23		0.35*	0.16		0.26
	U	-0.28	0.53***	0.44**	-0.51***	-0.36*	-0.37*	-0.41**
	V				0.44**		0.63***	
	Zn			0.50***				
1km Reaches	Ba		0.74***					
	Ca		0.89***					
	Cu	-0.19			-0.14		-0.25	
	Mg		0.82***					
	Ni				-0.16		-0.24	
	K		0.88***					
	Si	-0.17	-0.02	0.03	0.13	-0.04	0.25	0.00
	Na		0.75***					
	Sr		0.87***					
	U	-0.14	0.25		-0.33*	0.20	-0.17	0.01
2km Reaches	Ba		0.76***					-0.59***
	Cu	-0.12			-0.31		-0.25	
	Ni				-0.32*		-0.25	-0.37*
	Si		-0.04	-0.02	0.20	-0.12	0.35*	0.16
	Na							-0.66***
	U	-0.24	0.20		-0.29	-0.01	-0.22	0.01
3km Reaches	Ba		0.71***					-0.67***
	Cu	-0.07			-0.37*		-0.26	
	Mn			0.41**				
	Mo		0.63***					-0.71***
	Ni		0.40**		-0.38**		-0.29	-0.44**
	Si	-0.51***	-0.12	-0.06	0.24	-0.05	0.54***	0.19
	Na							-0.74***
	U	-0.24	0.10	0.29	-0.27	-0.15	-0.22	-0.01
	V						0.48***	

*p<0.1, **p<0.05, ***p<0.01

Note: All Pearson correlation analyses performed using n=28.

Table B22 Spearman correlation analyses performed on road density and annual water quality parameters (2013 or 2014) for buffer (5km-radius), catchment, and reaches (1km, 2km, and 3km-radius) landscape-scales.

	5km Buffer		Catchment		1km Reach		2km Reach		3km Reach	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Chl-a	-0.14	-0.13	0.42**	0.45**	-0.03	0.03	0.06	0.07	-0.04	-0.02
E.coli	0.22	0.43**	0.20	0.02	0.24	0.39**	0.21	0.34*	0.18	0.35*
pH	0.27	0.24	0.49***	0.63***	0.27	0.31	0.32*	0.37*	0.26	0.33*
CaCO3	0.33*	0.36*	0.78***	0.79***	0.39**	0.43**	0.41**	0.43**	0.41**	0.45**
DOC	-0.31	-0.35*	-0.23	-0.23	-0.19	-0.30	-0.30	-0.40**	-0.31	-0.40**
Cond	0.53***	0.54***	0.88***	0.89***	0.60***	0.60***	0.63***	0.62***	0.62***	0.63***
Cl	0.59***	0.62***	0.88***	0.90***	0.66***	0.68***	0.68***	0.70***	0.67***	0.71***
TP	0.54***	0.20	0.61***	0.59***	0.49***	0.38**	0.51***	0.37**	0.51***	0.30
TN	0.40**	0.44**	0.68***	0.78***	0.43**	0.53***	0.38**	0.50***	0.46**	0.54***
TKN	0.36*	0.38**	0.59***	0.71***	0.45**	0.50***	0.43**	0.50***	0.46**	0.50***
NO3	0.49***	0.54***	0.73***	0.81***	0.42**	0.51***	0.37*	0.49***	0.45**	0.54***
NO2	0.64***	0.55***	0.62***	0.74***	0.53***	0.49***	0.53***	0.49***	0.60***	0.55***
Al	-0.06	-0.09	-0.29	-0.30	0.06	0.06	-0.10	-0.05	-0.02	-0.05
Ba	0.58***	0.54***	0.82***	0.83***	0.59***	0.58***	0.58***	0.57***	0.60***	0.59***
Be	0.21	0.26	0.03	0.09	0.05	0.11	0.05	0.11	0.01	0.07
Bi	0.18	0.02	0.15	0.15	0.13	-0.01	0.21	-0.03	0.10	-0.09
Cd	0.49***	0.53***	0.46**	0.51***	0.43**	0.43**	0.43**	0.46**	0.38**	0.43**
Ca	0.34*	0.36*	0.78***	0.77***	0.41**	0.40**	0.41**	0.41**	0.42**	0.44**
Cr	0.26	0.12	0.13	0.04	0.10	0.00	0.11	0.01	0.06	-0.01
Co	0.67***	0.57***	0.80***	0.71***	0.72***	0.62***	0.70***	0.60***	0.73***	0.61***
Cu	0.49***	0.57***	0.81***	0.84***	0.62***	0.69***	0.64***	0.67***	0.60***	0.66***
Fe	0.33*	0.13	-0.05	-0.25	0.44**	0.25	0.25	0.05	0.39**	0.14
Pb	0.13	0.01	0.09	0.19	0.25	0.13	0.16	0.04	0.19	0.04
Li	0.52***	0.50***	0.76***	0.61***	0.53***	0.44**	0.58***	0.49***	0.57***	0.47**
Mg	0.50***	0.51***	0.89***	0.88***	0.59***	0.58***	0.60***	0.60***	0.59***	0.60***
Mn	0.28	0.03	0.58***	0.36*	0.48***	0.36*	0.43**	0.30	0.48***	0.28
Mo	0.55***	0.48***	0.61***	0.70***	0.49***	0.49***	0.52***	0.50***	0.50***	0.46**
Ni	0.42**	0.40**	0.82***	0.82***	0.52***	0.48***	0.56***	0.53***	0.54***	0.51***
K	0.30	0.29	0.72***	0.70***	0.33*	0.31	0.36*	0.32*	0.37**	0.38**
Si	0.07	-0.20	-0.19	-0.35*	0.15	-0.11	0.00	-0.26	0.12	-0.18
Ag	0.37*	0.41**	0.35*	0.35*	0.19	0.34*	0.21	0.35*	0.20	0.31
Na	0.58***	0.59***	0.91***	0.89***	0.66***	0.64***	0.67***	0.66***	0.66***	0.67***
Sr	0.38**	0.39**	0.74***	0.73***	0.44**	0.45**	0.43**	0.43**	0.48**	0.50***
Sn	-0.01	0.25	-0.18	0.05	-0.12	0.14	-0.16	0.05	-0.17	0.07
Ti	0.24	0.16	0.20	0.10	0.22	0.35*	0.18	0.22	0.19	0.14
U	0.55***	0.18	0.60***	0.34*	0.48***	0.33*	0.41**	0.28	0.51***	0.34*
V	0.34*	-0.04	0.31	-0.01	0.53***	0.01	0.36*	-0.08	0.43**	-0.12
Zn	0.12	-0.12	0.59***	0.41**	0.25	0.02	0.22	-0.02	0.18	-0.05
Zr		0.24		-0.02		0.16		0.07		0.16

*p<0.1, **p<0.05, ***p<0.01

Note: All Spearman correlation analyses performed using n=28.

Table B23 Pearson correlation analyses performed on road density and annual water quality parameters (2013 or 2014) for buffer (5km-radius), catchment, and reaches (1km, 2km, and 3km-radius) landscape-scales.

	5km Buffer		**Catchment**		**1km Reach**		**2km Reach**		**3km Reach**	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
pH		0.47**				0.41**		0.45**		0.43**
Cond	0.57***	0.58***							0.64***	0.65***
Cl	0.71***	0.66***			0.63***	0.60***	0.69***	0.67***	0.75***	0.72***
TP			0.69***							
TN									0.59***	0.63***
NO3			0.77***	0.79***					0.45**	
Ba	0.58***	0.56***			0.58***	0.57***	0.60***	0.59***	0.69***	0.69***
Co			0.76***	0.77***						
Cu						0.65***		0.65***		0.67***
Mg										0.65***
Mn						0.42**		0.35*		0.29
Mo				0.66***						
Ni			0.81***	0.80***						
Si		-0.17	-0.10	-0.33*	0.23	0.12	0.12	0.02	0.12	-0.01
Na	0.66***	0.66***							0.71***	0.71***
Ti						0.43**				
U		0.14		0.52***		0.34*		0.30		0.44**
V	0.09		0.20		0.54***		0.42**		0.43**	
Zn				0.49***						

*p<0.1, **p<0.05, ***p<0.01

Note: All Pearson correlation analyses performed using n=28.

Appendix C

Table C1 Total phytoplankton biomass for all sampling dates in 2013 and 2014.

	May 2013 (ug/L)	June 2013 (ug/L)	July 2013 (ug/L)	August 2013 (ug/L)	September 2013 (ug/L)	October 2013 (ug/L)	June 2014 (ug/L)	July 2014 (ug/L)	August 2014 (ug/L)	September 2014 (ug/L)	October 2014 (ug/L)	November 2014 (ug/L)
VER-1	129.20		35.58	59.15	48.46	17.84		54.09	16.32	107.9	269.30	125.00
VER-2	238.59	25.85	167.55	28.08	132.23	247.97	159.93	50.59	79.91	97.32	108.54	151.34
ONP-3		339.42		100.36		116.11	211.05	121.28	80.28	252.82	231.71	123.02
ONP-4	269.86	320.77	293.75	359.63	1474.88	849.04	126.56	254.88	251.76	163.21	1384.70	337.45
VER-5	371.67	450.56	404.92	726.78	594.08	751.95	186.99	269.49	1188.29	875.96	283.54	159.34
VER-6	377.69	1124.07	367.13	1419.35	683.13	507.59	348.06	553.1	807.47	607.92	625.95	232.97
WIT-7		613.38		248.10	285.58	209.99	1070.15	546.08	652.91	572.28	262.59	229.60
WIT-8		979.85		204.26		190.25	1079.83	816.95	321.27	184.74	286.56	118.25
LEV-9		1730.89		86.77	142.24	262.48	685.32	404.68	416.22	245.97	263.62	728.37
VER-10		473.29		427.41	371.13	627.03	385.74		483.42	517.67	469.77	141.18
LIL-11		140.63		436.09	660.59	764.77	391.59	224.91	13.96	444.25	63.59	236.10
CC-12	8.10	14.81	28.35	108.52	47.89	81.50	14.81	7.74	116.8	63.76		77.54
JUN-13		895.41		10299.92	1515.04	333.59	446.86	269.56	1948.16	3695.45	650.76	261.03
MB-14	595.45	398.24	336.25	324.27	335.71	237.69	1013.72	493.45	534.39	200.15	977.58	16.76
MUD-15	655.81	5987.91	736.18	2519.20	247.34	157.96	1155.57	789.35	1937.89	1190.72	1442.94	306.82
SIM-16	1455.50	226.88	3228.01	140.21	1088.61	374.56	564.06	1122.16	1616.83	561.09	1905.23	342.73
MC-17	572.92	1227.14	1161.84	1148.60	2206.00	1400.42	256.63	6427.35	4235.25	171.81	471.30	283.62
MC-18	110.04	565.85	483.39	369.56	254.46	329.58	373.28	4707.57	4503.12	1145.77	661.04	483.97
MC-19	350.46	517.80	778.64	303.92	715.14	361.01	707.61	1192.74	1316.73	850.98	796.22	160.74
FB-20	290.90	336.41	476.36	65.08	314.06	365.62	317.37	86.78	272.73	265.5	116.42	540.01
KUS-21	430.26	1049.00	871.02	736.67	294.38	163.33	837.78	937.79	623.68	1052.43	723.78	259.02
VER-22	308.16	737.11	1565.01	524.96	274.46	356.77	638.89	415.77	464.43	859.01	539.01	197.42
GRA-23	386.34	661.63	1020.27	494.38	284.05	379.55	710.97	961.72	809.43	895.75	996.45	269.38
ELA-24	376.92	716.39	513.20	779.17	337.69	317.69	779.48	946.44	228.72	905.81	697.17	218.71
ELA-25	1599.48	2866.71	2206.17	2795.28	857.94	899.52	1695.37	559.37	2570.2	3408.81	1399.67	605.21
WAB-26	702.68	1396.87	309.35	91.21	1049.24	1434.12	1145.46	643.44	745.6		760.50	239.92
WAB-27	826.61	1349.33	1523.42	277.71	509.99	407.57	1138.91	917.06	1511.96		969.38	187.00
VER-28	386.35	665.79	530.79	142.08	220.20	177.46	660.07		536.95	1547.5	615.53	220.90

Table C2 Major phytoplankton biomass for May 2013.

	Bacillariophyta (ug/L)	Chlorophyta (ug/L)	Chrysophyta (ug/L)	Cryptophyta (ug/L)	Cyanophyta (ug/L)	Dinophyta (ug/L)	Euglenophyta (ug/L)	Xanthophyta (ug/L)
VER-1	38.84	7.04	15.05	52.55	0.00	12.80	2.92	0.00
VER-2	74.80	71.83	5.91	55.39	5.08	25.59	0.00	0.00
ONP-3								
ONP-4	135.59	50.90	19.50	22.21	32.90	0.00	8.77	0.00
VER-5	77.03	27.76	82.62	167.98	3.48	12.80	0.00	0.00
VER-6	81.00	148.04	55.08	60.32	22.85	0.00	10.40	0.00
WIT-7								
WIT-8								
LEV-9								
VER-10								
LIL-11								
CC-12	4.75	3.35	0.00	0.00	0.00	0.00	0.00	0.00
JUN-13								
MB-14	470.63	2.81	20.11	9.41	0.00	89.57	2.92	0.00
MUD-15	301.70	21.41	0.30	332.40	0.00	0.00	0.00	0.00
SIM-16	142.04	64.65	0.00	1247.72	1.10	0.00	0.00	0.00
MC-17	92.01	38.88	13.45	419.87	5.79	0.00	2.92	0.00
MC-18	0.00	2.19	0.00	107.85	0.00	0.00	0.00	0.00
MC-19	62.52	21.20	72.24	143.31	0.00	51.18	0.00	0.00
FB-20	105.89	20.14	7.96	142.48	0.00	12.80	1.62	0.00
KUS-21	117.64	21.65	98.95	177.03	2.19	12.80	0.00	0.00
VER-22	101.45	15.42	14.62	176.67	0.00	0.00	0.00	0.00
GRA-23	232.99	6.94	12.80	120.82	0.00	12.80	0.00	0.00
ELA-24	172.30	6.80	61.74	134.90	1.18	0.00	0.00	0.00
ELA-25	573.40	56.08	278.71	637.39	26.69	25.59	1.62	0.00
WAB-26	167.39	10.73	61.74	447.10	0.00	12.80	2.92	0.00
WAB-27	169.70	35.42	114.59	467.76	0.76	38.39	0.00	0.00
VER-28	54.48	18.44	45.29	250.79	0.00	12.80	4.55	0.00

Table C3 Major phytoplankton group biomass for June 2013.

	Bacillariophyta (ug/L)	Chlorophyta (ug/L)	Chrysophyta (ug/L)	Cryptophyta (ug/L)	Cyanophyta (ug/L)	Dinophyta (ug/L)	Euglenophyta (ug/L)	Xanthophyta (ug/L)
VER-1								
VER-2	13.13	10.12	0.00	0.00	0.16	0.00	2.44	0.00
ONP-3	177.16	67.76	11.62	30.80	0.08	51.18	0.81	0.00
ONP-4	139.76	117.17	17.75	21.39	0.20	12.80	11.70	0.00
VER-5	74.87	77.16	72.00	131.24	17.72	76.77	0.81	0.00
VER-6	96.50	131.63	187.83	132.07	250.80	319.88	5.36	0.00
WIT-7	344.91	37.00	0.00	209.75	10.01	0.00	11.70	0.00
WIT-8	639.69	18.73	7.31	314.12	0.00	0.00	0.00	0.00
LEV-9	1503.95	110.07	16.98	84.91	2.19	12.80	0.00	0.00
VER-10	170.24	74.67	51.44	67.91	69.59	12.80	26.65	0.00
LIL-11	74.79	42.71	14.62	1.92	6.58	0.00	0.00	0.00
CC-12	14.26	0.55	0.00	0.00	0.00	0.00	0.00	0.00
JUN-13	751.58	18.44	0.00	125.39	0.00	0.00	0.00	0.00
MB-14	190.13	2.93	29.25	8.77	0.00	166.34	0.81	0.00
MUD-15	377.00	4277.40	53.25	1267.46	0.00	12.80	0.00	0.00
SIM-16	4.75	36.87	0.00	185.26	0.00	0.00	0.00	0.00
MC-17	43.76	271.91	0.00	885.89	0.00	25.59	0.00	0.00
MC-18	27.05	39.62	65.52	429.92	0.00	0.00	3.74	0.00
MC-19	185.92	56.13	24.57	158.11	54.67	38.39	0.00	0.00
FB-20	7.47	328.03	0.00	0.00	0.91	0.00	0.00	0.00
KUS-21	176.09	178.01	155.53	432.84	43.65	51.18	11.70	0.00
VER-22	212.29	29.70	93.53	280.03	44.78	76.77	0.00	0.00
GRA-23	148.92	55.72	86.07	321.53	46.47	0.00	2.92	0.00
ELA-24	88.66	75.51	70.31	375.27	52.82	38.39	15.44	0.00
ELA-25	2391.34	15.44	279.53	147.15	6.95	0.00	26.32	0.00
WAB-26	211.20	86.78	219.39	764.33	6.97	102.36	5.85	0.00
WAB-27	357.80	54.52	127.55	653.29	49.05	89.57	17.55	0.00
VER-28	206.04	32.78	18.93	368.23	8.37	25.59	5.85	0.00

Table C4 Major phytoplankton group biomass for July 2013.

	Bacillariophyta (ug/L)	Chlorophyta (ug/L)	Chrysophyta (ug/L)	Cryptophyta (ug/L)	Cyanophyta (ug/L)	Dinophyta (ug/L)	Euglenophyta (ug/L)	Xanthophyta (ug/L)
VER-1	18.72	6.81	0.00	10.05	0.00	0.00	0.00	0.00
VER-2	104.50	18.04	0.24	44.69	0.08	0.00	0.00	0.00
ONP-3								
ONP-4	192.85	58.35	2.07	1.28	0.00	38.39	0.81	0.00
VER-5	131.45	36.42	35.08	127.31	23.48	51.18	0.00	0.00
VER-6	59.33	11.81	15.68	169.90	2.19	102.36	5.85	0.00
WIT-7								
WIT-8								
LEV-9								
VER-10								
LIL-11								
CC-12	23.76	2.24	0.00	0.00	2.35	0.00	0.00	0.00
JUN-13								
MB-14	239.94	82.63	0.00	11.24	0.61	0.00	0.00	1.83
MUD-15	305.01	274.43	0.00	156.74	0.00	0.00	0.00	0.00
SIM-16	0.00	2606.82	8.21	585.20	2.19	25.59	0.00	0.00
MC-17	58.16	698.87	17.39	374.63	0.00	12.80	0.00	0.00
MC-18	2.72	112.99	0.00	342.09	0.00	25.59	0.00	0.00
MC-19	164.89	36.52	37.13	349.13	139.79	51.18	0.00	0.00
FB-20	43.50	12.36	0.00	257.00	81.24	0.00	82.26	0.00
KUS-21	174.30	35.17	204.78	157.29	276.44	12.80	10.24	0.00
VER-22	266.75	68.66	65.52	414.38	583.64	153.54	12.51	0.00
GRA-23	146.78	270.74	65.52	296.12	177.14	63.98	0.00	0.00
ELA-24	61.12	128.93	30.10	274.37	5.08	12.80	0.81	0.00
ELA-25	926.82	499.71	27.30	55.39	431.06	261.85	4.06	0.00
WAB-26	130.34	27.00	1.83	135.54	1.84	12.80	0.00	0.00
WAB-27	874.37	247.00	9.14	263.58	26.32	100.08	2.92	0.00
VER-28	390.68	46.85	9.79	59.22	2.35	12.80	9.10	0.00

Table C5 Major phytoplankton group biomass for August 2013.

	Bacillariophyta (ug/L)	Chlorophyta (ug/L)	Chrysophyta (ug/L)	Cryptophyta (ug/L)	Cyanophyta (ug/L)	Dinophyta (ug/L)	Euglenophyta (ug/L)	Xanthophyta (ug/L)
VER-1	23.76	25.17	0.00	0.00	10.22	0.00	0.00	0.00
VER-2	23.35	2.90	1.83	0.00	0.00	0.00	0.00	0.00
ONP-3	38.41	5.85	1.83	10.05	31.43	12.80	0.00	0.00
ONP-4	302.61	38.15	0.24	1.28	0.81	12.80	3.74	0.00
VER-5	331.46	9.32	35.38	129.87	112.54	0.00	108.21	0.00
VER-6	961.77	19.11	115.58	86.82	62.50	138.46	35.10	0.00
WIT-7	174.22	13.03	0.00	46.43	1.62	12.80	0.00	0.00
WIT-8	28.52	11.96	1.83	149.16	0.00	12.80	0.00	0.00
LEV-9	32.66	48.11	0.00	0.64	5.36	0.00	0.00	0.00
VER-10	319.04	18.31	31.44	36.38	19.32	0.00	2.92	0.00
LIL-11	65.79	356.04	0.00	0.00	14.26	0.00	0.00	0.00
CC-12	80.79	0.00	0.00	0.00	27.72	0.00	0.00	0.00
JUN-13	1928.55	8339.67	0.00	26.50	4.39	0.00	0.81	0.00
MB-14	129.14	115.79	18.28	8.77	1.10	51.18	0.00	0.00
MUD-15	126.92	2316.25	0.00	74.94	1.10	0.00	0.00	0.00
SIM-16	37.59	16.59	15.92	67.17	0.00	0.00	2.92	0.00
MC-17	693.44	435.32	0.00	19.83	0.00	0.00	0.00	0.00
MC-18	148.99	44.64	84.00	37.01	0.00	51.18	3.74	0.00
MC-19	97.17	8.27	27.54	106.75	58.34	0.00	5.85	0.00
FB-20	4.75	2.74	7.96	49.63	0.00	0.00	0.00	0.00
KUS-21	147.30	19.10	18.52	464.47	0.00	87.28	0.00	0.00
VER-22	173.86	14.15	43.30	280.86	0.00	12.80	0.00	0.00
GRA-23	151.34	31.68	11.62	204.45	5.08	87.28	2.92	0.00
ELA-24	190.26	18.34	72.47	498.10	0.00	0.00	0.00	0.00
ELA-25	1442.65	316.01	25.67	71.20	934.88	0.00	4.87	0.00
WAB-26	90.66	0.55	0.00	0.00	0.00	0.00	0.00	0.00
WAB-27	265.20	4.55	7.96	0.00	0.00	0.00	0.00	0.00
VER-28	114.40	9.57	7.96	0.00	10.15	0.00	0.00	0.00

Table C6 Major phytoplankton group biomass for September 2013.

	Bacillariophyta (ug/L)	Chlorophyta (ug/L)	Chrysophyta (ug/L)	Cryptophyta (ug/L)	Cyanophyta (ug/L)	Dinophyta (ug/L)	Euglenophyta (ug/L)	Xanthophyta (ug/L)
VER-1	7.46	7.29	0.79	10.69	22.22	0.00	0.00	0.00
VER-2	118.95	1.71	0.24	11.33	0.00	0.00	0.00	0.00
ONP-3								
ONP-4	859.59	456.37	7.68	11.97	97.15	38.39	3.74	0.00
VER-5	391.38	11.40	61.60	79.97	0.00	0.00	49.72	0.00
VER-6	126.97	28.11	188.23	97.06	15.23	174.56	52.97	0.00
WIT-7	176.24	3.33	0.00	93.50	0.00	0.00	12.51	0.00
WIT-8								
LEV-9	46.50	57.28	26.08	8.32	0.00	0.00	4.06	0.00
VER-10	26.89	17.13	132.18	55.20	54.26	0.00	85.46	0.00
LIL-11	86.55	357.94	84.08	37.65	67.14	25.59	1.62	0.00
CC-12	28.52	0.00	0.00	17.55	0.00	0.00	0.00	1.83
JUN-13	1404.19	43.73	0.00	51.27	1.22	0.00	14.62	0.00
MB-14	198.74	24.73	22.06	46.43	0.00	38.39	5.36	0.00
MUD-15	153.77	47.69	0.00	44.78	1.10	0.00	0.00	0.00
SIM-16	134.27	839.01	0.00	43.87	68.55	0.00	2.92	0.00
MC-17	177.79	1506.90	0.06	116.62	0.00	404.62	0.00	0.00
MC-18	53.92	11.13	7.96	178.04	3.41	0.00	0.00	0.00
MC-19	61.22	247.63	221.74	174.38	10.15	0.00	0.00	0.00
FB-20	50.03	13.79	17.75	157.47	0.00	12.80	62.23	0.00
KUS-21	149.36	7.91	8.29	111.23	17.59	0.00	0.00	0.00
VER-22	130.03	29.93	21.41	82.99	9.30	0.00	0.81	0.00
GRA-23	163.61	11.36	31.85	48.71	27.70	0.00	0.81	0.00
ELA-24	129.53	15.33	33.67	137.91	18.32	0.00	2.92	0.00
ELA-25	155.23	5.75	87.05	57.76	458.69	87.28	6.17	0.00
WAB-26	805.84	20.67	53.25	149.70	1.62	12.80	5.36	0.00
WAB-27	233.88	136.95	3.66	66.72	12.61	12.80	43.38	0.00
VER-28	58.04	18.24	17.34	112.69	1.37	0.00	12.51	0.00

Table C7 Major phytoplankton group biomass for October 2013.

	Bacillariophyta (ug/L)	Chlorophyta (ug/L)	Chrysophyta (ug/L)	Cryptophyta (ug/L)	Cyanophyta (ug/L)	Dinophyta (ug/L)	Euglenophyta (ug/L)	Xanthophyta (ug/L)
VER-1	12.22	4.73	0.24	0.64	0.00	0.00	0.00	0.00
VER-2	186.68	43.74	0.00	17.55	0.00	0.00	0.00	0.00
ONP-3	52.37	31.59	9.63	15.17	7.35	0.00	0.00	0.00
ONP-4	664.74	77.07	11.68	15.81	66.95	12.80	0.00	0.00
VER-5	460.32	40.13	36.90	79.33	2.49	87.28	45.49	0.00
VER-6	179.06	11.45	176.17	98.80	10.42	0.00	31.68	0.00
WIT-7	122.62	45.93	0.00	28.24	0.00	0.00	13.20	0.00
WIT-8	86.86	4.57	0.00	97.15	1.68	0.00	0.00	0.00
LEV-9	36.74	22.63	23.48	102.45	61.74	0.00	15.44	0.00
VER-10	97.12	14.91	220.04	74.85	19.74	87.28	113.09	0.00
LIL-11	158.24	422.89	74.94	29.52	72.51	0.00	6.66	0.00
CC-12	59.75	0.55	0.00	17.55	0.00	0.00	0.00	3.66
JUN-13	260.85	14.30	0.00	3.20	40.62	0.00	14.62	0.00
MB-14	130.73	38.35	19.25	46.43	0.00	0.00	2.92	0.00
MUD-15	91.49	4.14	0.00	62.33	0.00	0.00	0.00	0.00
SIM-16	254.72	26.34	0.00	93.50	0.00	0.00	0.00	0.00
MC-17	306.18	765.79	0.00	167.34	2.44	158.67	0.00	0.00
MC-18	157.45	28.23	7.96	134.81	1.14	0.00	0.00	0.00
MC-19	103.48	15.80	25.75	194.67	21.30	0.00	0.00	0.00
FB-20	137.49	6.70	5.48	179.96	0.08	0.00	35.91	0.00
KUS-21	91.95	4.58	11.62	52.83	0.73	0.00	1.62	0.00
VER-22	75.95	16.30	7.64	155.46	0.00	87.28	14.14	0.00
GRA-23	165.02	23.30	9.38	130.05	37.37	12.80	1.62	0.00
ELA-24	70.61	40.56	13.45	134.72	43.95	12.80	1.62	0.00
ELA-25	136.51	169.02	86.80	58.58	429.26	0.00	19.34	0.00
WAB-26	1141.79	31.94	20.76	187.82	4.94	25.59	21.28	0.00
WAB-27	150.28	7.98	41.19	178.22	0.65	0.00	29.25	0.00
VER-28	77.34	17.25	7.96	67.36	3.81	0.00	3.74	0.00

Table C8 Major phytoplankton group biomass for June 2014.

	Bacillariophyta (ug/L)	Chlorophyta (ug/L)	Chrysophyta (ug/L)	Cryptophyta (ug/L)	Cyanophyta (ug/L)	Dinophyta (ug/L)	Euglenophyta (ug/L)	Xanthophyta (ug/L)
VER-1								
VER-2	51.53	15.11	23.19	58.40	0.00	0.00	11.70	0.00
ONP-3	75.76	73.79	11.62	11.33	0.16	38.39	0.00	0.00
ONP-4	66.62	16.83	12.23	4.48	0.00	25.59	0.81	0.00
VER-5	13.79	20.70	43.63	98.25	7.70	0.00	2.92	0.00
VER-6	80.10	42.31	48.07	120.55	0.00	51.18	5.85	0.00
WIT-7	439.63	40.06	11.62	539.05	0.67	12.80	26.32	0.00
WIT-8	592.89	11.06	5.97	412.92	0.00	12.80	44.19	0.00
LEV-9	289.78	174.02	12.23	119.82	2.19	87.28	0.00	0.00
VER-10	148.33	34.78	26.61	125.21	16.45	25.59	8.77	0.00
LIL-11	96.88	272.50	0.00	18.19	1.10	0.00	2.92	0.00
CC-12	14.26	0.55	0.00	0.00	0.00	0.00	0.00	0.00
JUN-13	228.93	11.48	0.00	205.64	0.00	0.00	0.81	0.00
MB-14	904.87	36.67	29.49	18.19	0.00	12.80	11.70	0.00
MUD-15	194.87	274.34	9.26	674.86	2.24	0.00	0.00	0.00
SIM-16	8.07	27.44	7.96	506.69	1.10	12.80	0.00	0.00
MC-17	14.57	1.28	0.00	237.53	0.00	0.00	3.25	0.00
MC-18	95.36	1.35	0.00	263.40	0.37	12.80	0.00	0.00
MC-19	220.69	23.95	33.23	378.56	0.00	51.18	0.00	0.00
FB-20	171.15	9.77	1.83	67.72	0.00	63.98	2.92	0.00
KUS-21	136.93	32.61	27.84	614.81	0.00	25.59	0.00	0.00
VER-22	204.94	31.94	38.81	337.61	0.00	25.59	0.00	0.00
GRA-23	184.69	57.50	42.16	413.01	0.00	12.80	0.81	0.00
ELA-24	206.40	35.93	65.91	403.69	3.57	63.98	0.00	0.00
ELA-25	1196.52	161.85	58.09	162.41	52.52	63.98	0.00	0.00
WAB-26	265.94	171.15	60.36	631.35	0.41	0.00	16.25	0.00
WAB-27	280.54	101.16	47.16	659.96	0.00	38.39	11.70	0.00
VER-28	245.64	73.38	13.69	275.37	0.00	51.18	0.81	0.00

Table C9 Major phytoplankton group biomass for July 2014.

	Bacillariophyta (ug/L)	Chlorophyta (ug/L)	Chrysophyta (ug/L)	Cryptophyta (ug/L)	Cyanophyta (ug/L)	Dinophyta (ug/L)	Euglenophyta (ug/L)	Xanthophyta (ug/L)
VER-1	16.89	21.26	3.96	11.33	0.65	0.00	0.00	0.00
VER-2	39.12	5.64	1.83	3.84	0.16	0.00	0.00	0.00
ONP-3	14.17	59.69	12.35	22.03	0.24	12.80	0.00	0.00
ONP-4	155.63	49.43	15.46	8.77	0.00	25.59	0.00	0.00
VER-5	137.18	33.01	9.20	19.47	61.04	0.00	9.59	0.00
VER-6	271.55	39.61	6.05	125.30	8.23	102.36	0.00	0.00
WIT-7	255.25	49.49	4.14	196.22	2.96	0.00	38.02	0.00
WIT-8	432.81	16.62	15.92	314.31	0.00	25.59	11.70	0.00
LEV-9	164.03	57.80	0.97	180.78	1.10	0.00	0.00	0.00
VER-10								
LIL-11	36.89	167.40	19.98	0.64	0.00	0.00	0.00	0.00
CC-12	7.19	0.55	0.00	0.00	0.00	0.00	0.00	0.00
JUN-13	171.67	6.44	7.96	80.24	0.00	0.00	3.25	0.00
MB-14	353.17	75.51	22.58	26.96	15.23	0.00	0.00	0.00
MUD-15	424.11	135.23	39.81	176.30	1.10	12.80	0.00	0.00
SIM-16	14.26	785.99	15.92	304.16	0.00	0.00	0.00	1.83
MC-17	6177.86	39.55	0.00	94.78	0.00	115.16	0.00	0.00
MC-18	4303.46	80.92	9.79	223.83	0.00	89.57	0.00	0.00
MC-19	582.05	62.83	31.20	185.44	304.82	25.59	0.81	0.00
FB-20	41.38	7.75	0.00	10.69	1.37	25.59	0.00	0.00
KUS-21	629.49	64.73	7.80	69.37	150.68	12.80	2.92	0.00
VER-22	250.89	41.74	7.31	35.28	70.40	0.00	10.15	0.00
GRA-23	480.64	350.79	6.13	60.32	38.25	25.59	0.00	0.00
ELA-24	463.19	243.48	39.16	100.44	48.99	51.18	0.00	0.00
ELA-25	205.96	41.64	78.03	111.23	103.54	12.80	6.17	0.00
WAB-26	225.97	118.28	10.03	134.35	154.00	0.00	0.81	0.00
WAB-27	423.00	29.77	15.27	389.61	23.21	12.80	23.40	0.00
VER-28								

Table C10 Major phytoplankton group biomass for August 2014.

	Bacillariophyta (ug/L)	Chlorophyta (ug/L)	Chrysophyta (ug/L)	Cryptophyta (ug/L)	Cyanophyta (ug/L)	Dinophyta (ug/L)	Euglenophyta (ug/L)	Xanthophyta (ug/L)
VER-1	9.51	4.75	0.24	0.64	1.18	0.00	0.00	0.00
VER-2	71.39	6.63	0.24	1.28	0.37	0.00	0.00	0.00
ONP-3	29.60	20.18	3.66	19.47	1.52	0.00	5.85	0.00
ONP-4	118.26	82.85	7.96	29.89	0.00	12.80	0.00	0.00
VER-5	472.99	95.68	38.00	51.09	375.97	89.57	64.99	0.00
VER-6	272.91	35.63	132.22	191.47	41.80	89.57	43.87	0.00
WIT-7	267.03	17.29	2.32	335.97	14.58	12.80	2.92	0.00
WIT-8	199.48	7.53	15.92	63.98	8.77	25.59	0.00	0.00
LEV-9	258.50	87.88	7.96	23.49	2.19	12.80	23.40	0.00
VER-10	332.35	27.39	29.45	77.23	8.23	0.00	8.77	0.00
LIL-11	13.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CC-12	98.44	2.17	7.96	8.23	0.00	0.00	0.00	0.00
JUN-13	948.80	869.18	0.00	57.67	54.84	12.80	4.87	0.00
MB-14	387.67	21.05	3.66	90.94	5.48	25.59	0.00	0.00
MUD-15	844.42	191.73	558.03	288.26	16.25	38.39	0.81	0.00
SIM-16	6.70	1322.31	15.92	10.05	0.00	261.85	0.00	0.00
MC-17	813.20	3114.78	0.00	27.60	228.49	51.18	0.00	0.00
MC-18	1297.30	2902.76	47.77	74.03	130.08	51.18	0.00	0.00
MC-19	913.73	65.78	49.19	81.07	65.88	38.39	102.69	0.00
FB-20	169.43	4.68	7.96	87.74	0.00	0.00	2.92	0.00
KUS-21	155.44	17.05	9.79	386.87	3.35	51.18	0.00	0.00
VER-22	254.15	30.42	0.00	149.34	4.93	25.59	0.00	0.00
GRA-23	391.14	56.21	70.37	252.25	1.07	38.39	0.00	0.00
ELA-24	102.97	6.58	0.00	93.50	0.08	25.59	0.00	0.00
ELA-25	584.48	310.62	30.14	261.48	1169.72	212.95	0.81	0.00
WAB-26	443.52	1.22	26.24	150.62	0.00	87.28	36.72	0.00
WAB-27	1097.77	95.89	17.30	84.91	38.61	174.56	2.92	0.00
VER-28	372.88	38.42	22.99	48.53	50.88	0.00	3.25	0.00

Table C11 Major phytoplankton group biomass for September 2014.

	Bacillariophyta (ug/L)	Chlorophyta (ug/L)	Chrysophyta (ug/L)	Cryptophyta (ug/L)	Cyanophyta (ug/L)	Dinophyta (ug/L)	Euglenophyta (ug/L)	Xanthophyta (ug/L)
VER-1	54.59	18.21	18.30	1.28	1.10	12.80	1.62	0.00
VER-2	51.30	31.13	3.90	7.68	2.50	0.00	0.81	0.00
ONP-3	96.94	73.78	7.96	35.10	0.65	38.39	0.00	0.00
ONP-4	125.37	37.35	0.00	0.00	0.49	0.00	0.00	0.00
VER-5	256.30	76.66	76.97	150.53	299.25	0.00	16.25	0.00
VER-6	223.44	21.42	204.36	72.75	63.40	12.80	9.75	0.00
WIT-7	262.60	15.98	53.25	100.53	104.09	0.00	35.83	0.00
WIT-8	73.12	7.47	0.00	99.07	5.08	0.00	0.00	0.00
LEV-9	31.68	19.00	0.00	174.38	1.74	0.00	19.17	0.00
VER-10	269.30	19.26	89.93	118.26	12.15	0.00	8.77	0.00
LIL-11	208.03	138.62	0.00	96.51	1.09	0.00	0.00	0.00
CC-12	57.03	6.58	0.00	0.00	0.15	0.00	0.00	0.00
JUN-13	2557.69	903.06	0.00	234.70	0.00	0.00	0.00	0.00
MB-14	113.89	5.73	17.10	45.15	18.28	0.00	0.00	0.00
MUD-15	613.14	139.89	79.61	358.08	0.00	0.00	0.00	0.00
SIM-16	157.38	17.48	95.78	199.79	1.55	87.28	0.00	1.83
MC-17	55.93	4.13	56.22	42.13	13.40	0.00	0.00	0.00
MC-18	148.34	995.29	0.00	0.00	2.14	0.00	0.00	0.00
MC-19	363.80	50.65	77.18	98.98	250.95	0.00	9.42	0.00
FB-20	103.15	10.11	9.79	77.50	0.24	38.39	26.32	0.00
KUS-21	631.81	29.56	9.14	257.55	97.76	12.80	13.81	0.00
VER-22	186.48	15.91	18.93	528.44	80.20	12.80	16.25	0.00
GRA-23	264.29	32.06	15.27	399.58	4.14	174.56	5.85	0.00
ELA-24	606.10	47.32	7.96	215.14	2.19	12.80	14.30	0.00
ELA-25	717.88	199.46	25.71	88.10	2175.07	200.15	2.44	0.00
WAB-26								
WAB-27								
VER-28	836.23	29.75	60.38	223.09	153.42	212.95	31.68	0.00

Table C12 Major phytoplankton group biomass for October 2014.

	Bacillariophyta (ug/L)	Chlorophyta (ug/L)	Chrysophyta (ug/L)	Cryptophyta (ug/L)	Cyanophyta (ug/L)	Dinophyta (ug/L)	Euglenophyta (ug/L)	Xanthophyta (ug/L)
VER-1	16.21	174.34	7.74	30.80	14.62	25.59	0.00	0.00
VER-2	67.60	18.40	11.21	11.33	0.00	0.00	0.00	0.00
ONP-3	96.77	87.84	25.71	21.39	0.00	0.00	0.00	0.00
ONP-4	1177.62	25.44	10.03	13.25	94.38	63.98	0.00	0.00
VER-5	69.99	30.73	13.59	113.33	5.08	12.80	38.02	0.00
VER-6	273.76	2.75	30.75	202.90	21.39	0.00	94.40	0.00
WIT-7	112.84	15.84	7.96	96.70	0.00	0.00	29.25	0.00
WIT-8	164.67	5.48	18.36	73.39	6.30	0.00	18.36	0.00
LEV-9	32.62	62.22	0.00	105.47	49.17	0.00	14.14	0.00
VER-10	142.82	27.31	10.76	159.30	82.79	0.00	46.79	0.00
LIL-11	59.75	0.55	0.00	0.00	3.29	0.00	0.00	0.00
CC-12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
JUN-13	285.49	129.01	0.00	235.16	1.10	0.00	0.00	0.00
MB-14	479.75	15.66	344.25	64.62	34.00	38.39	0.00	0.91
MUD-15	740.25	44.46	0.00	645.43	0.00	12.80	0.00	0.00
SIM-16	243.57	1398.62	23.88	230.22	0.00	0.00	8.94	0.00
MC-17	168.59	11.50	15.92	166.89	0.00	87.28	21.12	0.00
MC-18	227.01	24.78	7.96	178.22	93.22	87.28	42.57	0.00
MC-19	237.45	288.63	33.31	178.86	4.27	25.59	28.11	0.00
FB-20	47.68	23.63	15.92	7.59	1.13	0.00	20.47	0.00
KUS-21	388.84	16.53	40.38	249.69	3.48	0.00	24.86	0.00
VER-22	222.78	41.66	12.10	238.63	4.87	12.80	6.17	0.00
GRA-23	355.53	81.47	44.26	289.08	197.06	12.80	16.25	0.00
ELA-24	360.87	21.36	28.03	249.78	9.67	0.00	27.46	0.00
ELA-25	61.22	155.97	30.55	215.23	352.81	583.08	0.81	0.00
WAB-26	116.16	279.81	71.73	267.33	0.16	12.80	12.51	0.00
WAB-27	199.28	56.82	43.46	588.03	35.89	25.59	20.31	0.00
VER-28	413.01	36.66	16.25	58.13	85.63	0.00	5.85	0.00

Table C13 Major phytoplankton group biomass for November 2014.

	Bacillariophyta (ug/L)	Chlorophyta (ug/L)	Chrysophyta (ug/L)	Cryptophyta (ug/L)	Cyanophyta (ug/L)	Dinophyta (ug/L)	Euglenophyta (ug/L)	Xanthophyta (ug/L)
VER-1	25.62	17.41	10.89	35.92	2.99	0.00	32.17	0.00
VER-2	36.07	30.70	5.06	67.81	0.00	0.00	11.70	0.00
ONP-3	19.69	18.45	7.49	24.59	0.16	0.00	52.64	0.00
ONP-4	240.17	15.33	23.23	32.72	0.41	25.59	0.00	0.00
VER-5	49.54	19.78	13.45	37.20	15.97	0.00	23.40	0.00
VER-6	55.71	15.09	34.28	90.66	1.52	12.80	22.91	0.00
WIT-7	98.55	6.12	3.66	31.07	86.95	0.00	3.25	0.00
WIT-8	69.23	3.77	0.00	35.10	10.15	0.00	0.00	0.00
LEV-9	248.21	120.57	60.81	277.84	2.74	0.00	18.20	0.00
VER-10	35.24	21.71	14.05	63.52	0.00	0.00	6.66	0.00
LIL-11	163.43	21.41	0.00	17.55	8.12	25.59	0.00	0.00
CC-12	76.89	0.65	0.00	0.00	0.00	0.00	0.00	0.00
JUN-13	238.49	9.93	0.00	12.61	0.00	0.00	0.00	0.00
MB-14	16.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MUD-15	270.90	1.95	0.00	18.37	0.00	0.00	5.85	9.75
SIM-16	137.32	7.92	0.00	190.83	0.00	0.00	6.66	0.00
MC-17	169.91	8.78	7.96	91.12	0.00	0.00	5.85	0.00
MC-18	91.69	8.24	10.03	290.27	0.63	25.59	57.52	0.00
MC-19	70.68	15.27	28.27	37.75	0.00	0.00	8.77	0.00
FB-20	7.47	8.56	13.45	123.02	4.87	0.00	382.64	0.00
KUS-21	71.93	25.83	26.79	57.49	4.27	25.59	47.12	0.00
VER-22	113.44	9.33	9.51	45.97	0.00	0.00	19.17	0.00
GRA-23	82.08	27.78	12.47	113.15	18.18	12.80	2.92	0.00
ELA-24	28.92	8.14	21.41	78.05	45.06	25.59	11.54	0.00
ELA-25	187.91	74.46	64.10	188.46	16.88	12.80	60.60	0.00
WAB-26	41.96	14.89	32.74	115.07	19.82	0.00	15.44	0.00
WAB-27	48.75	26.49	7.96	76.77	6.76	12.80	7.47	0.00
VER-28	60.55	27.10	25.96	104.37	0.00	0.00	2.92	0.00

Table C14 Annual averages for major phytoplankton group biomass for 2013.

	Bacillariophyta (ug/L)	Chlorophyta (ug/L)	Chrysophyta (ug/L)	Cryptophyta (ug/L)	Cyanophyta (ug/L)	Dinophyta (ug/L)	Euglenophyta (ug/L)	Xanthophyta (ug/L)
VER-1								
VER-2	86.90	24.72	1.37	21.49	0.89	4.27	0.41	0.00
ONP-3								
ONP-4	382.52	133.00	9.82	12.32	33.00	19.19	4.79	0.00
VER-5	244.42	33.70	53.93	119.29	26.62	38.00	34.04	0.00
VER-6	250.77	58.36	123.09	107.50	60.67	122.54	23.56	0.00
WIT-7								
WIT-8								
LEV-9								
VER-10								
LIL-11								
CC-12	35.30	1.12	0.00	5.85	5.01	0.00	0.00	0.91
JUN-13								
MB-14	226.55	44.54	18.16	21.84	0.28	57.58	2.00	0.30
MUD-15	225.98	1156.88	8.93	323.11	0.37	2.13	0.00	0.00
SIM-16	95.56	598.38	4.02	370.45	11.97	4.27	0.97	0.00
MC-17	228.56	619.61	5.15	330.70	1.37	100.28	0.49	0.00
MC-18	65.02	39.80	27.57	204.95	0.76	12.80	1.25	0.00
MC-19	112.54	64.26	68.16	187.72	47.38	23.46	0.97	0.00
FB-20	58.19	63.96	6.53	131.09	13.71	4.27	30.34	0.00
KUS-21	142.77	44.40	82.95	232.61	56.77	27.34	3.93	0.00
VER-22	160.06	29.03	41.00	231.73	106.29	55.07	4.58	0.00
GRA-23	168.11	66.62	36.21	186.95	48.96	29.47	1.38	0.00
ELA-24	118.75	47.58	46.96	259.21	20.22	10.66	3.47	0.00
ELA-25	937.66	177.00	130.84	171.24	381.25	62.45	10.40	0.00
WAB-26	424.54	29.61	59.49	280.75	2.56	27.72	5.90	0.00
WAB-27	341.87	81.07	50.68	271.59	14.90	40.14	15.52	0.00
VER-28	150.16	23.85	17.88	143.05	4.34	8.53	5.96	0.00

Table C 15 Annual averages for major phytoplankton group biomass for 2014.

	Bacillariophyta (ug/L)	Chlorophyta (ug/L)	Chrysophyta (ug/L)	Cryptophyta (ug/L)	Cyanophyta (ug/L)	Dinophyta (ug/L)	Euglenophyta (ug/L)	Xanthophyta (ug/L)
VER-1								
VER-2	52.83	17.93	7.57	25.06	0.50	0.00	4.03	0.00
ONP-3	55.49	55.62	11.46	22.32	0.46	14.93	9.75	0.00
ONP-4	313.94	37.87	11.49	14.85	15.88	25.59	0.14	0.00
VER-5	166.63	46.09	32.47	78.31	127.50	17.06	25.86	0.00
VER-6	196.24	26.13	75.96	133.94	22.72	44.78	29.46	0.00
WIT-7	239.32	24.13	13.82	216.59	34.87	4.27	22.60	0.00
WIT-8	255.37	8.66	9.36	166.46	5.05	10.66	12.38	0.00
LEV-9	170.80	86.91	13.66	146.96	9.85	16.68	12.48	0.00
VER-10								
LIL-11	96.49	100.08	3.33	22.15	2.27	4.27	0.49	0.00
CC-12	42.30	1.75	1.33	14.74	0.03	0.00	0.00	0.00
JUN-13	738.51	321.52	1.33	137.67	9.32	2.13	1.49	0.00
MB-14	376.02	25.77	69.51	40.98	12.17	12.80	1.95	0.15
MUD-15	514.62	131.27	114.45	360.22	3.26	10.66	1.11	1.62
SIM-16	94.55	593.29	26.58	240.29	0.44	60.32	2.60	0.61
MC-17	1233.35	530.00	13.35	110.01	40.32	42.27	5.04	0.00
MC-18	1027.19	668.89	12.59	171.62	37.74	44.40	16.68	0.00
MC-19	398.07	84.52	42.06	160.11	104.32	23.46	24.97	0.00
FB-20	90.04	10.75	8.16	62.38	1.27	21.33	72.55	0.00
KUS-21	335.74	31.05	20.29	272.63	43.26	21.33	14.79	0.00
VER-22	205.45	28.50	14.44	222.55	26.73	12.80	8.62	0.00
GRA-23	293.06	100.97	31.78	254.56	43.12	46.15	4.31	0.00
ELA-24	294.74	60.47	27.08	190.10	18.26	29.86	8.88	0.00
ELA-25	492.33	157.33	47.77	171.15	645.09	180.96	11.81	0.00
WAB-26								
WAB-27								
VER-28								

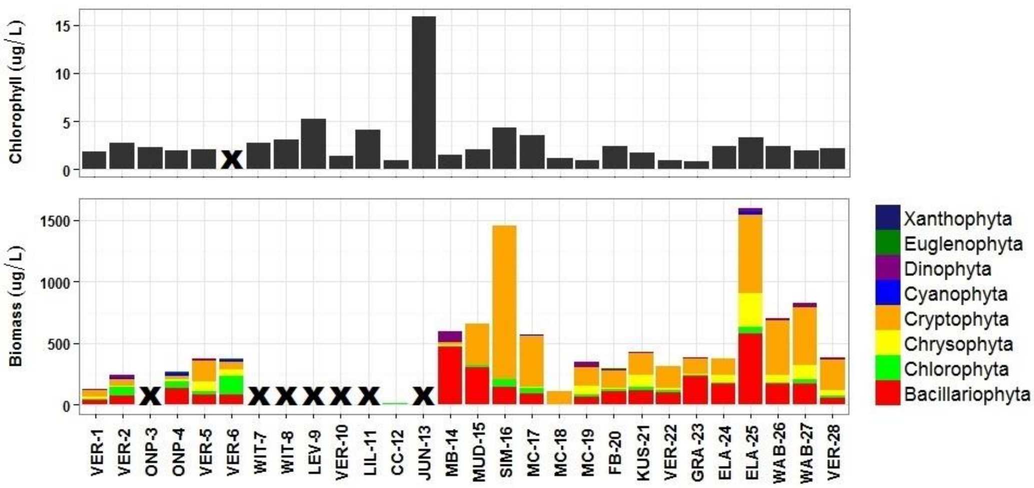

Figure C1 Spatial patterns of chlorophyll-a and phytoplankton biomass for May 2013.

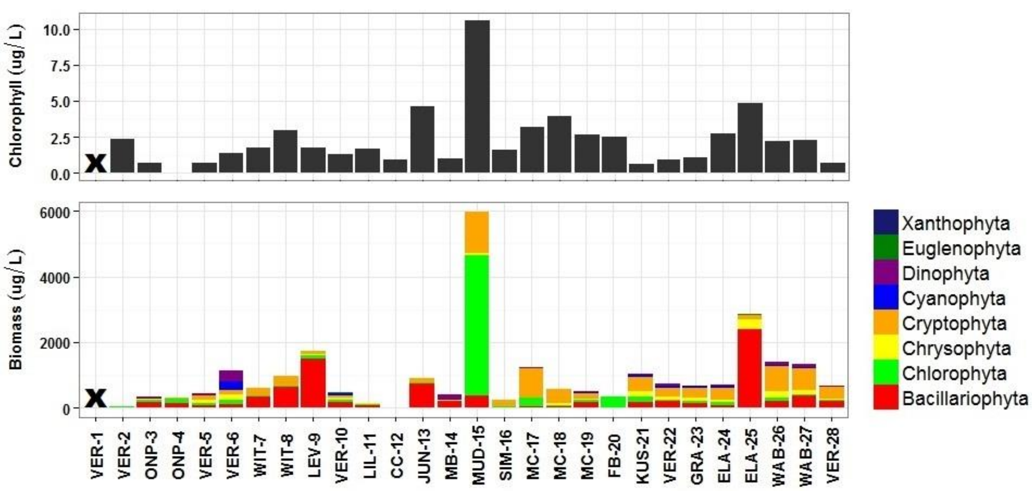

Figure C2 Spatial patterns of chlorophyll-a and phytoplankton biomass for June 2013.

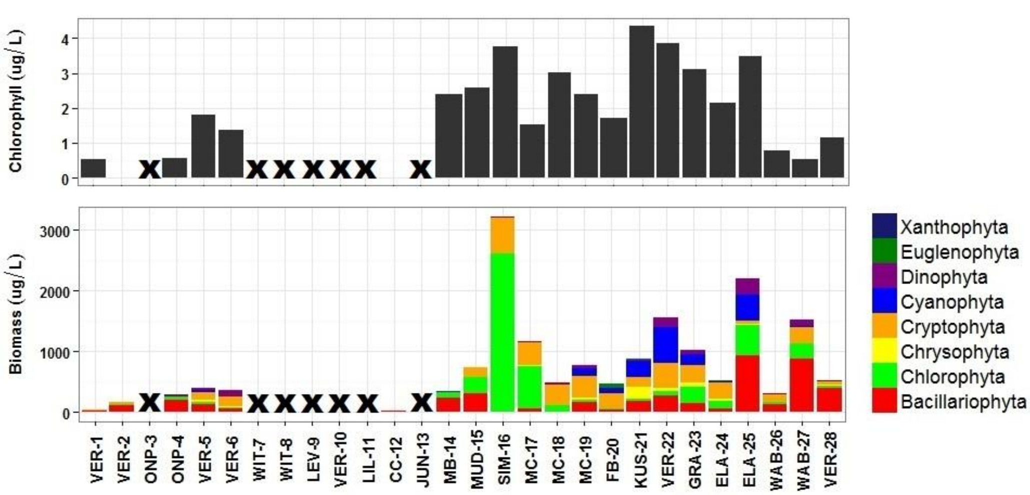

Figure C3 Spatial patterns of chlorophyll-a and phytoplankton biomass for July 2013.

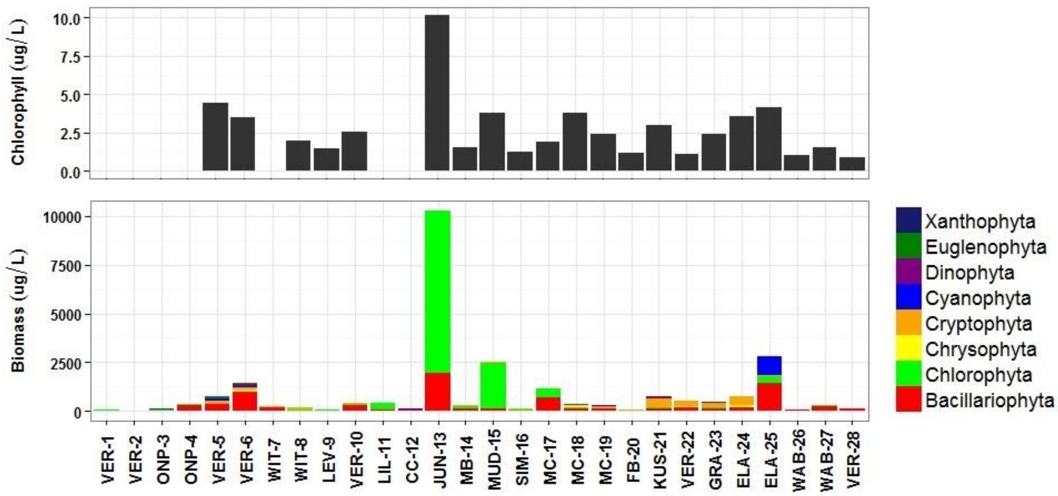

Figure C4 Spatial patterns of chlorophyll-a and phytoplankton biomass for August 2013.

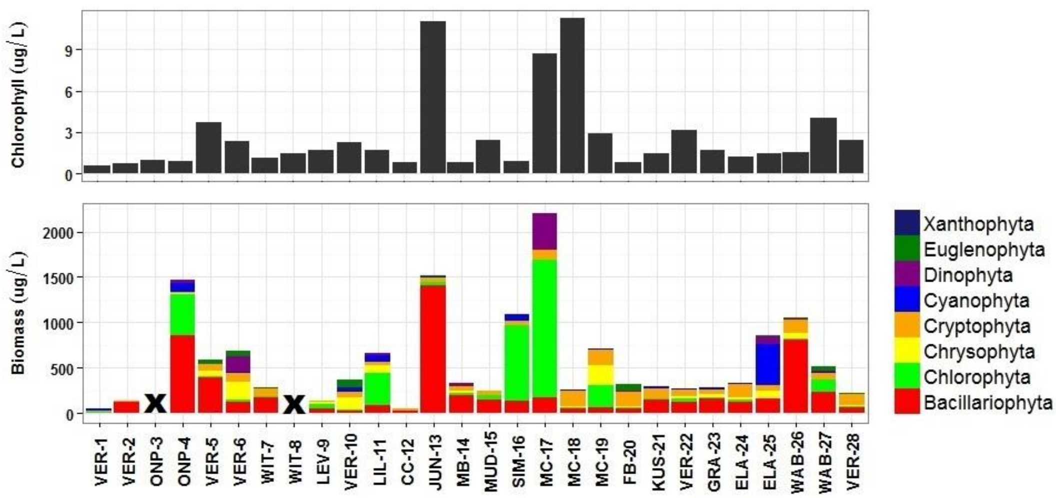

Figure C5 Spatial patterns of chlorophyll-a and phytoplankton biomass for September 2013.

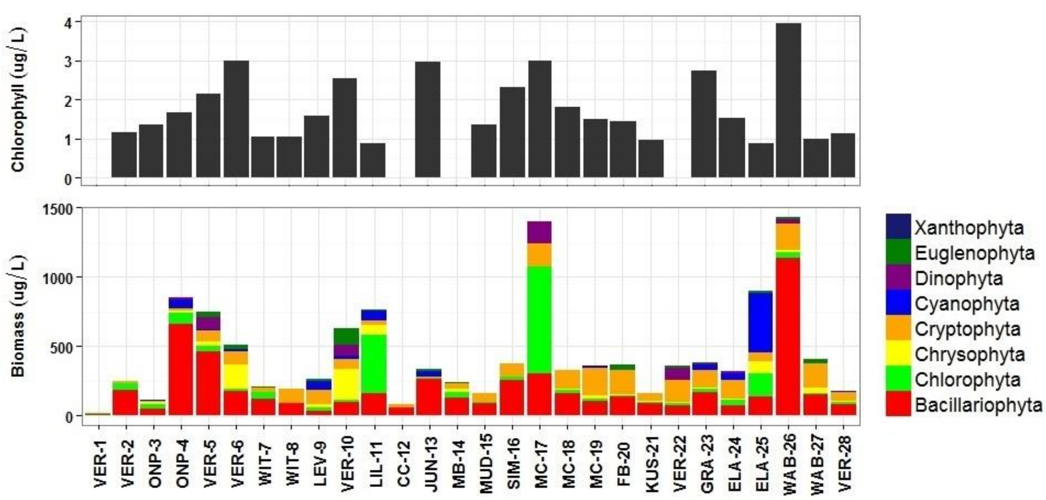

Figure C6 Spatial patterns of chlorophyll-a and phytoplankton biomass for October 2013.

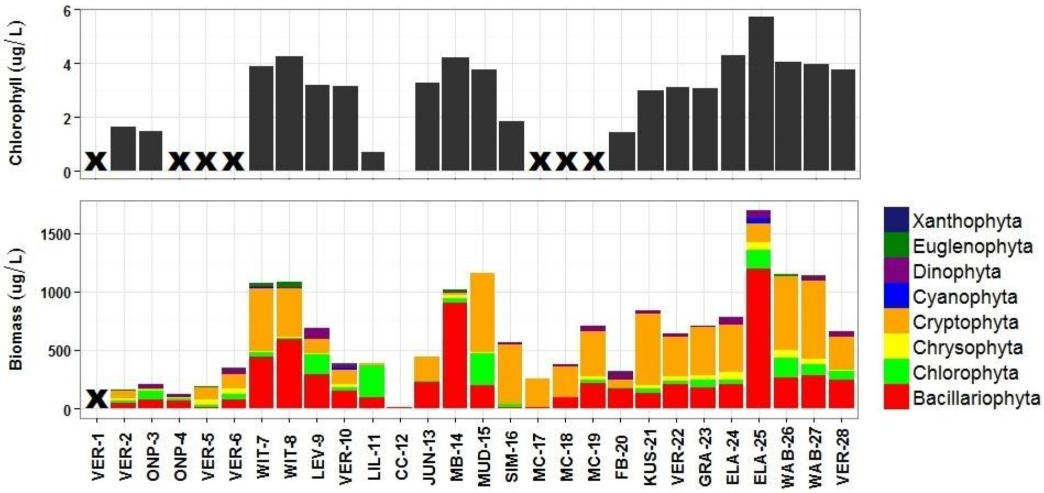

Figure C7 Spatial patterns of chlorophyll-a and phytoplankton biomass for June 2014.

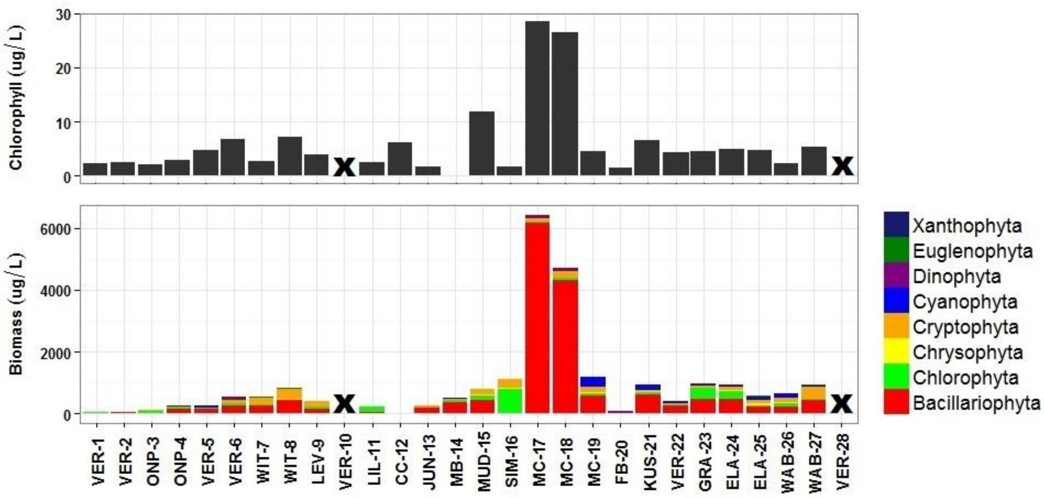

Figure C8 Spatial patterns of chlorophyll-a and phytoplankton biomass for July 2014.

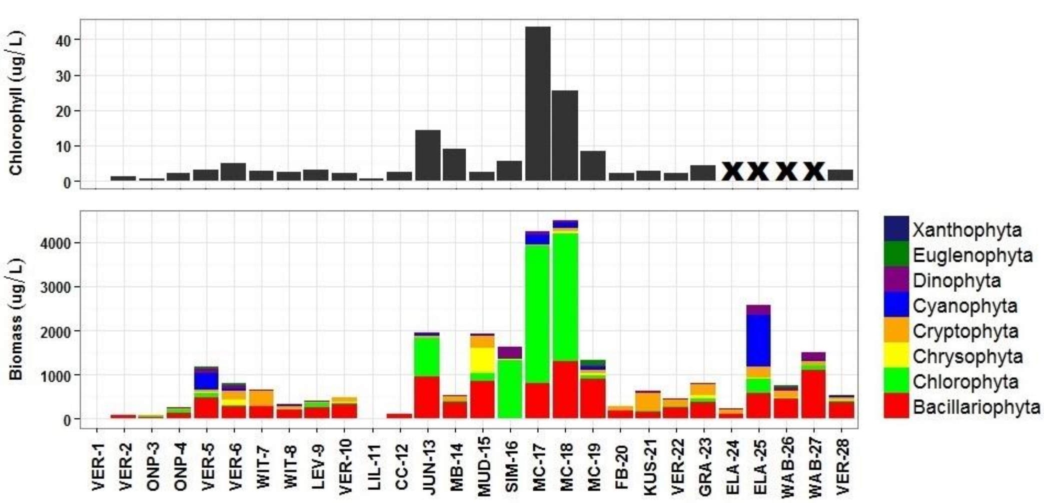

Figure C9 Spatial patterns of chlorophyll-a and phytoplankton biomass for August 2014.

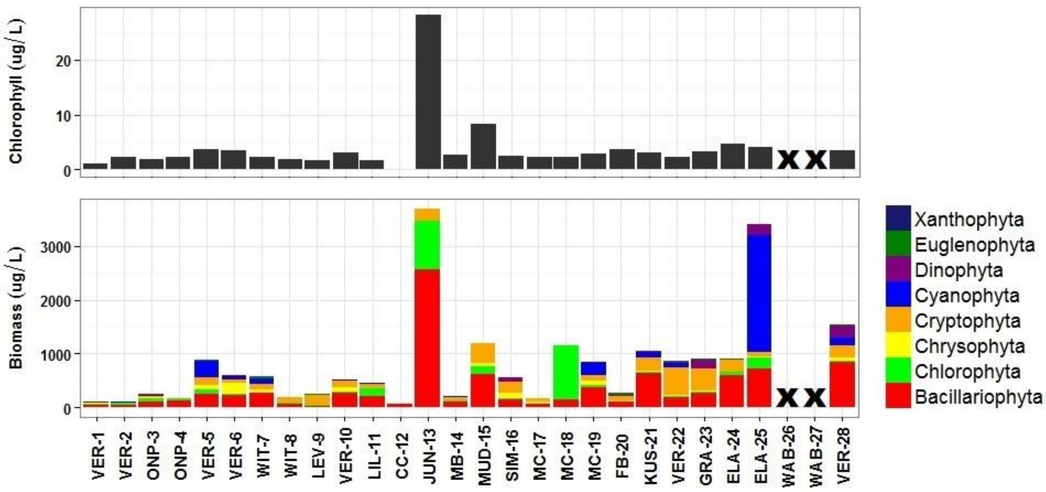

Figure C10 Spatial patterns of chlorophyll-a and phytoplankton biomass for September 2014.

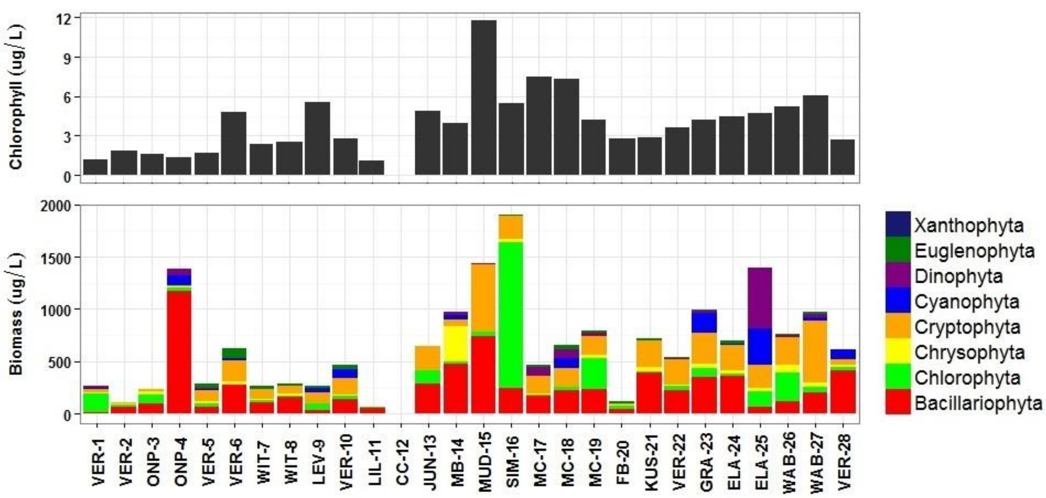

Figure C11 Spatial patterns of chlorophyll-a and phytoplankton biomass for October 2014.

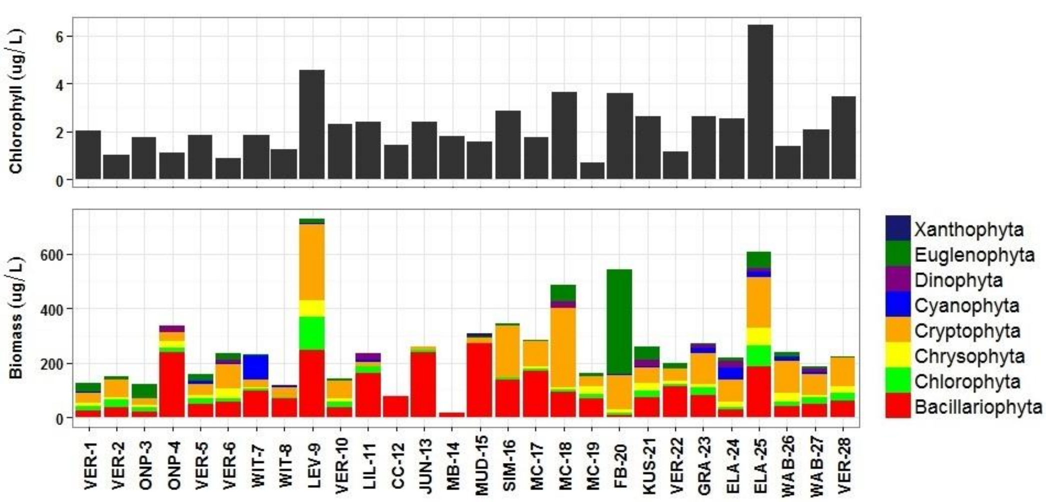

Figure C12 Spatial patterns of chlorophyll-a and phytoplankton biomass for November 2014.

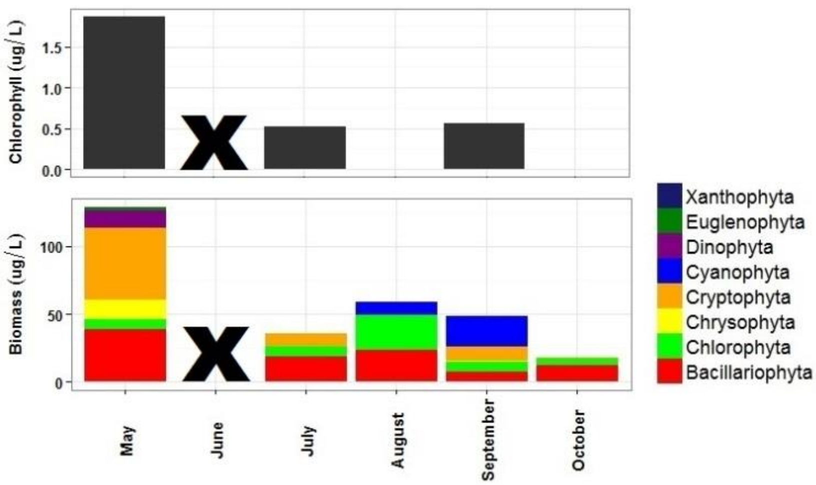

Figure C13 Temporal patterns of chlorophyll-a and phytoplankton biomass for VER-1 in 2013.

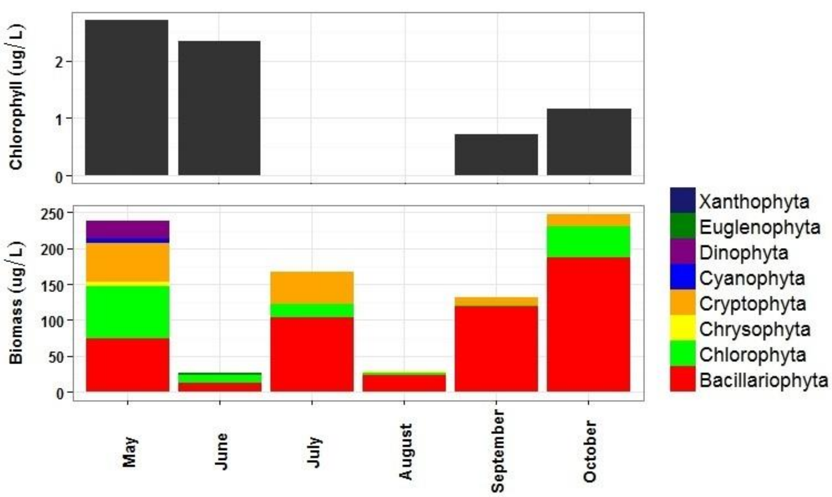

Figure C14 Temporal patterns of chlorophyll-a and phytoplankton biomass for VER-2 in 2013.

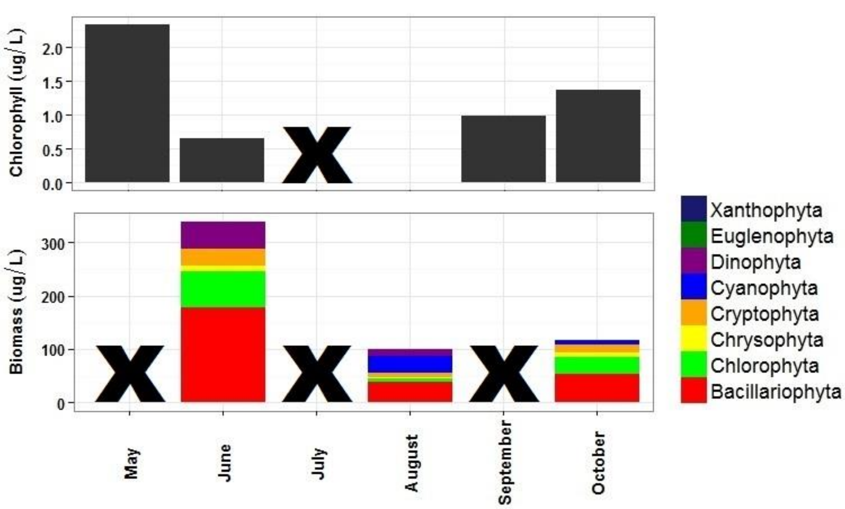

Figure C15 Temporal patterns of chlorophyll-a and phytoplankton biomass for ONP-3 in 2013.

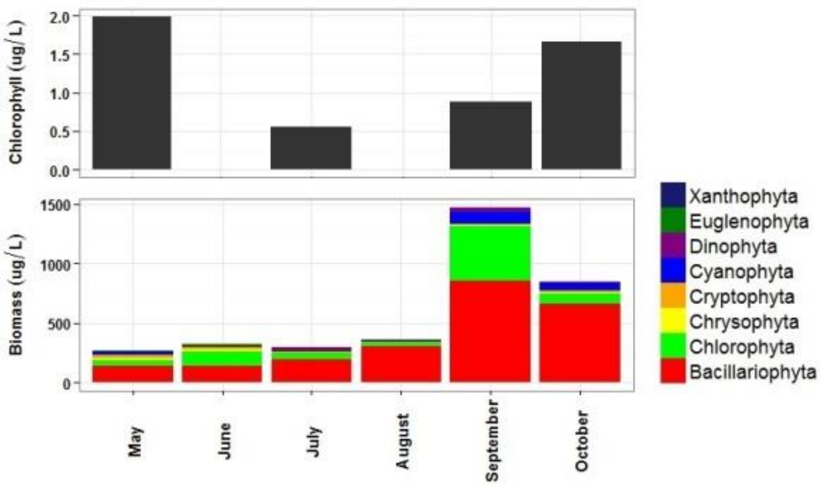

Figure C16 Temporal patterns of chlorophyll-a and phytoplankton biomass for ONP-4 in 2013.

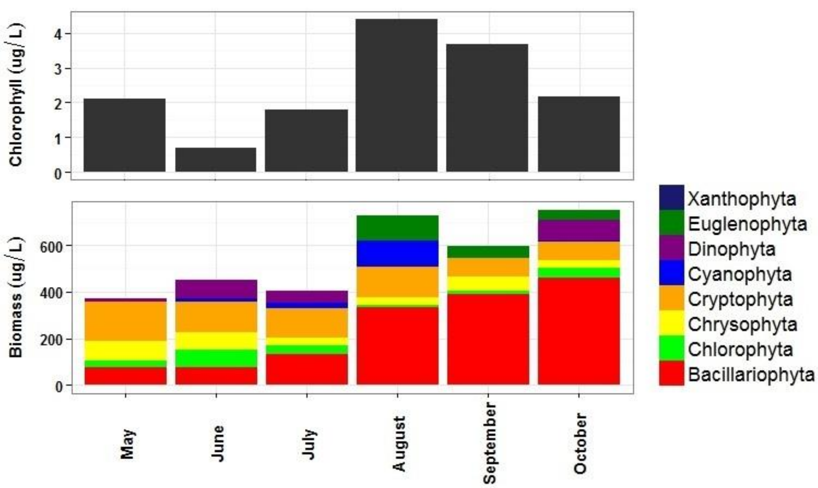

Figure C17 Temporal patterns of chlorophyll-a and phytoplankton biomass for VER-5 in 2013.

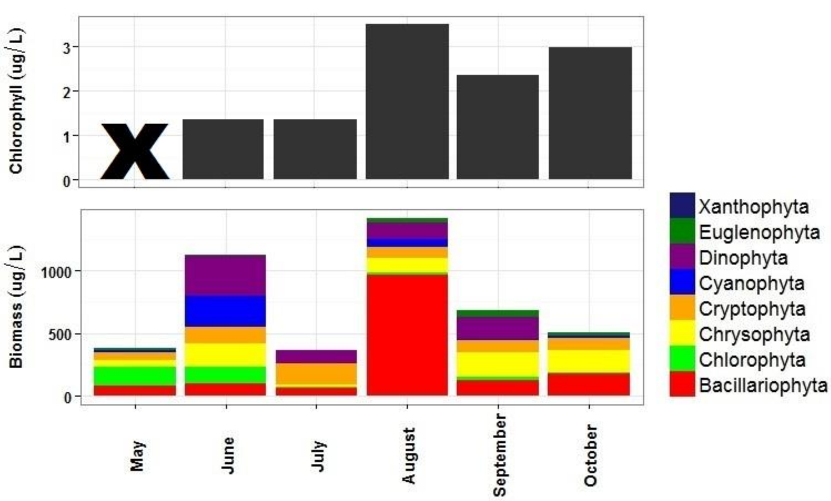

Figure C18 Temporal patterns of chlorophyll-a and phytoplankton biomass for VER-6 in 2013.

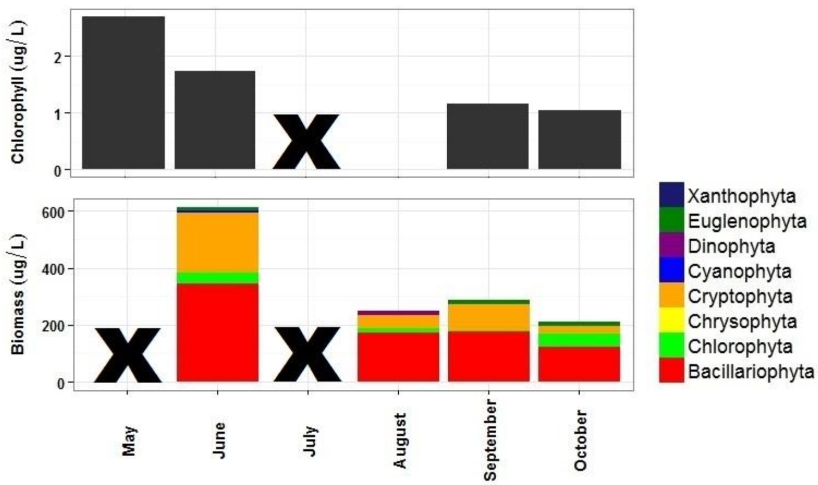

Figure C19 Temporal patterns of chlorophyll-a and phytoplankton biomass for WIT-7 in 2013.

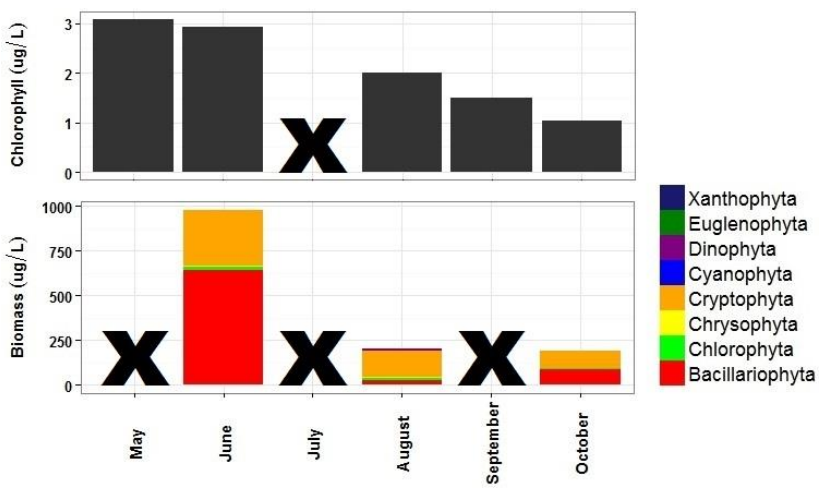

Figure C20 Temporal patterns of chlorophyll-a and phytoplankton biomass for WIT-8 in 2013.

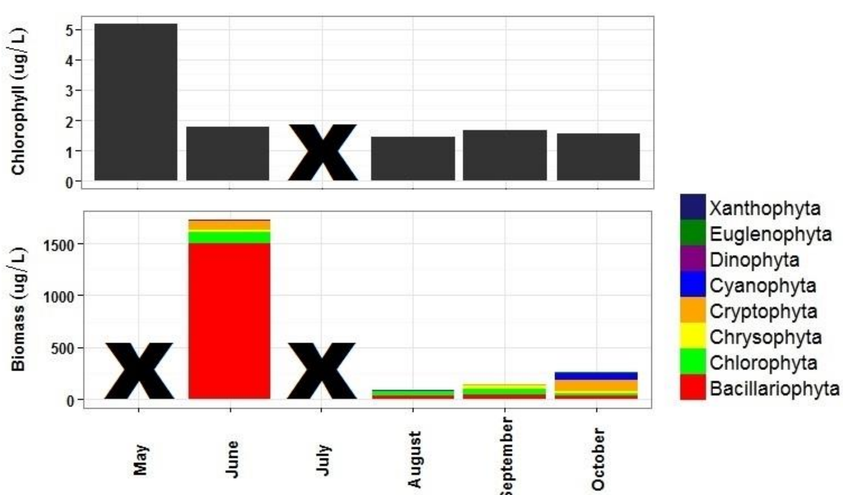

Figure C21 Temporal patterns of chlorophyll-a and phytoplankton biomass for LEV-9 in 2013.

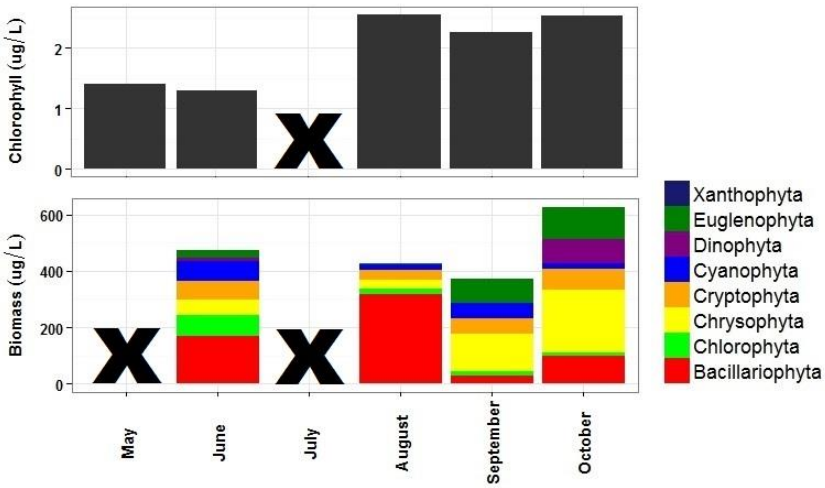

Figure C22 Temporal patterns of chlorophyll-a and phytoplankton biomass for VER-10 in 2013.

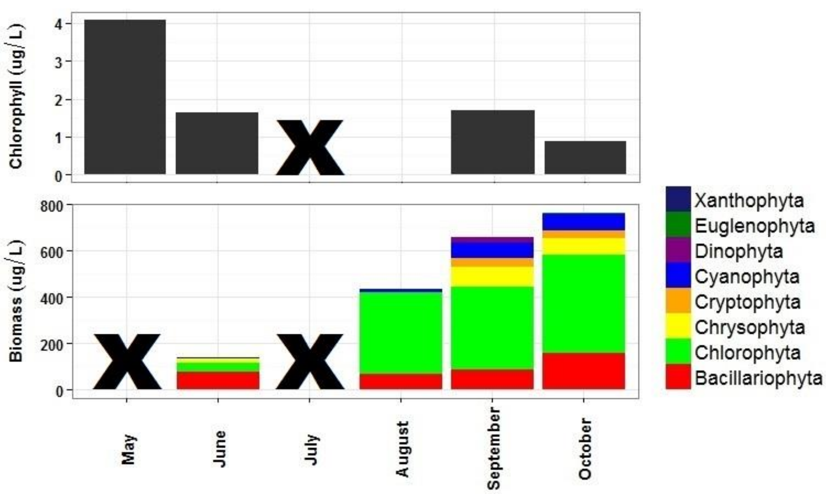

Figure C23 Temporal patterns of chlorophyll-a and phytoplankton biomass for LIL-11 in 2013.

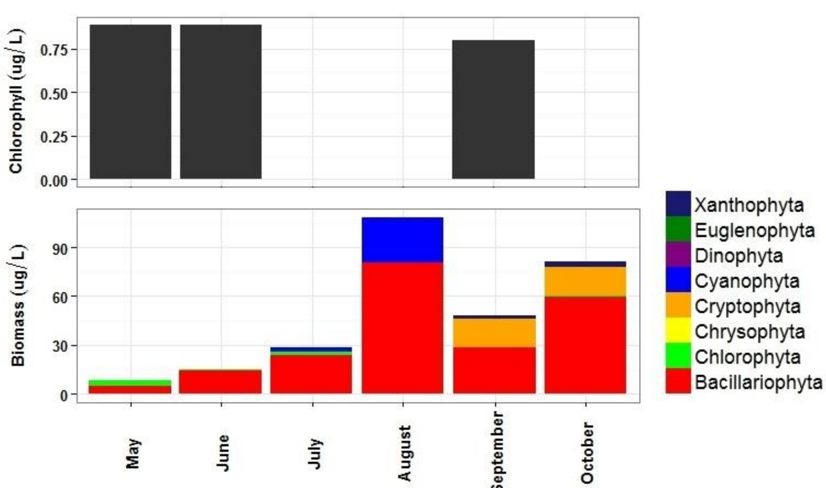

Figure C24 Temporal patterns of chlorophyll-a and phytoplankton biomass for CC-12 in 2013.

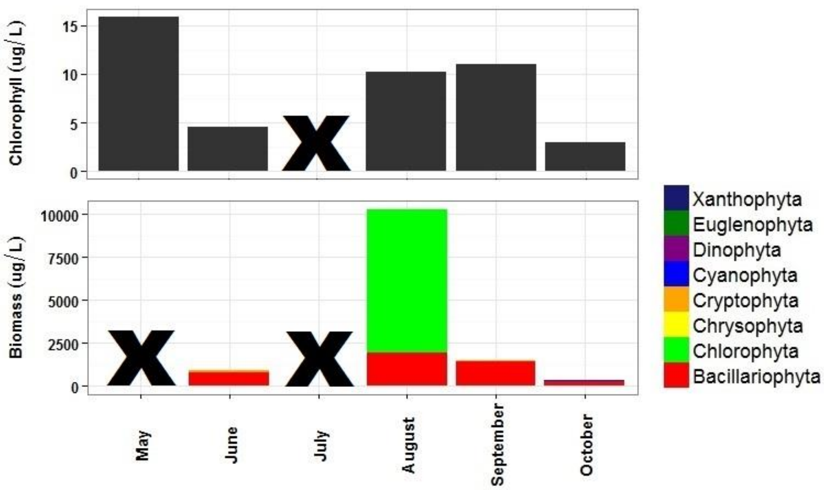

Figure C25 Temporal patterns of chlorophyll-a and phytoplankton biomass for JUN-13 in 2013.

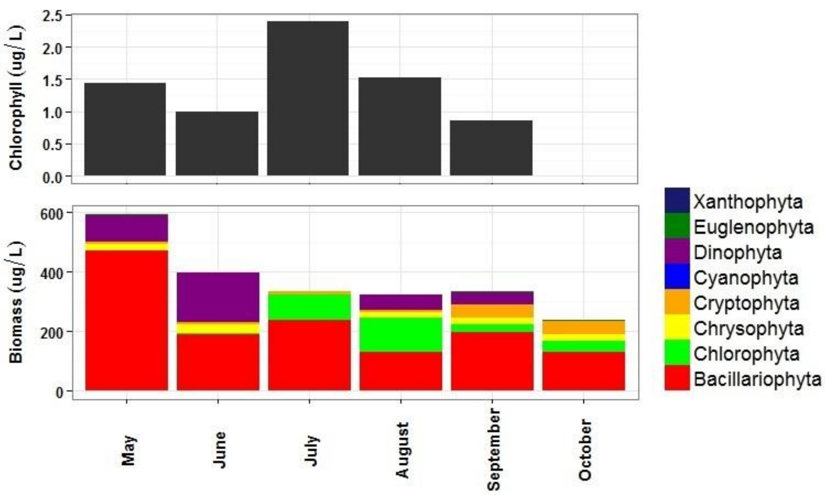

Figure C26 Temporal patterns of chlorophyll-a and phytoplankton biomass for MB-14 in 2013.

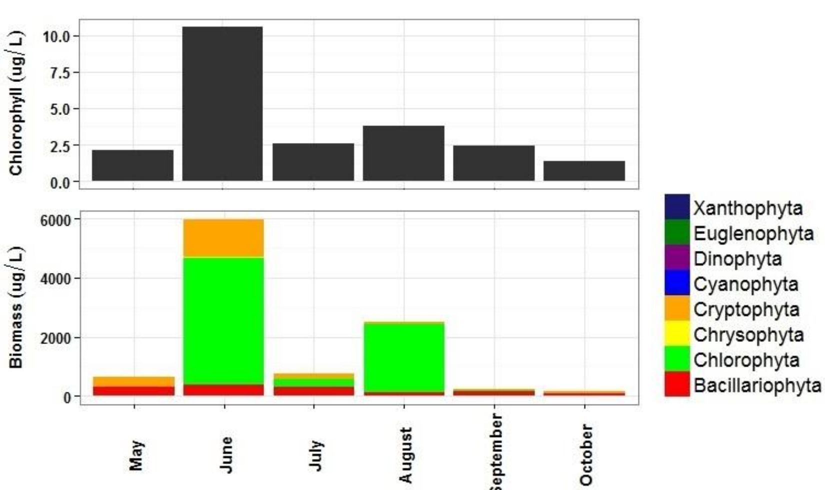

Figure C27 Temporal patterns of chlorophyll-a and phytoplankton biomass for MUD-15 in 2013.

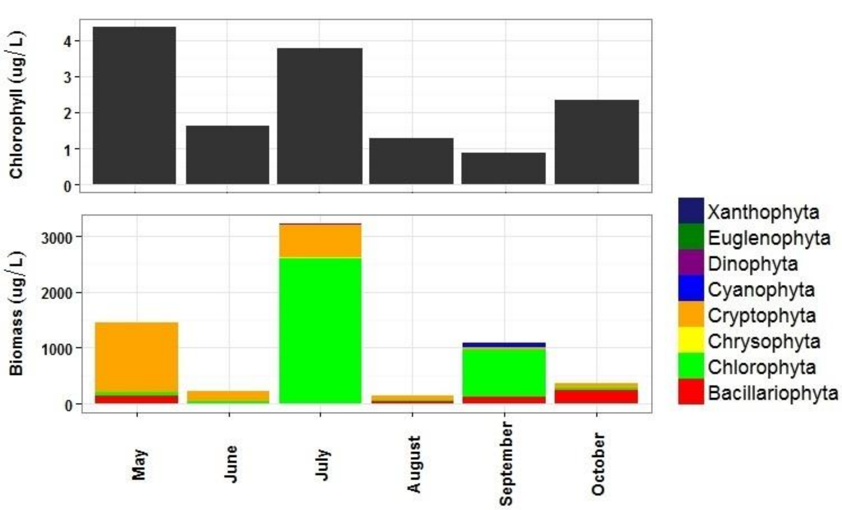

Figure C28 Temporal patterns of chlorophyll-a and phytoplankton biomass for SIM-16 in 2013.

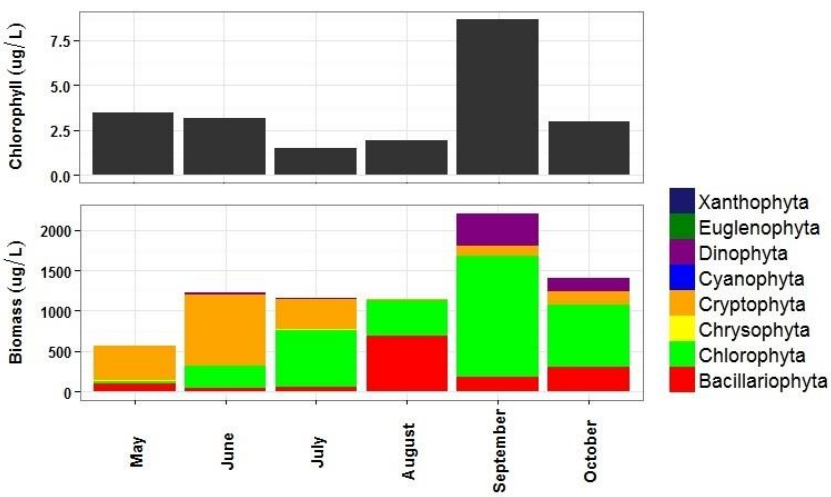

Figure C29 Temporal patterns of chlorophyll-a and phytoplankton biomass for MC-17 in 2013.

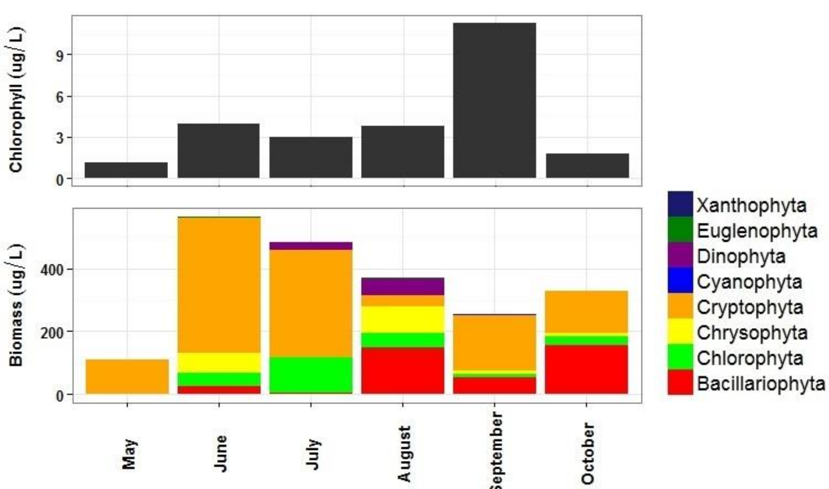

Figure C30 Temporal patterns of chlorophyll-a and phytoplankton biomass for MC-18 in 2013.

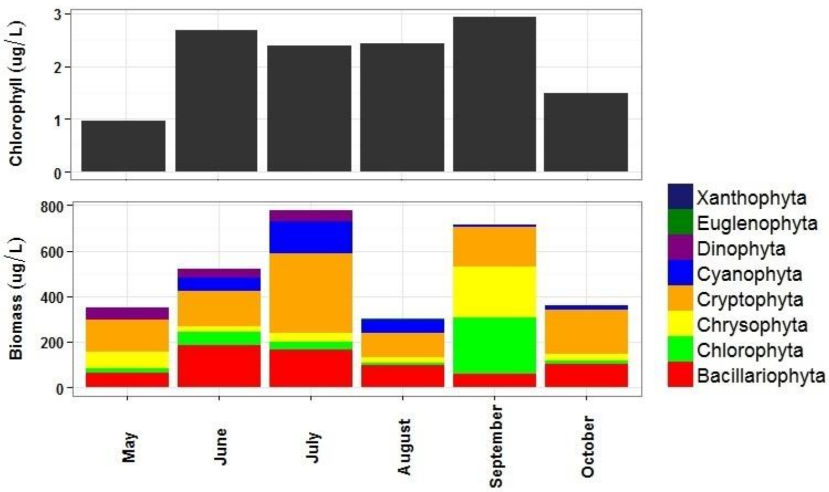

Figure C31 Temporal patterns of chlorophyll-a and phytoplankton biomass for MC-19 in 2013.

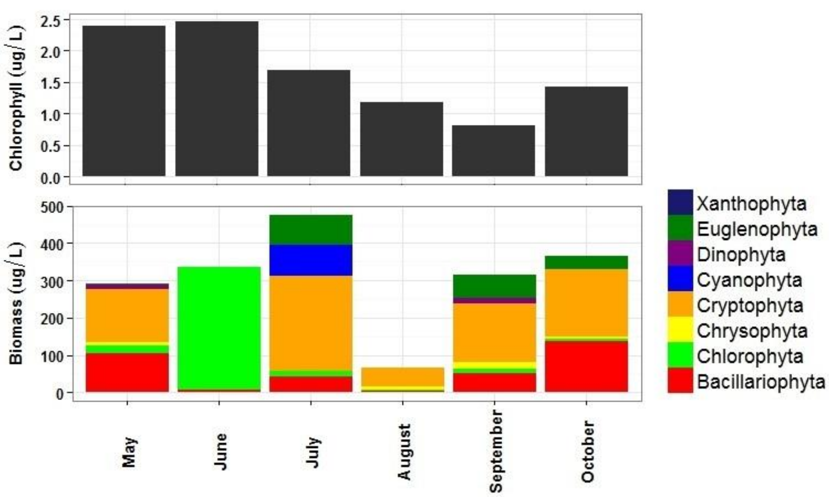

Figure C32 Temporal patterns of chlorophyll-a and phytoplankton biomass for FB-20 in 2013.

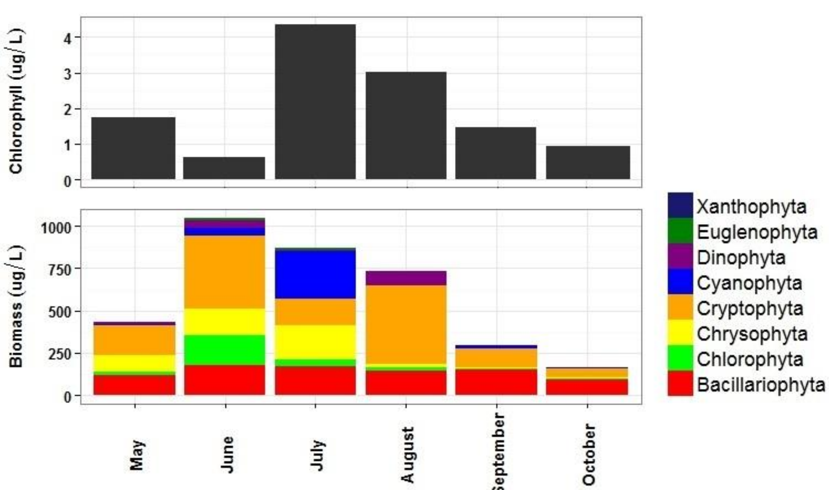

Figure C33 Temporal patterns of chlorophyll-a and phytoplankton biomass for KUS-21 in 2013.

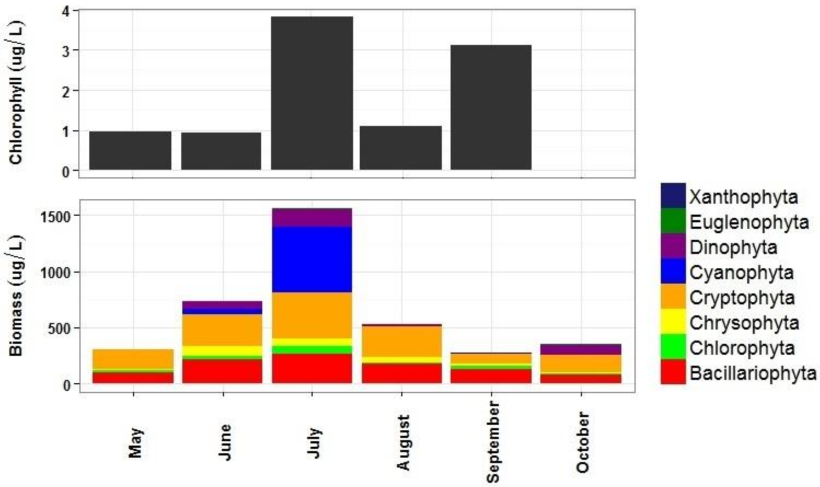

Figure C34 Temporal patterns of chlorophyll-a and phytoplankton biomass for VER-22 in 2013.

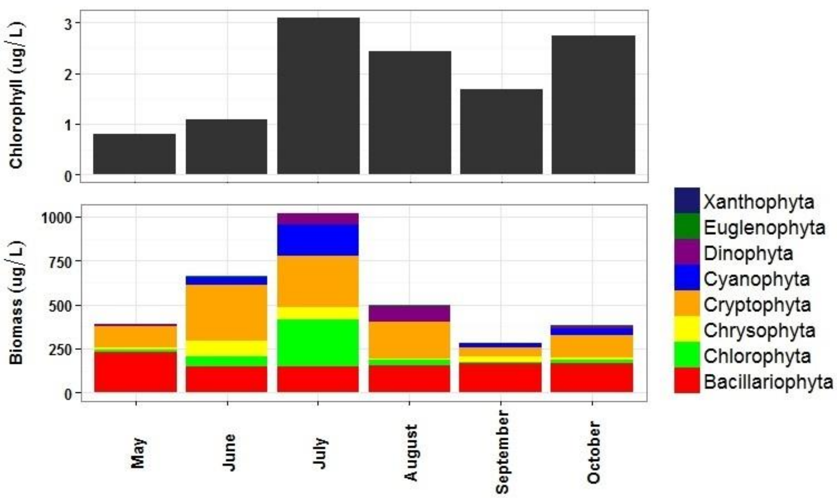

Figure C35 Temporal patterns of chlorophyll-a and phytoplankton biomass for GRA-23 in 2013.

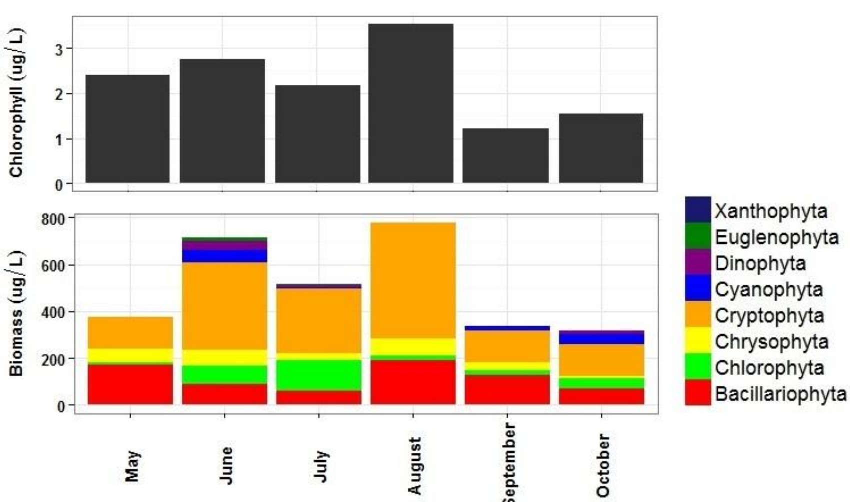

Figure C36 Temporal patterns of chlorophyll-a and phytoplankton biomass for ELA-24 in 2013.

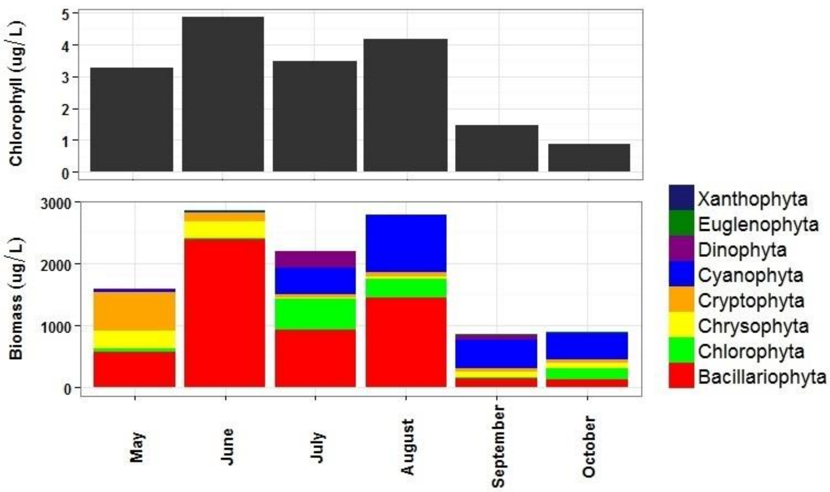

Figure C37 Temporal patterns of chlorophyll-a and phytoplankton biomass for ELA-25 in 2013.

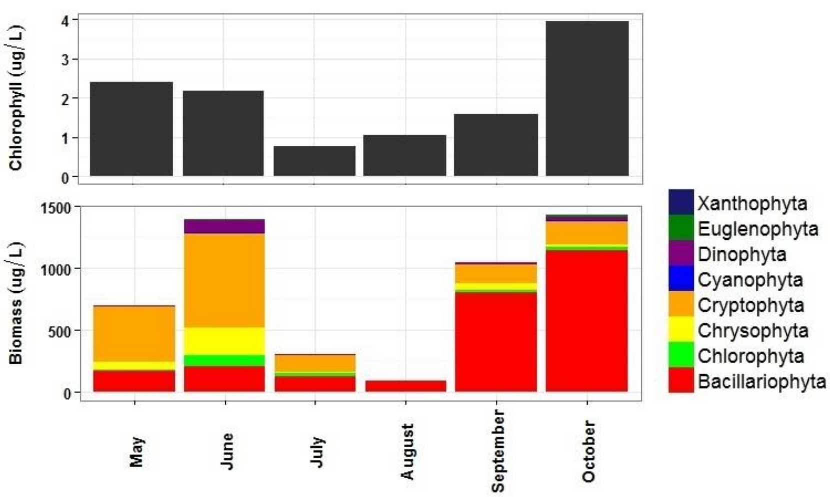

Figure C38 Temporal patterns of chlorophyll-a and phytoplankton biomass for WAB-26 in 2013.

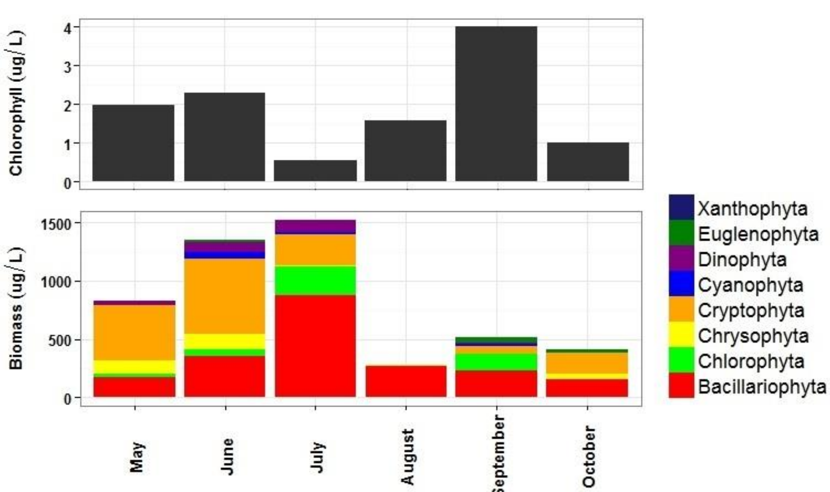

Figure C39 Temporal patterns of chlorophyll-a and phytoplankton biomass for WAB-27 in 2013.

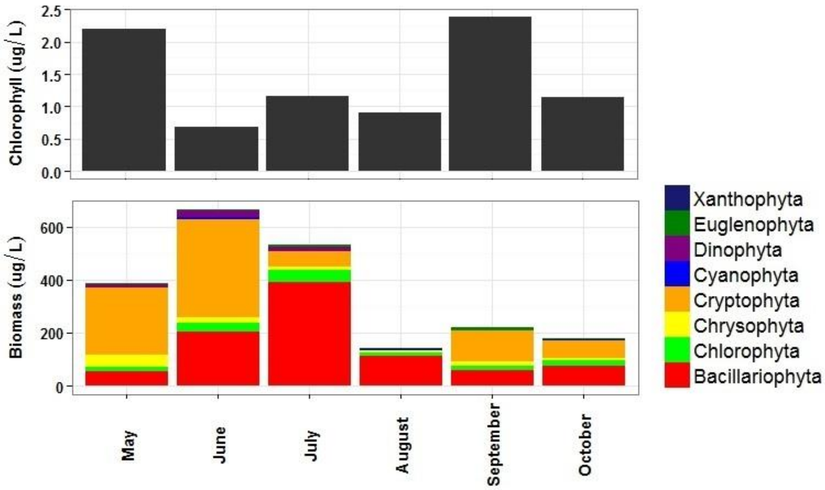

Figure C40 Temporal patterns of chlorophyll-a and phytoplankton biomass for VER-28 in 2013.

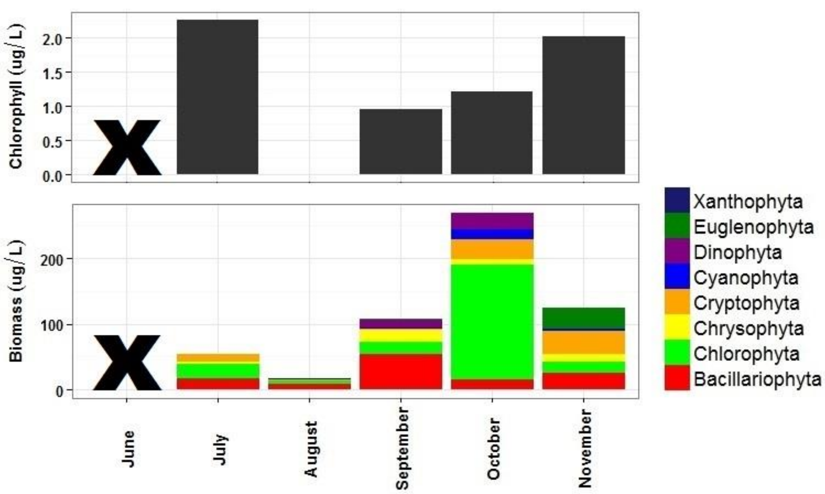

Figure C41 Temporal patterns of chlorophyll-a and phytoplankton biomass for VER-1 in 2014.

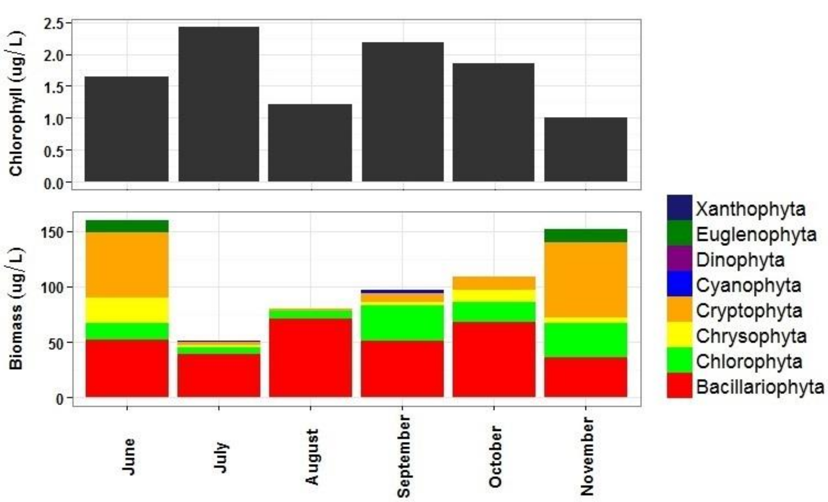

Figure C42 Temporal patterns of chlorophyll-a and phytoplankton biomass for VER-2 in 2014.

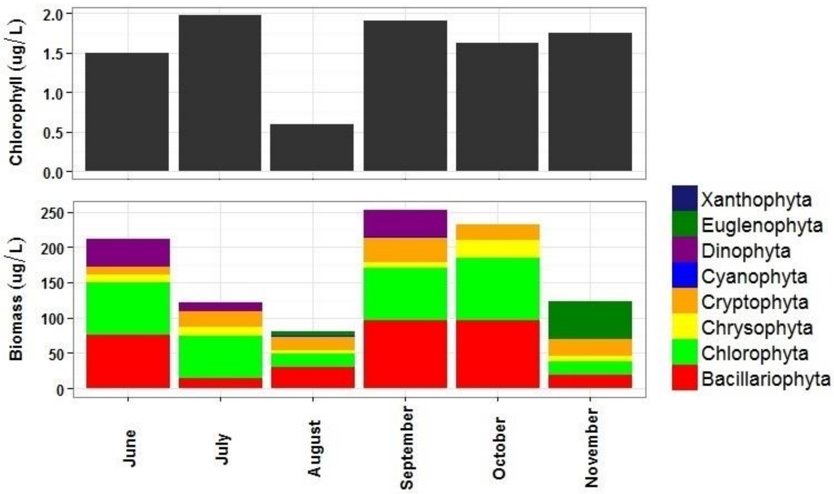

Figure C43 Temporal patterns of chlorophyll-a and phytoplankton biomass for ONP-3 in 2014.

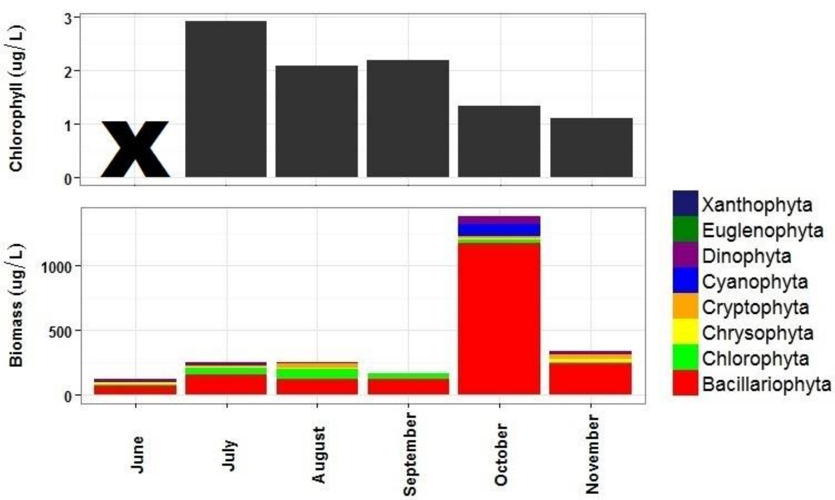

Figure C44 Temporal patterns of chlorophyll-a and phytoplankton biomass for ONP-4 in 2014.

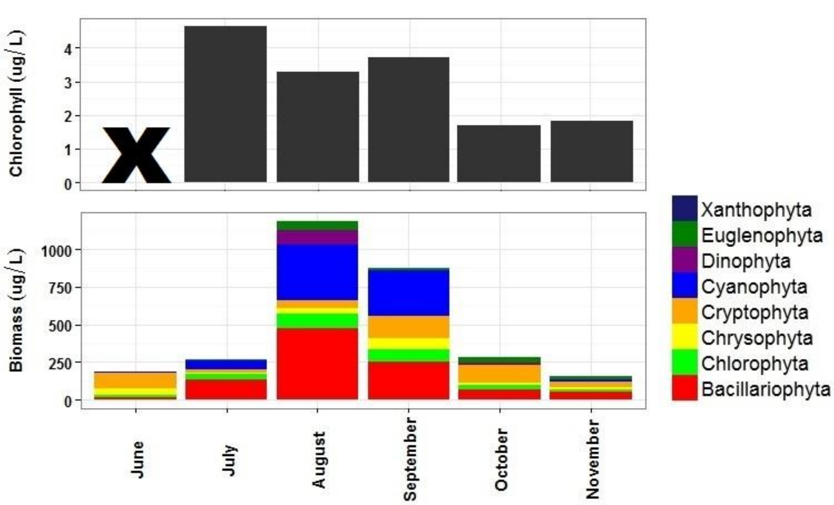

Figure C45 Temporal patterns of chlorophyll-a and phytoplankton biomass for VER-5 in 2014.

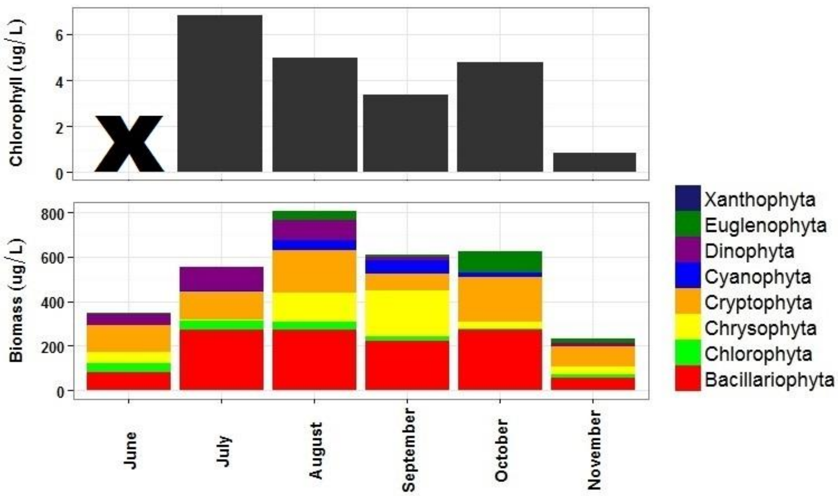

Figure C46 Temporal patterns of chlorophyll-a and phytoplankton biomass for VER-6 in 2014.

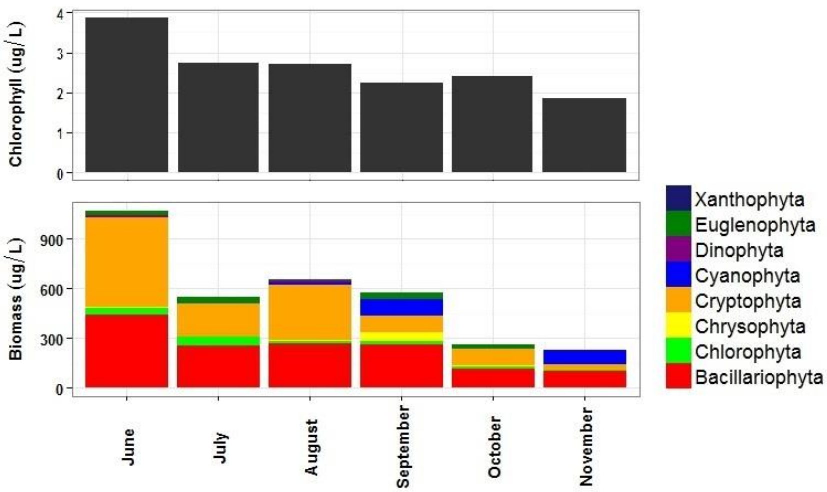

Figure C47 Temporal patterns of chlorophyll-a and phytoplankton biomass for WIT-7 in 2014.

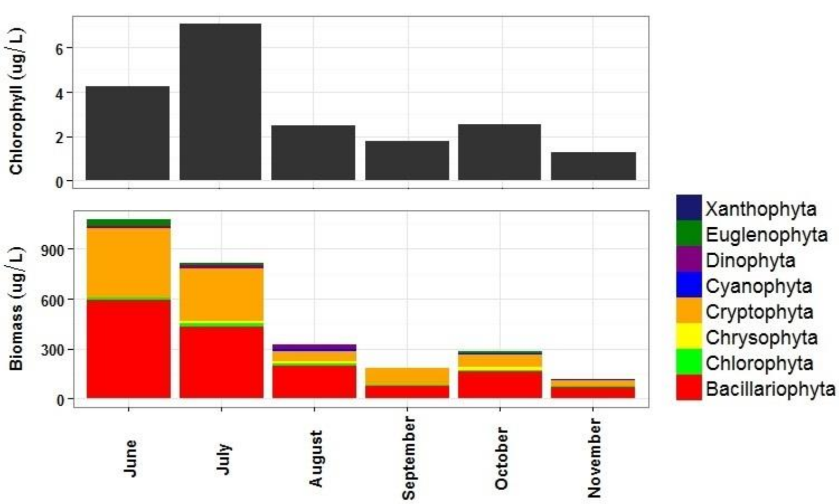

Figure C48 Temporal patterns of chlorophyll-a and phytoplankton biomass for WIT-8 in 2014.

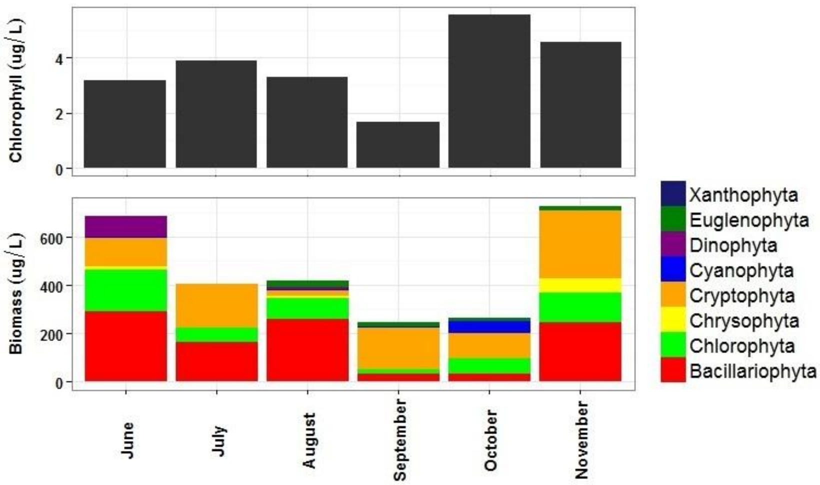

Figure C49 Temporal patterns of chlorophyll-a and phytoplankton biomass for LEV-9 in 2014.

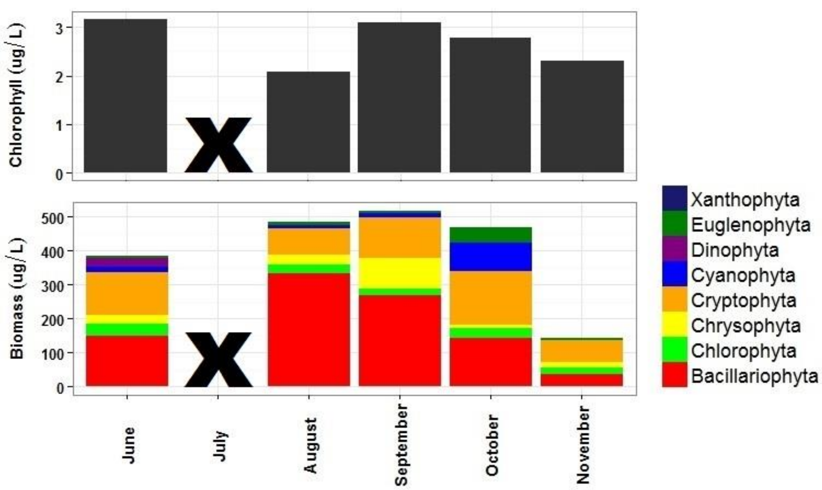

Figure C50 Temporal patterns of chlorophyll-a and phytoplankton biomass for VER-10 in 2014.

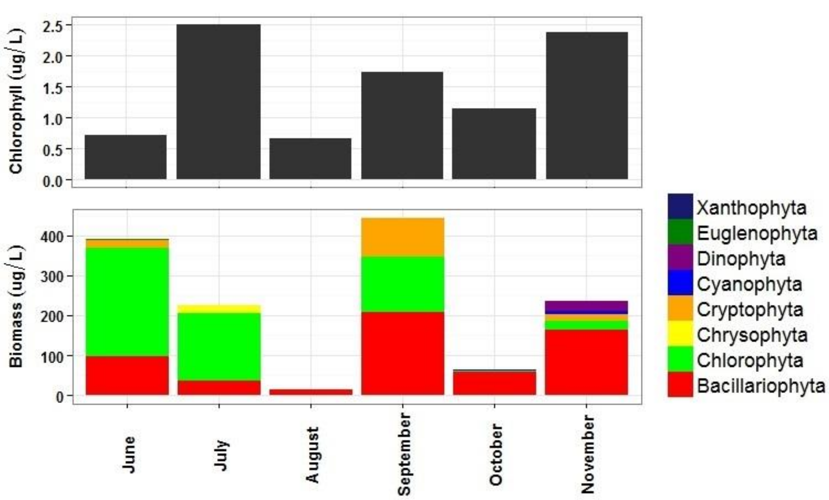

Figure C51 Temporal patterns of chlorophyll-a and phytoplankton biomass for LIL-11 in 2014.

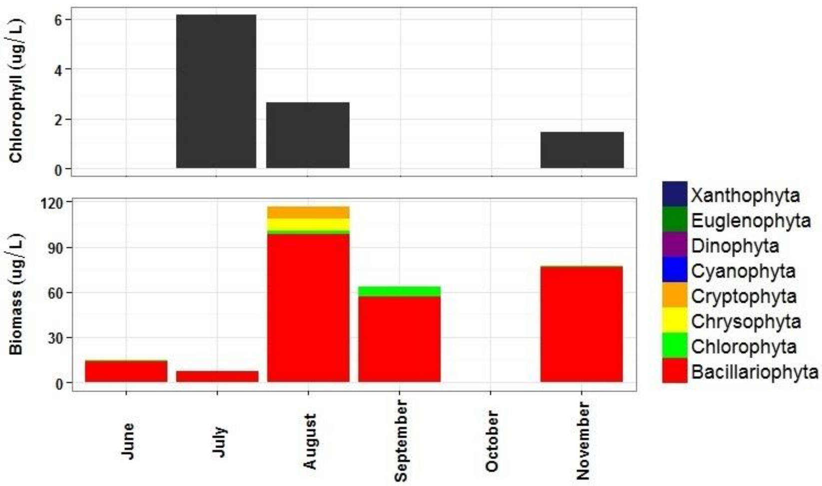

Figure C52 Temporal patterns of chlorophyll-a and phytoplankton biomass for CC-12 in 2014.

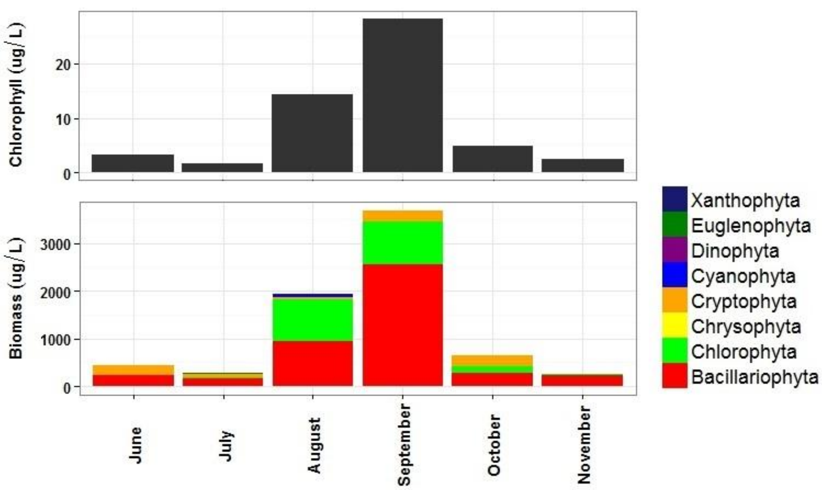

Figure C53 Temporal patterns of chlorophyll-a and phytoplankton biomass for JUN-13 in 2014.

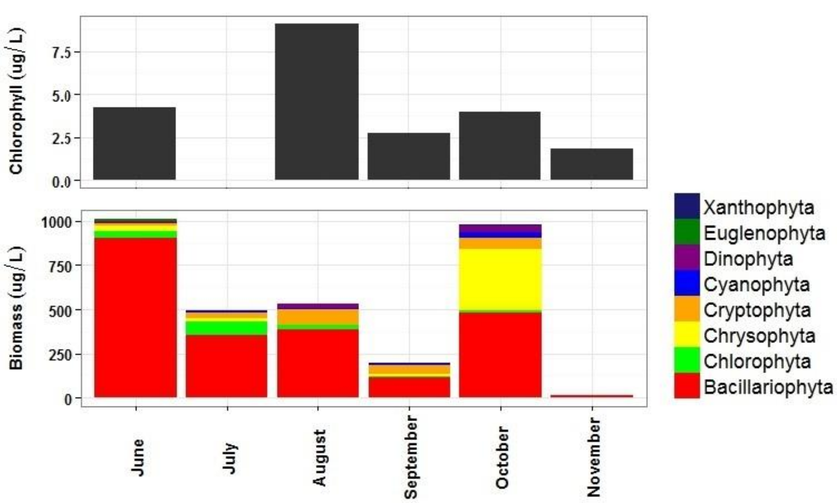

Figure C54 Temporal patterns of chlorophyll-a and phytoplankton biomass for MB-14 in 2014.

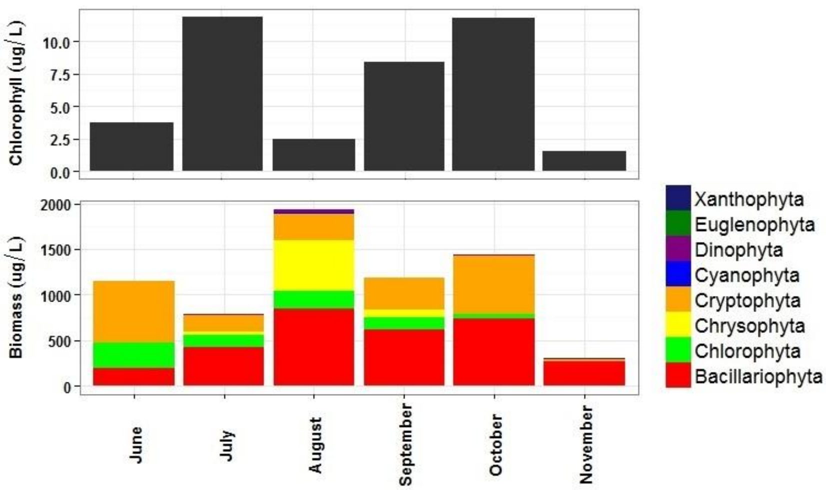

Figure C55 Temporal patterns of chlorophyll-a and phytoplankton biomass for MUD-15 in 2014.

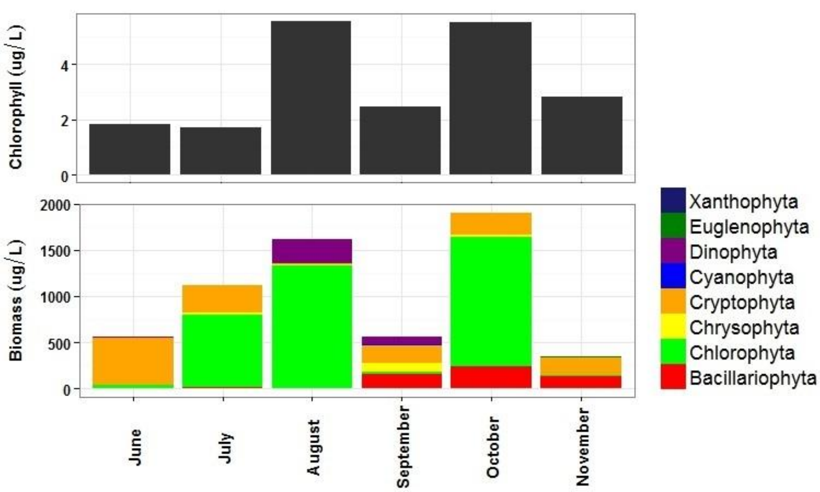

Figure C56 Temporal patterns of chlorophyll-a and phytoplankton biomass for SIM-16 in 2014.

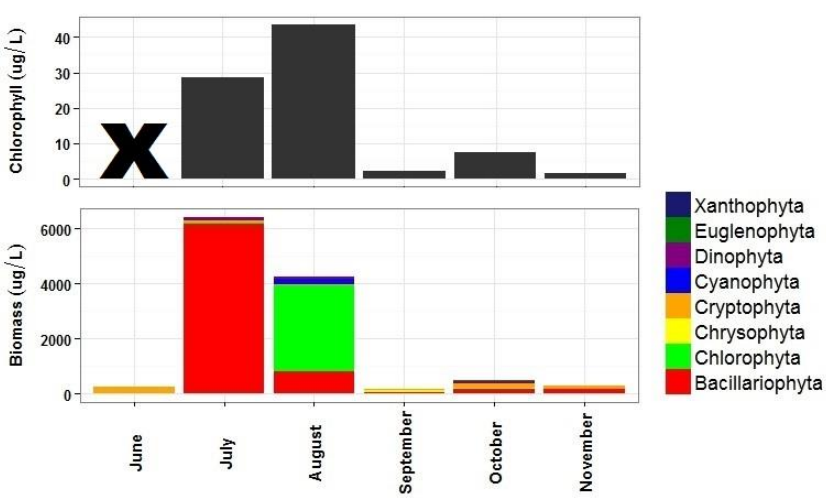

Figure C57 Temporal patterns of chlorophyll-a and phytoplankton biomass for MC-17 in 2014.

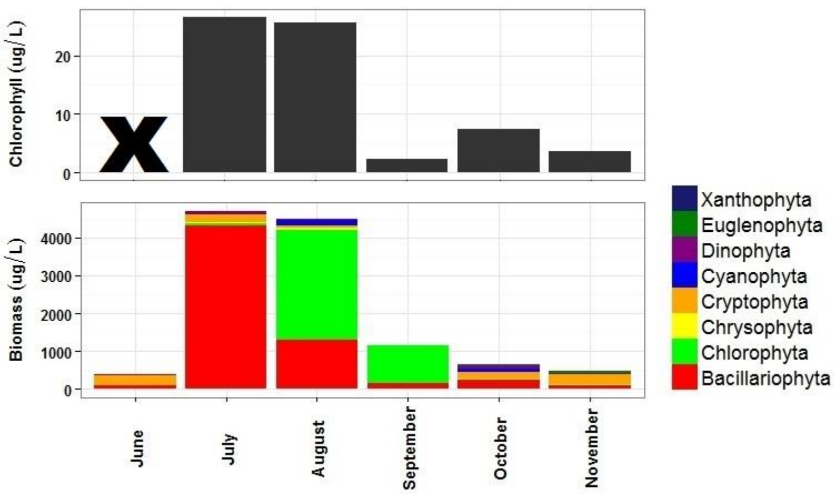

Figure C58 Temporal patterns of chlorophyll-a and phytoplankton biomass for MC-18 in 2014.

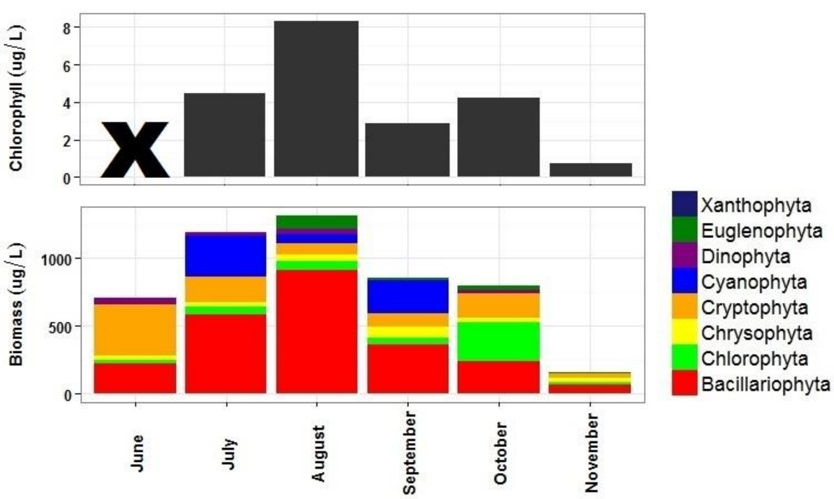

Figure C59 Temporal patterns of chlorophyll-a and phytoplankton biomass for MC-19 in 2014.

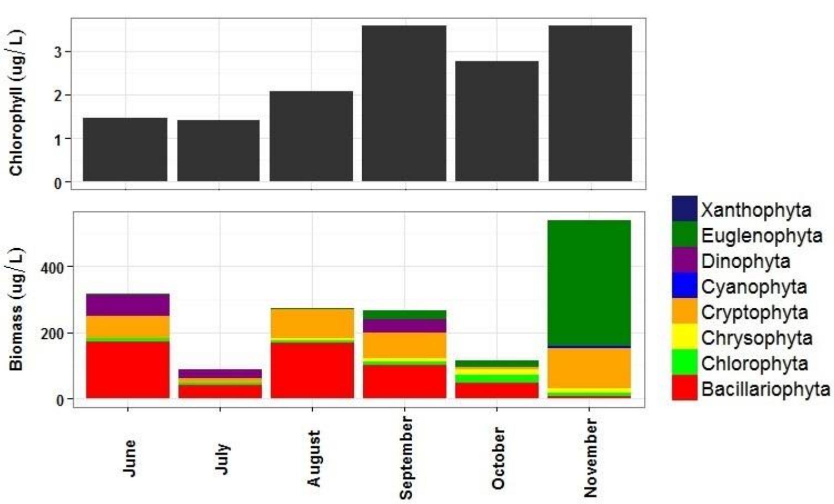

Figure C60 Temporal patterns of chlorophyll-a and phytoplankton biomass for FB-20 in 2014.

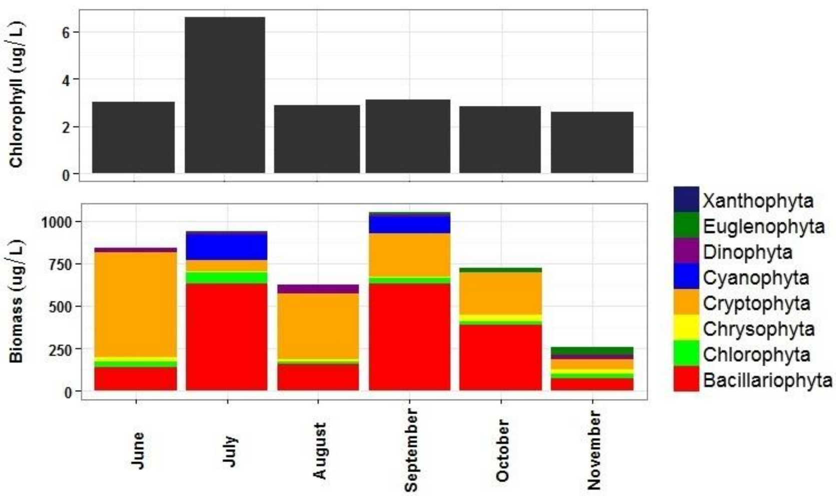

Figure C61 Temporal patterns of chlorophyll-a and phytoplankton biomass for KUS-21 in 2014.

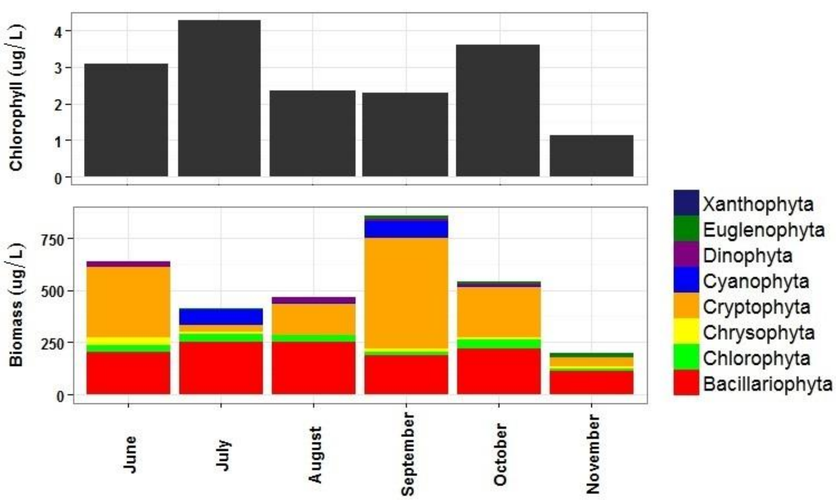

Figure C62 Temporal patterns of chlorophyll a-and phytoplankton biomass for VER-22 in 2014.

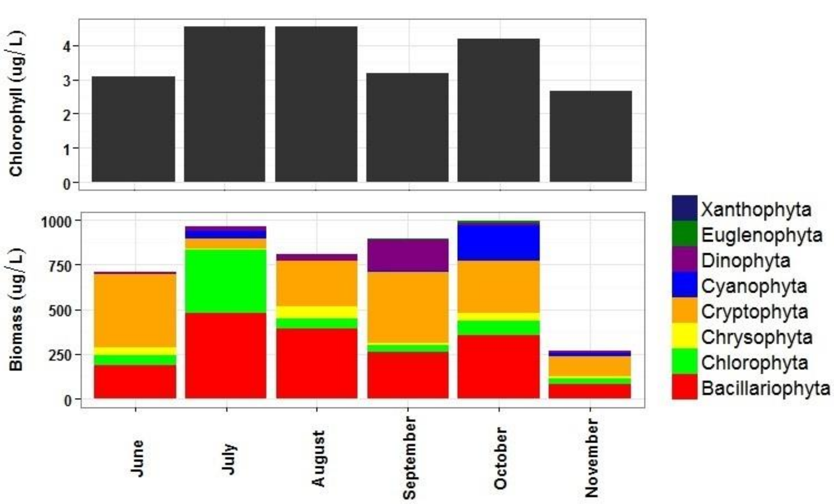

Figure C63 Temporal patterns of chlorophyll-a and phytoplankton biomass for GRA-23 in 2014.

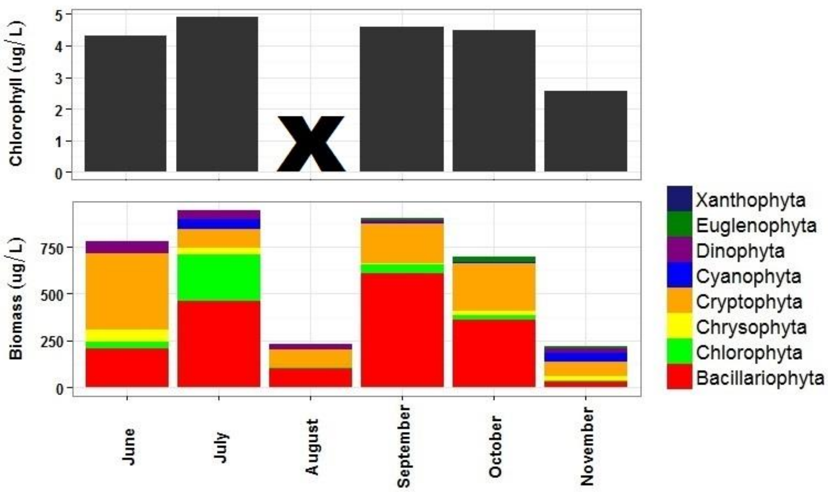

Figure C64 Temporal patterns of chlorophyll-a and phytoplankton biomass for ELA-24 in 2014.

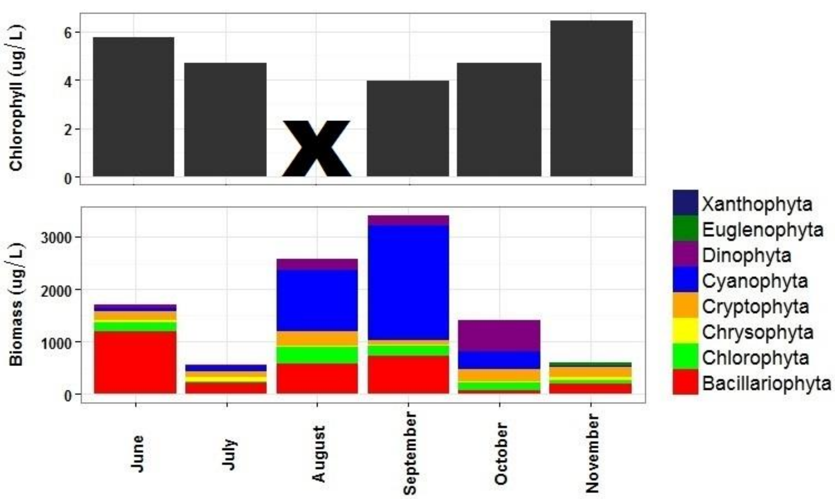

Figure C65 Temporal patterns of chlorophyll-a and phytoplankton biomass for ELA-25 in 2014.

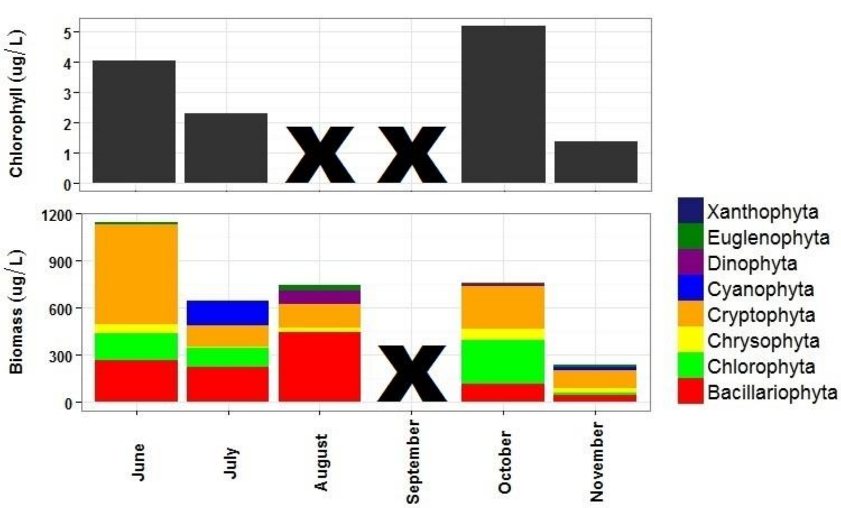

Figure C66 Temporal patterns of chlorophyll-a and phytoplankton biomass for WAB-26 in 2014.

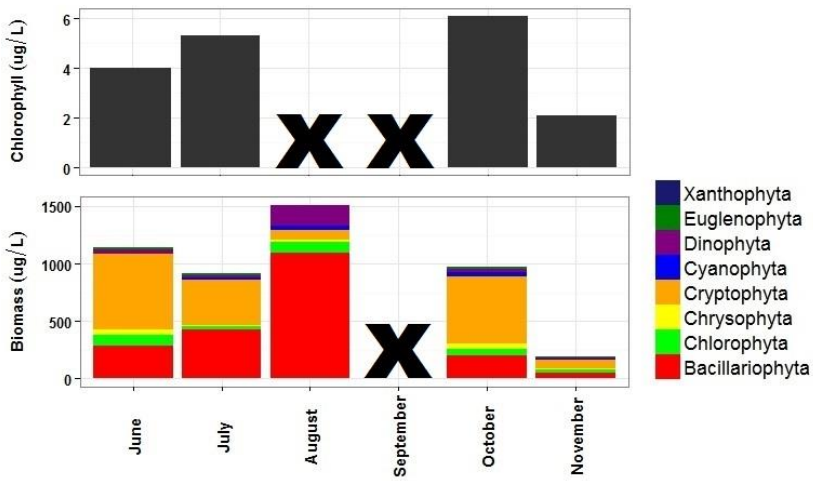

Figure C67 Temporal patterns of chlorophyll-a and phytoplankton biomass for WAB-27 in 2014.

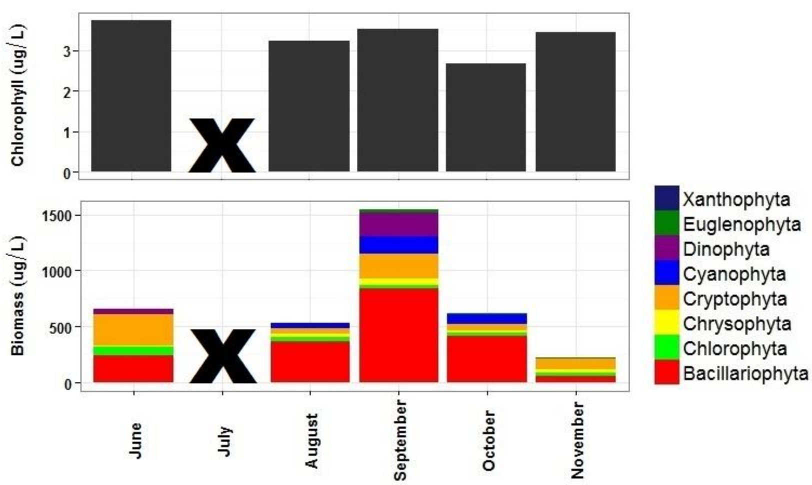

Figure C68 Temporal patterns of chlorophyll-a and phytoplankton biomass for VER-28 in 2014.

Table C16 Multiple pairwise comparisons to determine if chlorophyll-a and total phytoplankton biomass at the site upstream of the Sudbury WWTP (CC-12) was significantly different compared to the sites downstream.

	Chlorophyll a		Total Biomass
	2013	**2014**	**2013**
JUN-13	<0.001***	0.052*	<0.001***
MUD-15	0.008***	0.193	0.021**
SIM-16	0.121	0.668	0.148
MC-17	0.12	<0.001***	0.085*
MC-18	0.003***	0.005***	0.670
MC-19	0.168	0.542	0.523
KUS-21	0.200	0.632	0.447
VER-22	0.322	0.771	0.417
GRA-23	0.215	0.597	0.493
ELA-24	0.142	0.533	0.520
ELA-25	0.039**	0.389	0.012**
WAB-26	0.212	0.717	0.274
WAB-27	0.239	0.527	0.283
VER-28	0.431	0.682	0.668

*p<0.1, **p<0.05, ***p<0.01

Note: Previous one-way ANOVAs revealed that there was at least one site that was significantly different from the others in 2013 and/or 2014 for: Chl-a (2013: p<0.001 & 2014: p=0.019), and total phytoplankton biomass (2013: p=0.021). However, these analyses revealed that there were no significant differences between sites in 2013 and/or 2014 for: total phytoplankton biomass (2014: p=0.125). Chl-a and phytoplankton biomass means calculated using n=6 for both years, with the exception of MC-17, MC-18, MC-19 for Chl-a (n=5 in 2014, June was missing), ELA-24, ELA-25 for Chl-a (n=5 in 2014, August was missing), WAB-26, WAB-27 for Chl-a (n=4 in 2014, June and July was missing), JUN-13 for phytoplankton biomass (n=4 in 2013, May and July were missing), WAB-26 for phytoplankton biomass (n=5 in 2014, September was missing), WAB-27 for phytoplankton biomass (n=5 in 2014, September was missing), and VER-28 for phytoplankton biomass (n=5 in 2014, July was missing).

Table C17 Multiple pairwise comparisons to determine if major phytoplankton group biomass of the site upstream of the Sudbury WWTP (CC-12) was significantly different to the sites downstream.

	Bacillariophyta	Chrysophyta	Cryptophyta	Cyanophyta		Dinophyta	Euglenophyta	Xanthophyta
	2013	2013	2014	2013	2014	2014	2013	2013
JUN-13	<0.001***	0.002***	0.185	0.930	0.946	0.960	0.090*	<0.001***
MUD-15	0.300	0.051*	<0.001***	0.940	0.981	0.804	1.000	<0.001***
SIM-16	0.742	0.310	0.016**	0.920	0.998	0.163	0.804	<0.001***
MC-17	0.293	0.293	0.303	0.960	0.768	0.326	0.901	<0.001***
MC-18	0.871	0.947	0.092*	0.950	0.782	0.303	0.751	<0.001***
MC-19	0.674	0.914	0.118	0.520	0.446	0.585	0.804	<0.001***
KUS-21	0.558	0.941	0.006***	0.440	0.751	0.620	0.319	<0.001***
VER-22	0.497	0.962	0.027**	0.130	0.845	0.766	0.246	<0.001***
GRA-23	0.469	0.911	0.011**	0.510	0.752	0.284	0.725	<0.001***
ELA-24	0.649	0.937	0.060*	0.820	0.894	0.488	0.379	<0.001***
ELA-25	<0.001***	0.764	0.093*	<0.001***	<0.001***	<0.001***	0.010***	<0.001***
WAB-26	0.036**	0.961	0.013**	0.970	0.808	0.657	0.136	<0.001***
WAB-27	0.097*	0.891	<0.001***	0.880	0.884	0.243	<0.001***	<0.001***
VER-28	0.531	0.969	0.191	0.990	0.686	0.243	0.132	<0.001***

*p<0.1, **p<0.05, ***p<0.01

Note: Previous one-way ANOVAs revealed that there was at least one site that was significantly different from the others in 2013 and/or 2014 for: Bacillariophyta (2013: p<0.001), Chrysophyta (2013: p=0.003), Cryptophyta (2014: p=0.040), Cyanophyta (2013: p<0.001 & 2014: p=0.002), Dinophyta (2014: p=0.025), Euglenophyta (2013: p=0.006), and Xanthophyta (2013: p=0.023). However, these analyses revealed that there were no significant differences between sites in 2013 and/or 2014 for: Bacillariophyta (2014: p=0.565), Chlorophyta (2013: p=0.104 & 2014: p=0.323), Chrysophyta (2014: p=0.307), Cryptophyta (2013: p=0.533), Dinophyta (2013: p=0.174), Euglenophyta (2014: p=0.355), Xanthophyta (2014: p=0.478). Phytoplankton biomass means calculated using n=6 for both years, with the exception of JUN-13 for phytoplankton biomass (n=4 in 2013, May and July were missing), WAB-26 for phytoplankton biomass (n=5 in 2014, September was missing), WAB-27 for phytoplankton biomass (n=5 in 2014, September was missing), and VER-28 for phytoplankton biomass (n=5 in 2014, July was missing).

Table C18 Genera presence/absence for sites in 2013-2014.

Major Phytoplankton Groups	Genera	Abbr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Bacillariophyta	Achnanthidium	B_Ach	1	2	3	4	5	6	7	8	9	10	11		13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	Amphora	B_Amp		2		4		6	7	8	9		11		13	14	15	16	17				21		23			26		
	Asterionella	B_Ast		2		4	5	6	7	8	9	10	11		13	14	15	16	17	18	19		21	22	23	24	25	26	27	28
	Aulacoseira	B_Aul			3	4	5	6			9	10			13						19		21	22	23					
	Brachysira	B_Bra	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		19	20	21	22	23	24		26	27	28
	Caloneis	B_Cal	1	2	3	4			7	8	9										19	20		22						
	Cocconeis	B_Coc	1	2		4		6	7	8	9	10	11		13	14	15	16	17	18	19	20	21	22	23	24		26	27	28
	Craticula	B_Cra				4			7		9	10				14					19	20	21		23					
	Cyclotella	B_Cyc	1				5	6	7	8		10	11		13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	Cymbella	B_Cym	1	2	3	4	5	6	7	8	9	10	11		13	14	15	16	17	18	19	20	21	22	23	24		26	27	28
	Diadesmus	B_Dia	1		3	4	5		7		9	10	11	12						18	19			22		24	25			
	Diatoma	B_Diat		2		4	5	6	7	8	9	10	11		13		15	16	17	18	19		21	22	23	24	25	26	27	28
	Encyonema	B_Enc			3	4						10			13				17			20								
	Epithemia	B_Epi											11			14								22						
	Eunotia	B_Eun	1	2	3	4	5	6	7	8	9	10	11	12	13	14					19	20		22	23	24		26		28
	Fragilaria	B_Fra		2		4	5	6	7	8	9	10	11		13		15	16	17	18	19		21	22	23	24	25	26	27	28
	Fragilariaforma	B_Frag		2	3	4											15		17			20			23	24		26		28
	Frustulia	B_Fru		2	3	4	5		7		9				13	14						20	21	22	23			26		28
	Gomphonema	B_Gom	1	2	3	4	5	6	7	8	9	10	11		13	14	15	16	17	18	19	20	21	22	23	24		26	27	28
	Gyrosigma	B_Gyr						6	7				11			14									23					28
	Melosira	B_Mel				4				8			11		13	14	15	16	17		19			22		24		26		
	Navicula	B_Nav	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	Nitzschia	B_Nit	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	Pinnularia	B_Pin		2	3		5				9				13	14							21	22	23			26		
	Rhopalodia	B_Rho		2	3	4	5		7						13	14	15				19	20			23				27	
	Sellaphora	B_Sel														14														
	Surirella	B_Sur				4		6	7			10	11		13	14	15	16						22		24		26		28
	Synedra	B_Syn	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	Tabellaria	B_Tab	1	2	3	4	5	6	7		9	10	11			14				18	19		21	22	23		25	26	27	28
	Urosolenia	B_Uro	1			4		6			9													22	23		25	26		28
Chlorophyta	Acanthosphaera	Chl_Aca			3	4		6											17										27	
	Actinastrum	Chl_Act																16								24				
	Ankyra	Chl_Ank						6			9		11		13		15	16	17	18	19		21	22	23	24	25	26	27	28
	Botryococcus	Chl_Bot			3	4															19		21		23	24	25	26	27	
	Carteria	Chl_Car		2			5	6	7											18								26		
	Characium	Chl__Cha				4	5												17			20								
	Chlamydomonas	Chl_Chl	1	2	3	4	5	6	7	8	9					14		16	17	18	19	20	21	22	23	24	25	26	27	28
	Chlorella	Chl_Chlo	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28

Closteriopsis	Chl_Clo																					21					26		
Closterium	Chl_Clos			3	4	5		7													20			23	24	25	26	27	
Coelastrum	Chl_Coe	1	2	3	4	5	6	7	8	9	10	11			14			17	18	19	20	21	22	23	24	25	26	27	28
Cosmarium	Chl_Cos	1		3	4	5				9	10	11		13	14	15	16	17		19	20	21		23		25			
Crucigenia	Chl_Cru	1	2	3	4	5	6	7	8	9	10				14					19	20	21	22	23	24	25	26	27	28
Crucigeniella	Chl_Cruc	1													14							21	22			25		27	
Desmatractum	Chl_Des									9										19					24				
Diacanthos	Chl_Dia			3	4	5																		23					
Dictyosphaerium	Chl_Dic											11											22			25			
Didymocystis	Chl_Did	1	2	3	4	5	6	7	8	9	10			13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Elakatothrix	Chl_Ela	1	2	3	4	5	6	7	8	9	10	11	12		14			17		19		21	22	23	24	25	26	27	28
Euastrum	Chl_Eua			3	4																								
Eudorina	Chl_Eud										10	11										21	22			25			
Golenkinia	Chl_Gol	1	2				6		8	9	10			13					18	19	20				24			27	28
Gonium	Chl_Gon																												28
Haematococcus	Chl_Hae	1	2	3	4	5	6					11				15		17		19		21	22	23	24	25	26	27	28
Keratococcus	Chl_Ker																					21							
Kirchneriella	Chl_Kir	1	2	3																					24				28
Klebsormidium	Chl_Kle													13															
Lagerheima	Chl_Lag	1			4								12	13								21							
Micractinium	Chl_Mic	1		3						9	10						16			19		21							
Monoraphidium	Chl_Mon	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Mougeotia	Chl_Mou	1	2	3	4		6	7	8	9		11			14		16	17	18		20			23				27	
Nephrocytium	Chl_Nep									9																25			
Oedogonium	Chl_Oed													13				17											
Oocystis	Chl_Ooc	1	2	3	4	5	6		8	9	10	11		13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Palmella	Chl_Pal	1				5																							
Pandorina	Chl_Pan																		18				22						
Pediastrum	Chl_Ped		2	3	4	5	6		8	9	10			13	14	15	16	17	18	19		21	22	23	24		26	27	28
Planktosphaera	Chl_Pla					5	6															21	22	23			26		28
Pteromonas	Chl_Pte							7		9									18										
Pyriamimonas	Chl_Pyr	1	2	3		5													18	19		21		23	24		26	27	28
Quadrigula	Chl_Qua			3			6																	23		25			
Roya	Chl_Roy																	17											
Scenedesmus	Chl_Sce	1	2	3	4	5	6	7	8	9	10			13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Selenastrum	Chl_Sel																16				20	21			24				
Sphaerocystis	Chl_Sph	1			4	5	6				10	11		13	14	15		17					22	23	24	25			
Spinoclosterium	Chl_Spi																												28
Spondylosium	Chl_Spo		2	3	4	5	6	7		9	10			13	14	15			18	19	20	21		23	24	25		27	
Staurastrum	Chl_Sta		2		4					9		11			14					19	20			23		25		27	
Tetmemorus	Chl_Tet			3																									
Tetradesmus	Chl_Tetr															15													
Tetraedron	Chl_Tetra	1	2	3	4	5	6	7	8	9	10	11			14				18	19		21	22	23	24	25	26	27	28
Tetraspora	Chl_Tetras				4	5	6								14			17	18	19		21		23	24	25			28
Tetrastrum	Chl_Tetrast			3		5																							
Treubaria	Chl_Tre						6	7		9					14			17	18	19			22	23			26		28

	Treubaris	Chl_Treu																		18										
	Ulothrix	Chl_Ulo		2	3	4			7		9		11																27	28
	Westella	Chl_Wes																			19						25			
	Xanthidium	Chl_Xan				4															19	20								
	Zygnema	Chl_Zyg				4																								
Chrysophyta	Bitrichia	Chr_Bit					5	6				10									19				23	24	25	26		
	Chrysolykos	Chr_Chr						6																						
	Dinobryon	Chr_Din	1	2	3	4	5	6	7	8	9	10	11			14	15		17	18	19	20	21	22	23	24	25	26	27	28
	Epipyxis	Chr_Epi									9																25			
	Mallomonas	Chr_Mal	1	2	3	4	5	6	7	8	9	10		12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	Pseudokephyrion	Chr_Pse	1	2	3	4	5	6	7	8	9	10				14	15	16	17	18	19		21	22	23	24	25	26	27	28
	Synura	Chr_Syn		2			5	6		8		10	11				15				19			22		24	25		27	28
	Uroglena	Chr_Uro						6				10								18	19		21	22	23	24	25	26		
Cryptomonas	Chroomonas	Cr_Chr							7					12		14					19	20	21	22						
	Cryptomonas	Cr_Cry	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	Rhodomonas	Cr_Rho	1	2	3	4	5	6	7	8	9	10	11		13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Cyanophyta	Anabaena	Cy_Ana				4	5	6			9	10	11		13			16	17	18	19		21	22	23	24	25	26	27	28
	Aphanimezomenon	Cy_Aph																	17	18	19						25			
	Chroococcus	Cy_Chr	1			4		6		8	9	10	11		13	14	15	16			19		21		23	24	25	26		
	Coelosphaerium	Cy_Coe			3			6																	23		25			28
	Cyanothece	Cy_Cya															15													
	Geitlerinema	Cy_Gei				4																								
	Gloeocapsa	Cy_Glo					5						11														25			28
	Gloeocystis	Cy_Gloe				4							11											22	23					28
	Gomphosphaera	Cy_Gom	1				5	6															21	22	23		25		27	28
	Komvophoron	Cy_Kom						6			9																25			
	Limnothrix	Cy_Lim		2										12																28
	Lyngbya	Cy_Lyn	1		3	4				8					13				17			20	21							28
	Merismopedia	Cy_Mer	1	2	3	4	5	6	7			10					15				19	20	21	22	23	24	25	26	27	28
	Microcystis	Cy_Mic	1	2		4	5	6	7	8	9	10	11							18	19	20	21	22	23	24	25	26	27	28
	Oscillatoria	Cy_Osc				4									13	14											25			28
	Planktothrix	Cy_Pla																									25			
	Pseudanabaena	Cy_Pse	1	2		4		6	7				11	12		14	15	16	17	18	19	20	21	22	23			26		28
	Snowella	Cy_Sno			3	4	5	6				10				14					19	20	21	22	23		25			28
	Spirulina	Cy_Spi													13															
	Synechococcus	Cy_Syn			3	4									13							20						26		
	Woronichinia	Cy_Wor				4	5														19						25			
Dinophyta	Certaium	D_Cer					5	6			9	10						16	17	18			21	22	23		25	26	27	28
	Glenodinium	D_Gle		2	3	4		6		8			11			14		16		18	19	20			23	24	25	26	27	28
	Gloeodinium	D_Glo																									25			
	Gymnodinium	D_Gym	1		3	4	5	6	7	8		10	11		13	14	15			18	19		21	22	23	24	25		27	28
	Peridinium	D_Per	1		3	4	5	6	7	8	9	10				14	15	16	17	18	19	20	21	22	23	24		26	27	28
Euglenophyta	Euglena	E_Eug	1	2	3	4	5	6	7	8	9	10	11		13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	Phacus	E_Pha	1	2	3	4	5	6	7	8	9	10	11		13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	Trachelomonas	E_Tra		2		4			7	8	9	10								18	19	20		22			25	26	27	28

Xanthophyta	Ophiocytium	X_Oph			14		
	Pleurogaster	X_Ple	12		14		16
	Tribonema	X_Tri				15	