Monitoring of Agricultural Effluent Impacts on Anadromous Fish in the Merritt Area

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1 Background

The Nicola River is the largest tributary to the Thompson River downstream of Kamloops Lake, with a drainage area of 7,670km^2. Its watershed includes parts of the traditional territory of the Nlaka'pamux/Scw'exmx and Syilx peoples. The Nicola River watershed is a snowmelt-dominated system characterized by high flows in May and June and low flows through the summer and winter. Several sensitive anadromous fish populations including Chinook, Coho, and steelhead trout, spawn and rear in the Nicola River and its tributaries. These stocks have been declining as a result of natural and anthropogenic stressors, as well as their cumulative effects. They are especially vulnerable to freshwater-specific threats as they all follow a stream-type life history. The Committee on the Status of Endangered Wildlife in Canada listed both local Chinook and Steelhead populations as "Endangered" in 2020, and Interior Fraser Coho was listed "Threatened" in 2016. Salmon play an important role in the ecosystem of the Nicola Valley, and the are vital to local First Nations culture.

The increase of feedlot activities along the Nicola River and the Coldwater River has been an emerging concern in recent years. In response to regulations regarding the management of nutrients, wastes and byproducts in agricultural operations, British Columbia Lower Mainland dairy operations are moving non-lactating animals to B.C. Interior feedlots. This rotation practice has been prevalent in the Merritt area due to its proximity to Lower Mainland operations and its existing strong beef cattle industry. This increase in dairy feedlot operations has the potential to add to water pollution via different pathways including leaching manure which is produced by cattle but also spread to fertilize adjacent fields. Manure leaching during snowmelt and heavy precipitation can increase the nutrient load and introduce microorganisms into waterways, posing a threat to local fish populations. Pollutants can reach a stream through overland flow, via eroding streambanks as well as through ground water seepage. Note that overland flow from pollutant sources is prohibited under current Provincial regulations. Other types of land use including residential development, forestry, riparian disturbance, and water extraction play a role in water quality as they have the potential to alter the hydrology and the nutrient retention capacity of a system.

Coho and Chinook eggs and alevins are susceptible to pollutants during the fall and winter, especially after rain on snow events that can occur before the freshet. Salmon fry emerge from gravel during the onset of the freshet, and are susceptible to changes in water quality resulting from adjacent fields snow melt. Snowmelt in valley bottoms occurs before the freshet, which is primarily driven by snowpack in the headwaters. Juveniles rearing in the spring and summer in off-channel habitat and in the mainstem are susceptible to pollution at the tail end of the freshet and after storm events. Migrating, holding, and spawning salmon are also vulnerable to contaminants for most of the year due to the overlapping life cycles of anadromous species in the study area. The effects from cultural eutrophication and sensitivity to pollutants can be exacerbated during drought conditions, which are increasingly common in parts of the study watershed. Pollutants can be carried over from one life stage to the next, and bioaccumulation is a source of concern. In 2021, the Nicola Watershed Stewardship and Fisheries Authority collected water samples from across the watershed to gain a better understanding of temporal and longitudinal changes in water quality in the research area, as well as their impact on fish populations.

2 Methods

2.1 Spatial resolution

Water quality was monitored at fixed locations to allow for monitoring of trends over time (Figure 1). Sites were chosen in a way as to maximize overlap with other on-going studies. The most upstream site on the Coldwater River was located at the Coquihalla Highway Kingsvale exit. This reference site is a common sampling location for many studies, including the Canadian Aquatic Biomonitoring Network, the Province of B.C., and Simon Fraser University's Salmon Watershed Lab. This site was above most of the agricultural

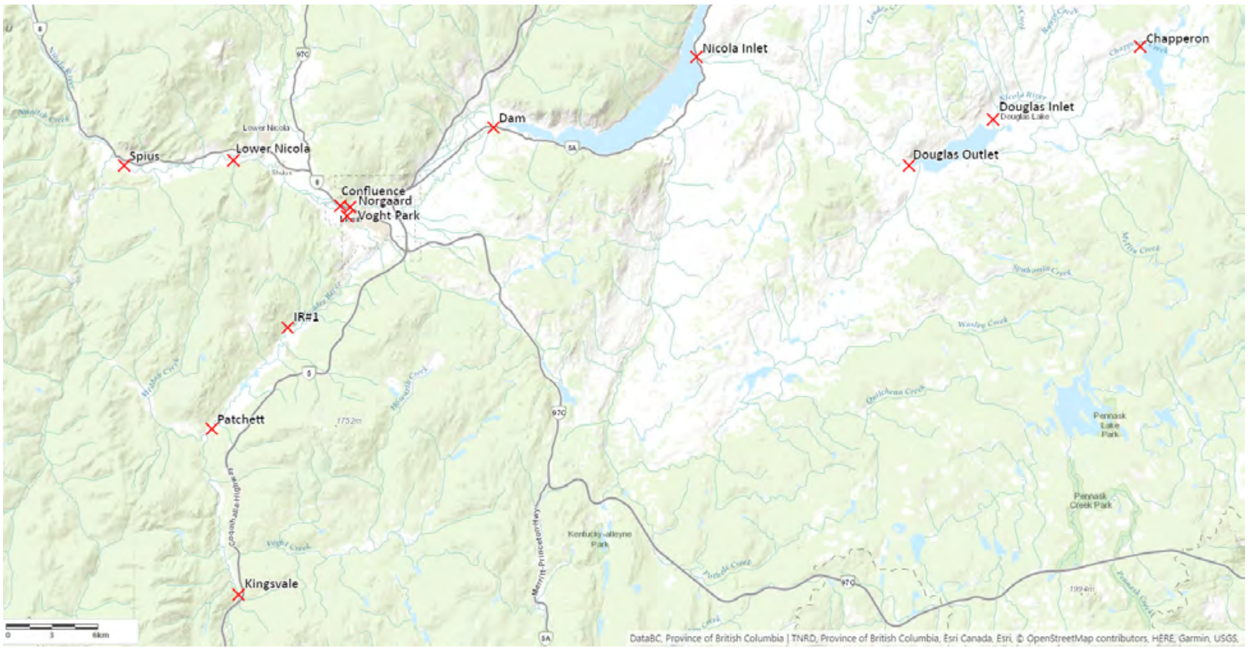


Figure 1: *Map of the study area and sites selected for water quality sampling.*

activity in the watershed, and human impacts on nutrient load and microorganism in the water are likely minimal upstream of this location. The next site on the Coldwater River was located at the Patchett Road bridge upstream of the "River Ranch", a dairy feedlot. This site also captured the effluents from Voght creek, and well as sedimentation from recent clear cuts on steep slopes south east of the site. This site is also monitored for water temperature by SFU's Salmon Watershed's Lab and it was investigated by the Province's Compliance branch after a report of manure leaching into the river in the spring of 2019. The next site on the Coldwater River was located on the Coldwater Indian Band Reserve (IR1) at the bridge north of the main community. This site is downstream of most agricultural operations along the Coldwater River, and reflects the cumulative impacts of upstream activities. The last site on the Coldwater River was located by Voght Park at the Main Street bridge, in the city of Merritt. There is a real-time Water Survey Canada station next to this site, and this section of the Coldwater River is used by Nicola Chinook salmon for spawning and rearing.

The most upstream site in the Upper Nicola watershed was located on Chapperon Creek immediately downstream of the Chapperon Lake dam. Chapperon Lake is surrounded by agricultural activity, and algae blooms are frequent during the summer in this shallow lake. Downstream, water samples at the Douglas Lake inlet reflected the cumulative impact from upstream activities in the Nicola River and Chapperon Creek. The outlet of Douglas Lake, located at the bridge at the south end of Douglas lake, was used as a reference site for the Nicola River between Douglas Lake and Nicola Lake. The Nicola Inlet site captured changes in water quality between Douglas Lake and Nicola Lake. This reach is used by kokanee salmon, rainbow trout and bull trout for spawning and rearing.

The Nicola River at the Nicola Dam outlet served as a reference site for the Nicola River downstream of the dam. This site is also monitored by Water Survey Canada, SFU's Salmon Watershed's lab and the Province of B.C. The next site on the Nicola River was located by ready-mix Norgaard (Norgaard), 30 meters upstream from its confluence with the Coldwater River. This site captured changes in water quality between the Nicola dam and the City of Merritt; the accumulation of pollutants is a concern in this slow stretch of river. This stretch is used for spawning by Chinook salmon, and Coho salmon to a lesser extent. It is used by juveniles in the spring and to overwinter especially in side-channels, and summer use is limited by high water temperatures.

The next site on the Nicola River was located 300 river meters downstream from its confluence with the Coldwater River (Confluence). This site served as a reference site for the Nicola River downstream of Merritt. This site is also monitored by SFU's Salmon Watershed's lab and it has existing water quality data as it is located downstream of the City of Merritt's rapid infiltration basins. This site is used by adult Chinook salmon for holding as they wait for the discharge in the Coldwater River to increase to levels allowing upstream migration. The next site, "Lower Nicola", was located on the Nicola River at the washed-out Kettle Valley Railway trestle at the east end of Gavelin Rd. This site aimed to capture the effects of agricultural activities downstream of the previous site, as well as pollutants from Guichon Creek. Guichon Creek was impacted by severe floods in 2017 and 2018 compromising the physical and ecological integrity of the system. Mamit Lake, a shallow lake connected to Guichon Creek, can experience algae blooms which may impact the Nicola River. The last station was located at the Sunshine Valley road West bridge on the Nicola River, 1.2 river kilometers upstream of its confluence with Spius Creek. This site lies downstream of the majority of agricultural activities in the Nicola River watershed, and results were not diluted by Spius Creek which is considerably less developed. The length of river between the Confluence and the Spius sites is the most used section of the Nicola River by Chinook salmon for spawning, and it is highly valuable to juveniles of all species.

Although the project was focused on agricultural impacts, we recognize that there are many confounding factors impacting water quality and it is challenging to isolate the effects from agriculture activities. We expect each site to reflect the cumulative impact of upstream conditions, and the goal is not to target specific ranching operations. Building on results from this screening work, this could be undertaken in the future using an upstream/downstream sampling approach.

Table 1: Summary table of sampling sites selected for water quality monitoring.

Site Name	**EMS #**	**Site Description**	**Lat**	**Long**
Kingsvale	E324052	Coldwater R at Kingsvale exit (d/s of bridge).	49.885407°	-120.903384
Patchett	E245980	Coldwater R at Patchett bridge.	49.983661°	-120.928486°
IR#1	E324071	Coldwater R at the IR#1 Bridge.	50.043866°	-120.858074°
Voght Park	E322355	Coldwater R at the WSC station.	50.110423°	120.803361°
Confluence	600534	Nicola R 300m Downstream from confluence with Coldwater R.	50.116531°	-120.809212°
Lower Nicola	E324091	Nicola R Downstream from confluence with Guichon Cr, at old KVR Bridge.	50.143457°	-120.908608°
Spius	E324092	Nicola R at Spius Bridge (Sunshine Valley rd. west).	50.140252°	-121.008996°
Norgaard	600533	Nicola R 30m Upstream from confluence with Coldwater R.	50.115258°	-120.800260°
Dam	E324093	Nicola R at Nicola Lake outlet.	50.161998°	-120.669585°
Douglas outlet	600091	Nicola R at Douglas Rd Bridge, downstream from Douglas Lake.	50.139799°	-120.283604°
Douglas inlet	600092	Nicola R at Douglas Rd Bridge, upstream from Douglas Lake.	50.167229°	-120.206605°
Chapperon	600250	Chapperon Creek downsteam from the Chapperon dam.	50.210230°	-120.070882°
Nicola inlet	0600094	Nicola R at Hwy 5A bridge.	50.203991°	-120.480628°

2.2 Sampling schedule

Agricultural leaching occurs via different pathways including soil erosion, surface runoff and subsurface flow, and is it most prevalent around the snow melt in May and June, as well as during precipitation events. Pollutants concentration in rivers depends on factors such as the timing of manure application (before versus after snow melt), soil characteristics, weather, the health of the riparian zone, and mitigation practices employed by ranchers. We collected water samples during 16 discrete events between March 30 and October 5, 2021. Due to access restrictions owing to the 2021 wildfires, we were unable to sample the Coldwater River at Kingsvale and the Nicola River at Spius on August 23rd.

2.3 Parameters

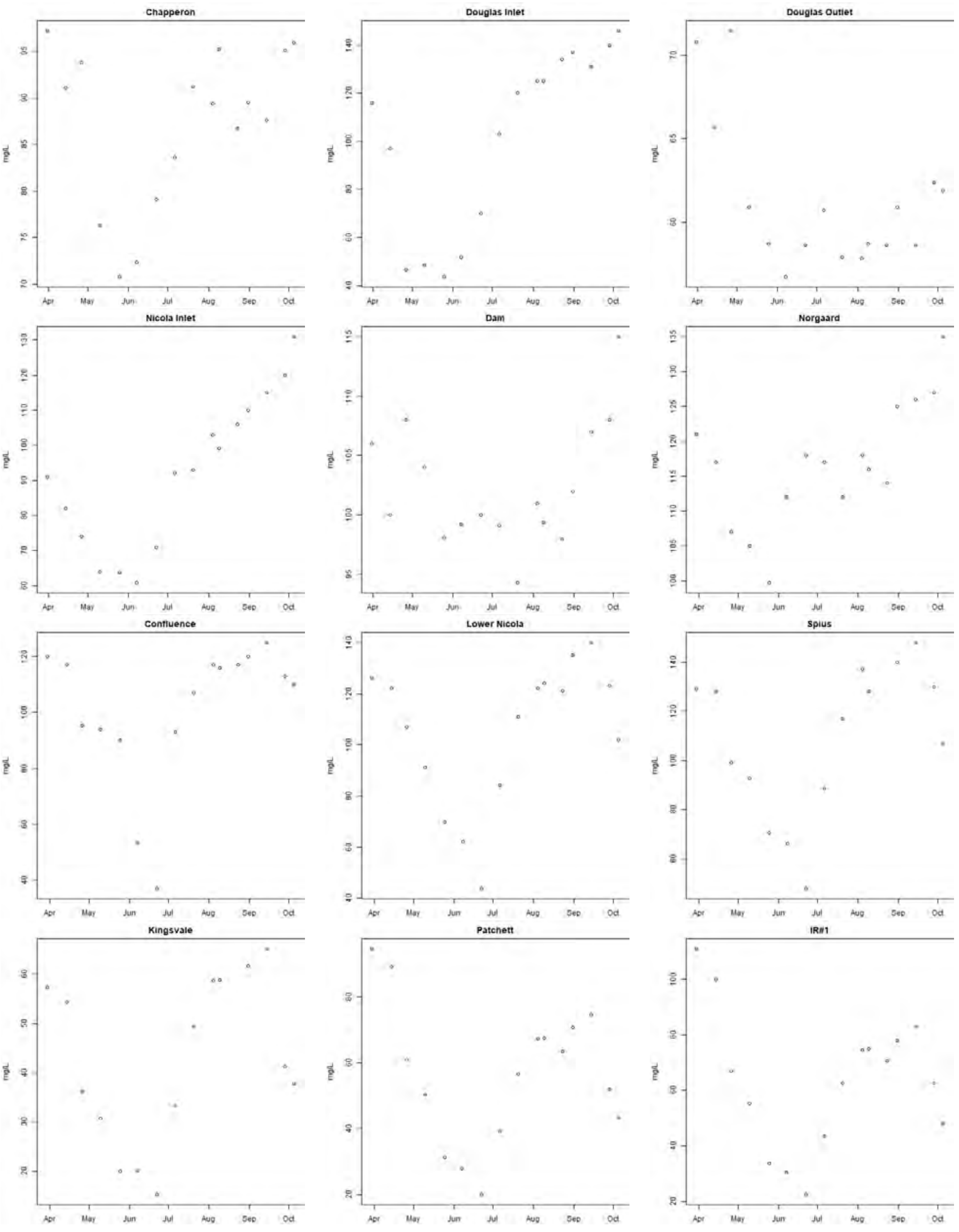
Parameters tested are listed in the table below. It should be noted that high flows will dilute nutrients, while low flows will increase nutrient concentration. Biological activity and dilution will also decrease nutrient concentration further downstream from pollution sources. Whenever possible, we collected water temperature and dissolved oxygen using a YSI ProDSS multiparameter tool. Photographs were taken at all sampling locations during each event.

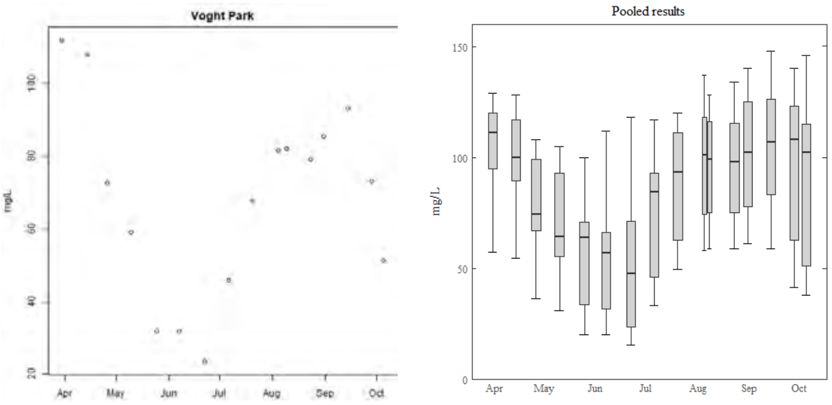
Table 2: Summary table of parameters tested during the project.

Parameter	**Description / Rational**
E. coli	Indicator of fecal contamination, subset of fecal coliforms.
Fecal Coliforms	Broad indicator bacteria of fecal contamination.
Bromide (Br)	Pollution from flame retardants and pesticides.
Alkalinity (Total as CaCO3)	Buffer against pH changes.
Total Organic Carbon (C)	Measure of organic matter content.
Total Inorganic Carbon (C)	Measure of primary productivity.
Dissolved Sulphate (SO4)	Indicator of eutrophication.
Dissolved Chloride (Cl)	Impact from road salt on aquatic organisms.
Ammonia (N)	Fish sensitive to even very small concentrations of ammonia in water (0.02mg/L). pH and temperature dependent.
Total Kjeldahl Nitrogen (Calc)	Sum of organic nitrogen, ammonia (NH3), and ammonium (NH4+). Useful to isolate organic N.
Total Organic Nitrogen (N)	Total Organic Nitrogen (N).
Nitrate (NO3) Dissolved	Mobile, common form of nitrogen. Toxic for aquatic life, and concern for eutrophication.
Nitrate + Nitrite	Isolate specific forms of nitrogen. Nitrite is an intermediate product and is usually short lived.
Total Organic Nitrogen	Carbon bound. Converts to ammonium and nitrate. Derived from Kjehldal nitrogen.
Total Nitrogen	Organic + Inorganic nitrogen. Used to assess downstream effect .
Dissolved Phosphorus (P)	Dissolved Phosphorus (P) in water.
Total Phosphorus (P)	Total Phosphorus. Primary nutrient causing eutrophication.
Orthophosphate (P)	Usable form of phosphate
Residue Non-filterable	Total Suspended Solids. Used to measure sediment load in water.
Turbidity	Suspended particles concentration.

3 Results

In this section, only metrics included in the approved water quality guidelines for British Columbia are discussed and illustrated. Similar graphs for the remainder of the parameters tested are available in the appendix. Bromide was not depicted as it not found above the detection threshold in any of the samples analyzed. Pooled result graphs incorporate data from all 13 sites to provide a visual representation of the overall trends over time as well as the spread within sampling events. Summary statistic tables show the minimum, median and maximum values for three geographical areas defined as the sites upstream of Nicola Lake, the Nicola River mainstem downstream of the Nicola dam, and the Coldwater River, during distinct times of the year. April to June includes samples collected between March 31st and June 22th, and represents conditions surrounding the freshet. The second period, July to November includes samples taken between July 6 and October 5 and represents dry conditions.

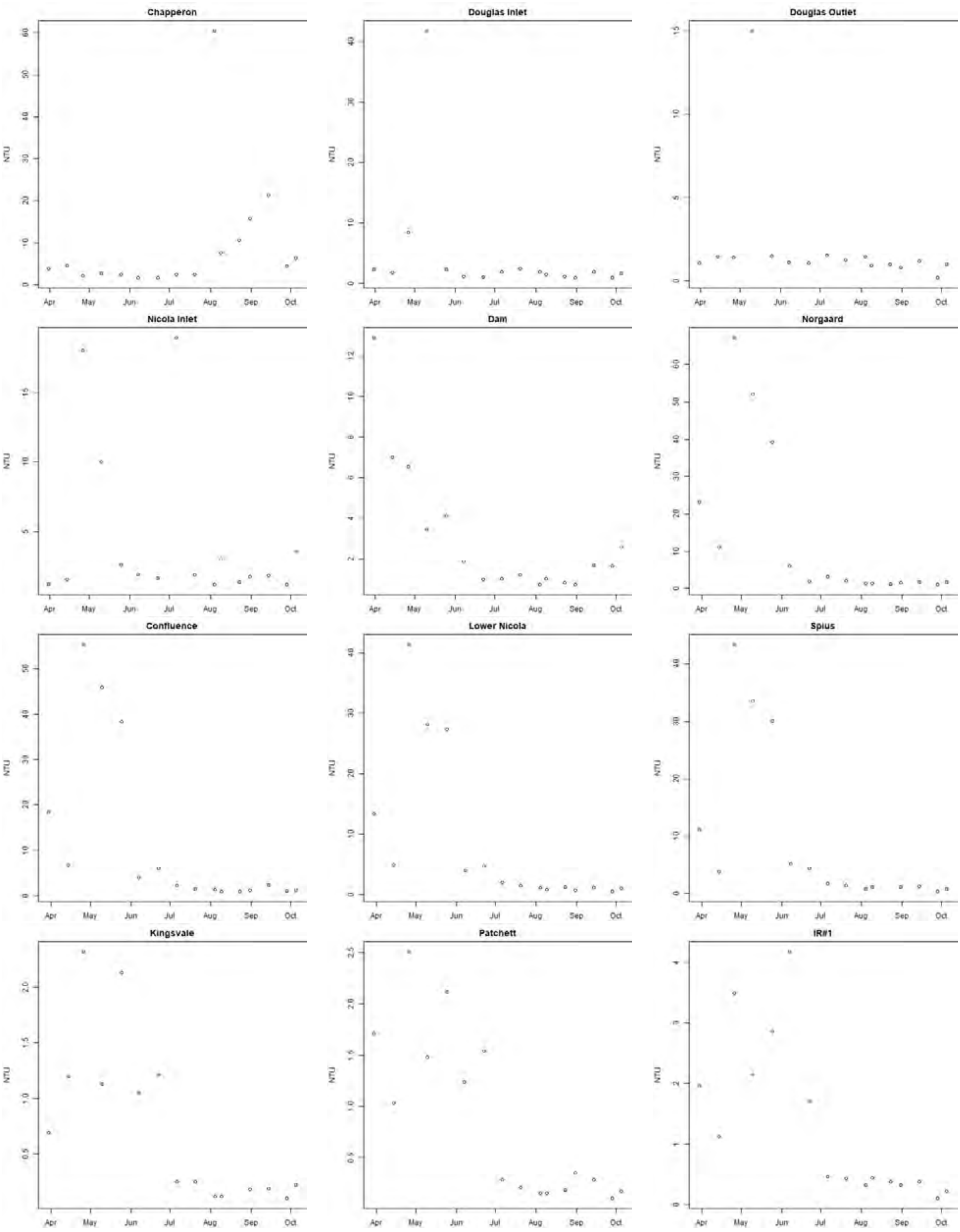


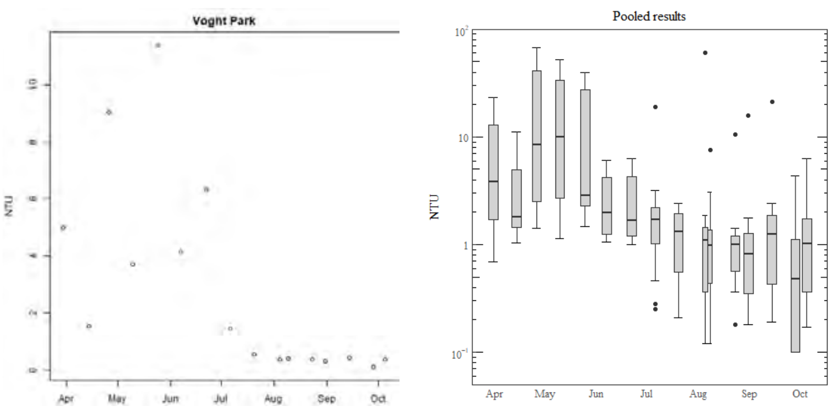


Summary statistics

April to June	Min	Median	Max
Upper Nicola	43.50	70.80	116.00
Nicola R. below dam	37.10	100.00	129.00
Coldwater R.	15.20	43.30	112.00
July to November			
Upper Nicola	57.80	95.15	146.00
Nicola R. below dam	116.50	1.21	148.00
Coldwater R.	33.20	63.50	93.20

Figure 2: Alkalinity, total (as CaCO3), mg/L



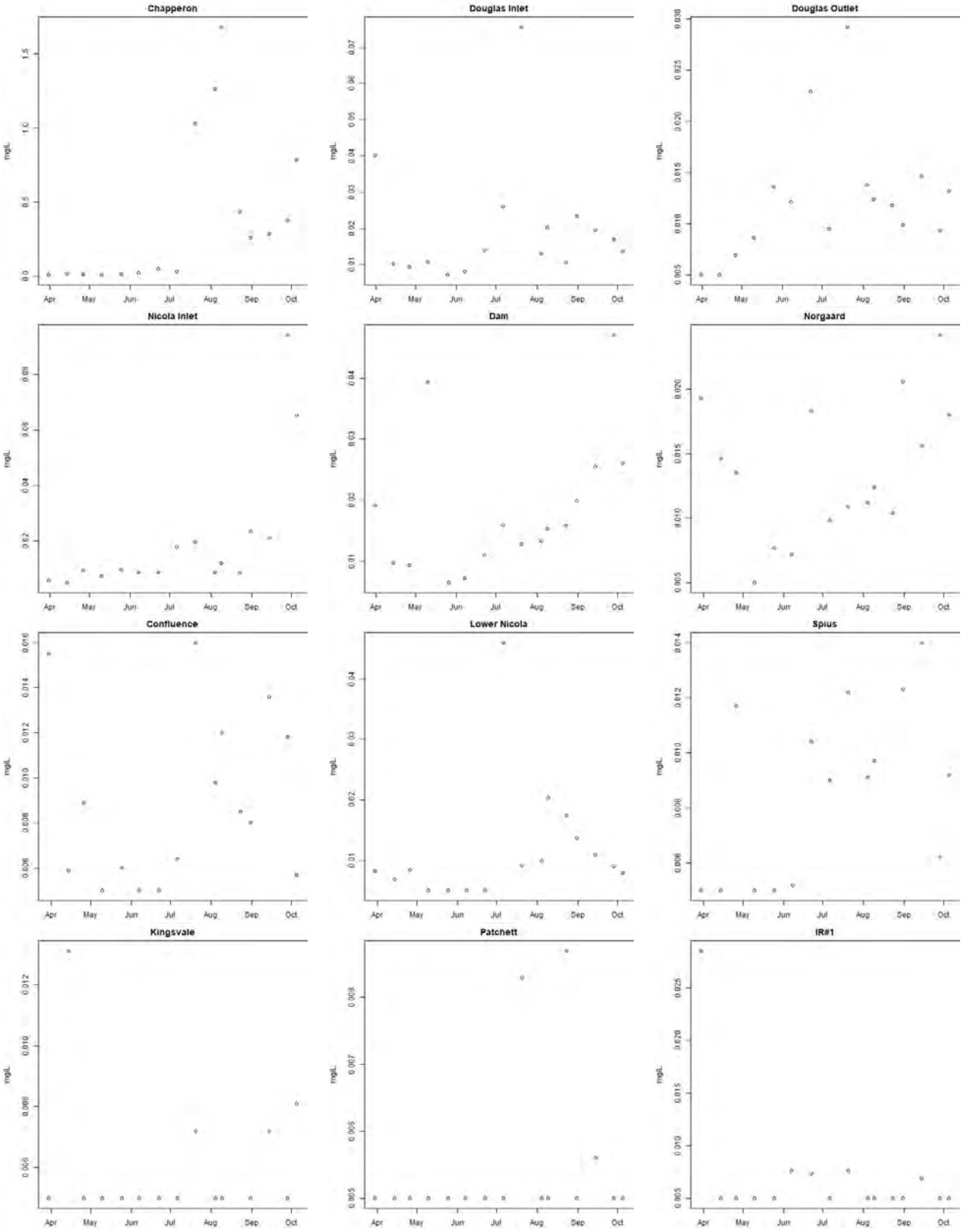


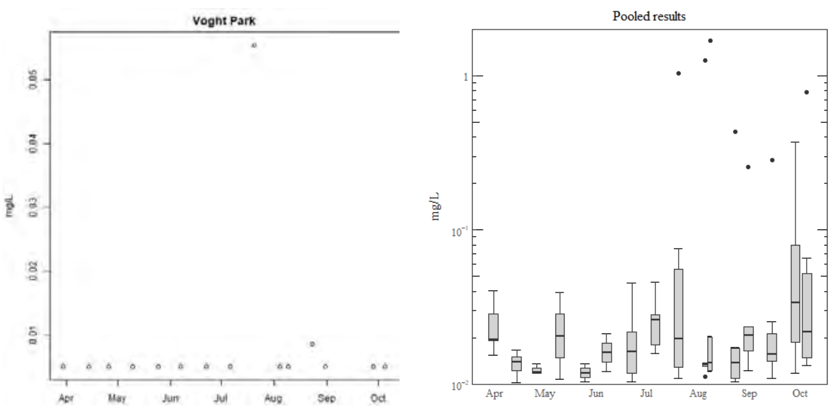
Summary statistics

April to June	Min	Median	Max
Upper Nicola	1.04	1.88	41.80
Nicola R. below dam	0.99	11.1	67.20
Coldwater R.	0.69	2.04	11.40

July to November			
Upper Nicola	0.19	1.82	60.50
Nicola R. below dam	0.30	1.21	3.17
Coldwater R.	0.10	0.28	1.44

Figure 3: Turbidity, NTU

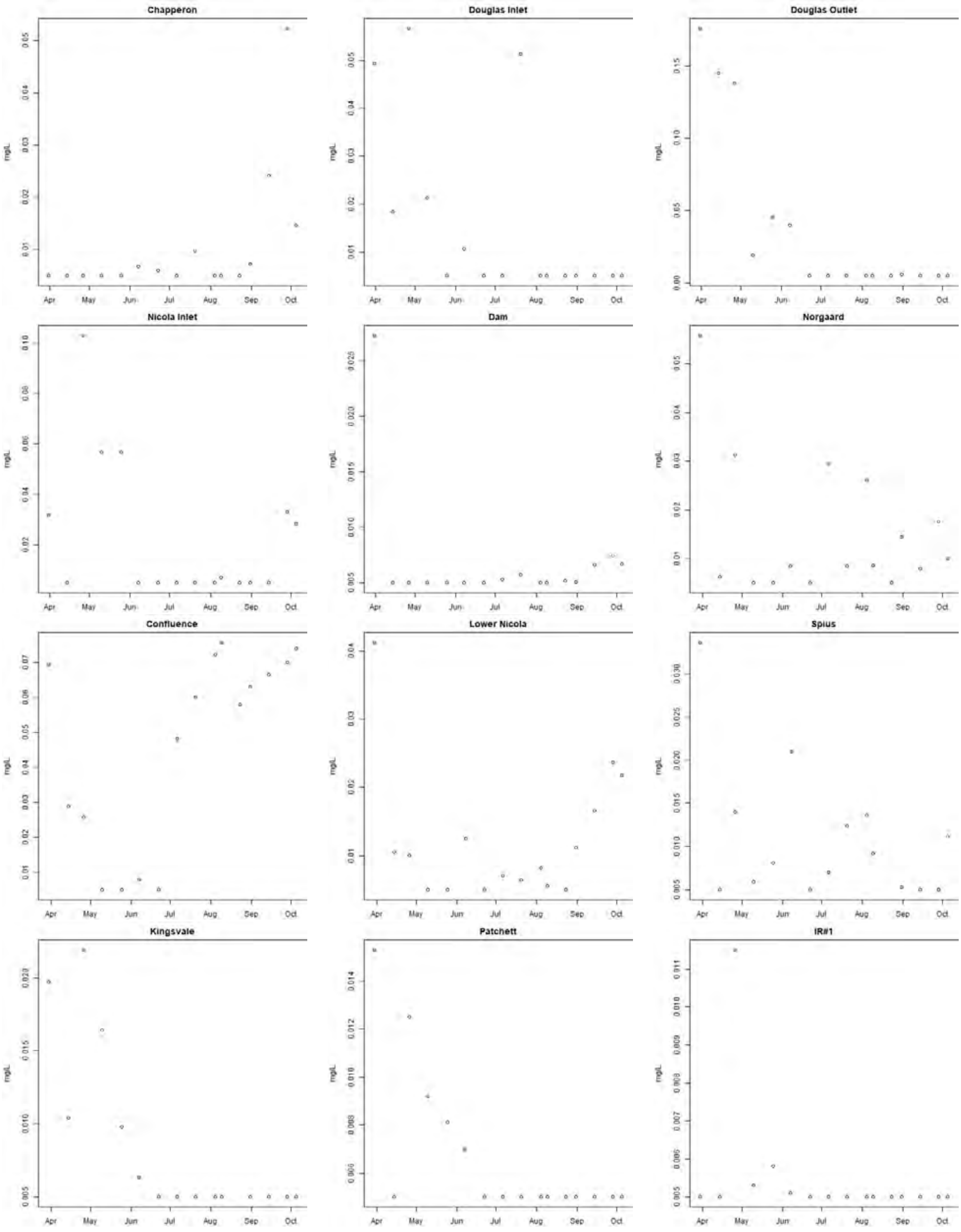


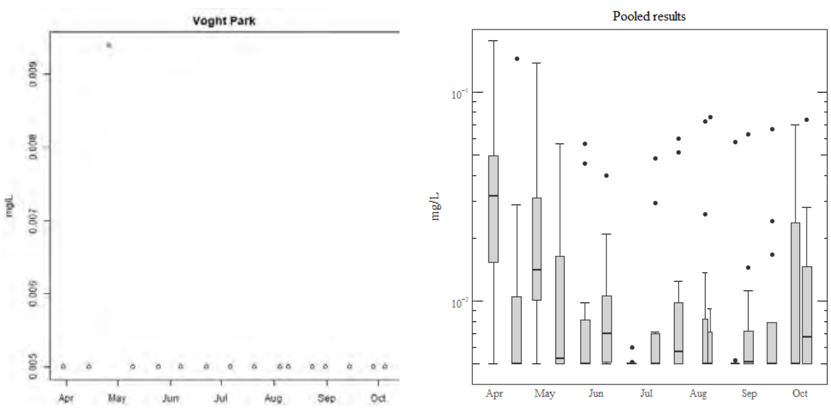


Summary statistics

April to June	Min	Median	Max
Upper Nicola	0.005	0.009	0.045
Nicola R. below dam	0.005	0.007	0.039
Coldwater R.	0.005	0.005	0.028
July to November			
Upper Nicola	0.005	0.019	1.680
Nicola R. below dam	0.012	0.012	0.047
Coldwater R.	0.005	0.005	0.055

Figure 4: Ammonia, total (as N), mg/L

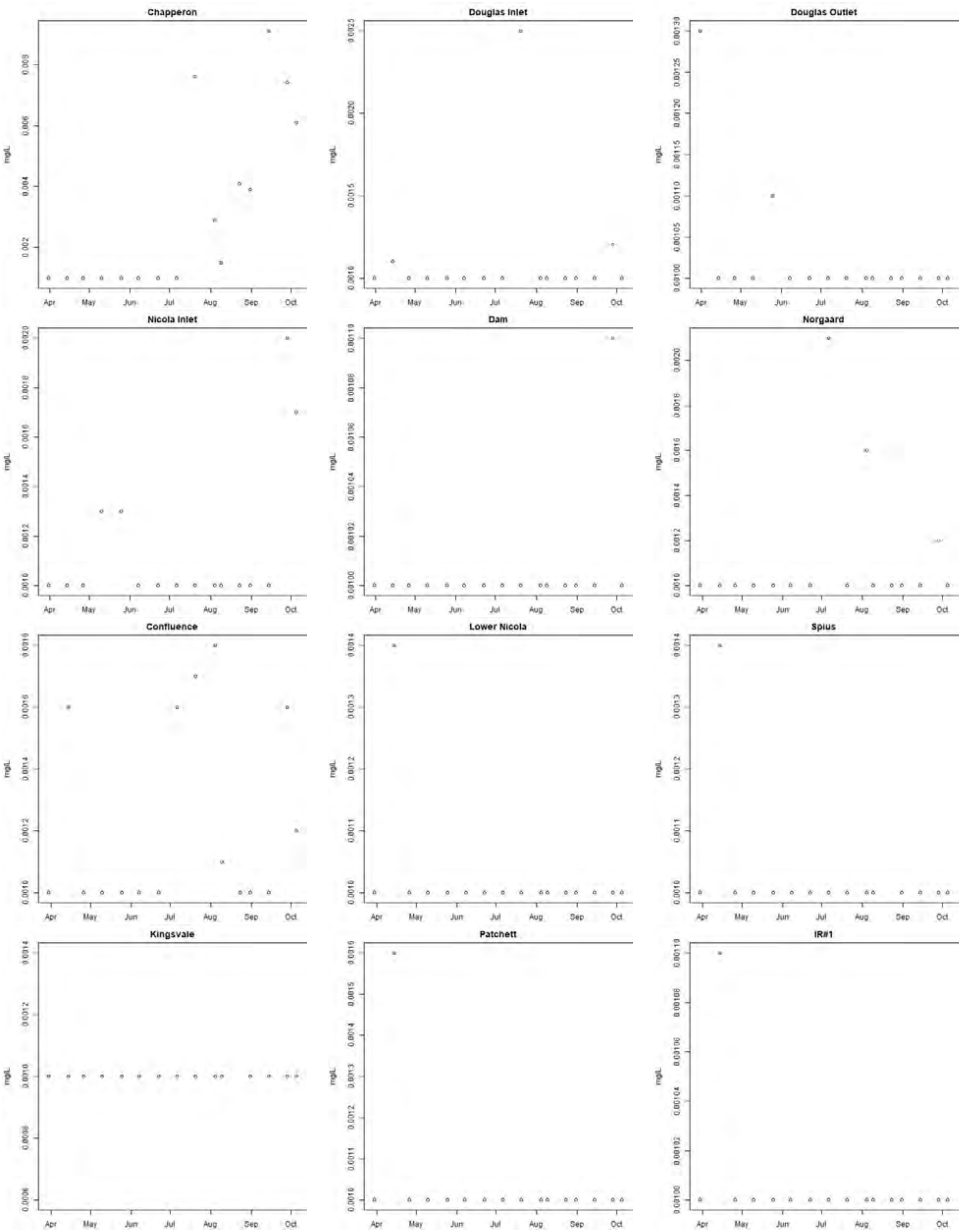


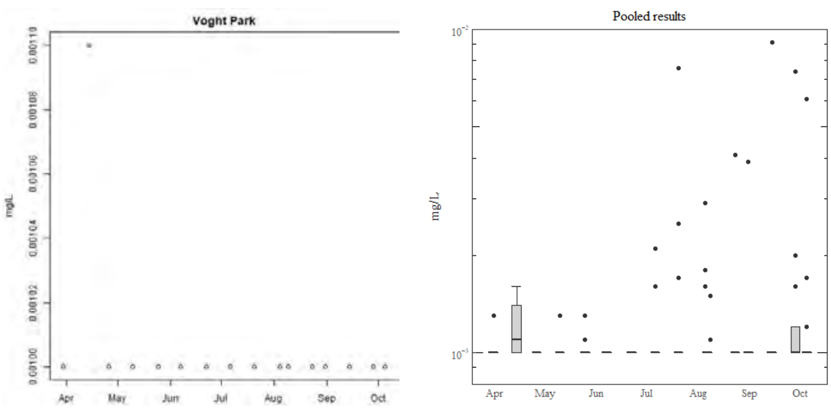


Summary statistics

April to June	Min	Median	Max
Upper Nicola	0.005	0.014	0.176
Nicola R. below dam	0.005	0.006	0.069
Coldwater R.	0.005	0.005	0.022
July to November			
Upper Nicola	0.005	0.005	0.052
Nicola R. below dam	0.005	0.009	0.076
Coldwater R.	0.005	0.005	0.005

Figure 5: Nitrate (as N), mg/L



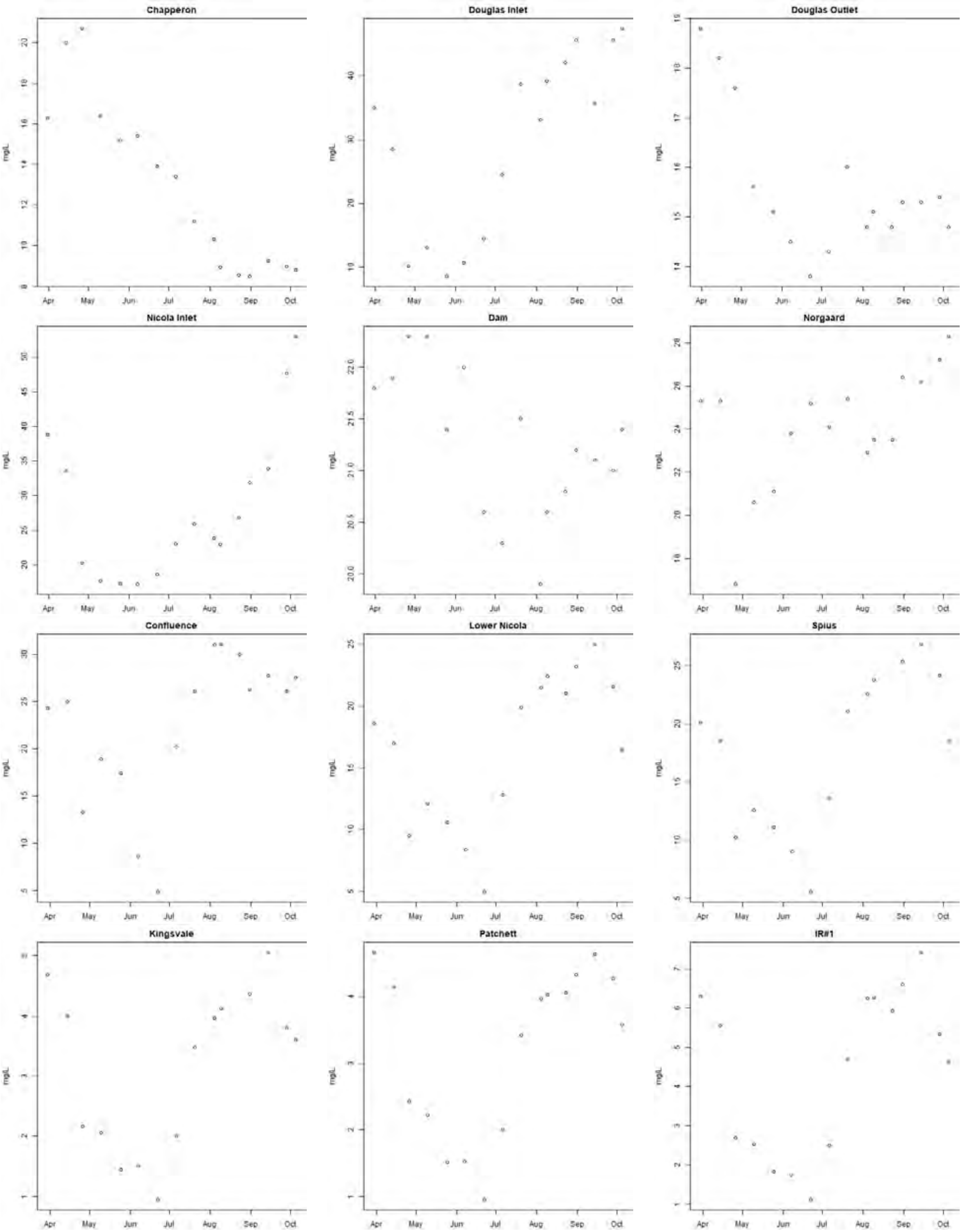


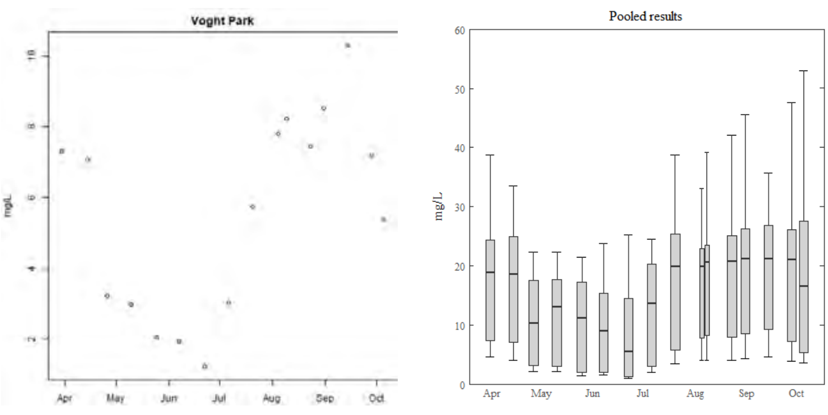
Summary statistics

April to June	Min	Median	Max
Upper Nicola	0.001	0.001	0.001
Nicola R. below dam	0.001	0.001	0.002
Coldwater R.	0.001	0.001	0.002

July to November	Min	Median	Max
Upper Nicola	0.001	0.001	0.009
Nicola R. below dam	0.001	0.001	0.002
Coldwater R.	0.001	0.001	0.001

Figure 6: Nitrite (as N), mg/L



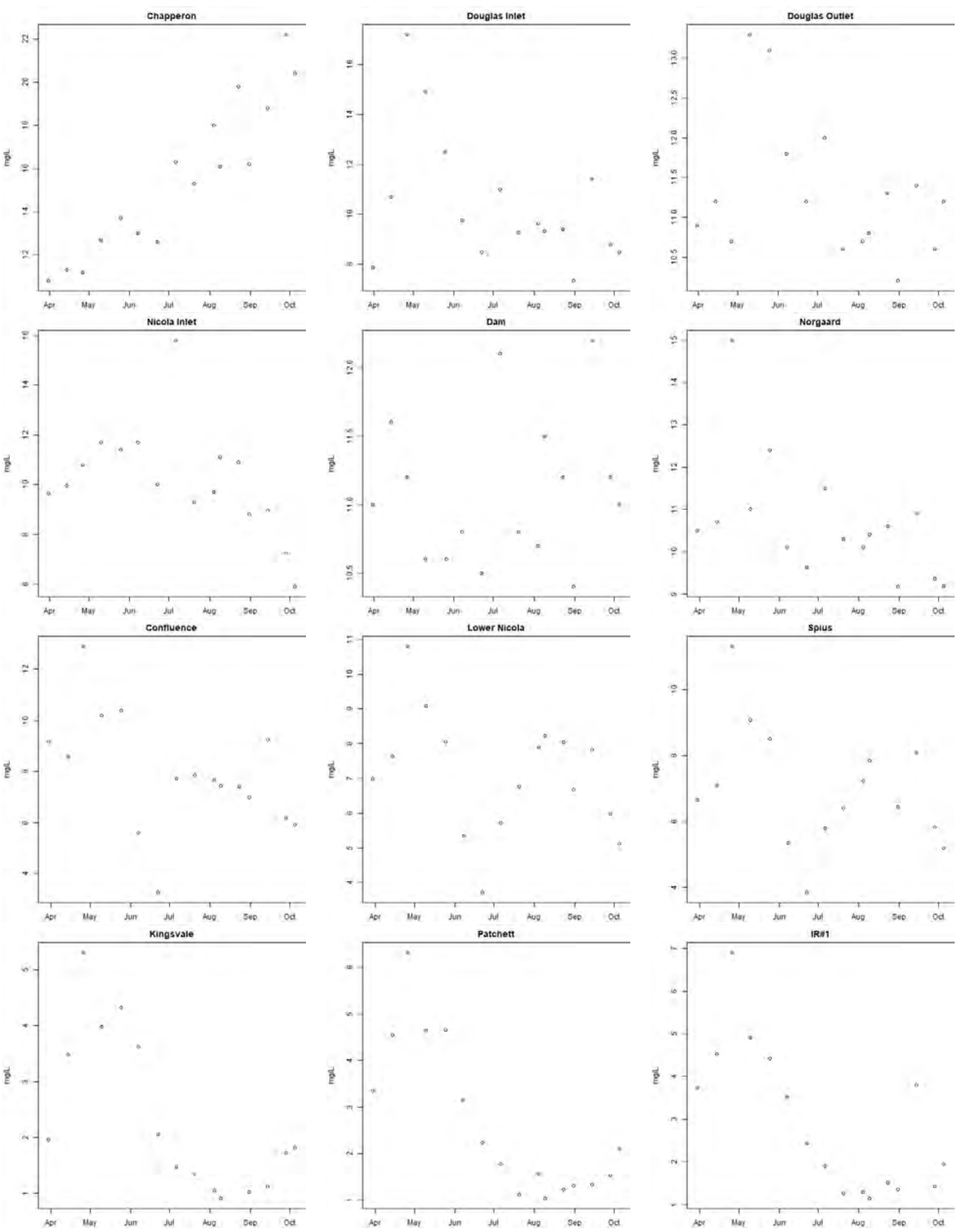


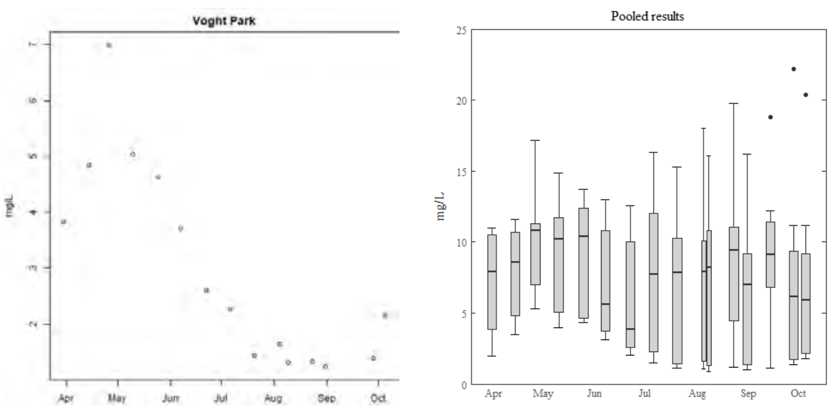
Summary statistics

April to June	Min	Median	Max
Upper Nicola	8.57	16.80	38.80
Nicola R. below dam	4.83	18.60	25.30
Coldwater R.	0.94	2.19	7.30

July to November			
Upper Nicola	8.48	19.45	53.00
Nicola R. below dam	12.80	23.05	31.10
Coldwater R.	2.00	4.630	10.30

Figure 7: Sulfate (as SO4), mg/L

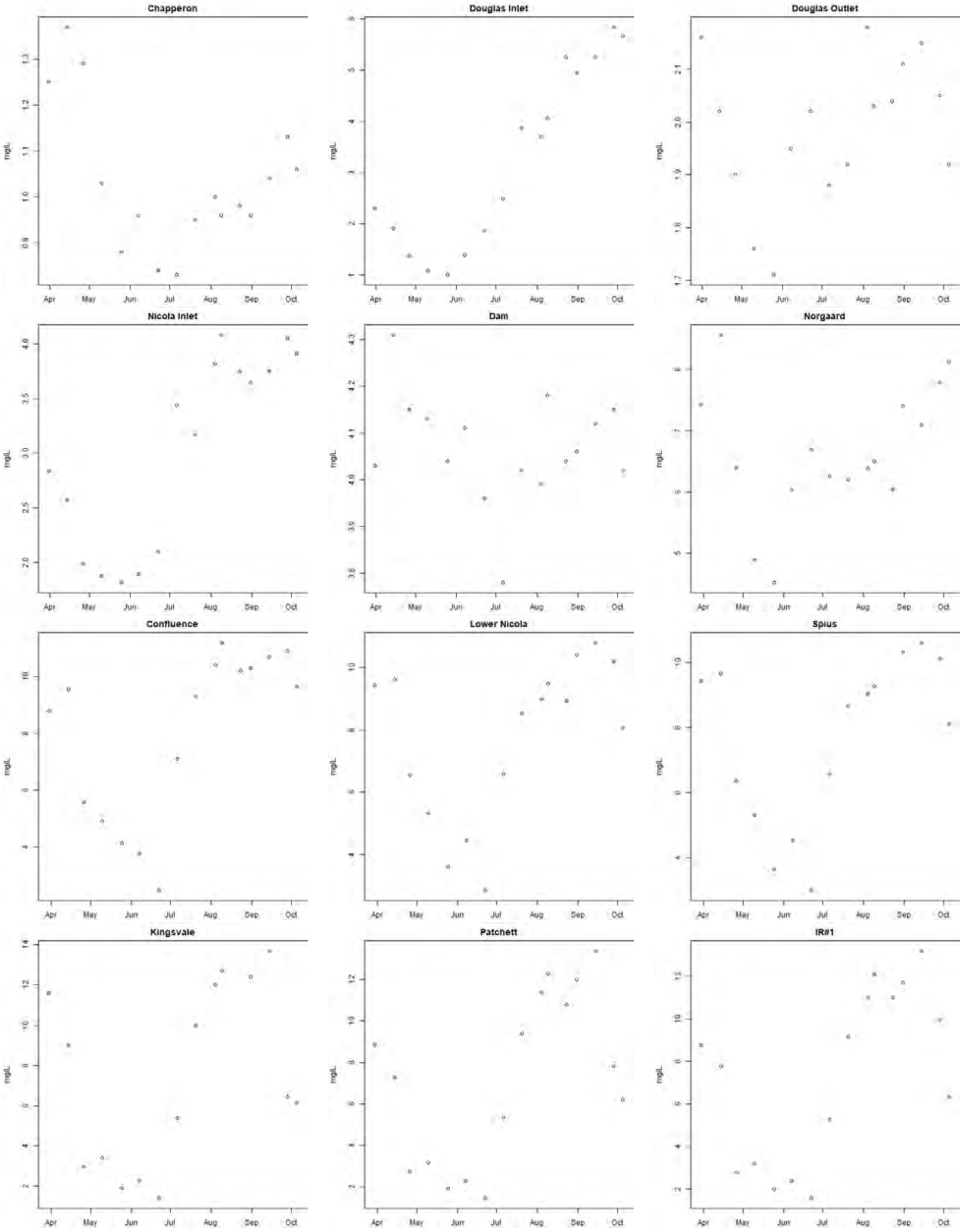


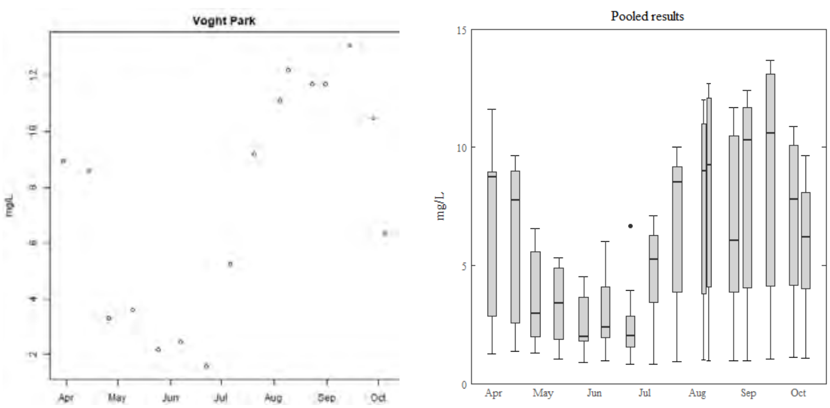


Summary statistics

April to June	Min	Median	Max
Upper Nicola	7.89	11.25	17.20
Nicola R. below dam	3.26	10.10	15.00
Coldwater R.	1.97	4.15	6.99
July to November			
Upper Nicola	5.89	10.85	22.20
Nicola R. below dam	5.12	7.97	12.20
Coldwater R.	0.91	1.37	3.80

Figure 8: Carbon, total organic [TOC], mg/L



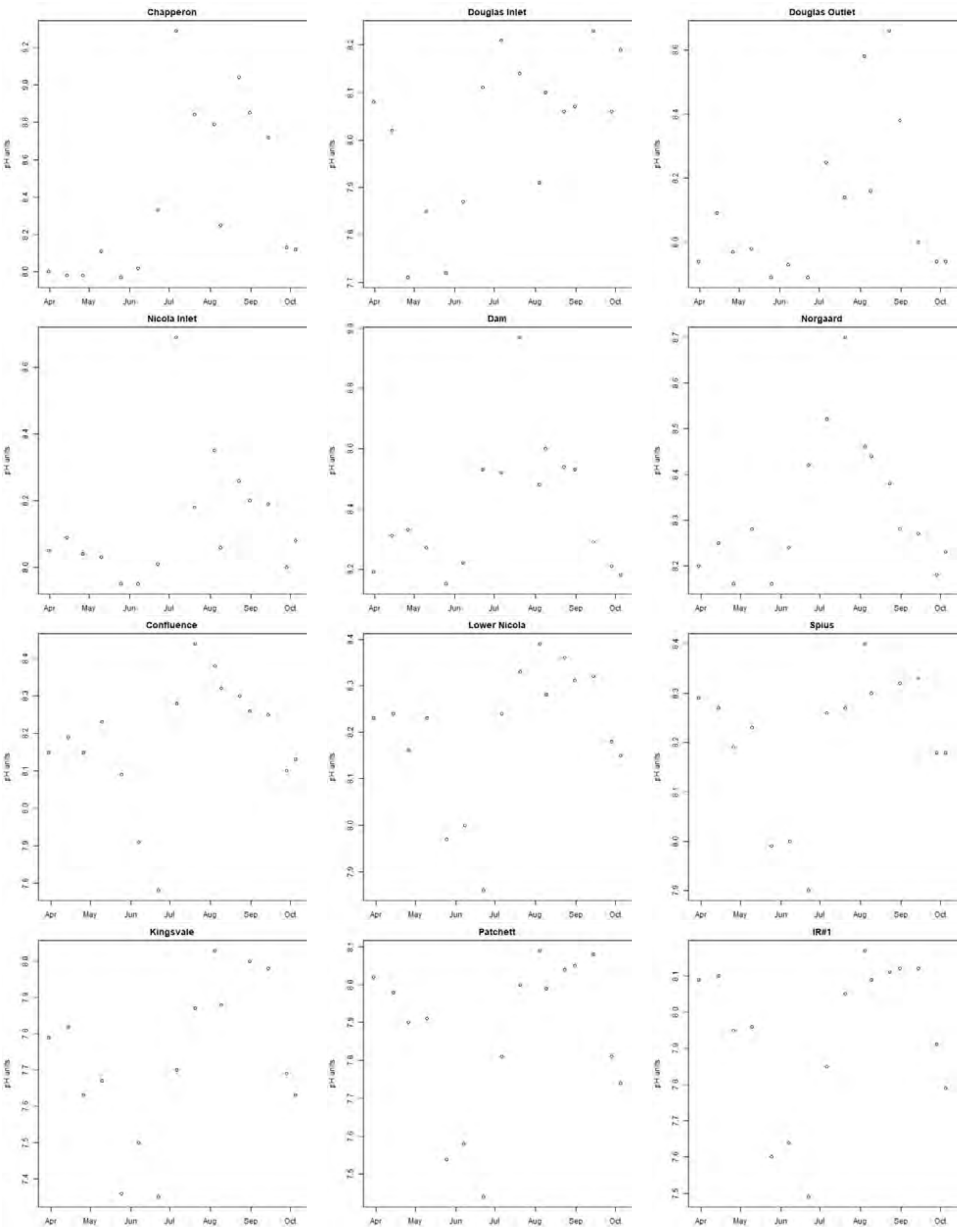


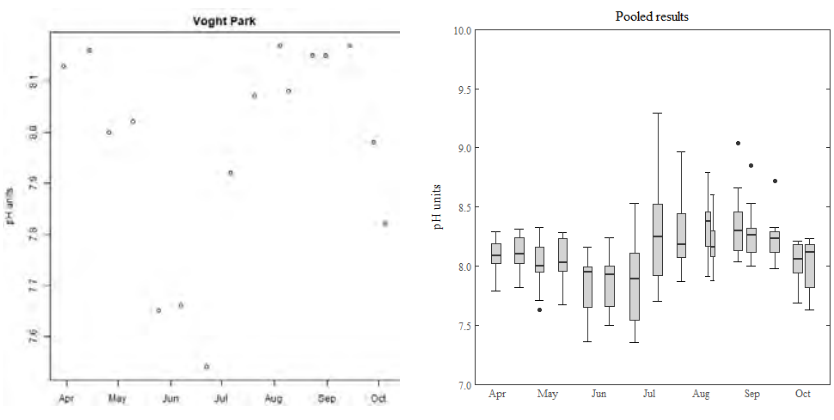
Summary statistics

April to June	Min	Median	Max
Upper Nicola	0.84	1.84	2.84
Nicola R. below dam	2.46	4.89	9.65
Coldwater R.	1.39	2.86	11.60

July to November			
Upper Nicola	0.83	2.33	5.84
Nicola R. below dam	3.78	8.11	11.20
Coldwater R.	5.23	11.00	13.70

Figure 9: Dissolved chloride, mg/L

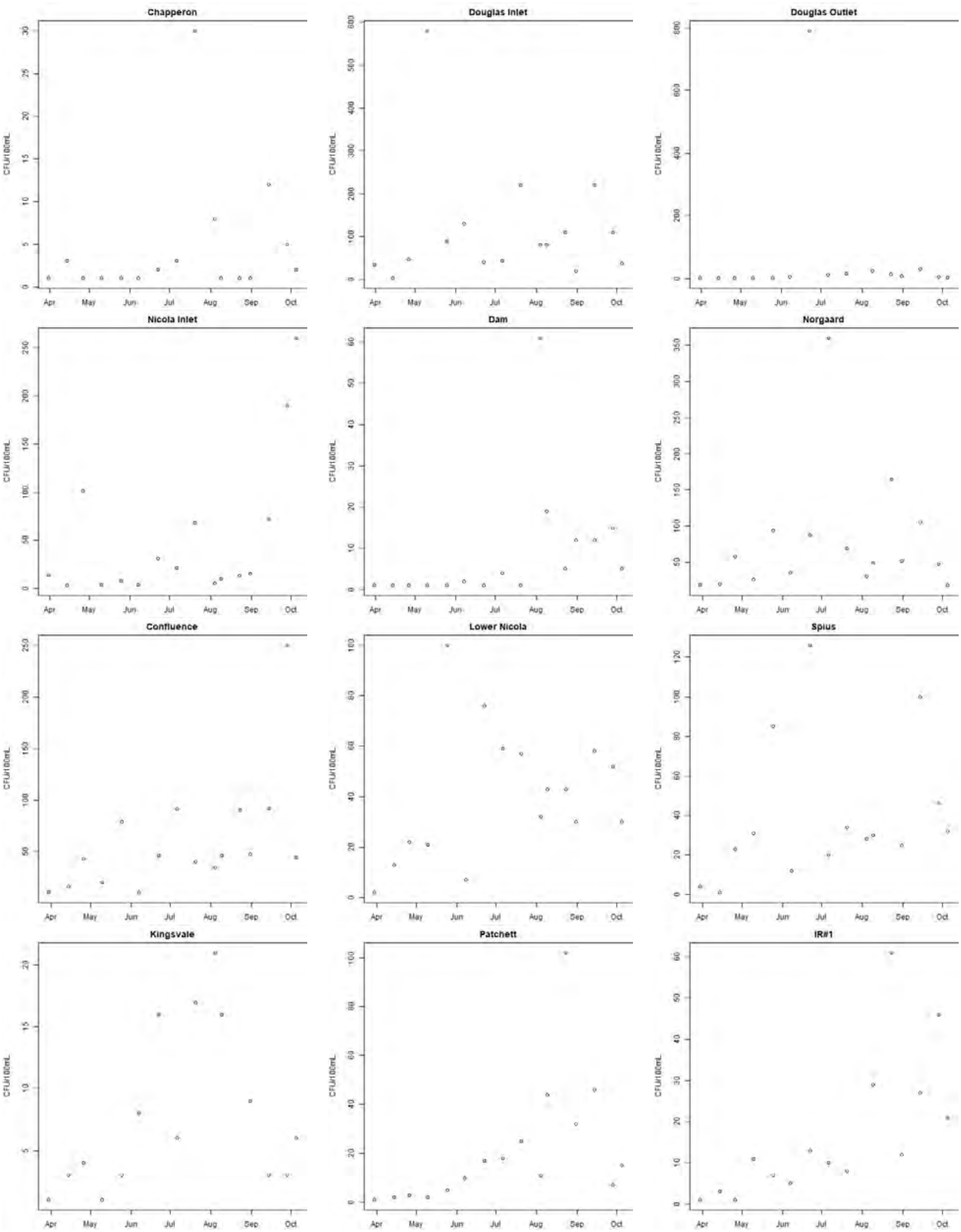


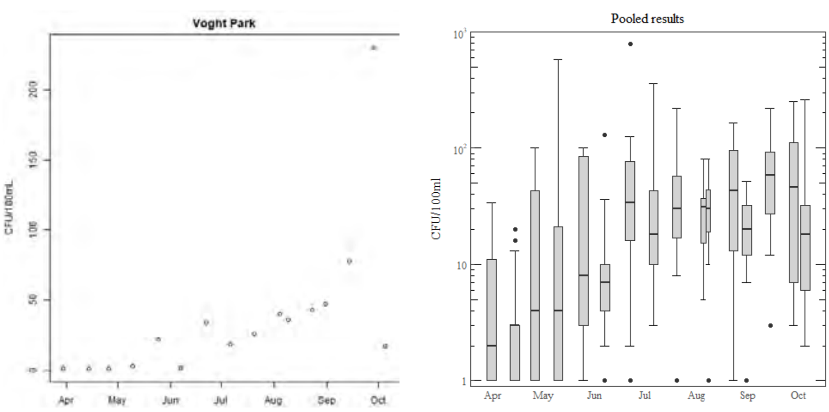


Summary statistics

	Min	Median	Max
April to June			
Upper Nicola	7.71	7.98	8.33
Nicola R. below dam	8.19	4.89	8.53
Coldwater R.	7.35	7.73	8.16
July to November			
Upper Nicola	7.91	8.19	9.29
Nicola R. below dam	8.30	8.11	8.97
Coldwater R.	7.63	8.00	8.17

Figure 10: pH, pH units



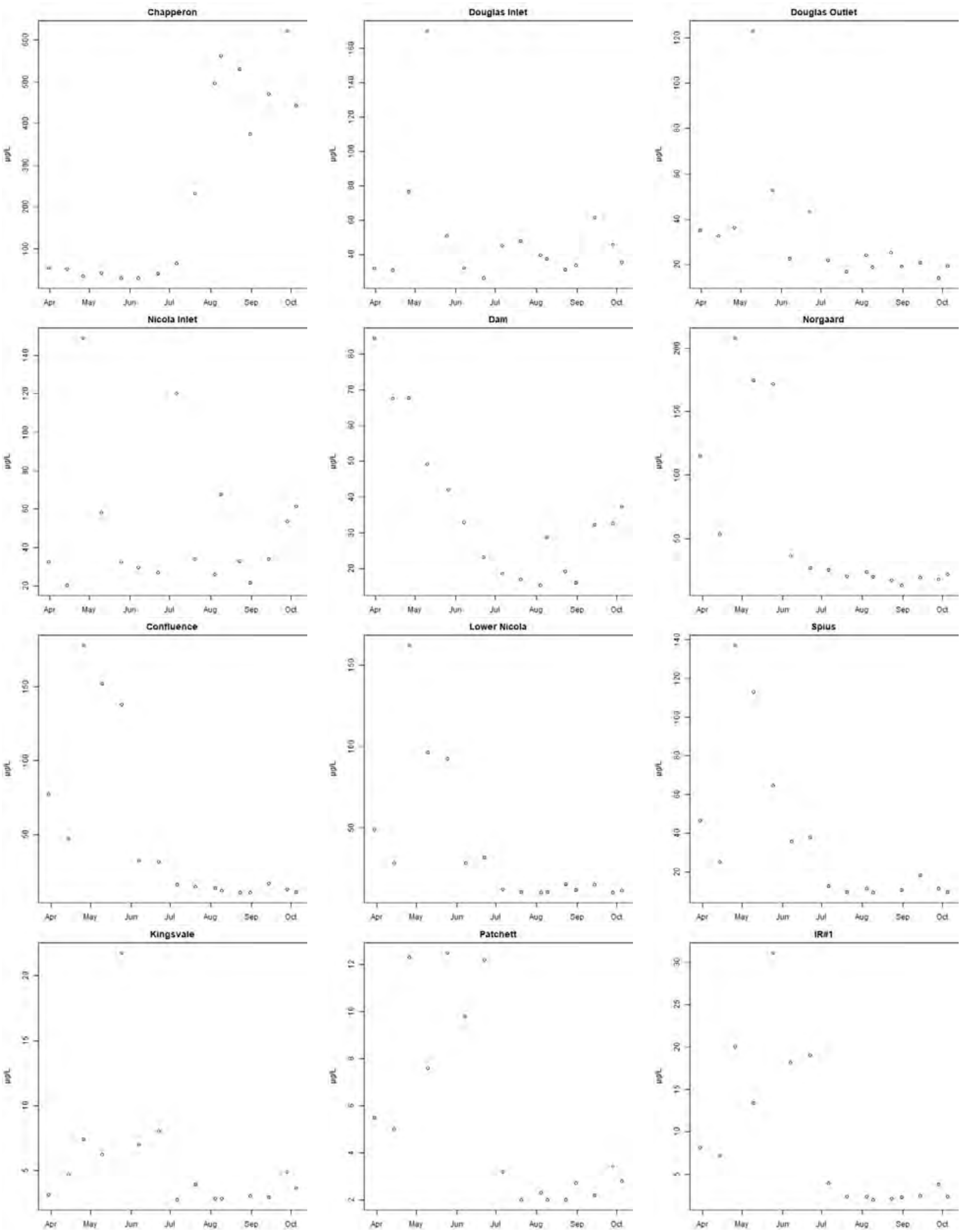


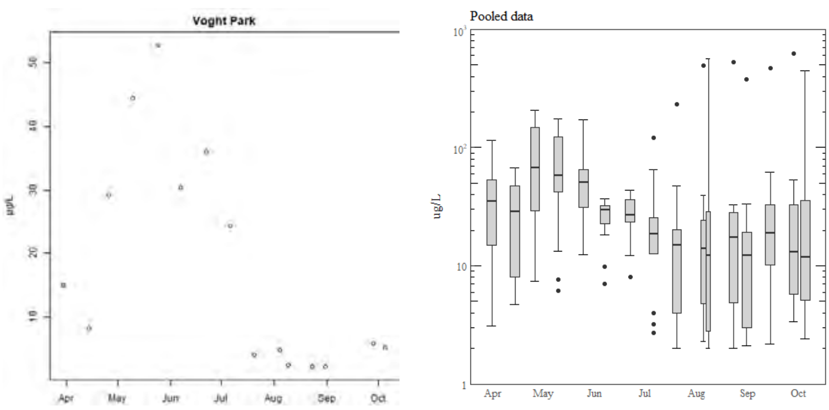
Summary statistics

April to June	Min	Median	Max
Upper Nicola	1	3.5	790
Nicola R. below dam	1	20	126
Coldwater R.	1	3	34

July to November	Min	Median	Max
Upper Nicola	1	16	260
Nicola R. below dam	1	43	360
Coldwater R.	3	21	230

Figure 11: E. Coli, CFU/100ml





Summary statistics

April to June	Min	Median	Max
Upper Nicola	20.30	35.75	443.00
Nicola R. below dam	9.80	42.10	208.00
Coldwater R.	3.10	12.25	52.80
July to November			
Upper Nicola	14.10	36.35	622.00
Nicola R. below dam	9.50	17.10	38.20
Coldwater R.	2.00	2.75	24.30

Figure 12: Total phosphorus, µg/L

3.1 Phosphorus

Water velocity, substrate, light, temperature, benthic invertebrate grazing pressure, and nutrient levels all influence the rate of algae development. In certain conditions, even very low phosphorus concentrations (3 µg/L) can result in large accumulations of stream algal biomass. Direct measurements of algal biomass are employed instead of phosphorus content in streams as it is a poor indicator of algal biomass (B.C. Ministry of Environment and Climate Change Strategy 2021a). There are no established thresholds for total phosphorous in stream in B.C., but local guidelines have been established in parts of the province, such as on Vancouver Island where the maximum total phosphorous was set at 10 µg/L (Ministry of Environment 2014). The concentration of usable ortho-phosphorus was correlated with phosphorous levels, although the ratio of orthophostphate to phosphorus varied.

Phosphorus levels were higher on average in the Upper Nicola watershed, with a peak concentration of 622µg/L recorded at the outlet of Chapperon Lake on September 28. Levels increased around the freshet and subsided during June, before increasing substantially from July through October at Chapperon Lake. This increase was not detectable at the inlet of Douglas Lake, despite Chapperon Creek accounting for most of the inflow into Douglas Lake during the summer.

In the Nicola River downstream of Nicola Lake, Norgaard had the highest phosphorus concentrations peaking at 208 µg/L on April 26, pointing to one or several significant sources of nutrients between the dam and the City of Merritt. This was less apparent in samples collected between August to October, when concentrations were more elevated at the dam. Downstream of Norgaard, phosphorus concentration decreased, with a small increase downstream of the Lower Nicola site. Guichon Creek did not appear to be a significant source of phosphorus for the Nicola River.

Total phosphorus in the Coldwater River was lower than in the Nicola River, peaking at 52.8 µg/L on May 25 at Voght Park. Levels increased downstream of Kingsvale, with the largest increase between the IR#1 bridge and Voght Park. The Canadian Water Quality Guidelines for the Protection of Aquatic Life has published "Trigger Ranges for Total phosphorus" (Table 3). Trophic status of streams in the study area varied widely, from ultra-oligotrophic in the Upper Coldwater to hyper-eutrophic in Chapperon Creek.

Table 3: *Total phosphorus trigger ranges for Canadian lakes and rivers (Canadian Council of Ministers of the Environment 2004)*

Trophic Status	Canadian Trigger Ranges, Total Phosphorus, µg/L
Ultra-oligotrophic	<4
Oligotrophic	4 - 10
Mesotrophic	10 - 20
Meso-eutrophic	20 - 35
Eutrophic	35 - 100
Hyper-eutrophic	>100

3.2 Ammonia, Nitrate, and Nitrite

In British Columbia, the nitrate guideline to protect freshwater aquatic life is set at a 30 day average concentration of 3.0 mg/L (chronic), or a maximum concentration of 32.8 mg/L (acute). Salmonids have been found to be very sensitive to nitrite, especially at low chloride concentrations. As such, allowable nitrite levels are dependant on ambient chloride concentration. At low chloride levels (below 2mg/L), guidelines for freshwater aquatic life recommends not exceeding a 30 day average concentration of 0.020 mg/L or a single sample concentration of 0.060 mg/L (B.C. Ministry of Environment and Climate Change Strategy 2021a).

Results for nitrate and nitrite were below both the acute and chronic established water quality guidelines for all samples analyzed in this project. We recorded a small increase in nitrite above detectable levels in late April, but levels were low overall. Nitrite concentration was the highest at the outlet of Chapperon Lake during the summer and fall, while nitrite levels in the Coldwater River and in the Nicola River below the dam were below the detection threshold with the exception of the Confluence site, downstream of the City of Merritt's rapid infiltration basins.

Nitrate levels were also low in samples collected in the study. While the Upper Nicola watershed had the highest nitrate concentration during the spring, the Confluence site had the highest levels from July on. Still, levels were well below the Provincial guidelines. Nitrate levels in the Coldwater River were very low.

Water quality guidelines for ammonia are dependent on pH and temperature. Ammonia concentration was overall higher in the Upper Nicola watershed, and ammonia levels exceeded the maximum (Acute) Concentration of Total Ammonia Nitrogen for Protection of Aquatic Life on August 4 and August 9 at the outlet of Chapperon Lake. However, this was not detectable at the Douglas Lake inlet, where ammonia levels were low in all the samples collected.

3.3 Sulphate

Increased sulphate levels result in increased phosphorus mobility, which can lead to eutrophication. In British Columbia, sulphate water quality guidelines vary between 128 and 429 mg/L depending on water hardness, with softer water resulting in higher sulphate toxicity (B.C. Ministry of Environment 2013). The sulfate levels found in the study ranged from 0.94 to 53 mg/L, below the Provincial guidelines across all hardness levels.

In most rivers, dissolved sulphate concentrations fluctuate seasonally, with lower concentrations around the freshet. This was evident in this study with the exception of the outlet of Chapperon Lake, Douglas lake outlet and the Nicola dam, where sulfate levels were higher in the spring. Overall, sulfate concentration was higher in the Nicola River downstream of Nicola Lake, particularly between the dam and the City of Merritt. Downstream, levels were diluted by the Coldwater River which had low sulphate levels. The highest single sample level was recorded at the inlet of Nicola Lake at 53 mg/L on October 5.

3.4 Total Organic Carbon

In British Columbia, there are no single value criteria for organic carbon in water; instead, it is advised that the samples of interest be compared to background and historical conditions. Deviations from background levels can impact the bio-availability and toxicity of metals and organics, primary productivity, buffering and acidification, as well as water's optical properties. The current guideline states that "the 30-day 50th percentile total organic carbon concentration shall be within 20% above or below seasonally-adjusted median background levels as measured historically or at appropriate reference sites" (Ministry of Environment 1998).

The Upper Nicola area had the highest total organic carbon (TOC) levels during the study, with the maximum concentrations found at the Chapperon Lake outlet on September 28. Temporal trends in TOC concentration varied by location, but TOC was often higher around the freshet and declined with water levels. The Chapperon Lake outlet is an exception, as levels increased through the duration of the study. This was not detected at the Doulgas Lake inlet, which had far lower TOC levels. TOC in the Nicola River downstream of Nicola Lake was highest at the dam's outlet and declined downstream. TOC levels at different locations in the Coldwater River were similar within sampling events, and levels were low relative to the rest of the study area.

3.5 Chloride

In British Columbia, the chloride concentration threshold to protect freshwater aquatic life from chronic effects is 150 mg/L over a 30-day period for chronic effects, and a maximum single sample concentration of 600mg/L for acute effects (B.C. Ministry of Environment 2003). Chloride levels in the samples collected ranged for 0.84 to 13.7 mg/L, below both the chronic and acute Provincial guidelines. The use of road salt is British Columbia's single largest utilization of salt and the primary anthropogenic release of chloride to the environment. The seasonal trend in chloride levels was consistent across locations, with levels decreasing around the freshet and rising in the summer, before dropping in the fall.

Chloride levels were lowest in the Upper Nicola watershed, which is consistent with the low road density in the area. In the Nicola River below the dam, chloride concentration nearly doubled between the dam and the City of Merritt, and further increased downstream of the confluence with the Coldwater River. The Coldwater River had the highest chloride concentration in the study area, with Kingsvale having the highest mean concentration. Much of the roadside snow had melted by the time we started sampling, and chloride levels may have been higher in February and March.

3.6 Bromide

Bromide was not found above the detection threshold (0.05 mg/L) in any of the samples collected in this study.

3.7 E. Coli

Coliforms are bacteria generally originating in the intestine of endothermic animals. Presence of fecal coliforms in freshwater is a sign of contamination by human or animal fecal material. This can be linked to agricultural runoff from manure spread on fields or allowing cattle to access riparian areas. Coliform bacteria can lower dissolved oxygen levels through aerobic decomposition, impacting aquatic life. Escherichia coli (E. coli), a bacteria part of the fecal coliform group, is a preferred indicator as its presence provides direct evidence of fecal contamination from warm-blooded animals. Strains of E.coli have been linked with gastrointestinal illness in humans, and it used a indicator for recreational use. Currently there are no freshwater environmental guidelines for coliform concentration in B.C. and Canada. The current guidelines in use for recreational freshwaters recommends not exceeding a geometric mean concentration over 30 days of 200 CFU/100 mL, or a single-sample maximum concentration of 400 CFU/100 mL (Health Canada 2012).

E. Coli levels above Nicola Lake differed greatly between sites. Chapperon Lake outlet had the lowest mean E. Coli concentration in the study with only 5 CFU/100ml, while the Douglas Lake inlet had the highest mean concentration with 115 CFU/100ml. We recorded two measurements above the single-sample limit for recreational use; the first was recorded in the Nicola River above the Douglas Lake inlet on May 10 at 580 CFU/100ml, and the second in the Nicola River at the outlet of Douglas Lake on June 22 at 790 CFU/100ml.

Downstream of Nicola Lake, Norgaard had the highest mean concentration and peaked at 360 CFU/100ml. E.Coli levels at the Nicola Dam were low, pointing to a significant source of E.Coli between the dam and the City of Merritt. E.Coli levels in the Coldwater River were generally lower than the rest of the study area, although we recorded a peak of 230 CFU/100ml at Voght Park on October 5.

3.8 pH

The British Columbia pH criteria to protect aquatic life are based on changes from background pH levels. Changes between 6.5 and 9 do not generally pose a concern for aquatic life as long as the resulting carbon dioxide concentration does not negatively impact the plankton and fish community. For pH above 9, guidelines recommend against significant long term variations from background levels (B.C. Ministry of

Environment and Climate Change Strategy 2021b). Median pH during the study was 8.1, which is typical for the B.C. interior Southern Plateau. We observed significant disparities between locations, which were more pronounced in the summer and fall. The Coldwater River had a lost pH overall, while the outlet of Chapperon Lake had the highest values, peaking at 9.3 on July 6. pH above 9.0 are uncommon but can be caused by photosynthetic activities in very eutrophic systems. The peak in pH coincides with the heat wave, and higher water temperatures likely stimulated photosynthesis. Although toxicity to fish is a concern above this level, short-term exposure is acceptable. It is worth noting that the high pH values were sampled in mid-afternoon, and levels likely dropped at night as a result of diurnal fluctuations.

3.9 Turbidity

As processes determining turbidity and total suspended solids (TSS) background levels are complex and variable, there are no fixed thresholds for these parameters in British Columbia. Instead, turbidity and TSS levels are compared to natural background levels following activities causing sedimentation. The permissible degree of variation from background levels depends on seasonality, with greater changes allowed when background levels are naturally elevated (B.C. Ministry of Environment and Climate Change Strategy 2021c). Turbidity and TSS levels were highly correlated, and only turbidity is discussed here.

In the study area, turbidity increased around the freshet and declined as water receded. However, turbidity increased over the summer and fall at the outlet of Chapperon Lake as a result of the high concentration of algae. The Nicola River at Norgaard had the highest turbidity in the spring, reaching 67.2 NTU on April 26. This spike in turbidity was detected when the outflow at the Nicola Dam was increased to 10 CMS, dislodging sediments that accumulated during the winter. Subsequent outflow increases up to 24.3 CMS resulted in lower turbidity levels, suggesting turbidity decreases past a certain flow as a result of dilution. Since excessive suspended sediment levels can adversely impact eggs and alevins in the gravel, this has possible implications for the Nicola Dam operations. Turbidity generally decreased downstream of Norgaard, with a minor increase between lower Nicola and Spius. Despite recent disturbances in Guichon Creek, we did not detect elevated turbidity levels in the Nicola River downstream.

Turbidity in the Coldwater River was lower than in the Nicola River, peaking at 11.4 NTU on May 25 at Voght Park. Turbidity increased downstream of Kingsvale, with the most significant increase between the IR#1 bridge and Voght Park. Turbidity was low in the summer and fall, despite extensive wildfires in the upper watershed and several rain events.

4 Discussion

The year this study took place was characterized by two major catastrophic events in the study area. The 2021 Brookmere and July Mountain fires impacted a large area in the upper reaches of the Coldwater River as far down as Kingsvale. The 2021 Lytton fire resulted in access restrictions to some of the sites, but only the area downstream of Spius Creek was directly impacted by the fires. On November 15, 2021, a 500-year flood impacted the Coldwater River and the Nicola River downstream of the City of Merritt. Record flows estimated at 405 cubic meters per second in the Coldwater River profoundly impacted the system causing channel widening, braiding, channel avulsions and bank failures. As a result, the system has become extremely volatile and much of the fish habitat in the main channel was lost. It is expected that both these events will adversely impact water quality in the future via several mechanisms including the lack of filtering of water pollutants by riparian vegetation, reduced nutrient uptake in burned areas, increased sediment input from burnt slopes and flood-impacted banks, and adverse impact from work associated with flood recovery and salvage logging. Warmer water temperatures resulting from channel widening and the loss of riparian vegetation may induce excess algal growth, further impacting water quality. The data collected in this study will provide a baseline to which we can compare future conditions as we monitor changes after the 2021 floods and fires as well as future development in the area. The Nicola Valley was also impacted by an extreme heat wave from late June through mid-July causing water temperatures to rise above 30°C downstream of Nicola Lake, creating the conditions for elevated algal growth and increasing organisms susceptibility to certain pollutants.

Parameters exceeding the Provincial guidelines were all found in samples collected above Nicola Lake. Agricultural impacts on water quality were significant upstream of Douglas Lake, as evidenced by the comparatively high coliform and sulphate levels in samples collected at the inlet. This was not observed at the outlet of Chapperon lake, pointing to a major source of coliforms and sulphate in Chapperon Creek downstream of the lake or in the Nicola River above Douglas Lake. The findings are consistent with the area's high concentration of cattle and extensive feedlot operations. We observed mortality on rainbow trout juveniles at the Douglas Lake inlet during the summer, although this was likely a result of elevated water temperatures.

Ammonia levels at the outlet of Chapperon Lake rose from a baseline of 0.012 mg/L in the spring to 1.68 mg/L in August, exceeding the Provincial guideline for aquatic life on two occasions. Although ammonia concentrations are unlikely to exceed 0.1 mg/L naturally, all the samples collected at this site after July 6 exceeded this level (B.C. Ministry of Environment and Climate Change Strategy 2021a). This may be linked to fertilizer leaching from adjacent fields and to the high concentration of cattle around Chapperon Lake. Ammonia can have a direct (acute or chronic) adverse impact on salmonids and is highly toxic to aquatic life including invertebrates and vascular plants. Elevated ammonia concentration can lead to low blood oxygen carrying capacity, depletion of ATP in the brain, damage to the gills, liver and kidney, and increased susceptibility to bacterial and parasitic diseases. Even sub-lethal concentrations can impact subsequent survival in different stages of the life cycle. Ammonia toxicity in fish was likely exacerbated by concurring elevated water temperatures and low dissolved oxygen levels.

Similarly, both phosphorus and nitrite concentration in the summer and fall increased by an order of magnitude from spring levels at the outlet of Chapperon Lake. Phosphorous and nitrite can have an indirect impact on fish by affecting habitat and water quality through cultural eutrophication, promoting excessive algae growth. Decomposing algae can lead to hypoxia, causing damage or death to fish and other organisms. Excessive growth of plant biomass can also induce changes in productivity and species composition of zooplankton and benthic invertebrates. Production of toxin-producing algae like cyanobacteria, dinoflagellates and diatoms can be stimulated by inorganic nitrogen and phosphorous pollution, especially during drought conditions. Elevated nutrient levels combined with record water temperatures during the heat wave resulted in Chapperon Lake experiencing elevated algal growth during the summer, causing a high pH as well as low dissolved oxygen levels from July onward. Effects from the algea bloom and elevated ammonia levels were not detected downstream, suggesting that the effects were localized and may not have impacted spawning Kokanee in the Nicola River above Douglas Lake. Additional sampling sites along Chapperon Creek, as well as both up and downstream of its confluence with the Nicola River would allow better characterizing the adverse impact from algea blooms and agricultural activities on Kokanee salmon and other fish species above Douglas Lake. Nutrient levels generally increased between the Douglas Lake outlet and the Nicola Lake inlet. This increase was more pronounced in the fall, when parameters including sulphate, nitrite and ammonia surged over spring and summer levels at the Nicola Lake inlet. Although levels for all the parameters were below the Provincial guidelines for aquatic life, this stretch of river supports the majority of Nicola Lake Kokanee spawning and should be closely monitored.

Downstream of Nicola Lake, we observed a significant increase in pollutants including nitrate, phosphorous and E. Coli between the dam and the City of Merritt at Norgaard. Combined with high water temperatures and low velocity, this may have contributed to the high concentration of algea observed during the summer in the Nicola River at Norgaard. The increase in pollutants may have been caused by agricultural operations along the Nicola River and by the golf course upstream of the sampling site. Despite the high number of Chinook carcasses recovered immediately upstream of the Norgaard sampling site in the fall of 2021, we did not detect an increase in total nitrogen and phosphorous concentration post spawning. All parameters in the samples collected were below the Provincial guidelines for aquatic life, and dissolved oxygen levels measured at Norgaard were acceptable (7.66 - 10.70 mg/L). This stretch of the Nicola River now hosts the majority of stable spawning habitat for Chinook salmon and to a lower extent Coho salmon after the 2021 floods, and should be monitored carefully. We recommend monitoring water quality in side channels below the dam given the potential for pollutant accumulation and the importance of this habitat type for rearing juveniles.

Downstream of the City of Merritt, we noticed an increase in nitrate and nitrite downstream of the City of Merritt's rapid infiltration basins. Values were well below the accepted guidelines and the increase was not detectable further downstream. Pollutant concentration generally decreased downstream of the City of Merritt, and we did not record an increase in pollutants downstream of Guichon creek despite significant instability and substantial agricultural activity along this system.

Water quality in the section of the Coldwater River studied was acceptable, and pollutant concentration was consistently lower when compared to the rest of the study area. Once exception was dissolved chloride, which can be traced to the application of road salts on the Coquihalla Highway. Still, chloride levels were well below the Provincial guideline for aquatic life. We may not have captured the peak chloride concentration as most of the roadside snow had melted when we started sampling on March 31. We recommend testing for chloride throughout the winter to better assess the potential for chloride toxicity from road salts in the Coldwater River. Chloride levels should also be measured in off-channel habitat adjacent to the Coquihalla Highway, including the Juliet rearing pond and the Zoltan-Kuun complex. Off channel habitat accounts for the majority of overwinter habitat for Coho salmon and other salmonids in the area, and the potential for chloride and other pollutants accumulating is greater in standing water (Bennett 2004). Nutrient and coliform levels were low in the Coldwater River and we did not observe a significant increase in pollutants between Kingsvale and IR#1, were most agricultural operations are concentrated.

This study provides an insight on temporal and longitudinal changes in water quality in the study area. However, because the results and their interpretation are limited to the sites and parameters chosen, the study may lack the level of detail required to fully comprehend the impact of agricultural operations and other factors on water quality and aquatic life. The impact from different concentrations of phosphorous and other nutrients on algae biomass is unclear, and identifying phosphorous levels associated with excess algae growth is needed to assess the adverse impact to fish and other organisms. We suggest testing for chlorophyll a in future studies to better understand the relationship between nutrients and algea biomass in the study area. To supplement future water quality monitoring projects, we advocate establishing a biomonitoring program. Biological monitoring, such as employing the CABIN framework to monitor benthic invertebrates, would allow tracking cumulative impacts, interactions between pollutants, and the influence of contaminants not tested for such as metals. As an important link of the food web, it would also provide important information on food availability and could be used as a direct measure of the health of the ecosystem.

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6 Appendix

Looking upstream Looking downstream

Figure 13: Chapperon Creek at the outlet of Chapperon Lake, July 20, 2021

Looking upstream Looking downstream

Figure 14: Nicola River at the Douglas Lake inlet, July 20, 2021

Looking upstream Looking downstream

Figure 15: Nicola River at the Douglas Lake outlet, July 20, 2021

Looking upstream Looking downstream

Figure 16: Nicola River at the Nicola Lake inlet, July 20, 2021

Looking upstream Looking downstream

Figure 17: Nicola River downstream of the Nicola dam, July 20, 2021

Looking upstream Looking downstream

Figure 18: Nicola River at Norgaard, July 20, 2021

Looking upstream Looking downstream

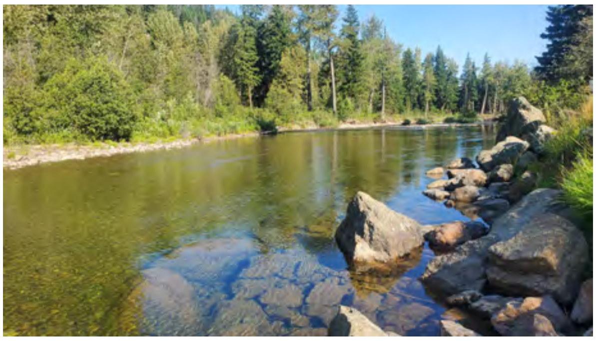
Figure 19: Nicola River below the confluence with the Coldwater River, July 20, 2021.

Looking upstream Looking downstream

Figure 20: Nicola River at the Gavlin KVR tresle, July 20, 2021


Looking upstream Looking downstream

Figure 21: Nicola River upstream of the Spius Creek confluence, July 20, 2021

Looking upstream Looking downstream

Figure 22: Coldwater River at Kingsvale, July 20, 2021


Looking upstream Looking downstream

Figure 23: Coldwater River at the Patchett bridge, July 20, 2021.

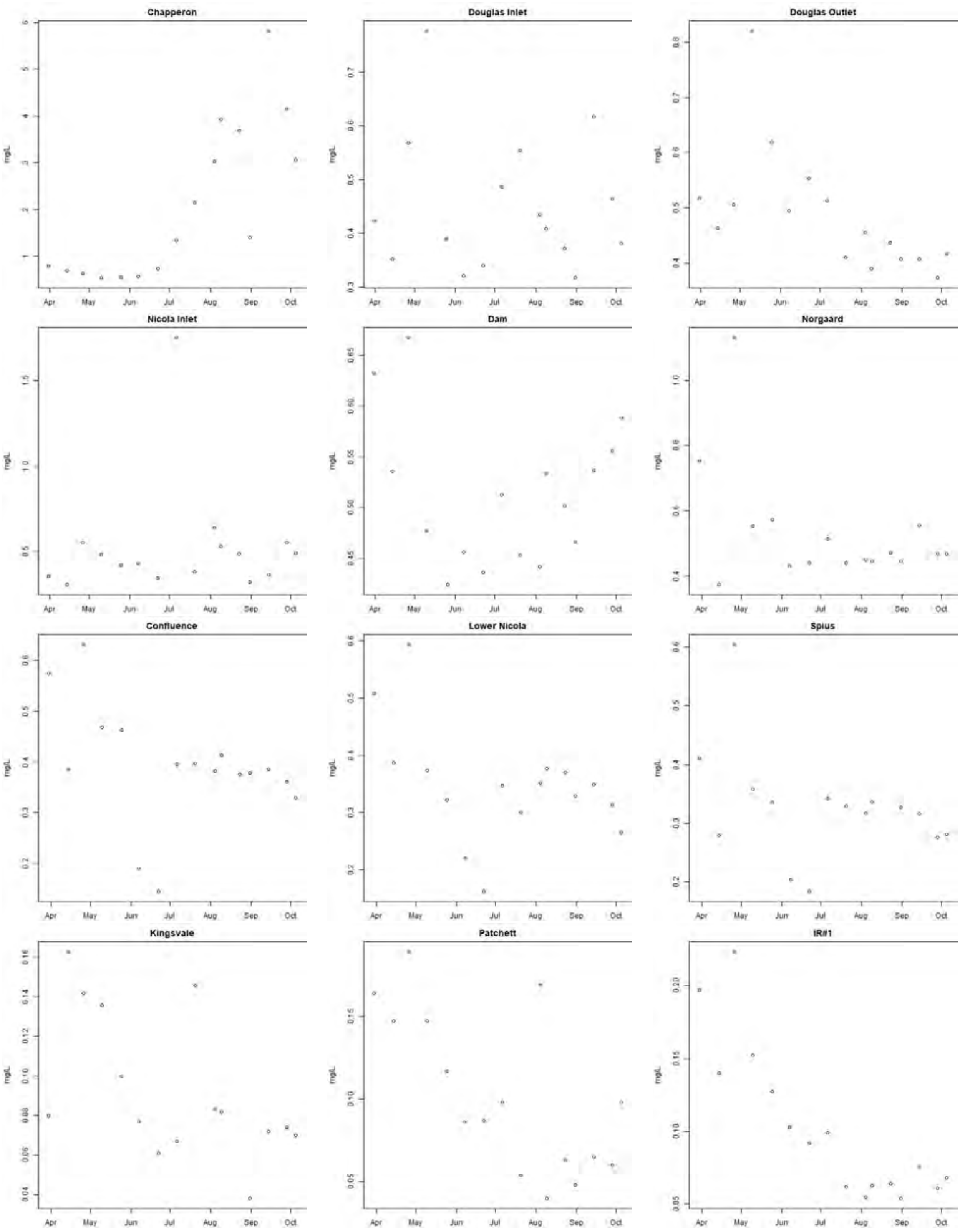

Looking upstream Looking downstream

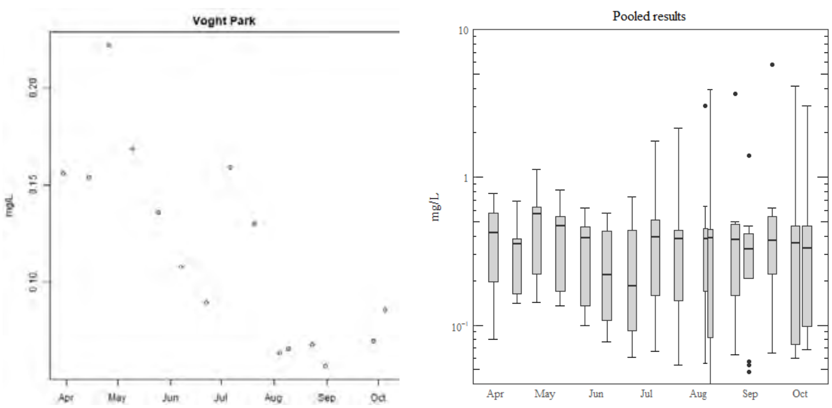
Figure 24: Coldwater River at the IR1 bridge, July 20, 2021.

Looking upstream

Looking downstream

Figure 25: Coldwater River at Voght Park, July 20, 2021.



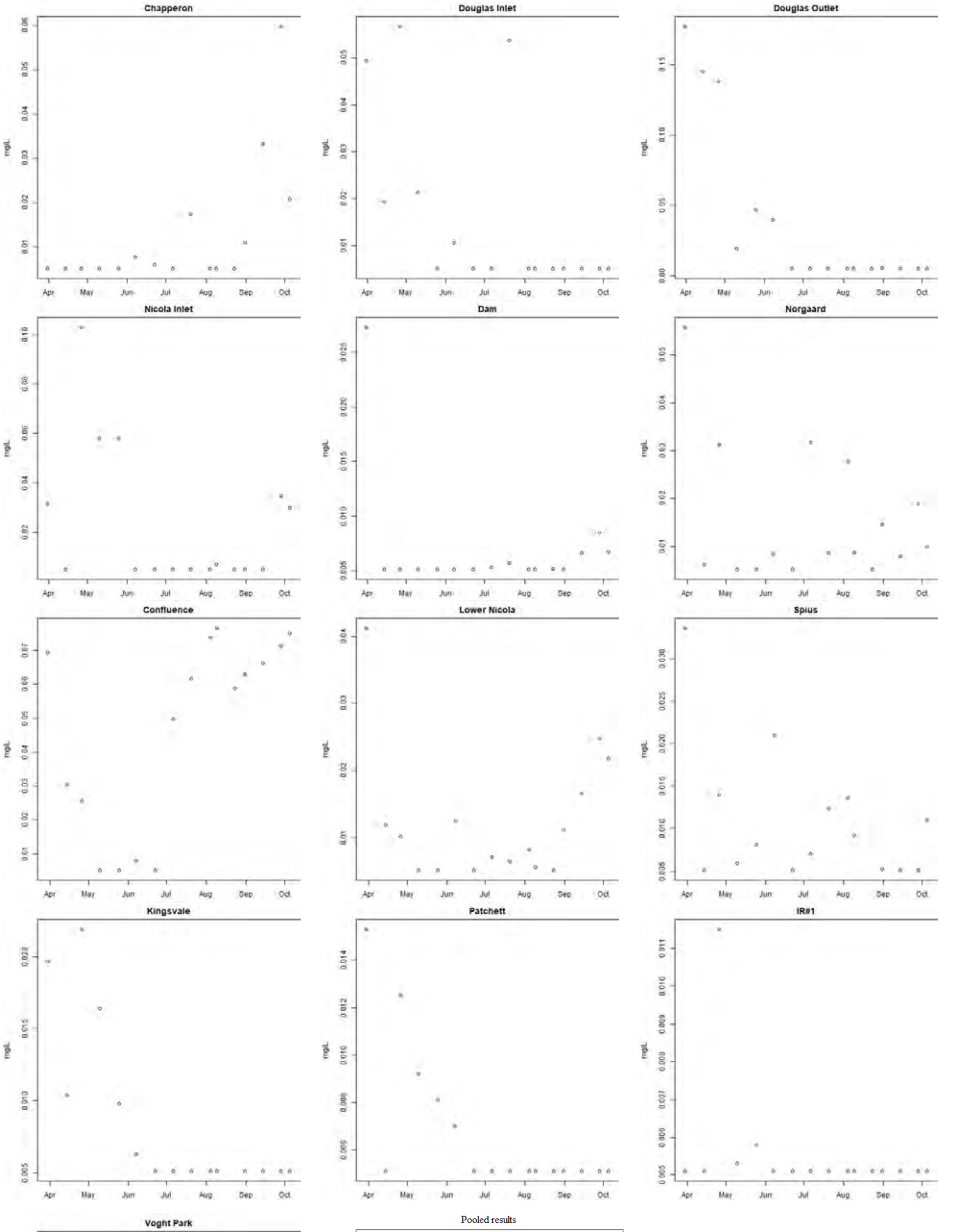


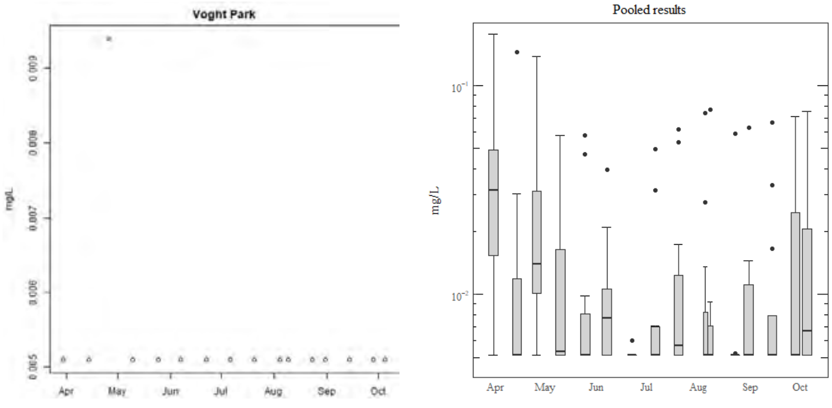
Summary statistics

April to June	Min	Median	Max
Upper Nicola	0.306	0.512	0.821
Nicola R. below dam	0.144	0.436	1.130
Coldwater R.	0.061	0.138	0.223

July to November	Min	Median	Max
Upper Nicola	0.317	0.487	5.820
Nicola R. below dam	0.265	0.384	0.589
Coldwater R.	0.038	0.067	0.169

Figure 26: Total nitrogen, mg/L

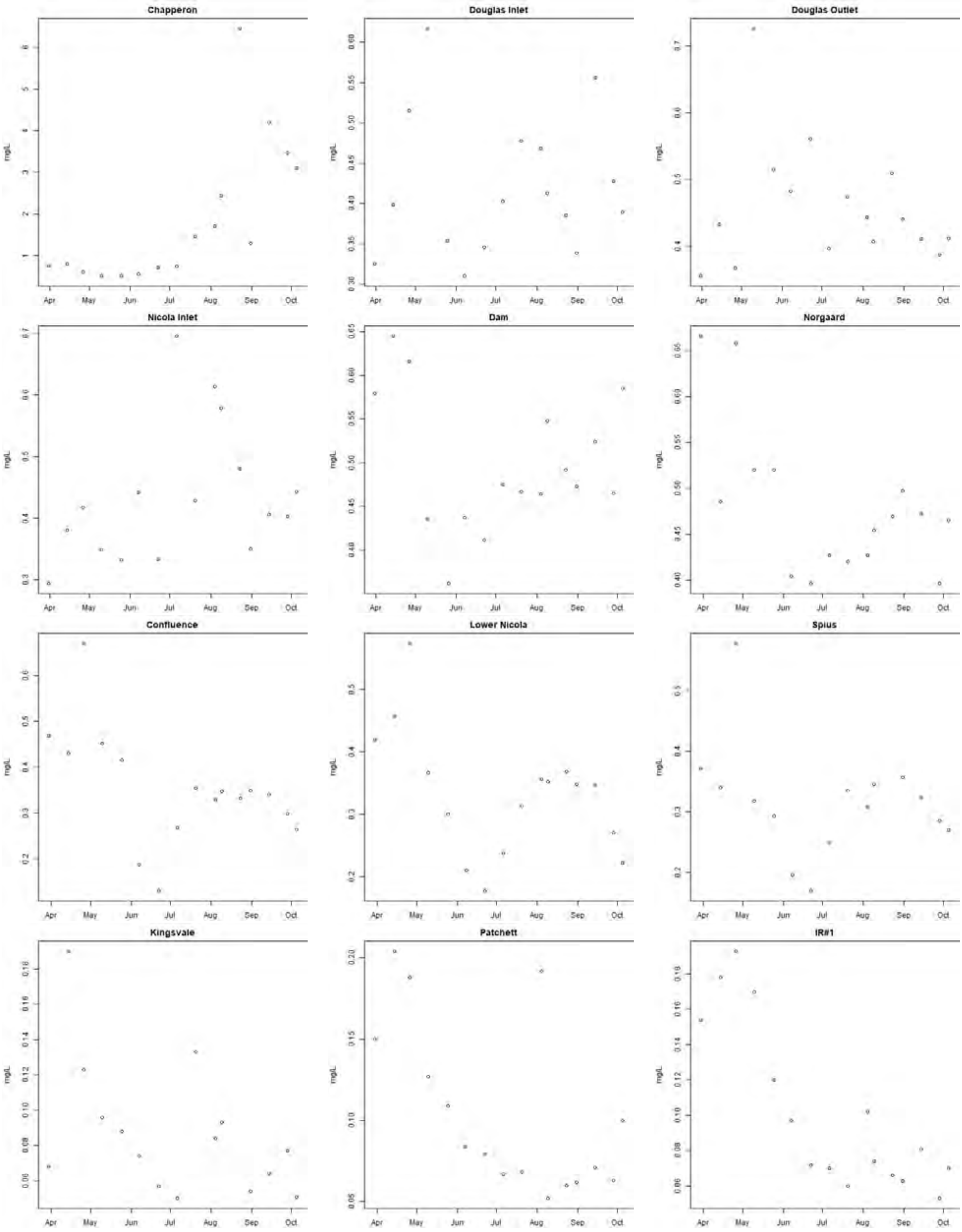


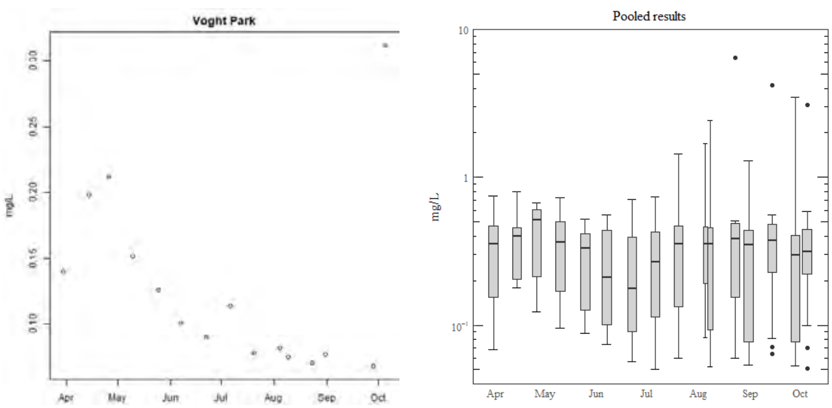


Summary statistics

April to June	Min	Median	Max
Upper Nicola	0.005	0.014	0.177
Nicola R. below dam	0.005	0.005	0.069
Coldwater R.	0.005	0.005	0.021
July to November			
Upper Nicola	0.005	0.005	0.059
Nicola R. below dam		0.005 0.008	0.076
Coldwater R.	0.005	0.005	0.005

Figure 27: Nitrate + Nitrite (as N), mg/L



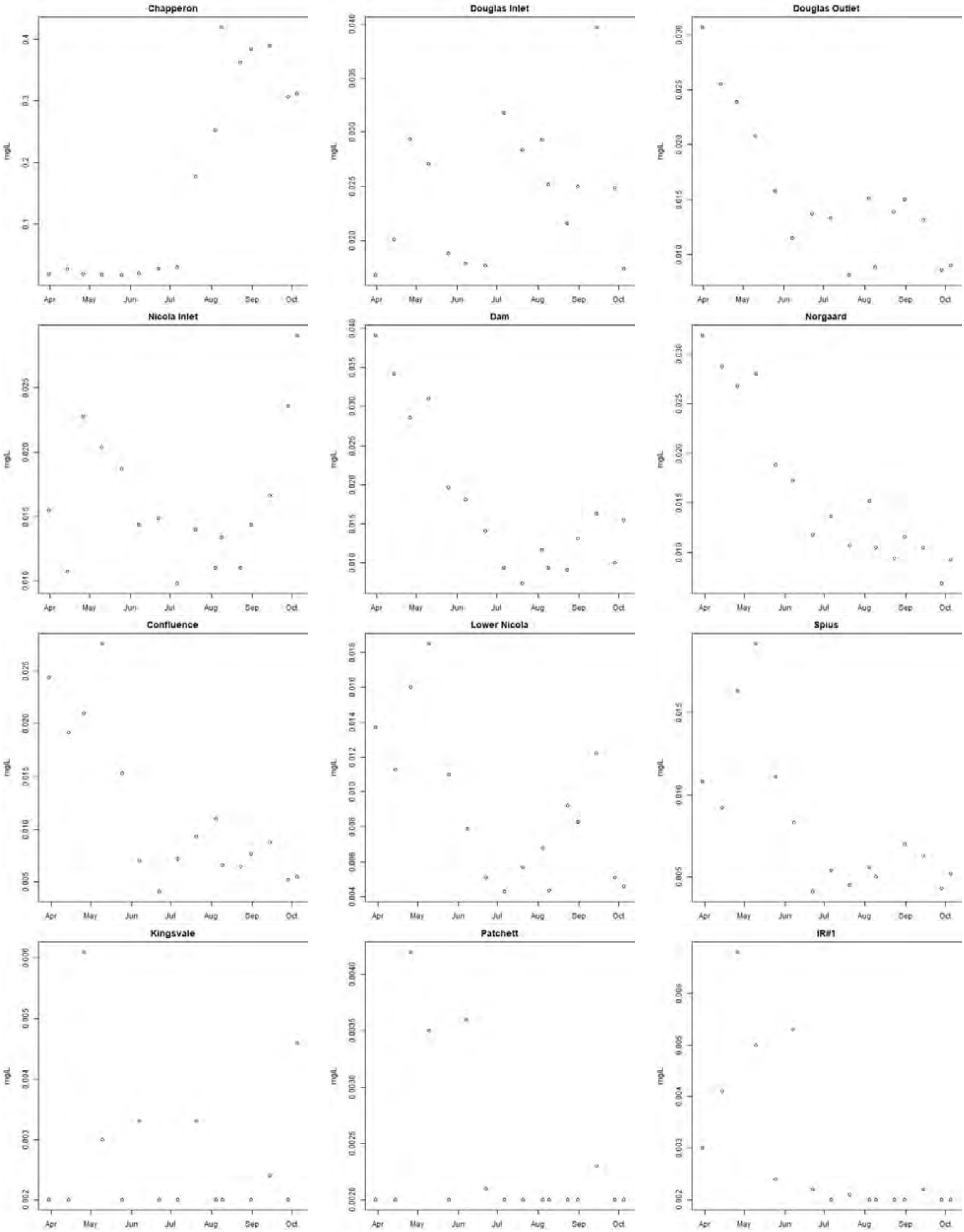


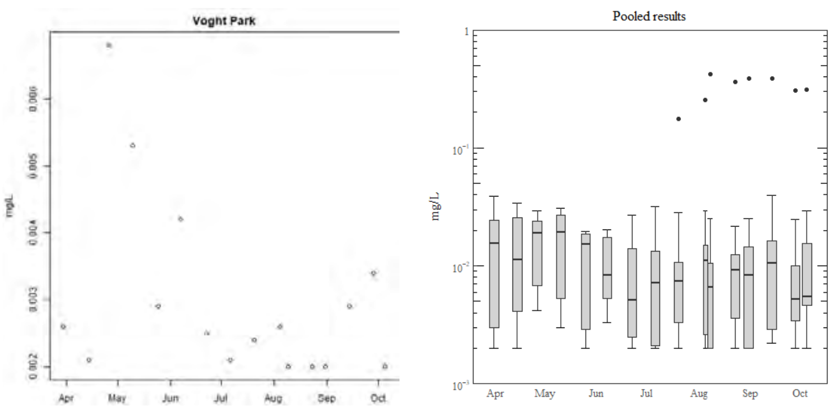
Summary statistics

April to June	Min	Median	Max
Upper Nicola	0.294	0.437	0.800
Nicola R. below dam	0.131	0.420	0.669
Coldwater R.	0.057	0.124	0.212

July to November			
Upper Nicola	0.339	0.455	6.450
Nicola R. below dam	0.222	0.353	0.585
Coldwater R.	0.050	0.070	0.312

Figure 28: Total organic nitrogen, mg/L

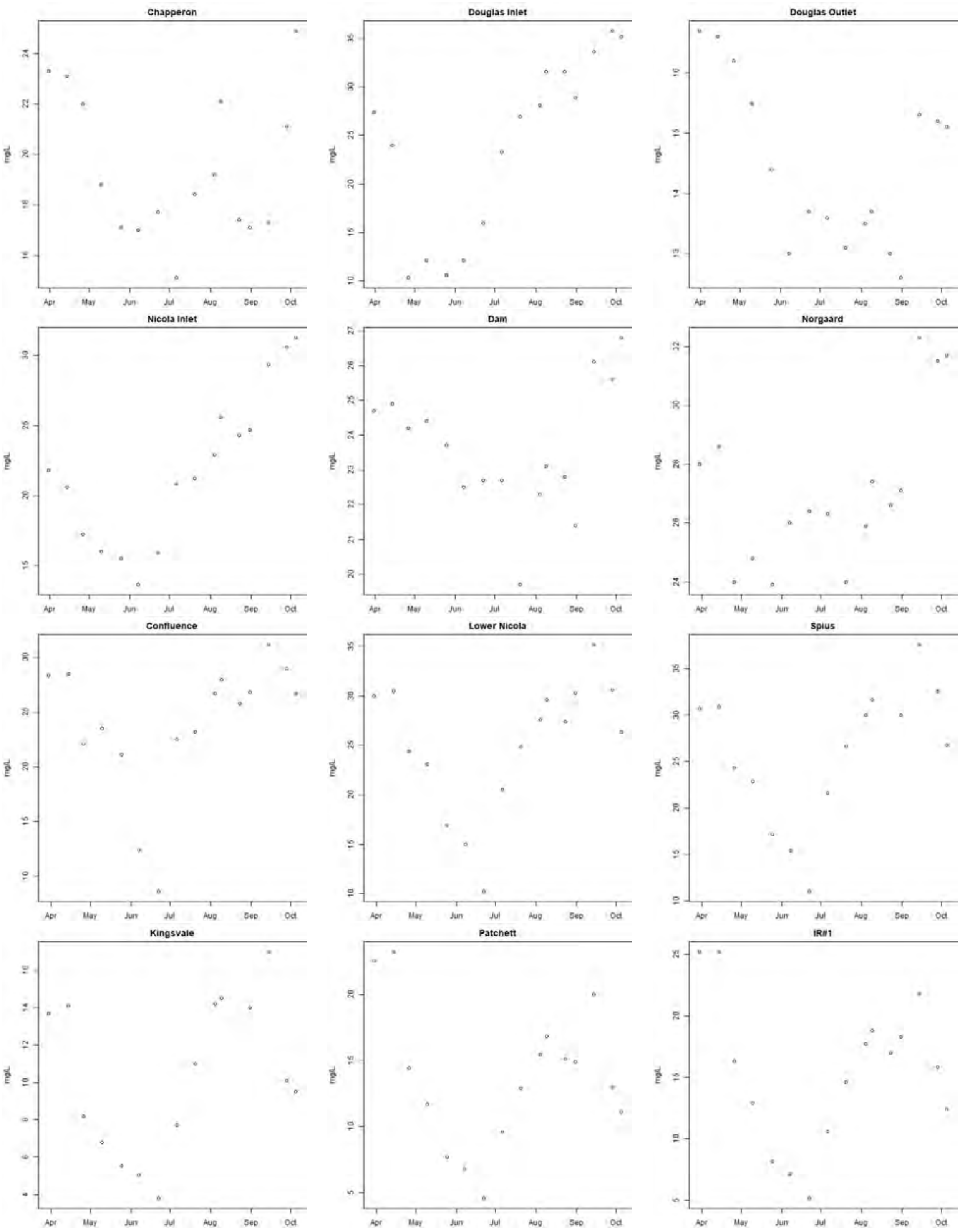


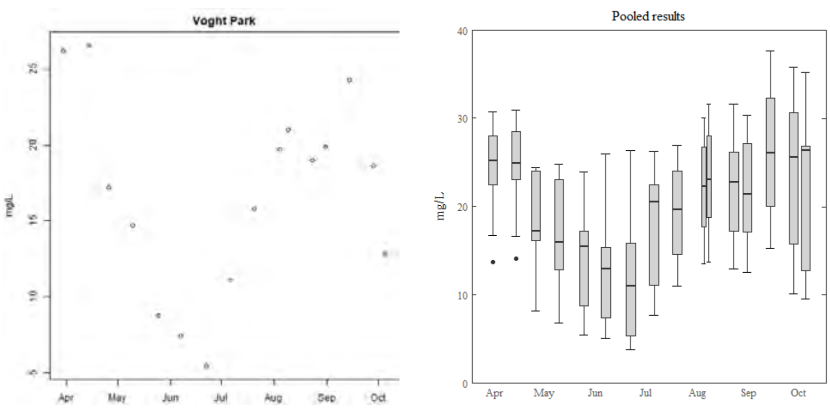


Summary statistics

April to June	Min	Median	Max
Upper Nicola	0.0107	0.0187	0.0307
Nicola R. below dam	0.0041	0.0173	0.0391
Coldwater R.	0.0020	0.00295	0.0068
July to November			
Upper Nicola	0.0081	0.0226	0.4200
Nicola R. below dam	0.0043	0.0080	0.0163
Coldwater R.	0.0020	0.0020	0.0046

Figure 29: Total dissolved phosphorus, mg/L



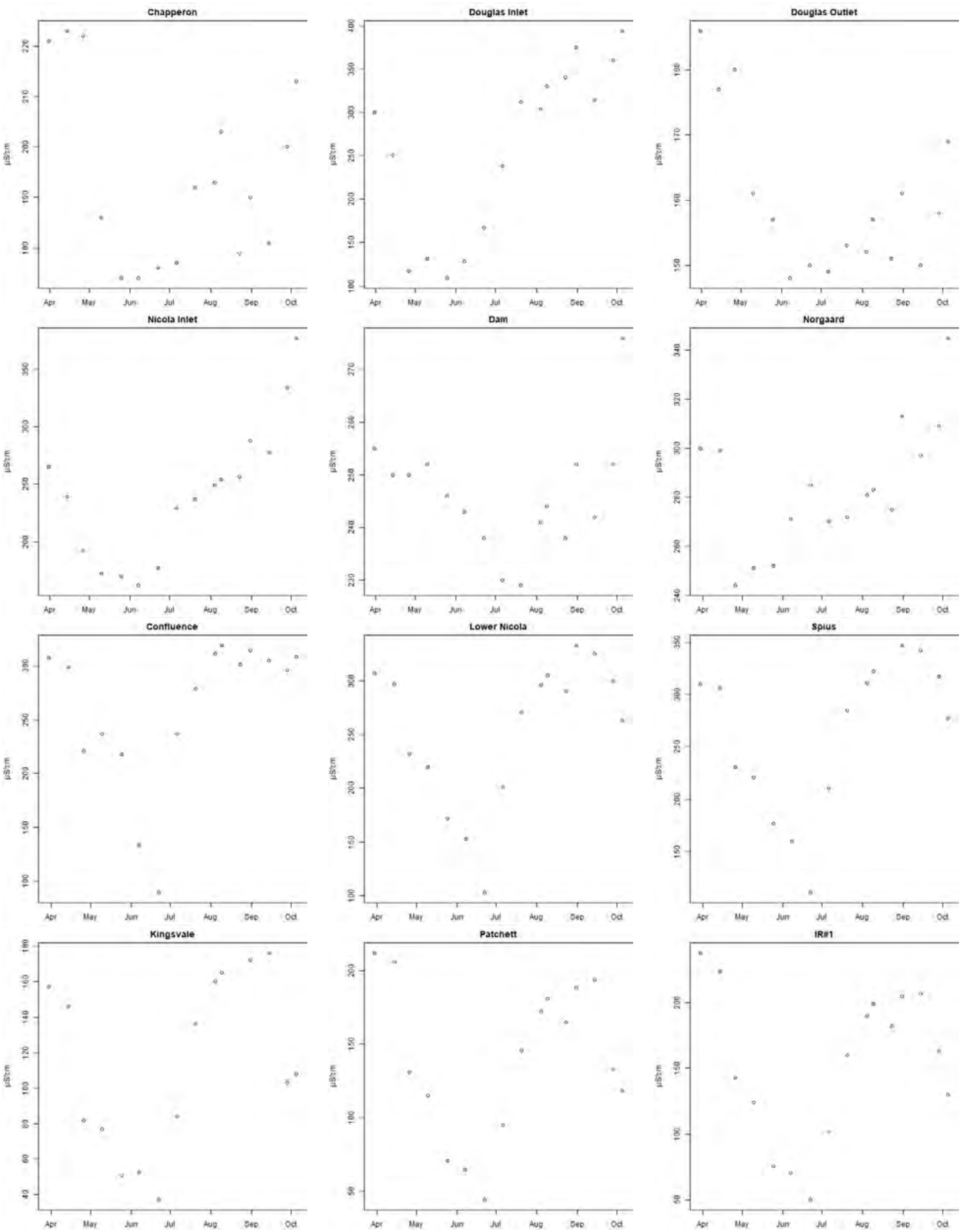


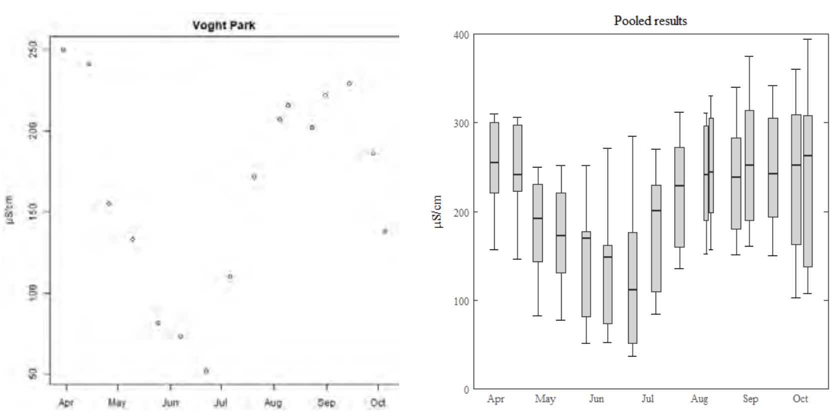
Summary statistics

April to June	Min	Median	Max
Upper Nicola	10.30	16.40	27.40
Nicola R. below dam	8.58	24.00	30.90
Coldwater R.	3.79	10.21	26.60

July to November			
Upper Nicola	12.60	21.65	35.80
Nicola R. below dam	19.70	26.75	37.60
Coldwater R.	7.72	15.10	24.30

Figure 30: Total inorganic carbon, mg/L



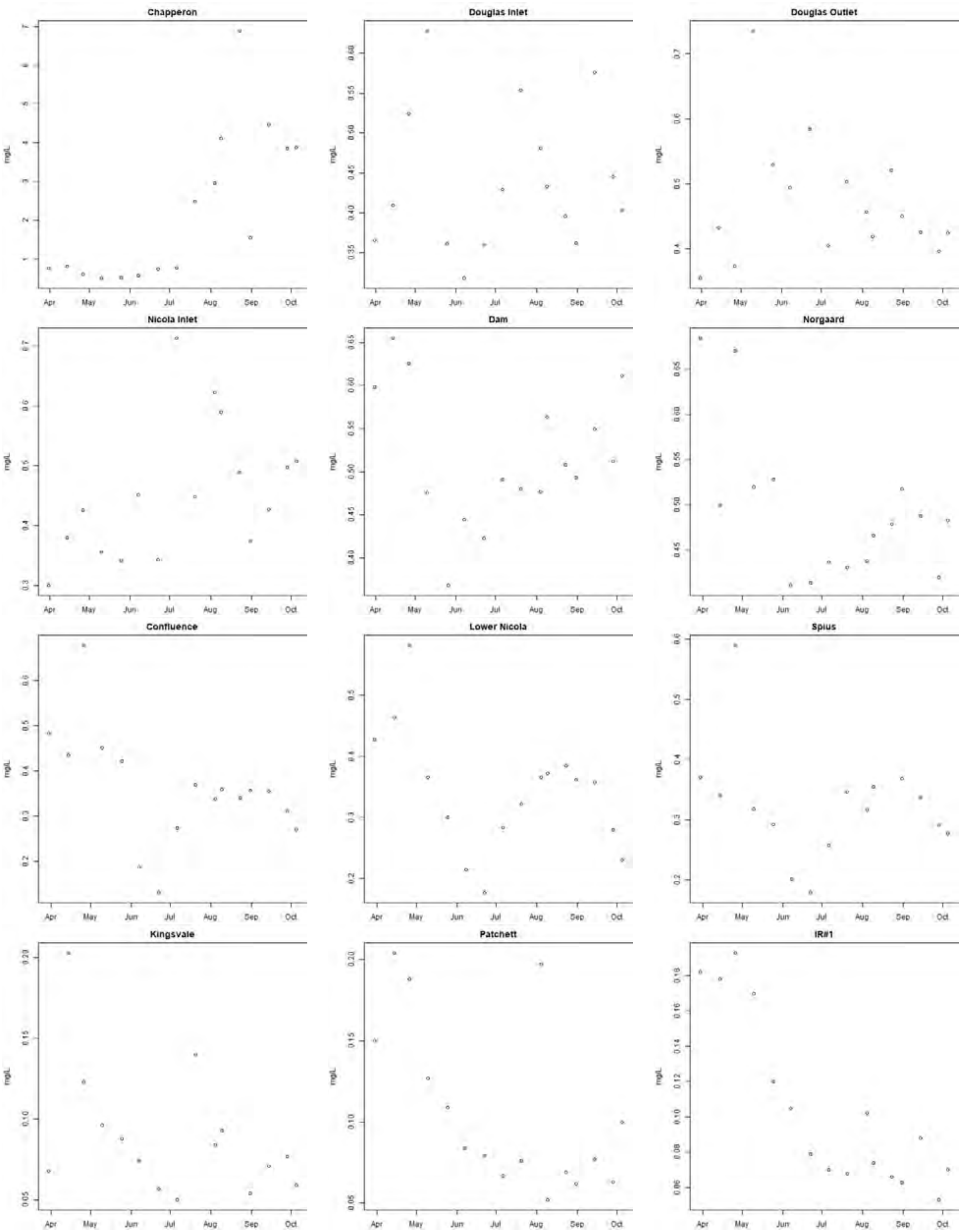


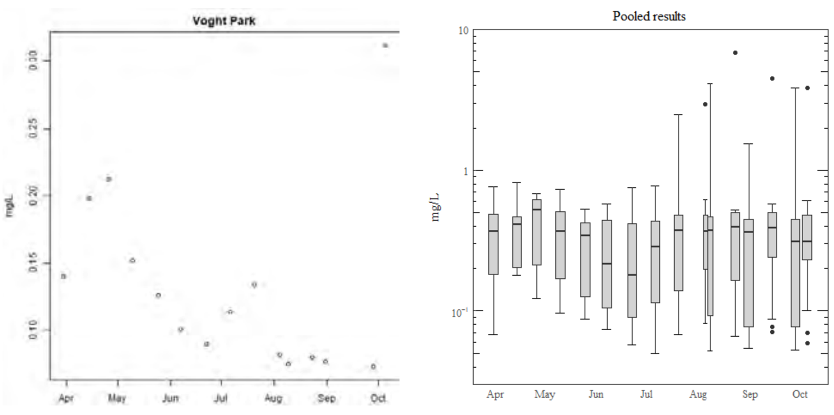
Summary statistics

April to June	Min	Median	Max
Upper Nicola	109.0	175.0	300.0
Nicola R. below dam	89.4	244.0	310.0
Coldwater R.	37.20	98.55	250.00

July to November	Min	Median	Max
Upper Nicola	149.0	221.0	394.0
Nicola R. below dam	201.0	287.5	347.0
Coldwater R.	84.1	172.0	229.0

Figure 31: Conductivity, g/cm



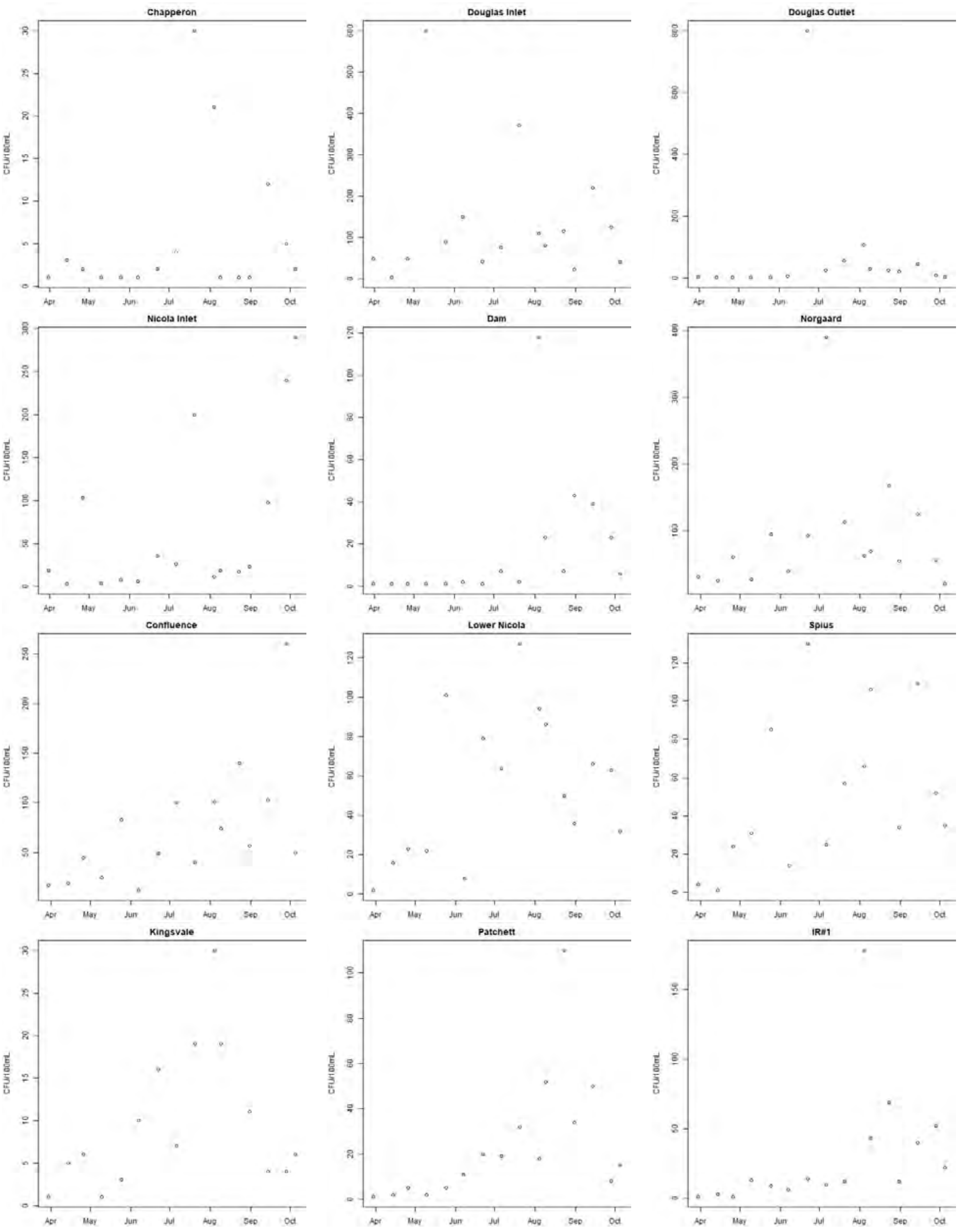


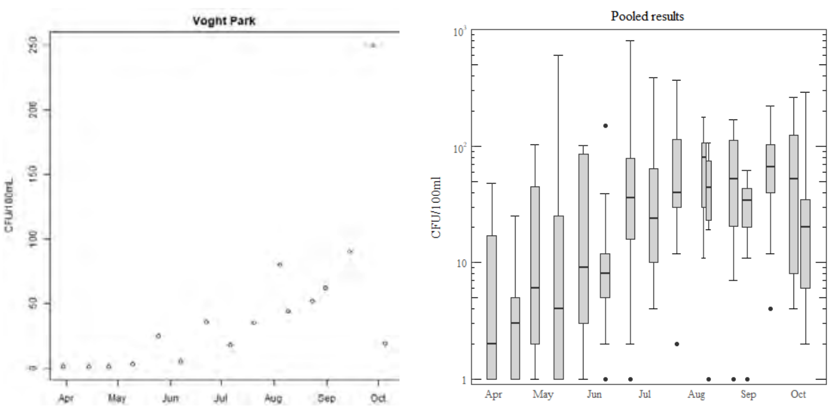
Summary statistics

April to June	Min	Median	Max
Upper Nicola	0.300	0.442	0.817
Nicola R. below dam	0.131	0.428	0.685
Coldwater R.	0.057	0.124	0.212

July to November			
Upper Nicola	0.362	0.492	6.880
Nicola R. below dam	0.230	0.367	0.611
Coldwater R.	0.050	0.074	0.312

Figure 32: Kjeldahl nitrogen, mg/L





Summary statistics

April to June	Min	Median	Max
Upper Nicola	1.0	3.5	800.0
Nicola R. below dam	1.0	23.00	130.0
Coldwater R.	1.0	5.0	36.0
July to November			
Upper Nicola	1.0	25.5	370.0
Nicola R. below dam	2.0	59.5	390.0
Coldwater R.	4.0	30.0	250.0

Figure 33: Coliforms, thermotolerant, CFU/100ml