SLOCAN LAKE 2010-2013 WATER QUALITY MONITORING PROJECT

FINAL REPORT

Prepared for:

SLOCAN LAKE STEWARDSHIP SOCIETY

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EXECUTIVE SUMMARY

The Slocan Lake Water Quality Monitoring Program was undertaken from 2010 to 2013 with funding from the Columbia Basin Trust. The research was conducted by Galena Environmental, with the assistance of volunteers from the Slocan Lake Stewardship Society, as well as other members of the community.

This report presents the methodology and research results of the program. The goal of the project was to obtain baseline information about Slocan Lake´s present conditions and potential trends to aid the development of a future lake management plan.

The program consisted of two components: a nearshore component conducted annually over a five-week period, and an offshore component carried out monthly from spring to fall each year. For the nearshore component water samples from seven nearshore sites were collected at 5 to 10 cm below the surface and analyzed for identification and counts of total coliforms, fecal coliforms and *Escherichia coli (E. coli).* For the offshore component measurements were taken of water temperature, dissolved oxygen, specific conductivity, total dissolved solids and pH, on the water column at five meter intervals, between 5 to 60 m depth, from four offshore sites. Water samples were taken at 5 and 50 m depths and analyzed for nitrate as N, nitrite as N, Kjeldahl nitrogen, total nitrogen, total phosphorus and chlorophyll-a. In three of the four sites, samples were taken for zooplankton identification and counts. In addition, water samples were taken at the four sites for analyses of heavy metals on a one time basis during the sampling season. Comparisons were made when appropriate with previous studies which had used the same sampling sites (Andrusak *et al*,. 2002; Galena Environmental, 2009).

General parameters readings as well as nutrient concentrations demonstrate the oligotrophic status of Slocan Lake. Thermal stratification takes place in the summer with a metalimnion forming at 15 to 25 m depth. Oxygen concentration profiles show an orthograde curve characteristic of oligotrophic lakes. Nutrient concentrations were low and did not show a trend, except in 2010 when total nitrogen was significantly lower and phosphorus was significantly higher than in the other years. However, this result has been attributed to laboratory error. Chlorophyll-a concentration generally ranged between <0.5 to 1.8 µg/L, exhibiting low productivity levels typical of oligotrophic conditions. No significant differences between sites were found.

Water hardness was below 50 mg/L, classifying Slocan Lake water as soft, and according to the alkalinity guidelines with *low sensitivity* to acidic inputs (>20 mg/L). Analyses of metals from 2008 Slocan Lake Water Quality Monitoring Program were compared to those from the present study and used for interpretation of metal results. Total metals concentrations tested were below the BC Water Quality Guidelines, with the exception of cadmium and zinc. Cadmium levels in all 20 samples taken between 2008 and 2011 exceeded the maximum concentration for the protection of freshwater life by approximately a magnitude of 10X. Mean concentrations of zinc were 15.6 µg/L in 2010 and 19.8 µg/L in 2011, with all twelve samples

above 10 μg/L, indicating that the 30-day average maximum guideline for freshwater life of 7.5 μg/L is likely being exceeded. Copper and nickel concentrations tested above the maximum guideline criteria for aquatic life in Site 4 in 2008, with values of 11.4 μg/L and 25 μg/L, respectively. In nearby Carpenter Creek water samples showed high concentrations close to or above the maximum guideline levels for the protection of aquatic life for aluminum, chromium, lead and nickel.

Coliform counts in the seven nearshore samples were below the maximum level for drinking water and primary contact recreational use (swimming or bathing). The two highest fecal coliform counts were in the samples taken from the Silverton Hotel site (9 and 8 cfu), while the third highest came from the site near Silverton Creek (7 cfu). These three counts occurred in the last two years, raising concerns about water quality deterioration at the Silverton Hotel site. It is recommended that microbial source tracking (MST) be incorporated into future analyses to discern bacteria leaching from septic tanks and those of animal origin.

The diversity of zooplankton species found at the three offshore sites saw a decrease from 2001 from eight species (three copepods and five cladocerans) to five (two copepods and three cladocerans). Also there has been a drastic reduction in zooplankton density (89%) and biomass (86%) in comparison to data from 2001, although the main decline took place in 2010 and 2012.

Due to the high cadmium and zinc concentrations in Slocan´s Lake´s water, as well as the decline in zooplankton, and the increase of *E.coli* counts at some of the nearshore sites, it is recommended that monitoring of Slocan Lake be continued. The high metal concentrations found in Carpenter creek are also of concern. According to a study by the Water Investigation Branch (1977), there are one hundred abandoned mines within Silverton and Carpenter Creek basins, and "at least thirteen are known to have abnormal mine drainage". It is recommended that in addition to continue monitoring of Slocan Lake, water and sediments from these creeks be tested. A study on the potential impact on fish and macroinvertebrate populations in these drainages is also recommended.

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- Moraia Grau and Associates: data analysis and report preparation.
- Richard Johnson: Technical Director for science and project supervision.
- Eva Schindler, limnologist, MOE: professional assistance in the planning of the offshore water quality program.
- Jennifer Yeow, microbiologist (Passmore Laboratory Ltd.): professional assistance in the planning of the nearshore water quality program and preferential rates for the microbiological analyses.

VOLUNTEERS, FIELD WORK AND EQUIPMENT

This project relied to a large extent on the volunteer help and contributions of SLSS members and community residents on both the nearshore and offshore components of the program as well as for the use of boats and canoes.

- Water sampling volunteers: Harvest Allcock, Barry Barker, Craig Besinque, John Conklin, Bruce Cottingham, Therese DesCamp, Jeremy Down, Hillary Elliott, Chloe Hartley, Jason Hartley, Margaret Hartley, Petra Hartley, Hank Hastings, Lane Haywood, Richard Johnson, Jane Murphy, Kevin Murphy, Luce Paquin, Kim Roshinsky, Wayne Schweitzer, Jonathan Sherrod, Sean Patrick Spriggs, Anita Werner, Barb Yeomans.
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GLOSSARY OF TERMS

Algae: group of simple, typically chorophyll-containing organisms, ranging from unicellular to multicellular species, that lack the distinct organ types found in land plants such as roots and leaves.

Alkalinity: parameter that indicates the capacity of a liquid to neutralize acids.

Cladocerans: Order Cladocera. Ubiquitous organisms mostly of freshwater habitats, usually unnoticed due to their small size (0.2–6.0 mm), and commonly called "water fleas". They are an important element of the aquatic food chain.

Coliforms: group of bacteria commonly used as indicator of the sanitary condition of foods and water. They are present in large numbers in the feces of warm-blooded animals, in soil and vegetation.

Copepods: Subclass Copepoda. A large group of small crustaceans found in salt and freshwater habitats. Some species drift in the water, others are attached to the under water substrate, or live in semi-wet areas such as ephemeral ponds and puddles, under leaves or on wet moss.

Epilimnion: upper layer that forms due to stratification in lakes and other large bodies of water, and characterized by warmer and less-dense water.

Eutrophic conditions: water bodies high in nutrients, such as nitrates and phosphates, allowing high production of algae. Eutrophic conditions are associated with lower dissolved oxygen concentrations and algal blooms.

Eutrophication: enrichment of bodies of water with nutrients, increasing algal production and sediment deposition.

Freshet: spring thaw or seasonal rains causing an increment of river flow and lake levels.

Hypolimnion: lower layer that forms in lakes or large bodies of water below the epilimnion, due to stratification, and characterized by colder and denser water.

Lake turnover: the warm surface water in the summer begins to cool in the fall. As it cools it becomes denser and sinks, producing a turnover affect of surface water and deeper layers.

Limnology: Science that studies freshwater ecosystems.

Macroinvertebrates: a large and varied group of small organisms that lack a backbone and are large enough to be seen without amplification. The aquatic macro-invertebrate community is often used as an indicator of freshwater ecosystems quality. It includes insects in larval or nymph form, crayfish, clams, snails, and worms.

Metalimnion: the middle water layer of a thermally stratified lake, characterized by a high gradient temperature and dissolved oxygen change with depth.

Oligotrophic: relatively nutrient-poor bodies of water. Oligotrophic lakes are characterized by clear water with deep water layers high in dissolved oxygen.

Orthograde curve: the orthograde profile in a plotted graph of dissolved oxygen concentrations with depth caused by stratification.

Periphyton: complex group of algae, microbes, and cyanobacteria that live attached to the submerged substrates.

Plankton: general term to describe organisms, mostly microscopic, that live in the water column and cannot swim against a current.

Phytoplankton: free floating algae.

Stratification: in reference to water, the condition created when layers with different properties form, usually arranged by density, and act as barriers to water mixing.

Thermocline: same as metalimnion but applied to other bodies of water besides lakes.

B.C. Water Quality Guidelines: Provincial science-based levels of substances, physical or biological characteristics, for the protection of given water uses such as aquatic life, drinking water, recreation, agricultural, and industrial.

Zooplankton: A large and varied group of animals, usually microscopic but some larger, such as jelly fish, that drift or wander in bodies of water. Cladocerans and copepods are part of the zooplankton.

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1. INTRODUCTION

Slocan Lake is one of the few relatively pristine and undeveloped large lakes remaining in BC´s southeastern corner. It is an oligotrophic lake – cold and low in nutrients – with very clear water except during spring runoff, when creeks and streams full of sediments flow into the lake. Its shoreline remains mostly unaltered by human disturbance, and its water flows undamned into the Slocan River. The region however, was home to a mining boom in the first part of the 19th century, when large deposits of galena with silver veins were discovered in the Selkirk Mountains. Silver, zinc and lead were the principal minerals produced, along with lesser amounts of gold, copper and cadmium. Most of the mining took place on the east side of the lake between Wilson Creek and Slocan City. Mine tailings were discharged directly from ore concentrators into the creeks without treatment. There are 100 abandoned mines within the Silverton and Carpenter Creek basins, of which at least 13 are known to have abnormal water drainage. The drainage from these old mines is carried by the various creeks into Slocan Lake. A study by the Ministry of Environment found higher than normal concentrations of zinc in Slocan Lake and recommended monitoring the levels of zinc and cadmium in Silverton, Carpenter, Enterprise and Springer Creeks (Rocchini *et al*. 1977).

The Ministry of Environment collected water samples in 2000 and 2001, and a limnology study was also carried out by the University of British Columbia at that time (Andrusak *et al*, 2002), but no regular water quality monitoring on Carpenter, Silverton and other creeks suspected of heavy metal contamination has taken place despite the recommendations of the 1977 report.

Another source of potential contamination is from human residue (refuse and sewage). There are no sewage treatment plants, since the urban centres are small and much of the population is dispersed. Thus, all sewage treatment is provided by septic fields. In addition, over the last two decades, Slocan Lake has experienced a considerable increase in recreational use and development pressures. Consequently, concerns of residents about potential impacts on the lake´s ecosystem and water quality has increased in later years. The

Slocan Lake Stewardship Society (SLSS) undertook a preliminary 30-day monitoring program in 2008 (Galena Environmental, 2009) to establish water quality conditions and form the basis for a more comprehensive study of the lake´s water quality parameters or trend-monitoring program. Trend-monitoring aims at detecting subtle changes over time that could result in potential long-term problems.

A three-year water-quality study was initiated by the SLSS in 2010 with funding provided by Columbia Basin Trust (CBT). The sampling began August of 2010 and ended September 2013. This report describes the methodology and results of the study.

2. METHODOLOGY

The program followed the methodology of the Resource Inventory Standards Committee (RISC) described in *Guidelines for Designing and Implementing a Water Quality Monitoring Program in British Columbia* (Cavanagh *et al*., 2004). The sampling program was comprised of two components: nearshore and offshore.

2.1. Nearshore Sampling Program

The nearshore component focused on microbiological (bacteriological) monitoring, i.e., the degree of contamination from animal and human organic waste and wastewater, as measured by coliform presence. Since coliforms are abundant in feces, their presence is used to indicate the potential presence of other pathogenic organisms of fecal origin.

2.1.1. Site selection

For comparative purposes, the same seven sites from the 2008 study were maintained (Figure 1). A detailed description of the sites is presented in Table 1.

The locations selected are areas prone to impact from defective septic systems (near the villages of New Denver, Silverton, and Slocan, and at creek outlets), and areas that exhibit high macrophyte growth. Since macrophyte growth is relatively low in Slocan Lake, areas exhibiting substantial aquatic plant growth could suggest the presence of excess nutrients (leachate from septic systems), although other factors may be contributing to macrophyte presence, such as shallow water, suitable sediment and protection from wave action.

Table 1. Location and description of nearshore sampling sites.

Nearshore sampling sites	
Site 1 — Slocan - Located approximately 10 m from the shore, at the end of the public dock - Lat: 49° 46´ 10″ N, Lon: 117° 28´ 23″W - Site is located within the town, in front of the public beach **Site 2 — Silverton** - Located approximately 15 m offshore - Lat: 49° 56´ 54″ N, Lon: 117° 21´ 26″ W - Site is located within the town, in a bay in front of Silverton Hotel - Site has abundant macrophytes **Site 3 — Silverton** - Located approximately 20 m south of Silverton Creek and approximately 20 m offshore - Lat: 49° 57´06″ N, Lon: 117° 21´ 44″ W - Site will provide information on coliform transport from septic systems to the creek **Site 4 — New Denver** - Located in front of the Slocan Lake hospital, approximately 20 m offshore - Lat: 49° 58´59″ N, Lon: 117° 22´ 31″ W - Site has some macrophytes	**Site 5 — New Denver** - Located approximately 20 m south of Carpenter Creek approximately 20 m offshore - Lat: 49° 59´ 16″ N, Lon: 117° 22´ 48″W - Site will provide information on coliform transport from septic systems to the creek **Site 6 — Rosebery** - Located approximately 20 m south of Wilson Creek , approximately 20 m offshore - Lat: 50° 01´ 44″ N, Lon: 117° 24´ 54″W - Site will provide information on coliform transport from septic systems to the creek **Site 7 — Hills** - Located in front of Hills public beach and cottage area approximately 15 m offshore - Lat: 50° 05´ 18″ N, Lon: 117° 28´ 12″W - Site has abundant macrophytes

2.1.2. Selection of parameters

Total coliforms is one of the standard criteria of microbiological water quality. It includes the subgroup of thermo-tolerant coliforms (fecal coliforms), which are common in the intestinal tract of human and warm-blooded animals. *Escherichia coli* (*E. coli*) is a sub-group of fecal coliforms common in the human intestinal tract. Most of the strains within the normal flora of the intestine are beneficial, but some are associated with disease. Total coliforms and total thermo-tolerant coliforms were counted in samples collected in 2010 and 2011. Identification and counts of *E. coli* were included in the analysis of 2012 and 2013 samples.

2.1.3. Sampling methodology

Sampling occurred on five days over a 30-day period in the summer each year, in accordance with the provincial sampling methodology (Cavanagh *et al*., 2004). All seven sites were sampled on the same day. Grab samples were collected in sterilized Nasco Whirl Pak sampling bags at the same depth (approx. 5 to10 cm below the surface and 10 to 20 m from shore, depending on the site). A non-motorized watercraft was used to collect the samples. All samples were shipped the same day, on ice, to Passmore Laboratory Ltd. for analysis and counts of coliform bacteria. Sampling was done by volunteers and SLSS members.

2.1.4. Analytical methods and data interpretation

Passmore Laboratory Ltd., certified by the Canadian Association for Laboratory Accreditation (CALA), was retained by SLSS to conduct the analyses and interpretation of the nearshore microbiological samples throughout the project. Analyses were performed in accordance with methods outlined in the *Standard Methods of Examination of Water and Wastewater* (Wallace and Abou-Zamzam, 1995). In 2010 and 2011 all tests were completed using membrane filtration. Passmore Laboratory also provided interpretation of the results (Appendix I).

2.2. Offshore Sampling Program

The offshore program was aimed at monitoring changes in physical and chemical water parameters, as well as the zooplankton community as an indicator of ecological change.

2.2.1. Site selection

For comparative purposes, the four sites and sampling depths from the 2008 baseline study were maintained, which included two of the sites used in the 2000-2001 study by Pieters *et al*. (2006). Site 2 and Site 3 in the current project correspond to sites SL2 and SL1 in the 2000-

2001 study, respectively. The offshore sampling sites are described in Table 2.

Table 2. Location and description of the offshore sampling sites

Offshore Sample Sites
Site 1 ➢ located 5.3 km north of the town of Slocan, in front of Cape Horn & Evans Creek ➢ Lat: 49^{0} 48′ 51″ N, Lon: 117^{0} 28′ 26″ W
Site 2 ➢ located 11 km north of the lake outlet, slightly downstream of Enterprise Creek ➢ Lat: 490 51′ 46″ N, Lon: 117^{0} 26′ 17″ W ➢ Site is the same as Site # SL2 in the UBC-MOE collection of reports
Site 3 ➢ located 23.2 km north of the lake outlet, slightly upstream of Wee Sandy Creek ➢ Lat: 500 00′ 35″ N, Lon: 117^{0} 24′ 39″ W ➢ Site is the same as Site # SL1 in the UBC-MOE collection of reports
Site 4 ➢ located 27.6 km north of the lake outlet, in front of Shannon Creek ➢ Lat: 500 04′ 20″ N, Lon: 117^{0} 27′ 22″ W

2.2.2. Selection of parameters

Five general chemistry parameters commonly used to characterize conditions and water quality in lakes – temperature, pH, dissolved oxygen (DO), specific conductivity (SC) and total dissolved solids (TDS) – were selected for monitoring.

Lake productivity plays a primary role in the functioning of lake ecosystems. The most common indicators of productivity are nitrogen, phosphorus and algal production. Five nutrients were selected for analysis: nitrate as N, nitrite as N, total nitrogen, total Kjeldahl nitrogen, and total phosphorus, and chlorophyll-a. Since water hardness has an effect on the behaviour and chemistry of metals, in 2011 hardness (as $CaC0_3$) was included in the analysis.

Although some metals are present naturally in water, higher concentrations of metals may be caused by human activities such as mining. A wide variety of metals were selected for water analysis, in order to assure a comprehensive database upon which to evaluate the present water quality of Slocan Lake and compare with future changes. Water samples were analyzed for 29 metals in 2010, including those most likely to be derived from mining effluents such as aluminum, arsenic, cadmium, copper, lead, nickel and zinc. Seven additional metals were added in 2011: lithium, mercury, strontium, tellurium, thallium, thorium and zirconium.

2.2.3. Sampling methodology

The offshore sampling was carried out entirely by volunteers and SLSS members, and was usually completed within five hours. A motor boat was used for transportation. The sampling crew was comprised of a boat operator and a team of two or three samplers. Sampling was conducted once a month at each of the four sites from May through the end of October, although sampling in 2010 did not start until August 23th, due to funding timing and technical problems with the Hanna multimeter probe, so only three months were sampled that year.

General chemistry parameters

The selected general chemical parameters – temperature, pH, specific conductivity, total dissolved solids and dissolved oxygen – were measured at the four sites with a Hanna multi-meter probe equipped with a 100 m cable. Readings were usually conducted at 12 different depths, at 5 m intervals, from 5 m to 60 m. Occasional readings were completed down to 100 m (at 20 depth levels).

Nutrients

At each of the four sites, grab samples were taken at two depths, 5 m and 50 m, and analyzed for the six selected nutrients. At both depths, samples were obtained using a 4.2

liter Beta bottle attached to a 60 m marked cable. Water was then poured into pre-identified bottles and shipped by courier to the laboratory for analysis. Total hardness was only sampled one day in August 2011.

Total metals

Grab samples were taken at 5 m and 50 m and analyzed for 29 metals in 2010 and 35 metals in 2011 once during the sampling season. The procedure was identical to that for nutrient sampling, and samples were shipped by courier to the laboratory. In 2010 grab samples were taken at Sites 1 and 4 in August, and at the four sites in August 2011. In addition, samples were taken at Carpenter Creek´s mouth and analyzed for 36 metals in August 2012.

Zooplankton

Grab samples were collected each month at sampling Sites 1, 2 and 3. Sampling was conducted using a Wisconsin Net attached to a 42 m cable. The 150 µm mesh Wisconsin net had a 0.5 m throat diameter and a 74 µm mesh window for straining water from the collection cup. Samples were hauled vertically from a depth of 40 m to the surface. Each sample was placed in a 250 ml glass jar and preserved in 90% isopropanol before being sent by courier to the laboratory.

2.2.4. Analytical methods and data interpretation

Eco Tech Laboratory from Kamloops conducted the 2010 analysis of nutrients and total metals. CARO Lab from Kelowna conducted the analyses in 2011, 2012 and 2013. Levels of several parameters were extremely low, below the Detection Limit (DL). The DL denotes a value below which it cannot be reliably differentiated from zero. The DL is determined by the level of resolution of the method or the equipment used for the analysis. The DL for nutrients and metals analyzed are shown in Appendix II.

Dr. Lidija Vidmanic from LIMNO Lab. Ltd. in Vancouver, conducted the analysis for zooplankton species composition, density and biomass. For each replicate, organisms were identified to species level and up to 200 organisms of the predominant species were counted. If 150 organisms were counted by the end of a split, a new split was not started.

The lengths of 30 organisms of each species were measured for calculation of the biomass using a mouse cursor on a live television image of each organism. Zooplankton species were identified using standard taxonomic keys (Sandercock & Scudder, 1996; Pennak, 1989; Wilson, 1959; Brooks, 1959). The lengths were converted to biomass (µg dry-weight) using empirical length-weight regression from McCauley (1984). Seasonal average values of zooplankton biomass were calculated from samples collected at three stations from August to November in 2010, and from May to September in 2011.

Interpretation for the general chemistry, nutrients and total metals results was completed by Moraia Grau and Associates. Values were compared to the BC Water Quality Approved Guidelines for drinking water and protection of aquatic life, as outlined in the Ministry of Environment website (January 2014). Parameters without approved water quality criteria, were compared to those in the BC Water Quality Working Guidelines.

Variations in general chemistry and nutrients among sites, according to month of sampling, depth and year were charted in a series of graphs. Variations in water pH, temperature, dissolved oxygen, specific conductivity, and total dissolved solids, were represented by profiles over the water column depth by month of sampling. Variables of potential significance were represented by box plots per year and month of sampling. Due to the short length of the program, trend analysis with sufficient power was not possible (Anderson, pers. comm.). Furthermore, no statistical analysis of metal concentrations was completed because the low number of samples. However, concentrations of total metals were compared between sites and to those in the 2008 baseline study (Galena Environmental, 2009), as well as in Carpenter Creek in 2012.

2.3. Quality Assurance and Quality Control

Quality assurance and quality control are essential components of a sampling program to maximize accuracy and ensure credible results and were an important component of this program.

2.3.1. Quality assurance

Quality assurance consists of a series of protocols that prevents introduced error due to operator procedures. Specific detailed protocols were established for field sampling, i.e., collection, preservation, filtration, and shipping, and analytical procedures. Before undertaking the sampling program, field staff were trained to maintain diligence and consistency in collecting, preserving and shipping samples. To ensure accurate readings, the Hanna multi-meter was calibrated regularly. All data was recorded on waterproof forms. Precautions were taken during deep-water sampling to avoid contamination of the grab samples from the boat or by turbulence caused by the boat (e.i., waiting fifteen minutes after stopping the motor to prevent higher DO readings).

To avoid sample contamination during the grab samples at 5 and 50 m depth, the inside of the Beta bottle was rinsed with distilled water at the start of each sampling day. Sample bottles and preservatives were issued by the laboratory and samples were sent by courier and arrived at the lab the same day they were collected. Laboratory personnel were notified regarding shipment prior to the field sampling.

2.3.2. Quality control

To assure accurate readings of the general water chemistry parameters, the Hanna multi-meter was recalibrated before each sampling day with calibration solutions. Sites were verified each time with a GPS, to ensure consistent sampling location. Field *blank* samples were used to provide information on contamination due to handling and from exposure to the atmosphere. Zooplankton replicate samples were submitted each month from the three zooplankton sampling sites. Reference samples were analyzed in the laboratory to document precision of the analytical process.

3. RESULTS

3.1. General Chemistry Parameters

A water quality guideline is a maximum and/or a minimum value for a physical, chemical or biological characteristic of water, which should not be exceeded, to prevent specified detrimental effects from occurring to a water use, including aquatic life, under specified environmental conditions (Ministry of Environment Approved Water Quality Guidelines, January 2014). The water quality guidelines for drinking raw untreated water, protection of aquatic life, and primary contact recreation for the five general chemistry parameters examined are shown in Table 3.

A large lake cannot not be expected to be homogenous, however when a parameter values significantly differ from year to year or approach water quality guidelines, variations should be examined and monitored. This was the case with unusual nitrogen and phosphorus concentrations in 2010, and with concentrations of metals such as chromium and nickel. Field sampling and laboratory results are presented in Appendices I and II.

3.1.1. Temperature

Water temperature is a critical factor directly affecting the physiological processes of all aquatic life along with other parameters such as concentration of dissolved oxygen and the solubility of chemical compounds. However at present, there are no industrial, agricultural or wastewater discharges into Slocan lake that could have an impact on water temperature. Therefore any subtle or progressive change in the lake´s temperature range would be a natural variation or result from changing climatic conditions.

The temperature graphs in Figure 2 show the formation of the metalimnion[1] in the summer months at about 15 to 25 m depth, with a warmer layer or *epilimnion* above, and a colder zone or *hypolimnion* below. Means, maximum and minimum temperature values across the

1 A distinct layer in which temperature changes more rapidly with depth than it does in the layers above or below, and which separates the upper warmer mixed layer from the colder and calmer deep water below.

four years for the epilimnion and the hypolimnion are shown in Table 4.

Table 3. Water Quality Guidelines for general chemistry parameters sampled.

		Water Quality Guidelines		
General Parameters	**Specifications**	**Drinking Water**	**Aquatic Life**	**Recreation Primary Contact**
Temperature		15 ºC recommended maximum	a discharge causing + or - 1 degree Celsius change from natural ambient background	Maximum 30 ºC
Dissolved Oxygen (mg/L)	Aquatic life refers to all life stages except buried embryo or alevin.	None	5 mg/L instantaneous minimum and 8 mg/L 30-day-geometric mean	No guideline
Specific Conductivity		No guideline	No guideline	No guideline
Total Dissolved Solids		No guideline	No guideline	No guideline
pH	This aquatic life criteria should be used cautiously if carbon dioxide concentrations exceed 10 µmol/L minimum or a 1360 µmol/L maximum.	6.5 - 8.5	6.5 - 9	5.0 - 9.0

For comparisons, the monthly mean temperature of the epilimnion and hypolimnion was calculated from the 5 to 20 m and the 25 to 50 m reading depths, respectively, for dates and sites sampled at those depths. Temperature readings at the surface and below 50 m were not introduced in the calculations.

The monthly mean temperature of the epilimnion from May to October ranged from 15.1 ºC in August to 5.6 ºC in May. The monthly mean temperature of the hypolimnion to 50 m depth ranged from 6.4 ºC to 4.4 ºC. Not surprisingly, the water was warmest in August and coldest in May. In previous studies (Pieters *et al*. 2006; Galena Environmental, 2009), the epilimnion was warmest at Site 2, and coldest at Site 4. Likewise, in the current study, Site 2 was slightly warmer in the fall but not at any other time sampled. There was no difference between the epilimnion temperature off Site 4 and the other sites.

Table 4. Mean, maximum and minimum temperatures in the epilimnion and hypolimnion in 2010, 2011, 2012 and 2013.

Epilimnion	Temp (ºC)	2010	2011	2012	2013
May	Mean		8.0	5.6	8.4
	Maximum		9.9	7.5	9.8
	Minimum		6.2	4.0	7.2
June	Mean		9.7	9.4	
	Maximum		11.7	12.1	
	Minimum		7.9	7.9	
July	Mean		12.1*	12.3	12.3
	Maximum		15.6	15.9	16.3
	Minimum		9.7	8.0	8.5
Aug	Mean	14.3	14.1	13.8	13.5
	Maximum	19.0	18.8	16.9	19.9
	Minimum	8.1	9.1	9.3	8.7
Sept	Mean	13.5	12.2	13.3	14.4
	Maximum	15.1	15.0	14.7	19.9
	Minimum	9.5	7.7	9.4	8.2
Oct	Mean	11.0	11.5		
	Maximum	11.4	12.0		
	Minimum	10.3	9.2		

Hypolimnion	Temp (ºC)	2010	2011	2012	2013
May	Mean		5.1	4.4	5.5
	Maximum		6.9	5.7	6.9
	Minimum		4.2	3.9	4.4
June	Mean		5.6		
	Maximum		7.7		
	Minimum		4.3		
July	Mean		5.8*	5.6	5.9
	Maximum		8.5	9.7	8.6
	Minimum		4.4	4.3	4.5
Aug	Mean	5.2	6.9	5.6	5.7
	Maximum	7.5	10.5	9.2	7.8
	Minimum	4.3	4.3	4.1	4.5
Sept	Mean	5.4	6.8	4.8	5.9
	Maximum	7.9	10.4	8.8	8.8
	Minimum	4.4	4.2	4.3	4.5
Oct	Mean	6.3			
	Maximum	10.9			
	Minimum	4.5			

* Mean calculated only from one site

The maximum temperature at the surface (excluded from mean calculations) ranged from 12.0 ºC to 7.5 ºC in May, 19.9 ºC to 22.2 ºC in July, and 17.9 ºC to 21.6 ºC in August. Maximum surface temperature in June and September was 15.7 ºC and 16.4 ºC, respectively. Minimum temperatures recorded to 20 m during the study were 4 ºC in May, 7.9 ºC in June, 8.0 ºC in July, 8.1 ºC in August, 8.2 ºC in September and 9.2 ºC in October.

3.1.2. Dissolved Oxygen

Figure 3 illustrates dissolved oxygen (DO) (mg/L) variation across the four sites per sampling season. Water quality guidelines for DO are presented in Table 5. There are no DO guidelines for drinking water and recreational use, only for freshwater aquatic life. The guidelines use two criteria: an instantaneous minimum and a 30-day mean.[1.] The minimum DO concentration required under water quality guidelines for fish (except alevin and buried embryo), is 5 mg/L of at all times, and above 8 mg/L average in a 30-day period. DO concentration means ranged from 6.0 mg/L to 12.2 mg/L in the epilimnion, and from 9.4 mg/L to 12.5 mg/L in the hypolimnion, overall meeting the minimum criteria. The lowest DO means both in the epilimnion (7.2 - 7.6 mg/L) and hypolimnion (7.3 - 8.4 mg/L) were recorded at Site 2 in May 2012 and July 2013. DO concentrations below the guidelines (5 mg/L) were only measured in the epilimnion in September and October 2010 but this was due to a technical problem with the DO probe (Galena Environmental, 2011). Mean, maximum and minimum DO values are presented in Table 6.

Table 5. Dissolved Oxygen (DO) Water Quality Guidelines for freshwater aquatic life

Dissolved Oxygen in water column	Aquatic Wildlife	
	All Life stages, except buried embryo or alevin	Buried embryo or alevin
Instantaneous Minimum[1]	5 mg/L	9 mg/L
30-day Mean[2]	8 mg/L	11 mg/L

Dissolved oxygen concentration and water temperature are closely related: the solubility of oxygen increases in cold water and decreases in warmer water. This inverse correlation can be seen in the water profile plots of DO versus temperature represented in Figure 4, which

1 The Instantaneous Minimum level is to be maintained at all times

2 The mean is based on at least five approximately evenly spaced samples in a 30-day period. If a diurnal cycle exists in the water body, measurements should be taken when oxygen levels are lowest (usually early morning) (BC Water Quality Guidelines, 2014).

illustrates a DO orthograde curve typical of an oligotrophic lake in late summer and early fall (Horne and Goldman,1994).

Dissolved oxygen was also measured by the rate of DO water saturation. In oligotrophic lakes, dissolved oxygen concentrations are determined by physical processes (atmospheric exchange and water temperature) rather than by biological processes (photosynthesis and respiration). The graphs in Figure 5 show the dependence of DO saturation on physical processes, increasing DO saturation at the surface with lowering temperatures in the fall, while remaining constant at depth.

Table 6. Mean, maximum and minimum DO (mg/L) values in the epilimnion and hypolimnion in 2010, 2011, 2012 and 2013.

Epilimnion	DO (mg/L)	2010	2011	2012	2013
May	Mean		11.6	7.2*	
	Maximum		11.9	7.2	
	Minimum		10.8	7.1	
June	Mean		11.6	12.2	
	Maximum		11.9	12.5	
	Minimum		11.1	11.4	
July	Mean		11.5	9.1	7.6*
	Maximum		12.1	10.4	7.9
	Minimum		10.4	7.6	7.4
Aug	Mean	9.8	11.1	10.7	11.4
	Maximum	12.3	11.8	11.4	12.8
	Minimum	5.5	10.0	9.9	9.5
Sept	Mean	8.2	11.6	9.1	12.3
	Maximum	14.3	12.3	11.0	13.8
	Minimum	4.6	11.0	5.5	10.5
Oct	Mean	6.0	9.1		
	Maximum	9.4	10.2		
	Minimum	4.3	8.2		

Hypolimnion	DO (mg/L)	2010	2011	2012	2013
May	Mean		11.3	7.3*	
	Maximum		11.8	7.4	
	Minimum		10.8	7.2	
June	Mean		11.5		
	Maximum		12.3		
	Minimum		10.5		
July	Mean		11.7	9.4	8.4*
	Maximum		12.1	10.9	8.6
	Minimum		11.3	7.9	7.9
Aug	Mean	10.7	11.6	11.8	12.1
	Maximum	12.5	11.9	12.0	12.4
	Minimum	8.9	11.1	11.3	11.6
Sept	Mean	13.8	11.9	10.8	12.5
	Maximum	16.8	12.2	11.3	13.7
	Minimum	9.8	11.7	10.1	10.7
Oct	Mean	9.4			
	Maximum	11.0			
	Minimum	5.5			

* Mean calculated from only one site.

3.1.3. Specific Conductivity

Conductivity is a measure of the resistance of a fluid solution to electrical flow and reflects the total concentration of dissolved ions in the water. The greater the ion content in the water (soluble compounds), the higher its ability to conduct electricity. Conductivity is measured in µS/cm. Temperature affects conductivity since it affects ion velocities. Specific conductivity (SC) avoids the variance introduced by temperature correcting the measurements to a water temperature of 25ºC.

There are no conductivity water quality guidelines for drinking water, aquatic life,or recreation. Specific conductivity means measured between 5 to 50 m depth throughout the study ranged from 95.8 to 150.3 µS/cm in May, 91.7 to 111.2 µS/cm in August, and 93.0 to 172.1 µS/cm in September. Due to technical problems with the probe, specific conductivity was only measured once in June, July and October. The means for these months was 144.8 µS/cm for June, 143.6 µS/cm for July and 63.9 µS/cm for October. Only sites with readings to 50 m depths were included in calculation of the means.

Measurements were corrected to 25 ºC for readings taken on days when the probe had not been calibrated in the field. The formula used was $C_{25} = C_m / 1 + 0.02 (t_m - 25)$, where

C_{25} = actual conductivity value adjusted to 25 ºC

C_m = actual conductivity before correction

t_m = water temperature at time of C_m measurement in ºC

(US Geological Survey TWRI Book 9 Field Manual, 1998)

Given the high natural variability of this parameter[2], coupled with uncertainty regarding some readings because technical problems, **a clear interpretation of the results is not possible**.

In previous studies, specific conductivity values in October and November were in the range of 86 to 91 µS/cm, and 97 to 98 µS/cm at 5 m and 50 m, respectively (Galena Environmental,

2 *Specific conductivity in freshwater lakes in the interior of British Columbia typically varies between 50 and 500 µS/cm (Pieters et al.* 2006).

2009; Pieters *et al*. 2006). In this study, readings in October were even lower than in the 2008 and 2001 studies, with a maximum of 81 µS/cm at 50 m depth. Conductivity values in all the other months were higher, especially in June, July and September with mean values as high as 172.1 µS/cm. The high variability of specific conductivity values in the study recommends caution in the interpretation of the data.

The graphs in Figure 6 indicate a clear pattern of increasing specific conductivity with depth, with the gradient becoming steeper in the months of May, June, and September. However, there are no patterns visible on some sampling days, and there are large differences between sites in July, August and September 2012. These variable patterns could indicate reading errors or be a result of natural variance.

3.1.4. Total Dissolved Solids

Total dissolved solids (TDS) are comprised mainly of inorganic salts, along with a small amount of organic matter. TDS concentration is largely a function of watershed geology and climate, but can also result from human agricultural activities, wastewater discharges, and road-salt. Aquatic organisms require a relatively constant concentration of the major dissolved ions in the water. However there are no TDS criteria under the BC Water Quality Guidelines or Working Guidelines for drinking water, aquatic life, or recreational use, but Canadian Guidelines establish <500 mg/L as the maximum concentration for drinking water. Often TDS is used as a measure of productivity, however, total phosphorus, total nitrogen and chlorophyll-a are more reliable parameters to assess productivity.

Previous Slocan Lake studies consistently found low TDS levels (mean 60 mg/L) with little variability (Galena Environmental, 2008). In this study however, means across all depths from 5 to 50 m ranged from 28 to 72 mg/L in July, 60 to 110 mg/L in August, and 60 to 86 mg/L in September. The means of 75 mg/L and 72 mg/L, for May and June 2011, respectively, were compiled from only one season with a full set of depth measurements, i.e., from 5 to 50 m. Mean, maximum and minimum values are shown in Table 7.

Figure 7 shows the distribution of TDS values across the water profile to a depth of 60 m in the four offshore sites from 2010 to 2013. TDS increases with depth, with the gradient being steeper in May and June than in the other months. The higher TDS values in these months could be associated with snow melt spring runoff and road salt reaching the lake.

However, the TDS values at Sites 3 and 4 in July 2012 have different distribution patterns than those of the other sites: Site 3 has increasing values from 5 to 40 m and then TDS decreases suddenly from 40 to 50 m; and Site 4 shows no increasing pattern with depth. Site 4 also has lower values than the other sites sampled in September 2012.

TDS and SC both indicate the abundance of dissolved ions in the water and are highly correlated. The lack of correlation of these two parameters in several months of the study signals that there may be problems with the data.

Table 7. Mean, maximum and minimum TDS in the epilimnion and hypolimnion in 2010, 2011, 2012 and 2013.

TDS Epilimnion	(mg/L)	2010	2011	2012	2013
May	Mean		71		45
	Maximum		75		49
	Minimum		65		42
June	Mean		66	61	
	Maximum		70	75	
	Minimum		61	55	
July	Mean			68	31
	Maximum			95	39
	Minimum			46	21
Aug	Mean	58	57	105	57
	Maximum	61	60	107	61
	Minimum	55	51	101	52
Sept	Mean	30	60	81	57
	Maximum	31	63	95	60
	Minimum	28	59	55	51
Oct	Mean	54	60		
	Maximum	56	62		
	Minimum	49	58		

TDS Hypolimnion	(mg/L)	2010	2011	2012	2013
May	Mean		77		50
	Maximum		85		53
	Minimum		70		47
June	Mean		77	77	
	Maximum		85	85	
	Minimum		66	66	
July	Mean			74	40
	Maximum			103	54
	Minimum			59	28
Aug	Mean	63	63	113	63
	Maximum	64	64	115	64
	Minimum	62	58	108	60
Sept	Mean	33	64	90	62
	Maximum	37	66	106	64
	Minimum	32	61	56	59
Oct	Mean	57			
	Maximum	64			
	Minimum	50			

3.1.5. pH

The acidity or alkalinity of a substance is measured in units called pH on a scale from 1 to 14. The term derives from the French "Puissance d'Hydrogène" (strength of the hydrogen), because the hydrogen ion controls the acidity of the water. Water with a low pH is acidic, and water with a high pH is basic, or alkaline, while water with a pH of 7.0 is neutral. Surface water from lakes and rivers typically has a pH between 6.5 and 8.5. Changes in water pH can have important ecological consequences, since many species of plants and animals do not tolerate acidic conditions. Canadian Water Quality Guidelines establish an acceptable pH range of 6.5 to 9.0 for protection of freshwater aquatic life, and of 5.0 to 9.0 for swimming. Monthly mean, maximum, and minimum pH values at the four offshore sites are shown in Table 8.

Table 8. Mean, maximum and minimum pH values in the epilimnion and hypolimnion in 2010, 2011, 2012 and 2013.

Epilimnion	pH	2010	2011	2012	2013	Hypolimnion	pH	2010	2011	2012	2013
May	Mean		7.5	8.2	7.5	May	Mean		7.5	7.4	7.5
	Maximum		7.9	9.9	7.7		Maximum		7.8	8.3	7.6
	Minimum		7.2	7.1	7.1		Minimum		7.2	7.1	7.4
June	Mean		7.3	7.8		June	Mean		7.4		
	Maximum		7.7	8.1			Maximum		7.6		
	Minimum		6.6	7.7			Minimum		7.0		
July	Mean				7.5	July	Mean				7.4
	Maximum				8.0		Maximum				7.7
	Minimum				7.0		Minimum				7.1
Aug	Mean	7.8	8.0	7.9	7.8	Aug	Mean	7.5	7.7	7.5	7.4
	Maximum	7.9	8.1	8.1	8.0		Maximum	7.6	7.9	7.6	7.6
	Minimum	7.7	7.8	7.7	7.5		Minimum	7.4	7.6	7.4	7.0
Sept	Mean	7.8	7.8	8.4	7.6	Sept	Mean	7.9	7.6	8.2	7.1
	Maximum	8.0	7.9	8.8	7.8		Maximum	8.1	7.7	8.4	7.5
	Minimum	7.5	7.7	8.1	7.1		Minimum	7.7	7.5	8.0	6.4
Oct	Mean	7.8	8.0			Oct	Mean	7.8			
	Maximum	8.6	8.1				Maximum	8.0			
	Minimum	7.0	7.9				Minimum	7.2			

In red: lowest and highest values recorded in the study.

Previously reported pH values had less variability than those in the present study (Galena

Environmental 2010, 2011). In general, the pH values at the four sampling sites from 5 m to 50 m depth ranged from 7.0 to 8.8. An unusually high pH of 9.9 was recorded at Site 2, at 5 m depth, in May 5th, 2012, while the pH dropped to 8.8 at 15 m depth in the same site. A high pH reading at the epilimnion in early May could be the result of high temperatures early in the season and/or spring runoff and road salt reaching the lake. However, since the high pH was restricted to Site 2, an explanation based on weather is not plausible. Another possibility could be reading error. Conversely, only one pH value below 7 was recorded at depth between 35 and 50 m at the same site in September, 2013.

The pH readings indicate that Slocan Lake is slightly alkaline. The pH slightly lowers with depth as is shown in Figure 8. The lower pH in the hypolimnion is likely due to production of carbon dioxide and consequent acidification resulting from decomposition processes.

3.2. Nutrients

The term nutrients refers to the chemical elements essential to plants and other forms of life. The most important nutrients in aquatic environments are nitrogen and phosphorus. On the one hand, deficiency of these elements can be limiting factors for productivity (plant growth), and on the other hand, an excess of these nutrients can promote excessive plant and algae growth; both circumstances can be detrimental to aquatic ecosystems. The dominant forms of nitrogen in fresh water are dissolved molecular nitrogen (N_2), nitrate (NO_3), and nitrite (NO_2). The common forms of phosphorus present in water are dissolved phosphorus as phosphate (PO_4-) and particulate phosphorus. Other measurements included in the study are the amount of chorophyll-a, as an indicator of lake productivity, and total Kjeldahl nitrogen (TKN), which is the sum of organic nitrogen, ammonia (NH_3), and ammonium (NH_4+).

In terms of nutrients, both excess as well as low supply could result in potential problems. Water Quality Guidelines for drinking water, freshwater aquatic life and recreation, and Detection Limits for the seven nutrients sampled are shown in Table 9. Lab analyses results are presented in Appendix II.

3.2.1. Nitrate, as N

The nitrate concentrations measured were very low, well below the water quality guidelines for protection of aquatic life of 3 mg/L average in a 30-day period, or a maximum (acute) value of 32.8 mg/L. In general, nitrate concentration increased slightly with depth. Values ranged from 0.01 to 0.11 mg/L, with an unusual high value of 0.16 mg/L at Site 3, at 50 m depth, in August 2011 (Figure 9). Values below the Detection Limit of 0.02 mg/L amounted to 5.6% of the samples.

3.2.2. Nitrite, as N

Nitrite is quickly oxidized and rarely accumulates unless organic pollution is high. The levels of nitrite measured during this study were very low. This was partly due to a change in the laboratory doing the analyses, which increased the detection limit from 0.003 mg/L in 2010 to 0.01 mg/L in 2011. As a result, the only measured nitrite concentration values are from 2010, ranging from 0.003 to 0.006 mg/L. From 2011 to 2013 nitrite concentration values were below the reported detection limit (<0.01 mg/L). Since the water quality guideline criteria for aquatic life for nitrite is an average of 0.02 mg/L in a 30-day period, the nitrite concentrations found are well below the criteria.

3.2.3. Total Kjeldahl Nitrogen

Total Kjeldahl nitrogen (TKN) measures the sum of organic nitrogen, ammonia (NH_3), and ammonium (NH_4+). As seen in Table 9, the allowable concentration of TKN under the guidelines depends on the pH and the temperature of the water, because these two factors largely determine the toxicity of ammonia to aquatic organisms. The higher the pH and the higher the water temperature are in a lake, the lower the maximum acute concentration criteria is. However, changes in pH have a greater influence on the TKN allowable concentration than changes in water temperature. For example, for water with a pH of 7 and with temperatures ranging from 6 ºC to 13 ºC, the guideline for the protection of aquatic life sets a maximum (acute) TKN concentration between 21.4 to 20 mg/L. At the same range of temperatures but with a pH of 7.5, the maximum TKN concentration is between 13.3 mg/L and 12.5 mg/L, which is significantly lower than at a pH of 7.

Table 9. Water Quality Guidelines and detection limits for nutrients sampled.

Nutrients	Raw Drinking Water	Freshwater Aquatic Life	Primary Contact Recreation	Detection Limit	Considerations
Nitrate as N (mg/L)	10 mg/L	- 3 mg/L 30-day average; -Maximum concentration 32.8 mg/L	10 mg/L	0.01 mg/L	General aquatic life
Nitrite as N (mg/L)	1 mg/L	- 30-day average 0.020 mg/L; -Maximum 0.060 mg/L	1 mg/L	0.003 and 0.01 mg/L[2]	Freshwater wildlife guideline for low chloride water (≤2mg/L)
Nitrate + Nitrite as N (mg/L)	10 mg/L		10 mg/L	0.01 mg/L	General aquatic life
TKN (mg/L)	No guideline	Maximum (acute) and 30-day average criteria dependent on pH and water temperature (see Appendix ?)	No guideline	0.05 mg/L	Toxicity of ammonia to freshwater aquatic organisms is dependent on the pH and temperature of the water environment.[1]
Total Phosphorus (mg/L)	Maximum 0.010 mg/L	Maximum within the range 0.005 to 0.015 mg/L	Maximum 0.010 mg/L	0.005 mg/L	In lakes: if residence time of the epilimnetic water is less than 6 months, mean concentration in the epilimnion during growing season
Chlorophyll-a (µg/L)	No guideline	No guideline	No guideline	0.5 and 0.1 µg/L [2]	
Total Hardness, as $CaCO_3$ (mg/L)	No guideline	No guideline	No guideline	1.25 mg/L	Water with < 75 mg/L soft; 75-150 moderately hard; 150-300 hard; >300 very hard
Alkalinity, as $CaCO_3$ (mg/L)	No guideline	up to 4 highly sensitive; 4-8 moderately sensitive; and > 8 low sensitivity	No guideline	1.25 mg/L	Sensitivity to acid inputs

1. Regarding assessment of Total P to comply with the Water Quality Guidelines, "the mean growing season phosphorous concentration should be calculated by sampling at three-week intervals over the summer growing period from near the surface, at the middle of the epilimnion and near the bottom of the epilimnion. The mean concentration over the summer growing period is then compared to the criterion. For lakes, a general correspondence between phosphorous concentration and mean growing season chlorophyll-a (..) exists. For example, a phosphorous concentration of 10 µg/L results in a chlorophyll-a concentration of 2.0 to 2.5 µg/L. The potential thus exists for setting chlorophyll-a criteria (..), however this is advantageous only in special cases. In general it is best to use phosphorous concentration as the criterion" (BC Water Quality Guidelines, 2014).

2. The Detection Limit was 0.5 µg/L in 2010, and 0.1 µg/L from 2011 to 2013.

The maximum temperature recorded in the study at 5 m depth was 19.9 ^{o}C and the highest pH values were 8.4 and 8.8. At 19.9 ^{o}C temperature and a pH of 7.5, the maximum acute TKN concentration would be 12 mg/L, while at the same temperature for a pH of 8.4, the maximum acute TKN concentration would be 2.36 mg/L and for a pH of 8.8 would be 1.07 mg/L. The mean TKN concentration values at 5 m and 50 m depth were 0.159 mg/L and 0.137 mg/L, respectively. However, under DL values were not taken into consideration in the calculation. About 30% of the samples, 15% at each sampling depth, were below the DL of 0.05 mg/L. Maximum values were 0.34 mg/L at 5 m depth and 0.47 mg/L at 50 m depth. There was no significant difference in TKN between the samples with depth, or between months (Figure 10). It would be of interest to compare these TKN values to those of other lakes in the region.

3.2.4. Total Nitrogen

Total nitrogen (TN) is the sum of various forms of nitrogen found in the water which includes nitrate, nitrite, organic nitrogen and ammonia. There is no water quality criteria for total nitrogen, except for the individual forms of nitrogen detailed in Table 9. Total nitrogen values slightly increased with depth (Figures 11 and 22). Mean, maximum and minimum values are shown in Table 10.

The TN concentration tended to be higher in May, decreased during the summer months and increased in October. This pattern is likely due to an increase of nitrogen inputs during spring freshet and lake turnover and rain events in the fall. Thus, the highest TN concentration occurs in the months of May and October, and the lowest in August. The highest concentration was found at 50 m depth in Site 2, with 0.569 mg/L in October 2011 (Figure 11B). However, variability was high, with the most stable months being July and August: TN values ranged from 0.05 to 0.40 mg/L at 5 m depth and from to 0.05 to 0.57 mg/L at 50 m depth. DL values amounted to 6% of the samples at 5 m depth, whereas the amount of DL samples at 50 m depth was negligible. No significant difference was found between sites on total nitrogen concentrations. However, TN concentration was significantly lower in 2010 compared to the other years (Figures 11 and 22), but this was attributed to a laboratory error. The TN concentration was lower in 2012 than in 2011 and 2013. This decrease in TN was correlated to a decrease in chlorophyll-a concentration in that year.

Table 10. Mean, maximum and minimum values of total nitrogen (TN) at 5 and 50 m depth in 2010, 2011, 2012 and 2013.

TN 5 m depth	(mg/L)	2010	2011	2012	2013
May	Mean		0.130	0.105	0.353
	Maximum		0.200	0.154	0.402
	Minimum		0.060	0.085	0.261
June	Mean		0.150	0.230	
	Maximum		0.160	0.295	
	Minimum		0.130	0.165	
July	Mean		0.150	0.190	0.226
	Maximum		0.180	0.227	0.233
	Minimum		0.110	0.133	0.202
Aug	Mean	0.050	0.086	0.122	0.071
	Maximum	0.050	0.162	0.171	0.107
	Minimum	0.050	<0.050	<0.050	<0.050
Sept	Mean	<0.050	0.263	0.126	
	Maximum	<0.050	0.381	0.163	
	Minimum	<0.050	0.175	0.092	
Oct	Mean	0.120	0.253		
	Maximum	0.353	0.377		
	Minimum	<0.050	0.194		

TN 50 m depth	(mg/L)	2010	2011	2012	2013
May	Mean		0.170	0.123	0.313
	Maximum		0.200	0.167	0.497
	Minimum		0.150	0.081	0.139
June	Mean		0.170	0.160	
	Maximum		0.210	0.170	
	Minimum		0.140	0.150	
July	Mean		0.160	0.213	0.241
	Maximum		0.200	0.392	0.267
	Minimum		0.080	0.072	0.190
Aug	Mean	0.100	0.185	0.127	0.075
	Maximum	0.100	0.275	0.181	0.110
	Minimum	0.100	0.092	0.087	<0.05
Sept	Mean	0.075	0.258	0.164	
	Maximum	0.080	0.380	0.325	
	Minimum	0.070	0.200	0.104	
Oct	Mean	0.100	0.327		
	Maximum	0.100	0.569		
	Minimum	0.100	0.222		

In red: maximum total nitrogen values at 5 m and 50 m depth.

3.2.5. Total Phosphorus

Total phosphorus (TP) includes dissolved and suspended particulate phosphorus forms. In aquatic environments, phosphorus is typically the limiting nutrient for biological productivity. Phosphorus naturally enters freshwater bodies from precipitation, ground water and surface runoff. In populated and agricultural areas, excess phosphorus in runoff is a common cause of excessive algal and plant growth, leading to accelerated eutrophication of freshwater bodies. According to Wetzel (1985), TP levels in non-polluted oligotrophic lakes are between 5 and 10 μg/L (0.005 to 0.010 mg/L).

Measured phosphorus concentration values were in general below 0.01 mg/L (10 µg/L) except for concentrations in 2010, when values ranged from 0.017 to 0.043 mg/L (Table 11). The high values in 2010 were attributed to contamination of the samples (Galena Environmental, 2011). In 2012 and 2013, all 60 samples were below 0.01 mg/L, except for one measuring 0.02 mg/L. However, in May and June 2011, concentrations higher than those found in 2010 were measured in eight samples at Sites 1,2, and 4; these measurements ranged from 0.014 mg/L to 0.064 mg/L. These higher concentrations are within the range previously found in 2008 (values in the hypolimnion between <0.01 to 0.09 mg/L). These high TP values, however, should be taken with extreme caution, given the other characteristics of Slocan Lake, and should be checked in future samplings.

Table 11. Mean, maximum and minimum values of total phosphorus (TP) at 5 m and 50 m depth in 2010, 2011, 2012 and 2013.

TP 5 m depth	(mg/L)	2010	2011	2012	2013
May	Mean		0.028	0.006	<0.005
	Maximum		0.050	0.007	<0.005
	Minimum		0.014	0.005	<0.005
June	Mean		0.015	0.0095	
	Maximum		0.033	0.010	
	Minimum		0.008	0.009	
July	Mean		<0.005	0.006	<0.005
	Maximum		<0.005	0.009	<0.005
	Minimum		<0.005	<0.005	<0.005
Aug	Mean	0.034	<0.005	0.010	<0.005
	Maximum	0.038	<0.005	0.020	<0.005
	Minimum	0.031	<0.005	0.005	<0.005
Sept	Mean	0.019	<0.005	0.007	
	Maximum	0.021	<0.005	0.013	
	Minimum	0.017	<0.005	<0.005	
Oct	Mean	0.035	<0.005		
	Maximum	0.037	<0.005		
	Minimum	0.032	<0.005		

TP 50 m depth	(mg/L)	2010	2011	2012	2013
May	Mean		0.032	0.007	<0.005
	Maximum		0.064	0.009	<0.005
	Minimum		0.008	0.006	<0.005
June	Mean		0.006	0.008	
	Maximum		0.009	0.008	
	Minimum		<0.005	0.008	
July	Mean		<0.005	0.006	<0.005
	Maximum		<0.005	0.006	<0.005
	Minimum		<0.005	0.006	<0.005
Aug	Mean	0.034	<0.005	0.007	<0.005
	Maximum	0.039	<0.005	0.007	<0.005
	Minimum	0.031	<0.005	0.007	<0.005
Sept	Mean	0.020	<0.005	0.004	
	Maximum	0.022	<0.005	0.006	
	Minimum	0.019	<0.005	<0.005	
Oct	Mean	0.036	<0.005		
	Maximum	0.043	<0.005		
	Minimum	0.023	<0.005		

Because the TP concentrations were generally very low, they were often below the DL established at 0.005 mg/L (5 µg/L). Overall 46% of the measured values were below DL

(24% at 5 m and 22% at 50 m depth), thus it was not possible to establish a defined mean for certain months. A reduction of 50% was applied to the DL (0.0025 mg/L) to calculate the means. The TP estimated average concentrations are from 0.0055 mg/L (5.5 µg/L) at 5 m depth, and 0.0053 mg/L (5.3 µg/L) at 50 m depth.

Variability between months was not consistent. May showed the highest phosphorus concentrations in 2011 (0.06 mg/L), but not in 2012 or 2013, when the highest concentrations occurred in August (0.02 mg/L) (Figure 12). Values at 5 m and 50 m depth showed similar concentrations. The lack of a defined pattern for phosphorus concentrations may be due to insufficient data, or to the marked effect of weather events in phosphorus concentration, without ruling out possible contamination of the samples or laboratory error.

The uncertainty over certain values due to meter malfunction or lab error, such as specific conductivity, total dissolved solids, total nitrogen and total phosphorus, makes interpretation of those parameters difficult.

3.2.6. Chlorophyll-a

Chlorophyll-a is a pigment that gives the green colour to plants and algae. Quantification of chlorophyll-a levels is commonly used to measure productivity and define the trophic state of water bodies. Values below 3 µg/L are considered to indicate low productivity, typical of oligotrophic conditions, and values greater than 15 µg/L are considered high productivity, characteristic of eutrophic conditions (RISC, 2008). Chlorophyll-a is part of the phytoplankton (free-floating algae) and the periphyton (substrate attached algae). In this study only chlorophyll-a originating in free-floating plankton in the water column was analyzed.

There are no water quality guidelines criteria for planktonic chlorophyll-a, however, since phosphorus concentration is directly related to algae productivity, phosphorus criteria guidelines in lakes are designed to limit chlorophyll-a to certain levels. Both chlorophyl-a and TP are used as indicators of trophic status.

Phytoplankton productivity is variable since it is influenced by factors that can change rapidly (e.g., light intensity), thus phytoplankton concentration varied markedly throughout the year, and from year to year. Chlorophyll-a levels tended to be higher in the spring and the fall than in the summer (Table 12, Figures 13 and 23). Particularly low concentrations occurred during the summer of 2012. Also, phytoplankton concentration was lower at 50 m depth than at 5 m depth. This is due to lower light levels with depth which limit algal growth. Chlorophyll-a concentrations were unusually low, below the detection limit (<0.5 µg/L), at the epilimnion in the fall of 2010. In the same months in 2011, however, chlorophyll values were close to or higher than 1 µg/L. In 2012 and 2013 values were also above detection levels.

Chlorophyll-a concentrations were well below 3 µg/L. The highest value was of 2.3 µg/L at Site 1 in September, 2011, which confirms the low productivity of Slocan Lake. Mean, maximum and minimum chlorophyll concentrations are presented in Table 12.

Tabla 12. Mean, maximum and minimum chlorophyll-a concentration in the epilimnion and hypolimnion in 2010, 2011, 2012 and 2013.

Chlorophyll-a Epilimnion	(µg/L)	2010	2011	2012	2013
May	Mean		1.3	0.9	1.0
	Maximum		1.6	1.0	1.0
	Minimum		1.1	0.6	1.0
June	Mean		0.7	1.0	
	Maximum		0.9	1.0	
	Minimum		0.4	1.0	
July	Mean		0.6	0.7	1.3
	Maximum		0.9	1.0	2.0
	Minimum		0.4	0.3	1.0
Aug	Mean	<0.5	1.0	0.5	0.7
	Maximum	<0.5	1.4	0.8	0.9
	Minimum	<0.5	0.6	0.1	0.2
Sept	Mean	<0.5	1.5	0.3	
	Maximum	<0.5	2.3	0.6	
	Minimum	<0.5	1.1	0.1	
Oct	Mean	0.6	1.4		
	Maximum	0.9	1.4		
	Minimum	<0.5	1.2		

Chlorophyll-a Hypolimnion	(µg/L)	2010	2011	2012	2013
May	Mean		1.1	0.7	0.9
	Maximum		1.5	1.0	1.0
	Minimum		0.8	0.4	0.8
June	Mean		0.4	0.3	
	Maximum		0.5	0.6	
	Minimum		0.3	0.4	
July	Mean		0.5	0.4	1.3
	Maximum		0.9	0.6	1.0
	Minimum		0.2	0.3	2.0
Aug	Mean	0.6	1.1	0.4	0.6
	Maximum	0.9	1.3	0.4	0.9
	Minimum	0.5	1.0	0.3	0.4
Sept	Mean	0.7	1.1	0.4	
	Maximum	0.8	1.8	0.7	
	Minimum	0.5	0.8	0.1	
Oct	Mean	0.4	1.2		
	Maximum	0.6	1.3		
	Minimum	<0.5	1.1		

Algae require a nitrogen / phosphorus ratio of 7.2 to 1. If the ratio is larger (for example 9 to 1), productivity is limited by phosphorus; i.e., additional phosphorus will stimulate growth. If the ratio is lower (for example 5 to 1), productivity is limited by nitrogen; i.e., additional nitrogen will stimulate growth.

The ratio of total nitrogen to total phosphorus from samples in 2011 to 2013 was in general larger than 7.2 to 1, which would indicate that phosphorus limits productivity. On the contrary, the 2010 samples show a N/P ratio lower than 2 (except Site 4 in October 2010, which with a TKN value of 0.31 mg/L had a ratio of 9.5). Not only the concentration of phosphorus in 2010 is higher than in the following years, but the concentration of nitrogen (related to a very low TKN) is lower than in the other years, which would indicate that Slocan Lake had a nitrogen limited productivity in August, September and October 2010. Obviously, and as reported by Galena Environmental (2011), the high unusual phosphorus values and the low unusual TKN values in 2010 are most likely related to a laboratory error.

The chlorophyll-a concentration values as well as Secchi depth, or water clarity, readings during four years of sampling by BC Lake Stewardship Monitoring Program (between 2007 and 2010). confirm the oligotrophic, or low productivity, condition of Slocan Lake. Average Secchi readings were from 10.9 m to 13.7 m. In addition, the estimated N to P ratio indicates that Slocan Lake´s productivity is limited by phosphorus.

3.2.7. Total Hardness, as $CaCO_3$

The hardness of water is generally due to the presence of calcium and magnesium in the water, but is reported in terms of calcium carbonate. Water is considered hard if the $CaCO_3$ levels are above 120 mg/L, and it is considered soft when $CaCO_3$ levels are below 60 mg/L. Water hardness originate mainly from the dissolution of geological minerals into rain and ground water.

There are no hardness water quality guidelines for drinking water, aquatic life, and recreational use. However, hardness between 80 -100 mg/L is considered the optimal range for drinking water, although it is acceptable to a maximum of 500 mg/L (RISC, 1998). A benefit of harder waters is the effect of reducing the toxicity of some metals (e.g., copper, lead, and zinc.), although hard water may result in scale deposits in metal pipes. On the contrary, soft water may have corrosive effects on metal plumbing.

Alkalinity, a measure of the acid-neutralizing capacity of water, is also commonly reported as equivalent of calcium carbonate ($CaCO_3$). The alkalinity guidelines for protection of aquatic life determines the sensitivity of water bodies to acidic inputs:

0 - 10 mg/L : high sensitivity

10 - 20 mg/L: moderate sensitivity

> 20 mg/L: low sensitivity

Since both parameters, hardness and alkalinity, are reported as $CaCO_3$ or equivalent, both can be assessed.

There was only one sampling day for water hardness. The results were comparable at the four sites with means of 38.7 mg/L and 46.3 mg/L at 5 m and 50 m depths, respectively. Maximum and minimum values ranged from 35.6 to 50.4 mg/L. These results are comparable to those from previous studies (Galena Environmental, 2008). Based on these values, the water in Slocan Lake could be typified as soft, with a low sensitivity to acidic inputs.

3.3. Total Metals

Water samples were analyzed for their metal contents. The measure *Total metal* includes all forms of a metal such as dissolved and suspended or particulate form. Trace quantities of many metals are included in natural waters, and are important for the development of many aquatic organisms. However, many of these metals can be dangerous contaminants when in excess quantities. Water quality guidelines have been approved or are being developed for many metals in order to protect both human health and aquatic life. The approved and interim guidelines for drinking water, protection of freshwater aquatic life, and primary contact recreation for metals analyzed in this study are shown in Appendix III. In general, the water guidelines are established based on concentration of total metals.

Water samples for total metals concentrations were collected twice in the lake and once in Carpenter Creek. In 2010 samples were taken from only two offshore sites due to budget constraints, whereas samples from the four offshore sites were taken in 2011. In order to have a larger time span to assess possible trends, metal analyses from 2008 were included in the review of total metals. Water concentrations of the metals sampled were compared to the BC Water Quality Guidelines (Table 13). In general, the most restrictive guidelines are those for the protection of freshwater aquatic life and were the ones used for this review.

In some cases, such as aluminum and mercury, the total concentration value does not permit comparison with the BC Water Quality Guidelines. The guidelines criteria for aluminum is based on the dissolved aluminum fraction and not on total metal; for chromium the guideline is specific for the hexavalent form of chromium (Cr VI) not for total chromium; for mercury the criteria is based on the percent of methyl mercury and not on total mercury; and for tin there are several criteria referred to tin´s various forms (Di-n-butyl, Triethyl, etc.), and not for total tin. Since the analyses only provided the total metal content, it was not possible to compare results of these metals concentrations with the guidelines.

Calcium, magnesium, potassium and sodium increased slightly with depth. Reactive silica was only sampled in 2012 and was not included in Table 13. Silica concentration ranged from 6.6 to 5.5 mg/L from May to July. Silica is essential for diatoms, and these concentrations are adequate for diatom´s growth. There are no water quality guidelines for silica except for food processing and industrial water. Values for many metals were below detection levels. The concentrations found for most metals in Slocan Lake were within the water quality guidelines, except cadmium and zinc. Mean values of total metals sampled are shown in Table 13. Plots of six metals of concern – cadmium, zinc, copper, lead, chromium and aluminum – are shown Figure 14.

Table 13. Total metals concentrations at 5 and 50 m depth in 2008, 2010 and 2011.

	Epilimnion Means			Hypolimnion Means			
Metal	2008	2010	2011	2008	2010	2011	Carpenter Cr.
Aluminum (µg/L)	<50	7.5	27.8	<50	2	7.3	289
Antimony (µg/L)	<3	<1	0.15	<3	<1	0.13	0.5
Arsenic (µg/L)	<5	0.06	<0.5	<5	0.09	<0.5	1.4
Barium (µg/L)	23	21.5	22.3	23.5	23.5	25.5	15
Beryllium (µg/L)	<2	<0.1	<0.1	<2	<0.1	<0.1	<0.1
Bismuth (µg/L)	<0.5	<1	<0.1	<0.5	<1	<0.1	<0.1
Boron (mg/L)	<0.02	<0.01	0.006	<0.02	<0.01	0.005	<0.004
Cadmium (µg/L)	0.753	0.109	0.13	0.26	0.105	0.12	0.84
Calcium (mg/L)	12,18	11.62	12.5	13.4	13.09	14.8	24.7
Chromium (µg/L)	<15	0.1	<0.5	<15	0.15	<0.5	0.9
Cobalt (µg/L)	<0.5	<0.1	<0.05	<0.5	<0.1	<0.05	0.28
Copper (µg/L)	3.98	0.25	0.33	<3	0.25	0.2	1.7
Iron (mg/L)	<0.20	0.005	0.01	<0.20	0.004	0.006	0.52
Lead (µg/L)	1.1	0.28	0.33	<1	0.02	0.35	3
Lithium (µg/L)	<2		0.93	<2		1.05	1.2
Magnesium (mg/L)	1.61	1.67	1.85	1.82	1.95	2.24	6.18
Manganese (µg/L)	<5	<1	1.5	<5	<1	0.75	20
Mercury (µg/L)	<0.3		0.01	<0.3		0.02	<0.01
Molybdenum (µg/L)	<1	<1	0.9	<1	<1	1.0	2
Nickel (µg/L)	8.13	<1	0.33	<5	<1	0.33	254
Potassium (mg/L)	0.45	0.425	0.46	0.49	0.46	0.54	0.6
Selenium (µg/L)	<5	0.315	0.4	<5	0.39	0.3	1.5
Silicon (mg/L)	3.03	2.53	2.5	3.3	2.75	2.78	3.2
Silver (µg/L)	<0.4	<0.005	0.04	<0.4	<0.005	<0.005	<0.05
Sodium (mg/L)	0.87	0.86	1.0	1.01	1.01	1.27	1.34
Strontium (mg/L)	0.194		0.188	0.21		0.22	0.211
Sulfur (mg/L)							5
Tellurium (µg/L)	<3		<0.2	<3		<0.2	<0.2
Thalllium (µg/L)	<0.5		<0.02	<0.5		<0.02	<0.2
Thorium (µg/L)	<3		<0.1	<3		<0.1	<0.1
Tin (µg/L)	<2	<0.1	<0.2	<2	<0.1	<0.2	<0.2
Titanium (mg/L)	<0.1	<0.007	<0.005	<0.1	<0.007	<0.005	0.01
Uranium (µg/L)	<0.5	0.29	0.30	<0.5	0.31	0.32	0.57
Vanadium (µg/L)	<10	0.2	<1	<10	0.15	<1	2
Yttrium (µg/L)		<1			<1		
Zinc (µg/L)	78.5	12.6	16.8	24.3	15.6	19.8	83
Zirconium (µg/L)	<5		<0.1	<5		<0.1	<0.1

3.3.1. Cadmium

Cadmium is known to have cumulative and highly toxic effects on trout and zooplankton. The presence of other heavy metals such as zinc and copper are known to increase its toxicity. Main sources of cadmium are industrial and mining effluents (RISC 1998).

Cadmium maximum concentrations in 2010 and 2011 were 0.113 µg/L and 0.140 µg/L, respectively. In 2008 the concentration at Sites 3 and 4 reached 0.30 and 2.34 µg/L, respectively, at 5 m depth, and 0.21 µg/L and 0.47 µg/L at 50 m depth. The present cadmium maximum concentration depends on water hardness (mg/L) according to the formula:

$$\text{total cadmium } (\mu g/L) = 10 \exp (0.86[\log\{\text{hardness}\}]-3.2)$$

Applying the mean hardness measured in 2011 of 42.5 mg/L, the maximum total cadmium for protection of aquatic life would be 0.016 µg/L. If we applied the mean hardness measured at the epilimnion (38.7 mg/L), the maximum total cadmium under the guideline would be 0.015 µg/L, and if applying the mean hardness at the hypolimnion (46.3 µg/L) the maximum total cadmium under the guideline would be 0.017 µg/L.

All samples from Slocan Lake (20 total) taken from 2008 to 2011 surpassed the guideline maximum cadmium concentrations by approximately a magnitude of 10X. The highest concentration was measured in Site 4 October, 2008 (2.34 µg/L), and the second highest was found in Carpenter Creek (0.84 µg/L) (Figure 14). The average concentration of all samples taken in 2010 and 2011 at Slocan Lake is 0.116 µg/L (Table 13).

3.3.2. Zinc

In the aquatic environment, zinc is most toxic to microscopic organisms; it also enters the food chain at this level and affects other species. However, it is an essential element as well, and its deficiency can have harmful effects when it is below certain levels. Soluble forms of zinc are considered the most toxic.

Zinc maximum concentrations were 15.8 µg/L in 2010 and 21 µg/L in 2011, with means of

15.6 (2010) and 19.8 µg/L (2011) at 50 m depth. The maximum acute concentration under the guidelines is 33 µg/L, but the 30-day average maximum is set at 7.5 µg/L. Within twelve samples, not one of them was below 10 µg/L; thus it can be expected that the zinc 30-day average maximum guideline is likely exceeded. The unusually high zinc concentrations measured in Site 4 in 2008 (Galena Environmental, 2009), were not found in samplings at that site during this study. As with cadmium, the highest concentration was found in Carpenter Creek (83 µg/L). The high concentration of zinc in Slocan Lake has been known since 1977. A study by the Water Investigation Branch found an above average zinc concentration of 43 µg/L in Slocan Lake. Natural zinc concentrations in other Kootenay Lakes averaged 5 µg/L (Rocchini *et al*. 1977).

3.3.3. Other metals

Other metals also showed high concentrations in Slocan Lake or Carpenter Creek. Copper and nickel were below the guidelines in Slocan Lake samplings from 2010 and 2011, but showed high concentrations in Site 4 in 2008 and in Carpenter Creek in 2012.

Copper is an essential element for plant and animal development. However, it can also be acutely toxic to most forms of aquatic life at relatively low concentrations. Under the BC Water Quality Guidelines the maximum acute concentration is dependent on water hardness, as defined by the following formula:

Maximum total copper (µg/L) = (0.094(hardness)+2), with hardness as mg/L of $CaCO_3$.

The mean hardness found in the epilimnion (38.7 mg/L) was applied in the equation, resulting in a maximum (acute) copper concentration guideline of 5.6 µg/L. The maximum 30-day average concentration set by the guidelines is equal to or less than 2 µg/L. Samplings in Slocan Lake in 2010 and 2011 measured concentrations below the maximum guideline criteria (Figure 14). However, in 2008 Site 4 was above the maximum acute guideline with a value of 11.4 µg/L, and in 2012 water from Carpenter Creek had a concentration of 1.7 µg/L, close to the 30-day average maximum criteria.

Similarly, in 2010 and 2011 nickel samples from Slocan Lake were below the guideline with mean values between 0.33 and 1 µg/L (Table 13). However, nickel reached the maximum acute guideline at Site 4 in 2008 with a concentration of 25 µg/L (Galena Environmental, 2009), and the sample from Carpenter Creek largely surpassed the guideline criteria with a value of 254 µg/L.

Silver is another metal of potential concern looking at the results. The maximum (acute) criteria under the guidelines is 0.1 µg/L, and the 30-day maximum average is 0.05 µg/L. Two samples from 2011 reached the latter concentration. Silver, particularly dissolved ions, is toxic to microscopic organisms or larval forms of aquatic animals.

In addition to the above metals, results from Carpenter Creek water samples show high concentrations close to or above maximum guideline levels for the protection of aquatic life for aluminum, chromium and lead (Figure 14). Although aluminum is not considered a threat for public health, in acidic, low-pH conditions, it can cause deformation of embryos. The guideline for the protection of freshwater aquatic life is set at 0.1 mg/L dissolved aluminum instantaneous maximum. The sample from Carpenter Creek had a concentration of 0.3 mg/L total aluminum.

Chromium enters bodies of water naturally through leaching from topsoil and rocks. Anthropogenic sources come from discharges or wastes from various industries such as ore and metal processing, as well as paint and wood preservatives. The guideline is presently under review , with an interim maximum of 1 µg/L, specific to hexavalent chromium, the form most related to ore processing. Even though the analysis provided amount of total chromium, Slocan Lake samples showed mean values of 0.15 µg/L in 2011, which would be below the guideline. On the other hand, Carpenter Creek showed a concentration of 1.9 µg/L (Table 13).

Lead is a toxic element that accumulates in the bones. Due to its solubility, lead is found in most natural waters in BC but at concentrations of less than 3 µg/L. Anthropogenic sources of lead are mining and industrial inputs. BC´s guideline for raw drinking water is set at 50 µg/L, however, other sources recommend less than 10 µg/L (RISC 1998). The guideline for freshwater aquatic life is dependent on water hardness, according to the following equations:

1) Maximum (acute) total lead = e(1.273 ln (hardness) - 1.460

At a mean hardness of 42.5 mg/L, the maximum (acute) concentration = 27.5 µg/L

2) Maximum 30-day average (µg/L) ≤ 3.31 + e(1.273 ln (mean hardness) - 4.704)

At a mean hardness of 42.5 mg/L, the maximum 30-day average concentration = 4.4 µg/L

Two samples approach the 30-day maximum concentration: Carpenter Creek with 3 µg/L in August 2012, and Site 4 in October 2008 with 2.9 µg/L but no sample was close to the maximum acute concentration.

3.3.4. Interpretation and limitations

Detecting a trend in total metal concentrations is not possible at this time because of the limited number of samples and the short time span of the study (2008-2011), as well as the limitations imposed by changing detection limits. However, magnesium and sodium show a slight progressive increase from 2008 to 2011. Little vertical stratification was detected except for sodium and calcium, which increased with depth, and copper and aluminum which decreased with depth.

Changing detection levels added a layer of difficulty to the analyses of the results. For example, the detection level in 2008 was higher than the guideline for copper, silver and vanadium. Also the detection level changed for many metals, from 2008 to 2010, and again in 2011. Generally, detection levels decreased (i.e.,lower levels of metals are detected) but in some cases increased (i.e.,only higher levels of metals are detected), such as with silver: in 2010 the DL was 0.005 µg/L and in 2011 the DL increased to 0.05 µg/L.

3.4. Microbiology

The bacteriological parameters investigated were total coliforms, thermo-tolerant coliforms (fecal) and *Escherichia coli.* Coliforms were counted by colony forming units (cfu). Since coliforms are abundant in feces, their presence is used to indicate that other pathogenic organisms of fecal origin may be present. The Water Quality Guidelines for Drinking Water and Primary Contact Recreational Use is shown in Table 14.

Table 14. Microbiological Water Quality Guidelines in British Columbia

	Drinking water - without treatment	Primary Contact Recreational Use
Total coliforms (cfu/100 ml)	0/100 ml	None applicable
Fecal coliforms (cfu/100 ml)	0/100 ml	Less than or equal to 200/100 ml geometric mean
E. coli (cfu/100 ml)	0/100 ml	Less than or equal to 77/100 ml geometric mean

None of the samples taken during the study surpassed the criteria established for primary contact recreational use (swimming or bathing) (Figure 15). The two highest fecal coliform counts were from the Silverton Hotel site (9 and 8 cfu). The third highest count was from the site near Silverton Creek (7 cfu). These three highest counts took place in 2012 and 2013. Fecal coliforms and *E.coli* were found in both sites in New Denver and Silverton, and in Hills and Bigelow Bay sites. In particular, *E.coli* counts have experienced a progressive increase from 2010 to 2013 at the Silverton Hotel site (Figures 15 -17). The microbiology results and interpretation by Passmore Laboratory can be found in Appendix IV.

3.5. Zooplankton

Zooplankton refers to a a myriad of unicellular or multicellular organisms with animal-like traits that drift or weakly swim in the water. Large cladocerans such as *Daphnia* spp exercise an important control on the algal community by grazing on the algae. Zooplankton species are an essential part of aquatic ecosystems, and play a crucial role in the aquatic food chain, as a food source for fish and as a control for phytoplankton (algae).

Prior to the present study, zooplankton had been sampled only once in Slocan Lake. That study was conducted by Wilson and Dolecki in 2000-2001 (2002), in collaboration with the Pieters *et al.*´s 2000-2001 limnology study (2006). Yearly water samples from Slocan Lake from 2010 to 2013 were examined by limnologist Lidija Vidmanic for species identification, density and biomass calculation. The results from the present study were compared to the previous zooplankton study done in Slocan Lake by Wilson and Dolecki. Lab reports and results are included in Appendix V.

3.5.1. Species present

The diversity of zooplankton species has decreased from 2001. Only four species – two copepods and two cladocerans – were found from 2010 to 2012, and one more cladoceran was identified in 2013. In the 2000-2001 study, eight species – three copepods and five cladocerans – were identified (Table 15).

Table 15. List of zooplankton species identified in samples

Species	Sampling Year					
Copepoda	2000	2001	2010	2011	2012	2013
Cyclopoida						
Diacyclops bicuspidatus thomasi	x	x	x	x	x	x
Calanoida						
Leptodiaptomus pribilofensis	x	x	x	x	x	x
Leptodiaptomus ashlandi	x	x				
Cladocera						
Daphnia rosea	x	x	x	x	x	x
Bosmina longirostris			x	x	x	x
Alona sp.	x	x				
Eubosmina longispina	x	x				
Sida cristallina	x	x				
Scapholeberis kingi	x	x				
Scapholeberis rammneri	x	x				

3.5.2. Density and biomass

Two numerical parameters are used to define the zooplankton community: density and biomass. Density is based in the number of organisms, whereas biomass is based on the body weight relative proportion of the various groups that form the community.

In all the sampling years, the zooplankton population was dominated numerically (density) by copepods, from 94% of the population in 2000 to 78% in 2013, while zooplankton biomass was dominated by *Daphnia* from 2001 (57%) to 2013 (56%), except in 2011, when *Daphnia* biomass only made up for 30% of total zooplankton (Figures 18-21). Zooplankton density and biomass mostly peaked between August and September with slight variations.

In comparison to the 2000-2001 data, there has been a drastic reduction in zooplankton density (89%) and biomass (86%). Over the same period, the decrease in copepod biomass (80%) was slightly lower than that of *Daphnia* (86%). However, zooplankton population experience rapid changes in relatively short periods of time. In 2001 *Daphni*a biomass increased 96% over the previous year.

Changes in zooplankton can be the result of top-down forces; for example, fish predation may reduce the numbers and biomass of certain groups such as *Daphnia;* or bottom-up forces; for example a lower availability of nutrients decreases algae production, which in turn lowers the population of zooplankton. Other factors found to affect zooplankton negatively are metal contamination, a lack of calcium, and UV-radiation (Whitmore and Webster, 2008). Also the introduction of a foreign species may have unexpected consequences in a lake ecosystem, and in particular in the zooplankton community, such it was the drastic reduction in zooplankton in many lakes as a result of the introduction of the crustacean *Mysis relicta* in the 1970´s. With the current available data, the decrease in zooplankton may be within the natural variability cycle of the community or may be the result of an unknown new factor(s). Laboratory results and interpretation are included in Appendix V.

4. RECOMMENDATIONS

The 2010-2013 Water Quality Monitoring Project has established a baseline for various chemical, physical and microbiological parameters of Slocan Lake; it has also raised some questions and issues that need further investigation. A long term monitoring program of a minimum of six years is needed to detect trend changes and indicate potential problems.

Such a monitoring program would be most effective if conducted in cooperation with municipalities, other governing agencies and SLSS. Community participation in a monitoring program increases awareness of water quality and freshwater ecosystems health for local residents, as well as visitors and nearby communities.

4.1. Recommendations for Nearshore Sampling

Future studies should especially focus on thermo-tolerant coliform monitoring

- Areas where there is a higher risk of septic runoff entering the lake, such as Silverton and New Denver should be a priority. To be able to differentiate between wildlife and domestic animals´ fecal coliforms from septic leaching coliforms, microbial source tracking (MST) should be incorporated into the analysis. Of the various methods of bacterial source tracking, the Antibiotic Resistance Analysis (ARA) has been widely used and has given good results when used to differentiate human versus wild animal sources (Meays *et al*., 2004). It will also likely be the least expensive at that level of detail.

- If budgetary constraints are a concern, of the seven nearshore sites, the ones with highest *E.coli* bacteria counts should be a priority. This applies particularly to the nearshore sites Silverton Hotel, Silverton Creek, New Denver Carpenter Creek, Bigelow Bay and Hills. The analysis could concentrate in *E. coli* exclusively. The sampling should take place annually, consistently in five days, regularly spaced, from mid-August to mid-September.

Future studies should continue to monitor metals

- Sampling for metals which tested high in Carpenter Creek (aluminum, cadmium, chromium, lead, nickel, and zinc) should be incorporated into a heavy metals nearshore program. Given the untreated mining tailings and effluents in the Carpenter Creek watershed, copper, mercury and silver should be included in metal monitoring. Following the B.C. Water Quality Guidelines criteria, the analyses of metals should include total and dissolved aluminum, cadmium, and zinc, and the analyses of mercury should report the portion of methyl mercury. Appropriate nearshore sites would be Silverton Hotel and New Denver Carpenter Creek.
- The water of Carpenter, Silverton, and Enterprise Creek should all be tested for heavy metals concentrations, preferably 5 times in a 30-day period each year, at spring freshet or summer. Sediment samples from each of the creeks should also be tested for metal content.

Future studies should include fish population and macroinvertebrates

- No data has been collected on the biology of Carpenter Creek, an important fish producing stream of rainbow (*Onchorhynchus mykiss*) and bull trout (*Salvelinus confluentus*). The high levels of heavy metals in water and sediments have likely had an effect on fish and invertebrates. A study of the aquatic macroinvertebrate community would assess the condition of this important part of the aquatic food chain. A fish study to evaluate the condition of the fish population should be contemplated to investigate for disease and abnormalities. In addition, fish samples should be taken to measure the level of metals in fish tissue. Two fish samples were taken by the Water Investigations Branch in 1971 and found detectable amounts of copper, mercury and zinc. No more analyses have been done since that time (J. Raggett, pers. comm).

4.2. Recommendations for Offshore Sampling

- General parameter measurements (Temperature, pH, DO, TDS, SC) should be taken consistently three times per year – early June, early August and early October, at 5 m increments to a depth of 50 m..There should be a better protocol in place for meter calibration and use, as well as the inclusion of lab reference samples to monitor the accuracy of the readings.

- Zooplankton sampling should continue with one sampling per year, following the same procedure as in the present study and at the same sites (Sites 1, 2, and 3).
- Lake water should be tested for nutrients and metals. Ideally, five samples regularly spaced in a 30-day period should be done once per year, consistently in early August, at least at three sites (1, 2, and 3), at 5 and 50 m depths. At minimum, water samples should be tested for total and dissolved aluminum, cadmium, chromium, copper, lead, mercury, nickel, and zinc. The program should maintain the same sampling sites in order to be able to compare the results with those from the present study.

5. CONCLUSION

The goal of the Water Quality Monitoring Program was to establish a baseline on the condition of Slocan Lake, in order to be able to identify future variations and potential trends. The three years of water quality monitoring has provided that baseline. However, a three-year program does not permit the inference of trends, particularly in samples taken once per year such as total metals.

The parameters tested demonstrated the oligotrophic or low productivity condition of Slocan Lake. Most of the parameters were within the Provincial Water Quality Guidelines in regards to raw drinking water, protection of aquatic life and primary contact recreation. However, measurements of cadmium and zinc concentrations were above the guidelines, and there were occasional high concentration measurements of copper, chromium and nickel. All of these metals require further monitoring.

Analyses of water from Carpenter Creek have also shown concentrations of several metals to be higher than the Water Quality Guidelines. Like Carpenter Creek, other creeks such as Silverton Creek and Enterprise Creek, collect the drainage from abandoned mines in their watersheds. Water and sediment from these creeks should be tested, and a study on the potential impact on fish and macroinvertebrate populations in these drainages is recommended.

In addition, zooplankton sampling has shown a drastic decline in species diversity, density and biomass in Slocan Lake since studies done in 2001 and 2010. It is recommended that the monitoring of zooplankton in Slocan Lake continues in order to establish the cause of the change.

In general, the microbiological sampling has shown a low incidence of *E.coli* bacteria in the seven nearshore program sites. In the last two years, however, the number of *E.coli* in the water samples has increased, making it advisable to continue the program in the five sites with higher *E. coli* counts. In order to discern leaching septic tanks bacteria from those of animal origin, microbial source tracking (MST) should be incorporated into the analysis.

6. REFERENCES AND PERSONAL COMMUNICATIONS

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FIGURES

Figure 1.

Location of the four offshore and seven nearshore sampling sites

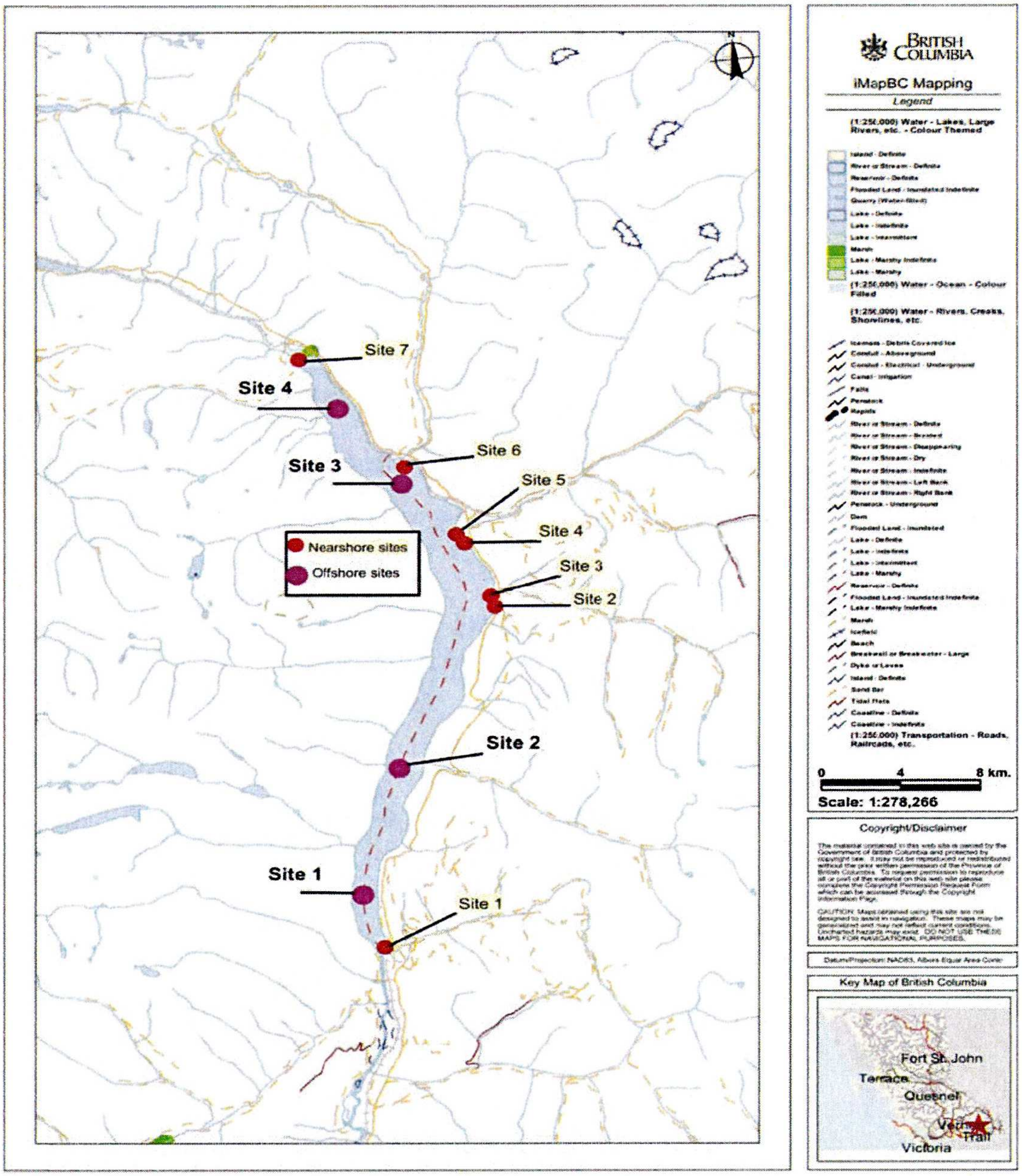
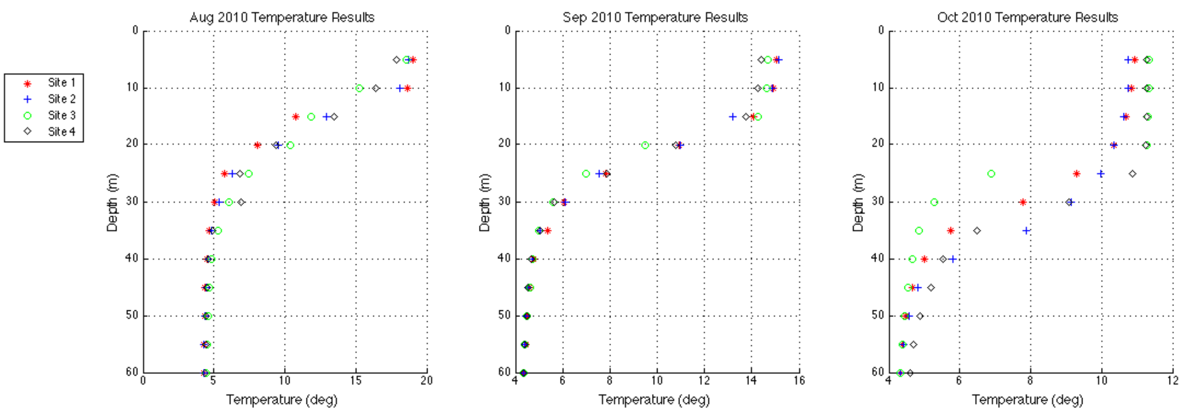


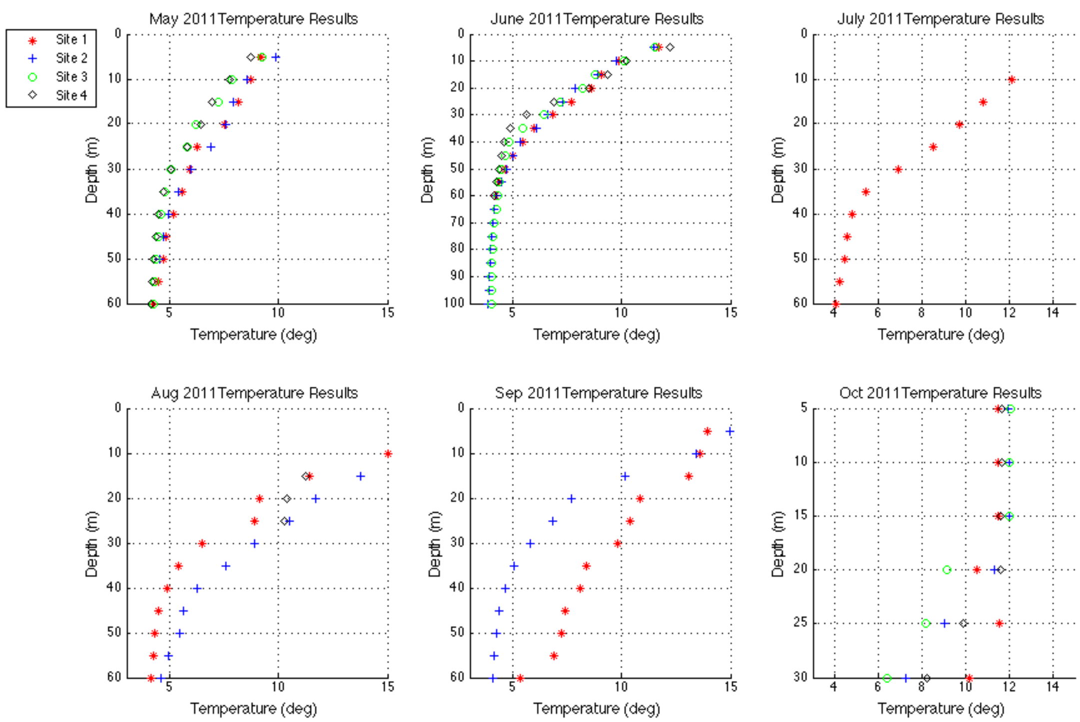
Figure 2.

Profiles of water temperature per sampling season in 2010, 2011, 2012, and 2013.

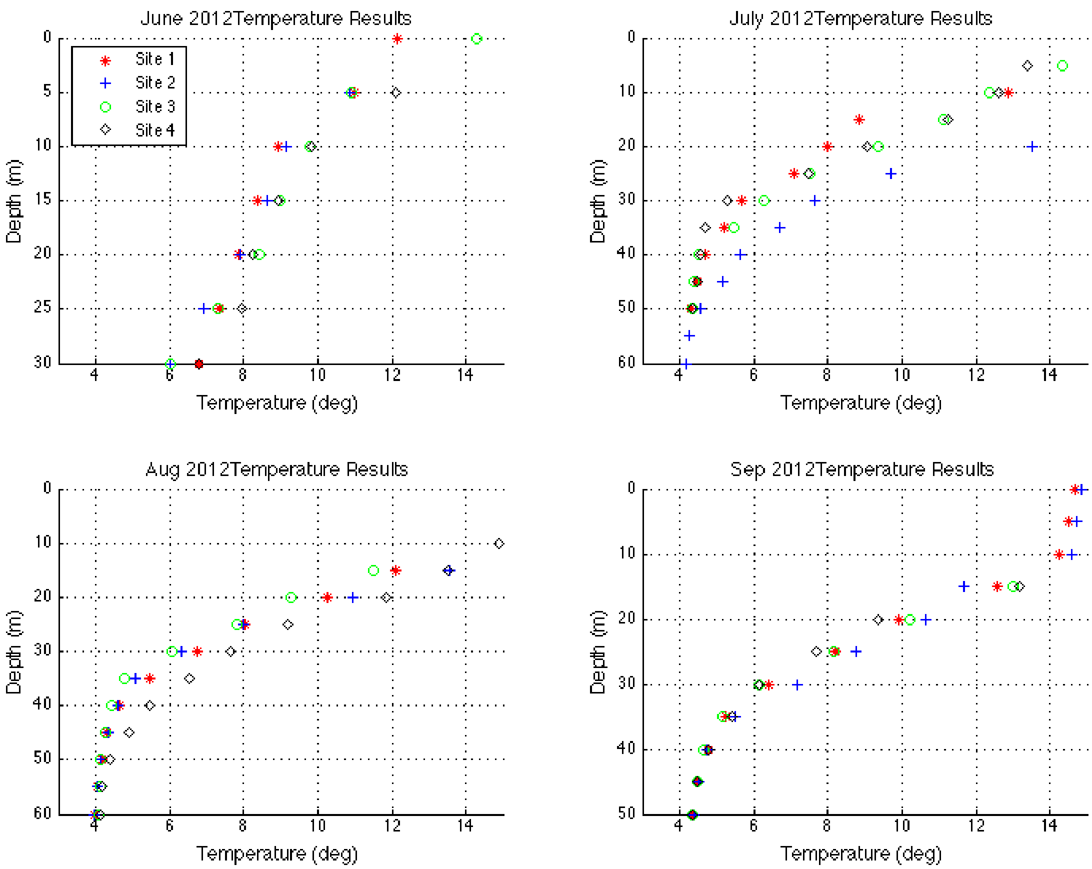
a) 2010



b) 2011



2012)


June 2012Temperature Results
Site 1
Site 2
Site 3
Site 4
Depth (m)
Temperature (deg)
July 2012Temperature Results
Depth (m)
Temperature (deg)
Aug 2012Temperature Results
Depth (m)
Temperature (deg)
Sep 2012Temperature Results
Depth (m)
Temperature (deg)

2013)

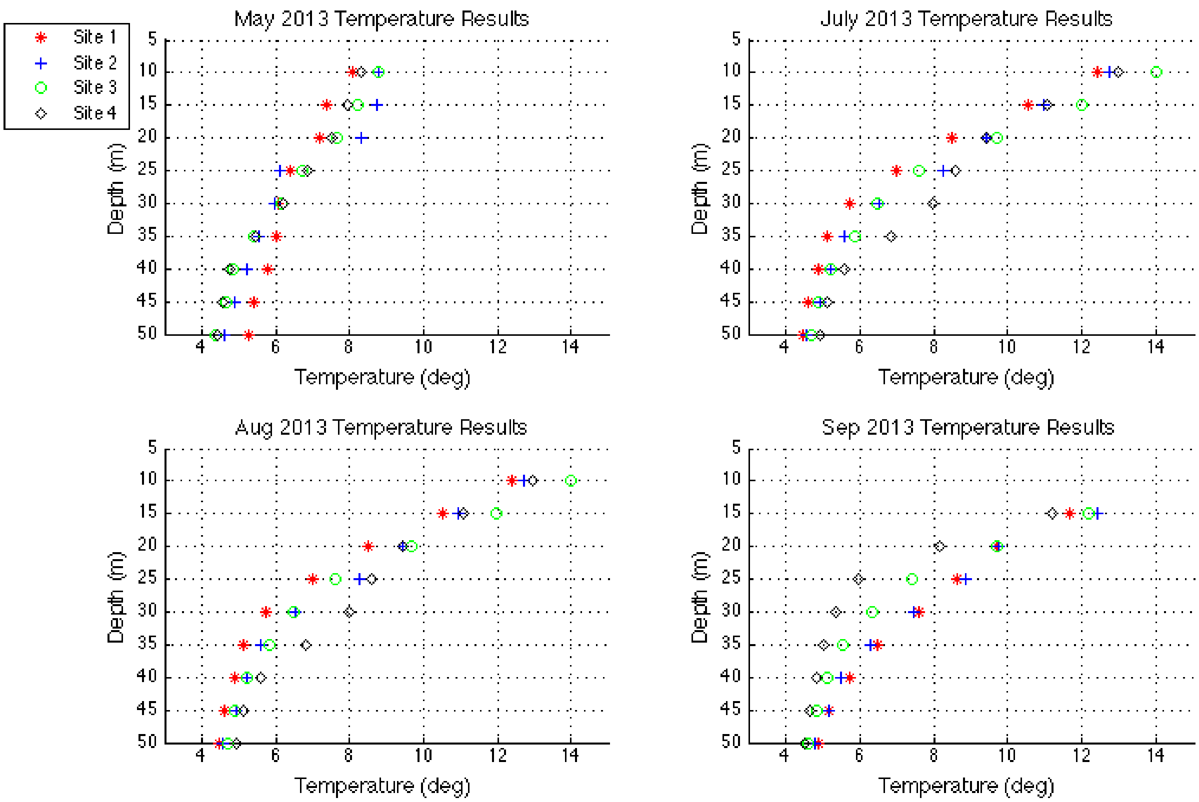
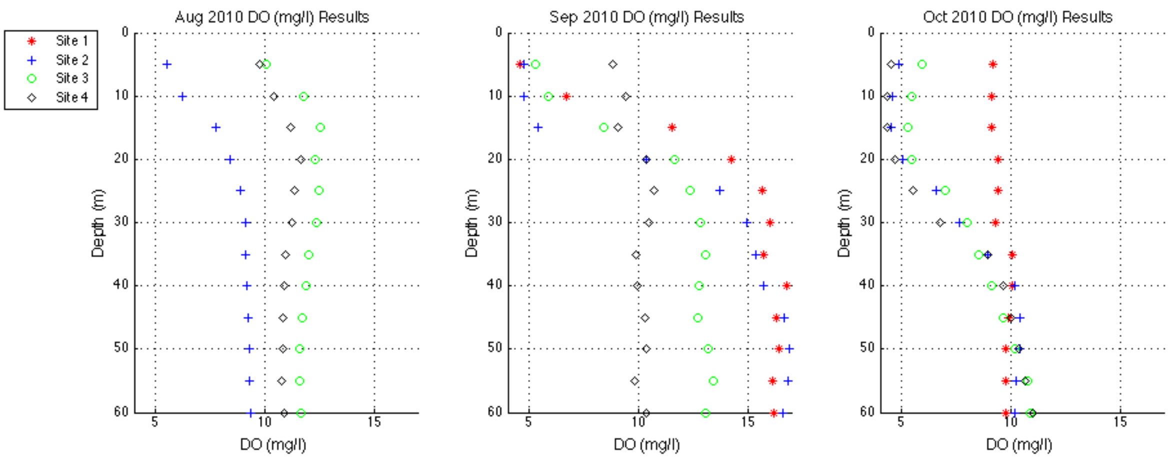

May 2013 Temperature Results
July 2013 Temperature Results
Aug 2013 Temperature Results
Sep 2013 Temperature Results
Site 1
Site 2
Site 3
Site 4
Depth (m)
Temperature (deg)

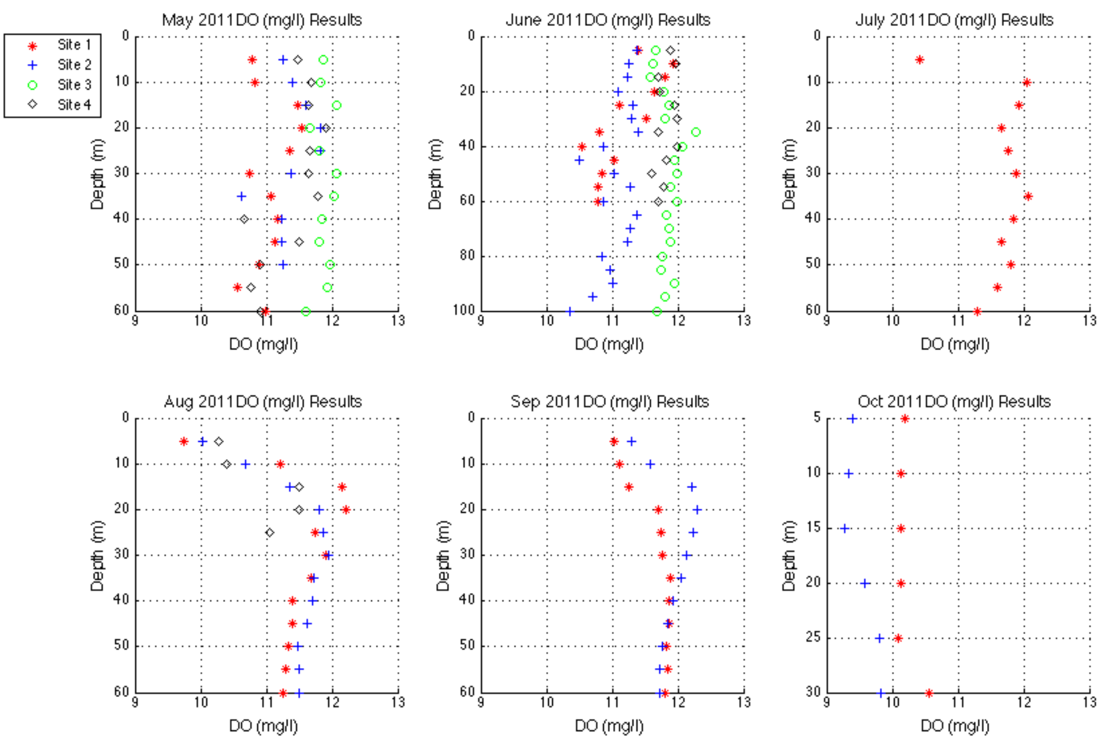
Figure 3

Dissolved oxygen concentration in 2010, 2011, 2012 and 2013 sampling seasons

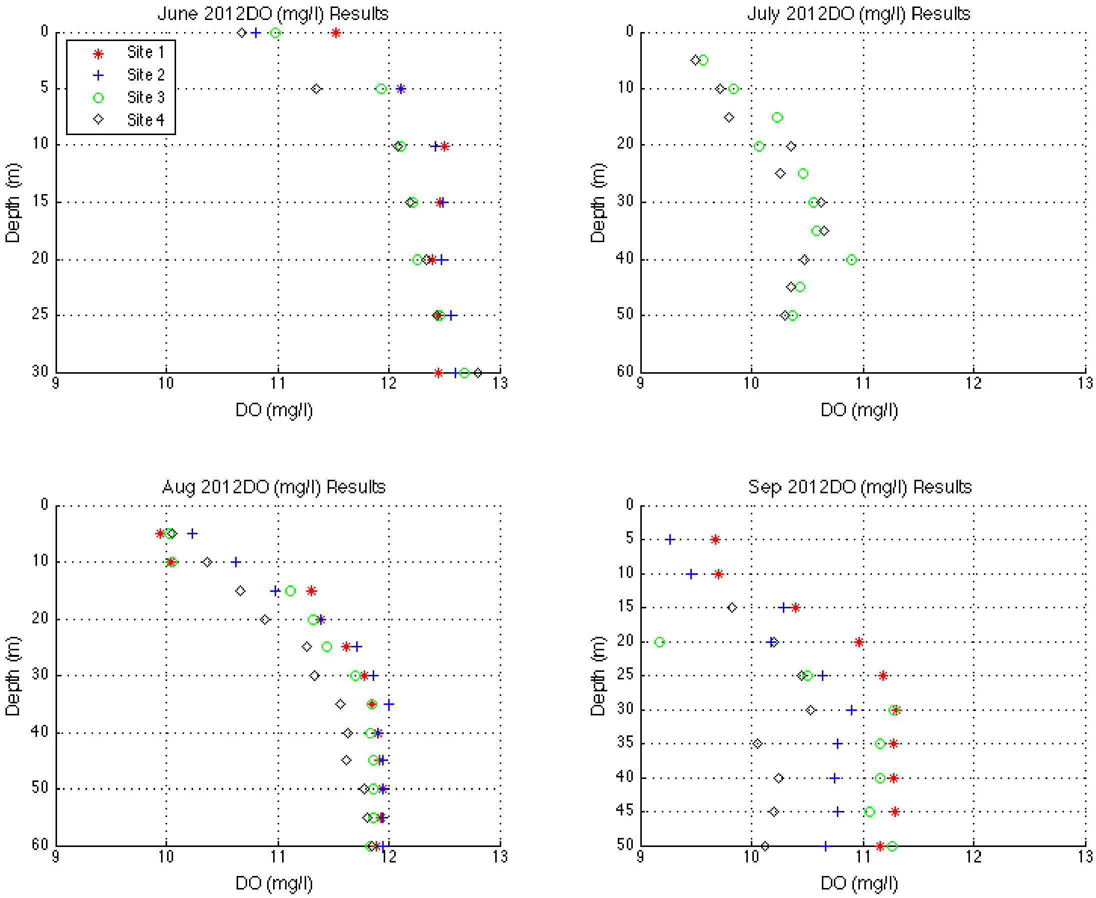
a) 2010



b) 2011



c) 2012


June 2012DO (mg/l) Results
July 2012DO (mg/l) Results
Aug 2012DO (mg/l) Results
Sep 2012DO (mg/l) Results
Site 1
Site 2
Site 3
Site 4
Depth (m)
DO (mg/l)

d) 2013

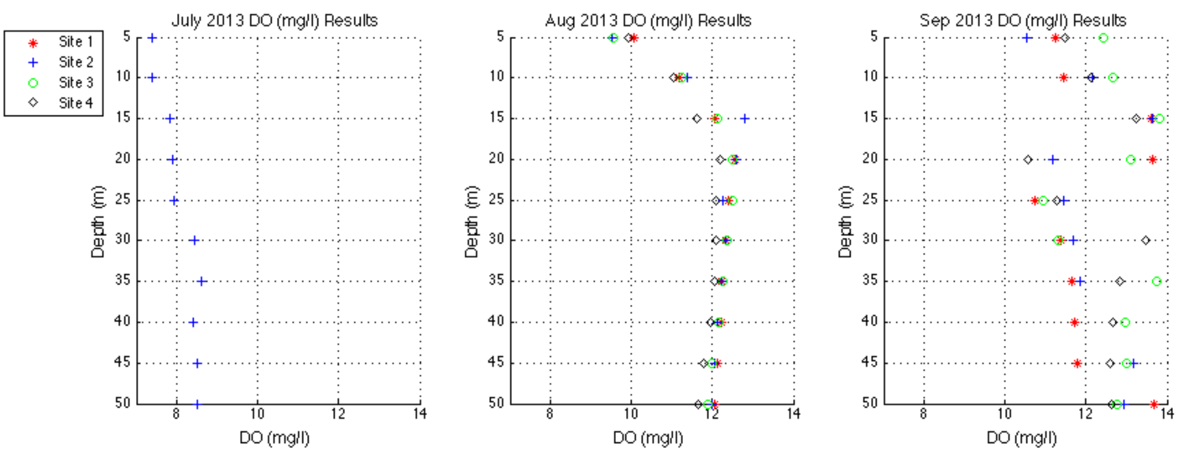
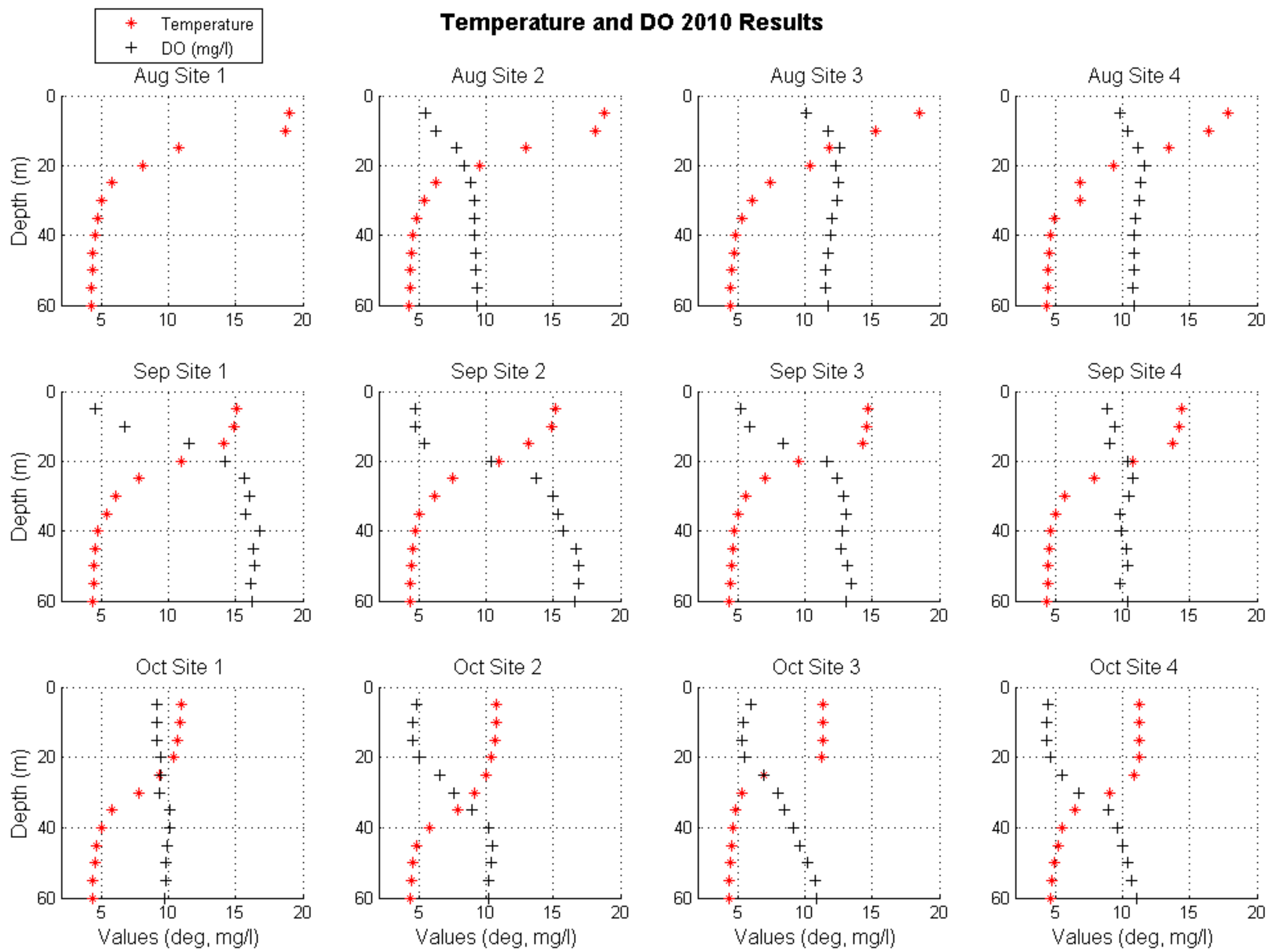
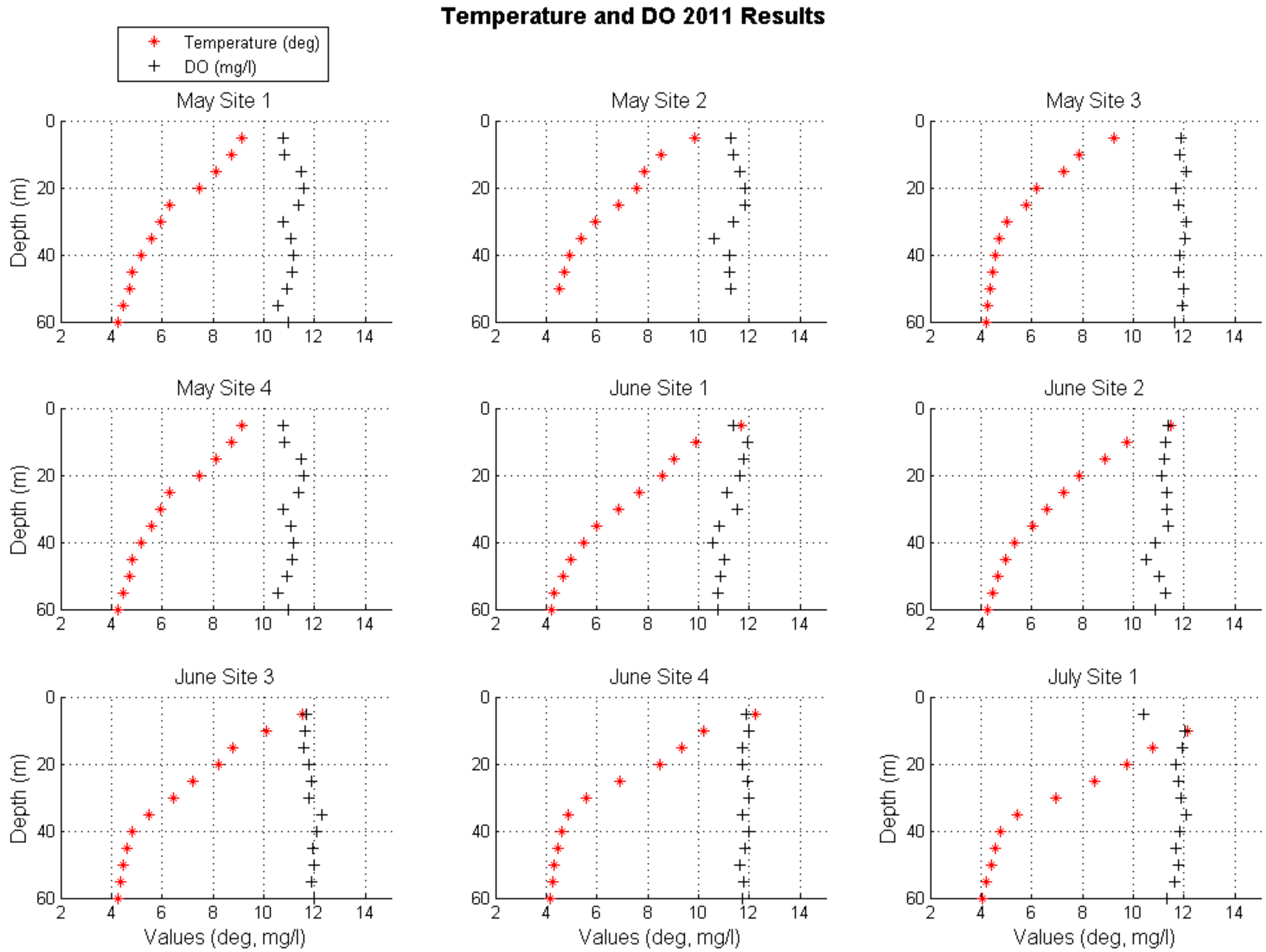
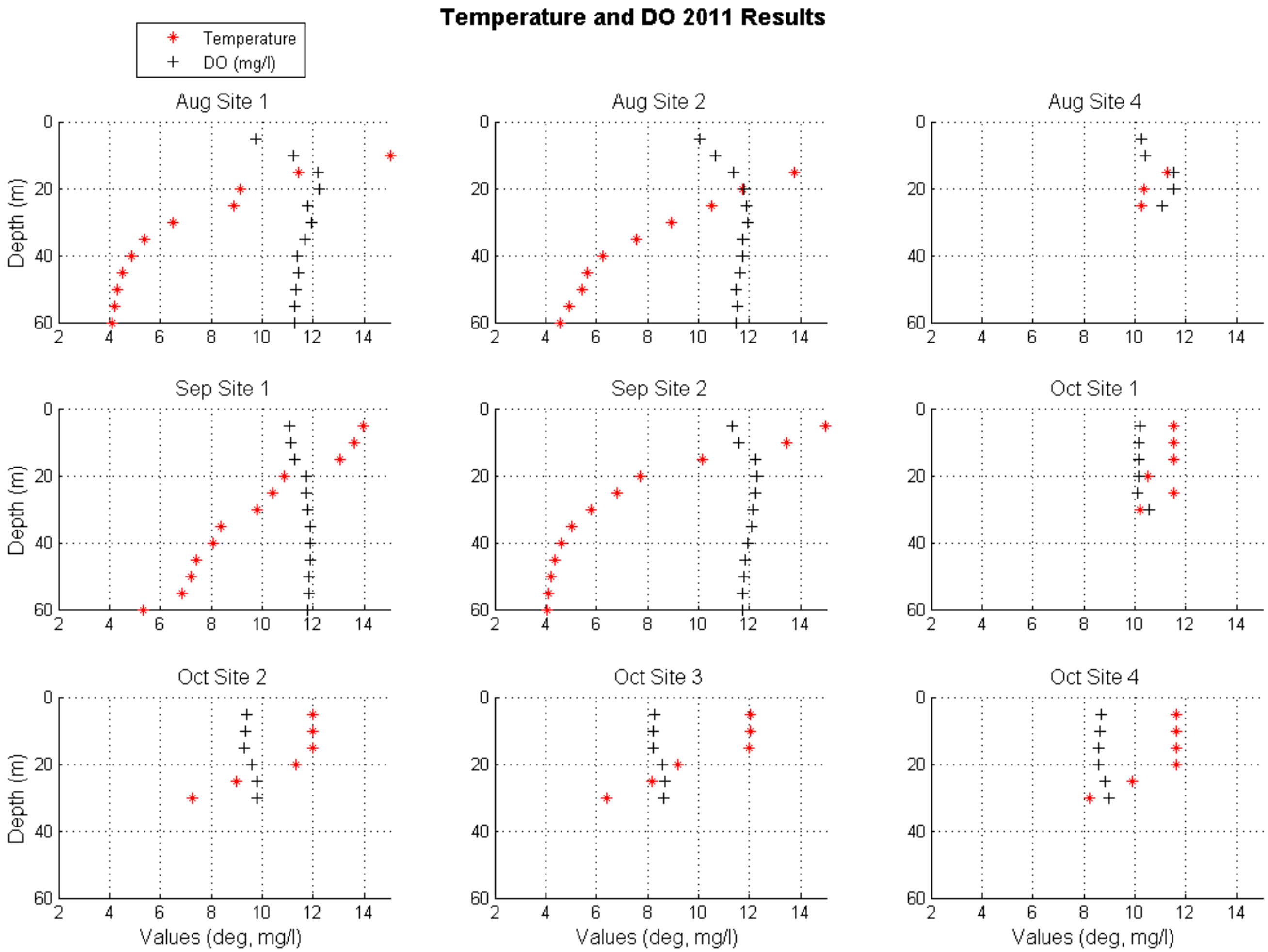

July 2013 DO (mg/l) Results
Aug 2013 DO (mg/l) Results
Sep 2013 DO (mg/l) Results
Site 1
Site 2
Site 3
Site 4
Depth (m)
DO (mg/l)

Figure 4.

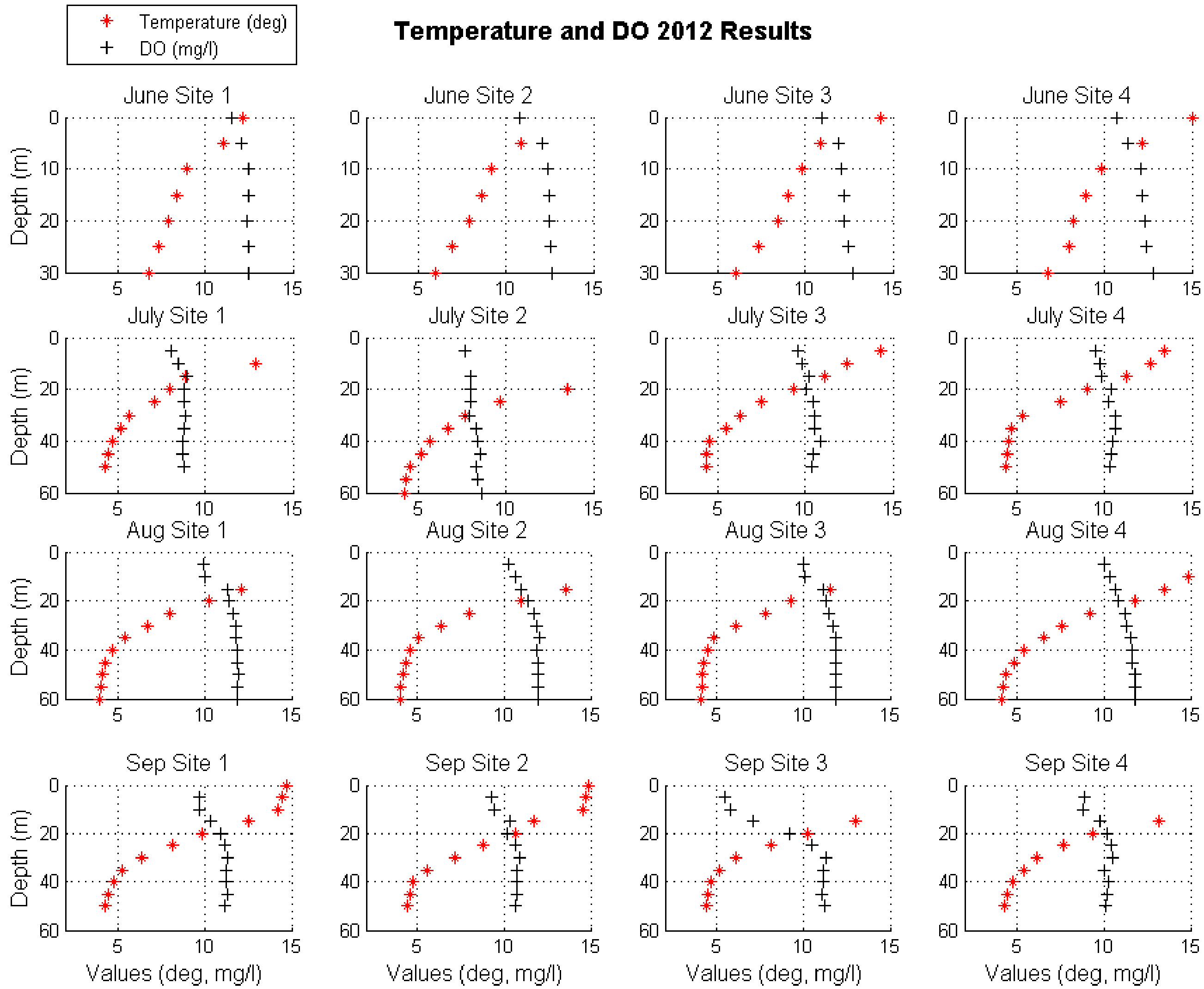
Profiles of temperature and dissolved oxygen at sampling sites measured in 2010, 2011, 2012 and 2013




Temperature and DO 2011 Results
Temperature (deg)
DO (mg/l)
May Site 1
May Site 2
May Site 3
May Site 4
June Site 1
June Site 2
June Site 3
June Site 4
July Site 1
Depth (m)
Values (deg, mg/l)
0
20
40
60
2
4
6
8
10
12
14



Moraia Grau & Associates, email:moraia@bosquesyrios.org


Temperature (deg)
DO (mg/l)
Temperature and DO 2012 Results
June Site 1
June Site 2
June Site 3
June Site 4
July Site 1
July Site 2
July Site 3
July Site 4
Aug Site 1
Aug Site 2
Aug Site 3
Aug Site 4
Sep Site 1
Sep Site 2
Sep Site 3
Sep Site 4
Depth (m)
Values (deg, mg/l)

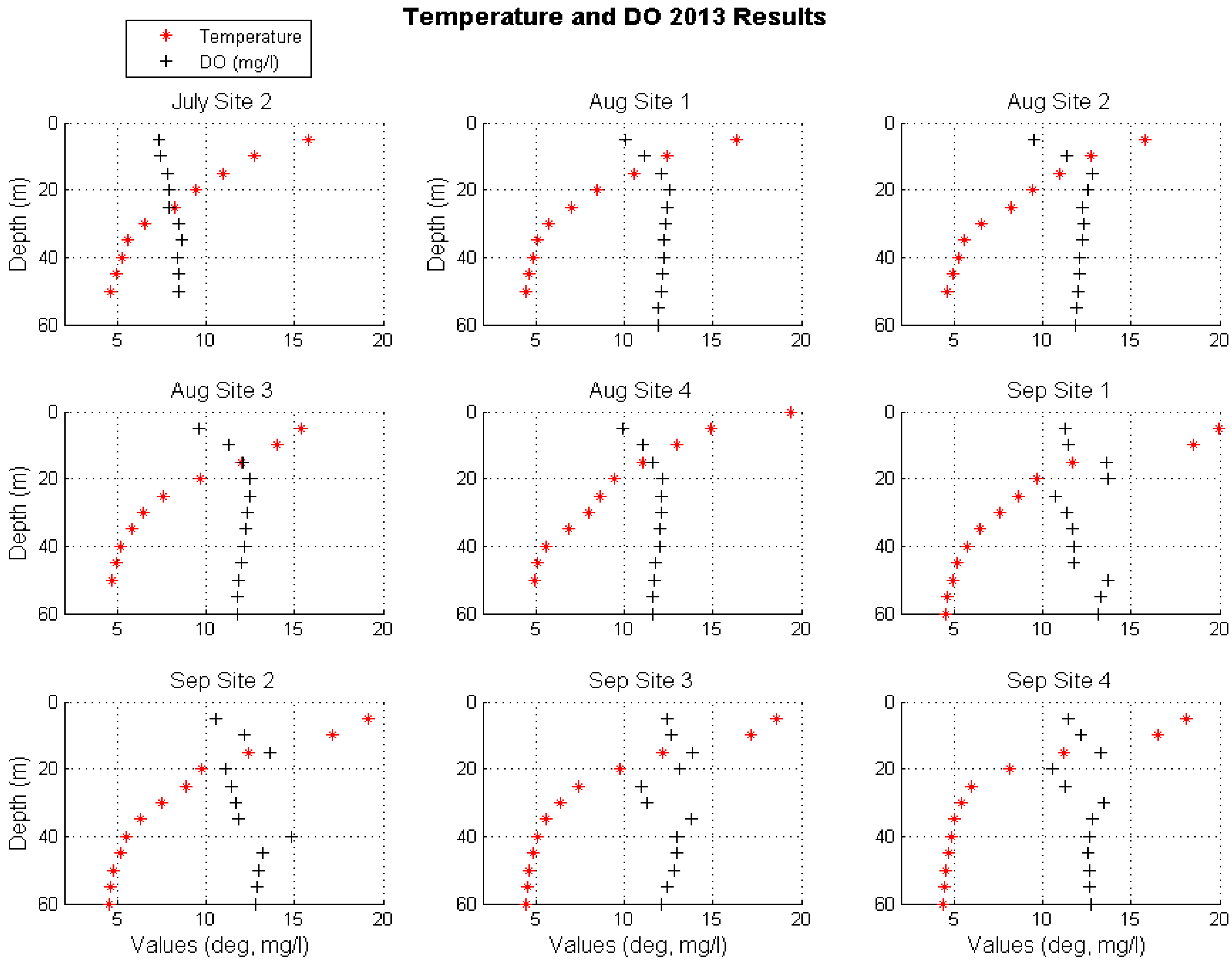
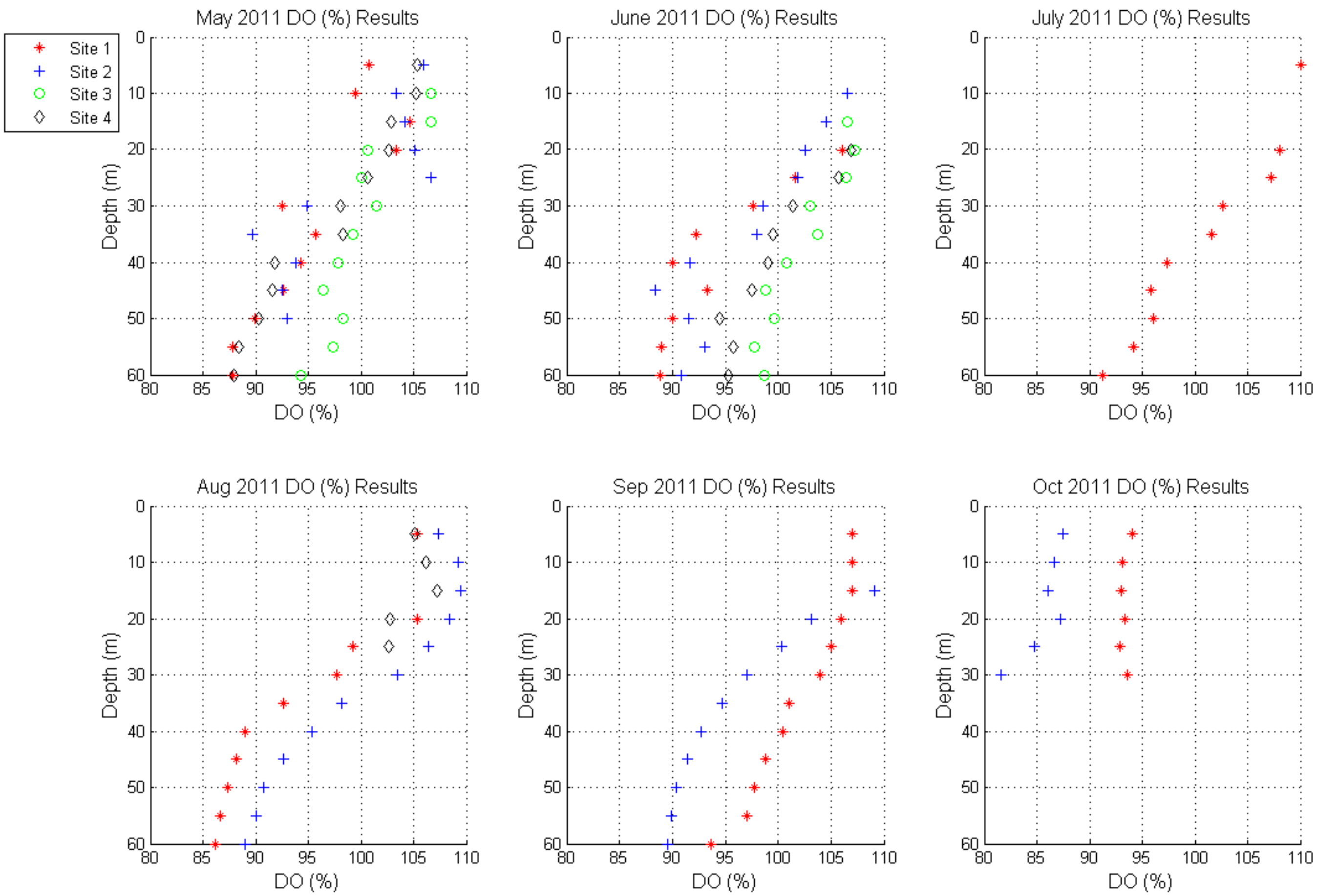

Temperature and DO 2013 Results
Temperature
DO (mg/l)
July Site 2
Aug Site 1
Aug Site 2
Aug Site 3
Aug Site 4
Sep Site 1
Sep Site 2
Sep Site 3
Sep Site 4
Depth (m)
Values (deg, mg/l)
0
20
40
60
5
10
15
20

Figure 5

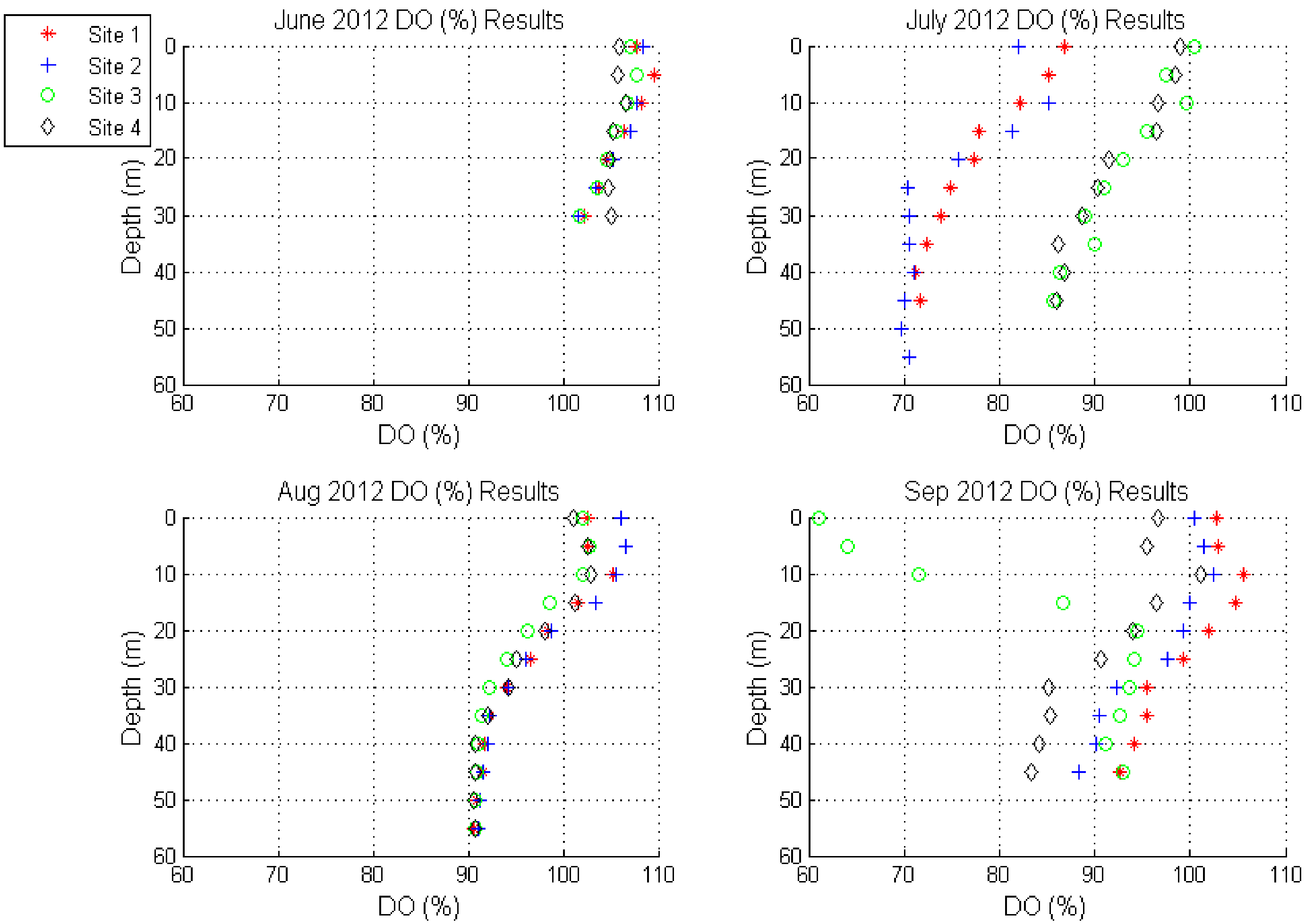
Dissolved oxygen saturation at sampling sites measured in 2011, 2012 and 2013

A) 2011



Moraia Grau & Associates, email:moraia@bosquesyrios.org

B) 2012


Site 1
Site 2
Site 3
Site 4
June 2012 DO (%) Results
July 2012 DO (%) Results
Aug 2012 DO (%) Results
Sep 2012 DO (%) Results
Depth (m)
DO (%)
0
10
20
30
40
50
60
70
80
90
100
110

C) 2013

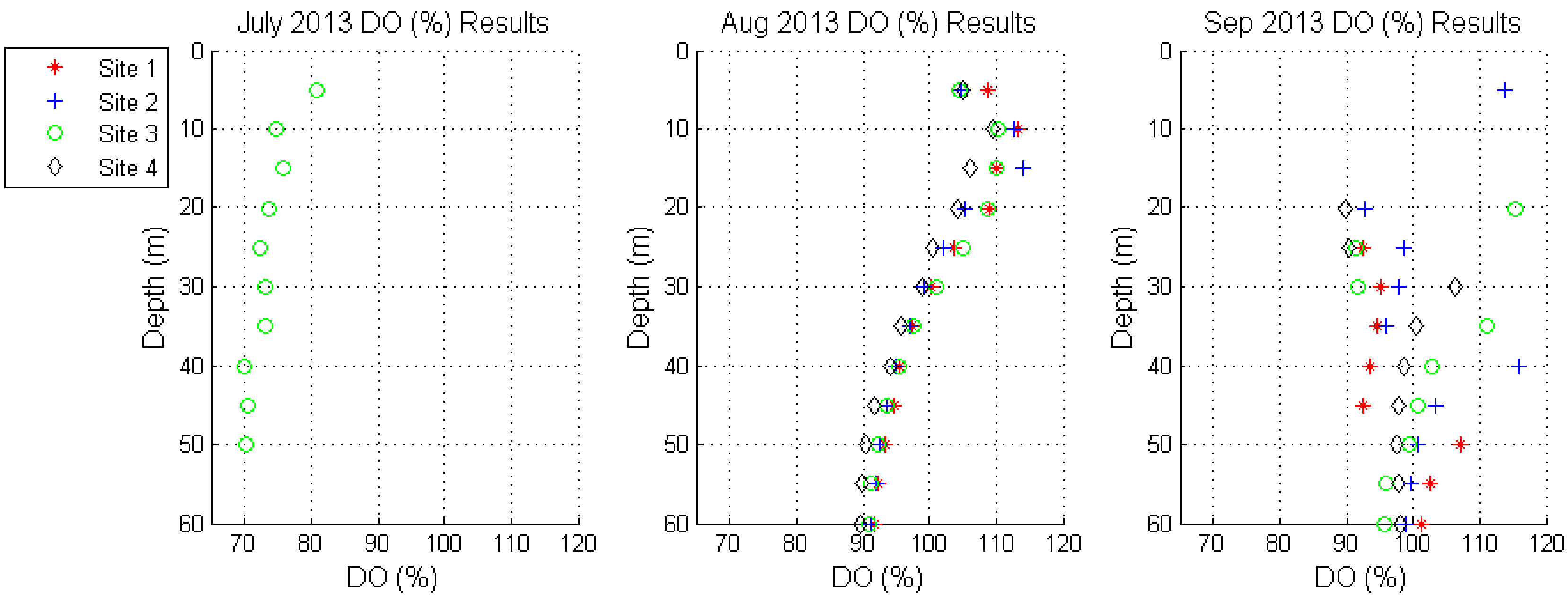
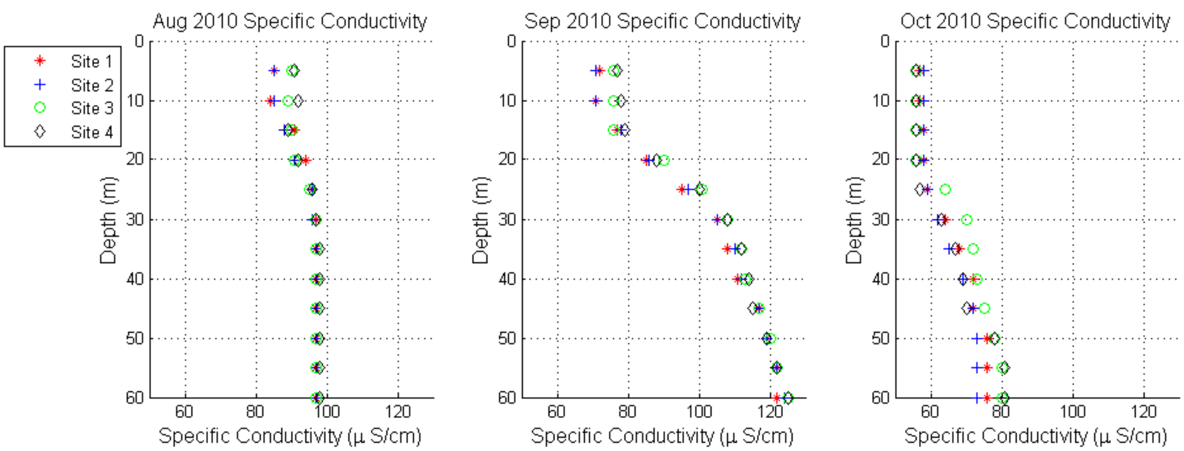

July 2013 DO (%) Results
Aug 2013 DO (%) Results
Sep 2013 DO (%) Results
Site 1
Site 2
Site 3
Site 4
Depth (m)
DO (%)
0
10
20
30
40
50
60
70
80
90
100
110
120

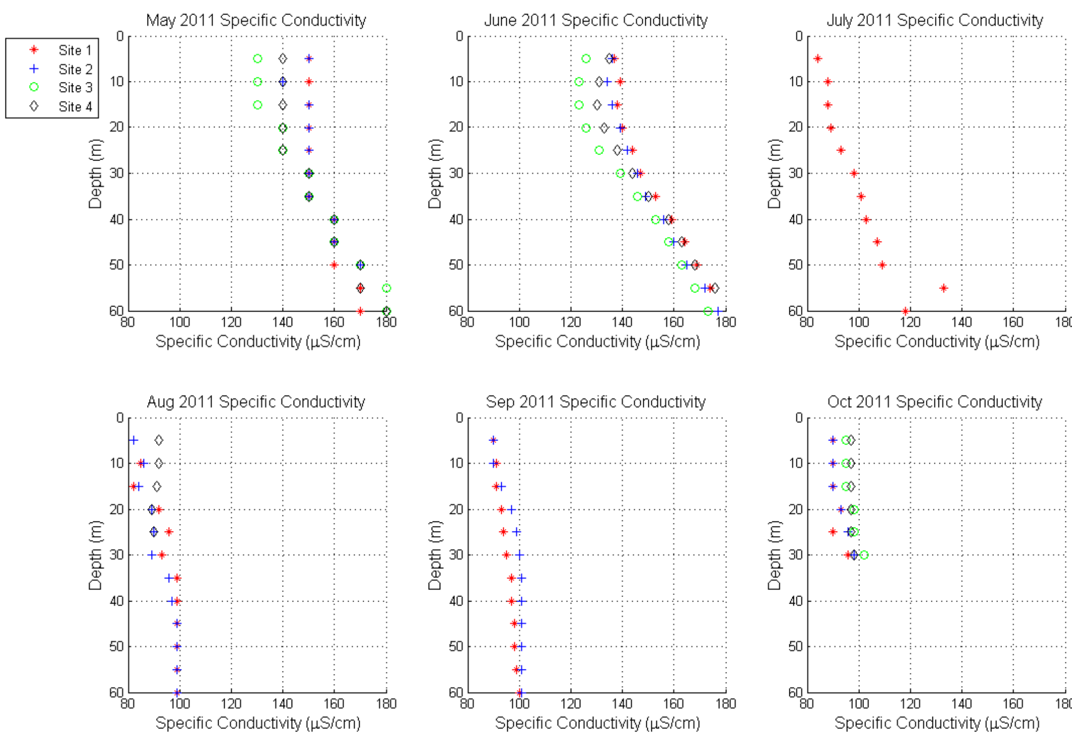
Figure 6

Specific conductivity profiles for 2010 - 2013 sampling seasons

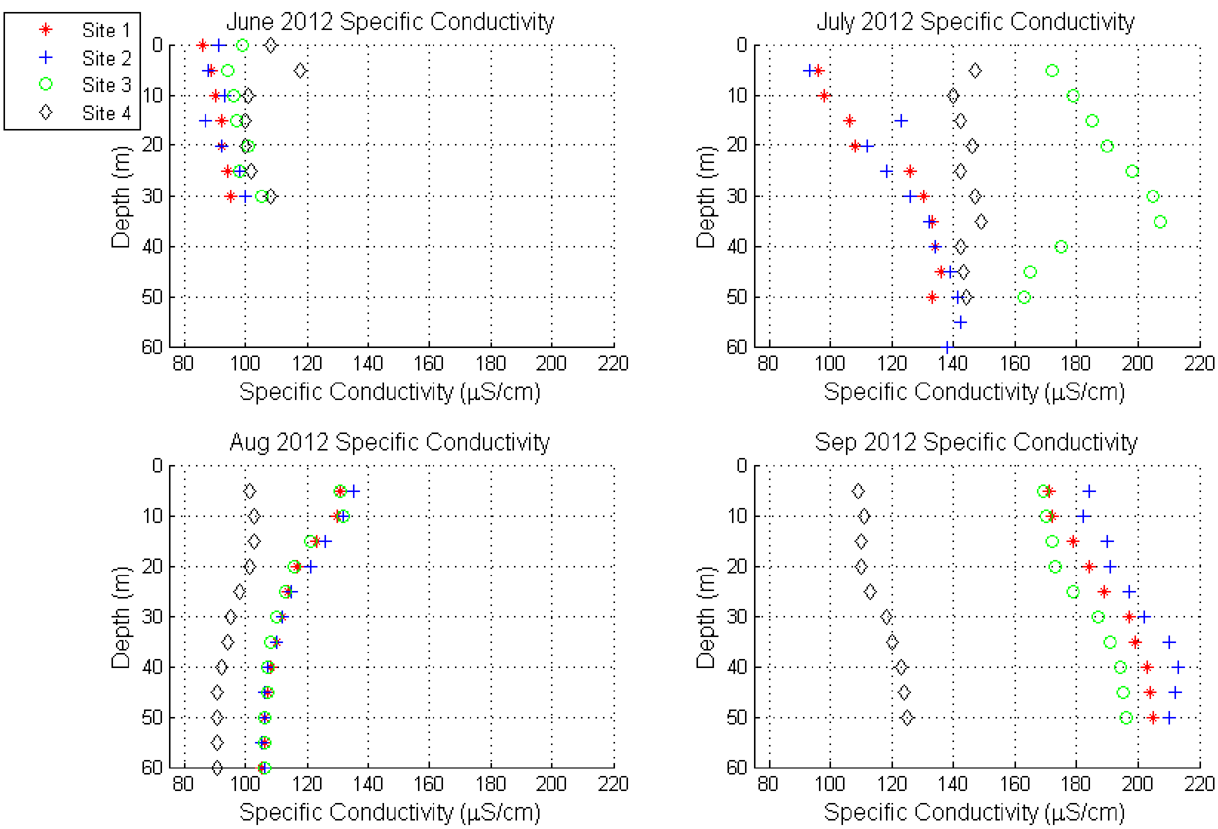
A) 2010



B) 2011



C) 2012


Site 1
Site 2
Site 3
Site 4
June 2012 Specific Conductivity
July 2012 Specific Conductivity
Aug 2012 Specific Conductivity
Sep 2012 Specific Conductivity
Depth (m)
Specific Conductivity (µS/cm)

D) 2013

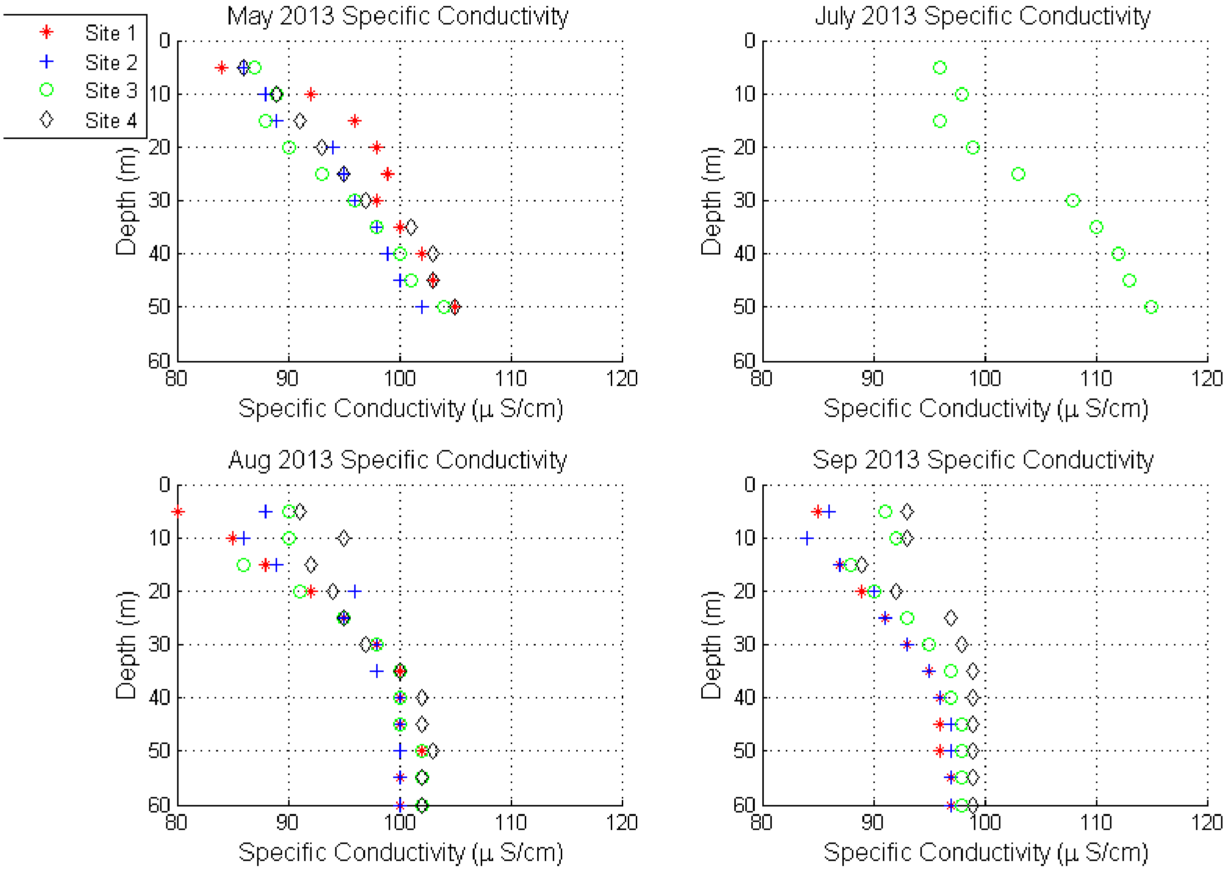
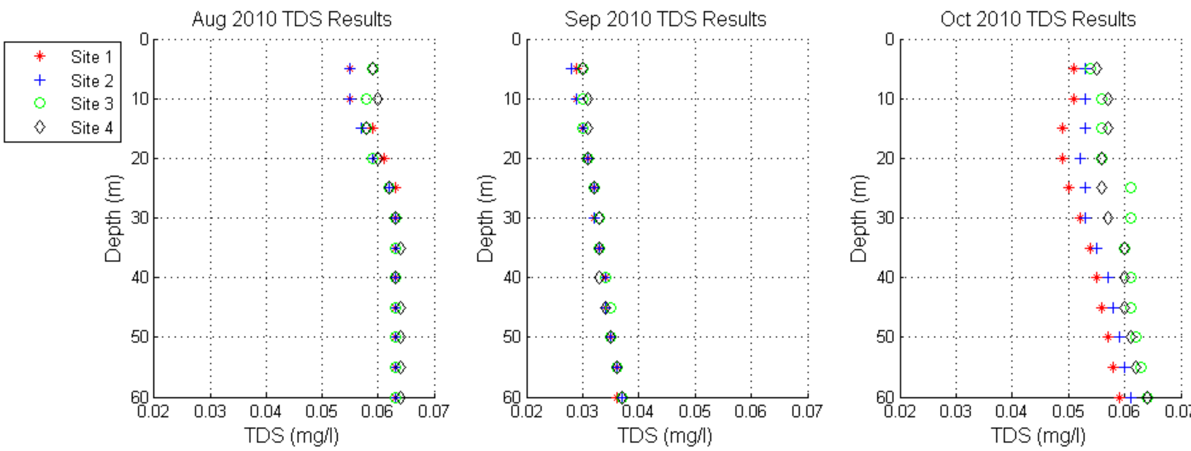

May 2013 Specific Conductivity
July 2013 Specific Conductivity
Aug 2013 Specific Conductivity
Sep 2013 Specific Conductivity
Site 1
Site 2
Site 3
Site 4
Depth (m)
Specific Conductivity (µ S/cm)
0
10
20
30
40
50
60
80
90
100
110
120

Figure 7

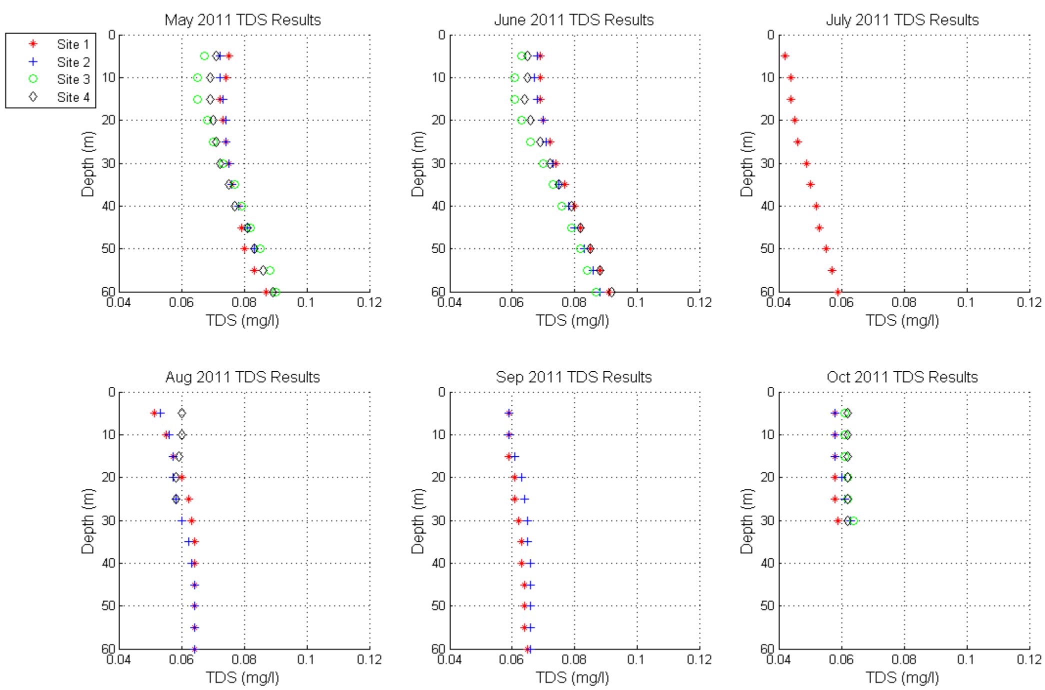
Profiles of Total Dissolved Solids (TDS) measured in 2010, 2011, 2012 and 2013

Note: X axis should read g/L

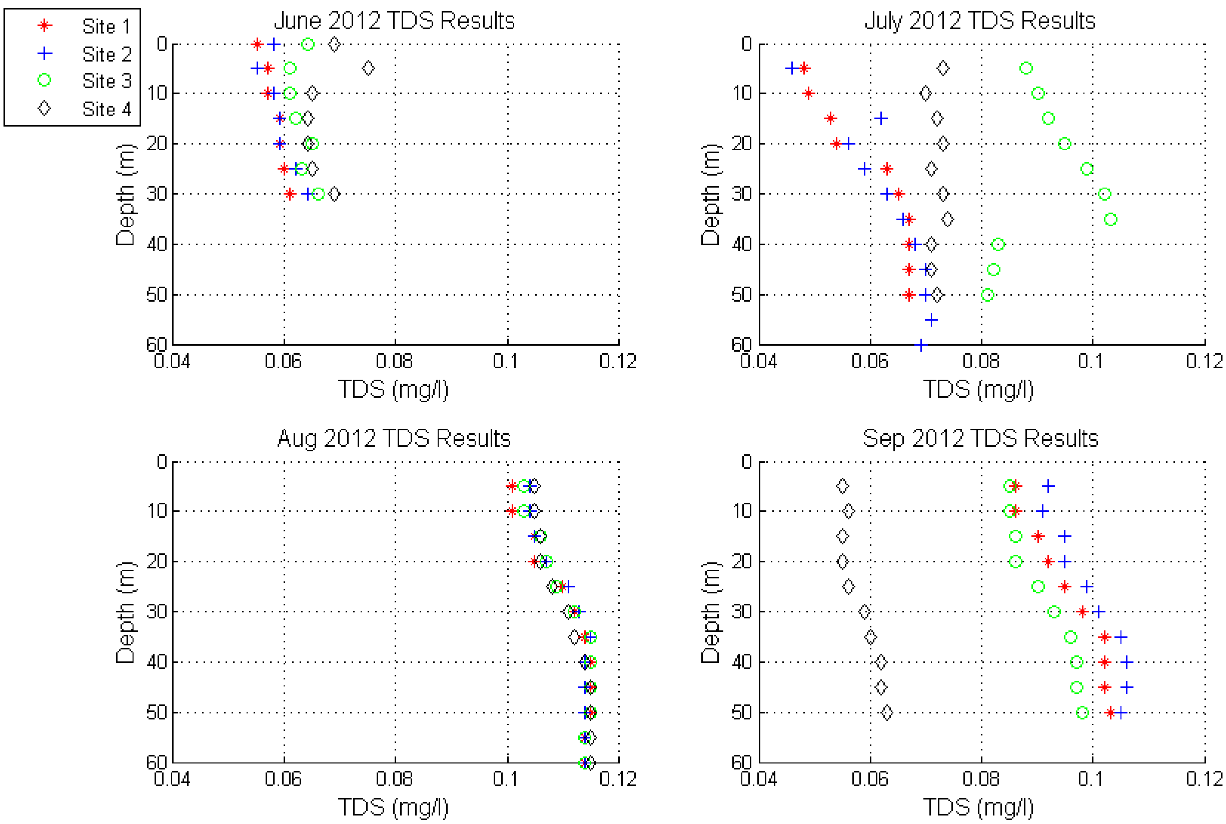
A) 2010



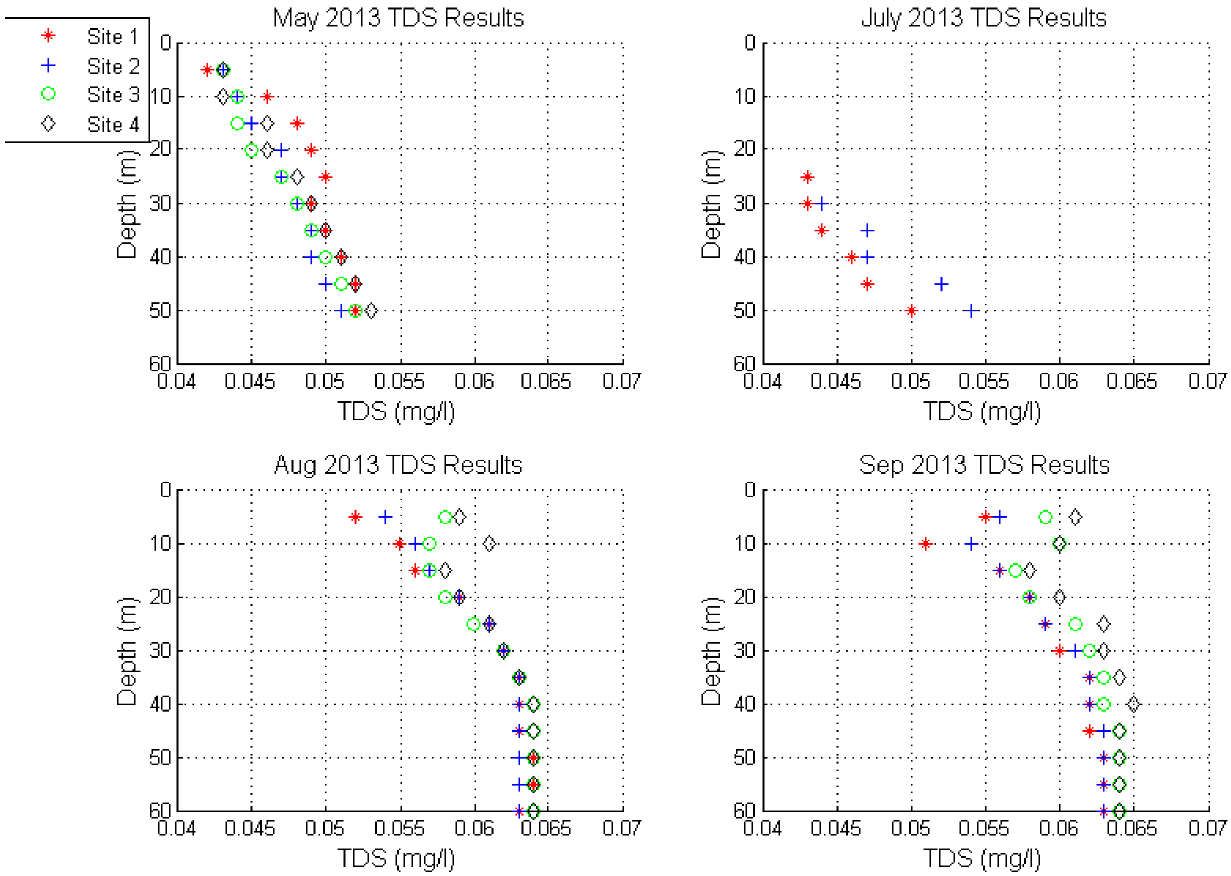
B) 2011



C) 2012


Site 1
Site 2
Site 3
Site 4
June 2012 TDS Results
July 2012 TDS Results
Aug 2012 TDS Results
Sep 2012 TDS Results
Depth (m)
TDS (mg/l)
0
10
20
30
40
50
60
0.04
0.06
0.08
0.1
0.12

D) 2013

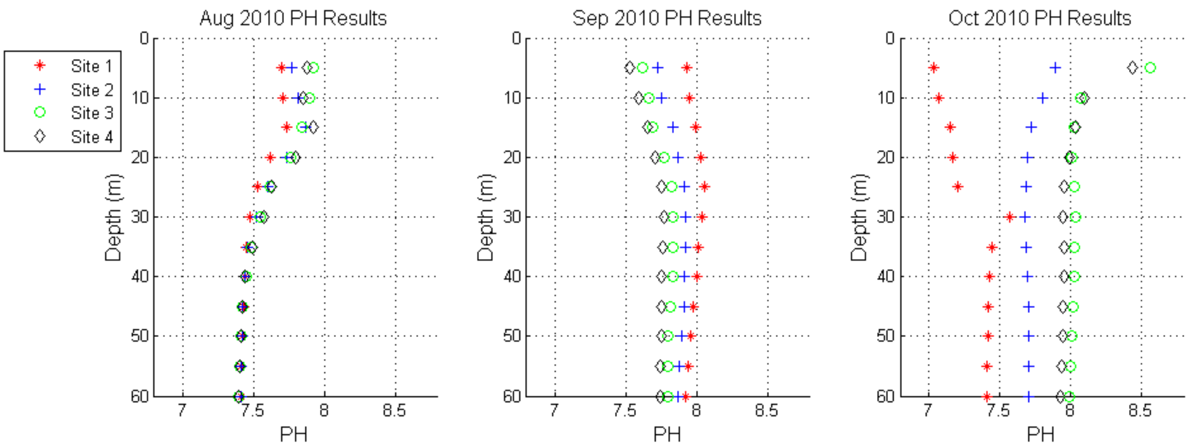


Site 1
Site 2
Site 3
Site 4
May 2013 TDS Results
July 2013 TDS Results
Aug 2013 TDS Results
Sep 2013 TDS Results
Depth (m)
TDS (mg/l)
0
10
20
30
40
50
60
0.04
0.045
0.05
0.055
0.06
0.065
0.07

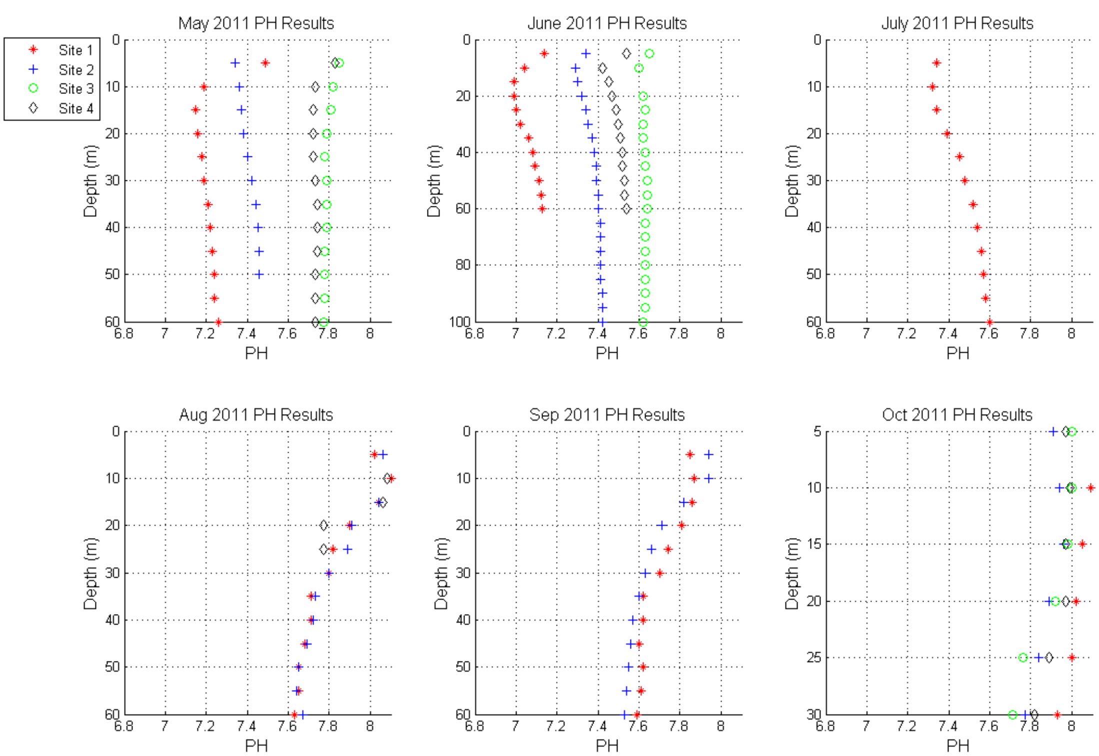
Figure 8

Profiles of pH values at sampling sites measured in 2010, 2011, 2012 and 2013

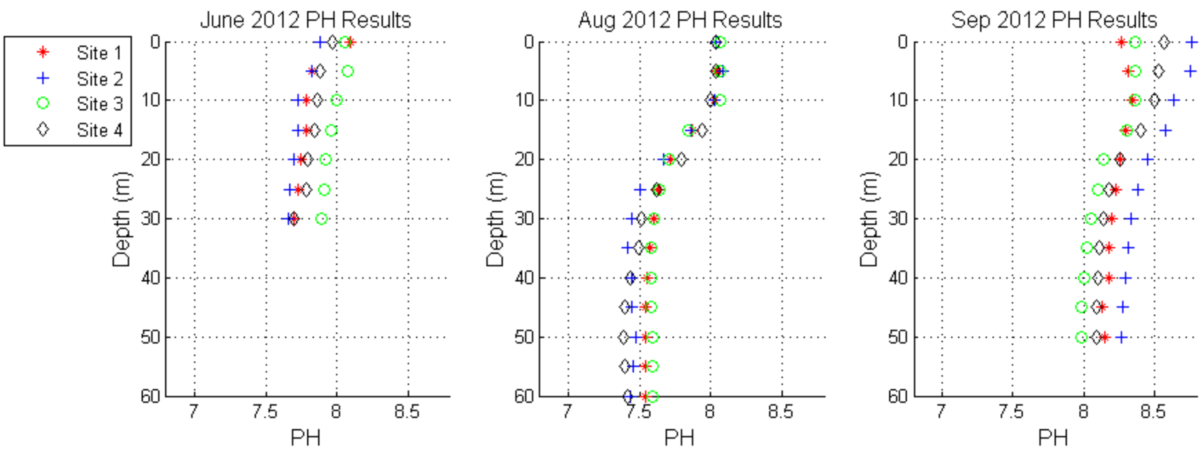
A) 2010



B) 2011



C) 2012


June 2012 PH Results
Aug 2012 PH Results
Sep 2012 PH Results
Site 1
Site 2
Site 3
Site 4
Depth (m)
PH

D) 2013

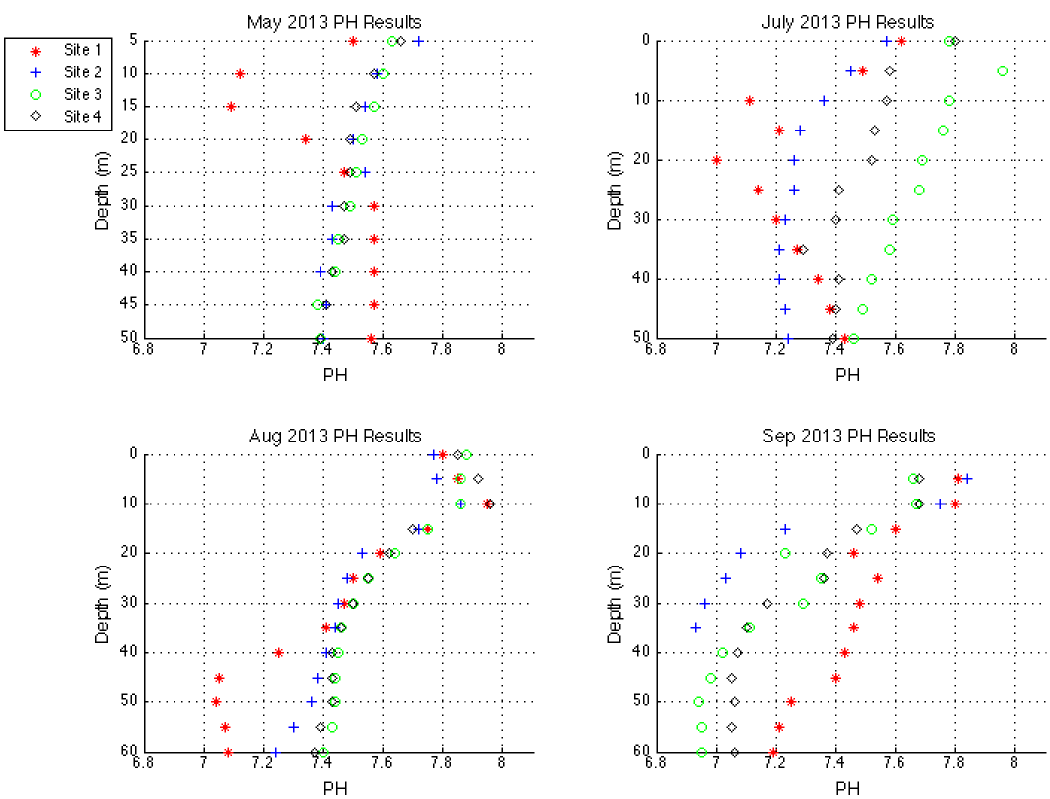
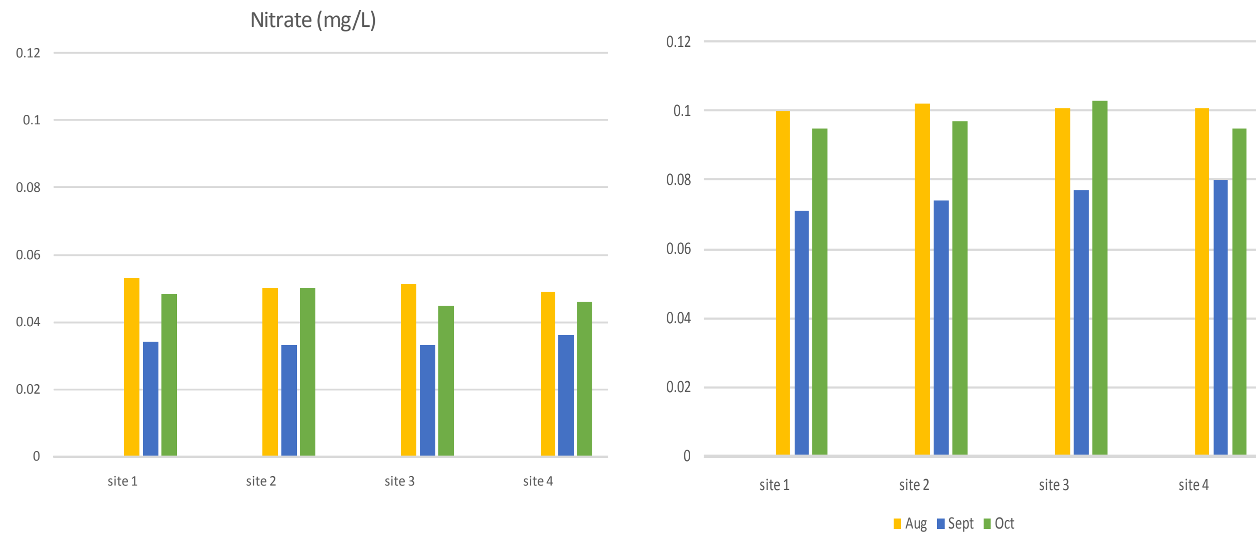
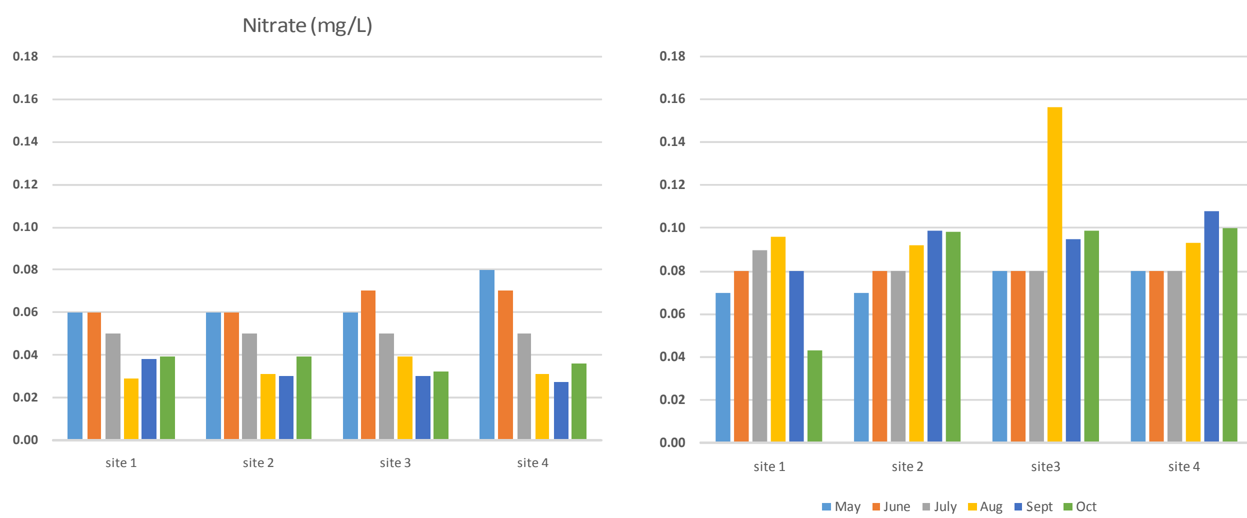

May 2013 PH Results
July 2013 PH Results
Aug 2013 PH Results
Sep 2013 PH Results
Site 1
Site 2
Site 3
Site 4
Depth (m)
PH

Figure 9. Nitrate, as N, concentration per month at the four sampling sites at two depths.

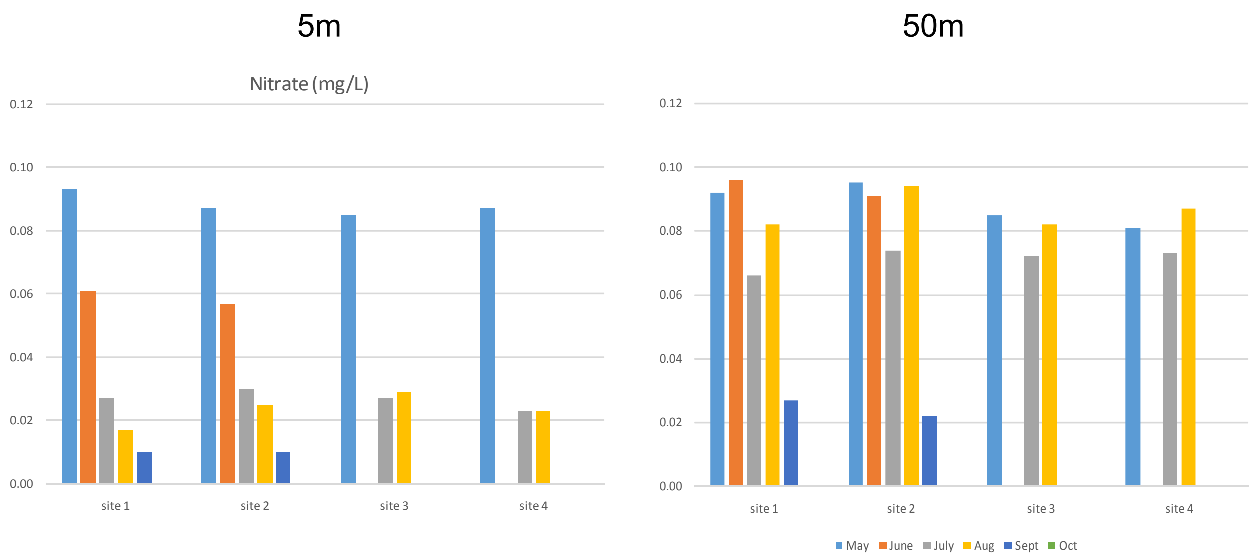
A) 2010 5m 50 m



B) 2011



C) 2012


5m
50m
Nitrate (mg/L)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
site 1
site 2
site 3
site 4
May June July Aug Sept Oct

D) 2013

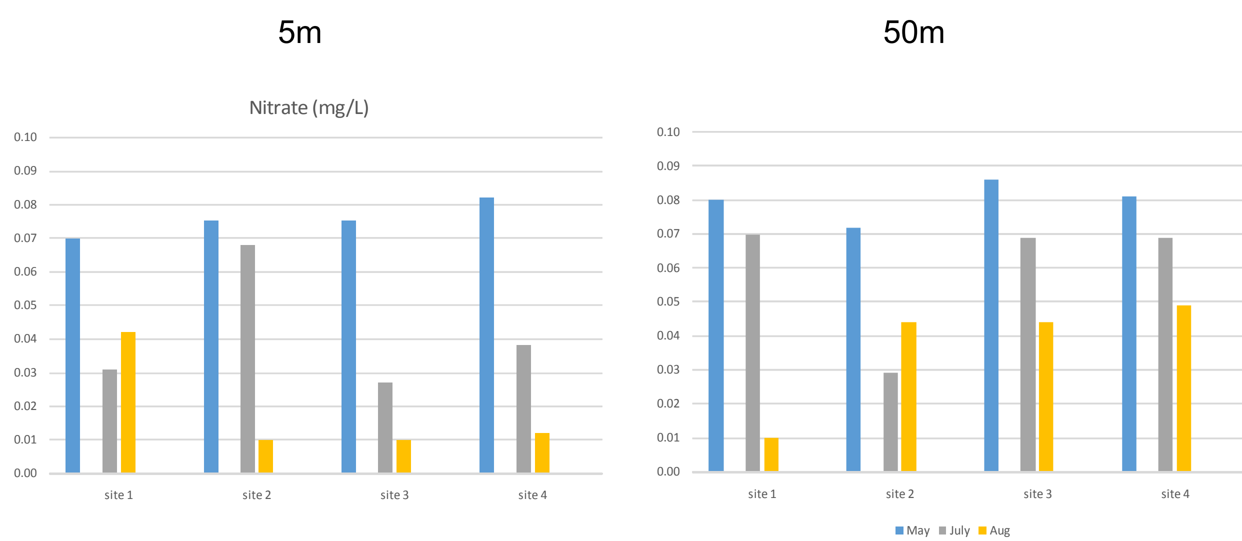
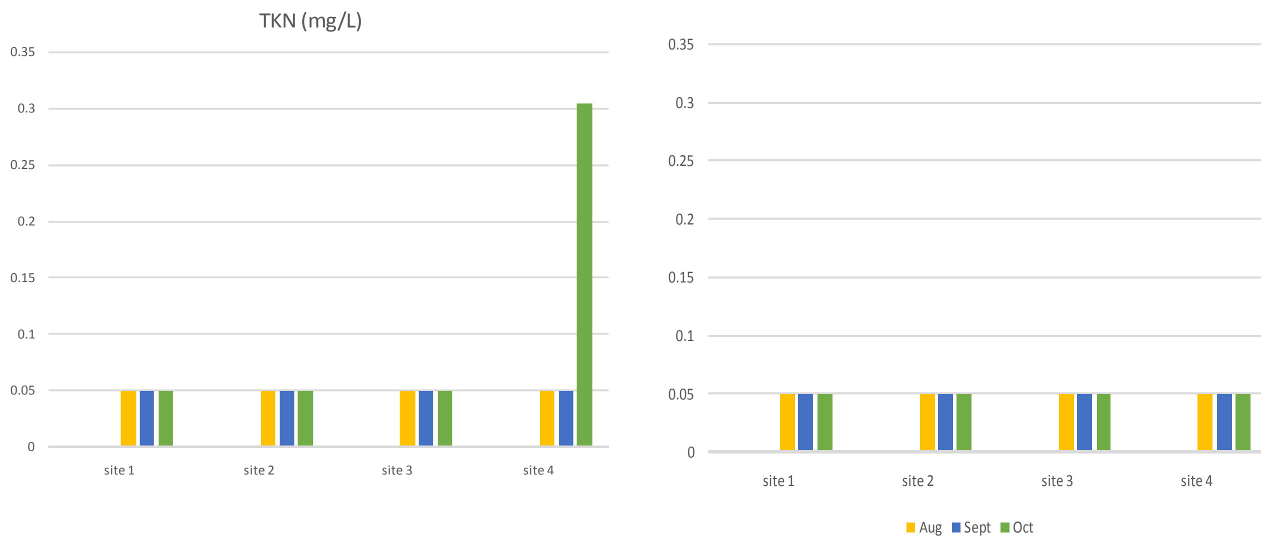

5m
50m
Nitrate (mg/L)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
site 1
site 2
site 3
site 4
May July Aug

Figure 10. Total Kjeldahl nitrogen concentration per month at the four sampling sites.

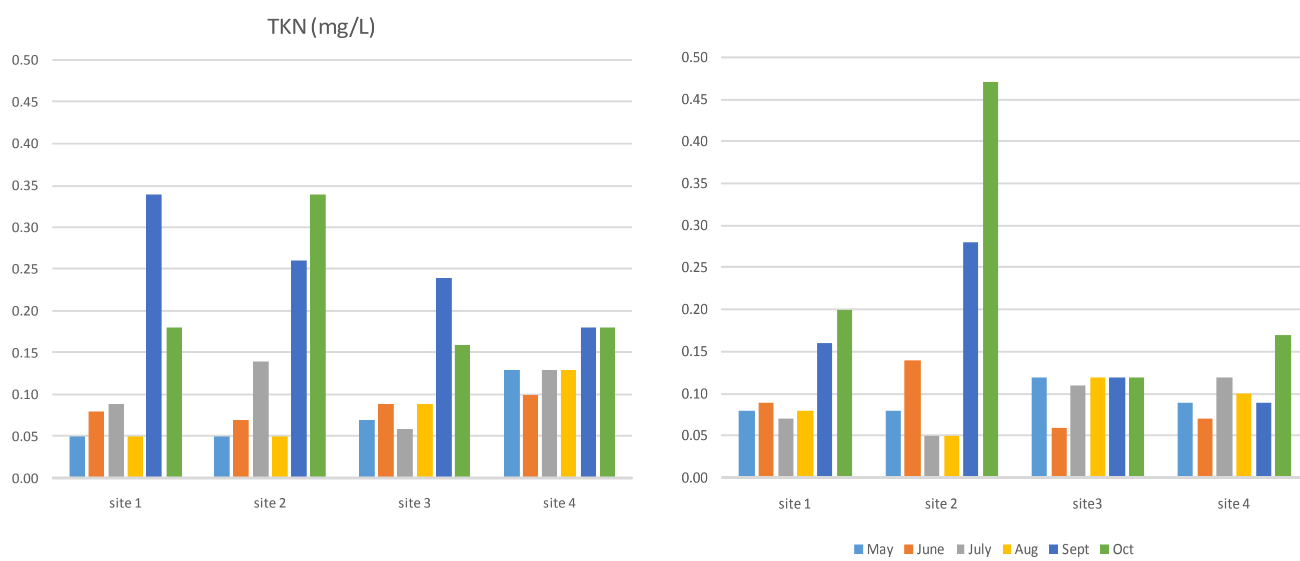
A) 2010

5m depth

50m depth

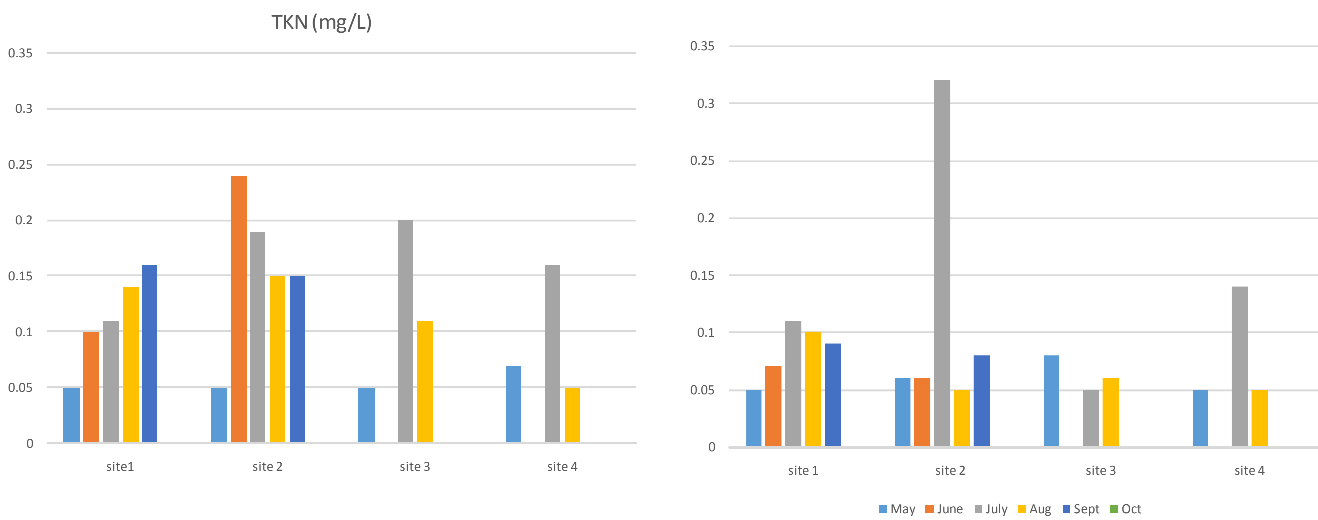


B) 2011



C) 2012

5m depth 50m depth



D) 2013

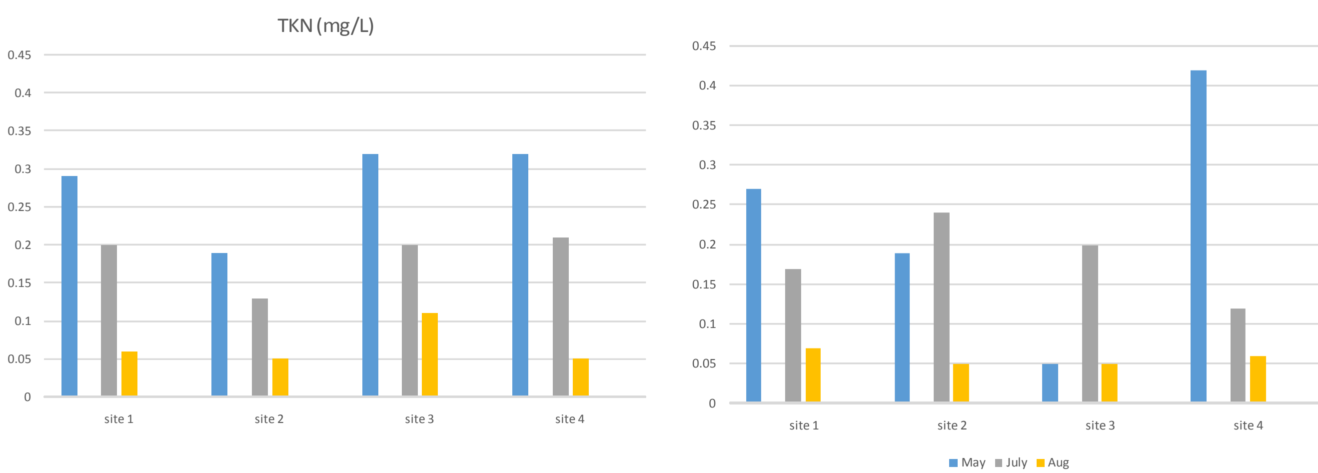
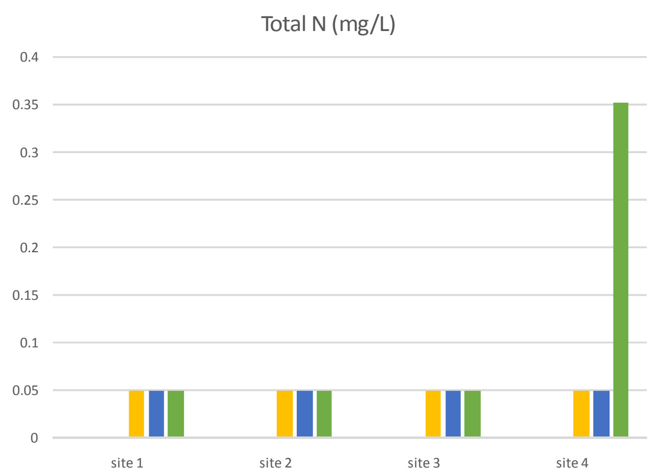


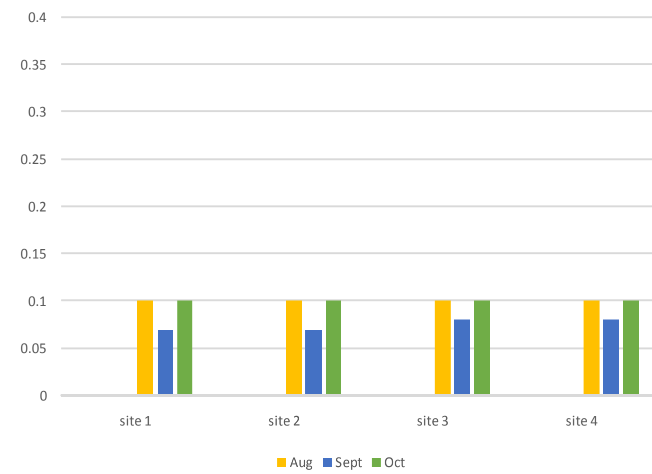
Figure 11. Total Nitrogen per month and depth at the four sampling sites.

A) 2010

5m depth

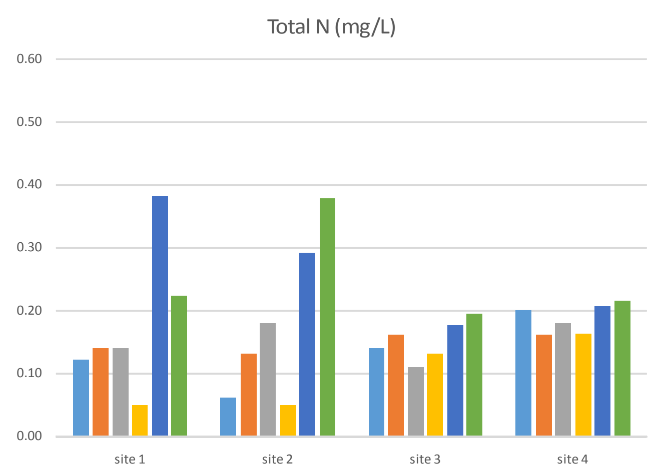


50m depth

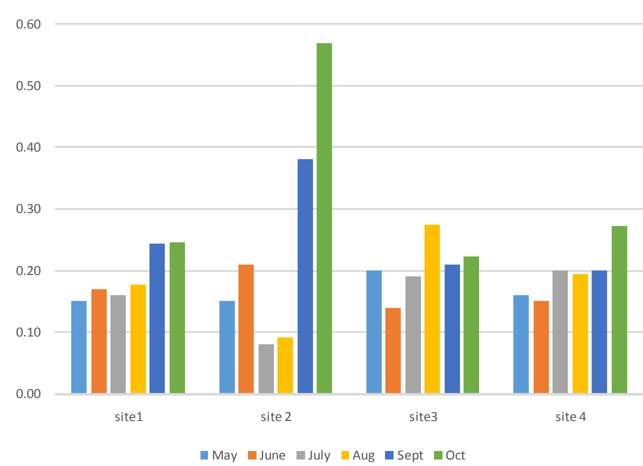


B) 2011

5m depth



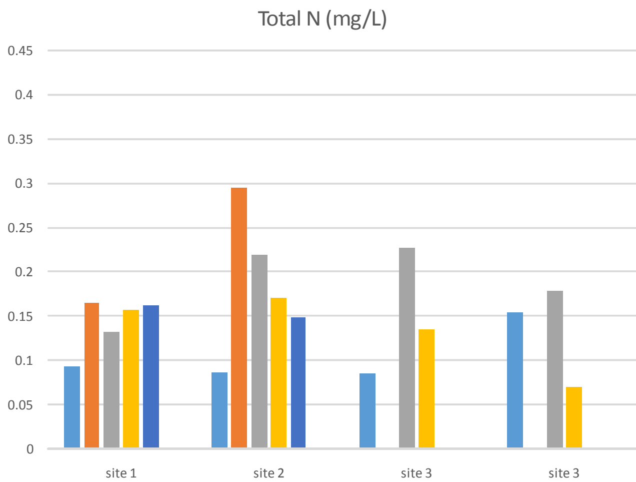
50m depth

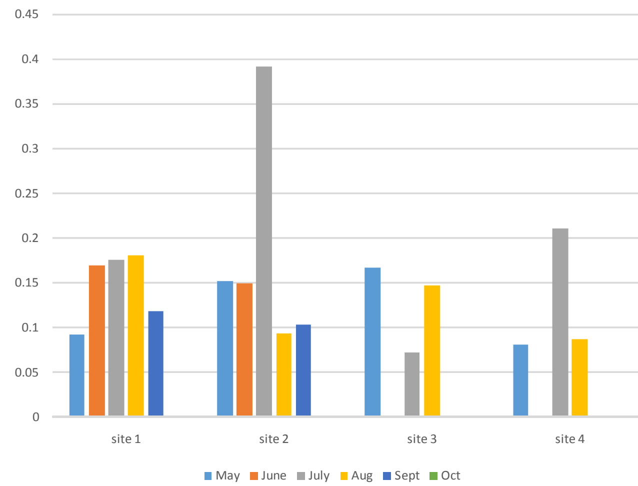


C) 2012

5m depth

50m depth

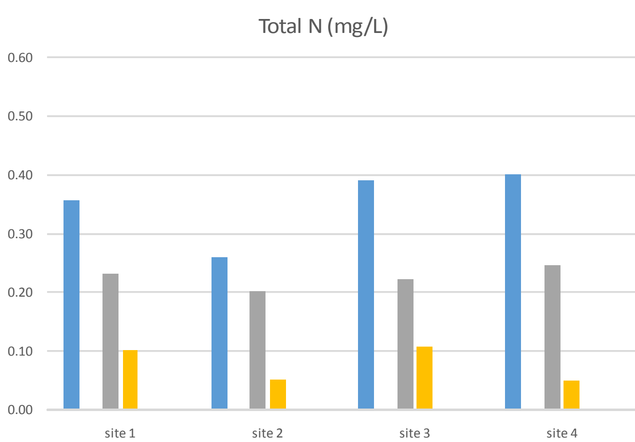




D) 2013

5m depth

50m depth



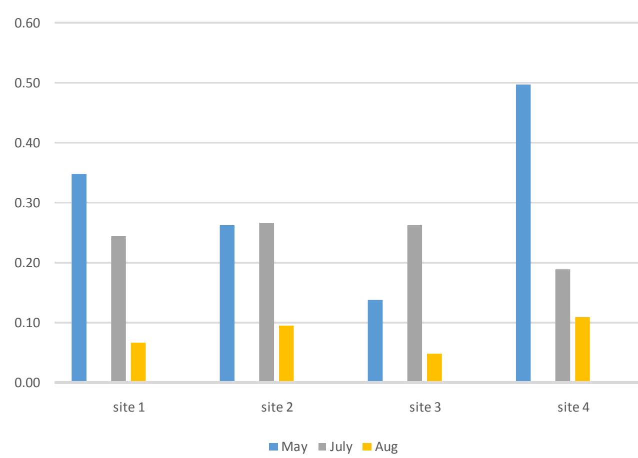
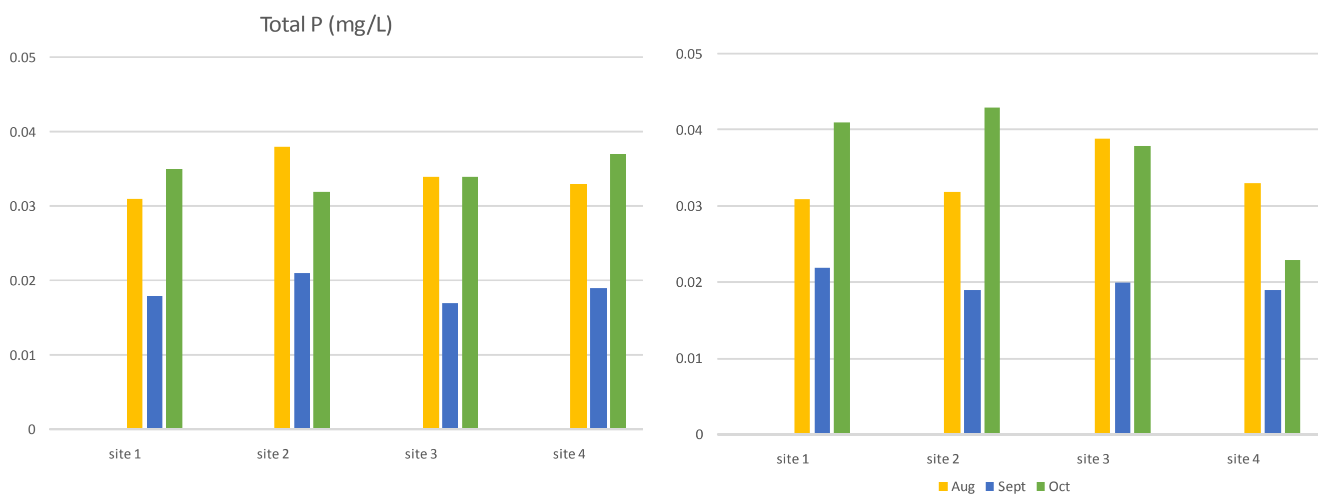


Figure 12. Total Phosphorus per month and depth at the four sampling sites.

A) 2010

5m depth

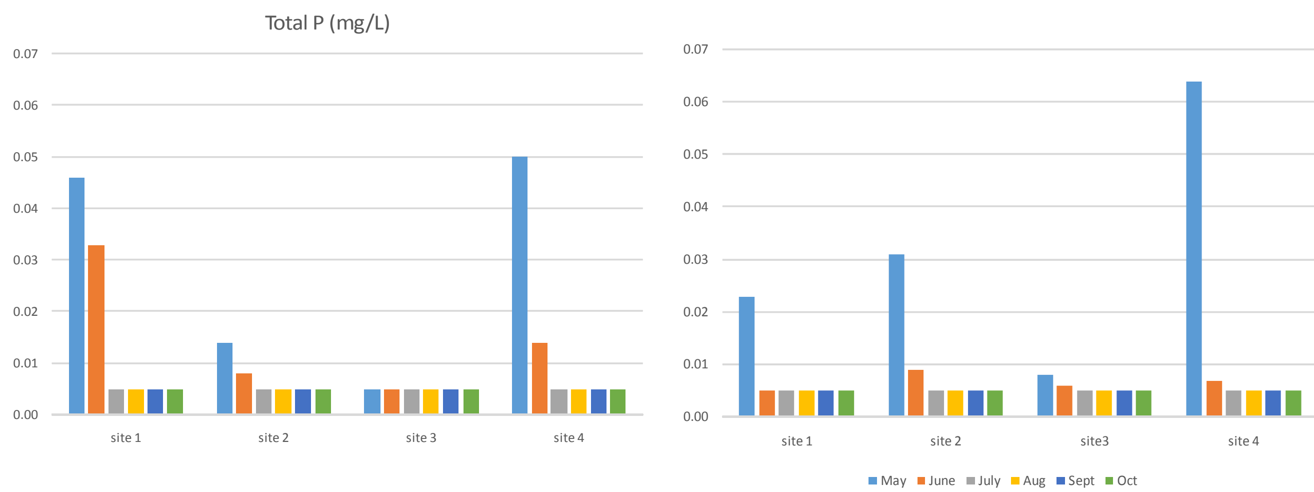
50m depth



B) 2011

5m

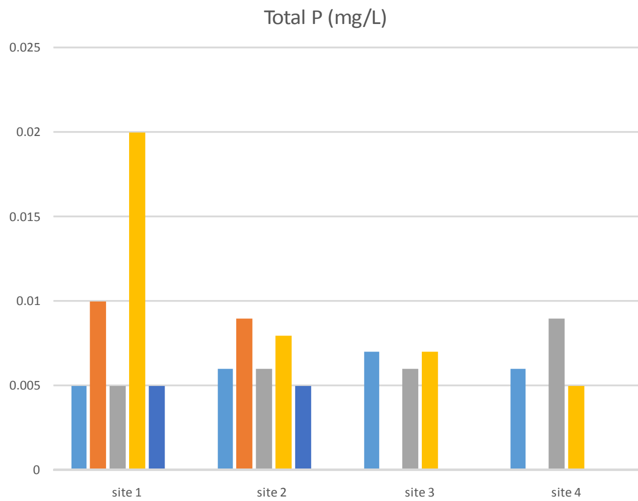
50m



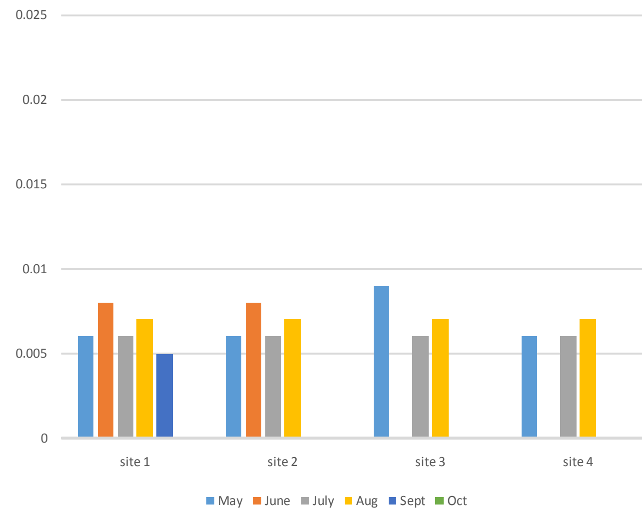
*Values at 0.005 mg/L mark Detection Limit.

C) 2012

5m

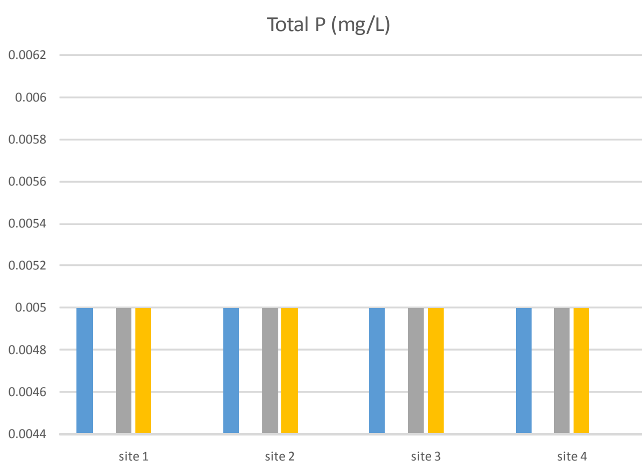


50m

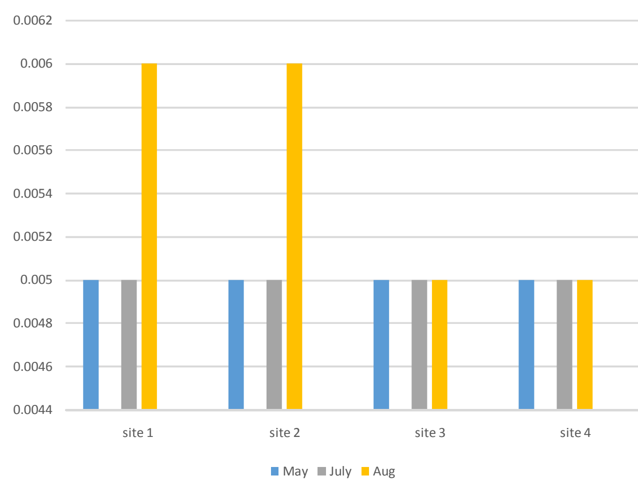


D) 2013

5m



50m



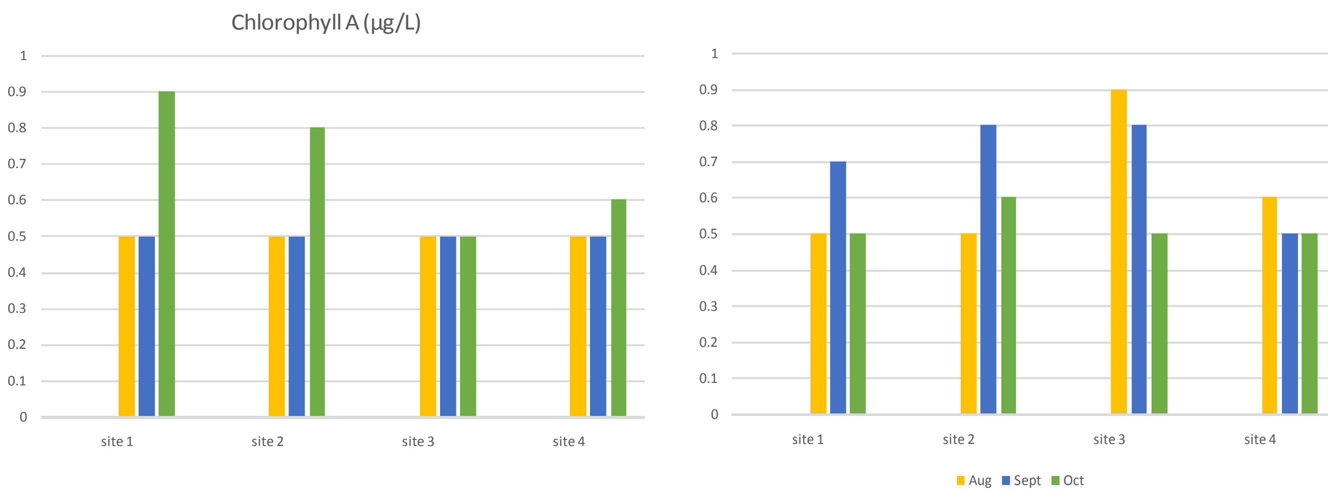
* Values at 0.005 mg/L mark Detection Limit.

Figure 13. Total Chlorophyll-a per month and depth at the four sampling sites

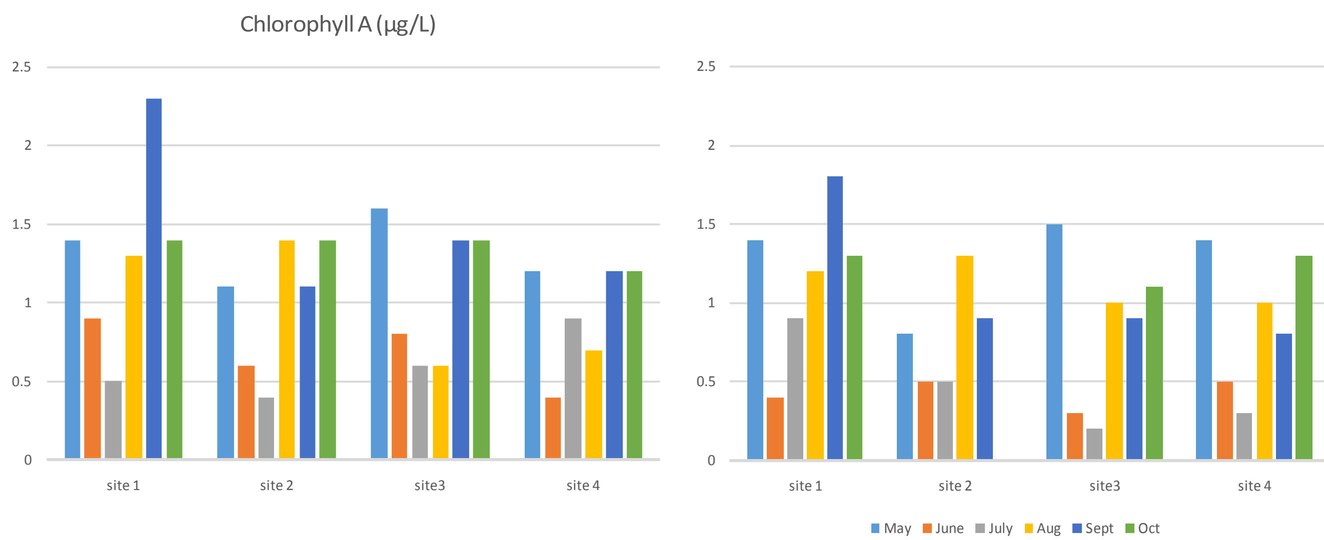
A) 2010

5m depth

50m depth

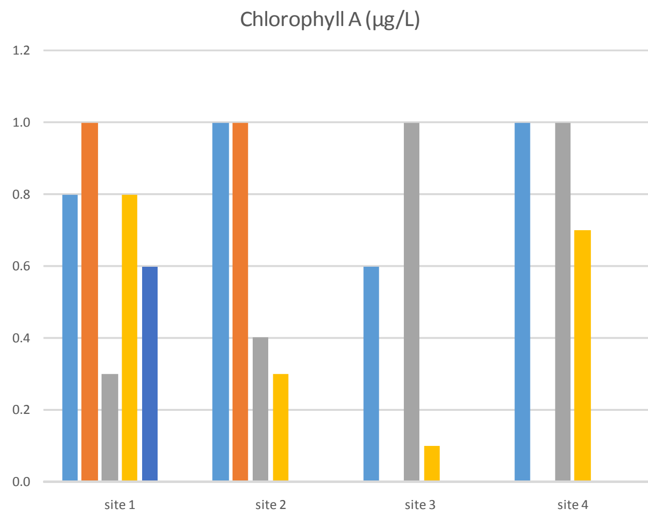


B) 2011

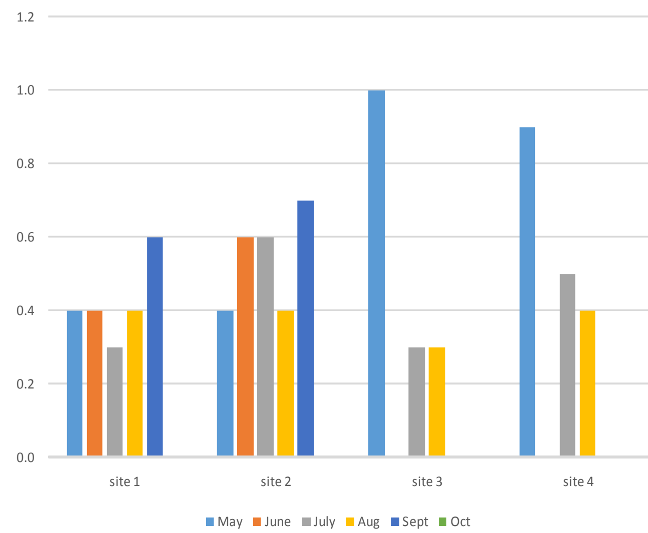


C) 2012

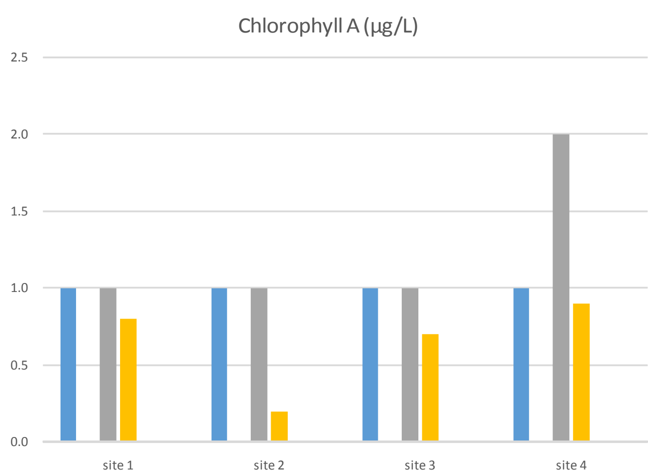
5m depth



50m depth



D) 2013



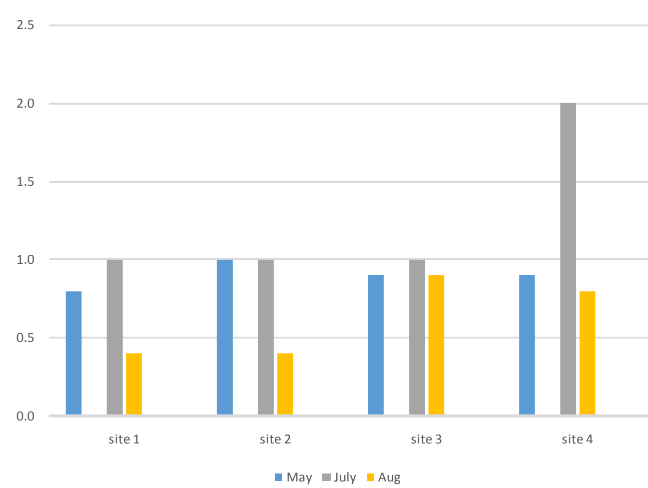
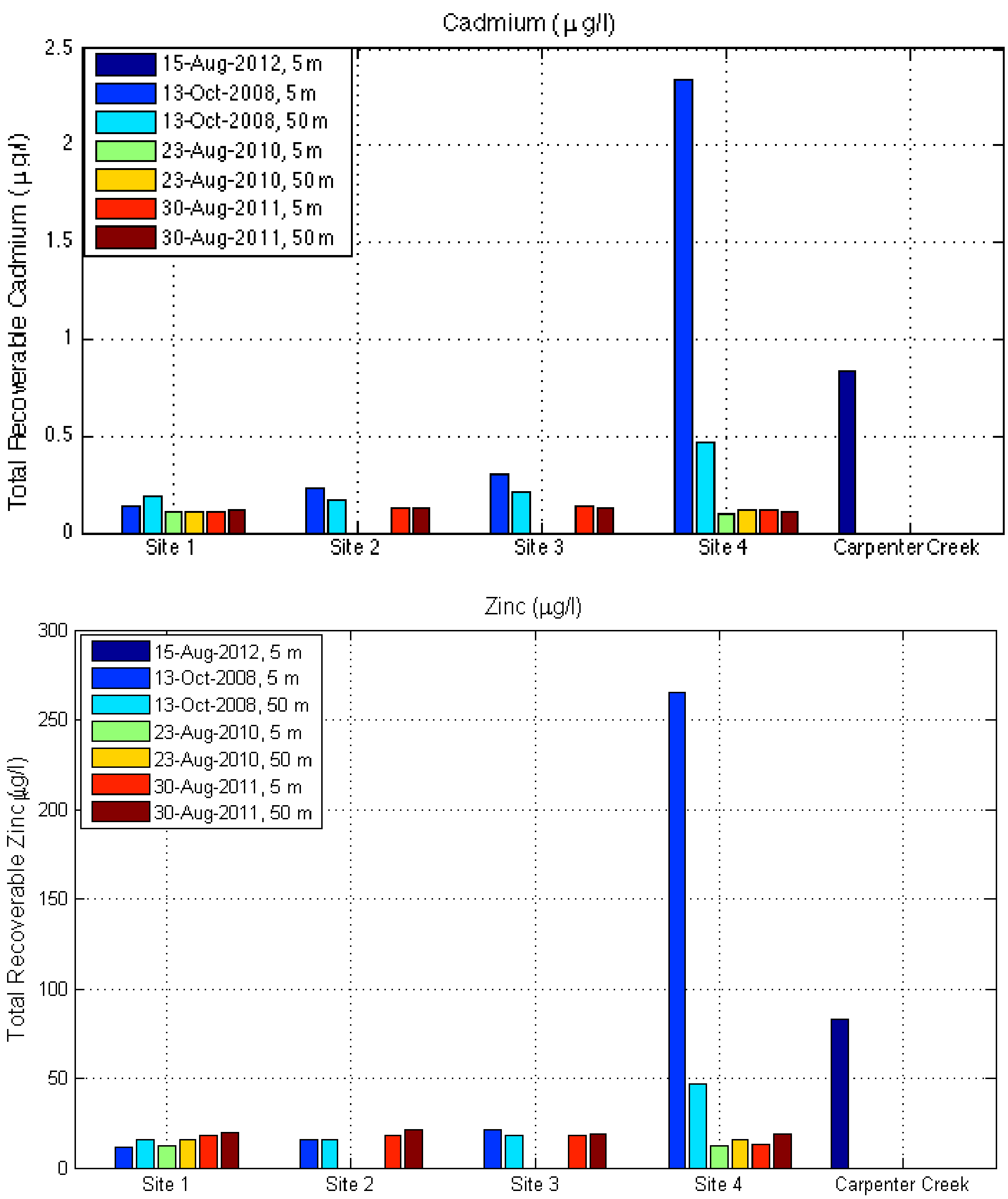
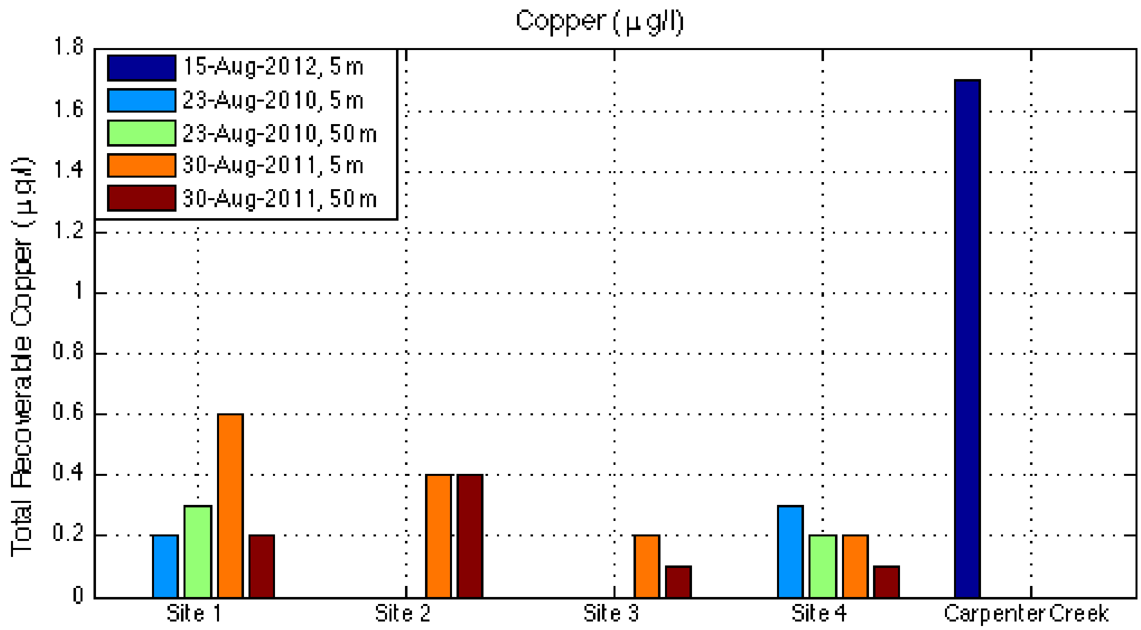
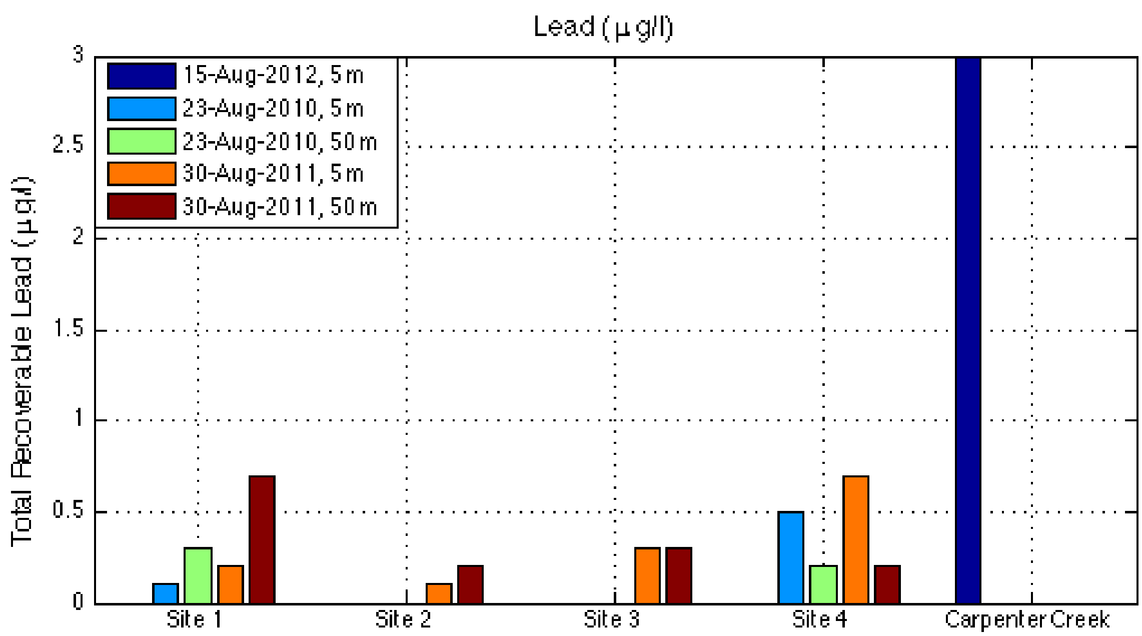


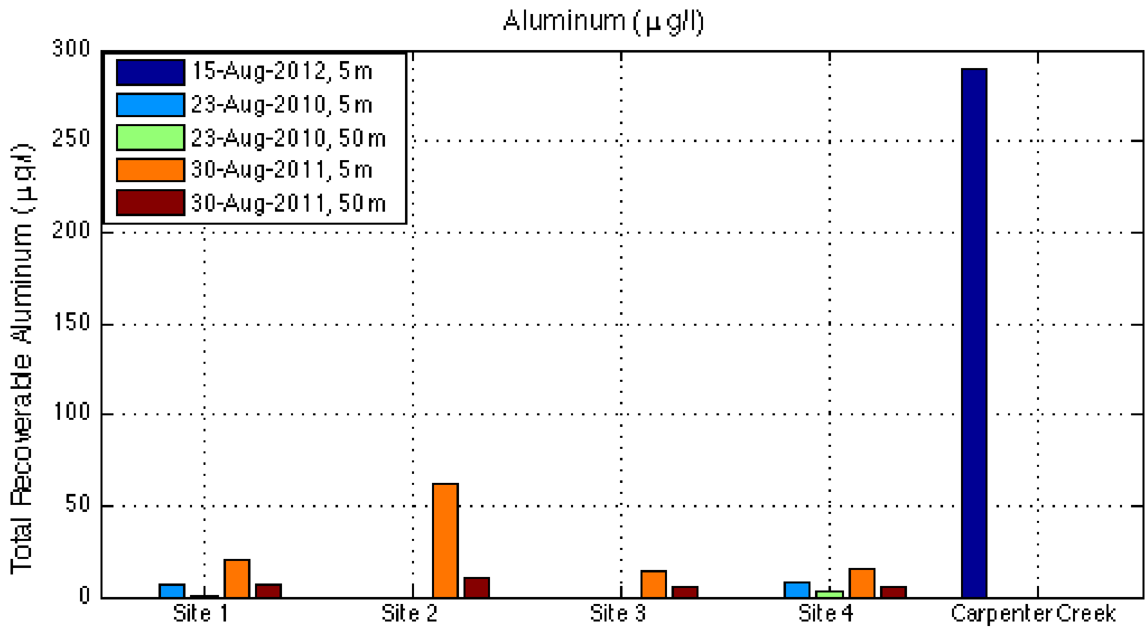
Figure 14.

Heavy metals of concern concentrations in Slocan Lake and Carpenter Creek (2008 to 2012)




Copper (µg/l)
Total Recoverable Copper (µg/l)
15-Aug-2012, 5 m
23-Aug-2010, 5 m
23-Aug-2010, 50 m
30-Aug-2011, 5 m
30-Aug-2011, 50 m
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
Site 1
Site 2
Site 3
Site 4
Carpenter Creek


Lead (µg/l)
Total Recoverable Lead (µg/l)
15-Aug-2012, 5 m
23-Aug-2010, 5 m
23-Aug-2010, 50 m
30-Aug-2011, 5 m
30-Aug-2011, 50 m
0
0.5
1
1.5
2
2.5
3
Site 1
Site 2
Site 3
Site 4
Carpenter Creek


Aluminum (µg/l)
Total Recoverable Aluminum (µg/l)
300
250
200
150
100
50
0
15-Aug-2012, 5m
23-Aug-2010, 5m
23-Aug-2010, 50m
30-Aug-2011, 5m
30-Aug-2011, 50m
Site 1
Site 2
Site 3
Site 4
Carpenter Creek

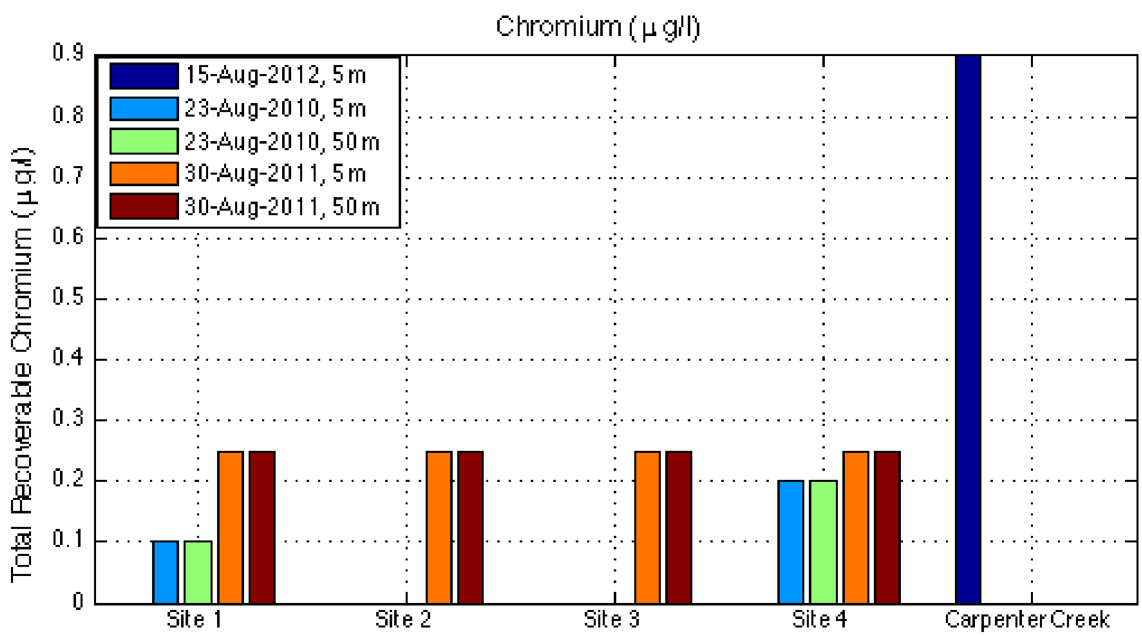
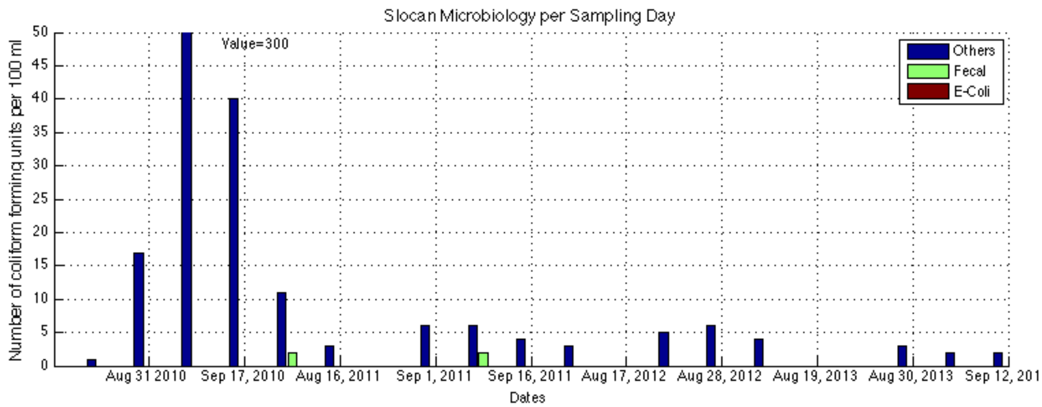
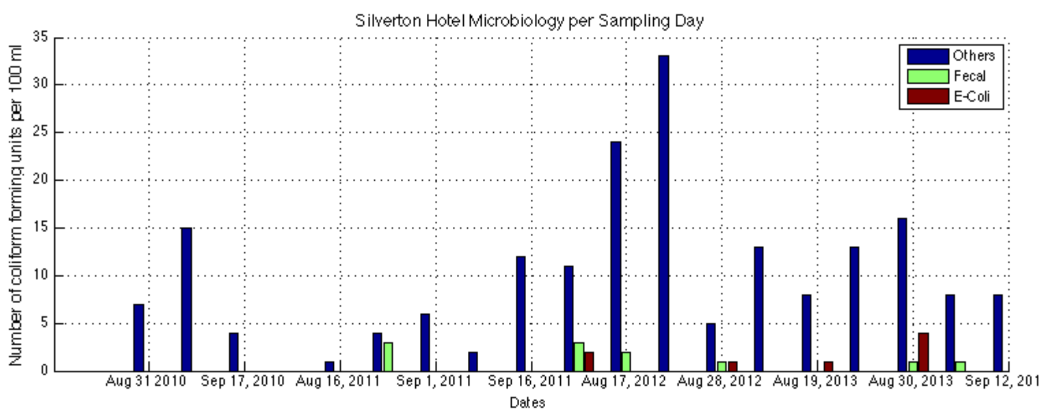
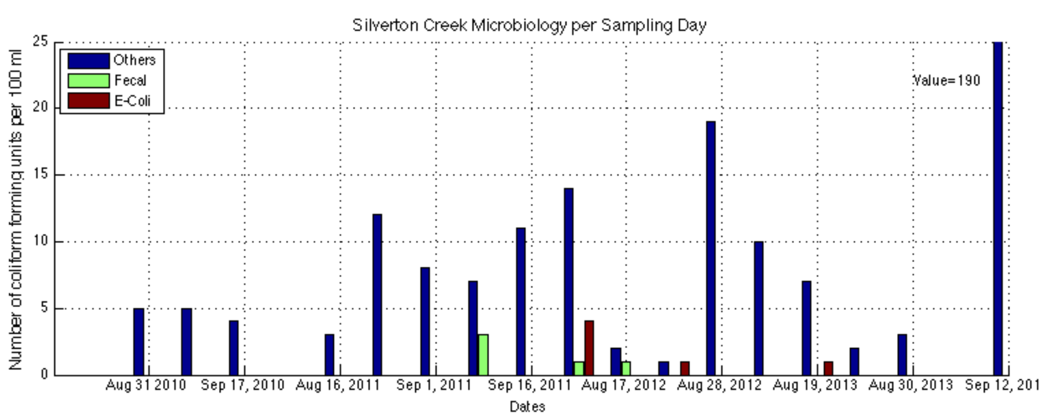
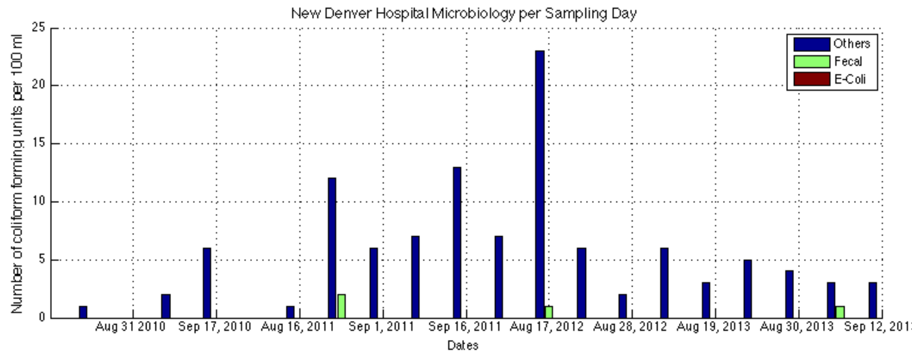

Chromium (µg/l)
Total Recoverable Chromium (µg/l)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
15-Aug-2012, 5m
23-Aug-2010, 5m
23-Aug-2010, 50m
30-Aug-2011, 5m
30-Aug-2011, 50m
Site 1
Site 2
Site 3
Site 4
Carpenter Creek

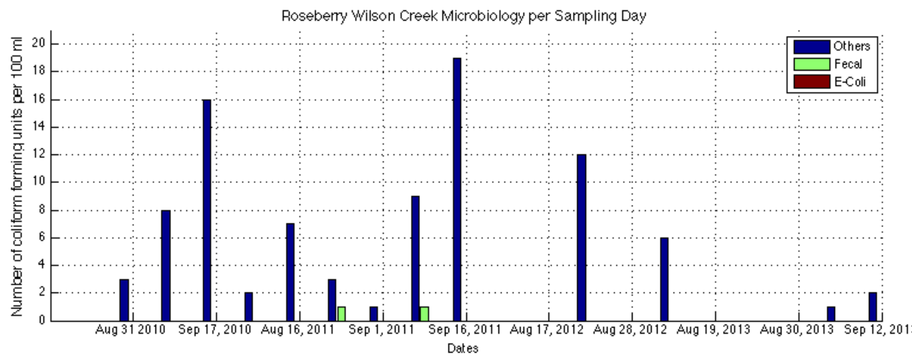
Figure 15. Coliform counts in the seven study sites in 2010, 2011, 2012 and 2013

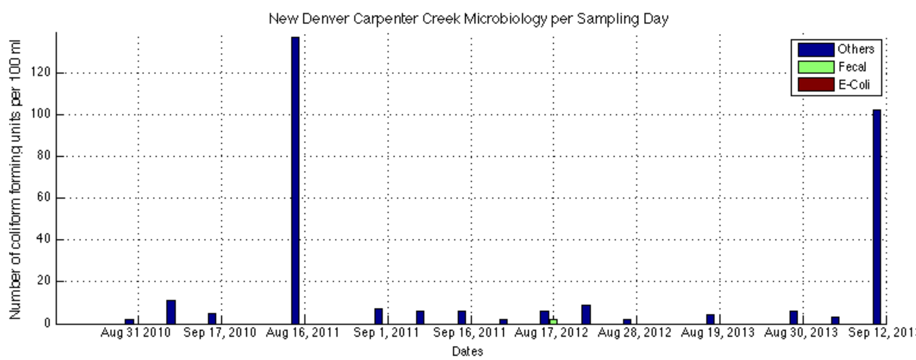







New Denver Hospital Microbiology per Sampling Day
Number of coliform forming units per 100 ml
0
5
10
15
20
25
Aug 31 2010
Sep 17, 2010
Aug 16, 2011
Sep 1, 2011
Sep 16, 2011
Aug 17, 2012
Aug 28, 2012
Aug 19, 2013
Aug 30, 2013
Sep 12, 2013
Dates
Others
Fecal
E-Coli


Roseberry Wilson Creek Microbiology per Sampling Day
Number of coliform forming units per 100 ml
0
2
4
6
8
10
12
14
16
18
20
Aug 31 2010
Sep 17, 2010
Aug 16, 2011
Sep 1, 2011
Sep 16, 2011
Aug 17, 2012
Aug 28, 2012
Aug 19, 2013
Aug 30, 2013
Sep 12, 2013
Dates
Others
Fecal
E-Coli


New Denver Carpenter Creek Microbiology per Sampling Day
Number of coliform forming units per 100 ml
0
20
40
60
80
100
120
Aug 31 2010
Sep 17, 2010
Aug 16, 2011
Sep 1, 2011
Sep 16, 2011
Aug 17, 2012
Aug 28, 2012
Aug 19, 2013
Aug 30, 2013
Sep 12, 2013
Dates
Others
Fecal
E-Coli

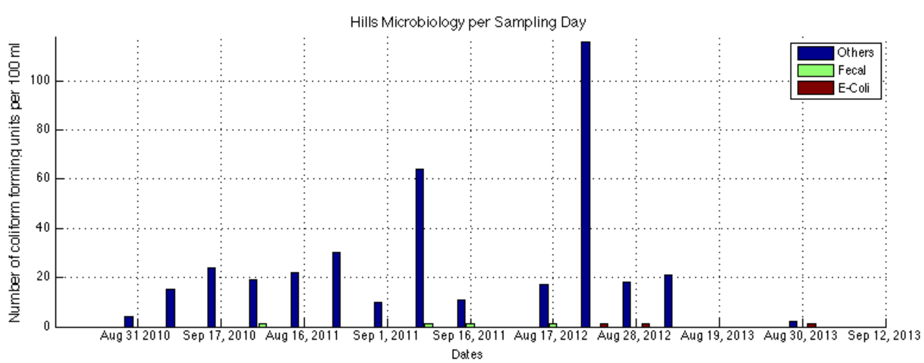
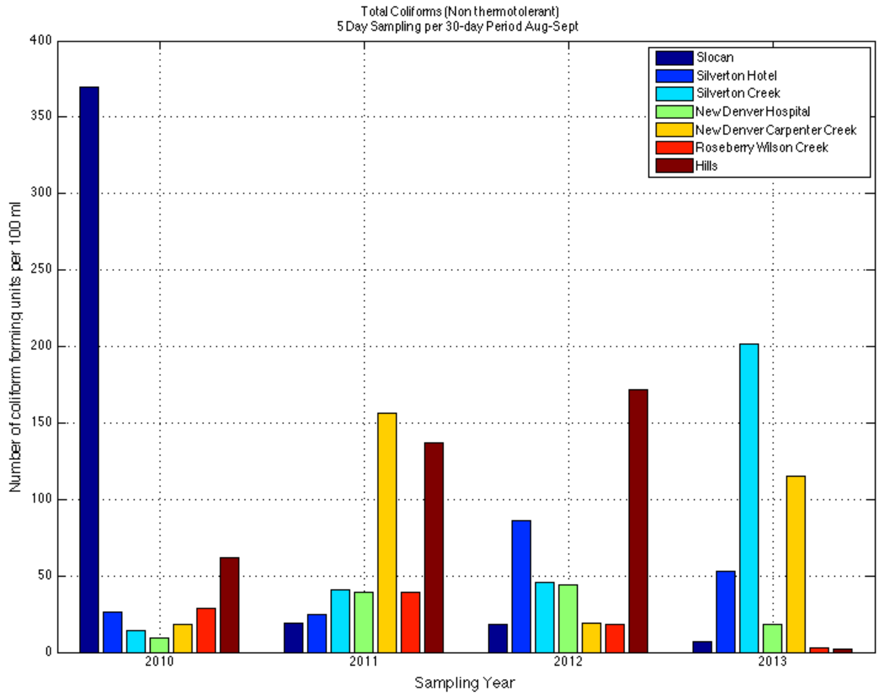

Hills Microbiology per Sampling Day
Number of coliform forming units per 100 ml
0
20
40
60
80
100
Aug 31 2010
Sep 17, 2010
Aug 16, 2011
Sep 1, 2011
Sep 16, 2011
Aug 17, 2012
Aug 28, 2012
Aug 19, 2013
Aug 30, 2013
Sep 12, 2013
Dates
Others
Fecal
E-Coli

Figure 16. Total coliform forming units (cfu) counts in 2010, 2011, 2012 and 2013



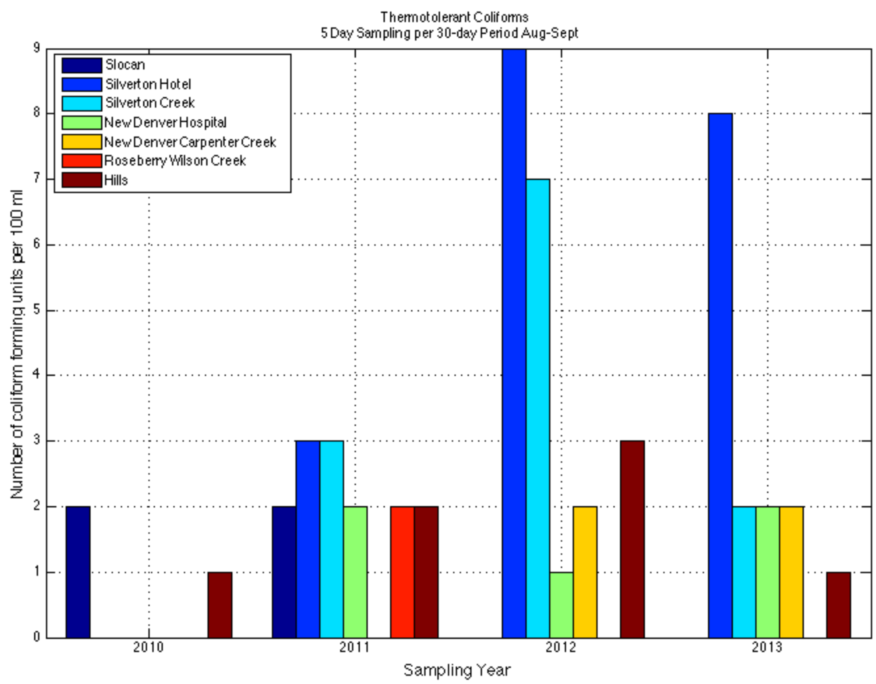


Figure 17. Total *E. coli* cfu counts in 2012 and 2013 per 5-day sampling season

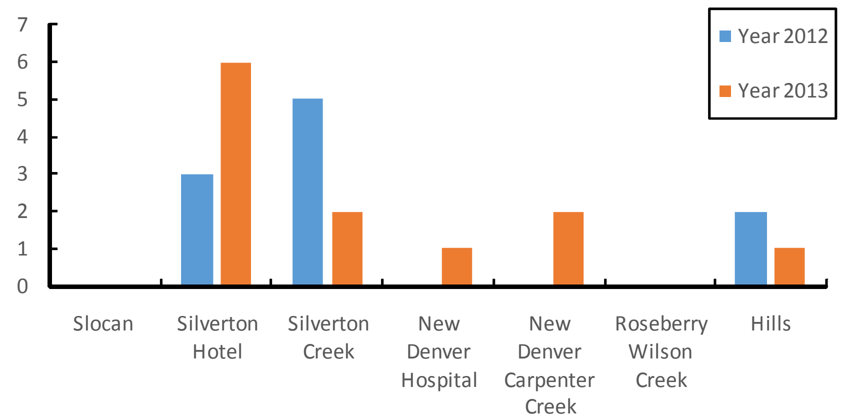


Figure 18. Seasonal average (July-September) zooplankton density and biomass 2000-2013

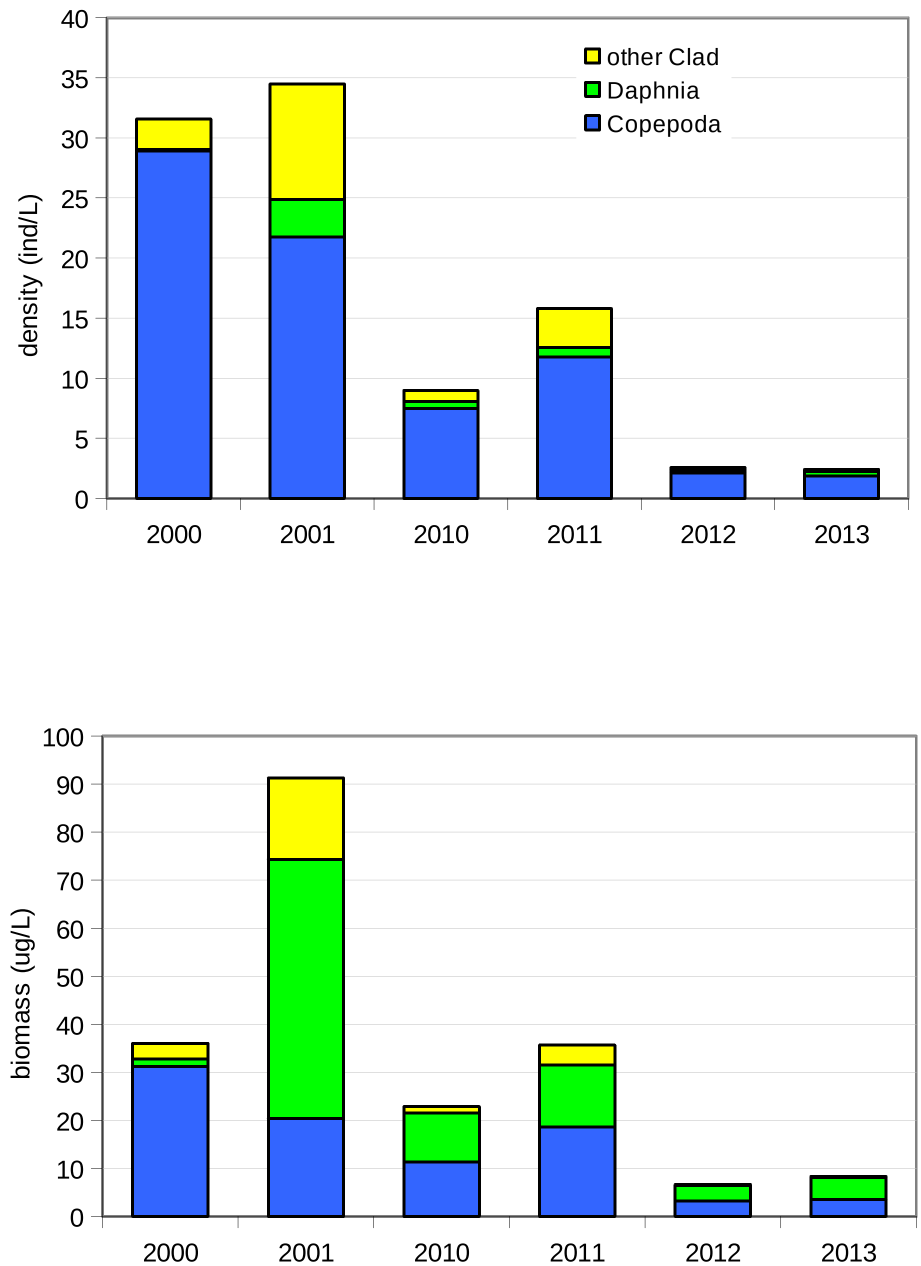
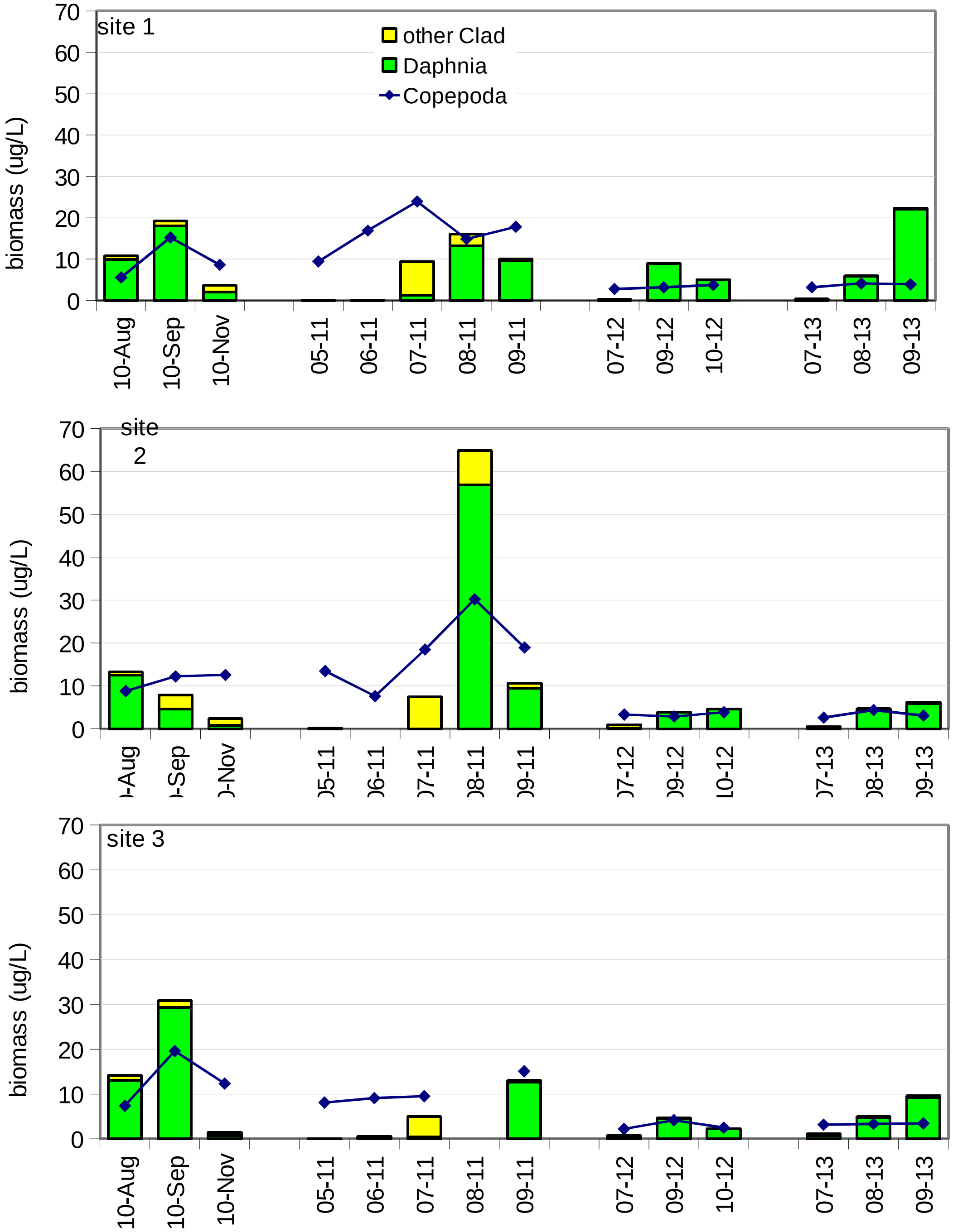


Figure 19. Zooplankton biomass at three sites in Slocan Lake in 2010, 2011, 2012 and 2013



Moraia Grau & Associates, email:moraia@bosquesyrios.org

Figure 20. Seasonal average composition of zooplankton density in Slocan Lake in 2010, 2011, 2012 and 2013

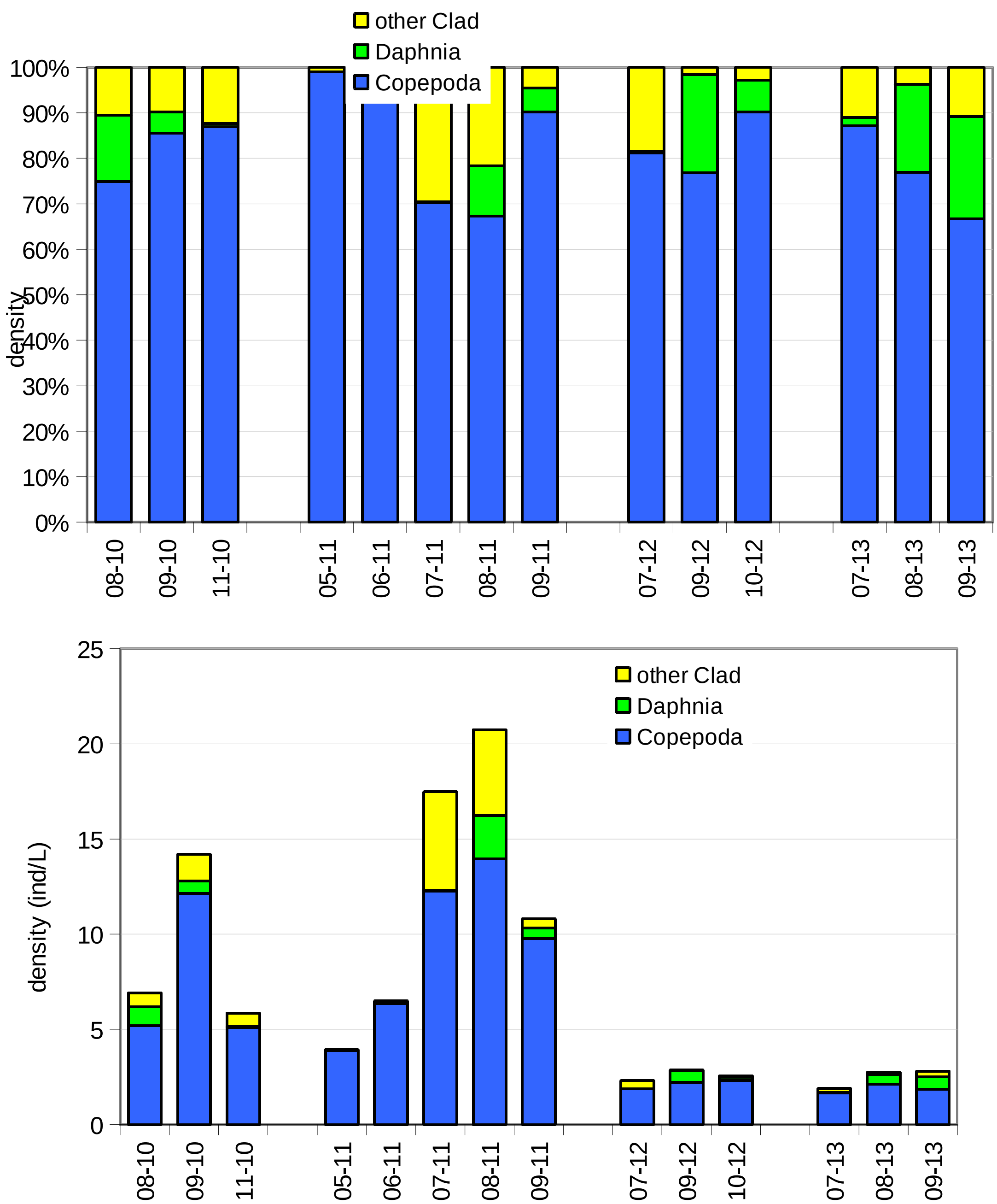


Figure 21. Zooplankton density at the three sites in 2010, 2011, 2012 and 2013

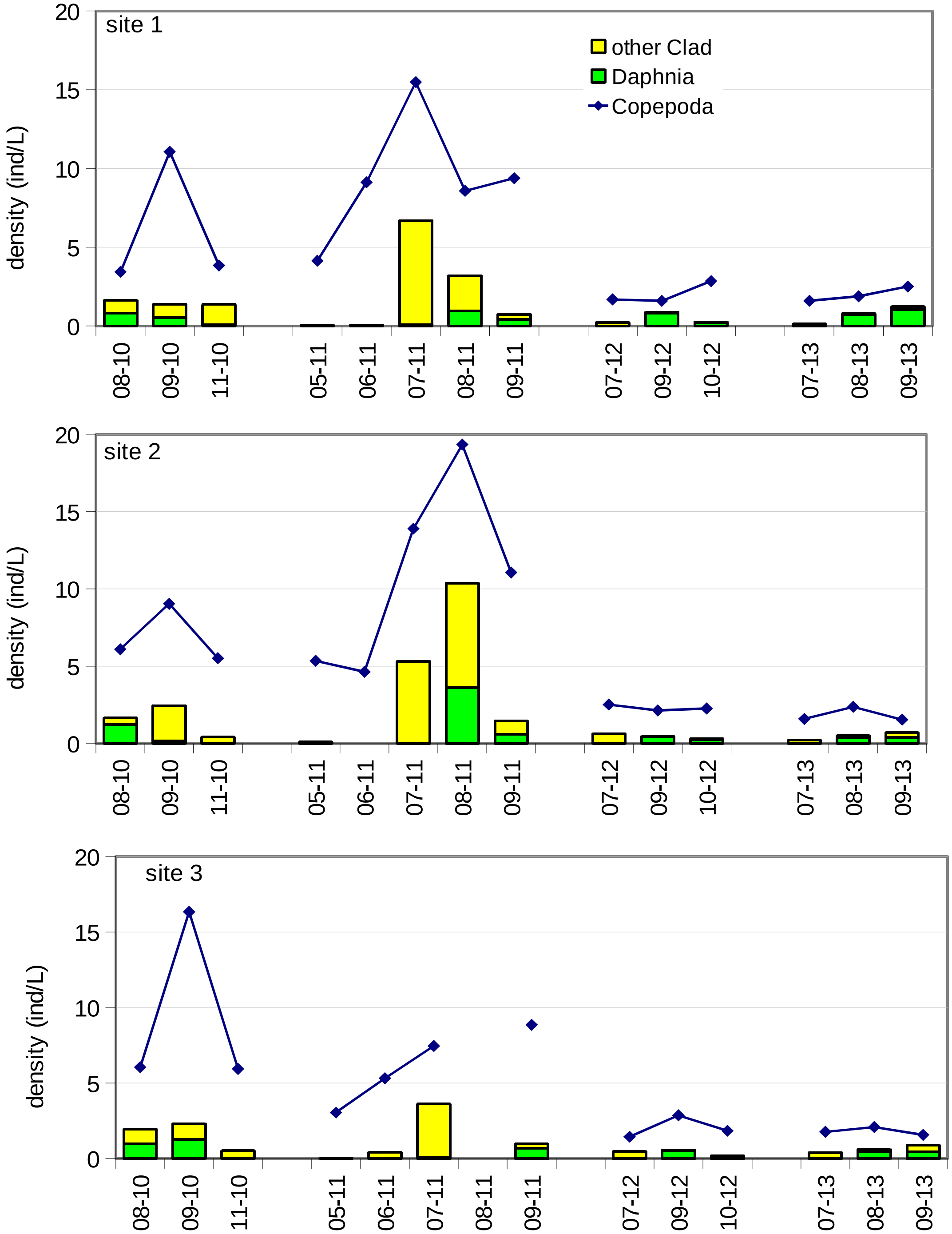
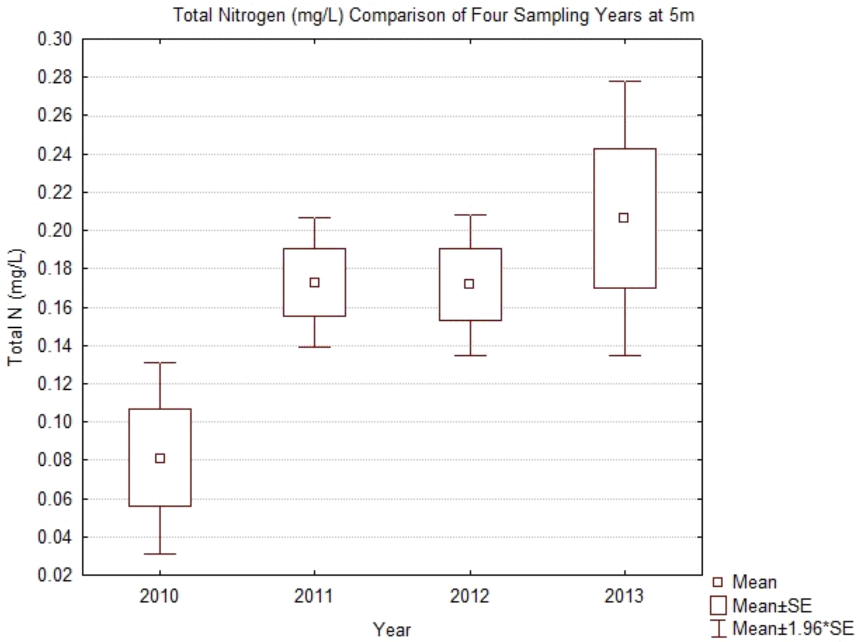
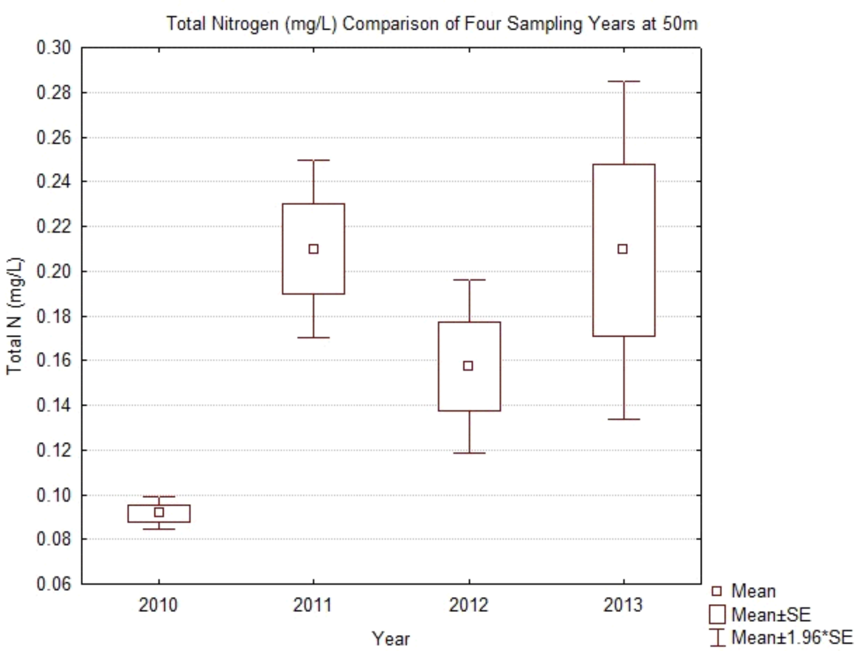
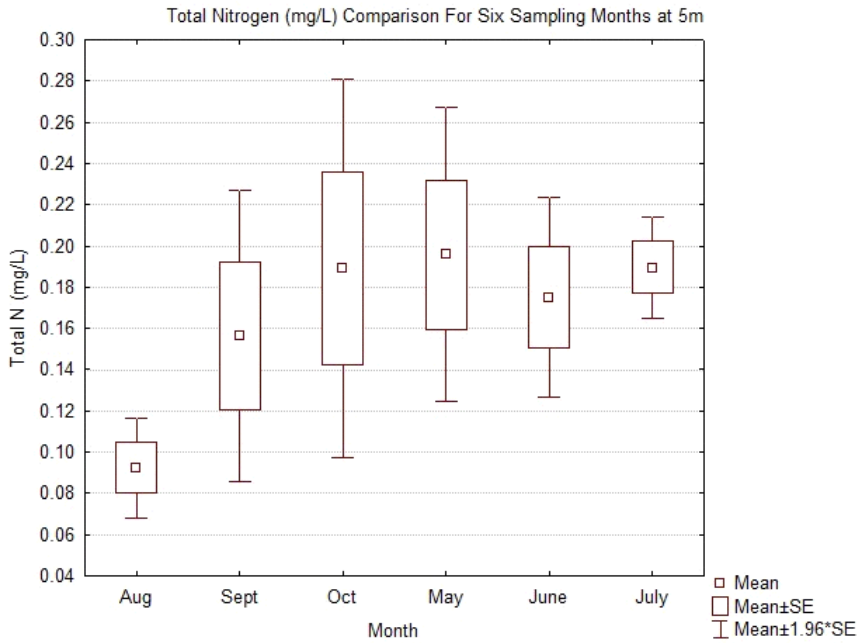
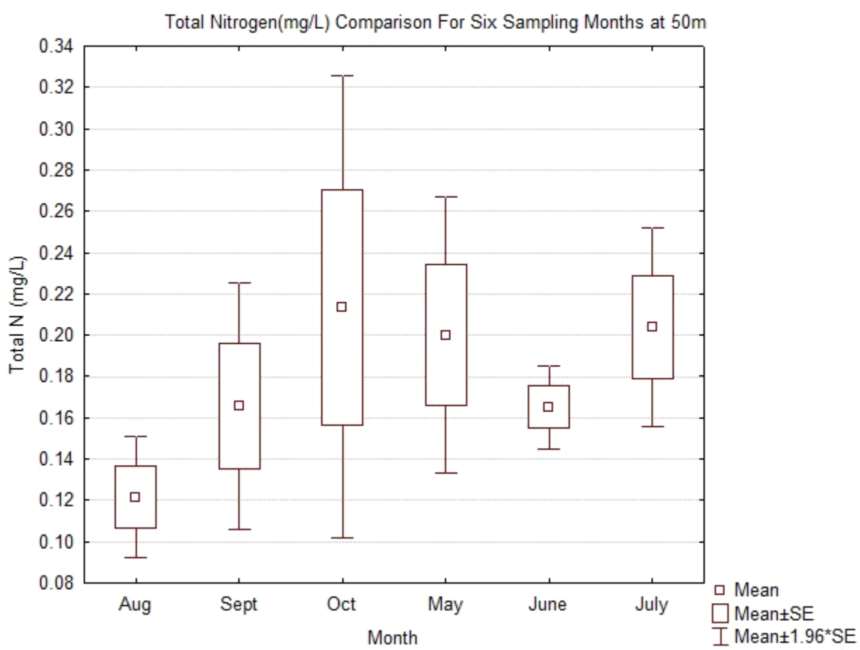


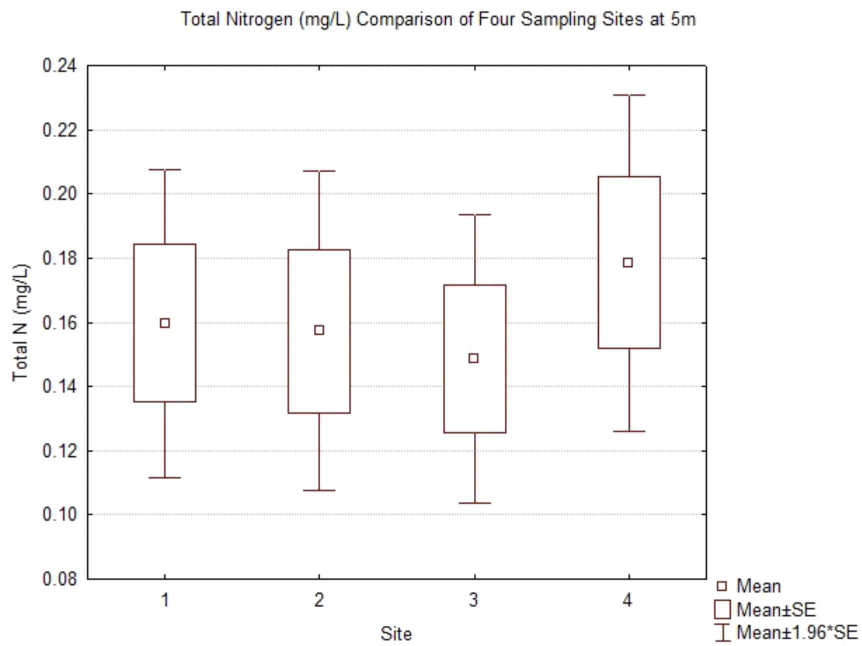
Figure 22. Total Nitrogen concentration means per year, month, and site at 5 and 50m depth

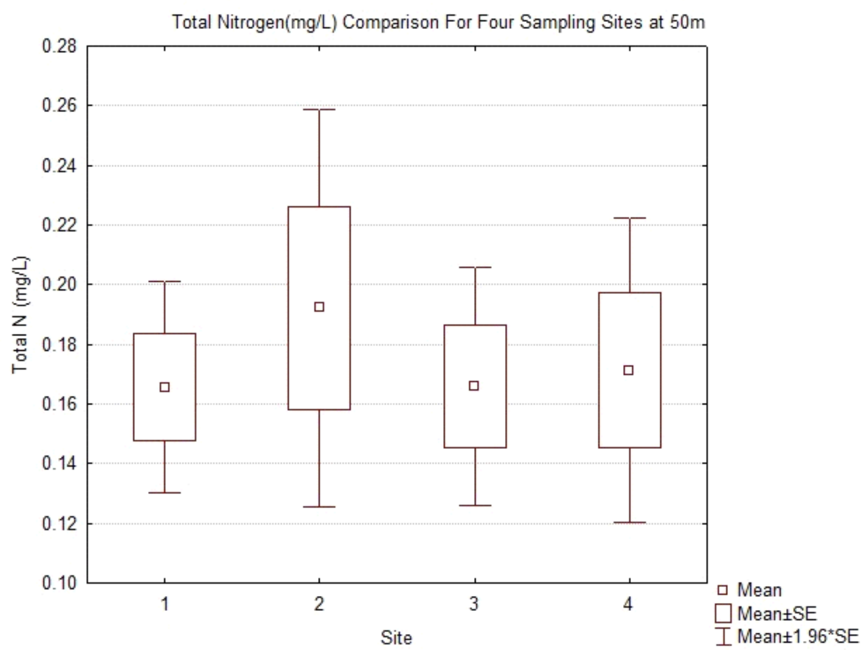





Total Nitrogen (mg/L) Comparison For Six Sampling Months at 5m
Total N (mg/L)
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
Aug
Sept
Oct
May
June
July
Month
Mean
Mean±SE
Mean±1.96*SE

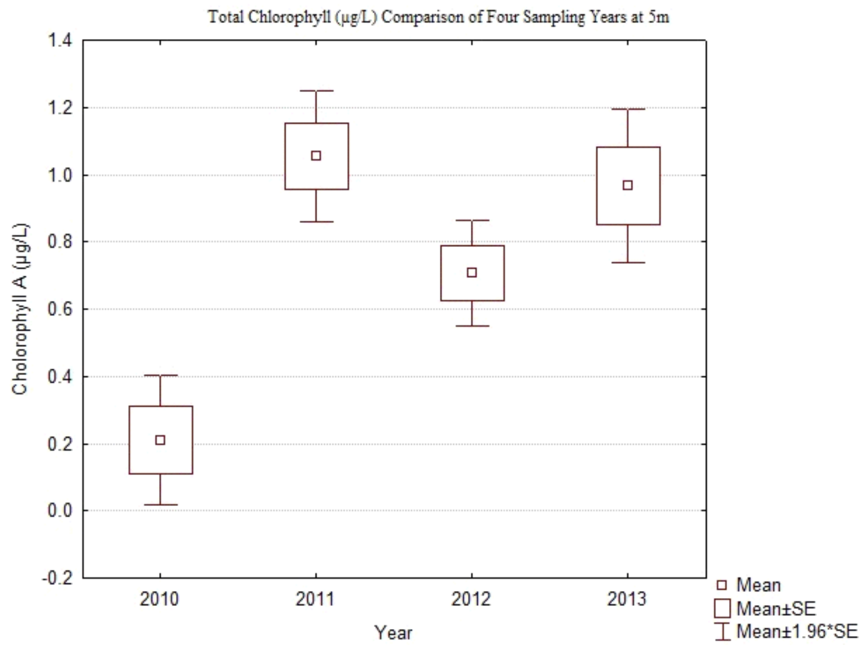

Total Nitrogen(mg/L) Comparison For Six Sampling Months at 50m
Total N (mg/L)
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
Aug
Sept
Oct
May
June
July
Month
Mean
Mean±SE
Mean±1.96*SE

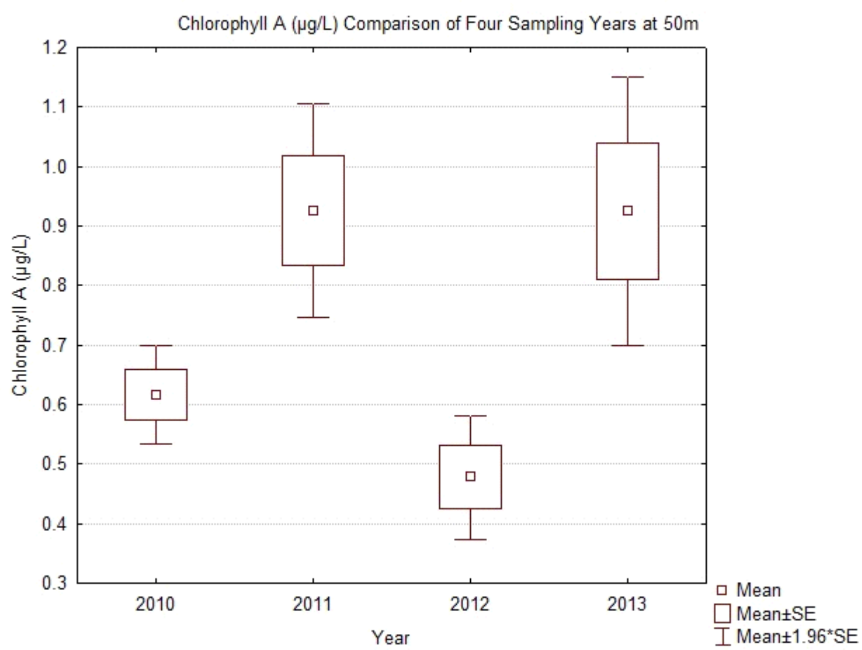




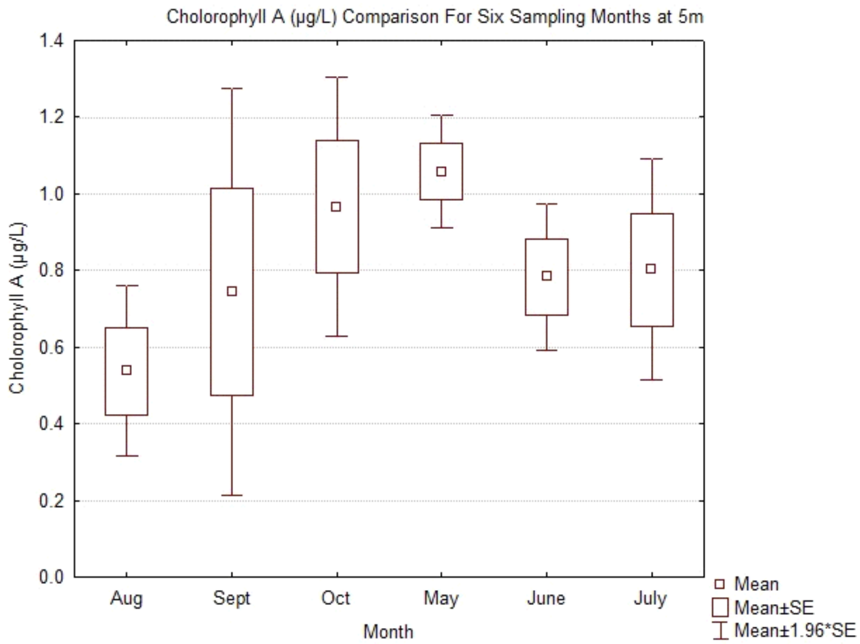
Moraia Grau & Associates, email:moraia@bosquesyrios.org

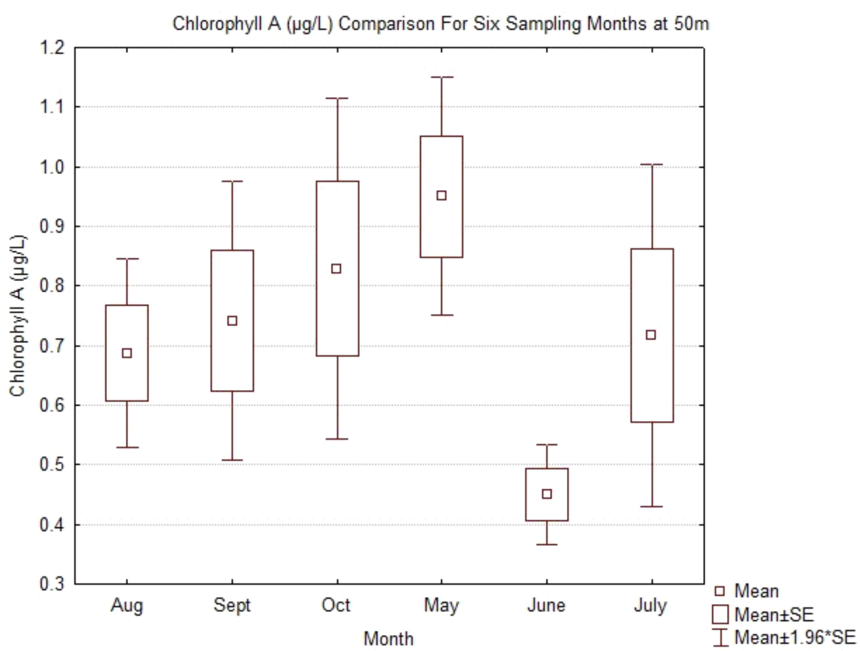
Figure 23. Chlorophyll-a concentrations: means per year, month, and site at 5 and 50m depth



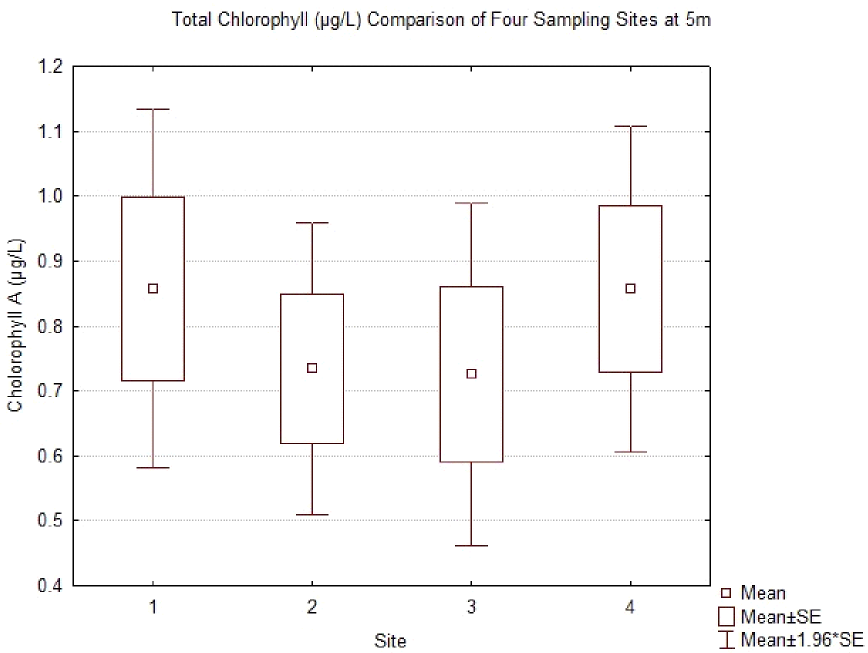


Moraia Grau & Associates, email:moraia@bosquesyrios.org





Moraia Grau & Associates, email:moraia@bosquesyrios.org


Total Chlorophyll (µg/L) Comparison of Four Sampling Sites at 5m
Cholorophyll A (µg/L)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
1
2
3
4
Site
Mean
Mean±SE
Mean±1.96*SE

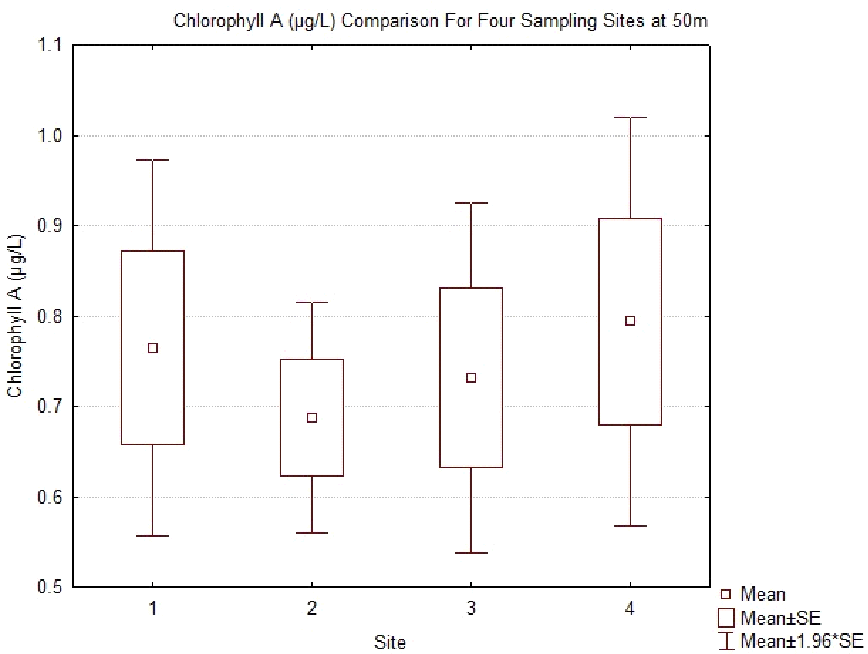
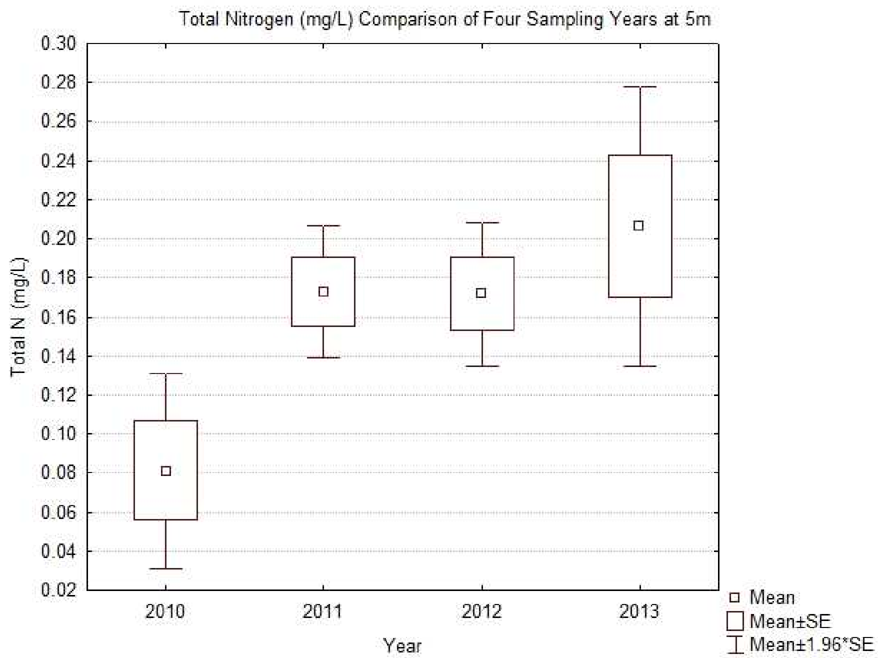
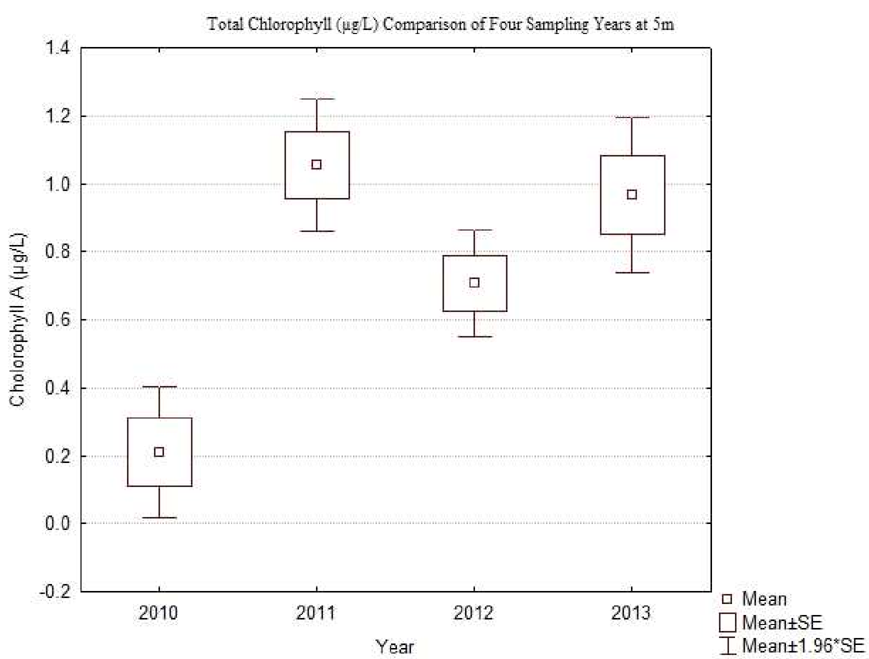
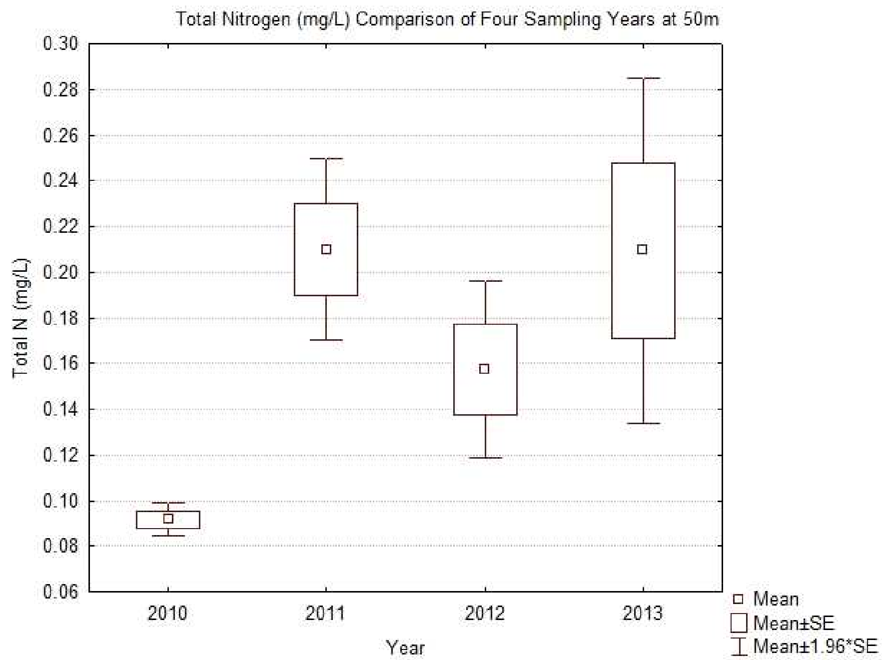
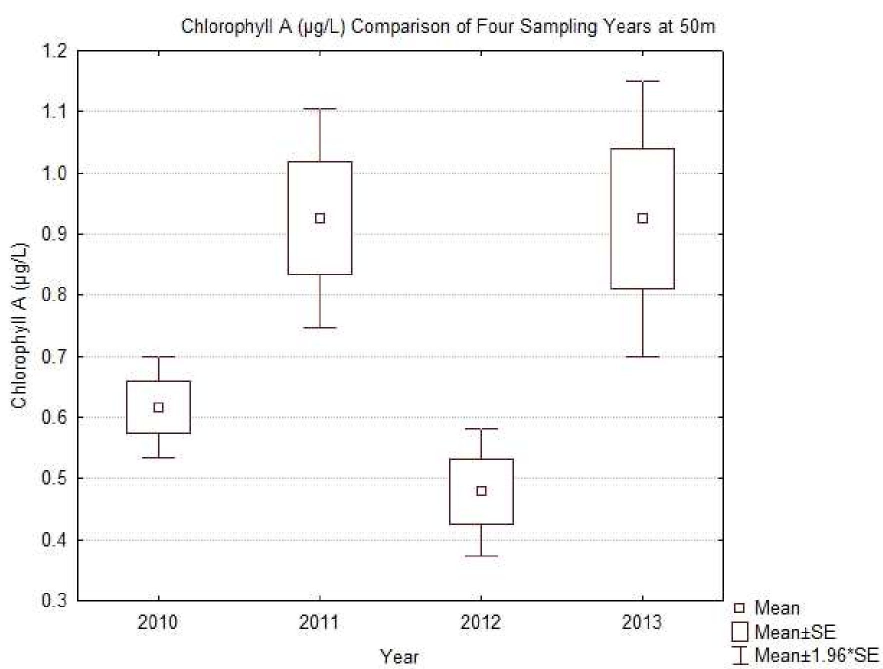

Chlorophyll A (µg/L) Comparison For Four Sampling Sites at 50m
Chlorophyll A (µg/L)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
1
2
3
4
Site
Mean
Mean±SE
Mean±1.96*SE

Figure 24. Total nitrogen and chlorophyll-a concentration annual means






Total Nitrogen (mg/L) Comparison of Four Sampling Years at 50m
Total N (mg/L)
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
2010
2011
2012
2013
Year
Mean
Mean±SE
Mean±1.96*SE


Chlorophyll A (µg/L) Comparison of Four Sampling Years at 50m
Chlorophyll A (µg/L)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
2010
2011
2012
2013
Year
Mean
Mean±SE
Mean±1.96*SE