Department of Planning and Environment

Ecological Health Assessment of Victoria Creek and Tilba Tilba Lake, NSW

An interim report with baseline data

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Cover photo: Completed stock exclusion fence and newly planted trees at Victoria Creek (VC2 monitoring site). Uthpala Pinto/DPE

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Background

This project is funded through the NSW Marine Estate Management Strategy (MEMS) and was initiated to gather scientific evidence to support on-ground rehabilitation improvement works planned by the South East Local Land Services (LLS) in the Tilba Tilba region. Science, Economics and Insights Division, Department of Planning and Environment (the department) was engaged to develop a scientifically rigorous monitoring program to better understand the baseline ecosystem health of Victoria Creek and the Tilba Tilba Lake prior to and during rehabilitation works undertaken by LLS, thus facilitating an assessment of the effectiveness of those works. Between January 2019 and October 2020, seven landholders were engaged, 12 hectares of riparian zone revegetated with 15,000 trees, 14 kilometres of fencing was established, 9 hectares of saltmarsh protected (private and public land) and 19 off-stream livestock watering troughs established. This formed part of a larger program addressing water quality and ecological health issues in Tilba Tilba Lake. The three key aims of this project were to:

1. understand the ecological health of Victoria Creek and Tilba Tilba Lake prior to and during stream rehabilitation works
2. understand the relationships between ecological health indicators important for coastal waterways, and
3. build capacity among local landowners and the community to assess stream health.

Indicator groups

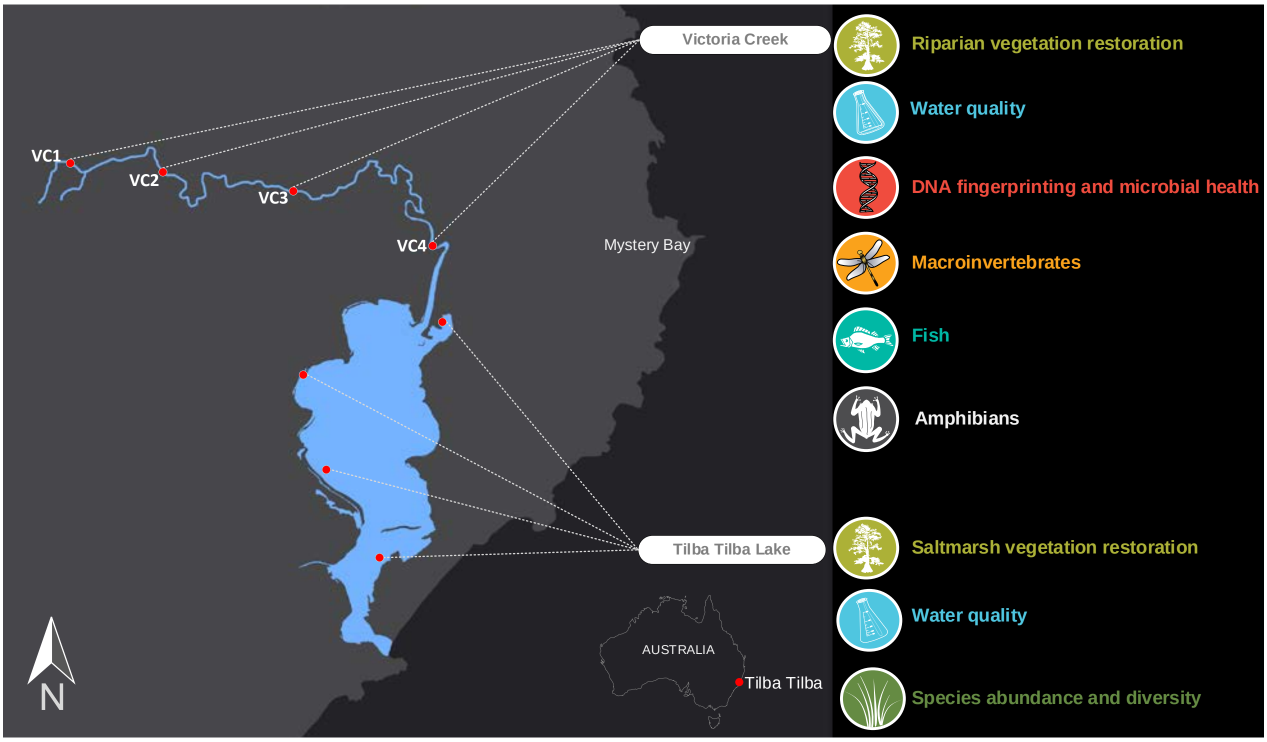
The data collected from three projects were collectively used to establish a baseline for the creek and Tilba Tilba Lake system. The lake data was gathered through the long-term NSW Natural Resources Monitoring, Evaluation and Reporting Program (MER). A saltmarsh health monitoring project along the foreshore of Tilba Tilba Lake and the Victoria Creek health monitoring project were initiated in 2019.

To address the first two project aims, a range of environmental indicators related to water quality, (temperature, turbidity, pH, conductivity, oxygen, nutrients, bacteria and phytoplankton), stream bank and riparian vegetation health (species richness and cover), aquatic fauna diversity (macroinvertebrates, fish and frogs), visual aspect, and various weather-related indicators (rainfall, water level) were monitored at four sites. A higher-level summary of the results is provided in **Table A**. Three of the sites (VC1–3) were freshwater (**Map 1**) with the most downstream site (VC4) being brackish with salinity influenced by both the lake's entrance condition and freshwater inflows. Water quality indicators at freshwater sites were compared with the Australia and New Zealand Environmental Conservation Council/Agriculture and Resource Management Council Australia and New Zealand default trigger values developed for aquatic ecosystem health assessment in South-east Australia (ANZECC/ARMCANZ 2000).

This report contains a summary of monitoring data collected from Victoria Creek and Tilba Tilba Lake.

Main findings

Overall, the results from this baseline study indicate that Victoria Creek is moderately impaired with slumped stream banks, exceedances in water column nutrient and chlorophyll-a concentrations, low dissolved oxygen levels and extensive sedimentation of the creek's streambed reducing the diversity of instream habitats available for aquatic fauna. Macro and micro algal blooms are also evident due to nutrient enrichment. Faecal microbial contamination occurred at all monitored sites although the main source has not yet been identified. Fish, macroinvertebrate and frog survey data show the creek health still support some aquatic fauna and it is anticipated the diversity and abundance of these species will expand as more favourable habitat conditions become available in future.



Map 1 Locations of monitoring sites in Victoria Creek and Tilba Tilba Lake

Some icons courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (IAN 2021).

As the riparian buffer grows and expands there will be more shade, and less nutrient and sediment run-off into creek waters, providing favourable conditions for the stream health to recover. Similarly, by excluding cattle any further pugging or trampling damage to the creek system will be prevented. Cattle exclusion fences will also reduce faecal matter entering creek waters, prevent livestock from grazing down instream vegetation and allow riparian vegetation to expand and further stabilise banks.

Visual surveys undertaken in 2019 and 2020 identified a range of stream health issues related to geomorphic (active bank erosion and increased sedimentation) and riparian condition (reduced longitudinal continuity, riparian and canopy width, sparse shrub layer and groundcover) and presence of filamentous green algae across all sites.

The dry weather conditions that prevailed in 2019 were consistent with the El Niño episodes characterised by Southern Oscillation Index. Water levels in Victoria Creek declined from August to December 2019 due to increased evaporation, low precipitation and catchment inflows. The year 2020 in contrast, was a relatively wet year. Waters at the most downstream site, VC4, were always warmer than the three upstream freshwater sites. As the freshwater entering the fluvial delta is colder than the warmer water at VC4, thermal stratification is likely at the mixing zone.

During the monitoring project total and dissolved forms of nutrients, nitrogen and phosphorus were assessed. The total nutrients exceeded the ANZECC/ARMCANZ (2000) trigger values while the dissolved forms remained below the trigger values. The creek system was also dominated by dissolved organic nitrogen and very few organic and inorganic fractions of dissolved phosphorus remained in the creek waters. The dissolved inorganic nitrogen to total dissolved nitrogen ratios estimated gradually increased from upstream to downstream sites with site VC4 having the highest ratio. This indicates the bioavailability of nitrogen for aquatic plant growth around the fluvial delta of Tilba Tilba Lake. These results agree with high variability in chlorophyll-*a* concentrations observed at VC4. Rainfall driven nutrient run-off events are also evident in the monitoring data.

pH is an indicator of the acidity of water. pH levels were within the default trigger value range at freshwater sites and suitable for a range of aquatic species; however, alkalinity was relatively low at freshwater sites compared to VC4, which was influenced by seawater. Alkalinity buffers pH changes in water, meaning that aquatic life at freshwater sites may be relatively more vulnerable to changes in pH with increased external pollution due to low alkalinity compared with site VC4.

Heavy sedimentation from bank erosion and catchment run-off is evident at all sites. There was a fine sediment layer sitting on the streambed, which is highly prone to resuspension by wind, livestock crossing and during and following rainfall events.

Median chlorophyll-*a* concentrations calculated from 19 sampling surveys exceeded the trigger values at site VC1. Also, high chlorophyll-*a* values were reported for other sites indicating algal blooms occurring in the system. A significant correlation between chlorophyll-*a* and most types of total and dissolved forms of nutrient levels suggests the presence of algal blooms and elevated nutrients co-occurring in the system.

Dissolved oxygen concentrations at freshwater sites (VC1–3) were below the minimum trigger values (<85%) indicating the creek's waters were deoxygenated. This indicates that instream oxygen demand exceeded oxygen inputs from photosynthesis by algae and macrophytes, and from reaeration at the air–water interface. Oxygen concentrations in the water column are influenced by factors such as temperature, salinity, air pressure, stream flow, chemical oxygen demand and community metabolism rates (i.e. respiration and photosynthesis rates).

Two indicators of enteric bacteria were used to assess the faecal microbial contamination in Victoria Creek. While *E. coli* was used as a screening tool in the field, Enterococci in samples were quantified at a laboratory. Both tests confirmed the sites have some level of faecal contamination although the source of this pollution is not clear from the present study. The two bacterial indicators were significantly correlated with rainfall and this indicates run-off associated bacterial contamination in the creek.

Three types of ecosystem receptor indicators, macroinvertebrates, frogs and fish were monitored. In general, more macroinvertebrate taxa were reported across all sites in 2020 compared to the previous year; however, the AUSRIVAS and SIGNAL-2 macroinvertebrate indices calculated based on two surveys in spring 2019 and 2020 suggested that Victoria Creek has some degree of biological impairment. Frog call surveys identified three frog species that are known to be common in the Bega Valley, namely common eastern froglet (*Crinia signifera*), Verreaux's tree frog (*Litoria verreauxii*) and Peron's tree frog (*Litoria peronii*). A total of 444 fish belonging to 12 species were captured during the surveys, in which a majority were natives (81%). Over time, less habitat disturbance is anticipated to occur at these sites as a result of the stock exclusion fences. It is expected that as habitat complexity and extent increases throughout the riparian zone, frog and fish breeding activity will increase, and additional species will be recorded.

Three riparian vegetation surveys were undertaken to establish the baseline vegetation conditions at sampling sites. These baseline surveys found the groundcover at all four sites was dominated by the non-native grass kikuyu. While sites VC1 and VC2 had slightly more native species (50–58%) than non-native species, VC3 and VCR were dominated mainly by non-native species (37–51%). With the presence of native species already at all sites, we hypothesise that fencing and subsequent elimination of livestock will increase the cover of native species instream and along the riparian zone of the creek. Additionally, the cover of kikuyu grass will decrease over time as other species establish. It is expected that opportunistic species (mainly non-native) will initially dominate the riparian zone; however native plantings and potentially native seed banks could establish over time. Due to the obvious bank erosion occurring along Victoria Creek, it is recommended planted species include species to act as bank stabilisers such as *Lomandra* spp. *Lomandra* spp. already occur within the Victoria Creek catchment and were observed as efficient bank stabilisers, especially at VC3 and nearby Corunna State Forest.

The extent of saltmarsh coverage in Tilba Tilba Lake at any time is influenced by seasonal growth cycles and the naturally fluctuating hydrological regime associated with the ocean entrance dynamics and catchment inflows. Species richness during the study period was significantly greater at sites on the eastern foreshore compared to sites on the western foreshore. Prior to the introduction and/or replacement of fencing, saltmarsh coverage was impacted by grazing pressure on the south-eastern foreshore adjacent to the lake entrance and the north-western foreshore. Communities at all monitoring sites showed temporal changes in structure in terms of the dominant species and their coverage. Monitoring is continuing to collect sufficient data to isolate any recovery trend due to cattle exclusion from this seasonal change that is punctuated by entrance closure events. One of the clearest trends over the monitoring period was the steady reduction in bare groundcover at all the monitoring sites, indicating an overall improvement in saltmarsh extent and condition during the monitoring period.

Tilba Tilba Lake water quality assessed through the MER Program reflects what was observed in the Victoria Creek. Lake water quality continues to show symptoms of nutrient enrichment, algal blooms and turbidity. For example, the total and dissolved forms of major plant nutrient phosphorus exceeded the trigger value in three sampling surveys indicating nutrient accumulation in the lake. Similarly, total and dissolved nitrogen showed an increasing trend over time and exceeded the trigger value in the 2019–20 survey. In addition, chlorophyll-*a* and turbidity also exceeded the trigger values in samples taken in the 2008–09, 2014–15 and 2019–20 surveys. However, pH, dissolved oxygen, ammonia and oxidised nitrogen concentrations were generally within the trigger values.

Engagement with the community

One of the aims of the project was to 'build capacity amongst local landholders and the community to assess stream health'. This was successfully achieved as demonstrated by their engagement in on-grounds works, attendance at training workshops, and involvement in a community promotional video and the water sample collection program throughout the monitoring period.

Future monitoring

It is expected exclusion of livestock and improvement of the riparian vegetation through planting of native trees, shrubs and rushes will improve the overall ecological health of the system through time. Changes are expected to be time and variable dependent. For example, while riparian vegetation will, in the short term, still be dominated by non-native grasses, this will slowly change as planted species grow to dominate vegetation cover, and native seed banks establish. With the regrowth of riparian vegetation and re-stabilisation of the banks, macroinvertebrates and instream macrophytes will also establish, thereby also improving water quality over time.

Through the current monitoring project we were able to test a range of indicators that may be suitable for assessing ecological health to establish a baseline prior to a rehabilitation project. While we found most indicators are useful, some redundancies can be made to make the monitoring program cost effective without compromising the rigour of the information.

Although a range of positive ecosystem health benefits are expected following the rehabilitation works, a long-term monitoring program with assistance from the local community is required to capture changes occurring beyond the life of this project.

We recommend a future monitoring program that includes regular monitoring using water quality and biannual riparian vegetation, macroinvertebrate, fish and frog surveys to track the health of the system during and post rehabilitation works. Information from such a program will be vital to understand the indicators suitable for informing the effectiveness of stream rehabilitation works.

To continue the high level of community engagement, we also recommend that the community continue to be involved in the water quality sampling using easy to measure water quality variables and citizen science toolkits available through initiatives such as NSW Waterwatch. In addition, we recommend developing a citizen science program that could include the use of mobile phone apps to record the growth of riparian vegetation as well as observations or recordings of frogs, birds and other water and riparian dependent fauna. These multiple lines of evidence will be able to show how recolonisation of aquatic and terrestrial fauna occurs in the rehabilitated areas as a sign of recovery.

Overall, this project has successfully achieved its primary aims and will contribute considerably to establishing a solid understanding of the relationships between ecological health indicators important for NSW coastal waterways.

Table A Indicator group results from Victoria Creek monitoring program, based on the median from multiple sampling periods between March 2019 and October 2020

Indicator	VC1	VC2	VC3	VC4
Turbidity	Within the trigger value	Within the trigger value	Within the trigger value	Trigger values not applied
Total suspended solids	–	–	Highest median compared to other sites	Lowest median compared to other sites
pH	Within the trigger value range	Within the trigger value range	Within the trigger value range	Trigger values not applied
Alkalinity	Lowest median compared to other sites	–	–	Highest median compared to other sites
Electrical conductivity (EC)	Freshwater and low electrical conductance	Freshwater and low electrical conductance	Freshwater and low electrical conductance	Site is highly saline due to seawater intrusion.
Dissolved oxygen (DO) saturation	Outside the trigger value range and deoxygenated conditions	Outside the trigger value range and deoxygenated conditions	Outside the trigger value range and deoxygenated conditions	Trigger values not applied
Nutrients	Total nutrients exceeded the trigger value, dissolved nutrients are below the trigger value	Total nutrients exceeded the trigger value, dissolved nutrients are below the trigger value	Total nutrients exceeded the trigger value, dissolved nutrients are below the trigger value	Trigger values not applied
Bacteria	Both indicator bacteria types within the guideline with occasional peaks	Both indicator bacteria types within the guideline with occasional peaks	Both indicator bacteria types within the guideline with occasional peaks	Both indicator bacteria types within the guideline with occasional peaks
Phytoplankton	Above the trigger value	Within the trigger value	Within the trigger value	Trigger values not applied
Riparian vegetation	Species richness dominated by native species Cover dominated by kikuyu	Species richness dominated by native species Cover dominated by kikuyu	Species richness dominated by non-native species Cover dominated by kikuyu	Species richness dominated by non-native species Cover dominated by kikuyu
Woody vegetation extent	About 33% of the Victoria Creek catchment riparian zone (the area within 20 metres of the mapped streamlines) was mapped as woody vegetation			
Macroinvertebrates	Biologically impaired	Biologically impaired	Biologically impaired	Biologically impaired
Fish and frogs	Baseline data collected	Baseline data collected	Baseline data collected	Baseline data collected
Visual assessment	Some degradation	Some degradation	Some degradation	Some degradation
Weather related indicators	Mostly dry weather conditions in 2019 and wet weather conditions in 2020			

Acknowledgements

We would like to acknowledge the traditional owners and custodians of the Tilba Tilba region, past, present and future.

This work would not have been possible without the continuous support from Ms Monica Considine who collected water samples to complement the department's sampling program and Ms Sonia Bazzacco at South East Local Land Services who coordinated the landowners in Tilba Tilba. Mr David Crass also assisted with vegetation and water quality monitoring.

We greatly acknowledge all the landowners at sampling sites including Ms Sally Pryor, Ms Robyn Lucas, Ms Teresa Stubbings, Mr Mark Stubbings, Ms Sally Hawkins, Rob Hawkins, Mr John Wiffen and Dr Kent Doust and all other community members who participated at training workshops. We thank Mr Dieter Neuber and Ms Robyn Lucas for hosting training workshops and meetings on their properties with department staff and other landowners.

Drs Peter Scanes, Jaimie Potts and Michael Hughes, Mr Adrian Dickson and Mr Aaron Wright provided invaluable inputs during the project development and review process. We also thank Dr Joanne Ling and Mr Nakia Belmer at the department for undertaking the macroinvertebrate identification and Dr Marco Giardina, Adam Wethered, Michael Orr and Ms Jamie Maclean for assisting with fieldwork.

Dr Amelia Walcott identified frog species in this study and we greatly appreciate her advice in frog monitoring surveys.

This project forms part of a larger program addressing water quality and ecological health issues in Victoria Creek and Tilba Tilba Lake and is funded by the MEMS Stage 1 Implementation Plan.

1. Background

This project is funded through the NSW Marine Estate Management Strategy (MEMS) Implementation Plan Stage 1 and was initiated to gather scientific evidence to support on-ground rehabilitation improvement works planned by the South East Local Land Services (LLS) in the Tilba Tilba region. The 10-year strategy was developed by the NSW Marine Estate Management Authority and funded by the NSW Government to coordinate the management of the marine estate.

Victoria Creek is an ephemeral coastal creek system that flows into Tilba Tilba Lake. The lake and the creek system have been under pressure due to a range of human activities occurring in the catchment since first European settlement in the region. Cumulative effects of these pressures together with weather events have resulted in poor water quality in the Tilba Tilba Lake. A summary of the seasonal water quality trends in the Lake is provided in **Section 1.2**.

To reduce these pressures and improve the health of Victoria Creek and Tilba Tilba Lake, a series of rehabilitation activities were initiated to improve both the creek's and the lake's environmental health. The riparian rehabilitation works included erecting stock exclusion fences parallel to the stream and establishing a riparian zone with varying depths at lands adjacent to Victoria Creek and the foreshores of Tilba Tilba Lake. The on-ground works continued during 2019 and 2020 (**Photo 1**). While the LLS coordinated this project, rangers were also involved in tree planting activities. Between January 2019 and October 2020:

- seven landholders were engaged
- 12 hectares of riparian zone were revegetated with 15,000 trees
- 14 kilometres of fencing was established
- 9 hectares of saltmarsh were protected (private and public land)
- 19 off-stream livestock watering troughs were established.


Photo 1 Tree planting activities at the foreshore of Tilba Tilba Lake by Wagonga rangers (R Hawkins, 2019)

The Science, Economics and Insights Division at the Department of Planning and Environment (the department) was engaged to develop a scientifically rigorous monitoring program to better understand the baseline ecosystem health of Victoria Creek and Tilba Tilba Lake prior to the rehabilitation works.

The data collected from three projects were collectively used to establish a baseline for the creek and Tilba Tilba Lake system. The lake data were gathered through the long-term NSW Natural Resources Monitoring, Evaluation and Reporting Program (MER). A saltmarsh health monitoring project along the foreshore of Tilba Tilba Lake was initiated in 2019. A Victoria Creek health monitoring project was also started in 2019 to collect baseline data and build capacity among interested community volunteers to undertake stream health monitoring in the region, with the view that they become stewards of their local environmental management activities.

A range of positive benefits are expected from stream rehabilitation works on Victoria Creek such as reduced bank erosion, suspended solids, nutrients and faecal contamination into estuarine receiving waters. Re-establishment of trees and shrubs along the riparian zone will also increase shading and habitat complexity allowing various aquatic and terrestrial fauna and flora to recolonise. However, the magnitude of improvements in stream health are dependent on the scale of the rehabilitation works (Rutherfurd et al. 2004). A long-term monitoring program may be required to capture changes occurring beyond the life of this project.

1.1 Project purpose

This stream health monitoring program was developed by scientists at Science, Economics and Insights Division of the department to address both short-term and long-term research objectives that included:

- understanding the ecological health of Victoria Creek and Tilba Tilba Lake prior and during stream rehabilitation works
- understanding the relationships between ecological health indicators important for coastal waterways
- building capacity among local landowners and the community to assess stream health.

Results and recommendations of this study will be used to inform ecological health assessments in other NSW coastal catchments and contribute to the development of standardised guidelines for assessing ecological health of freshwater streams in New South Wales.

During the project, the department team delivered a training workshop (30 July 2019) to local landowners and community volunteers on sample collection and handling techniques. Subsequently, about 35% of the water samples essential to the success of the monitoring program were collected and stored by community members, before being transported to Sydney for laboratory analysis.

To establish a baseline understanding of pre-rehabilitation works, the monitoring program was designed to collect multiple lines of evidence related to a range of environmental variables. This understanding will provide insights on how to address a range of known pressures and threats to the health of the system. The program will also track the condition of Victoria Creek, based on known pressures such as septic overflows, nutrient and sediment run-off, and impacts from cattle on stream banks and land clearing (see conceptual models for Victoria Creek, **Appendix A**). The three conceptual diagrams represent the pressures pre-European settlement, in the present, and the likely future situation following the rehabilitation works.

This technical report outlines the methods and results used to monitor and understand the baseline ‘pre-livestock exclusion’ condition of Victoria Creek and Tilba Tilba Lake.

1.2 Water quality of Tilba Tilba Lake

Tilba Tilba Lake is a 'back dune lagoon' system in New South Wales (Scanes et al. 2014). Back dune lagoons are relatively shallow systems (<6 metres) with three distinct zones: fluvial delta, central mud basin and marine delta. The fluvial and marine delta is home for a wide variety of saltmarsh and seagrass species. The ocean entrance is intermittent and influenced by waves and volume of catchment run-off into the lake. When the lake entrance is open the system becomes shallower and marine dominated. When the entrance is closed, the lake level rises (if rain continues) and the area of aquatic flora expands.

The water quality of the Tilba Tilba Lake is monitored through the MER program, which captures the health of NSW estuaries in summer months and provides a snapshot of the condition of each estuary (see OEH 2016 for data collection methods). **Table 1** compares the means of key water quality indicators assessed through the MER program in summer months of 2008–09, 2014–15, 2018–19 and 2019–20, with relevant trigger values for aquatic ecosystem health. A report card grade is also calculated based on turbidity and algae data collected through each season (e.g. A = excellent condition to E = poor condition) (OEH 2016). Over the four reporting periods, Tilba Tilba Lake received one B (good) grade for the 2018–19 season.

Total and dissolved forms of major plant nutrient phosphorus exceeded the trigger value indicating nutrient accumulation in the lake in three sampling surveys. Similarly, total and dissolved nitrogen showed an increasing trend over time and exceeded the trigger value in the 2019–20 survey. In addition, chlorophyll-*a* (Chl-*a*) and turbidity also exceeded the trigger values in samples taken during the 2008–09, 2014–15 and 2019–20 surveys. However, pH, dissolved oxygen (DO), ammonia and oxidised nitrogen (NO_x) concentrations generally remained within the trigger values.

During the years 2008 and 2009, central Tilba received low annual rainfall (804 and 573 millimetres respectively). This dry spell resulted in a considerable drop in lake water level triggering a chain of events. First the salinity level in the lake increased, surpassing the average salinity level of seawater (35 practical salinity units). This hypersaline condition led to the death and decay of macroalgae in the main body of the lake. This consumed oxygen and created anoxic conditions increasing the turbidity and Chl-*a* levels. Some of these events were repeated in 2014–15 and 2019–20 as noted in elevated Chl-*a* and turbidity results.

A range of long and short-term natural and anthropogenic pressures have influenced the lake's water quality. The naturally steep catchment surrounding the lake in Tilba Tilba has been cleared for agriculture over many years allowing large volumes of overland run-off to enter the lake and the creek system during heavy rainfall events. Without adequate tree cover to slow the flow velocity, the surface run-off transports sediment, nutrients and bacteria into the stream network. At the marine delta the exchange of seawater helps to off-set some high levels of nutrients and turbidity in the lake; however, the dynamics of this is governed by a range of factors including volume of freshwater inflows, surface flow water extraction and wave action.

While the MER program continues to capture the condition of the lake system, the riparian rehabilitation and stock exclusion works will support the recovery of the stream and lake's health over time.

Table 1 Mean values of water quality indicators assessed through the MER program for Tilba Tilba Lake

Water quality results exceeding the trigger value are highlighted.

Mean values of water quality indicators	2008–09	2014–15	2018–19	2019–20	Trigger value for back dune lagoons in NSW (Scanes 2018)
pH	NA	8.3	8.2	8.8	7.9–9.1
Salinity	56.7	34.0	23.3	63.0	35*
Turbidity	29.5	16.7	3.9	5.8	4.2 NTU
DO concentration	NA	6.6	7.0	5.4	5.8–9.5 mg/L
Chlorophyll-*a*	80.9	6.0	3.8	22.0	5.3 µg/L
Total nitrogen	NA	570.1	673.4	2238.0	1380 µg/L
Total dissolved nitrogen	NA	334.0	566.5	1448.0	1250 µg/L
Ammonia	NA	20.1	15.9	35.0	222 µg/L
Oxidised nitrogen	NA	3.6	2.4	2.0	23 µg/L
Total phosphorus	NA	72.2	73.1	357.4	32 µg/L
Total dissolved phosphorus	NA	25.4	35.5	185.8	13 µg/L
Phosphate	NA	14.0	21.4	63.0	2 µg/L
Report card grades	E	D	B	D	1.

*35 practical salinity units is not a trigger value. It represents the average salinity of marine water.

Photo 2 Tilba Tilba Lake in 2008

Left: dead seagrass, right: salt building up on the lake due to increased evaporation (J Potts, 2008)

2. Study location

Tilba Tilba Lake (–36.3281, 150.1156) is situated between the coastal towns of Narooma and Bermagui. Victoria Creek is a major tributary flowing into the lake to the north. In comparison with other nearby coastal lagoon systems (e.g. Wallaga Lake, Lake Mummuga), the catchment of Victoria Creek and Tilba Tilba Lake is largely cleared of native vegetation. Clearing occurred for various purposes including mining, forestry, dairy and beef farming, improved pasture, building and road constructions, and began as early as the 1850s (Hope et al. 2006). Today, only a few patches of remnant vegetation remain in the Victoria Creek catchment. These land practices have altered the natural catchment characteristics and delicate freshwater and estuarine sections of the system.

Some of these pressures in Victoria Creek include:

- removal of the natural vegetation resulting in increased surface overflows, increased bank erosion, reduced shading in streams, and increasing wind velocity and vertical mixing of water caused by a lack of riparian trees (Hashemi Monfared et al. 2019; Helfer et al. 2010)[1]
- presence of cattle resulting in vegetation trampling, stream bank slumping and increased sediment, nutrient and faecal matter loads in run-off and receiving waters
- application of pasture fertilisers that result in increased nutrient run-off into the waterways
- increased housing and subsequent pollutants of anthropogenic origin
- surface water flow extraction (MEMA 2017).

2.1 Site selection

Water quality and riparian vegetation monitoring sites are shown in **Figure 1** and **Table 2**. Sites were selected based on accessibility and proximity to proposed rehabilitation works.

Water quality monitoring sites have been established at VC1, VC2, VC3 and VC4. Within 2 metres of the monitoring station upstream and downstream, one randomly selected site was sampled using ‘grab’ sampling and in-situ data collection, for each site visit.

Riparian vegetation sites have been established at VC1, VC2, VC3 and VCR3 to complement the water quality monitoring sites. Site VC4 is excluded from the riparian vegetation survey, as the plant community is influenced by estuarine processes including tidal inundation. In addition, sites VCR1 and VCR2 have been established to capture a range of grazing histories and management actions in the vegetation monitoring program (**Table 2**). Saltmarsh sites are located in the foreshore of Tilba Tilba Lake (SM1, SM2, SM3 and SM4).

1. [1] The meaning of Tilba has an Aboriginal origin. It may mean ‘windy’ according to Hope et al. (2006) and ‘many waters’ according to the NSW Geographical Names Board (2020).

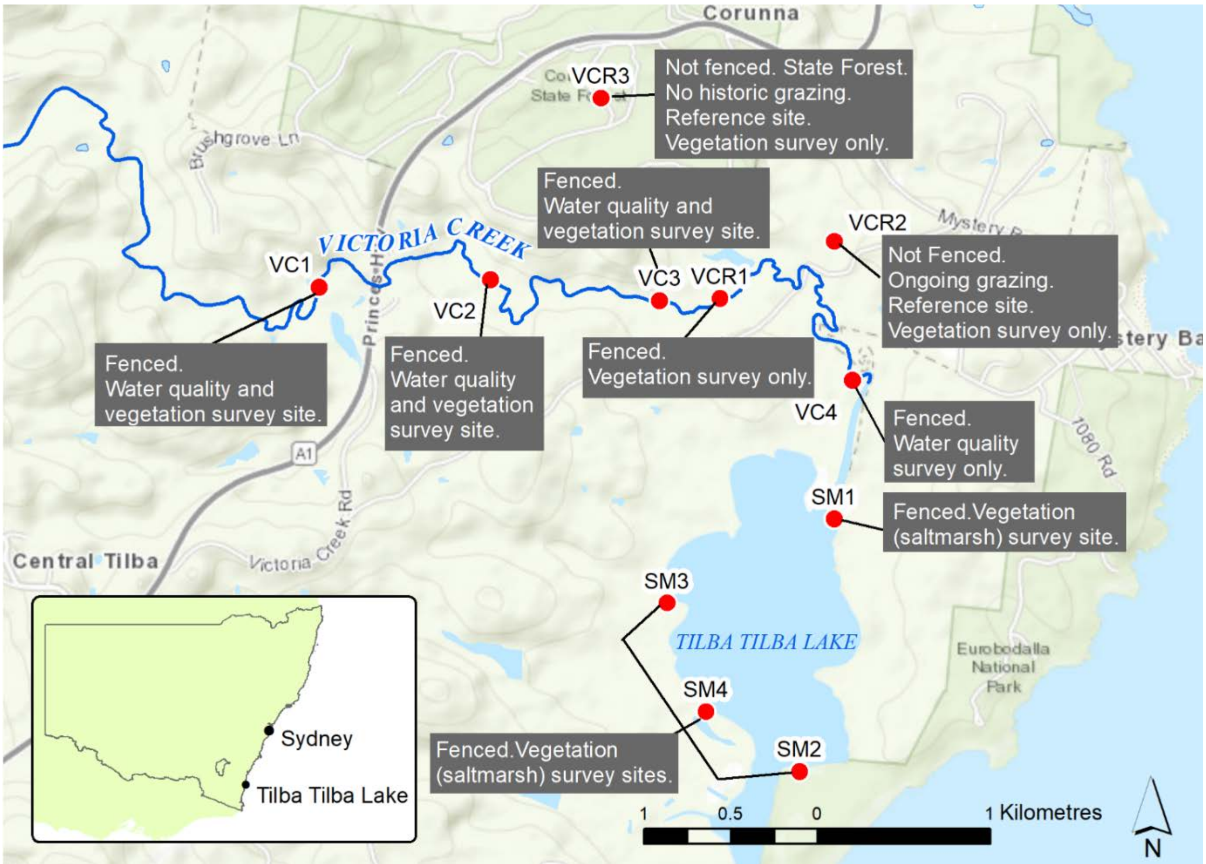


Figure 1 **Map of the water quality sites (VC1, VC2, VC3, VC4), vegetation survey sites (VC1, VC2, VC3, VCR1, VCR2, VCR3) and saltmarsh survey sites (SM1, SM2, SM3, SM4)**

Base map courtesy NSW Department of Finance Services and Innovation 2018.

Table 2 **Location of water quality and riparian vegetation monitoring sites**

Site ID	Latitude	Longitude	Works completion status (as of October 2020)	Distance from Tilba Tilba Lake ocean entrance (km)
VC1	–36.30091	150.09111	Fence established. Trees planted.	7.21
VC2	–36.3006	150.10001	Fence established. Trees planted.	6.02
VC3	–36.30148	150.10878	Fence established. Trees planted.	4.77
VC4	–36.30482	150.11882	Fence established.	2.85
VCR1	–36.301339	150.111995	Fence established. Trees planted.	4.10
VCR2	–36.299162	150.117885	Not fenced. Historic and ongoing grazing. Reference site.	4.06
VCR3	–36.293436	150.105746	Not fenced. Located in State Forest. Minimal to no historic or current grazing.	5.92

3. Methods

3.1 Overview

To monitor the changes in water quality and ecosystem health in Victoria Creek, a mix of stressor and condition indicators linked to known pressures of the system have been identified through conceptual models (see **Appendix A**). Some known pressures of the system include nutrient and sediment run-off, impacts from cattle on stream banks and land clearing. A range of ecosystem condition indicators such as vegetation, frogs, fish and macroinvertebrates were also included to better understand and characterise the baseline conditions of the stream and lake system in response to pressures. The environmental indicator groups and the specific indicators selected for the study are provided in **Table 3**.

Table 3 Environmental indicators assessed in the monitoring program

Indicator groups	Indicators assessed
Water clarity	Turbidity, total suspended solids, sediment grain-size
Acidity	pH, alkalinity
Salts	Electrical conductivity
Oxygen	Dissolved oxygen
Nutrients	Total nitrogen, NOx, ammonium, total phosphorus, filterable reactive phosphate
Bacteria	Enterococci, E. coli
Phytoplankton	Plant green pigment chlorophyll-a
Vegetation	Riparian vegetation cover and species richness
Saltmarsh	Saltmarsh cover and diversity
Aquatic fauna	Macroinvertebrates, fish and frogs
Visual	Instream, riparian and geomorphic condition
Weather related	Rainfall, water temperature, stream water level

The four sites in Victoria Creek were each sampled for water quality up to 19 times between March 2019 and October 2020 (**Table 4**). A detailed description of the sampling and analytical procedures for each indicator is provided in **Section 3.3** (water quality), **Section 3.5** (vegetation) and **Section 3.6** (saltmarsh).

Table 4 Dates and environmental variables for which sites on Victoria Creek were sampled on 19 occasions

D = samples were collected by department staff, C = samples were collected by a community volunteer.

Environmental indicators recorded	Trip-01 (19/03/19)	Trip-02 (07/06/19)	Trip-03 (30/07/19)	Trip-04 (12/08/19)	Trip-05 (26/08/19)	Trip-06 (19/09/19)	Trip-07 (08/10/19)	Trip-08 (21/10/19)	Trip-09 (04/11/19)	Trip-10 (20/11/19)	Trip-11 (02/12/19)	Trip-12 (17/12/19)	Trip-13 (21/01/20)	Trip-14 (11/02/20)	Trip-15 (24/02/20)	Trip-16 (23/06/20)	Trip-17 (18/08/20)	Trip-18 (29/09/20)	Trip-19 (19/10/20)
Collected by	D	D	D	C	C	D	C	C	D	C	C	D	D	C	D	D	D	D	D
Water quality-physico-chemical and nutrients	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
E. coli	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
Enterococci				✓	✓	✓	✓	✓			✓	✓	✓					✓	✓
Phytoplankton	✓	✓	✓			✓			✓			✓	✓		✓	✓	✓	✓	✓
Riparian vegetation						✓									✓				✓
Aquatic macroinvertebrates									✓										✓
Visual condition		✓				✓													✓
Water temperature and rainfall						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Freshwater macroinvertebrates were collected in spring 2019 and 2020 while fish and frog surveys were undertaken once in spring 2020. The vegetation data reported reflects the condition of the Victoria Creek between July 2019 and October 2020. The establishment of riparian vegetation and fencing continued throughout this monitoring period.

The data collection procedure at each site was as follows:

- collect water samples for analyses of nutrients, Chl-*a* (department staff only) and total suspended solids
- log water temperature, pH, conductivity, turbidity and DO using the ProDSS^{TM} multiprobe water quality meter
- measure alkalinity using the field titration kit (Hach Total Alkalinity test kit with 25 millilitres of sample and a low range solution (0.16 N sulfuric acid)
- photograph each stream reach (department staff only)
- collect and live-pick aquatic macroinvertebrates in accordance with AUSRIVAS protocols and undertake fish surveys (undertaken in spring and autumn seasons by department staff only)
- undertake frog call surveys (department staff only)
- visually assess the condition of the geomorphic, riparian zone vegetation and instream condition using a rapid reach assessment technique (department staff)
- survey and record riparian vegetation in two 20x20 metre plots (department staff only)
- download water level and water temperature data from data loggers (department staff only)
- undertake saltmarsh surveys (department staff only).

3.2 Water quality comparison and interpretation

A summary of all water quality data is presented as a box and whisker plot for each site (see **Sections 4.5–4.10**). Individual water quality data recorded during each sampling trip are also provided in **Appendix C**. Each box and whisker plot shows the minimum, maximum and median values for the entire period for which the indicator has been assessed (**Figure 2**). Outliers are indicated by a dot in the box and whisker plot. These are very large or small values compared to the interquartile range denoted by the middle box in the box and whisker plot. The interquartile range is a measure of the spread of the entire data set.

Any results reported as below the laboratory detection limit were included in the analysis as the minimum reported value.

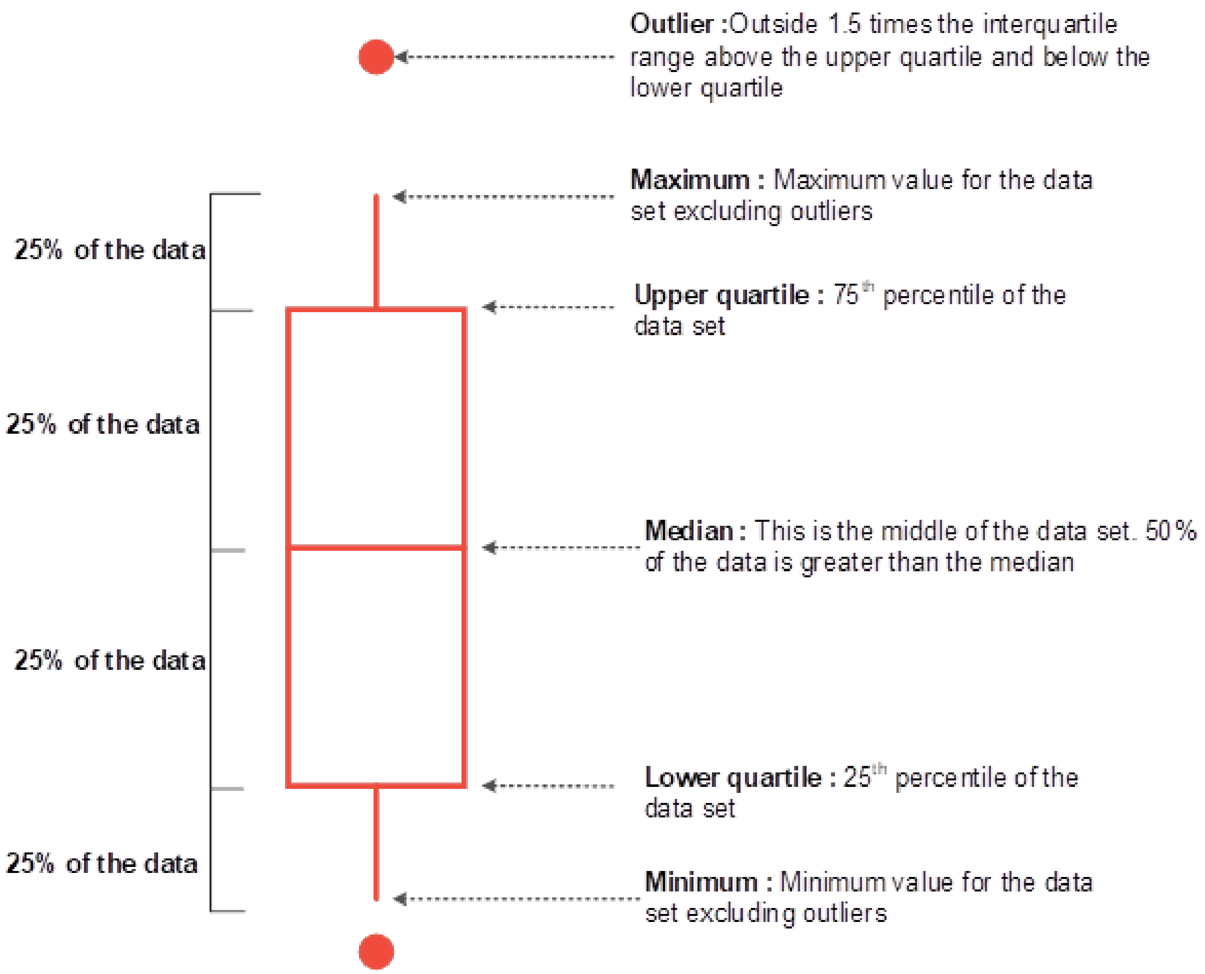


Figure 2 Interpretation of the water quality results using a box and whisker plot

The guidelines used for comparison of physico-chemical-biological data are from ANZECC/ARMCANZ (2000) for aquatic ecosystem health assessment, with the default trigger values adopted for lowland rivers in south-east Australia (**Table 5**). The trigger values are the 80th percentile values of reference site data and indicate 'concentrations of a chemical or nutrient that if exceeded have the potential to cause a problem and so trigger a management response' (ANZG 2019).

The three most upstream sites consisted of freshwater and for the purpose of this report, only water quality results for VC1, VC2 and VC3 are compared against the default trigger values. For pH and DO, upper and lower trigger value ranges are available and used for comparison.

The most downstream site, VC4 is located at the fluvial delta and tidally influenced when Tilba Tilba Lake is open to the ocean. The water at site VC4 can range from brackish to marine depending on the tidal cycle and estuary entrance conditions. The ANZECC/ARMCANZ (2000) default guidelines are not applicable to estuarine waters. The department has developed guidelines for estuaries although these are not applicable to streams that contain both saline and freshwater conditions. Therefore, site VC4 was not compared against the default trigger values.

The Tilba Tilba Lake entrance was opened to the ocean on 26 December 2018 and closed in August 2019. It opened again after 12 months in August 2020 for a short period and closed again in October 2020. When the lake mouth is open, the tidal movement influences the water quality at lower reaches of Victoria Creek.

Table 5 ANZECC/ARMCANZ (2000) default trigger values for lowland rivers in south-east Australia for aquatic ecosystem health used to compare water quality indicators from the freshwater sites VC1–3

Water quality indicators	Abbreviation	Unit	Default trigger value
Chlorophyll-*a*	Chl-*a*	(µg/L)	3.0
Total phosphorus	TP	(mg/L)	0.025
Filterable reactive phosphorus	FRP	(mg/L)	0.02
Total nitrogen	TN	(mg/L)	0.35
Nitrogen oxide	NO_x	(mg/L)	0.04
Ammonium	NH_4^+	(mg/L)	0.02
DO	DO	%	85–110
pH	–	–	6.5–8.0
Turbidity	TURB	NTU	6.0–50.0*

*Turbidity at the lower end is most likely from vegetated catchments at low flow conditions. The upper turbidity values are likely from slightly disturbed catchments at high flow conditions (ANECC/ARMCANZ 2000).

3.3 Water quality

3.3.1 Water clarity

Water clarity was assessed using three indicators: turbidity, total suspended solids and grain-size.

Turbidity is defined as the cloudiness of water caused by suspended and dissolved particles. It includes clay and silt, fine organic and inorganic matter, coloured organic compounds, algae and microscopic organisms. Increased turbidity reduces the aesthetic value of streams and light availability for instream macrophytes and macro and microalgal photosynthesis. It can also interfere with biological processes including development of fish egg and larvae, fish growth rates, and may cause blockage of gills (USGS 2008).

Measured values were compared against a turbidity default trigger value range of 6–50 NTU. Two other indicators, total suspended solids (TSS is the dry weight of suspended particles that are not dissolved) and grain-size of the sediment fraction (all particles less than 3 millimetres in diameter) were also assessed to better understand the causes of turbidity.

Water samples for TSS analysis were collected in 1 litre polyethylene terephthalate bottles. The containers were rinsed three times with water from the test sites before taking the final sample. TSS samples were chilled and kept dark during transport and stored prior to analysis in a cool room at 4°C. TSS analysis was conducted in-house using modified American Public Health Association method 2540-D (Eaton & Franson 2005).

The sediment layer up to 20 centimetres was sampled during two visits. At each site, 100 grams of five sediment samples were collected from three random locations within a site (**Photo 3**). Sediment samples were analysed using an LA-960 laser particle size analyser following the manufacturer's instructions (HORIBA Scientific, 2020a). The analysis only included less than 3 millimetre fraction and grain-size was allocated into a category based on sizes of soil separated according to the US Department of Agriculture classification system (HORIBA Scientific, 2020b).

Photo 3 Taking a sediment sample from VC2 and VC3 (U Pinto, October 2020)

3.3.2 Acidity

The acidity indicator group was assessed using two indictors: pH and alkalinity.

The pH in Victoria Creek was compared against the ANZECC/ARMCANZ (2000) default trigger values of 8.0 (upper) and 6.5 (lower). A suitable pH range relevant to the waterbody type (i.e. freshwater, estuarine or marine) is essential to support plant and animal life by maintaining biological availability of nutrients and metals. The pH in streams is influenced by factors such as geological formations of the bedrock, catchment run-off and wastewater discharge. A suitable pH range is essential to maintain healthy plant and animal life and determines the biological availability of nutrients and metals. A pH value ranging from 0–6 indicates acidic condition, 7 neutral and 8–14 alkaline.

Alkalinity is the water's capacity to resist changes in pH (buffer capacity). Alkalinity protects aquatic life against rapid pH changes in water. Alkalinity in freshwater systems originates from several sources including weathering of rocks and soils, ion exchange reactions in soil, atmospheric deposition of dust, evaporation and precipitation of minerals (Mattson 2009). The sum of carbonates, bicarbonates and hydroxides of calcium, magnesium, sodium and potassium determines the level of alkalinity (Brandt et al. 2016). Industrial discharges that include soap and detergents could also influence the alkalinity in freshwater systems. Precipitation has little direct effect on alkalinity (Mattson 2009). There is no trigger value for alkalinity; however, an alkalinity range from 20–200 milligrams per litre is typical for freshwater systems.

3.3.3 Salts

The salts indicator was assessed using a single indicator: electrical conductivity (EC).

EC is a measure of water's ability to pass electrical flow due to dissolved salts. As dissolved inorganic salt levels increase in water so does the EC. Both negatively (e.g. Cl^-, NO^{3-}, SO_4^{2-}, PO_4^{2-}) and positively charged ions (e.g. Na^+, Mg^{2+}, Ca^{2+}, Al^{3+}) are responsible for increased EC levels (USEPA 2012). The EC of a stream is influenced by catchment geology, groundwater inflows and various anthropogenic influences (Khatri & Tyagi 2015). The EC of marine water is over 50 times higher than that of freshwater due to the high concentration of dissolved salts in the ocean.

3.3.4 Oxygen

The oxygen indicator was assessed by the amount of DO in the water column.

Oxygen is critical for supporting a healthy aquatic ecosystem, by enabling respiration of aquatic organisms. Oxygen concentrations are affected by multiple factors such as rainfall, water depth, water and atmospheric temperature, salinity, pressure, turbulence, photosynthetic activity, time of day and amount of labile organic matter (O'Connor 1967; Wang et al. 2003; Wetzel 2001). As such the DO spot measurements, while useful, are difficult to interpret in isolation and should be used with caution.

The ANZECC/ARMCANZ (2000) default trigger value for DO saturation has a lower and upper limit of 85–110% and these were used to compare the observed values. The lower value is set to protect a wide range of aquatic species. For example, many Australian aquatic invertebrate taxa living in both upland and lowland streams have been shown to withstand very low DO levels (<10%) for generally up to five days (Connolly et al. 2004). This study further suggested that moderately poor DO concentrations (25–35% and 10–20%) affect the drift response of macroinvertebrates, which experience sublethal effects that may be detrimental in the long-term.

3.3.5 Nutrients

The nutrient indicator group consists of five indicators: total nitrogen (TN), oxidised nitrogen (NO_x), ammonium (NH_4^+), total phosphorus (TP) and filterable reactive phosphate (FRP). TN and TP are the total forms of nutrients while the remaining indicators are dissolved inorganic forms of nitrogen and phosphorus and are the most bioavailable. The total and dissolved forms of nitrogen and phosphorus were assessed in this study to better understand the current nutrient levels in the creek.

Nitrogen is an essential plant nutrient although presence in excess amounts could lead to eutrophication. Sources of nitrogen include fertilisers, industrial discharge and domestic wastewater. The TN is the sum of all dissolved (nitrate, nitrite, organic nitrogen and ammonia) and particulate forms of nitrogen. The ANZECC/ARMCANZ (2000) default trigger value of 0.35 milligrams per litre was used to compare the TN levels in streams.

NO_x is the sum of nitrate (NO_3^-) and nitrite (NO_2^-) in water. These, together with ammonia (collectively called dissolved inorganic nitrogen (DIN)), are the most bioavailable forms of nitrogen that can stimulate plant growth. NO_x is associated with fertiliser run-off, industrial discharge and oxidation of NH_4^+ in soil and water by nitrifying bacteria. In freshwater systems, increased NO_x levels can stimulate the growth of algae and other aquatic flora. During rainfall events, NO_x enters the streams through overland flows. The ANZECC/ARMCANZ (2000) default trigger value of 0.04 milligrams per litre was used to compare the NO_x levels in Victoria Creek.

We measured levels of NH_4^+ in Victoria Creek as it can be toxic to aquatic fauna and an ANZECC/ARMCANZ (2000) default trigger value is available for comparison. NH_4^+ co-exists with ammonia (NH_3) in aquatic systems. In aquatic environments, the un-ionic form NH_3 is dissolved in water to produce NH_4^+ and hydroxyl (OH^-) ions. The pH, water temperature and ionic strength determines the levels of NH_3 and NH_4^+. At high pH levels toxic NH_3 is produced and at low pH, toxic NH_4^+ ions are produced. Decaying organic matter, sewage and industrial effluent, and fertilisers are the common sources of NH_4^+ in waterways. Nitrifying bacteria also turn ammonia into nitrite and nitrate, which is captured through the NO_x indicator. The trigger value for NH_4^+ of 0.02 milligrams per litre was used to compare the NH_4^+ levels in Victoria Creek.

Phosphorus is an essential plant nutrient although its presence in excess amounts can lead to eutrophication. Phosphorus occurs in aquatic systems as orthophosphates, condensed phosphate (pyro, meta and polyphosphate forms) and as organic phosphate. These forms are either present as dissolved or suspended form attached to particles. The TP test undertaken for the water samples collected from the Victoria Creek detects all forms of phosphorus in water. Sources of phosphorus in streams include fertilisers, manure, cleaning products, industrial discharge, sanitary landfills and sewage effluent. Phosphorus also strongly attaches to soil particles, and large floods and overland flows could mobilise a considerable amount of phosphorus bound soil particles that then enter waterways. The ANZECC/ARMCANZ (2000) default trigger value of 0.025 milligrams per litre was used to compare the TP in Victoria Creek.

FRP is a measure of the amount of orthophosphate (PO_4^{3-}) in water and can be detected directly using the colorimetric method in a filtered sample. This is the form of phosphorus that is readily available for algae and plant growth. The ANZECC/ARMCANZ (2000) default trigger value of 0.02 milligrams per litre was used to compare the FRP in Victoria Creek.

In addition, dissolved organic nitrogen (DON) was calculated by subtracting DIN (sum of NO_x and NH_4^+) from total dissolved nitrogen (TDN); while dissolved organic phosphorus (DOP) was calculated by subtracting dissolved inorganic phosphorus (DIP) from total dissolved phosphorus (TDP) (Caffrey et al. 2007). DIP is equal to orthophosphates in water assessed as FRP following the APHA 4500-P-E-Ascobic acid method at the department's Soil and Water Environmental Laboratory.

At all sites, three water samples were collected for nutrient analysis. All sample vials were pre-labelled with the location, date, time and test analyte. One unfiltered sample was collected using a disposable syringe and transferred directly into a 30 millilitre autoclaved vial (Sarstedt™, Germany) for total nutrient analysis. Two additional samples were collected and passed through a 0.45 micron cellulose acetate syringe filter (Minisart®, Germany) into each of two additional tubes for total dissolved and dissolved inorganic nutrient analysis. All nutrient samples were immediately frozen and sent to a department Soil and Water Environmental Laboratory at Yanco New South Wales (Australia) for analysis. Samples were analysed using standard methods: nitrate and nitrite (APHA 4500-NO3-I -Cadmium reduction method), NH_4^+ N (APHA 4500-NH3-H: phenate method), FRP (APHA 4500-P-E-Ascobic acid method), TN, TP, TDN, TDP (APHA 4500-P-J: persulfate digestion method) (Eaton & Franson 2005).

3.3.6 Phytoplankton

Chlorophyll-*a* (Chl-*a*) is a plant pigment that converts light energy into chemical energy during photosynthesis. It is found in many plant groups including macroalgae and phytoplankton in surface waters. Chl-*a* concentrations in water are commonly used to estimate phytoplankton biomass. Phytoplankton communities respond to light, temperature and nutrient inputs. A high Chl-*a* concentration is usually an indication of increased nutrient enrichment (eutrophication) at the site or upstream.

To estimate Chl-*a* concentrations, a 110-millilitre water sample was taken from the stream and filtered in the field through a 0.45 micron glass fibre filter for Chl-*a* analysis. The filter paper was then frozen and returned to the laboratory for analysis of Chl-*a* concentration using modified APHA method 10200-H at the department's Water Studies laboratory (Eaton & Franson 2005).

The amount of Chl-*a* pigment detected through laboratory analysis is directly related to the amount of pigment present in water. The ANZECC/ARMCANZ (2000) default trigger value of 3 micrograms per litre was used to compare the Chl-*a* levels at all sites.

3.3.7 Bacteria

Two common indicators enterococci and *Escherichia coli* (*E. coli*) were used to assess the bacterial health of Victoria Creek. A positive test result for either indicator suggests faecal contamination of the waterway.

Enterococcus is a genus of gram-positive bacteria that live in the gastrointestinal tract of warm-blooded animals. The ANZECC/ARMCANZ (2000) primary contact recreational guideline value of 35 organisms/100 millilitres (lower value) was used to compare the enterococci in Victoria Creek. The enterococci were analysed using: *Method 14 – Enterococci count in water by Membrane Filtration* (AS/NZS 4276.9 – 2007: Water Microbiology – Enterococci – Membrane filtration method (ISO 7899–2:2000, MOD)) at a NATA accredited laboratory.

E. coli bacteria live in the intestines of warm-blooded animals. They are rod shaped, facultative aerobic bacteria, meaning they can thrive with or without oxygen. While there are many strains of *E. coli* bacteria, only some cause illness to humans. A positive test result indicates the presence of *E. coli* in the stream that has arisen from animal faecal matter. In freshwater systems, *E. coli* could survive up to four months with no fresh external inputs and the persistence could be prolonged by low temperature (Zoumis et al. 2001; Davis et al. 2005). In marine environments the survivability of *E.coli* is weakened by temperature, sedimentation and ultraviolet light (Orlob 1956; Rittenberg et al. 1958; Gameson & Saxon 1967). The ANZECC/ARMCANZ (2000) primary contact recreational guideline value of 150 organisms/100 millilitres was used to compare the *E. coli* concentrations in Victoria Creek. Medians of six samples were calculated and used in the comparison.

For the assessment of *E. coli*, a field rapid test kit with chromogenic media was used. The Coliscan test™ kits contained two special chromogenic substrates that react with two enzymes, galactosidase and glucuronidase, produced by *E. coli*. When the water sample contains *E. coli*, they will appear as dark/blue colonies on the media after the incubation period (35°C for 48 hours). *E coli* was used as an additional indicator to test the presence of faecal matter in the creek and no guideline values were used for comparison.

3.3.8 Training community volunteers

Prior to the field monitoring program, department staff delivered a training workshop (30 July 2019) to community volunteers and interested landowners explaining the sampling techniques, preservation and safety aspects of the monitoring program (**Photo 4**). A detailed step by step guide was also provided to the community describing these techniques. There were more than 10 attendees who observed and practised the procedures at site VC2. One of the trained community volunteers completed seven sampling trips, and these samples were frozen and stored until collection by department staff.

Photo 4 Community training workshop, July 2019 at site VC2 (U Pinto, 30 July 2019)

3.4 Visual assessment

All sites were visually assessed using a department developed rapid reach assessment (RRA) technique. During the assessment a 100 metre reach at each site was scored against a range of visual indicators relating to geomorphic, riparian and in-channel condition. Where some sections of stream had good riparian vegetation and there were some cleared or weedy patches, the assessment provided an average score for the whole reach, approximately 50 metres upstream and downstream of the water quality site. During each assessment, three metrics related to geomorphic condition, five metrics related to riparian condition, three metrics related to in-channel habitat features, and five metrics related to stream health issues were scored (**Appendix B**). Three visual assessment surveys were undertaken in July and September 2019 and again in October 2020 at each site using this categorical scoring system. The scores are presented in **Section 4.2**.

An aggregated score for geomorphic, riparian and instream conditions was calculated by summing three geomorphic, five riparian and four instream condition indicators. A high RRA score is associated with visually better geomorphic, riparian and in-channel conditions that support a wide variety of ecosystem functions.

3.5 Riparian vegetation

Initially, four sites were chosen to document changes in riparian vegetation: VC1, VC2, VC3, VCR1. VC1–3 were the same as the water quality sites, and all three sites have recently or will soon be fenced to exclude stock. VCR1 was initially selected as a reference site to act as a control for fencing (it will not be fenced); however, due to changes in the fencing strategy, the initial VCR1 reference site was fenced in June 2020, and so data will be used as additional ‘Before fencing data’.

From October 2020, two additional reference sites were sampled: VCR2 and VCR3. VCR2 is a control site for fencing (that is, it will not be fenced), and is located north of Sunnyside Road on a tributary flowing into Victoria Creek. VCR3, in Corunna State Forest, will act as the reference of 'vegetation greenness' for the remote sensing woody (tree) cover project component, and as a record of native species in an undisturbed–ungrazed state. This site was also used as a water quality site. The water quality site VC4 was not surveyed or sampled for changes in riparian vegetation as the vegetation community (saltmarsh) at this location is significantly influenced by saline water inputs from Tilba Tilba Lake.

3.5.1 Extant survey plots

Extant vegetation plots were surveyed to better understand the current species composition of the vegetation on Victoria Creek. A fixed and random 20 x 20 metre plot (**Photo 5**) was surveyed at each of the sites between 18–20 September 2019, 24–25 February 2020 (VC1, VC2, VC3, VCR1) and 19–23 October 2020 (VC1, VC2, VC3, VCR2, VCR3). Fixed sites were located at the water quality location (where appropriate), while the random plot was located using a random number system within 100 metres downstream of the fixed plot. Species presence, abundance and cover was recorded in each plot as required by the Biodiversity Assessment Method (OEH 2018; Sivertsen 2009). Growth forms of native species were assigned using the lookup table developed in the BAM calculator (OEH 2018). Voucher specimens were taken for most species. Each species was allocated to its water plant functional group (WPFG) and wetland plant indicator list (WPIL) status as identified in Ling et al. (2019). WPFG are groups of water plants based on the species responses to depth and water-level change (Casanova & Brock 2000; Casanova 2011) and adapted to incorporate life history (i.e. annual vs perennial) and life form (Capon & Reid 2016). The WPIL is a list of plants with a strong association with wet conditions that can be used diagnostically (Ling et al. 2019).

Photo 5 20 metre tape running through centre of 20 x 20 metre quadrat at VC2 (J Ling, 18 September 2019)

The PRIMER-E statistical package was used for the multivariate analyses of data including non-metric multidimensional scaling (nMDS), Analysis of Similarity (ANOSIM) and Similarity of Percentages (SIMPER) analyses (Clarke & Gorley 2006).

3.5.2 Soil seed bank

One of the hypotheses for the Victoria Creek project is that the exclusion of cattle from access to the creek will allow riparian vegetation (planted and native) to regenerate to improve the buffer zone and consequently the water quality of the creek.

Regeneration of riparian vegetation can be addressed using a number of strategies: planting, direct seeding, or natural regeneration from the seed bank. The LLS have supplied and coordinated the planting of native plants at each of the Victoria Creek sites. There is, however, a risk that these may perish. Where planting is successful, regeneration of native plants from the seed bank could also be used to complement the planted species to achieve optimal habitat complexity and diversity. Therefore, it would be efficient and cost effective if the underlying seed bank within Victoria Creek is also able to regenerate naturally with the exclusion of cattle.

Understanding the availability of both options for regenerating the creek will provide the community with more confidence that their investment in the project can achieve good restoration outcomes.

Study design

Surface soil samples were collected in February 2020 from three zones (A: instream, B: riparian slope, C: top of bank) within each of four sites along Victoria Creek (VC1, VC2, VC3 and VCR1, see **Figure 1**). In a plant growth laboratory, samples from each site and zone are currently subjected to two inundation treatments in a crossed three-factor analysis (site x zone x treatment), totalling 72 samples (4 sites x 3 zones x 2 treatments x 3 replicates). The treatments are: (a) rain, where soil is wetted daily and allowed to drain; (b) waterlogged, where the water level is maintained at soil surface; and (c) flooded, where the water level is maintained 100 millimetres above the soil surface. A waterlogged inundation regime has been shown to provide the highest species richness in previous germination trials (Kelleway et al. 2020), and was thus used for all experimental treatments. With this in mind, and due to the limitation of resources (space in the laboratory), the flooded treatment was only used for Zone A (instream) samples, and rain treatments were only used for Zones B and C. The glasshouse experiment will be continued for 6–12 months to enable time for plants to become established and identifiable. This duration is considered sufficient and is the commonly adopted duration for published seed bank trials. Once identified, seedlings will be recorded and removed.

Field sampling

At each site, 15 replicate cores of sediment (60 millimetres diameter, 100 millimetres depth) were taken randomly from the top layer from three zones, within a 100 metre stretch of the reach. Zone A was instream at Victoria Creek, Zone B was on the slope adjacent to the water, and Zone C was on the top bank. Each core from each zone (at each site) was pooled in a plastic bag and returned to the laboratory for processing.

Seed bank experiment

In the laboratory, each composite soil sample was handled according to the improved seedling-emergence method by Ter Heerdt et al. (1996): washing each sample with water on a coarse (4.0 millimetres width) sieve to remove roots, etc. and on a fine (0.212 millimetres width) sieve to remove clay and silt. Compared with unconcentrated samples, this method increases the number of species and individuals emerging from the samples and the germination rates of the species involved (Ter Heerdt et al. 1996). A total of 72 buckets (20 centimetres high, 20 centimetres in diameter) were prepared with vermiculite (Brunnings 5 litre vermiculite), perlite (Brunnings 5 litre perlite potting mix) and seed potting mix (Brunnings 15 litre coir seed raising potting mix block), and labelled with the site, zone, inundation treatment and replicate.

An additional three containers containing only soil preparation mixture and reverse osmosis (RO) water were prepared as controls (one container per treatment) to detect possible plant germinations from wind-blown propagates or impurities in the soil mixture. Holes were drilled in the base of the rain treatment buckets to ensure there was no accumulation of water in the base of the buckets. The residue (0.212 millimetres < material < 4.0 millimetres) of the washed soil samples was divided between the buckets for each site–treatment–replicate (**Figure 3**). Each bucket was watered with RO water to the experimental water inundation regime: flooded treatment buckets were filled to at least 100 millimetres above the top of the sediment; waterlogged treatment buckets were filled to no more than 5 millimetres above the top of the sediment; and rain treatment buckets had no standing water in the bucket. Each bucket was then covered with plastic food wrap to reduce the evaporation and create a greenhouse effect.

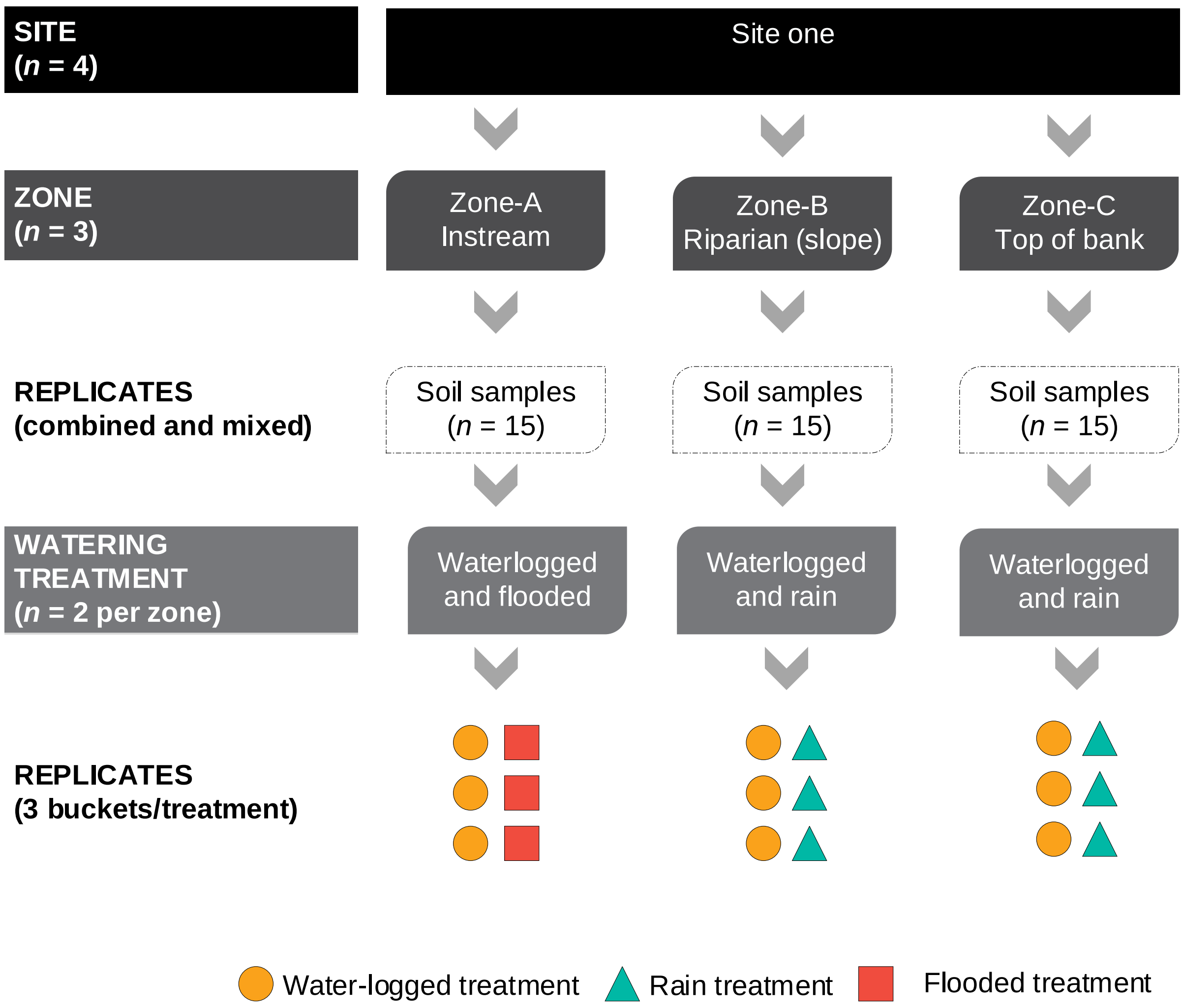


Figure 3 Experimental design for the soil seed bank study

The plant-growth laboratory lights were set for 12 hours during the day and were switched off overnight for 12 hours. The laboratory is airconditioned to keep the air temperature at 26°C. Photos were taken at least fortnightly initially, and then monthly over the experimentation period (**Photos 6–8**), as well as checking for water levels and identification. Once counted and identified, the entire seedling was removed to avoid self-seeding, and preserved as a dried voucher specimen.

Most remaining samples were harvested after 300 days.

Photo 6 Germination of seed bank from VC1 – Zone B – rain (J Ling, 14 April 2020)

Photo 7 Germination of seed bank at VC3 – Zone C – waterlogged (J Ling, 14 April 2020)

Photo 8 Potamogeton ochreatus germinated from VC2 – Zone A – waterlogged

Interestingly this species has not been recorded or observed at the site (J Ling, 2 April 2020)

3.5.3 Desktop assessment – catchment woody (tree) cover

Spatial analyses using GIS desktop techniques were completed to understand the extent of woody (forest and woodland) vegetation in the Victoria Creek catchment prior to initiation of the stock exclusion and riparian vegetation regeneration program. The development of this baseline dataset will enable future monitoring of the recovery of riparian vegetation tree cover at the stock exclusion sites, and assessment of the contribution of vegetation regrowth at these managed sites to catchment wide riparian and terrestrial vegetation cover and habitat connectivity.

All spatial analyses were completed using the ArcGIS 10.4 software package. First a catchment boundary and area for Victoria Creek was determined from a 5 metre LiDAR derived Digital Elevation Model using ArcGIS drainage basin tools. A state-wide woody vegetation dataset (2011) was then clipped to the catchment boundary. This dataset was then manually updated using the most recent high resolution (1.5 metre) SPOT satellite imagery (2019) to provide the area of woody vegetation for the whole catchment. Finally, the area of riparian woody vegetation cover was calculated by applying a 20 metre buffer to the mapped streamline dataset, and then clipping the woody vegetation cover spatial layer to this riparian buffer zone.

Table 6 outlines the spatial datasets and data sources used to map the Victoria Creek catchment and woody vegetation extent.

Table 6 Source datasets for analysis of woody vegetation extent

Dataset title	Custodian and source	Date accessed
Digital Elevation Model 5 m derived from LiDAR	Geoscience Australia elevation.fsdf.org.au	14/04/2020
NSW Woody Vegetation Extent and FPC	NSW Department of Planning Industry and Environment (DPIE) datasets.seed.nsw.gov.au/dataset/nsw-woody-vegetation-extent-fpc-20119bb42/resource/5f7c56f3-d619-4f99-b0be-004468bfcb01	09/04/2020
NSW Hydrography Hydroline	Department of Customer Service Spatial Services NSW maps.six.nsw.gov.au/arcgis/rest/services/public/NSW_Hydrography/MapServer	09/04/2020
SPOT 6/7 Imagery 2019 NSW	Department of Customer Service Spatial Services NSW Provided under a whole of government licence to NSW Department of Planning, Industry and Environment.	09/04/2020

3.6 Saltmarsh monitoring

This section describes progress of the saltmarsh monitoring theme, which aims to:
(i) investigate saltmarsh dynamics in this intermittently closed and open estuary, and
(ii) investigate the response of saltmarsh following the installation of new fences and planting of riparian vegetation.

Tilba Tilba Lake has two broad areas of saltmarsh, one on the south-eastern foreshore associated with the flood-tide delta at the ocean entrance and one on the north-eastern foreshore associated with the fluvial delta where Victoria Creek enters the lake (**Figure 4**). Saltmarsh areas along the western foreshore are narrow and restricted by steeper topography. Saltmarsh monitoring was focused on four sites: site 1 is the saltmarsh area situated on the fluvial delta, site 2 is the area situated on the flood-tide delta, site 3 is an area of saltmarsh occupying a small bay on the north-western foreshore, and site 4 is an area on the south-east foreshore.

Figure 4 Aerial photograph of Tilba Tilba Lake (courtesy: SIX Maps) showing areas of saltmarsh mapped previously by DPI Fisheries (DPIE 2008) as shaded areas and the location of the four saltmarsh areas being monitored in this study

Field methods

Monitoring of saltmarsh coverage and diversity has been done using the standard Daubenmire method (Coulloudon et al. 1999). A one-metre square quadrat was used to estimate percent coverage of species canopy. The same quadrat positions at each site were re-visited and this was achieved using an RTK-GPS system (**Photo 9**).

To date five saltmarsh surveys have been completed approximately seasonally, the first in April 2019 and then June 2019, September 2019, February 2020 and September 2020. Autumn and winter surveys in 2020 were missed due to COVID-19 restrictions.

A total of 193 quadrat locations were re-visited during each survey across the four sites: 51 at site 1, 63 at site 2, 47 at site 3 and 32 at site 4.

It is anticipated that any response of the saltmarsh to actions undertaken in the catchment will be significantly tempered by the natural saltmarsh dynamics associated with a fluctuating hydrological regime driven by the intermittent opening and closing of the lake entrance. Lake water levels have been monitored by NSW Manly Hydraulics Laboratory since commencement of the saltmarsh monitoring program, using a pressure logger installed in the lake and surveyed to the Australian Height Datum (AHD).

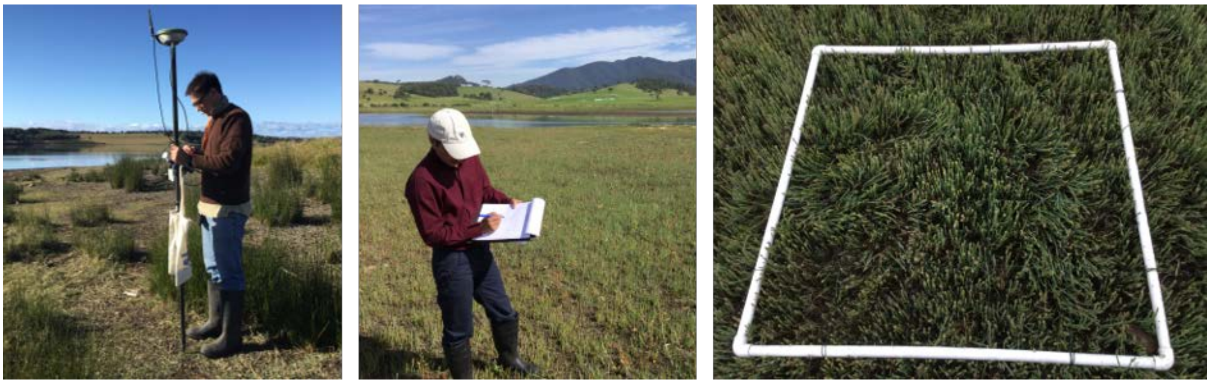


Photo 9 Photographs (left to right) of an observer using the RTK-GPS system, recording coverage of each species, and a one-metre square quadrat

Data analysis methods

We summarised all surveyed plots into community matrices (species x site), and all analyses were based on the community–species matrices. In compiling the community matrices, we excluded all weeds such as pasture grass and *Portulaca oleracea*.

Diversity profiles

To correct the bias caused by different sampling efforts/coverage, we calculated sample-size-based rarefaction and extrapolation of Hill numbers to infer 'true' species diversity (Chao et al. 2014). We used the iNEXT package (Hsieh et al. 2016) in R 4.0.3 (R core team 2020) to estimate three Hill numbers (or the effective number of species): richness ($q = 0$), which counts species equally without regard to their relative abundances; Shannon diversity ($q = 1$), which weights all species by their abundance without favouring either common or rare species; and Simpson diversity ($q = 2$), which discounts all but the dominant species and can be interpreted as the effective number of dominant species in a community. We reported the asymptotic analysis, which provides a comparison of estimated asymptotic or true diversities (Hsieh et al. 2016). The statistical significance of the diversity difference between sites was based on 1000 bootstrap replications.

3.7 Macroinvertebrates

Macroinvertebrates were collected following NSW AUSRIVAS sampling protocols (Turak et al. 2004). Ten metres of edge habitat was sampled using a 250 micron mesh D-framed net within 50 metres upstream and downstream of the monitoring station. All available habitats (i.e. logs, macrophyte beds, fringing vegetation and undercut banks) were sampled where present.

Samples were 'live-picked' in the field following the NSW AUSRIVAS protocols (Turak et al. 2004). The live pick was carried out in a tray using forceps and additional utensils for a minimum of 40 minutes per sample with the aim of collecting a representative sample of taxa present. Picking was extended for a further 10 minutes, up to a maximum of 60 minutes, if new taxa were found in the last 10 minutes of the picking process. Picked animals were placed into a jar of ethanol (85%) labelled with the site ID, sample date, sample habitat and initials of the staff who collected and picked the sample.

Macroinvertebrate samples were identified in the laboratory using a dissecting microscope following the NSW AUSRIVAS protocols (Turak et al. 2004), identified to family taxonomic level with the exception of Oligochaeta (class), Polychaeta (class), Ostracoda (subclass), Nematoda (phylum), Nemertea (phylum), Acarina (order) and Chironomidae (subfamily). All macroinvertebrates are identified using the taxonomic keys listed in Hawking (2000) or, where available, more recently published and accepted taxonomic keys.

3.7.1 Macroinvertebrate analysis

The macroinvertebrate community structure was assessed using four indices: taxa richness, EPT taxa richness, SIGNAL2-Family and AUSRIVAS. The underlying principles for each of these indices are different and provide multiple lines of evidence to better understand how the macroinvertebrate communities have responded to the stream condition on a spatio-temporal scale. When examined together, these indices are considered the best indicators of freshwater aquatic ecosystem health.

Taxa richness refers to the number of different macroinvertebrate taxa contained in a sample. This index considers variable level taxonomy where each taxon is unique and has no other specimens that have been identified to a higher taxonomic level. Taxonomic classifications are predominantly to family level with some exceptions as described in the procedures for identification above. The taxa richness index is a measure of total number of macroinvertebrate taxa sampled at a site. A high taxa richness score generally implies a healthy stream.

The EPT taxa richness index uses the sum of three orders of pollutant sensitive macroinvertebrate: Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) (Lenat 1988). The index can be reported as the number of unique EPT taxa (at family or higher levels) but can also be reported as the EPT ratio, a percentage the EPT taxa richness compared to the taxa richness for a given site. The EPT taxa richness indices are based on the principle that streams with persistently good water and habitat quality yield greater richness in more sensitive taxa.

SIGNAL is a biotic index based on pollution sensitivity grades assigned to aquatic macroinvertebrates and can be applied to the taxonomic level of order or family. This report used results of macroinvertebrate families as SIGNAL2-Family grades have been assigned for most families in south-eastern Australia. The SIGNAL2-Family grade is a number assigned to each family, ranging from 1 (tolerant) to 10 (sensitive) and was based on ecotoxicity data derived from published data and unpublished information (Chessman 2003). The SIGNAL2-Family scoring scheme is based on the approach of the British Biological Monitoring Working Party (Armitage et al. 1983). Families that have no assigned SIGNAL2 grade are excluded from the SIGNAL2-Family index calculations. Using an unweighted approach (discounting any taxa abundance data), the average of SIGNAL2 grades for each site is the SIGNAL2-Family score. A site that has high diversity and many sensitive macroinvertebrates will have a higher SIGNAL2-Family score. Low scores are associated with sites that are less diverse and dominated by pollution tolerant macroinvertebrate families. SIGNAL2 scores are often presented on a biplot with quadrant boundaries defined using guidelines by Chessman (2003). A biplot places the SIGNAL2 scores in context. Individual scores are plotted against the total number of families used to calculate SIGNAL2 scores and the possible explanation for each quadrant by Chessman (2003) was used to put the results in context.

AUSRIVAS is based on a predictive computer model originally developed for the National River Health Program in Australia and based on the River Invertebrate Prediction and Classification System developed by Wright (1997) for UK freshwater systems. The AUSRIVAS models developed for New South Wales compare test sites to reference sites with similar types of streams (based on comparisons of physical habitat) in the region (Turak et al. 2004). If the test site is lacking the macroinvertebrate families that are expected to occur according to model comparison of the reference site database, the test site is said to be impaired to some extent. An impaired result suggests the test site has been disturbed by human activities.

The AUSRIVAS model works by calculating the probability that test sites fall into reference site groups that are based on the physical habitat variables, and comparing the macroinvertebrate taxa observed (O) in a site sample with taxa expected (E) to occur with >50% probability. The resultant index is a ratio of observed to expected taxa called the

O/E50 and is considered a measure of biological impairment. A score close to 1 indicates the test site is equivalent to reference condition while the lower scores indicate the severity of impairment. O/E50 scores are compared with five bands representing different levels of biological condition. These bands represent the change from better than reference condition (Band X) to extremely impaired biological condition (Band D) (**Table 7**).

The derivation of band widths is based on the distribution of O/E50 ratios of reference sites used to create the AUSRIVAS models (DEC 2006).

Table 7 O/E50 thresholds and interpretation for the NSW spring edge AUSRIVAS model

Band	O/E50 thresholds	Label	Interpretation
X	>1.17	More biologically diverse than reference sites	More families found than expected Potential biodiversity 'hot-spot' Possible mild organic enrichment
A	0.84–1.16	Reference condition	Most/all expected families found Water quality and/or habitat condition roughly equivalent to reference sites Impact on water quality and habitat condition does not result in a loss of macroinvertebrate diversity
B	0.52–0.83	Significantly impaired	Fewer families than expected Potential impact either on water and/or habitat resulting in a loss of families
C	0.20–0.51	Severely impaired	Many fewer families than expected Loss of families from substantial impairment of expected biota caused by water and/or habitat quality
D	0–0.19	Extremely impaired	Few of the expected families remain Severe impairment

3.8 Frogs

Frogs are important ecological indicators as their lifecycle encompasses aquatic and terrestrial habitats, they have highly permeable skin and require specific microhabitats (Stebbins & Cohen 1997; Welsh Jr & Ollivier 1998). Frogs have been used in many bioassessments; for example, the response of frog communities to rainfall, flow regime, wetland condition and livestock grazing intensities, as well as how their densities influence the structure and function of tropical streams, which have been previously documented (Ocock 2013; Jansen & Healey 2003; Ranvestel et al. 2004).

The frog monitoring component was included in the program in October 2020. A frog call survey was conducted at sites VC1–3 during spring using an outdoor audio recorder (Song Meter Mini™ USA). The recorder was set approximately 5 metres away from the creek and was set to record hourly 30-minute audio recordings at a 96,000 Hertz sample rate between sunset and midnight. Data files were retrieved the next day and frog calls were identified to species and a rough estimate of abundance made.

3.9 Fish

Fish play important roles in aquatic ecosystems as consumers and often as apex predators within smaller lotic systems. They are important contributors to nutrient cycling, and with the potential to consume terrestrial as well as aquatic derived nutrients, fish can constitute the dominant biomass of consumers in the system and are important contributors to ecosystem metabolism. Fish are sensitive to changes in a wide range of environmental parameters including water chemistry (particularly DO concentration, salinity and pH), temperature, the presence of pollutants such as pesticides and other toxicants, and alterations to flow regimes or habitat destruction. Monitoring fish populations is relatively cost effective and a range of techniques such as netting, trapping, electrofishing, eDNA, and baited underwater cameras are available for this purpose. Fish were included in this monitoring program to track the improvements in the creek health and habitat quality as a result of on-ground works.

Photo 10 Setting up fyke nets at VC2 (U Pinto, October 2020)

As habitat conditions become more favourable, it is expected that more individual fish of more species will inhabit the creek system over time. Fish sampling was undertaken in spring 2020 as a once off screening survey.

Two downstream facing 4 millimetre mesh fyke nets were set for 24 hours at each site (**Photo 10)**. All captured animals were identified on site and subsamples of the first 50 individuals of each species were measured (total length in millimetres) and if sexually dimorphic, sexed. Additional animals were identified and counted prior to release. All native fish were released following capture and non-native species (such as *Gambusia holbrooki*) were euthanised in AQUI-S® (50 parts per million).

VC1–4 were sampled representing the regions downstream of, adjacent to and upstream of fencing and revegetation works.

3.10 Rainfall, stream water level and water temperature

The climate indicator group included rainfall, instream water level and temperature. These were assessed using Hobo data loggers at a fixed point across the four sites.

The closest rainfall gauge is located at Narooma and the rainfall recorded at this station was used to assess the wet weather condition at Tilba Tilba in conjunction with a rainfall gauge deployed at VC1, because local weather can vary considerably even at such small spatial scales. Narooma station (Lat: 36.21°S, Lon: 150.14°E, station number 69022) is maintained by the Bureau of Meteorology (BOM) and located approximately 7 kilometres away from Victoria Creek. The rainfall data logger was installed at VC1 in September 2019.

Stability of water temperature is critical to the health of fish, amphibians and macroinvertebrates living in the stream. Literature suggests that wooded riparian zones regulate large fluctuations in water temperature, particularly the maximum water temperatures in streams (Bowler et al. 2012). The baseline data collected will be useful to compare any future changes in the water column as a result of the riparian rehabilitation works.

Water level loggers (Hobo U20L-04) were deployed from August 2019 at each sampling site to assess the variation in water level. Water level was automatically recorded every six minutes (from October 2020 this was changed to 15-minute intervals) and converted to water depth by compensating for air pressure. From the logged data, a daily average value was calculated and visualised to understand the magnitude of change in water level in relation to rainfall.

4. Results and discussion

4.1 Rainfall, stream water level and temperature

4.1.1 Rainfall

The year monitoring began, 2019, was the driest in a decade (**Figure 5**). Annual rainfall at Narooma was 585 millimetres. The dry weather conditions during 2019 were consistent with El Niño episodes characterised by the Southern Oscillation Index (BOM 2020). In contrast, 2020 was a relatively wet year.

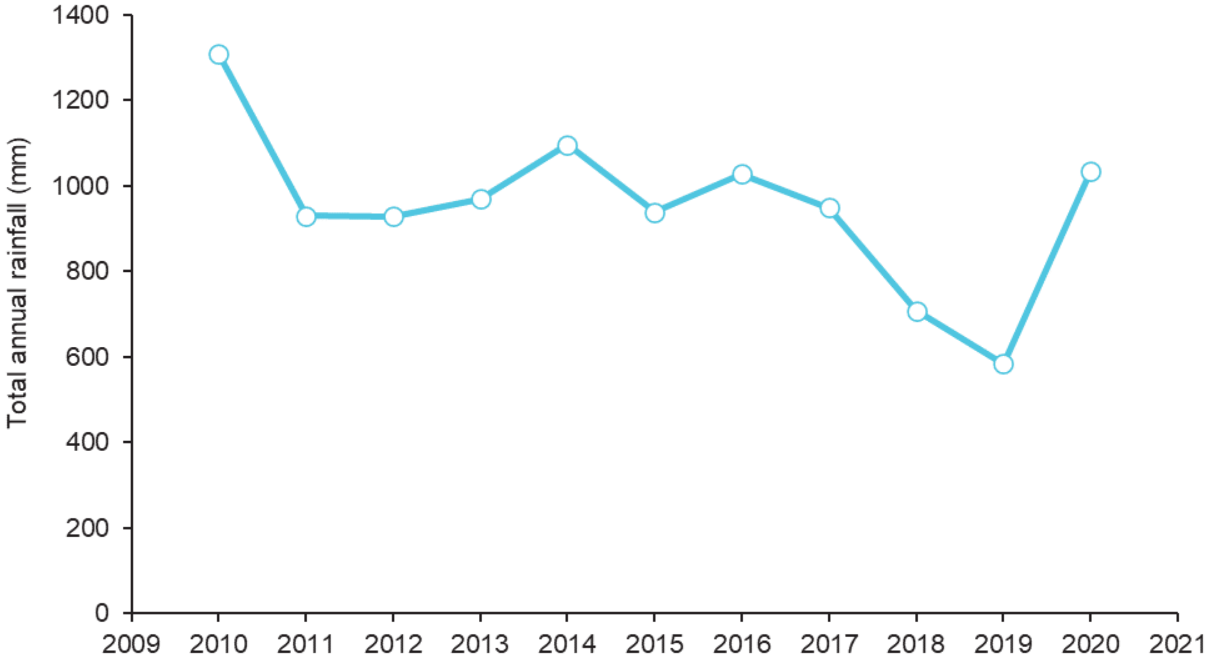


Figure 5 Total annual rainfall measured at Narooma BOM gauging station (station number 069022), 7 km from Victoria Creek

Rainfall data for the year 2020 is the sum of annual data until November.

When rain falls on the ground a proportion of it is absorbed into the surface and seeps into the groundwater reserves. The remaining water flows over the surface into the stream. A range of meteorological factors (e.g. rainfall intensity, rainfall duration) and physical characteristics of the surface (e.g. gradient, land use, vegetation cover, soil type) determine how much overland flow is generated.

Figure 6 shows total rainfall five days prior to undertaking water sampling. Trip 1 and trip 14 were preceded by enough rainfall to generate overland flows into the creek, although communication with landholders suggest that creek water levels increased only marginally following these rain events. It was also noticed following extended dry weather conditions that any rainfall below 20 millimetres did not generate overland flows.

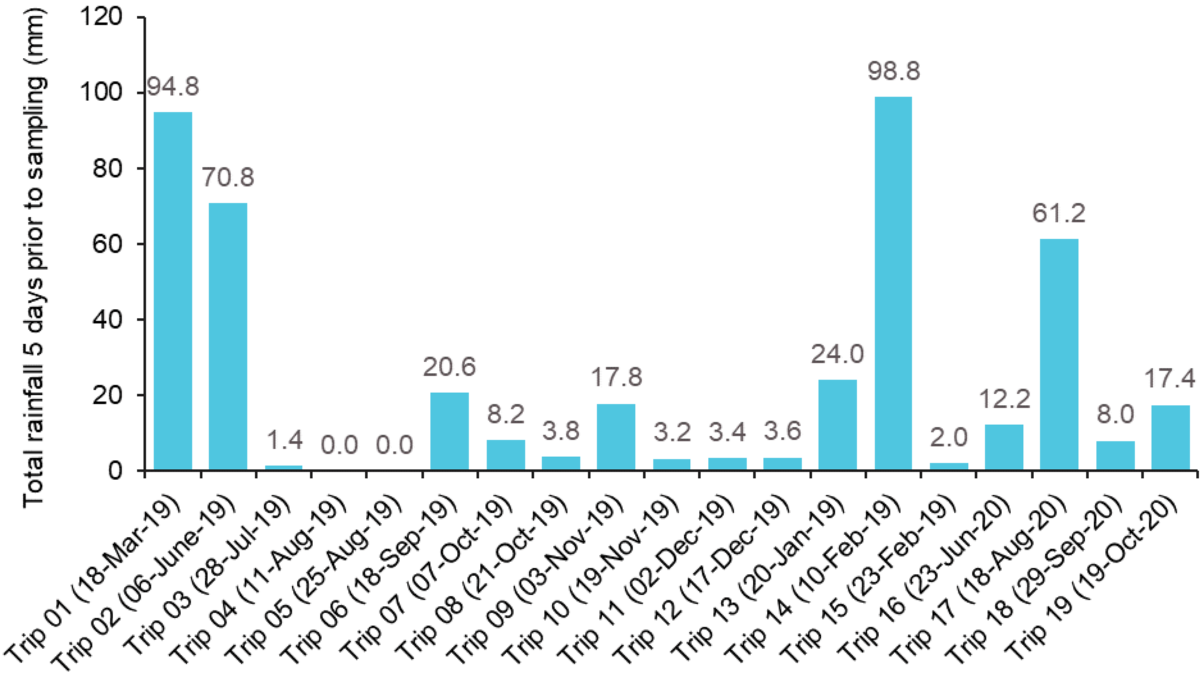


Figure 6 Total rainfall for five days prior to each sampling trip

Data prior to Trip 6 are based on records from Narooma BOM rainfall gauging station. Data from Trip 6 onwards are from a rain gauge deployed at site VC1.

The highest rainfall occurred on the 27 July 2020 (104 millimetres). The wettest months in 2019 were September and October receiving on average a total of 40 millimetres per month. The wettest month in 2020 was July (300 millimetres) followed by August (153 millimetres) and February (132 millimetres) (**Figure 7**).

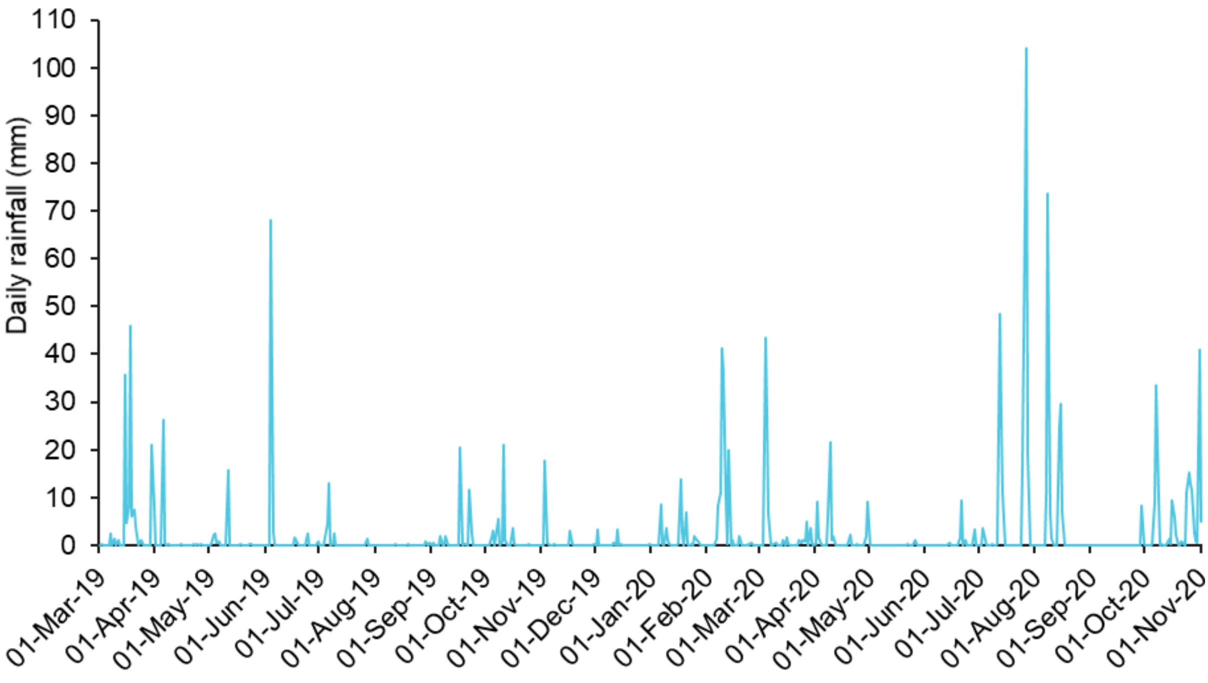


Figure 7 Daily rainfall recorded at site VC1

Data prior to September 2019 are based on records from Narooma BOM rainfall gauging station.

4.1.2 Stream water level

The stream water level data presented here are not intended for comparison between sites, but rather provide an indication of the magnitude of change in water level within each site.

Water levels were generally stable at each site and showed a declining trend from August to December 2019 corresponding to increased evaporation with little precipitation and inflow (**Figure 8**). Although the lake mouth closed in August 2019, the water level drop at VC4 was steady for another two months until October and dropped sharply in November.

There is a general pattern of rainfall over 20 millimetres generating overland flow as there are corresponding peaks in stream water levels; however, this pattern is not evident if the rain falls following an extended dry period.

Water level at three freshwater sites responded to rainfall in a similar pattern. Site VC4, being the most downstream site and the only site influenced by tides, was more responsive to large rainfall events than small events. Note the flat curve corresponding to 77 millimetres of rainfall from 5–7 May in 2020 and the peak corresponding to 104 millimetres rain on 27 July 2020.

The four sampling sites vary greatly in their geomorphology, riparian width and stream cross sections, which may explain the differences in the hydrographs at each site. It requires further investigation of the cross-sectional profiles and discharge at different points, to clarify where flooding may present issues such as bank instability and loss of riparian zones, and the likelihood of success of restoration activities.

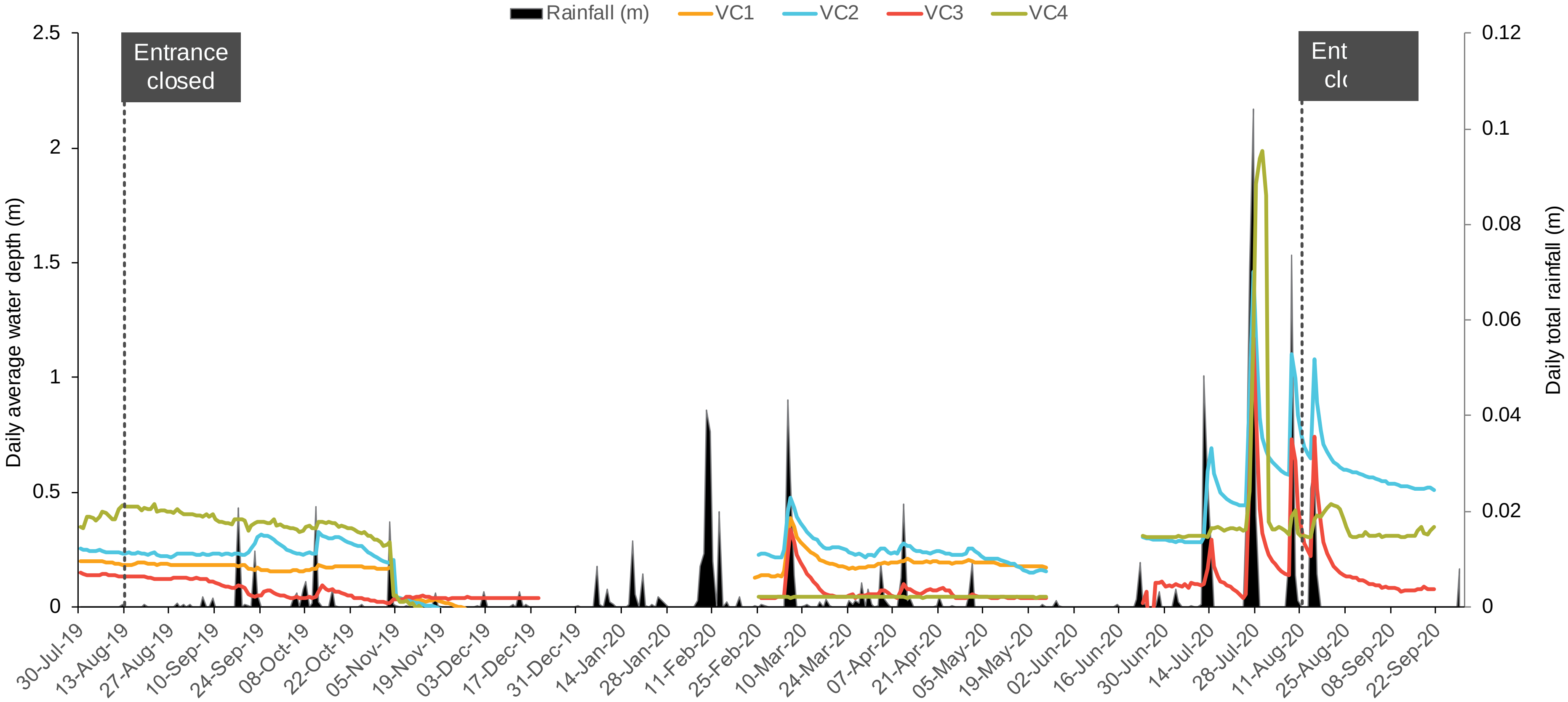


Figure 8 Water level data recorded at sampling sites VC1–4 using depth loggers deployed at each site between July 2019 and September 2020

Rainfall data are collected at the most upstream site VC1.

4.1.3 Stream temperature

Water temperature was monitored at each site using the temperature function in the water level loggers described previously. The data set presented in **Figure 9A–D** are related to logged data collected between 1 September 2019 and 21 September 2020 and include two spring seasons, and one summer, autumn and winter season.

On average, across all seasons, site VC4 had warmer waters than the three upstream freshwater sites; however, the minimum temperature across sites varied with the season. Colder water is denser than warmer water and the above observations create an ideal situation for thermal stratification at the mixing zone; however, it is unknown how the salinity and wind affect the stratification dynamics at fluvial delta and in the lake.

On average the diurnal temperature (difference between the maximum and minimum temperature) variation across all sites doubled during summer (~11^{0}C) compared with other seasons.

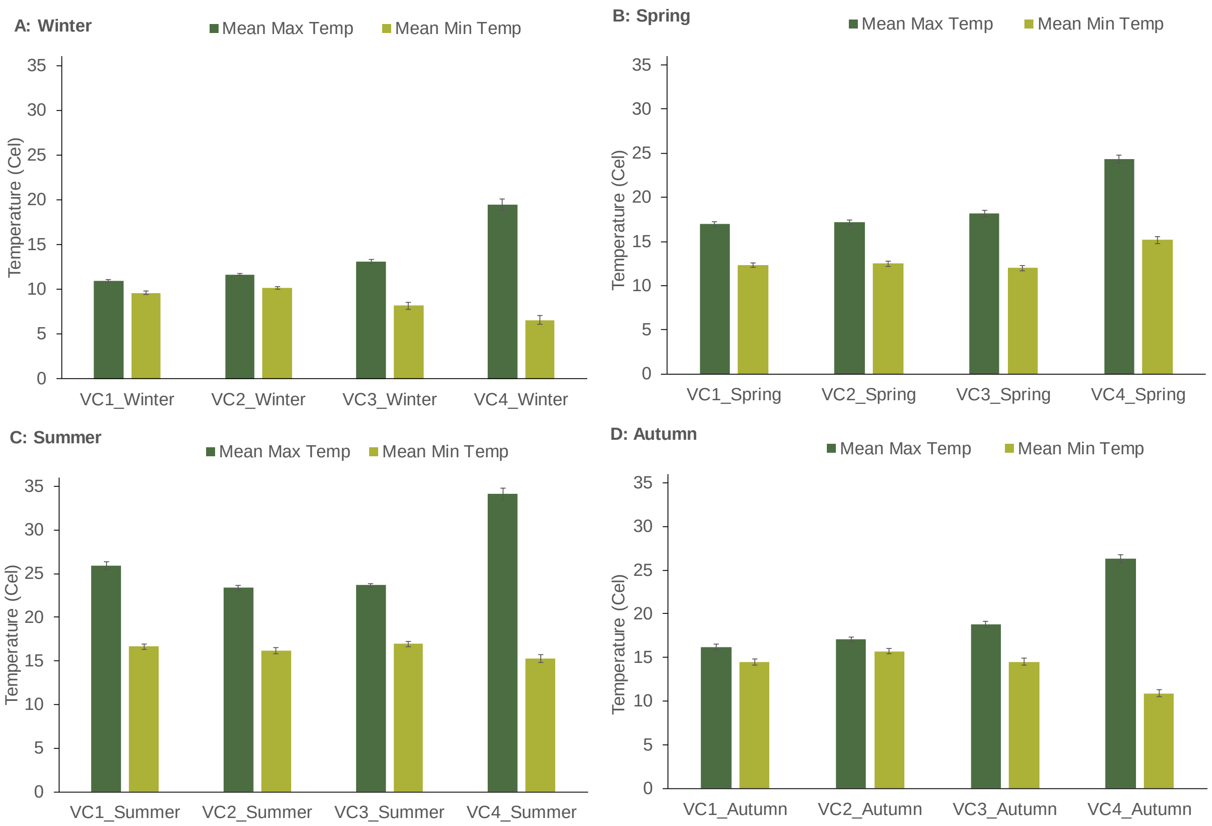


Figure 9 Mean maximum and minimum water temperatures across seasons: (A) winter, (B) spring, (C) summer, (D) autumn

Data set relates to 2019–20 September. Error bars represent ± standard error.

4.2 Visual assessment

Three visual assessment surveys were undertaken in 2019 and 2020. The scores provided in **Figure 10** are the averages of both years and provide a baseline for future comparisons**.**

Visual assessments indicated that geomorphological condition was low across all sites due to increased sedimentation, bank erosion and embeddedness (**Figure 10A, Photo 11**).

Riparian condition scores were also low across all sites and gradually declined towards the downstream sites due to reduced longitudinal continuity, riparian and canopy width, sparse shrub layer and groundcover (**Figure 10B**).

Instream condition was highest at VC1 and lowest at VC4 (**Figure 10C**). The lowest score was attributable to absence of macrophyte cover (emergent, submerged and floating types), leaf litter, large woody debris and in-channel habitat types. Five stream health issues were assessed on a binary scale (grease and oil, odours, rubbish, invasive weeds, filamentous green algae). On average, filamentous algae were present at all sites, invasive weeds at sites VC3 and VC4, odours at sites VC2 and VC4 and oil was noted at VC2. Rubbish was not present at any site.

Photo 11 Bank erosion at site VC4 (U Pinto, 4 November 2019)

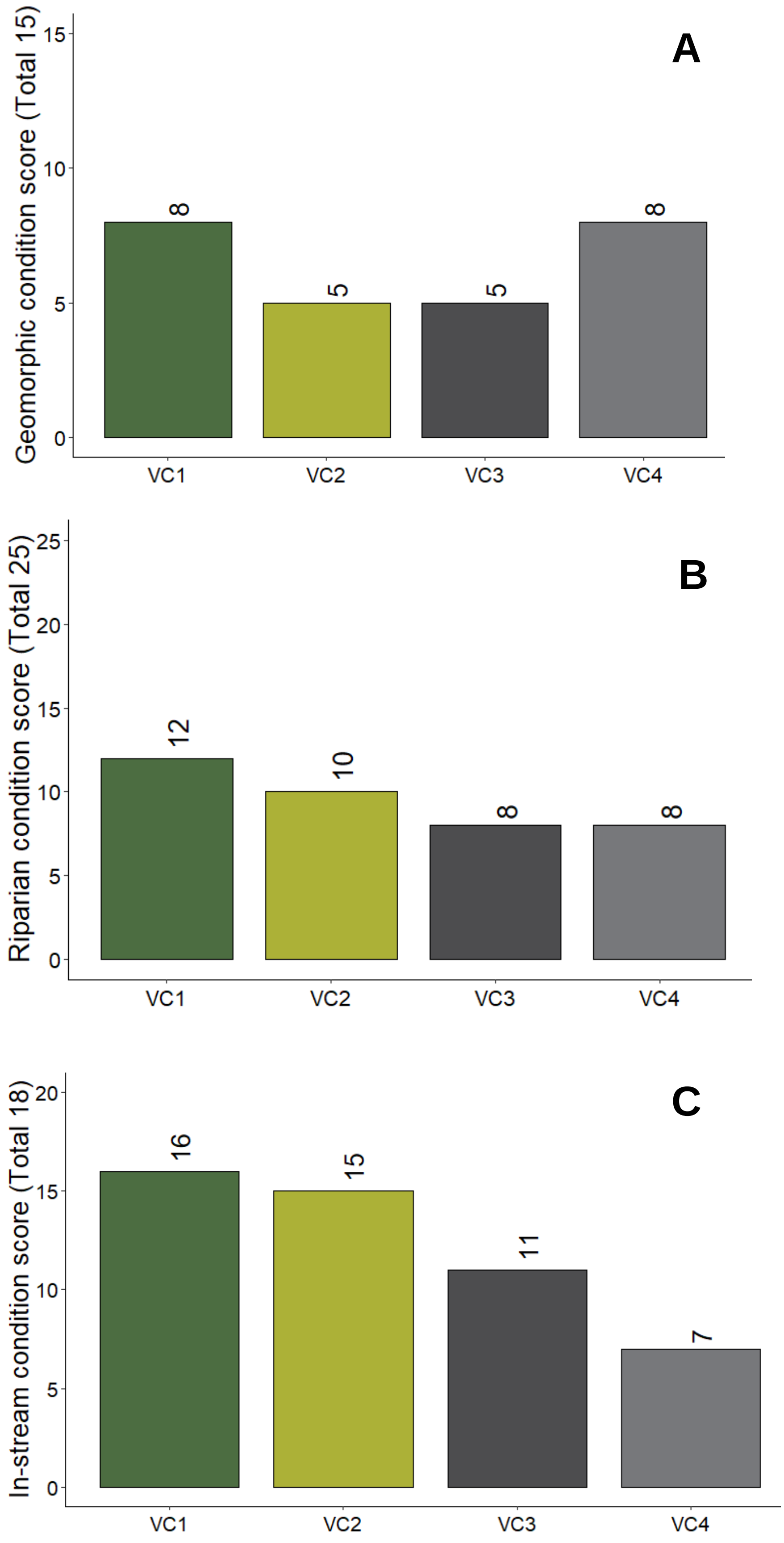


Figure 10 Mean visual assessment scores at four sites: (A) geomorphic condition, (B) riparian condition, (C) instream condition

Scores are averages of three surveys.

Photo 12 Photos of monitoring sites

(A) VC1, (B) VC2, (C) VC3, (D) VC4 (U Pinto, taken on different sampling trips in 2019).

4.3 Riparian vegetation

4.3.1 Extant survey plots (20 x 20 metres)

This riparian vegetation survey provides baseline data of the vegetation composition and cover along Victoria Creek at sites prior to fencing (except VC1) and the elimination of the presence of large ruminant animals (mainly cattle).

At the time of this baseline survey in September 2019, and February and October 2020, the landscape of Victoria Creek around the study sites could be described as a meandering creek surrounded by grazing pastures with little or no riparian vegetation, apart from non-native grasses (mainly kikuyu, *Cenchrus clandestinus*), some instream rushes, and limited tree and shrub cover. A total of 158 species were recorded with 90 native and 68 non-native species over the three survey times over six sites (**Appendix F**).

Generally, across all sites that had historically been exposed to grazing practices (VC1–VCR2), plot data show that the proportion of native and non-native species was more or less equal, and the vegetation cover of these sites was dominated by non-native grasses (predominantly kikuyu) (**Tables 8 and 9, Figure 11**). In contrast the 'ungrazed' reference site in Corunna State Forest (VCR3) was found to have only native species (100% native species).

Table 8 Number of species (native and non-native), proportion of native species and average cover of native and non-native species of random and fixed 20 X 20 m plots at sites surveyed in September 2019, February and October 2020

Fenced sites are VC1, VC2 and VC3. Reference and control sites were VCR1 (control for no fencing but was fenced in mid-2020), VCR2 (control for grazing), and VCR3 (reference site).

Site	Survey date	Total no. of species	Number of native species	Number of non-native species	% native species	Average % cover of native	Average % cover of non-native
VC1	Sep-19	40	23	17	57.5	29.6	91.7
	Feb-20	46	23	23	50.0	99.5	102.5
	Oct-20	35	19	16	54.3	67.5	81.5
VC2	Sep-19	41	24	17	58.5	49.7	46.9
	Feb-20	53	30	23	56.6	105.0	92.8
	Oct-20	53	26	27	49.1	117.8	163.0
VC3	Sep-19	30	14	16	46.7	6.6	86.7
	Feb-20	37	14	23	37.8	53.8	107.5
	Oct-20	41	15	26	36.7	58.4	126.6
VCR1	Sep-19	33	17	16	51.5	18.2	88.3
	Feb-20	32	14	18	43.7	27.9	107.7
	Oct-20	–	–	–	–	–	–
VCR2	Sep-19	–	–	–	–	–	–
	Feb-20	–	–	–	–	–	–
	Oct-20	23	13	10	56.5	83.3	87.8
VCR3	Sep-19	–	–	–	–	–	–
	Feb-20	–	–	–	–	–	–
	Oct-20	37	37	0	100.0	127.6	0.0

Table 9 Similarity of percentages (SIMPER) results of the vegetation cover (fourth root transformed data) highlighting the dominance of the non-native grass kikuyu (Cenchrus clandestinus) at all sites with a grazing history

The numbers indicate the % contribution of the species to either the total (a) cover or (b) species composition (presence–absence data) at each site. * = non-native species.

Species names	VC1	VC2	VC3	VCR1	VCR2	VCR3
(a) Species that dominated the vegetation cover						
Cenchrus clandestinus (Hochst. ex Chiov.) Morrone *	17.7	14.98	19.43	13.69	22.72	
Trifolium repens L.*				13.04	18.41	
Eucalyptus botryoides Sm.		10.17				
Cycnogeton procerum (R.Br.) Buchenau					18.41	
Typha domingensis Pers.					11.67	
Corymbia maculata (Hook.) K.D.Hill & L.A.S.Johnson						12.88
Carex appressa R.Br.						10.43
Gahnia radula						10.43
Lomandra longifolia Labill.						10.43
(b) Species that dominated the species composition						
Cenchrus clandestinus (Hochst. ex Chiov.) Morrone *	6.58	5.06	6.57	18.78	11.11	
Rorippa microphylla (Boenn. ex Rchb.) Hyl.*	6.58					
Trifolium repens L.*	6.58		6.57	18.78	11.11	
Senecio madagascariensis Poir*		5.06	6.57	18.78		
Rumex conglomeratus Murray*	6.58				11.11	
*Callitriche stagnalis**					11.11	
Persicaria strigosa (R.Br.) H.Gross	6.58	5.06	6.57			
Pteridium esculentum (G.Forst.) Cockayne	6.58					
Acacia mearnsii De Wild		5.06				
Dichondra repens J.R.Forst. & G.Forst.		5.06				
Isolepis prolifera (Rottb.) R.Br.		5.06				
Ludwigia peploides subsp. *montevidensis* (Spreng.) P.H.Raven		5.06	6.57	18.78		
Pteridium esculentum (G.Forst.) Cockayne		5.06				
Persicaria decipiens (R.Br.) K.L.Wilson		5.06				
Juncus usitatus L.A.S.Johnson			6.57	18.78	11.11	
Lemna disperma Hegelm.			6.57			
Paspalum distichum L.			6.57	18.78		
Schoenoplectus validus (Vahl) A.Löve & D.Löve			6.57	18.78		
Senecio madagascariensis Poir*						
Paspalum dilatatum Poir.				18.78		
Cycnogeton procerum (R.Br.) Buchenau					11.11	
Typha domingensis Pers.			6.57		11.11	

Species names	VC1	VC2	VC3	VCR1	VCR2	VCR3
Cotula coronopifolia L.					11.11	
Ranunculus sceleratus					11.11	
Acacia irrorata Sieber ex Spreng.						6.25
Acacia sp.						6.25
Billardiera mutabilis						6.25
Carex appressa R.Br.						6.25
Corymbia maculata (Hook.) K.D.Hill & L.A.S.Johnson						6.25
Dianella caerula						6.25
Entolasia stricta						6.25
Exocarpus cupressifolia						6.25
Gahnia radula						6.25
Glycine microphylla						6.25
Gonocarpus sp.						6.25
Lemna disperma Hegelm.						6.25
Lomandra longifolia Labill.						6.25
Pittisporum undulatum						6.25
Poa sieberiana						6.25

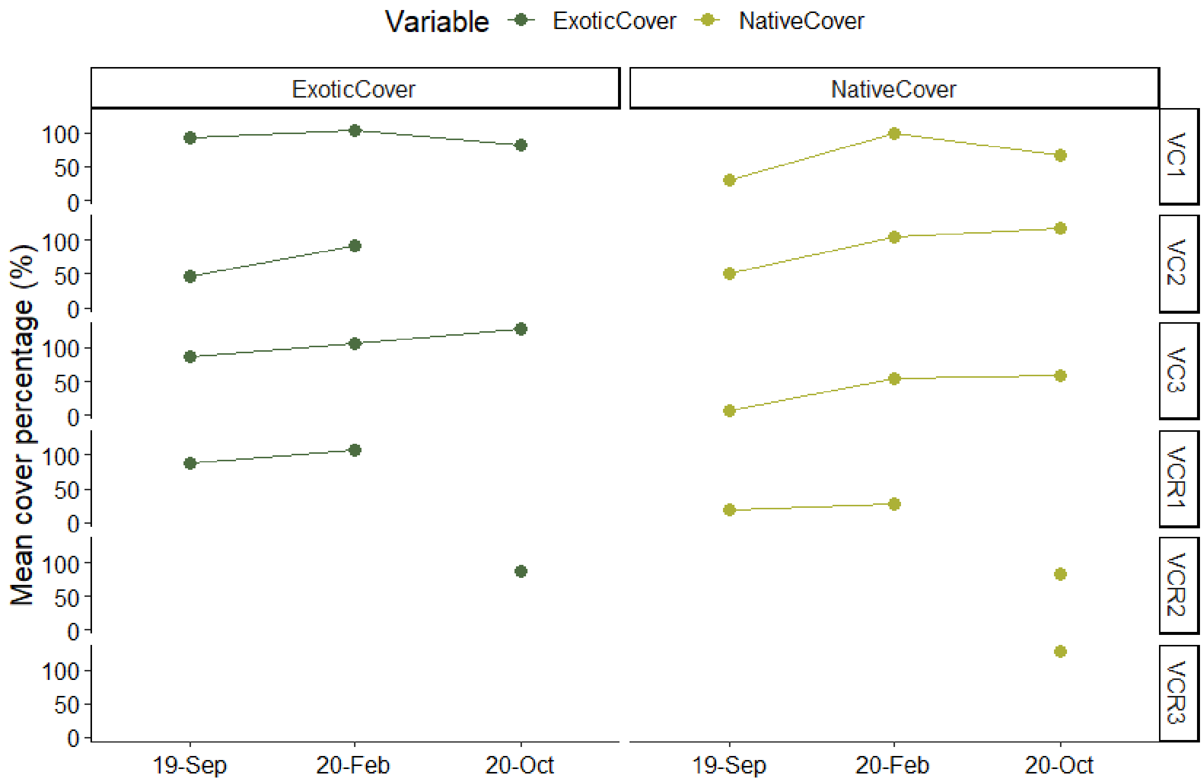


Figure 11 Plots of the average cover of native and non-native species in the baseline time periods prior to fencing

The SIMPER analyses identify species that characteristically dominate a site (**Table 9**). This highlights the dominance of non-native species at grazed sites both in the cover of the sites, and the number of species.

Pairwise analysis of each site to determine the similarity of the vegetation cover and species composition across sites showed significant differences between sites (ANOSIM, $p<0.05$), except between VC3, VCR1 and VCR2 (**Table 10**). This highlights the similarity between VC3, VCR1 and VCR2, which were all near site VC3 and within one kilometre of each other. This result was consistent for each time period (survey event), and when times were combined, and is also evident in the ordination (nMDS) and cluster analysis (**Figure 12**).

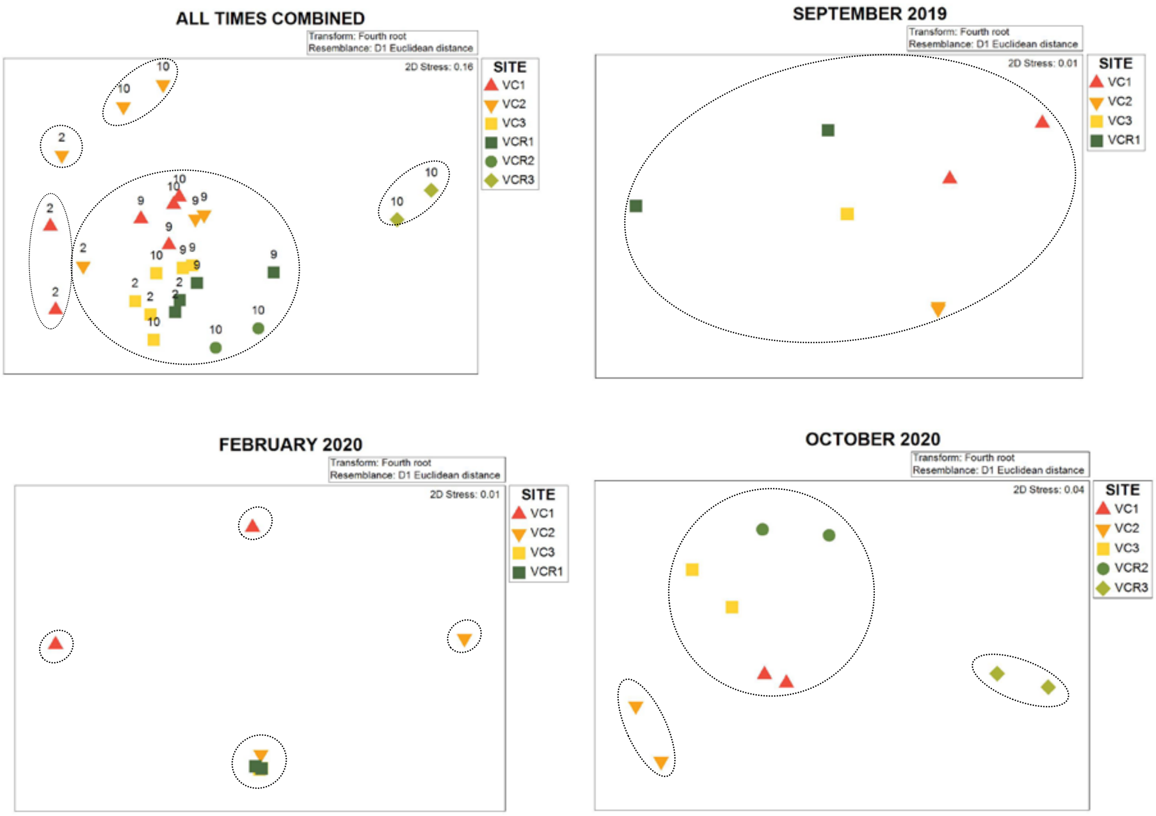
When all times are combined for vegetation cover data (**Figure 12a**), differences between seasons are notable (February samples are more different to September and October samples). Using presence–absence data (**Figure 12b**), the reference site in Corunna State Forest is shown to have a very different species composition to all other sites. Dotted lines highlight Bray-Curtis similarity at 65%, which is consistent with the ANOSIM results (1-way ANOSIM, $p>0.05$) that suggest vegetation plots (random and fixed plots) were more similar within each site than between sites.

The SIMPER analysis calculates the contribution of each species (%) to each site's uniqueness or which species contribute to the variations between sites that are shown to be different by ANOSIM analysis. That is, the SIMPER analysis identifies which plant species contribute the most to the differences between sites (**Table 9**); in terms of cover (**Table 9a**) or species composition (**Table 9b**). Sites with a grazing history are dominated by kikuyu in their cover, with VC2 also having an over storey of bangalay, and VCR2 having a higher cover of ribbon weed. The cover at VCR3 in the Corunna State Forest is unsurprisingly dominated by spotted gum.

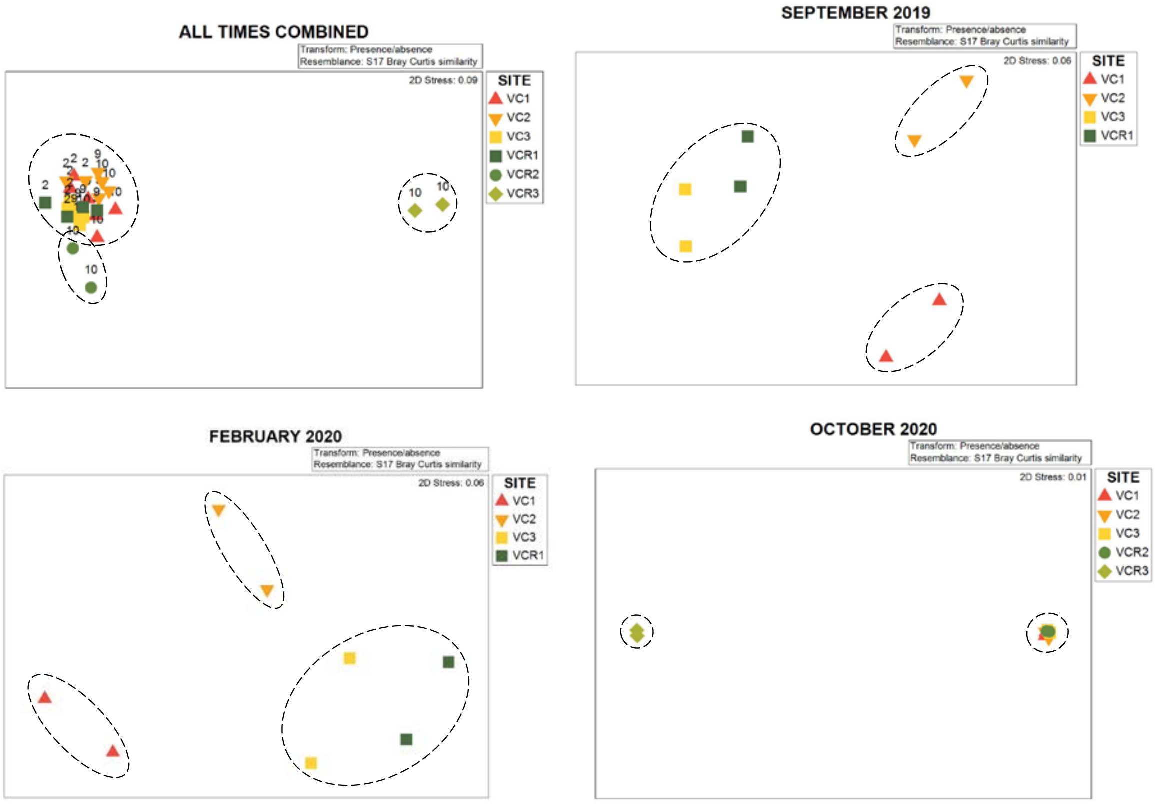
Table 10 Pairwise (ANOSIM) tests comparing the vegetation cover (%) and plant species composition (presence–absence data) between sites

This highlights the similarity between VC3, VCR1 and VCR2 which were all on the same property and within 1 km of each other. Bold indicates no significant differences (p>5%).

Groups	Vegetation cover		Vegetation species composition	
	R-statistic	Significance level (%)	R-statistic	Significance level (%)
VC1, VC2	0.309	0.6	0.451	0.2
VC1, VC3	0.507	0.2	0.517	0.2
VC1, VCR1	0.448	0.5	0.504	1
VC1, VCR2	0.677	3.6	0.333	10.7
VC1, VCR3	1	3.6	1	3.6
VC2, VC3	0.524	0.2	0.515	0.2
VC2, VCR1	0.329	3.3	0.389	2.9
VC2, VCR2	0.646	3.6	0.563	3.6
VC2, VCR3	0.927	3.6	0.99	3.6
VC3, VCR1	0.052	33.8	0.079	29
VC3, VCR2	0.823	3.6	0.552	3.6
VC3, VCR3	1	3.6	1	3.6
VCR1, VCR2	0.286	20	0.5	13.3
VCR1, VCR3	1	6.7	1	6.7
VCR2, VCR3	1	3.33	1	3.33



a.



b.

Figure 12 nMDS ordinations using (a) vegetation, and (b) presence–absence data of species for all times combined and for times separately

4.3.2 Seed bank experiment

Appendix G documents photographs taken of seed bank germination samples for each site, zone and replicate. Verification of seedling identification must be undertaken before final data analysis can be completed.

Preliminary results suggest that from 72 soil samples, 40 species germinated: 21 native species and 19 non-native species, after 300 days (31/12/2020) of growth. Of the 40 species, 20 species were identified as water dependant according to the WPIL (**Table 11**). Notably of the 20 water dependent species (WPIL <3.1), 17 species were native and only three were non-native species. Also notable is that these water dependent species germinated from all zones from the instream (zone A) to the top of the bank (zone C) at all sites. Further analysis of the soil seed bank data will be completed for the next report.

Table 11 Preliminary list of species that germinated from soil seed bank samples collected from four sites on Victoria Creek in February 2020 (samples harvested 30/12/2020)

Family	Species	Native/ non-native	WPIL	WPFG
Poaceae	*Axonopus fissifolius**	E	5	
Plantaginaceae	*Callitriche stagnalis* Scop.*	E	1	Atl
Asteraceae	*Conyza* sp (Retz.) E.Walker*^	E	5	
Plantaginaceae	*Cymbalaria muralis* G.Gaertn., B.Mey. & Schreb.*^	E	5	
Asteraceae	*Gamochaeta* sp.*	E	5	
Poaceae	*Holcus lanata**	E	5	
Cyperaceae	*Isolepis prolifera**	E	2	Arp
Cyperaceae	*Juncus articulata**	E	1.82	Ate
Malvaceae	*Malva sylvestris* L.*	E	5	
Fabaceae: Faboideae	*Medicago polymorpha* L.*	E	5	
Oxalidaceae	*Oxalis incarnata**	E	5	
Plantaginaceae	*Plantago major**	E	5	
Polygonaceae	*Rumex* sp*	E	3	
Asteraceae	*Senecio madagascariensis**	E	5	
Asteraceae	*Sonchus oleracea**^	E	5	
Caryophyllaceae	*Stellaria* sp.*	E	5	
Verbenaceae	*Verbena incompta**	E	5	
Malvaceae	*Malva* sp.*	E	5	
Fabaceae: Mimosoideae	*Acacia mearnsii*	N	3.92	Tdr
Pteridaceae	*Adiantum aethiopicum*	N	2.92	Tda
Alismataceae	*Alisma plantago-aquatica*	N	1.33	Arf
Dicksoniaceae	*Calochlaena dubia*^	N	3.65	Tda
Juncaginaceae	*Cycnogeton procerum* (R.Br.) Buchenau^	N	1.33	Se

Family	Species	Native/ non-native	WPIL	WPFG
Elatinaceae	*Elatine gratioloides* A.Cunn.	N	1.67	ATl
Cyperaceae	*Isolepis inundata*	N	1.97	ATl
Cyperaceae	*Juncus usitatus*	N	1.67	Ate
Araceae	*Lemna disperma*	N	1.33	ARf
Campanulaceae	*Lobelia anceps* L.f.	N	2.15	Tda
Phormiaceae	*Dianella caerulea* Sims^	N	5	
Plantaginaceae	*Ludwigia peploides* subsp. *montevidensis* (Spreng.) P.H.Raven	N	1.48	ARp
Poaceae	*Paspalum distichum*	N	1.34	Ate
Polygonaceae	*Persicaria decipiens*	N	1.33	ARp
Potamogetonaceae	*Potamogetan ochreatus*	N	1.33	Sk
Primulaceae	*Samolus valerandi*	N	3.65	Tda
Cyperaceae	*Schoenoplectus validus*	N	1.33	Se
Typhaceae	*Typha domingensis*	N	1.33	Se

Note: Identifications are only preliminary and have not been verified. * indicates non-native species; # indicates not recorded in extant surveys; ^ species identification requires confirmation. Water plant functional groups (WPFG) and wetland plant indicator list (WPIL) codes are from Ling et al. (2019). The WPIL codes are defined as follows: 1–2.99, wetland indicator species; 3–3.99, discretional wetland indicator; 4–5, non-wetland indicator species. A, annual; B, biennial; P, perennial; ARp, amphibious fluctuation responder – plastic; ATe, amphibious fluctuation tolerator – emergent; ATl, amphibious fluctuation tolerator – low-growing; ATw, amphibious fluctuation tolerator – woody; Se, perennial – emergent; Sk, submerged – perennial; Sr, submerged – annual; Tda, terrestrial damp; Tdr, terrestrial dry.

4.3.3 Desktop assessment – extent of forest and woodland (tree) cover

The GIS analysis provided an assessment of the drainage area (catchment) for Victoria Creek and evaluation of the extent of woody vegetation within this catchment. The catchment area of Victoria Creek above VC4 (the approximate tidal limit) was found to be 1135 hectares. Of this catchment area, 493 hectares (43%) was covered with woody vegetation in 2019. Most of the woodland and forest area is in the very upper catchment of Victoria Creek within the Gulaga National Park, and also in the north-east of the catchment at Corunna State Forest, where the land drains to an unnamed tributary before joining the very lower reaches of Victoria Creek.

Similarly, the riparian zone (the area within 20 metres of the mapped streamlines) was found to be 291 hectares. Of this area, 94 hectares (33%) was mapped as woody vegetation. The middle and lower reaches of the Victoria Creek catchment are where most riparian vegetation clearing has occurred; remaining vegetation patches are small and highly fragmented along these lower reaches of the creek. **Appendix H** shows the location and extent of woody vegetation across the Victoria Creek catchment and within the defined riparian buffer zone.

4.4 Saltmarsh

4.4.1 Lake water levels

Lake water levels are shown in **Figure13**. Prior to commencement of this record the lake re-opened after an extended period of closure on 26 December 2018 and remained open through to the commencement of this record (M Stubbings, personal communication). Prior to the 26 December opening it is anticipated that most of the saltmarsh would have died off due to the extended period of inundation.

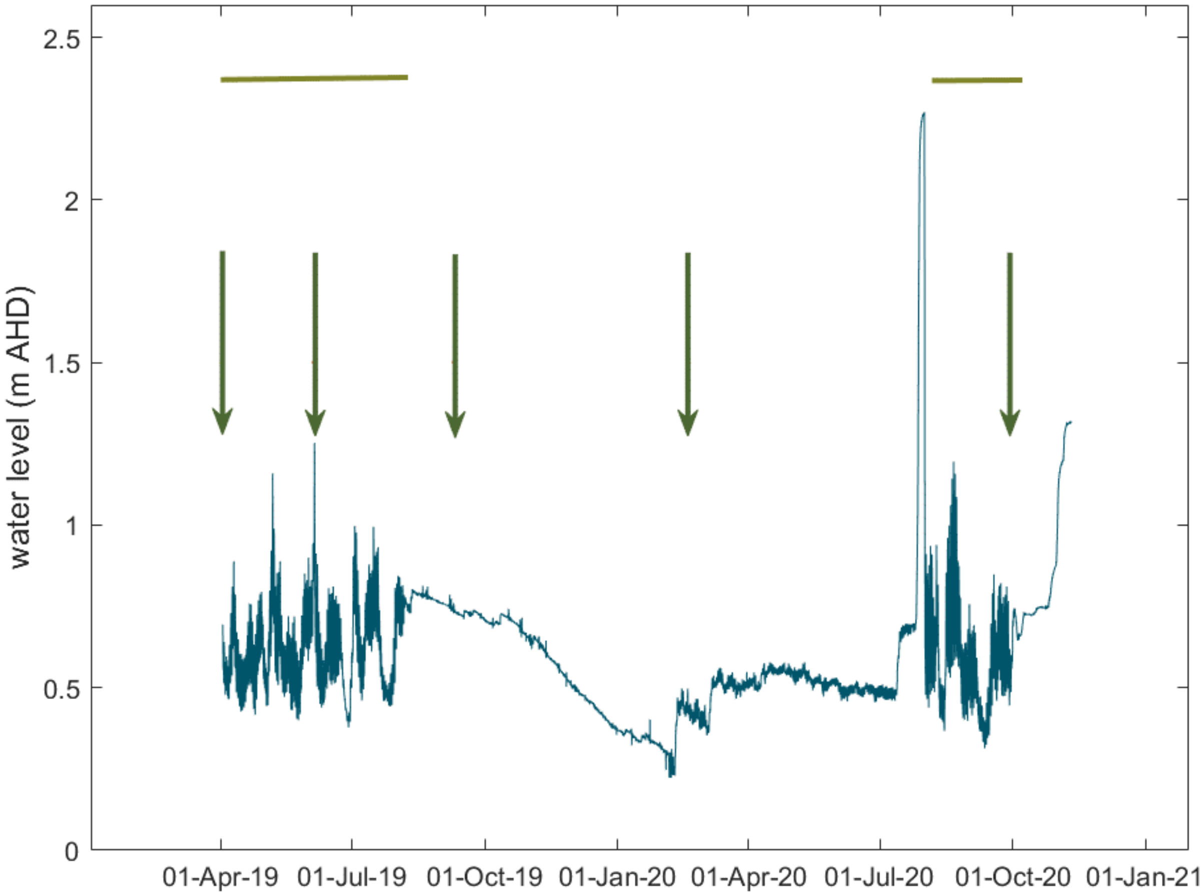


Figure 13 Water level record (blue line) for Tilba Tilba Lake showing times of saltmarsh surveys (arrows) and periods when the lake entrance was open to tidal exchange (horizontal lines)

For the remaining periods the ocean entrance was closed and lake water level changes were due to catchment inflows only.

The first two saltmarsh surveys were performed when the entrance was open and the lake was tidal. The following two surveys were performed when the entrance was closed, the first when the water level was in the intertidal range for open entrance conditions and the second when the water level was lower. The fifth survey was again during open entrance conditions with tidal exchange (**Figure 13**).

The elevation ranges for the saltmarsh sites 1 to 4 are 0.72–1.97 metres AHD, 0.69–1.88 metres AHD, 0.72–1.86 metres AHD, and 0.69–1.60 metres AHD, respectively. During periods when the entrance is open tidal fluctuations in water level regularly inundate the lower part of the elevation range occupied by saltmarsh. The upper part of the saltmarsh elevation range is only inundated during closed entrance conditions and elevated lake water levels from catchment inflows. Thus, the lower saltmarsh is likely to be inundated by lake water with a maximum salinity approximately equal to ocean salinity, whereas the upper saltmarsh is likely to be inundated by brackish lake water due to dilution from catchment inflows.

4.4.2 Saltmarsh coverage

The amount of saltmarsh coverage in Tilba Tilba Lake at any time is expected to be influenced by seasonal growth cycles and the naturally fluctuating hydrological regime associated with the ocean entrance dynamics and catchment inflows. In addition, saltmarsh coverage is impacted by grazing pressure; for example, cattle tracks and pug marks modify local inundation, soil compaction and soil moisture characteristics that all have an impact on saltmarsh coverage and condition (**Photo 13**).

Figure 14 groups the quadrat results by sites 1 to 4 and by surveys through time 1 to 5 and shows various statistics for the percentage of bare ground. The most obvious trend in the data across all sites is a reduction in the median percentage of bare groundcover in surveys 4 and 5 compared to the earlier three surveys. Compared to survey 3 this reduction is significant at the 95% confidence level at sites 1, 3 and 4.

There is also a clear change in the interquartile range of percentage bare groundcover between surveys 3 and 4 at sites 2 and 3. These are the two sites most impacted by grazing during the first half of 2019. Further work to investigate the relative roles of lake hydrology and fencing on the percentage of saltmarsh cover in the quadrat data continues, since more data is required to separate these effects.

Photo 13 Photographs showing the impact of cattle on saltmarsh coverage and condition: (A) cattle tracks, (B) pug marks, (C) and (D) grazing

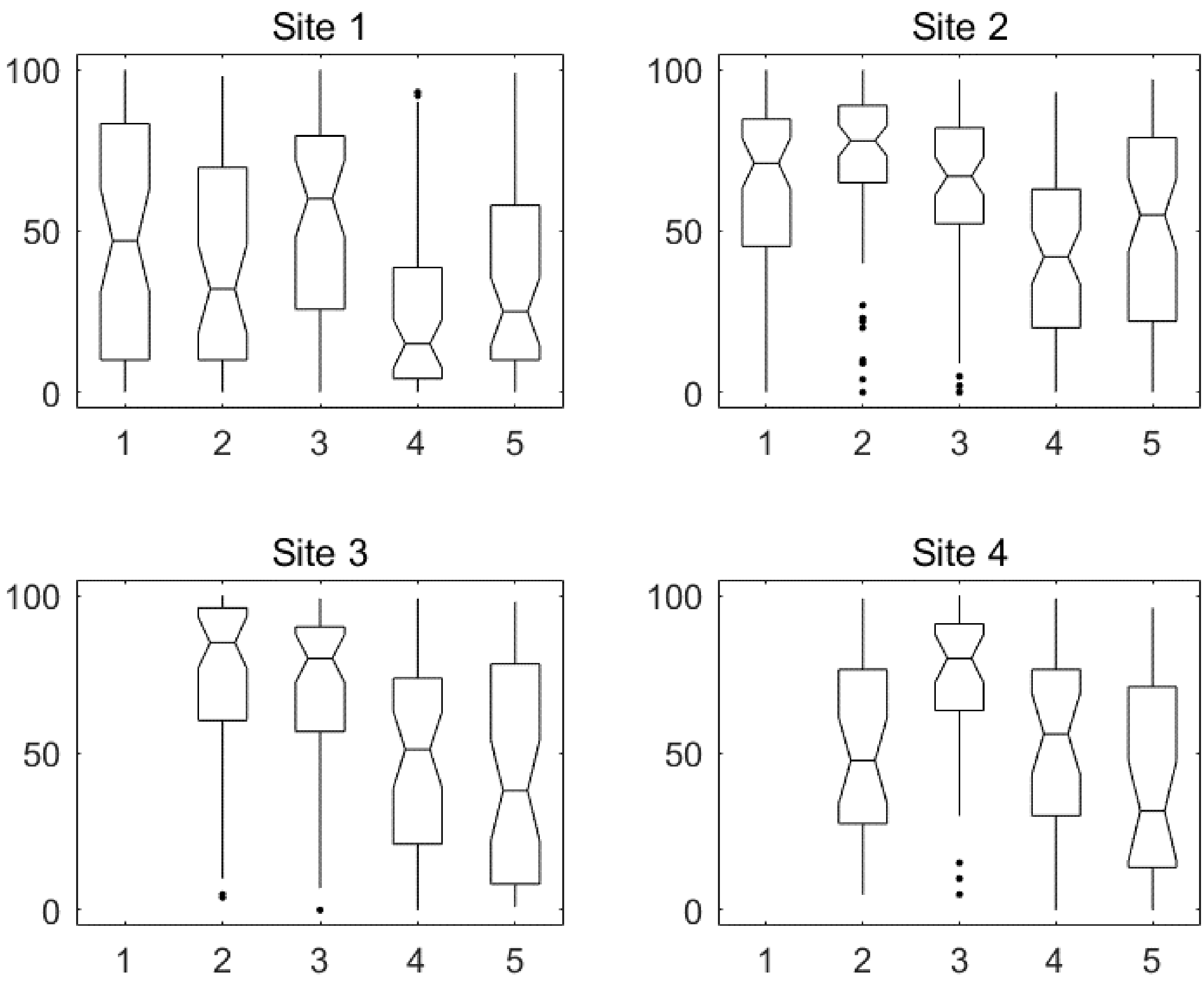


Figure 14 Box and whisker plots of the percentage cover of bare ground at survey sites 1 to 4 across the five surveys through time

The horizontal line is the median percentage of bare groundcover, and the notch is the 95% confidence interval about the median. There is no significant difference between the medians if the notches overlap. The maximum and minimum boundary of the box is the interquartile range of the data distribution. The whisker lines represent the expected data range for a normally distributed sample and the dots are outliers from a normally distributed sample.

4.4.3 Differences in species cover among sites and seasonal species cover dynamics

The saltmarsh species found at Tilba Tilba Lake over the survey period are:

- *Apium prostratum*
- *Baumea juncea*
- *Chenopodium* spp. (x5)
- *Cotula coronopifolia*
- *Cyperaceae polystachyos*
- *Ficinia nodosa*
- *Juncus kraussii*
- *Phragmites australis*
- *Portulaca oleracea*

- *Sarcocornia quinqueflora*
- *Selliera radicans*
- *Sporobulus virginicus*
- *Thyridia repens*
- *Triglochin striata*.

All communities showed temporal changes in structure in terms of the dominant species and their coverage (**Figures 15 to 17**). In general, the annual *Apium prostratum* increases its coverage and dominance after generating in spring until autumn, after which it dies off and disappears from many plots in winter. *Chenopodium* spp. has a similar lifecycle except it can remain dominant in some sites until winter. In contrast, the perennials, such as *Sarcocornia quinqueflora*, *Selliera radicans* and *Sporobolus virginicus* can retain relatively constant coverage if not grazed (e.g. site 3). Other perennials, like *Phragmites australis* can increase their coverage during a year.

In spring, *Sarcocornia quinqueflora* was the dominant species at sites 1 and 4 with average coverage of 28.4% and 33.0%, respectively. Site 3 was predominantly covered by *Sporobolus virginicus* (28.8% mean coverage); *Selliera radicans* (14.4%) and *Sarcocornia quinqueflora* (12.0%) were the most abundant species in site 2 (**Figure 15**).

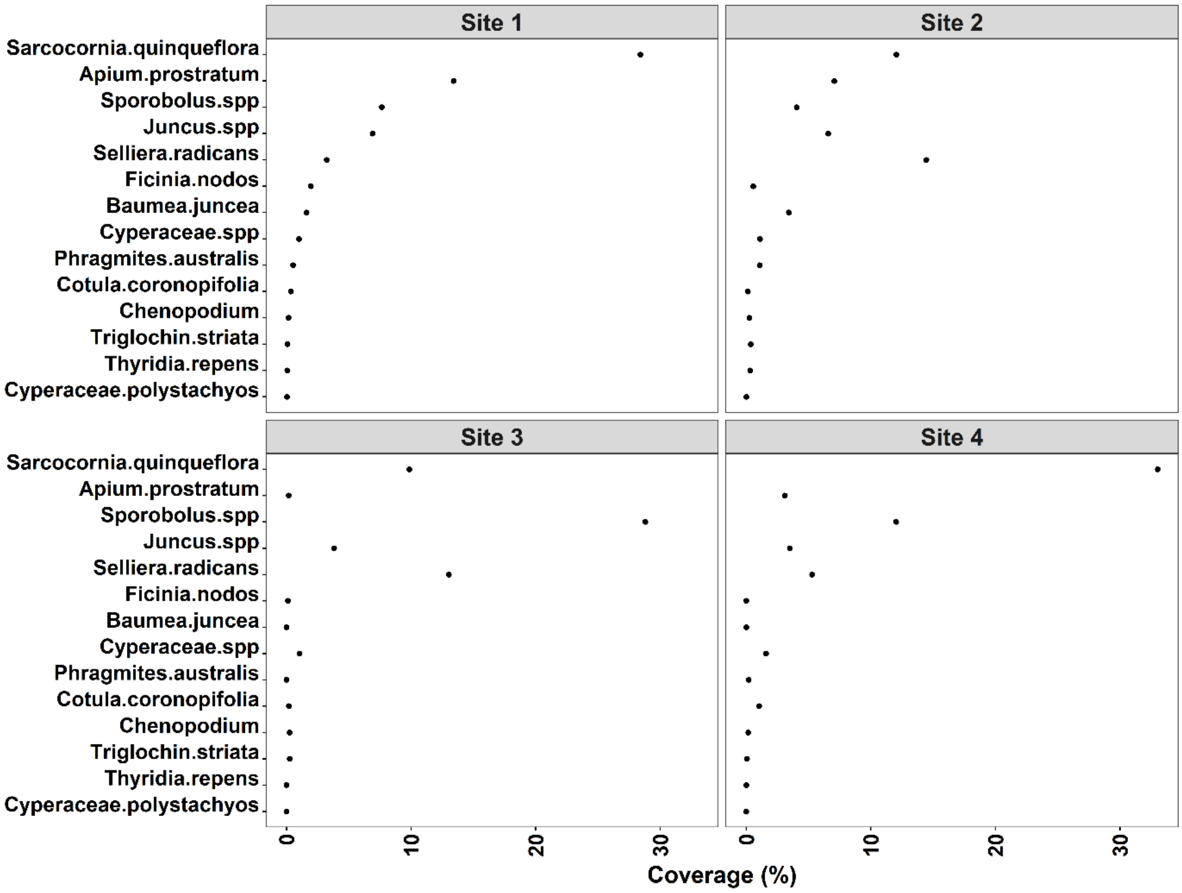


Figure 15 Distribution of plant species abundances in saltmarsh in spring (surveyed on 30 September 2020)

In summer, while the most abundant species at sites 1, 3 and 4 remained unchanged, *Apium prostratum* replaced *S. radicans* and became the most abundant, having mean coverage of 17.4%, while the mean coverage of *S. radicans* stayed more or less the same (13.8%). While the losses and gains were different for each site, the coverage of *S. radicans* was reduced at all sites.

In autumn, we had survey data for two sites only. While *S. quinqueflora* (20.7%) kept its dominance at site 1, The coverage of *Chenopodium* spp. increased dramatically, becoming the second dominant species (17.0%). *Chenopodium* spp. (12.1%) also became one of dominant species together with *Juncus* spp. (13.6%) at site 2 (**Figure 16**).

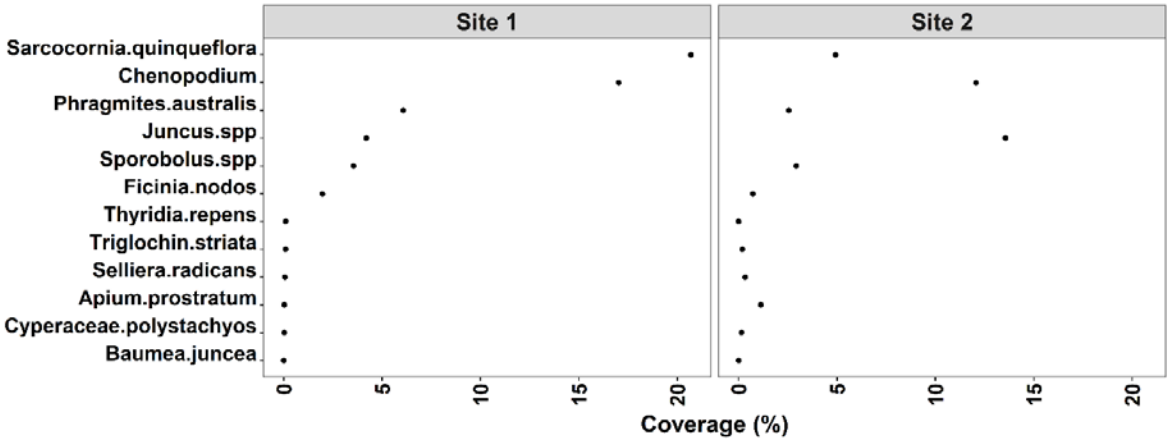


Figure 16 Distribution of plant species abundances in saltmarsh during autumn (surveyed on 2/04/2019)

Note only two sites were surveyed.

In winter, the dominant species at site 1 were *S. quinqueflora* (24.2%) and *Chenopodium* spp. (12.2%). *Baumea juncea* took over *Juncus* spp. as the most abundant species (12.3%). At site 3, saltwater couch maintained its dominance (15.7%), and was far more abundant than other species (**Figure 17**). At site 4, *S. radicans* (20.2%) and *Chenopodium* spp. (18.8%) were the dominant species.

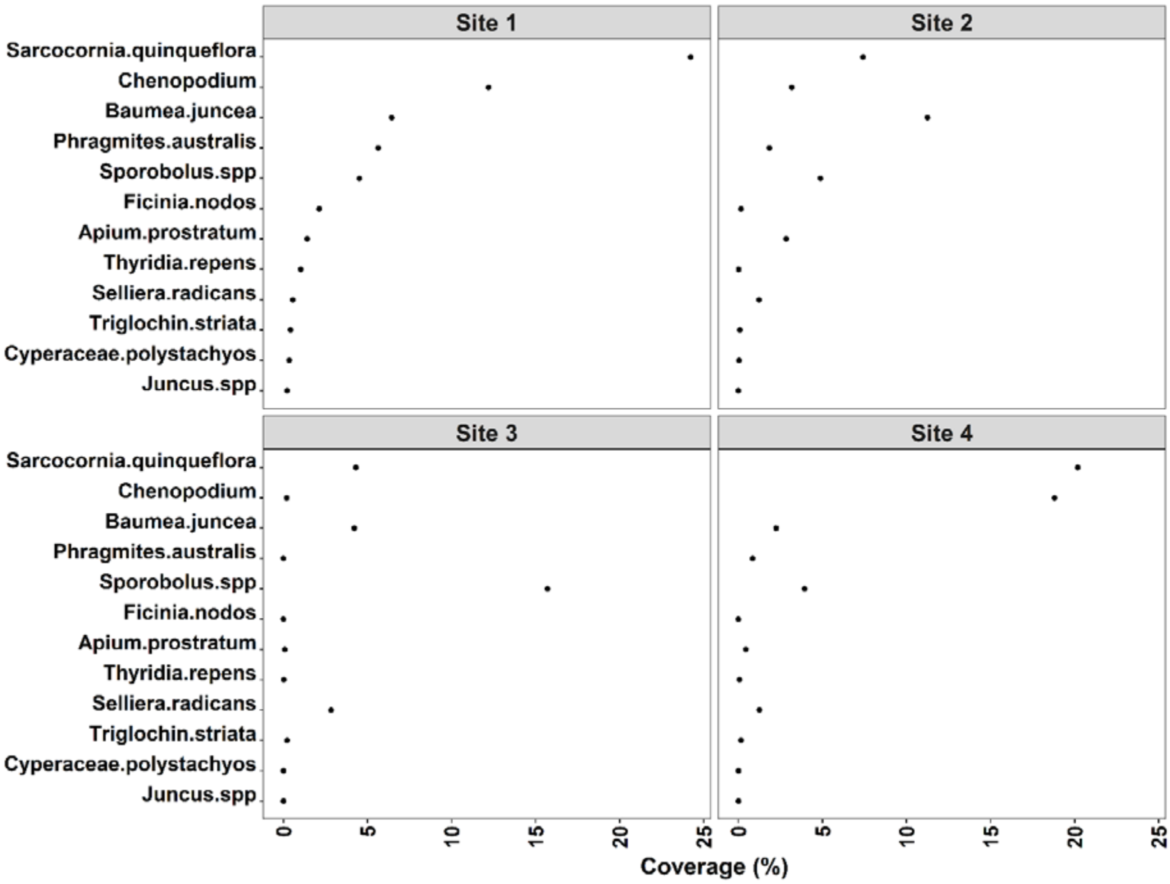


Figure 17 Distribution of plant species abundances in saltmarsh during winter (surveyed on 5/06/2019)

4.4.4 Vegetation diversity comparison between sites

In general, sites 1 and 2 had significantly higher diversity than sites 3 and 4 based on the sample-size-based extrapolation of survey data (**Figures 18 to 20**). Also, the comparisons change with survey seasons.

In spring, species richness was comparable between sites 1 and 2 and was significantly higher than at sites 3 and 4. The difference between site 3 and 4 was not significant (**Figure 18**). In summer, site 2 had the highest richness, followed by site 1 and site 4, and site 3 had the lowest. In addition, the difference between estimated asymptotic richness was significant. In autumn, species richness was significantly higher at site 1 than site 2. Note that the autumn survey occurred in April 2019, four months after the saltmarshes emerged after a long period of inundation. Therefore, the vegetation community might not have been fully established. Thus, the results should be interpreted with caution. In winter, as some annuals died off, the richness decreased for all sites, and the differences between site 1, site 2 and site 4 became insignificant; however, the species richness at site 3 remained significantly lower than other sites (**Figure 18**).

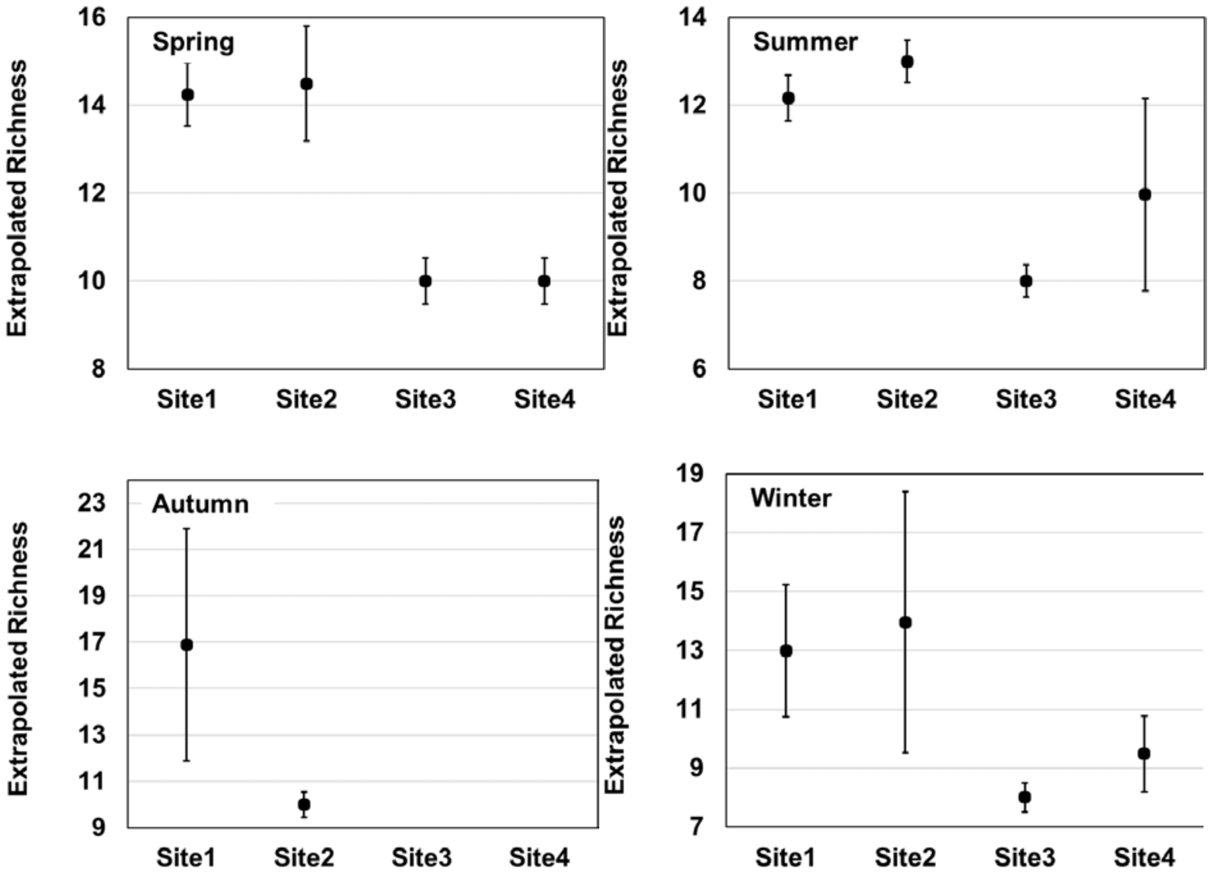


Figure 18 Estimated vegetation richness at four sites in Tilba Tilba Lake using sample-size-based rarefaction and extrapolation

Dots are the extrapolated asymptotic richness; bars are the standard variation based on 1000 bootstrap replications. Overlap of the confidence intervals suggests no significant difference.

Shannon’s diversity index, which accounts for both the number of species present and their abundance, was always significantly higher at sites 1 and 2 than at sites 3 and 4 (**Figure 19**). Among the four surveyed sites, site 3 had significantly lower diversity than other sites except in winter, when the diversity difference between sites 3 and 4 was not significant. Seasonally, the Shannon’s diversity index was highest in spring and lowest in winter.

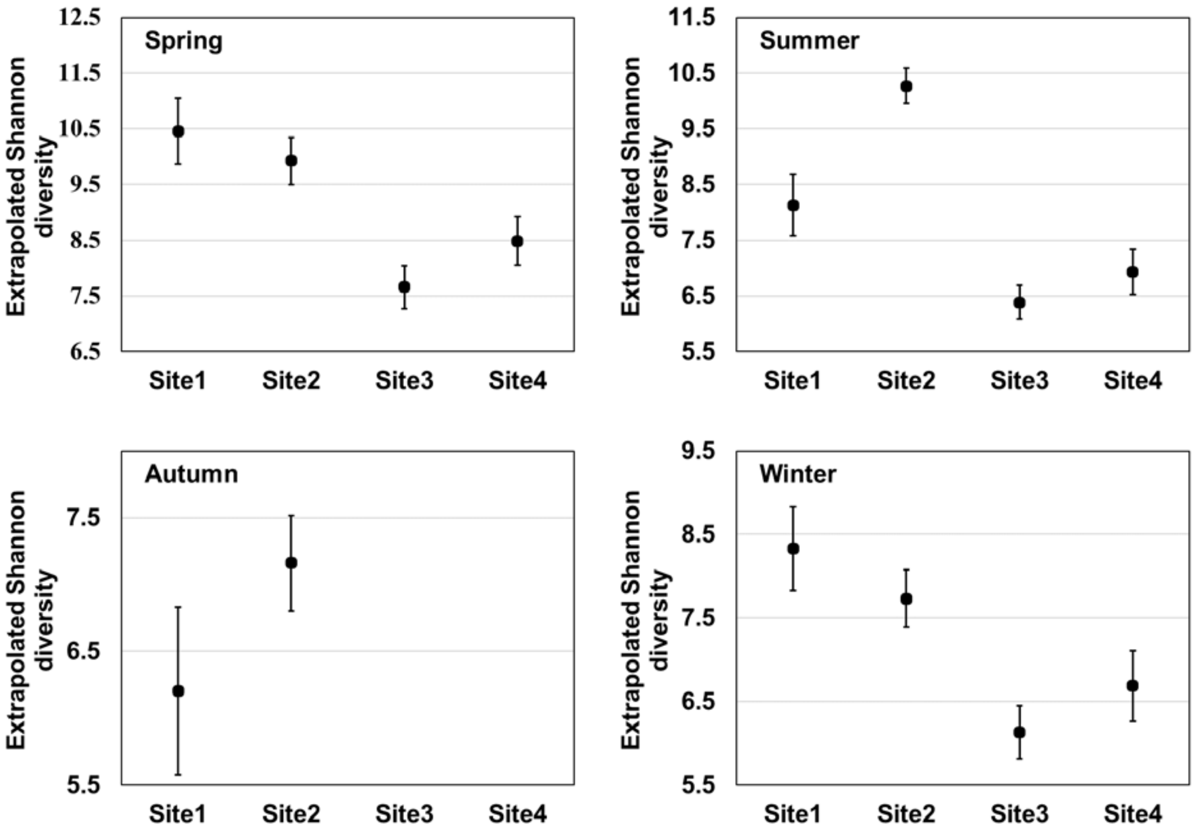


Figure 19 Estimated vegetation Shannon's diversity index at four sites in Tilba Tilba Lake using sample-size-based rarefaction and extrapolation

Dots are the extrapolated asymptotic Shannon's diversity index; bars are the standard variation based on 1000 bootstrap replications. Overlap of the confidence intervals suggests no significant difference.

Compared with Shannon's diversity, the Simpson's diversity, which measures the dominance in a community, showed fewer variations among the sites (**Figure 20**). Among the four surveyed sites, site 3 had the lowest diversity; however, the difference between sites 3 and 4 was not significant. In contrast, site 2 had the highest Simpson diversity. In particular, site 2 had significantly higher Simpson diversity than other sites (**Figure 20**) in summer and winter.

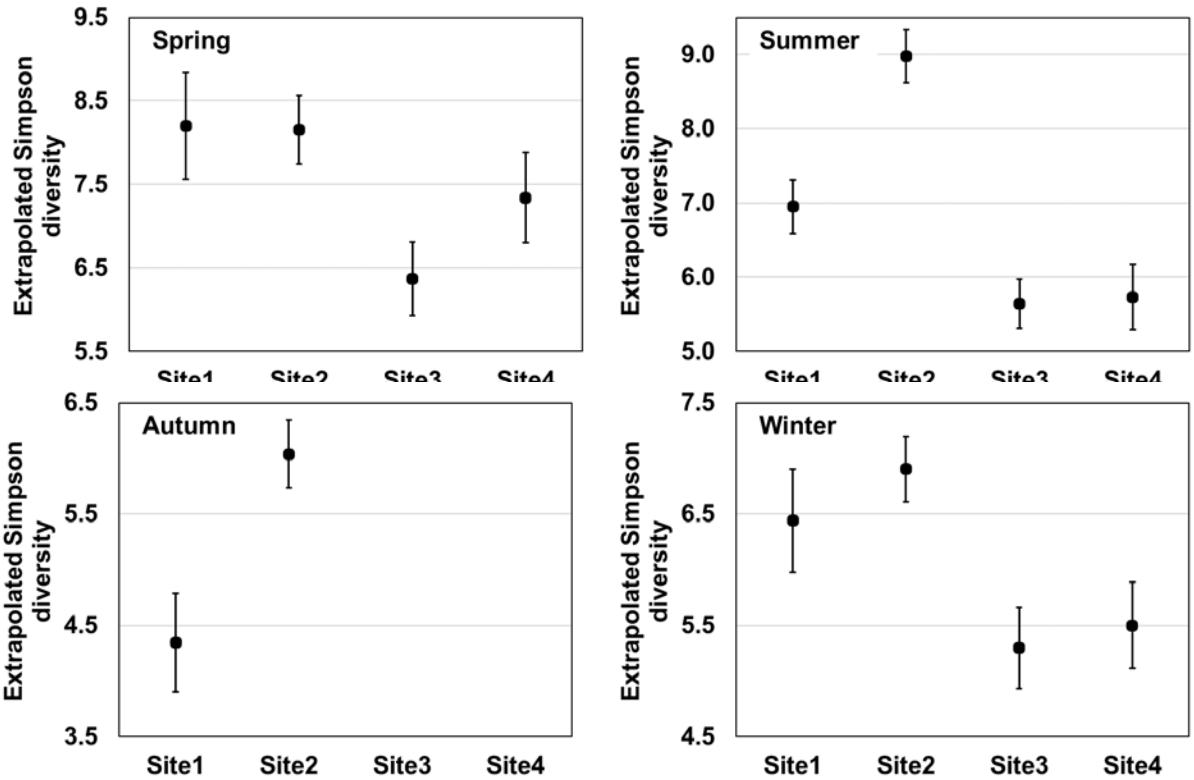


Figure 20 Estimated vegetation Simpson's diversity index at four sites in Tilba Tilba Lake using sample-size-based rarefaction and extrapolation

Dots are the extrapolated asymptotic richness; bars are the standard variation based on 1000 bootstrap replications. Overlap of the confidence intervals suggests no significant difference.

4.5 Water clarity

In general, the median turbidity was high at upstream sites (VC1–3) and decreased towards the downstream site (VC4) (**Figure 21A, Appendix Ca.**). Overall, the median turbidity estimated from 19 monitoring surveys remained within upper and lower trigger values.

There were trigger value exceedances for turbidity measured during Trip-2, Trip-5, Trip-12, Trip-13 and Trip-16 (**Appendix Ca.**). While some of these peaks are related to the heavy rainfall events (70 millimetres and 24 millimetres of rain five days prior to Trip-2 and Trip-13), the weak and non-significant correlation between turbidity and rainfall suggests factors other than rainfall causing the turbidity (**Appendix D**).

The median TSS was highest at VC3 and lowest at VC4 (**Figure 21B**). Generally, TSS at VC1–3 followed a similar pattern over time (**Appendix Cb.**).

Photo 14 Dense fine sediment layer at site VC1 (U Pinto, 27 July 2019)

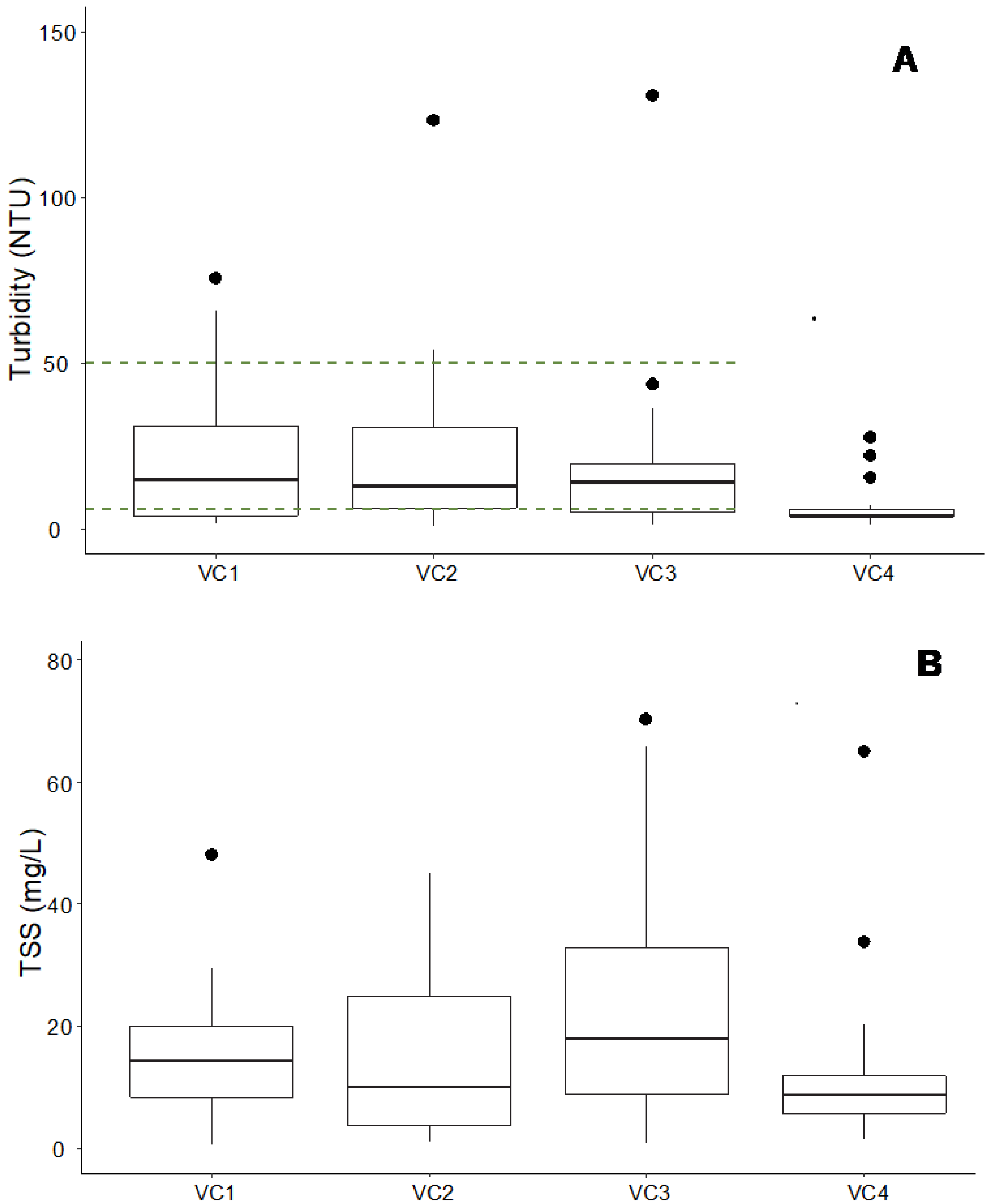


Figure 21 Box and whisker plots of (A) turbidity (NTU) and (B) TSS values recorded from four sites in Victoria Creek

Solid line indicates median value. Dots are outliers. Dashed lines indicate the ANZECC/ARMCANZ (2000) default trigger value range for turbidity (6–50 NTU). Median is based on results from 19 sampling surveys.

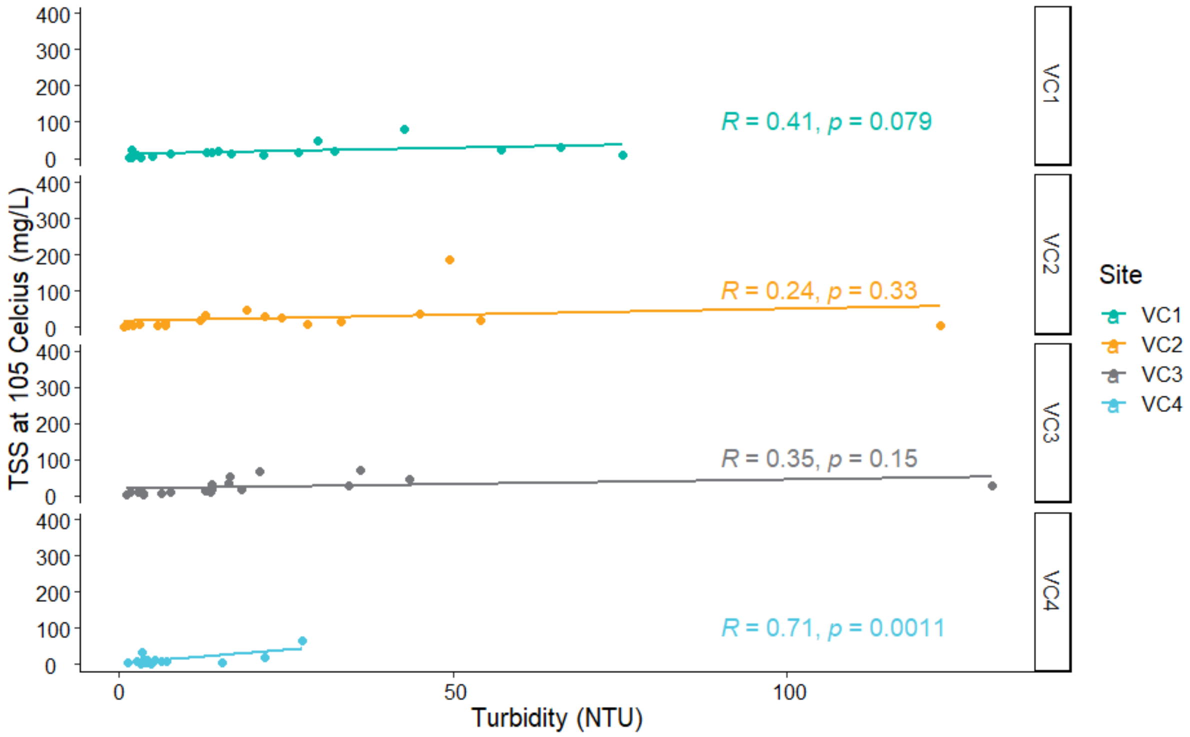


Figure 22 Correlations between turbidity (NTU) and TSS (mg/L) that show a significant correlation at VC4

R values indicate Pearson's correlation coefficient. Significance at p<0.05.

Pearson's correlations were assessed between turbidity and TSS for each site (**Figure 22**). Only at VC4 was the correlation between turbidity and TSS significant (R = 0.71 *p<0.05*). This positive and significant correlation indicates that when turbidity was high, the TSS was usually high as well.

Usually turbidity and TSS have a linear relationship as the former is a result of both suspended and dissolved particles, while the latter is only related to suspended particles. This relationship differs between the lower site (VC4) and the upper sites (VC1, VC2 and VC3). This suggests that coloured organic compounds or microscopic organisms may be causing the high levels of turbidity in the three upper sites, rather than suspended solids, which may explain the lack of correlation between TSS and turbidity measurements and may warrant confirmation through further sampling surveys.

The sediment core analysis indicated all sites were dominated by silt and sand (**Figure 23**). During the sampling surveys a dense layer of fine sediments was observed at each site (**Photo 14**). The fine sediment layer currently sitting on the streambed is highly prone to resuspension by wind and animals, causing a turbidity peak.

In general, median turbidity gradually decreased from upstream to downstream sites and for sites VC1, VC2 and VC3 the median turbidity level was below the default ANZECC/ARMCANZ (2000) trigger value range. The seasonal variability of turbidity at each site followed a sinusoidal pattern over time, particularly at sites VC1 and VC2, but was less evident at VC3 and VC4 (**Appendix Ca.**). The streambed sediment sample analysis indicated all sites were dominated by fine sediments and this may explain why some turbidity readings were close to or at times exceeded the default trigger value in sites VC1 and VC2. Possible causes of the decline in water clarity on a spatio-temporal scale are likely to be due to moderate to high levels of active bank erosion and sedimentation, associated with reduced a riparian zone and surrounding catchment vegetation. Presence of livestock may be increasing sediment mobilisation from run-off, by trampling and destabilising the bank and stream substrate. The impacts on overall ecological health are unclear, but possible outcomes may be loss of diversity of aquatic fauna and flora due to reduced clarity and introduction of other substances liberated from the surrounding catchment.

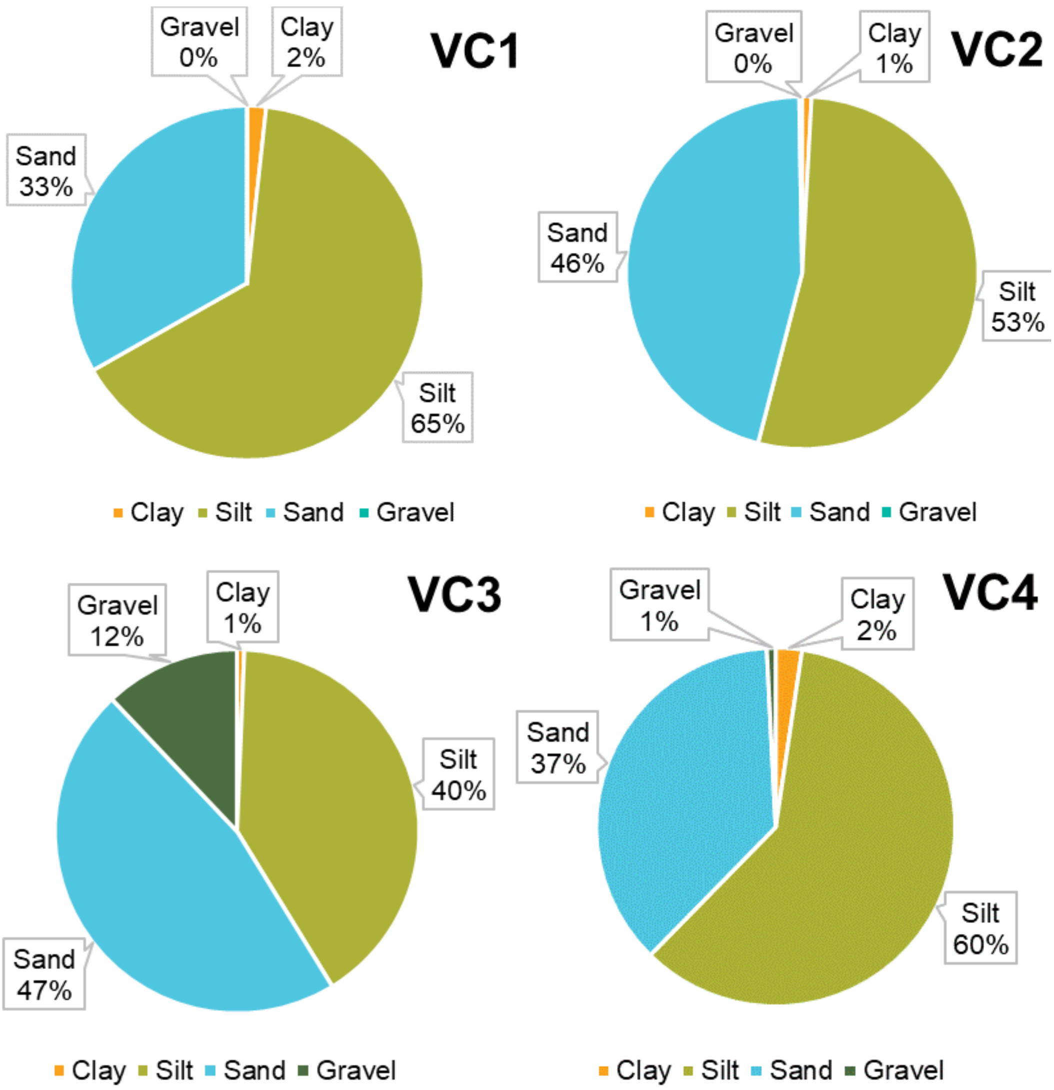


Figure 23 Distribution of sediment fraction less than 3 mm in sediment samples from four sites (VC1–4)

Results are means of sediment samples taken on 19 September and 29 July 2019.

4.6 Acidity

4.6.1 pH and alkalinity

The median pH at VC1, VC2 and VC3 remained within the pH trigger value range (**Figure 24A, Appendix Cc.**). The pH range for these sites was close to a neutral pH of 7 and at the most downstream site (VC4) was close to 8. Site VC4 had a higher median pH, perhaps due to seawater infiltration.

Box and whisker plot of electrical conductivity at sites VC1 to VC4. VC1 to VC3 are very low, VC4 is higher, see interpretive text for details.Alkalinity shows upward trend from VC1 to VC4.

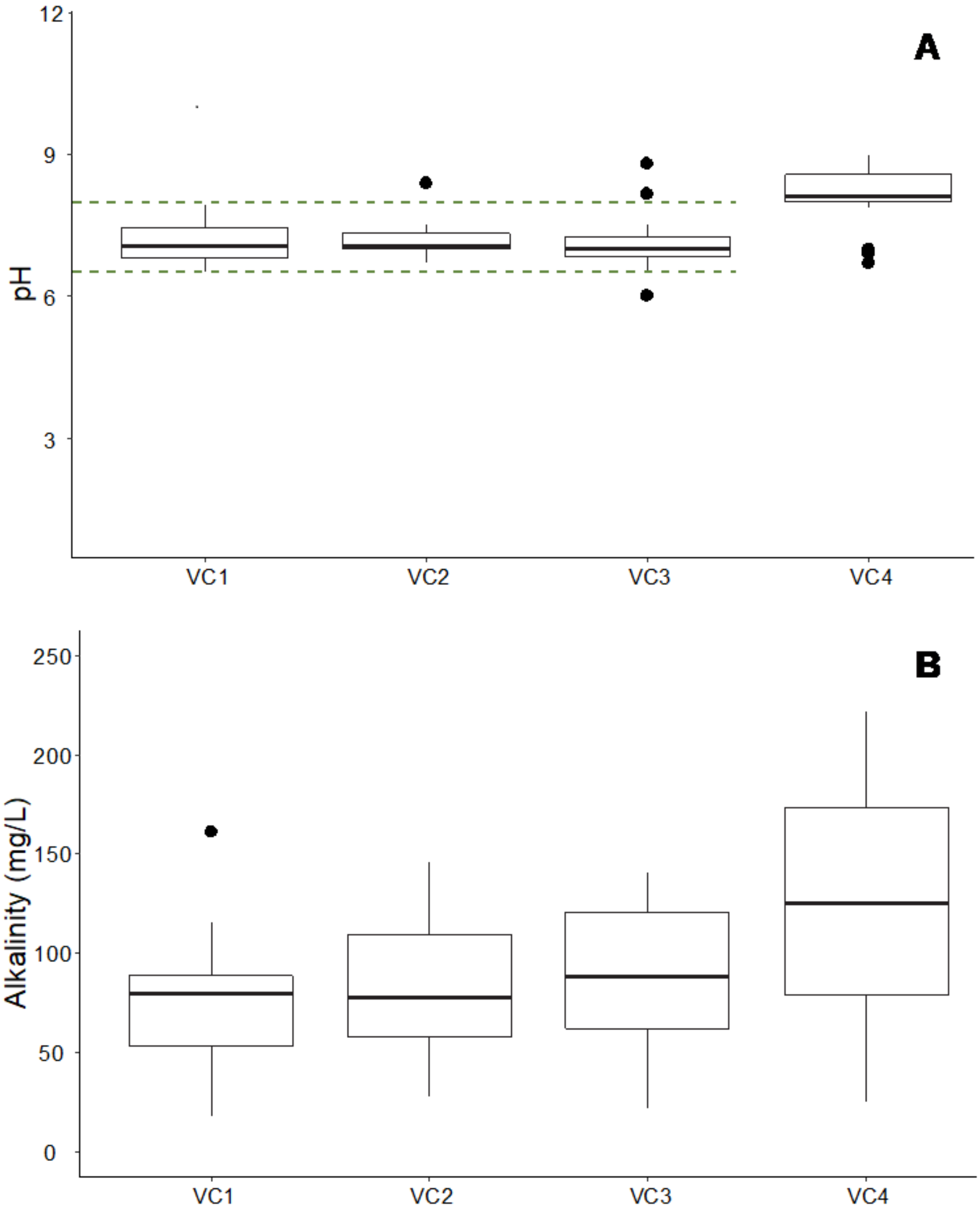


Figure 24 Box and whisker plot of (A) pH and (B) alkalinity across the four sites in Victoria Creek

Dashed lines indicate the pH ANZECC/ARMCANZ (2000) default trigger value range of 6.5–8.5. Median is shown as a solid line and is based on results from 19 sampling surveys.

Overall, pH remained within the trigger value range for all sites, ranging from 7 to 7.5, for the freshwater sites (VC1–3). In Victoria Creek, the results for pH do not suggest impaired conditions for aquatic ecosystem health.

Alkalinity increased moving downstream due to the influence of saltwater rich in carbonates and bicarbonate ions (**Figure 24B**). Increased alkalinity protects aquatic life against rapid pH changes in water. A drop in alkalinity is evident at all sites during Trip 14 possibly due to the dilution effect from heavy rainfall as there were over 90 millimetres total rainfall within five days prior to sampling (**Appendix Cd.**).

The minimum and maximum alkalinity was between 28 and 161 milligrams per litre for sites VC1–3; however, this was between 25 and 222 milligrams per litre for site VC4, perhaps due to the presence of carbonates and bicarbonate ions from seawater. Alkalinity regulates pH changes in water, meaning aquatic life at freshwater sites may be relatively more vulnerable to changes in pH with increased external pollution due to low alkalinity compared with site VC4.

4.7 Salts

4.7.1 Electrical conductivity

EC was monitored to assess the amounts of dissolved salts such as chlorides, sulphides and carbonates in Victoria Creek. The median EC was highest at the most downstream site (87,614 microsiemens per centimetre), which was close to that of seawater due to proximity to the ocean. VC4 also had the highest conductivity range, influenced by the lake's entrance conditions. The three upstream sites (VC1–3) ranged from 3–1854 microsiemens per centimetre **(Figure 25)**.

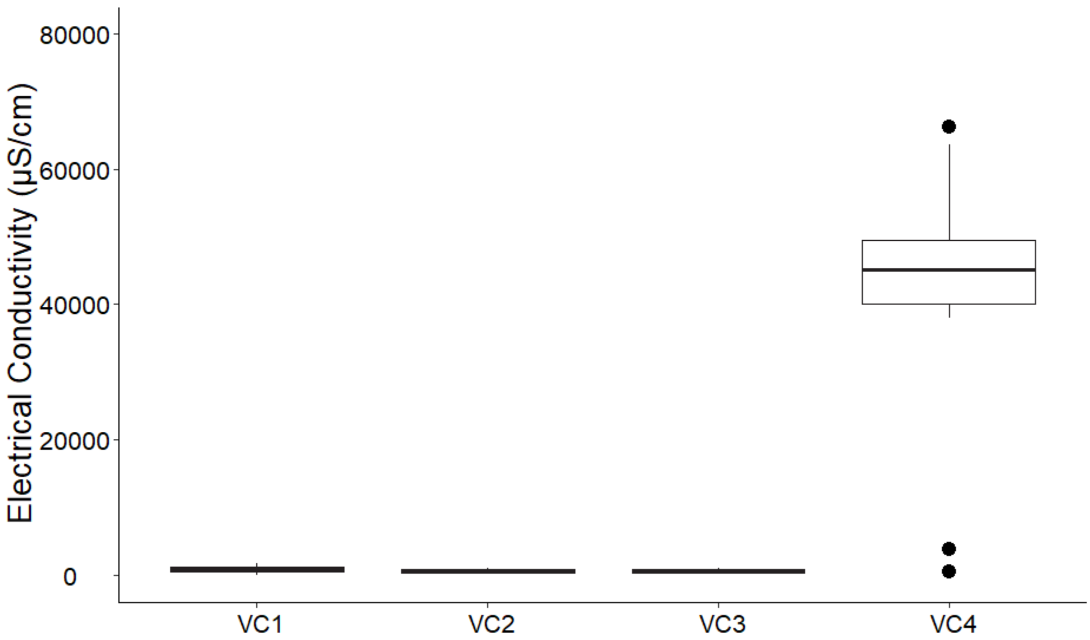


Figure 25 Box and whisker plots of dissolved EC (µS/cm) values across four sites in Victoria Creek

Median is shown as a solid line and is based on results from 19 sampling surveys.

When the lake's entrance is closed, increased salinity occurred around the lake's fluvial delta; however, it did not go beyond approximately four kilometres from the lake entrance. Freshwater inflows due to rainfall events reduced the salinity levels although the effect of dilution was only short term, up to about two weeks. The drops in EC at VC4 during Trips 1, 14 and 17 were due to freshwater inflows as this catchment received 95, 99 and 61 millimetres of rainfall respectively, five days prior to sampling (**Appendix Ce.**). The lagoon entrance opened in December 2018 and closed in August 2019. Following the closure of the lagoon entrance, EC level of VC4 gradually increased until November 2019 and then continued to increase due to the ongoing drought in summer 2019 (**Appendix Ce.)**.

Overall, the EC levels indicate that the upstream sites (VC1–3) have lower salinity than the downstream site (VC4) and there is no indication of dryland salinity, associated decline in the water table, or other inputs of dissolved salts.

4.8 Oxygen

Overall median DO saturation (%) was below the lower ANZECC/ARMCANZ (2000) trigger value for the freshwater sites VC1, VC2 and VC3 (**Figure 26**), indicating these sites are impaired from a healthy aquatic ecosystem perspective.

The deoxygenated conditions were dependent on the time of day. DO levels prior to 2pm mostly remained low at sites VC1–3 (**Figure 27)**. Relative to freshwater sites, VC4 had elevated oxygen levels most of the day.

Significant positive correlations were also observed between DO and pH ($r = 0.57$, $p<0.001$) and conductivity ($r = 0.62$, $p<0.001$) (**Appendix D**). Oxygen concentrations in the water column are influenced by factors such as organic matter load, temperature, salinity, air pressure, stream flow, chemical oxygen demand and community metabolism rates (i.e. respiration and photosynthesis rates). While our surveys were spot assessments, data collection through continuous loggers would provide high resolution datasets to better understand how the DO levels behave diurnally and over time. Such data together with aquatic bio-assessments will help better understand the effects of deoxygenated conditions on aquatic biota in the creek.

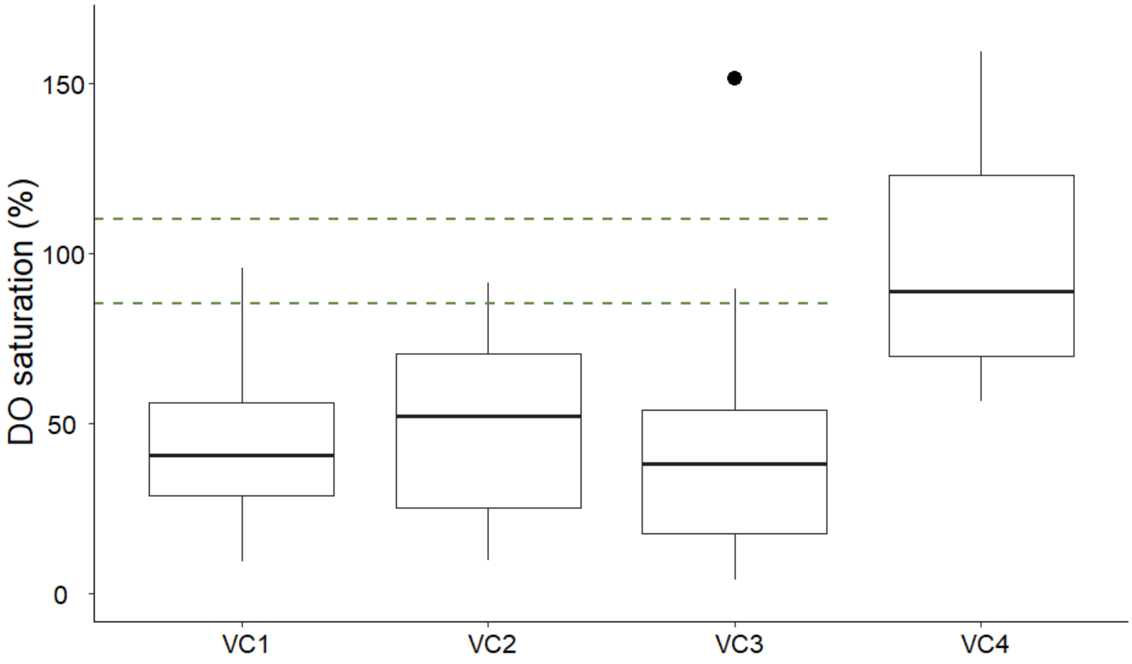


Figure 26 Box and whisker plots of DO saturation (%) across the four sites in Victoria creek
Dashed lines indicate ANZECC/ARMCANZ (2000) DO saturation (%) trigger value range 85–110%. Median is shown as a solid line and is based on results from 19 sampling surveys.

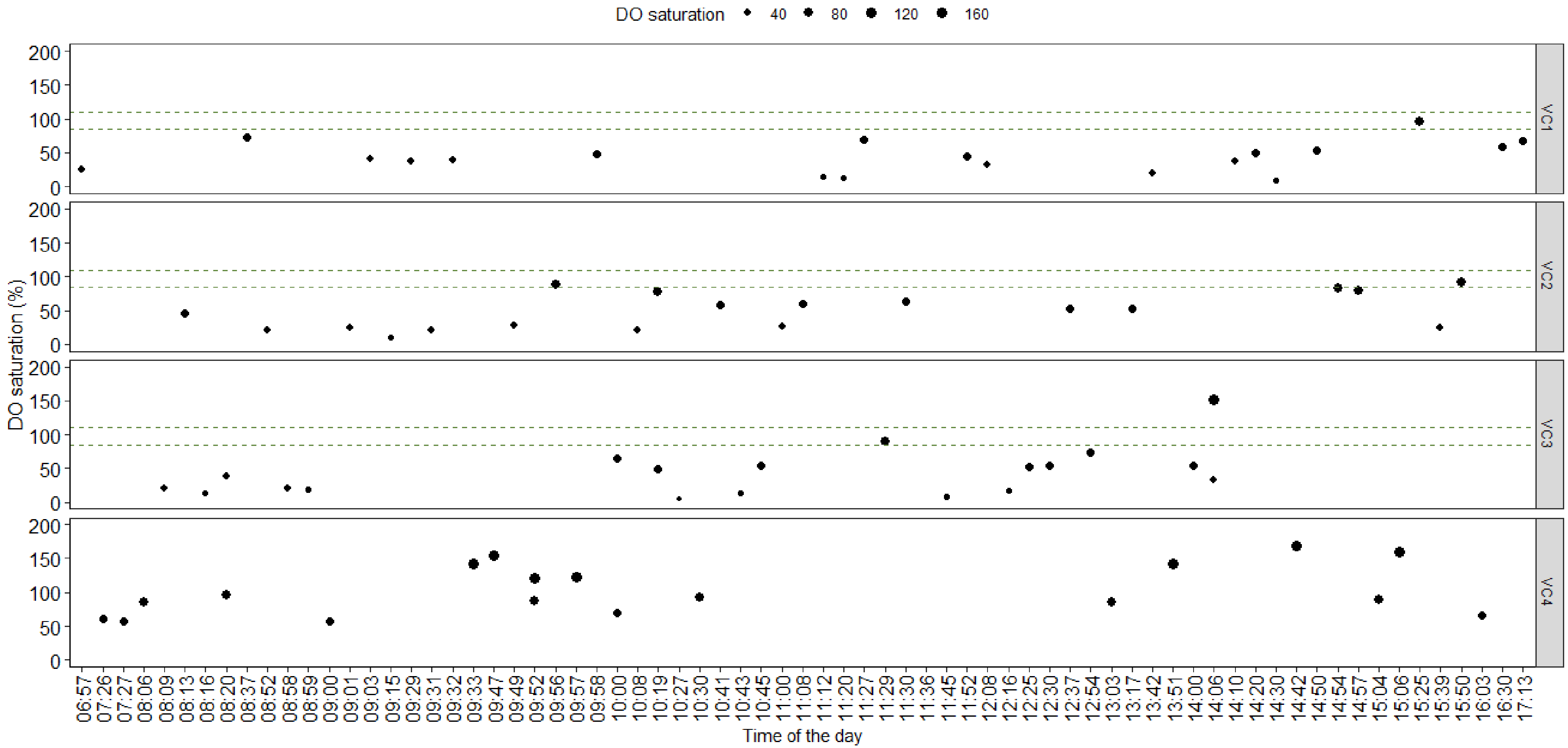


Figure 27 Diurnal variability in DO saturation (%) values recorded at each site at various times

Dashed line indicates ANZECC/ARMCANZ (2000) DO saturation (%) trigger value range 85–110%.

4.9 Nutrients

Overall the median and observed TN and phosphorus levels for all sites frequently exceeded the trigger values (**Figures 28A and 29A, Appendix Cf. and Ci.**), although the median for all dissolved nutrients typically fell below the trigger values (**Figures 28B, 28C and 29B**). The highest median TN and TP were recorded at VC4.

4.9.1 Total and dissolved forms of nitrogen

Median NO_x concentrations were below the ANZECC/ARMCANZ (2000) trigger value (**Figure 28B, Appendix Cg.**) for all sites.

Median NH_4^+ concentrations at the upstream freshwater sites (VC1–3) were below the ANZECC/ARMCANZ (2000) trigger value levels though there were some exceedances over the monitoring period (**Figure 28C**). Site VC4 was dominated by macroalgal mats (species unknown) that died due to high temperature, increased salinity and shallow water following extended drought throughout most of 2019 (**Photo 15**). The elevated NH_4^+ concentrations observed during Trips 11–13 may be due to the decomposing algae in the system (**Appendix Ch.**). The very high NH_4^+ concentrations reported as outliers at site VC4 are concerning as at alkaline pH conditions (median pH of VC site is above 7 and alkaline) this could result in more toxic ammonia in the system, which is harmful for aquatic fauna.

VC4 had the highest median TN value based on data from 19 sampling surveys.

Elevated TN and NO_x (nitrite + nitrate) mostly occurred following wet weather, whilst during the remaining sampling surveys (mostly during dry weather), the total and dissolved forms of nitrogen levels remained relatively stable.

Photo 15 Mats of dead and decomposing macroalgae at site VC4 (U Pinto, 4 November 2019)

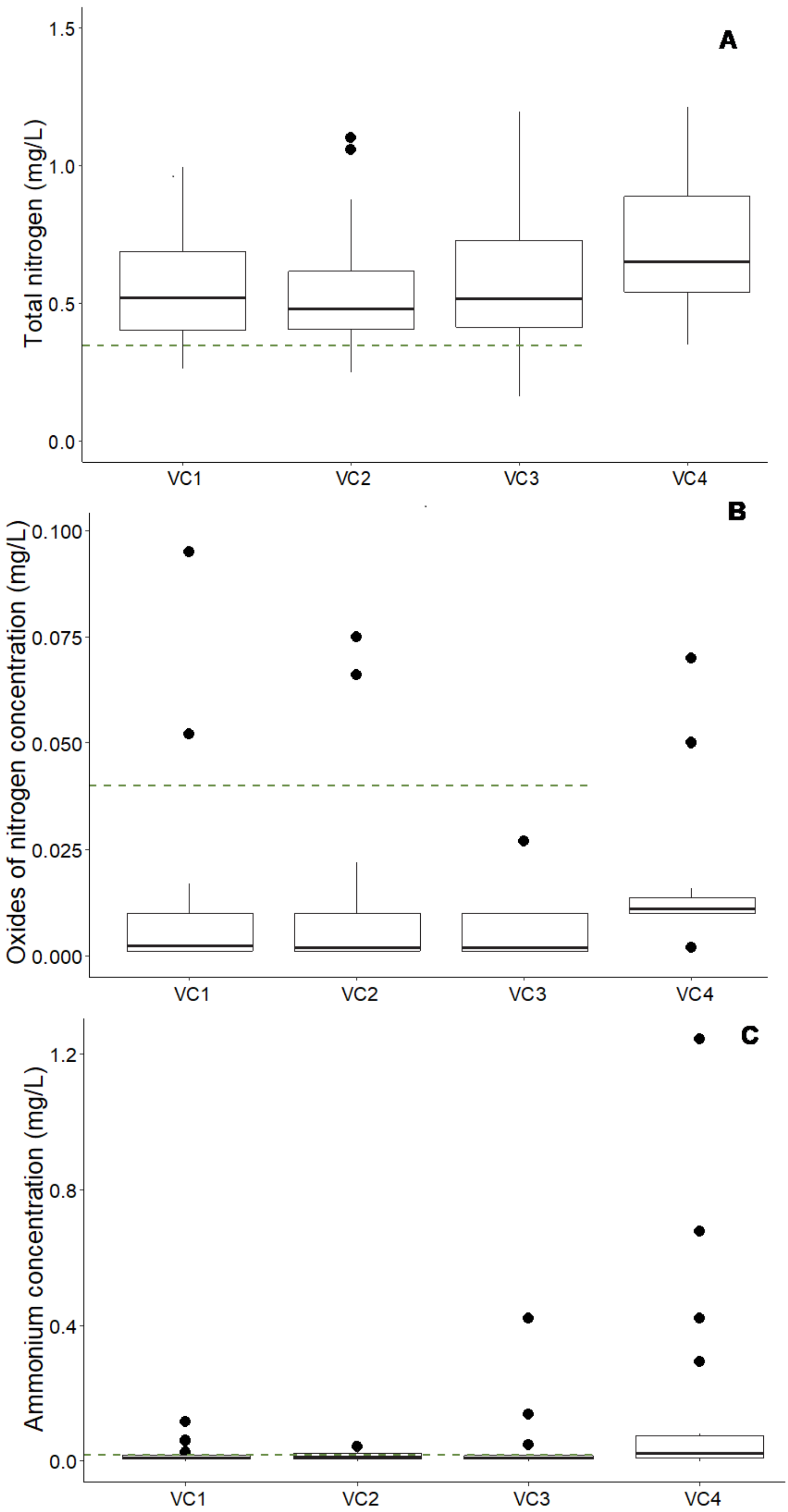


Figure 28 Box and whisker plots of (A) TN, (B) NOx, (C) NH4+ across all sites

Dashed lines indicate ANZECC/ARMCANZ (2000) default trigger values for TN (0.35 mg/L), NOx (0.04 mg/L) and NH4+ (0.02 mg/L). Median is shown as a solid line and is based on results from 19 sampling surveys.

4.9.2 Total and dissolved forms of phosphorus

Median TP for VC1–3 exceeded the trigger value (**Figure 29A).** FRP (**Figure 29B**), was generally stable and below the trigger value across sites VC1–3 and over time (**Appendix Cj.)**. While TP level are generally above the trigger value, both total and dissolved forms of phosphorus do not show considerable peaks with the amount of rainfall received five days prior to sampling of VC1–3.

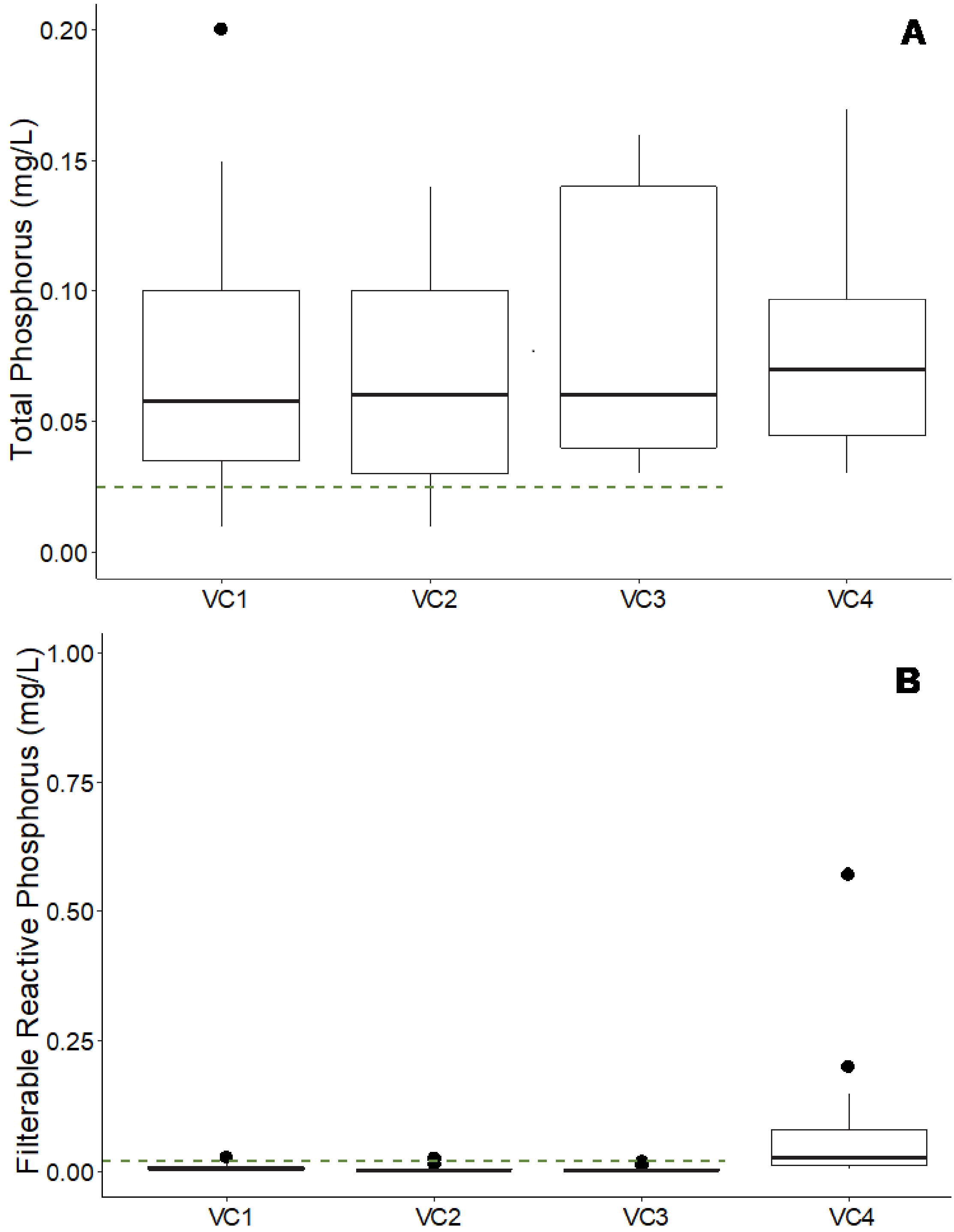


Figure 29 Box and whisker plot of (A) TP (mg/L) and (B) FRP (mg/L) values across sites

Dashed lines indicate ANZECC/ARMCANZ (2000) default trigger values for TP (0.025 mg/L) and FRP (0.02 mg/L). Median is shown as a solid line and is based on results from 19 sampling surveys.

The total and dissolved nutrient results suggest that Victoria Creek is nutrient enriched. Livestock grazing in the catchment increases the supply of nutrients through increased sediment transport, faecal matter, which may only enter the creek following rainfall or if livestock are accessing the creek directly. Consequently, the creek may become eutrophic temporarily, whilst nutrient levels increase with rainfall events. The elevated nutrient levels at VC4 suggest downstream accumulation of nutrients especially when the lake entrance is closed.

An increase in dissolved nutrient following rainfall events is also evident; however, this trend will become clearer with more wet weather data in future. For example, the Pearson correlations assessed between rainfall and TN (0.33, $p<0.01$), TDN (0.39, $p<0.001$), NO_x (0.56, $p<0.001$), DIN (0.26, $p<0.1$), DON (0.33, $p<0.001$) and DOP (0.38, $p<0.001$) were significant (**Appendix E**). However, the correlations between rainfall and TP, FRP and TDP were weak and non-significant.

Also, there were significant and high correlations observed between TN and TDN (0.96, $p<0.001$), DIN (0.51, $p<0.001$), DON (0.86, $p<0.001$), TP (0.86, $p<0.001$), FRP (0.76, $p<0.001$), TDP (0.84, $p<0.001$), DOP (0.71, $p<0.001$) and TDP, indicating their similar behaviour in the system (**Appendix E**).

4.9.3 Distribution of organic and inorganic fractions of dissolved nutrients

DIN and DIP are readily available for plant uptake, stimulating growth. The creek system is dominated by DON and there is very little DIP and DOP (**Figure 30**). DON in freshwater systems includes nucleic acids from cellular RNA and DNA, amino sugars in plankton and bacteria, and excretion products such as urea (Likens 2009). Unlike the inorganic fraction of the nitrogen, the organic nitrogen is not directly available for plant uptake; however, the microbial activity turns DON into an inorganic form so plants can utilise it.

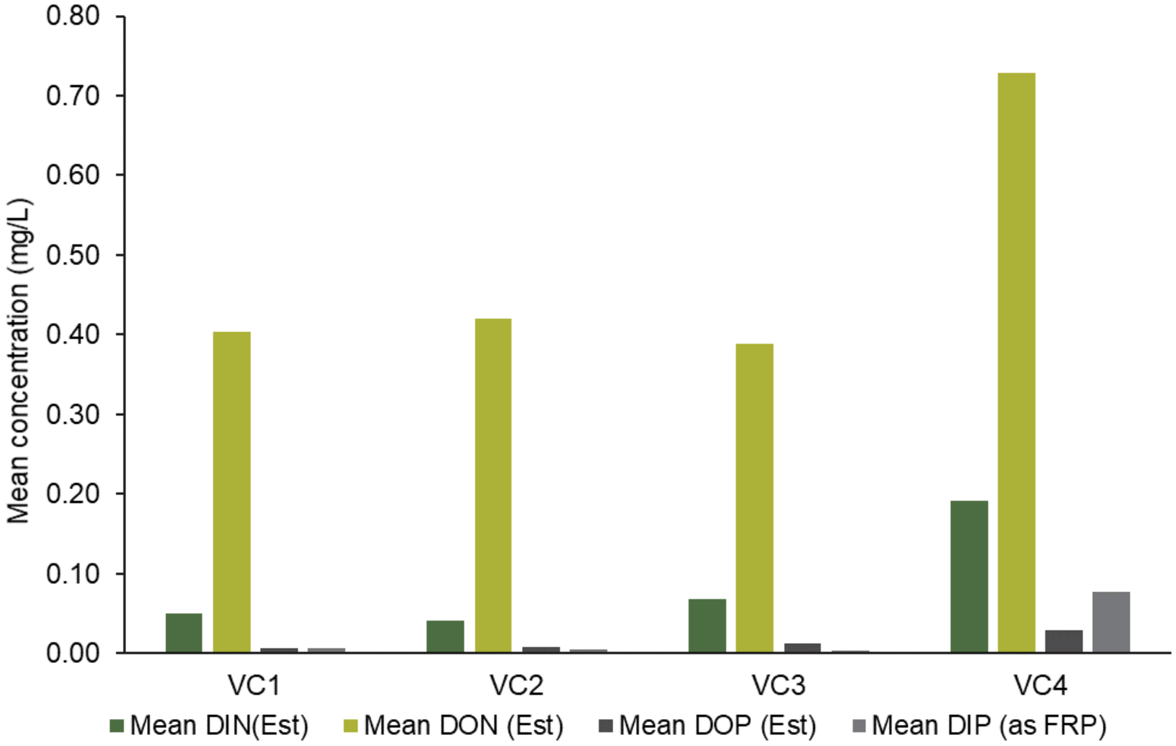


Figure 30 Mean concentrations of inorganic and organic fractions of dissolved nitrogen and phosphorus in Victoria Creek based on 19 sampling trips

DIN, DON and DOP are estimated values. DIP concentrations are same as FRP.

DIN to TDN ratio is a measure of the bioavailability of nitrogen in the system. High ratios indicate readily bioavailable nitrogen, most probably from anthropogenic sources in the catchment. The ratios estimated for Victoria Creek gradually increased from upstream to downstream sites (**Figure 31**). Site VC4 showed the highest DIN:TDN ratio, indicating more nitrogen is available for aquatic plant growth around the fluvial delta of Tilba Tilba Lake.

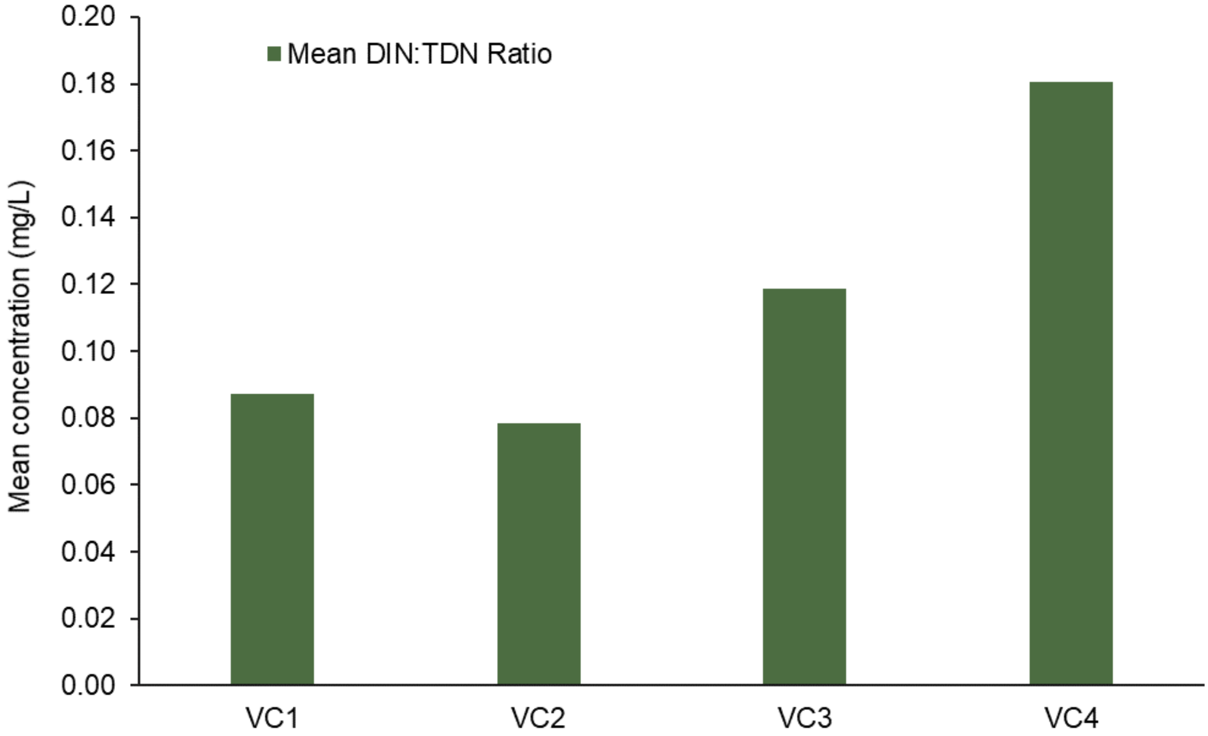


Figure 31 Mean DIN:TDN ratios at each site estimated from 19 sampling trips

4.10 Phytoplankton

Chl-*a* concentrations in the water column are measured as a proxy for phytoplankton biomass. They are commonly used as an indicator of nutrient enrichment. High phytoplankton biomass can lead to large diurnal oxygen variations, toxic blooms, fish kills and decreased light availability for benthic flora.

The median Chl-*a* concentration only exceeded the ANZECC/ARMCANZ (2000) default trigger value at site VC1, while the medians for sites VC2–3 were below the trigger value throughout the sampling period (**Figure 32**). Overall, all sites indicated a large seasonal variation (**Appendix Cm.**). Chl-*a* concentrations at the brackish site VC4 were more variable than at the freshwater sites. The high DIN: TDN ratios observed at this site (**Figure 31**) explains the large variation of Chl-*a* at this site.

Significant correlations were found between Chl-*a* and all nutrients except NH_4^+, TDP (0.42, $p<0.01$), FRP (0.35, $p<0.1$), TP (0.5, $p<0.001$), DOP (0.53, $p<0.001$), DON (0.42, $p<0.01$), TDN (0.4, $p<0.01$) and TN (0.47, $p<0.001$), suggesting phytoplankton biomass and elevated nutrients in the system are related (**Appendix E**).

The significant but low correlation between Chl-*a* and TSS ($r = 0.44$, $p<0.01$) may partly explain the observations made in Section 4.5, as dead or live macroalgae and microalgae contribute to the total suspended material load. Another possibility is nutrients attached to suspended particles supporting the growth of algae, increasing Chl-*a* in the water column.

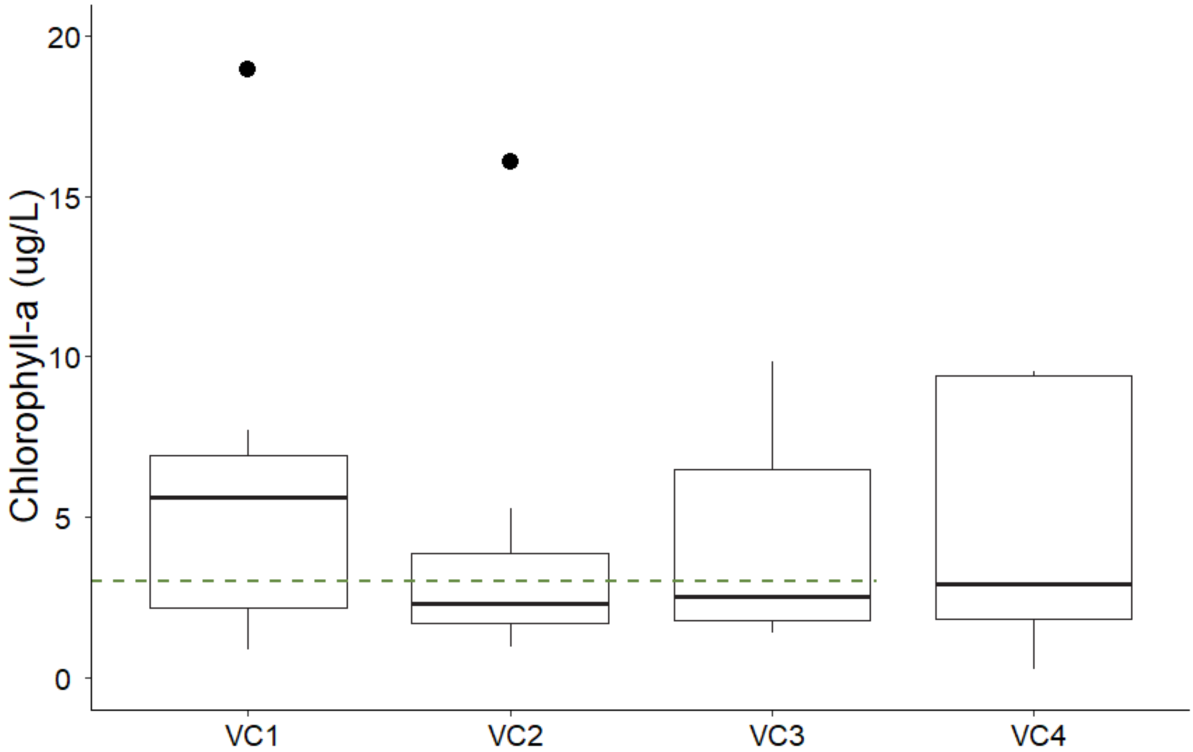


Figure 32 Box and whisker plots of Chl-a concentrations (µg/L) across sites in Victoria Creek

Dashed line indicates ANZECC/ARMCANZ (2000) trigger value for Chl-a (3 µg/L). Median is based on results from 12 sampling surveys.

4.11 Bacteria

All sites tested positive for both enterococci and *E. coli* indicating the creek is polluted with animal faeces. In comparison with primary contact recreational guidelines, both indicator organisms were generally below the guidelines (**Figure 33 and Table 12)**. The presence of faecal bacteria in the creek is likely due to large amounts of cow dung in the catchment, and near and in the creek bed; however, it is likely that other sources are also having an effect (e.g. birds, wallabies) (**Photo 16**).

Enterococci and *E. coli*. indicated high values that generally occurred during and following rainfall (**Appendix Ck. and I.**). Rainfall correlated significantly with both bacterial indicators (r = 0.53 for enterococci and r = 0.40 for *E. coli* at p<0.001) indicating that faecal matter is being washed into the creek's waters during rain events. Both bacterial indicators were significantly correlated (r = 0.67, p<0.001) suggesting that only one of the indicators may be required for further monitoring (**Appendix D**).

While the two bacterial indicators provide evidence of faecal contamination in the stream it does not confirm the source of the contaminants. A DNA-based analytical tool initiated in 2020 will help understand the main source of the faecal matter (i.e. cattle, human, bird).

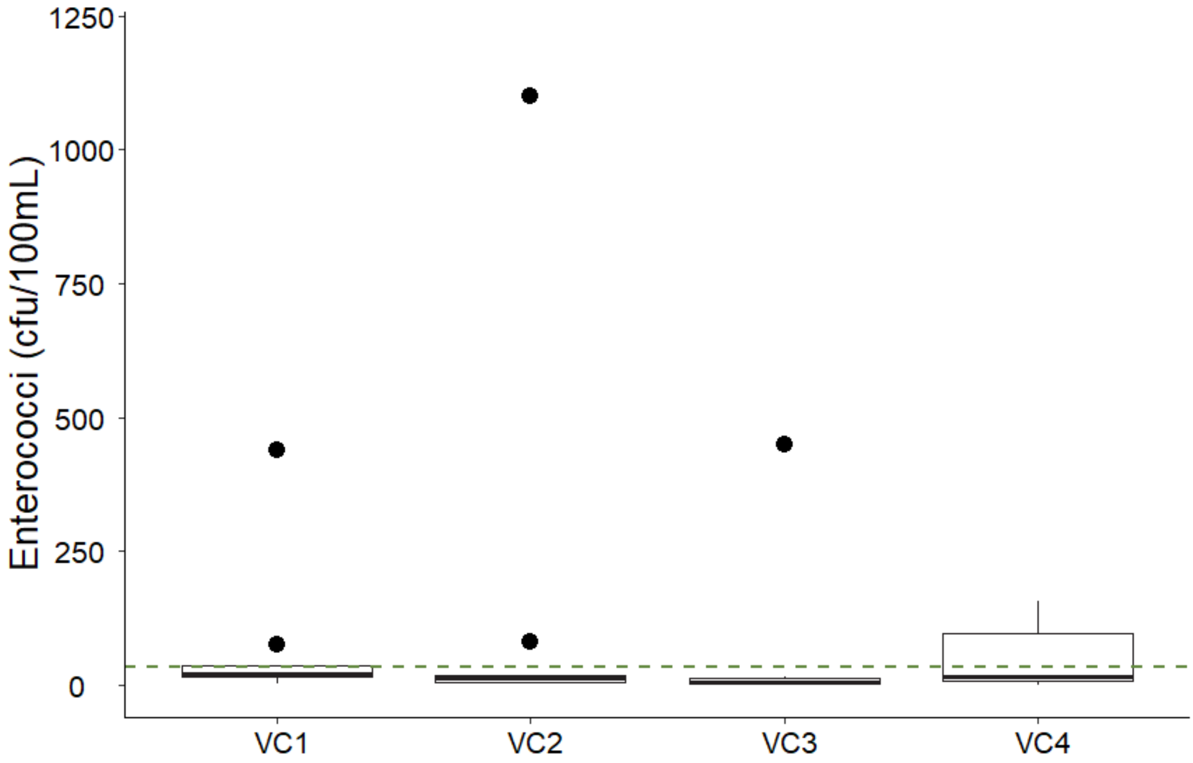


Figure 33 Box and whisker plot of enterococci across four sites

Dashed line indicates ANZECC/ARMCANZ (2000) guideline value (lower) for primary contact recreation (maximum number in one sample 35 CFU/100mL). Median is based on results from 10 (enterococci) sampling surveys.

Table 12 Median E. coli calculated from six samples compared with 150 CFU/100mL ANZECC/ARMCANZ (2000) guideline for primary contact recreation

Site	Monitoring trip						Median
3.	**Trip_1**	**Trip_2**	**Trip_3**	**Trip_4**	**Trip_6**	**Trip_7**	**4.**
VC1	975	60	140	100	133	0	117
VC2	600	80	0	NA	617	0	80
VC3	225	120	0	100	100	33	100
VC4	2200	60	0	NA	67	33	60
5.	**Trip_8**	**Trip_9**	**Trip_10**	**Trip_12**	**Trip_13**	**Trip_14**	**6.**
VC1	33	0	83	75	300	467	79
VC2	0	0	0	82	800	400	41
VC3	33	166	0	17	567	200	100
VC4	0	233	266	7	0	33	20
7.	**Trip_15**	**Trip_16**	**Trip_17**	**Trip_18**	**Trip_19**	**Trip_20**	**8.**
VC1	467	33	33	267	33	NA	33
VC2	100	0	33	333	33	NA	33
VC3	33	33	100	533	0	NA	33
VC4	17	0	33	433	17	NA	17

Photo 16 Site VC2 and faecal matter from cattle next to the creek (VC4) (U Pinto, left – June 2019, right – September 2019)

4.12 Macroinvertebrates

The freshwater macroinvertebrates in Victoria Creek were sampled in spring 2019 and spring 2020 and results compared among sites using four different macroinvertebrate indices (**Figure 34**). Without any prior data from Victoria Creek, this will only provide a snapshot of macroinvertebrate communities in response to the existing water quality and habitat condition. As more data become available, trends in macroinvertebrate communities and aquatic ecosystem health, should be more evident over time.

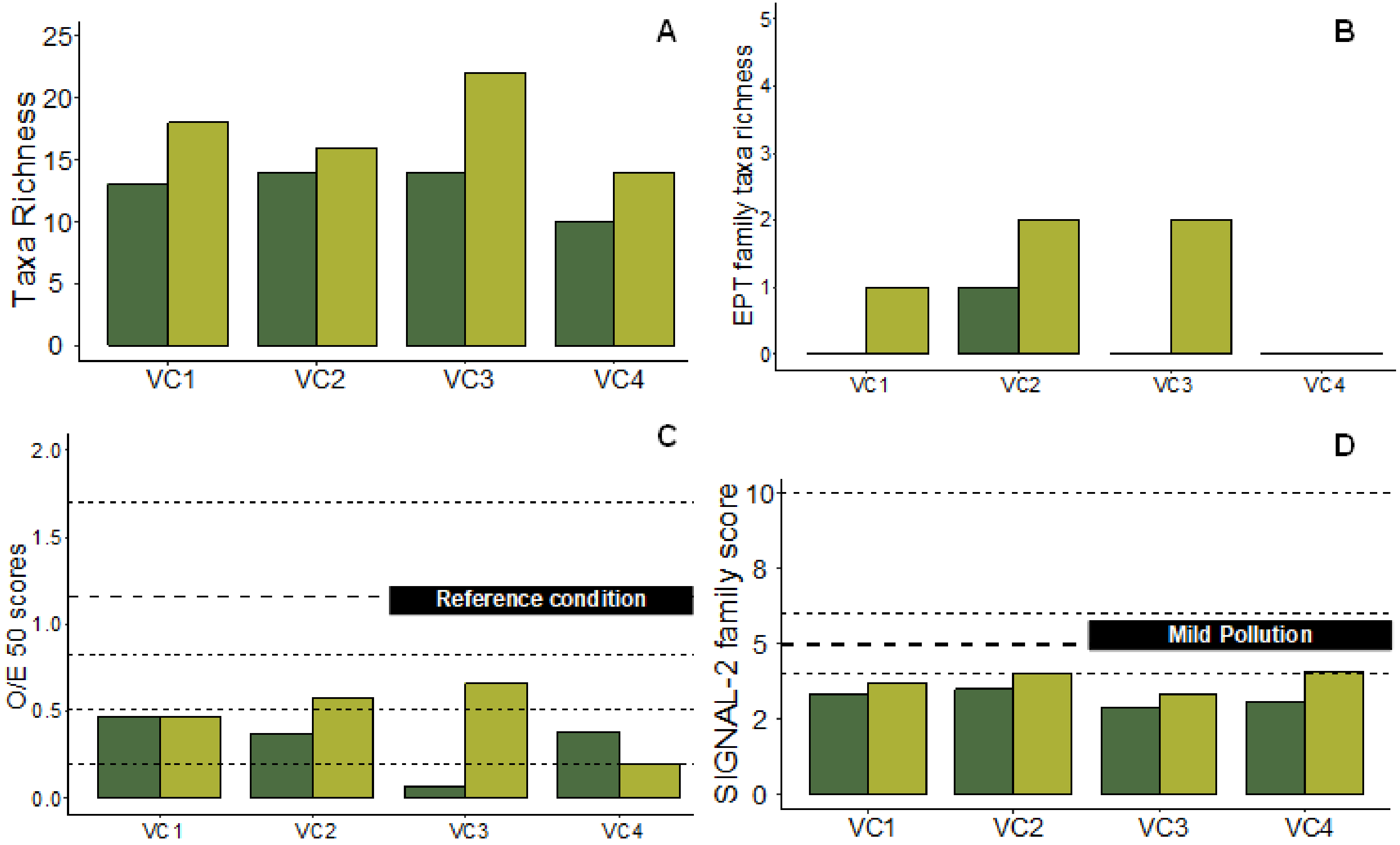


Figure 34 Macroinvertebrate indicators assessed at four sites during the spring 2019 and spring 2020 seasons: (A) taxa richness, (B) EPT family taxa richness, (C) AUSRIVAS O/E50 scores, (D) SIGNAL2-Family scores

Dashed lines in panel (C) from bottom to top indicate score thresholds: 0–0.19 = extremely impaired, 0.20–0.51 = severely impaired, 0.52–0.83 = significantly impaired, 0.84–1.16 = reference condition and above top line = more biologically diverse than reference site. Dashed lines in panel (D) from bottom to top indicate score thresholds: score <4 = severe pollution, score 4–5 = moderate pollution, score 5–6 = mild pollution and score 6–10 = healthy habitat (Victoria 2020).

The taxa richness index increased from 2019 to 2020 across all sites (**Figure 34A**). Site VC3 had five additional taxa in 2020 compared to spring 2019.

Overall, the EPT taxa richness was low across all sites and VC4 reported zero EPT taxa for both seasons (**Figure 34B**). On average 1–2 EPT taxa were reported at VC1, VC2 and VC3 in the 2020 spring season.

While these results indicate a positive trend, ongoing monitoring with more replicate sites will confirm if the increases in richness indices from 2019 to 2020 are a consistent trend and an indication of improving macroinvertebrate community condition.

Both AUSRIVAS and SIGNAL2-Family scores for spring 2019 and spring 2020 indicated all sites have some level of biological impairment. In particular, VC3 reported the lowest scores for both sample events (**Figure 34C and 34D**). For the SIGNAL2-Family results all site scores fell in the bottom left quadrant (**Figure 35**). Results in this quadrant generally indicate urban, industrial or agricultural pollution, which may be due to high salinity or nutrient levels (Chessman 2003).

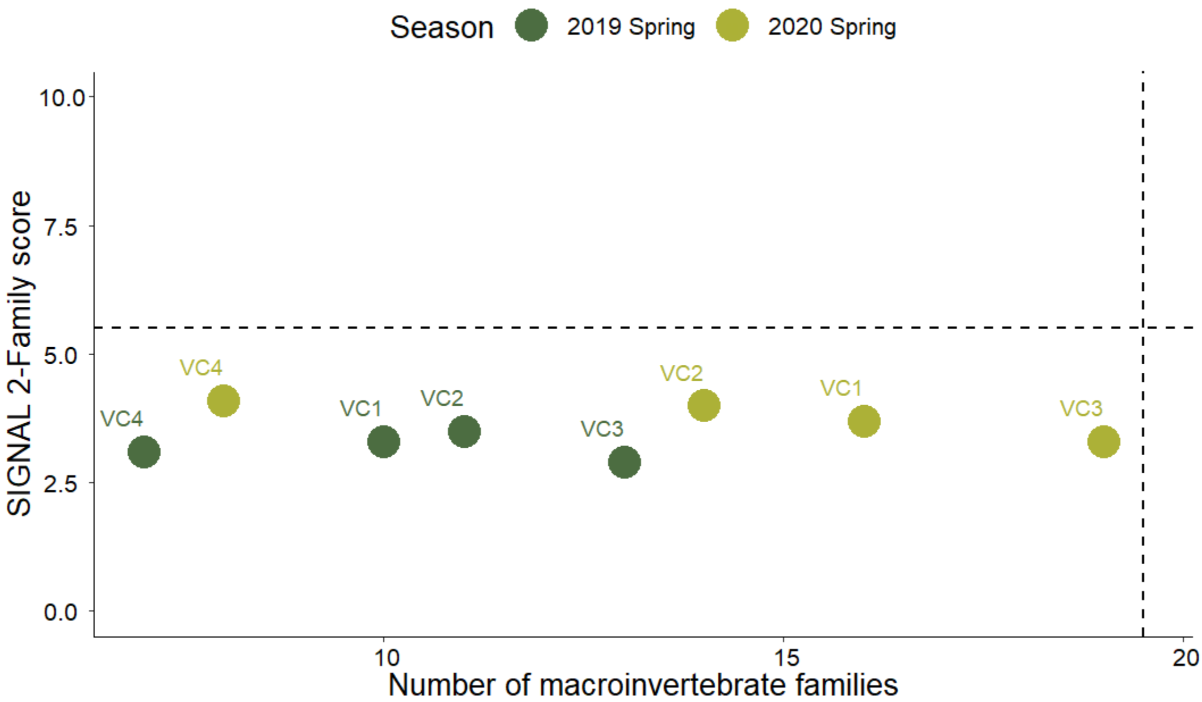


Figure 35 A biplot of the SIGNAL2-Family scores

The quadrant boundaries are set at 19.5 on the x-axis and 5.5 on the y-axis, following guidelines by Chessman (2003).

Macroinvertebrate diversity reflects the ecological integrity of the habitat in which they live and responds to changes caused by environmental variability (seasonal changes) and anthropogenic pressures (e.g. pollutants and/or habitat degradation). Victoria Creek has poor overall riparian and geomorphic condition (discussed in **Section 4.2**), which means suitable habitats may not be available for some highly sensitive taxa, whilst poor water quality in the creek may explain the absence of sensitive taxa, which may have specific tolerance thresholds.

The metrics we used collectively indicate some level of biological impairment occurring in Victoria Creek; however, a range of other environmental factors such as extended drought condition prior to sampling, lack of suitable habitats and pollutants not assessed through the current monitoring program, could also determine the macroinvertebrate community composition. Ongoing monitoring will assist in filling these knowledge gaps.

4.13 Fish

Fish abundance and species richness give an indication of the current fish community structure in Victoria Creek. They will serve as a baseline for future comparisons.

A total of 444 fish belonging to 12 species were captured during the surveys, in which 81% and 19% were native and non-native fish species respectively. Both fish abundance and species richness were low in the freshwater sites of Victoria creek (**Table 13**). Although 12 species were recorded in this initial survey of Victoria Creek, half of these were estuarine species found only at VC4 and both species richness and the proportion of native fish declined upstream from the estuary (**Table 14**). The comparatively high abundance at VC2 was largely due to relatively high numbers of non-native *Gambusia holbrooki*.

The Simpson's diversity index score showed a decreasing trend toward the downstream freshwater sites but was relatively high at the estuarine site VC4. The Simpson's diversity index is driven by both species number and relative abundance. The low index score for VC3 was due to a numerical dominance of common galaxids (*Galaxias maculatus*) in the catch. In VC1 relative abundance was uniformly low, even leading to a relatively high diversity index although the non-native mosquitofish (*Gambusia holbrooki*) constituted nearly half of captured fish (n=18). No clear species dominance was apparent in VC2, where catches were predominantly composed of both native galaxids (n=64) and non-native mosquitofish (n=62) with the shared high abundance bolstering the diversity index despite the low species richness. At VC4, catches were dominated by black bream (*Acanthopagrus burcheri*) (n=118), but this was offset by the highest species richness of all sites and relatively high abundance of dwarf flathead gudgeon (*Philypnodon macrostomas*) (n=57).

Table 13 Summary of captures during initial fish survey in Victoria Creek

Non-native species are highlighted. Family names are in uppercase.

Family name	Common name	Scientific name	Total fish	Site
Anguillidae	Southern shortfin eel	*Anguilla australis*	*7*	VC3, VC4
	Longfin eel	*Anguilla reinhardtii*	*3*	VC3
Atherinidae	Smallmouth hardyhead	*Atherinosoma microstoma*	*18*	VC4
Eleotridae	Striped gudgeon	*Gobiomorphus australis*	*13*	VC1, VC2, VC3
	Flathead gudgeon	*Philypnodon grandiceps*	*21*	VC1, VC3, VC4
	Dwarf flathead gudgeon	*Philypnodon acrostomus*	*57*	VC4
Galaxiidae	Common galaxid	*Galaxias maculatus*	*118*	VC1, VC2, VC3, VC4
Girellidae	Luderick	*Girella tricuspidata*	*2*	VC4
Poeciliidae	Mosquitofish	*Gambusia holbrooki*	*85*	VC1, VC2, VC3, VC4
Rombosoleidae	Greenback flounder	*Rombosolea tapirina*	*1*	VC4
Sparidae	Black bream	*Acanthopagrus butcheri*	*113*	VC4
Terapontidae	Crescent grunter	*Terapon jarbua*	*6*	VC4
Total number of species:			*12*	
Total number of native individuals captured:			*444*	

Table 14 Fish species indices calculated for spring 2020 data

Indices	VC1	VC2	VC3	VC4
Number of individuals	38	128	60	218
Species richness	4	3	6	10
Percentage nativeness	52.63	51.56	98.33	98.17
Simpson's diversity index	0.68	0.52	0.35	0.65

4.14 Frogs

There have been over 20 frog species identified in the Bega Valley, with the most common species being the common eastern froglet (*Crinia signifera*), Verreaux's tree frog (*Litoria verreauxii*) and Peron's tree frog (*Litoria peronii*) (Sass 2011). Bega Valley is also home to six threatened species including the giant burrowing frog (*Helioporus australicus)*, green and golden bell frog (*Litoria aurea*), heath frog (*Litoria littlejohni*), southern bell frog (*Litoria raniformis*), stuttering frog (*Mixophyes balbus*) and southern barred frog (*Mixophyes iteratus*).

Frog call surveys identified three frog species that are known to be common in the Bega Valley (**Table 15**). *Crinia signifera* inhabits a wide range of habitats including creeks, swamps and ponds, particularly within riparian vegetation and underneath rocks. It is known to be a disturbance tolerant species and tends to reappear in its habitat after several years of disturbance (Lauck et al. 2008; Hero et al. 2002). Verreaux's tree frog and Peron's tree frog have also been reported in the region and are known to share similar habitats to *C. signifera*, including disturbed areas near human habitation (Anstis 2017; Sass 2011; Hazell et al. 2004).

Over time, less habitat disturbance is anticipated to occur at these sites due to the stock exclusion fences. Subsequent higher proportions of riparian vegetation and habitat complexity is thereby likely to support higher levels of frog breeding activity and by more species. While the data from the present study provide some baseline information on frog species presence and breeding activity, additional species inhabiting the creek will be identified through further frog call surveys.

Table 15 Frog species identified at each site through frog call surveys ('P' indicates presence of the species)

Common name	Scientific name	VC1	VC2	VC3
Common eastern froglet	*Crinia signifera*	P	P	P
Verreaux's tree frog	*Litoria verreauxii*	P	P	P
Peron's tree frog	*Litoria peronii*		P	P

5. Conclusions and recommendations

Over two centuries the catchment of Victoria Creek has been cleared for timber industry, housing and road developments and dairy farms. The catchment area of Victoria Creek above VC4 (the approximate tidal limit) was found to be 1135 hectares and about 43% was covered with woody vegetation in 2019. Most of the woodland and forest area is in the upper catchment of Victoria Creek within the Gulaga National Park, and also in the north-east of the catchment at Corunna State Forest. Symptoms of poor ecosystem health observed in the creek and the lake system can be related back to poor land management practices that have occurred in the catchment for many decades.

Overall, the results from this study suggest that the creek system has signs of impairment such as slumped stream banks, exceedances in nutrient levels, very low DO levels and signs of heavy sedimentation, which smother suitable habitat available for macroinvertebrates. Algal blooms are also evident due to nutrient enrichment in the system. All sites monitored indicated faecal contamination in Victoria Creek although the exact source has not been identified. Fish, macroinvertebrate and frog data collected through this study showed the creek health could support some aquatic fauna and it is anticipated the diversity and abundance of these species will expand as more favourable habitat conditions become available in future.

As the riparian buffers expand there will more shade, and less nutrient and sediment run-off into creek waters, providing more favourable conditions for the stream health to recover. Similarly, by excluding cattle any further pugging or trampling damage to the creek system will be prevented. Cattle exclusion fences will also minimise direct defecation by animals and allow riparian vegetation to stabilise banks.

5.1 Water quality, macroinvertebrates, fish, frogs and visual health assessment

Rainfall, stream water level and water temperature

- The dry weather conditions observed during 2019 are consistent with the El Niño episodes characterised by the Southern Oscillation Index. The year 2020 was a relatively wet year. In general, over 20 millimetres of rainfall can generate overland flow in the catchment. Trips 1 and 14 were undertaken following extreme wet conditions as the total rainfall received five days prior to sampling surveys exceeded 90 millimetres.
- Water levels in the creek declined from August to December in 2019 due to increased evaporation and low precipitation. While water levels at three freshwater sites responded to rainfall in a similar pattern, site VC4 was more responsive to large rainfall events and is also influenced by whether the lake is open to the ocean.
- The most downstream site, VC4, always recorded warmer waters compared with the three upstream freshwater sites. As the fresh water entering into the fluvial delta is colder than water at VC4, thermal stratification is likely at the mixing zone. Further, the diurnal temperature (difference between the maximum and minimum temperatures) variation across all sites doubled during summer (~11°C) compared with other seasons.

Water clarity

- Median turbidity values at sites VC1–3 were within the ANZECC/ARMCANZ (2000) trigger value range. Elevated turbidity levels were associated with upstream sites and displayed a gradual decline towards the downstream sites.

- The fine sediment layer currently sitting on the streambed is highly prone to disturbance by wind, livestock crossing and rainfall. This is evident from occasional high turbidity readings reported for all sites.

pH and alkalinity

- pH was within the trigger value for freshwater sites. Alkalinity was relatively low at freshwater sites compared to VC4, which was influenced by carbonate and bicarbonate ions in seawater. Alkalinity regulates pH changes in water, meaning that aquatic life at freshwater sites may be relatively more vulnerable to changes in pH with increased external pollution due to low alkalinity compared with site VC4.

Dissolved oxygen

- The median DO saturation values at freshwater sites VC1–3 were below the lower trigger value (<85%). Factors affecting DO include high organic matter load, reaeration, stream flow, chemical oxygen demand and community metabolism rates (i.e. respiration and photosynthesis rates). However, further investigation is required using loggers over a diurnal cycle to identify potential drivers.

Nutrients

- Total nutrients TP and TN concentrations exceeded the default trigger values for coastal streams; however, the bioavailable dissolved inorganic nutrients (NH_4^+, NO_x, FRP) remained below the trigger values. Higher nutrient concentrations towards the downstream reach of the creek are also evident.
- Very high NH_4^+ concentrations reported as outliers at site VC4 are concerning as at alkaline pH conditions (median pH of VC site is above 7 and alkaline) this could form more toxic ammonia in the system, which is harmful for aquatic fauna.
- The creek system is dominated by DON and there is very little DIP and DOP. The DIN:TDN ratios estimated for Victoria Creek gradually increased from upstream to downstream sites with site VC4 having the highest DIN:TDN ratio, indicating the bioavailability of nitrogen for aquatic plant growth around the fluvial delta of Tilba Tilba Lake.
- Significant correlations occurred between rainfall and TN (0.33, $p<0.01$), TDN (0.39, $p<0.001$), NO_x (0.56, $p<0.001$), DIN (0.26, $p<0.1$), DON (0.33, $p<0.001$) and DOP (0.38, $p<0.001$); however, the correlations were non-significant for TP, FRP and TDP. The correlations do not suggest causations and more evidence will be gathered through multiple future wet weather sampling surveys to confirm these relationships.

Phytoplankton

- Chl-*a* was used as a proxy indicator for phytoplankton biomass in Victoria Creek. Chl-*a* levels varied highly on spatio-temporal scales, and the median Chl-*a* at VC1 exceeded the default ANZECC/ARMCANZ (2000) trigger value. High Chl-*a* levels indicate algal blooms due to nutrient enrichment.
- A significant correlation between Chl-*a* and all nutrients except with NH_4^+, TDP (0.42, $p<0.01$), FRP (0.35, $p<0.1$), TP (0.5, $p<0.001$), DOP (0.53, $p<0.001$), DON (0.42, $p<0.01$), TDN (0.4, $p<0.01$) and TN (0.47, $p<0.001$) levels, suggests the nutrient enrichment is driving phytoplankton biomass the system.
- Warmer, more saline shallow water following the extended drought throughout most of 2019 resulted macroalgal dieback. This was observed at the most downstream site (VC4) in November 2019. Macroalgal dieback often occurs in estuaries and lakes along the NSW coast in November/December following the spring bloom.

Enterococci and E. coli

- Victoria Creek is contaminated with faecal microbes. Although the faecal bacterial levels were generally low, very high counts were occasionally recorded. These high observations may be associated with close interaction of cattle with the stream as cow dung was observed near the stream during sampling surveys.
- The two bacterial indicators significantly correlated with rainfall (*E. coli*: 0.4, $p<0.01$ and enterococci: 0.53, $p<0.001$) indicating there may be some level of run-off associated impacts, although the source of this pollution is not evident from the present study.
- The two bacterial indicators were also significantly correlated with each other (0.67, $p<0.001$), showing the similar behaviour of the two indicator bacteria in the creek.

Macroinvertebrates, fish and frogs

- Macroinvertebrates were collected from four sites in spring 2019 and spring 2020. In general, more taxa were reported across all sites in 2020 compared to the previous year. The EPT taxa richness increased from 2019 to 2020 at two of the four sites, which suggests an improvement in aquatic ecosystem condition in 2020. However, the AUSRIVAS and SIGNAL2-Family indicator scores suggested that Victoria Creek has some degree of biological impairment. A range of other environmental factors such as lack of suitable habitats, weather and climate (i.e. El Niño and drought) prior to sampling, and pollutants not assessed through this monitoring program, could also determine the macroinvertebrate community composition of the Victoria Creek monitoring sites. Ongoing macroinvertebrate monitoring, combined with water quality monitoring and surveys of riparian and stream channel condition, should assist with filling these knowledge gaps.
- The first fish survey undertaken in spring 2020 set a baseline against which future changes in fish populations may be compared. During the survey, more native fish (81%) were captured than the non-native species (19%). The non-native fish species *Gambusia holbrooki* was recorded at all sites. Fish monitoring will continue biannually, initially allowing an assessment of seasonal variation and in the medium term providing an indication of the effectiveness of rehabilitation works in improving stream health. As riparian revegetation establishes and stock exclusion mediates the historical impacts of livestock on stream morphology and water quality, an improvement in available fish habitat and fish passage is expected. These changes directly impact fish diversity and pest fish abundance quantified through the continuation of this survey program.
- frog species, the common eastern froglet (*Crinia signifera*), Verreaux's tree frog (*Litoria verreauxii*) and Peron's tree frog (*Litoria peronii*), were identified through frog call surveys in spring 2020. While the data from the present study provides some baseline information on frog species presence and breeding activity, additional species inhabiting the creek will be identified through further frog call surveys.
- The indicators assessed in the study were able to capture the baseline ecological condition of Victoria Creek. The patterns observed in various physico-chemical and biological variables may be due to the moderate to high levels of active bank erosion and sedimentation, associated with a reduced riparian zone and surrounding terrestrial vegetation from historical clearing, increased livestock activity causing sediment mobilisation in run-off, by trampling and destabilising of the bank and stream substrate. Water quality parameters, particularly nutrient pollution, appear to fluctuate with rainfall.

5.2 Riparian vegetation and GIS desktop assessment

- This baseline survey of the riparian vegetation before the elimination of large ruminant animals (mainly cattle) found that the vegetation cover at all sites with historical grazing practices was essentially dominated by the non-native grass kikuyu, and had more or less equal numbers of native and non-native species. Only the reference site in Corunna State Forest (VCR3) was dominated (100%) by native species.
- With the presence of native species already at all historically grazed sites, as well as the evidence of native species in the soil seed bank at all zones of the riparian buffer zone, we hypothesise that the cover of native species will increase over the medium to long-term period with the elimination of large ruminant animals. While initially in the short-term the cover of non-native grasses and opportunistic species (mainly non-native species) will dominate the riparian area, continued management of weeds will allow native plantings and native seed banks to establish over the medium to long term.
- Due to the obvious bank erosion occurring along Victoria Creek, it is recommended that planted species should include species that act as bank stabilisers such as *Lomandra longifolia*. *Lomandra longifolia* already occurs within the Victoria Creek catchment and was observed as an efficient bank stabiliser, especially at VC3 and Corunna State Forest.
- The GIS analysis of tree cover in the riparian zone and for the whole catchment has established a baseline against which rehabilitation actions and future change can be compared. In the medium to longer term it is expected the rehabilitation of riparian vegetation will increase the amount of tree cover in the riparian zone, and this will contribute to the health of the catchment including water quality outcomes. The use of remotely sensed datasets and GIS analyses enables a relatively rapid and easily repeated assessment of tree cover across the whole of the Victoria Creek catchment, and an assessment of the contribution of rehabilitation work to whole of catchment vegetation cover.

Visual health indicators

- Visual indicator scores are based on surveys undertaken in 2019 and 2020. The moderate geomorphic scores indicated active bank erosion and increased sedimentation occurring at all sites. The low riparian condition scores were related to the reduced longitudinal continuity, riparian and canopy width, sparse shrub layer and groundcover. All sites were presented with filamentous green algae.
- Although improvements are expected with the exclusion of livestock, restoration will be a long-term achievement. Ongoing annual assessment of the visual health will assist tracking the improvement in the riparian zone.

5.3 Saltmarsh

- The extent of saltmarsh coverage in Tilba Tilba Lake at any time is influenced by seasonal growth cycles and the naturally fluctuating hydrological regime associated with the ocean entrance dynamics and catchment inflows.
- Species richness during the study period was significantly greater at sites on the eastern foreshore compared to sites on the western foreshore.
- Prior to the introduction and/or replacement of fencing, saltmarsh coverage was impacted by grazing pressure on the south-eastern foreshore adjacent to the entrance and the north-western foreshore.
- Communities at all monitoring sites showed temporal changes in structure in terms of the dominant species and their coverage. Monitoring is continuing to collect sufficient

data to isolate any recovery trend due to cattle exclusion from this seasonal change that is punctuated by entrance closure events.

- One of the clearest trends over the monitoring period was the steady reduction in bare groundcover at all the monitoring sites indicating an overall improvement in saltmarsh extent and condition during the monitoring period.

5.4 Community engagement

- The achievement of the final aim of the project, to 'build capacity amongst local landholders and the community to assess stream health', was evidenced not only by high attendance at meetings and training workshops, but also through their support of the on-ground works, promotional video and actively engaging in water sample collection. The interested landowners were also provided with a detailed sampling manual that highlights standard protocols for sample collection and preservation. To continue with the high level of community engagement, we recommend development of a citizen science program allowing the local community to be involved in the monitoring of water quality, growth of riparian vegetation, and of presence of frogs, birds and other fauna as an indication of the return of terrestrial life following stream rehabilitation works.

5.5 Future monitoring

- With the exclusion of livestock and the improvement of the riparian vegetation through replanting of native trees, shrubs and rushes it is expected that overall ecological health will show some improvement, albeit at different time scales. That is, any changes reported with future monitoring are expected to be time and variable dependent. For example, while riparian vegetation might still be dominated by non-native grasses in the short term, this will probably slowly change as planted species grow and dominate cover, and native seed banks establish. With the regrowth of riparian vegetation and re-stabilisation of the banks, macroinvertebrates and instream macrophytes are also expected to establish, thereby also improving water quality over time.
- We recommend fish surveys be repeated biannually to assess seasonal variation and in the longer term assess the impacts of on-ground works on fish diversity, intra-stream distribution and abundance. The impact of these works has potential to affect fish populations in all sites through water quality changes downstream, altered habitat and food availability in managed areas, and facilitation of improved fish passage to and from upstream areas.
- During sampling surveys, two microorganisms *E. coli* and enterococci in Victoria Creek were assessed. While these standard bacterial tests detected and quantified faecal contamination in the creek, it did not explain the source of the bacteria. As a screening study, water samples taken in March 2019 were examined for specific DNA markers. This study was undertaken in collaboration with the University of Technology Sydney. The DNA extracted from these samples was compared with a library of DNA extracted from ruminants, birds and humans. Results indicated a majority of samples contained DNA markers similar to ruminants, but only one of 10 sites had a human marker. We recommend continuing this study with additional samples to better understand the source of the bacteria in Victoria Creek and Tilba Tilba Lake.
- We recommend a future monitoring program that includes regular water quality monitoring and biannual riparian vegetation and macroinvertebrate surveys. Where possible, seasonal frog, fish and bird surveys will provide multiple lines of evidence showcasing the recovery of the ecosystem health.
- Overall, this project has successfully achieved its primary aims and will contribute considerably to establishing a solid understanding of the relationships between ecological health indicators important for other NSW coastal waterways.

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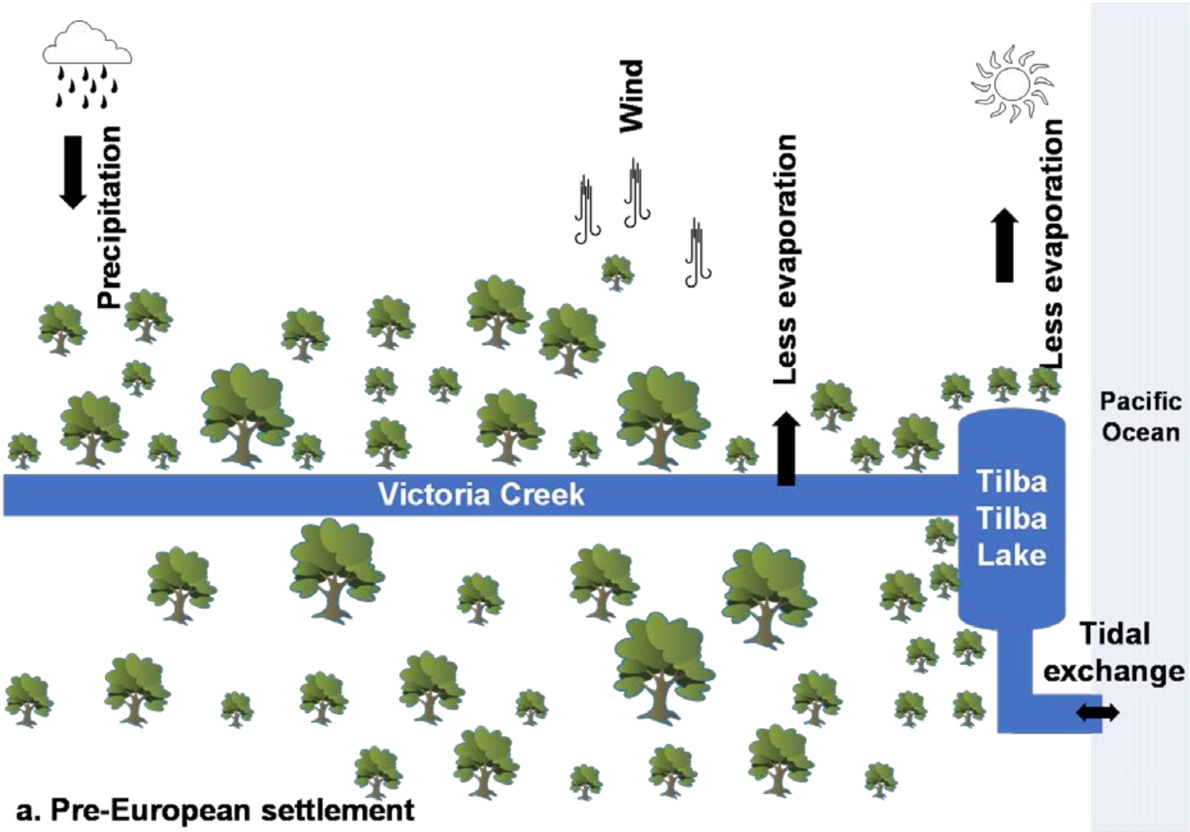
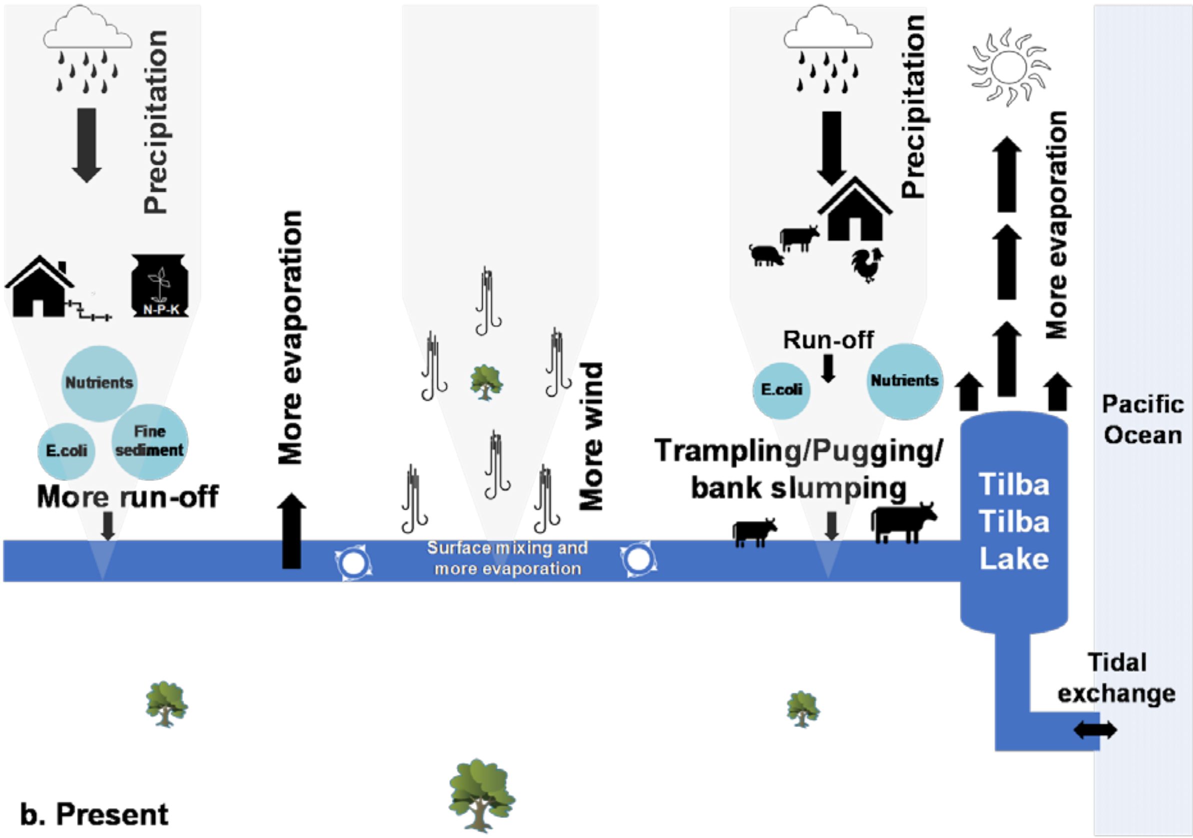
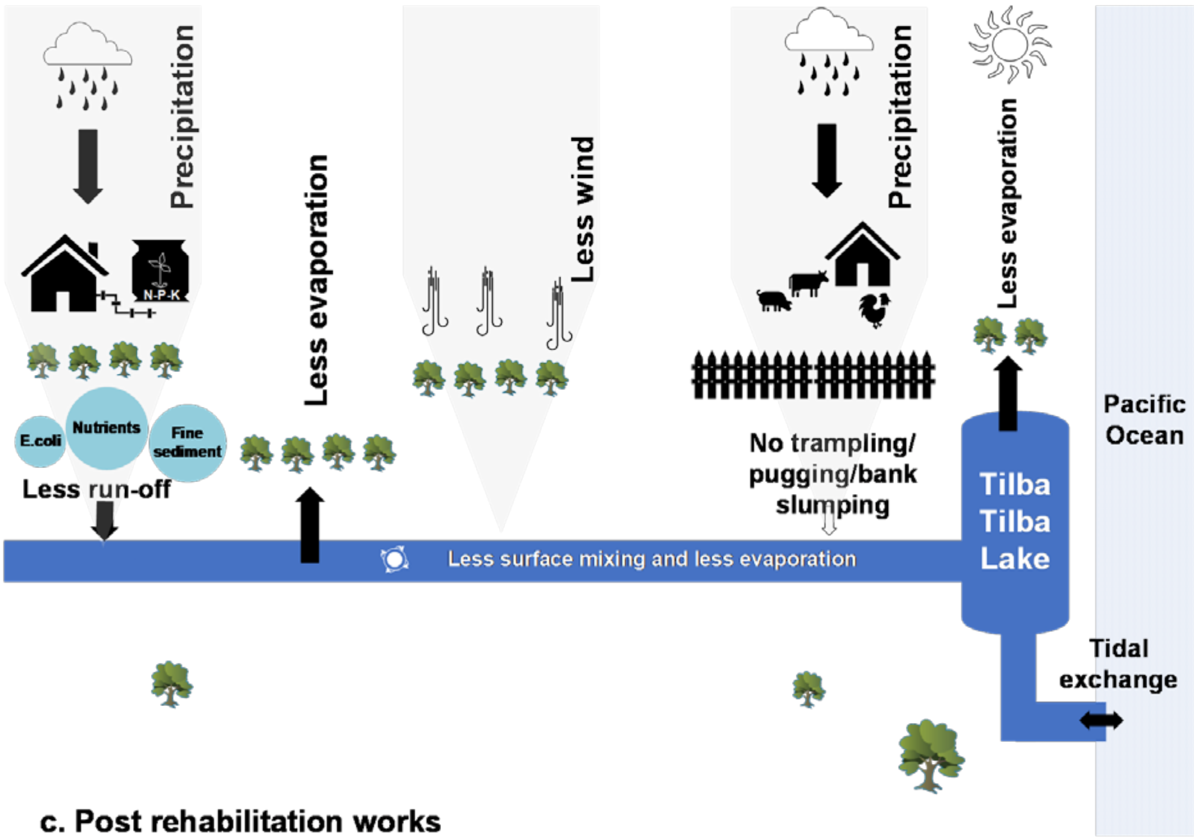
Appendix A. Conceptual models of the Victoria Creek and its catchment

a. pre-European settlement, b. present situation, c. likely situation post rehabilitation works





b. Present



c. Post rehabilitation works

Appendix B. Visual indicators assessed through RRA

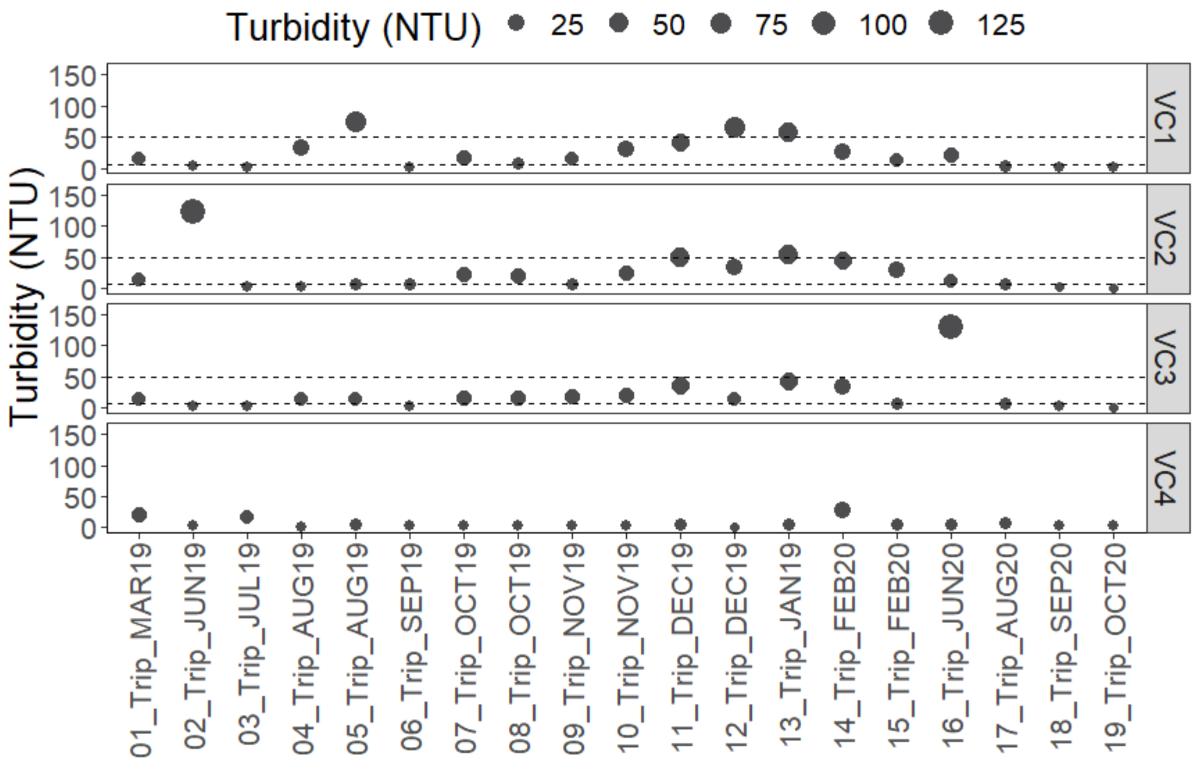
	Indicators	Indicators score criteria
Geomorphic condition (n=3, sum score = 15)	Sedimentation	1–Channel features buried by sediment 2–Sediment slug, bars and some infilling 3–Some sediment, habitat still available 4–Minor sediment, most habitat available 5–No evidence of sedimentation
	Bank erosion	1–Banks with slumping and undercutting 2–Banks vertical with some undercutting 3–Banks not vertical but erosion evident 4–Banks with minor erosion evident 5–No erosion evident, banks in natural condition or modified, but stable condition
	Embeddedness	1–Boulders, cobbles and logs embedded 2–At least 25% of habitat not embedded 3–At least 50% of habitat not embedded 4–At least 75% of habitat not embedded 5–All habitat including cobbles not embedded
Riparian condition (n=5, sum score = 25)	Riparian longitudinal continuity	1–No riparian vegetation 2–Up to 25% continuous 3–25 to 50% continuous 4–50 to 75% continuous 5–More than 75% continuous
	Riparian width	1–No riparian vegetation 2–Up to 10m 3–Between 10 and 20m 4–Between 20 and 30m 5–Continuous with bushland
	Riparian canopy	1–No canopy (but would be expected) 2–Canopy sparse, <25% cover 3–Canopy disturbed, 25 to 50% cover 4–Canopy slightly disturbed, 50 to 75% cover 5–Canopy greater than 75% cover
	Riparian shrub layer	1–No shrub layer (but would be expected) 2–Less than 25% of shrub layer remaining 3–25 to 50% of shrub layer intact 4–50 to 75% of shrub layer intact 5–More than 75% of shrub layer intact
	Groundcover	1–Groundcover absent 2–Groundcover less than 25% 3–Groundcover between 25 and 50% 4–Groundcover between 50 and 75% 5–Groundcover >75%

	Indicators	Indicators score criteria
Instream condition (n = 4, sum score = 18)	In-channel habitats	1–No habitat, straight sediment channel 2–One habitat type present 3–2 to 3 habitat types present 4–3 to 4 habitat types present 5–More than 4 habitat types present
	Large woody debris	1–None 2–Up to 20% 3–20% or more
	Leaf litter	1–None 2–Low 1 to 10% 3–Moderate 11 to 20% 4–High 21 to 30% 5–Very high >30%
	Macrophytes	1–None 2–Low 1 to 10% 3–Moderate 11 to 20% 4–High 21 to 30% 5–Very high >30%
Stream health issues (n = 5)	Grease and oil	0–Presence 1–Absence
	Odours	0–Presence 1–Absence
	Rubbish-instream	0–Presence 1–Absence
	Invasive weeds	0–Presence 1–Absence
	Filamentous green algae	0–Presence 1–Absence

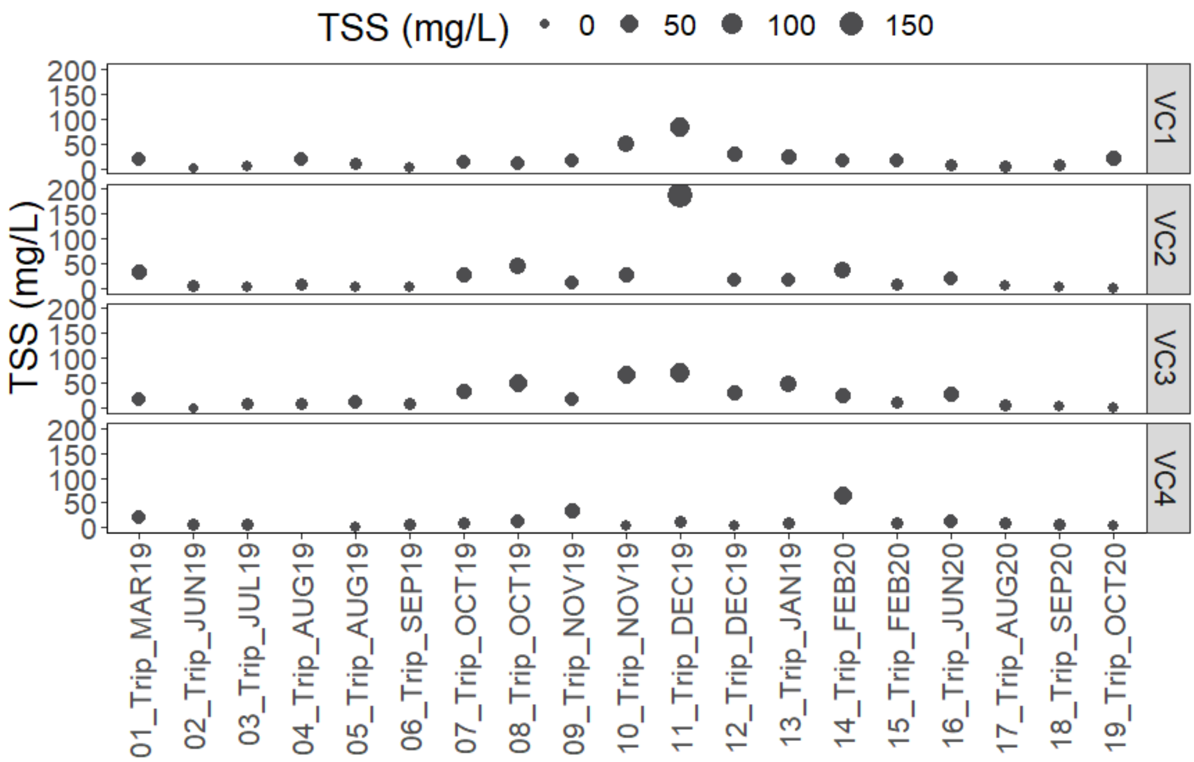
Appendix C. Variability in water quality over sampling trips

Dashed lines indicate ANZECC/ARMCANZ (2000) default trigger values for freshwater streams in south-east Australia.

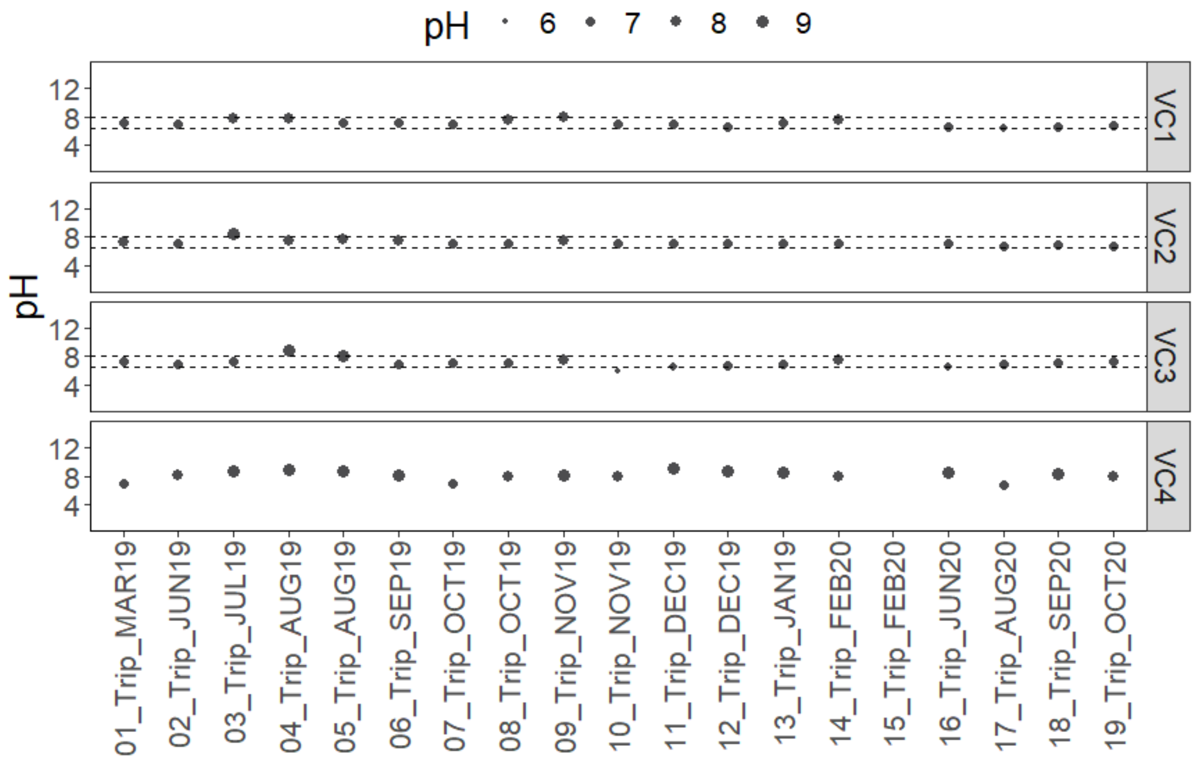
Ca. Turbidity (NTU)



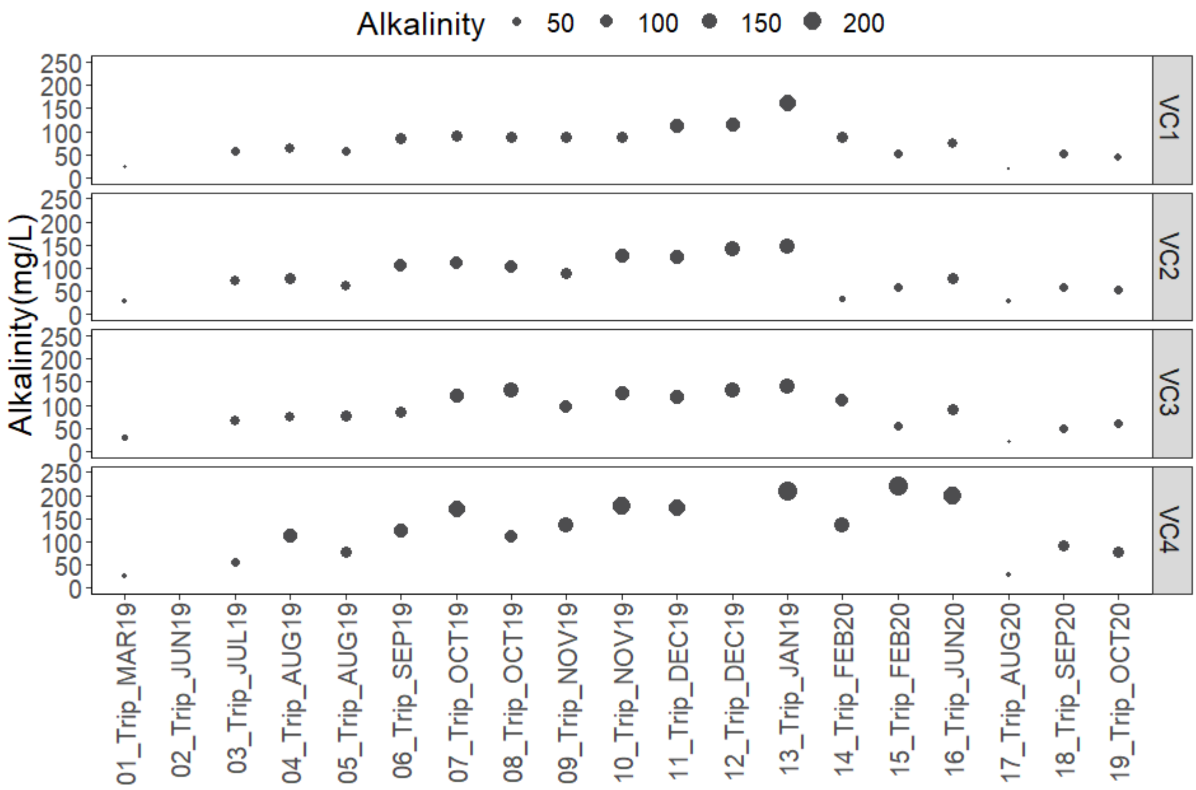
Cb. Total suspended solids (TSS)



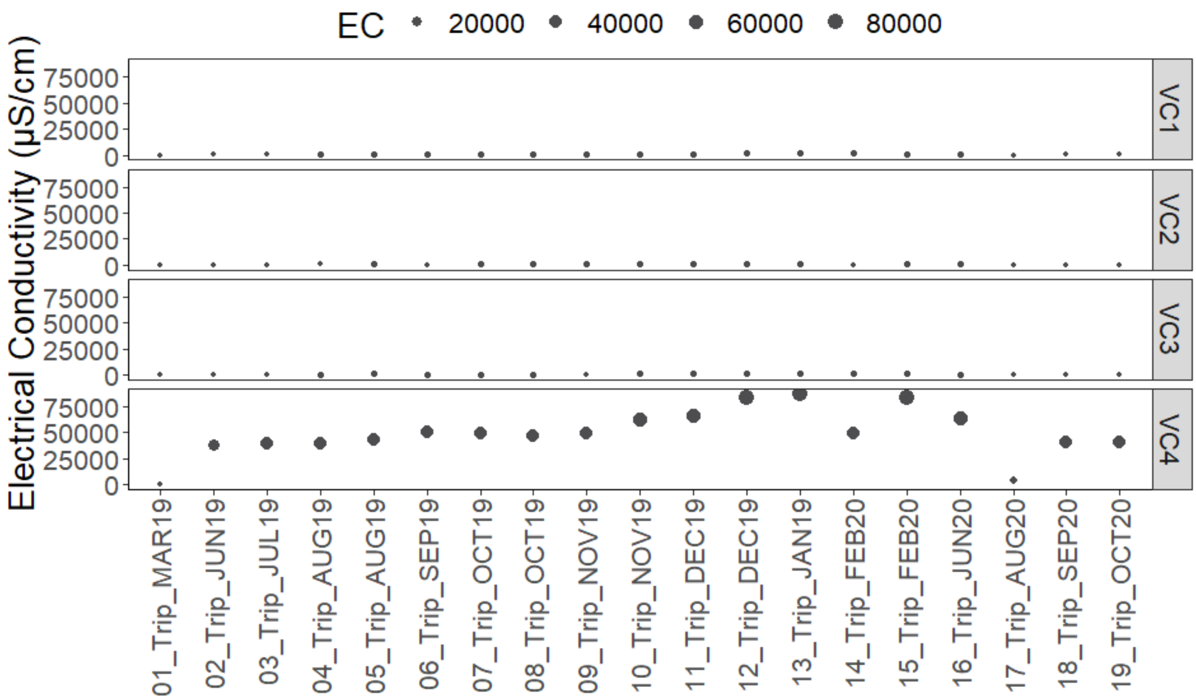
Cc. pH



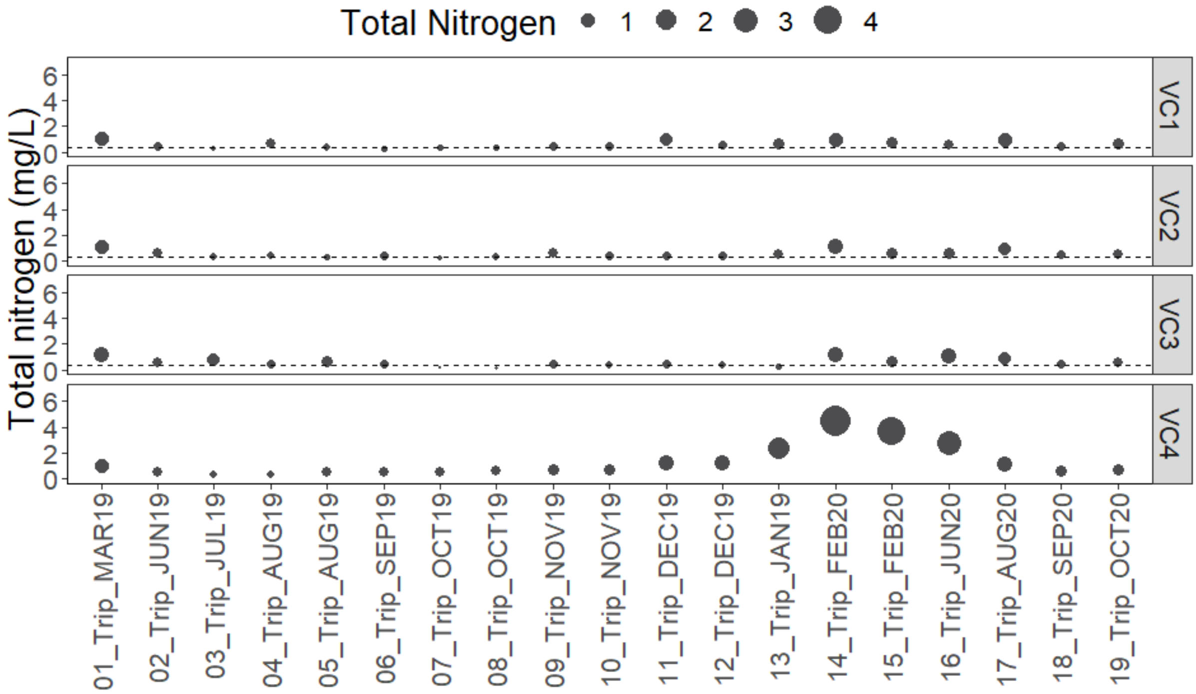
Cd. Alkalinity



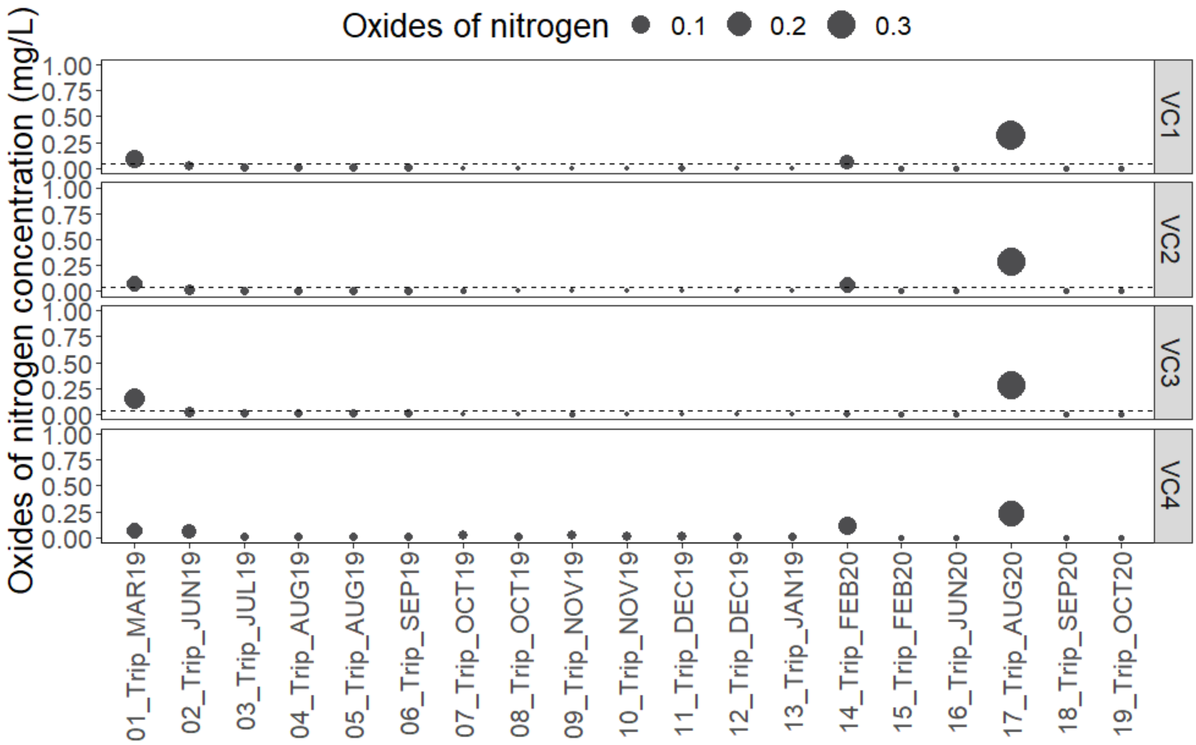
Ce. Electrical conductivity



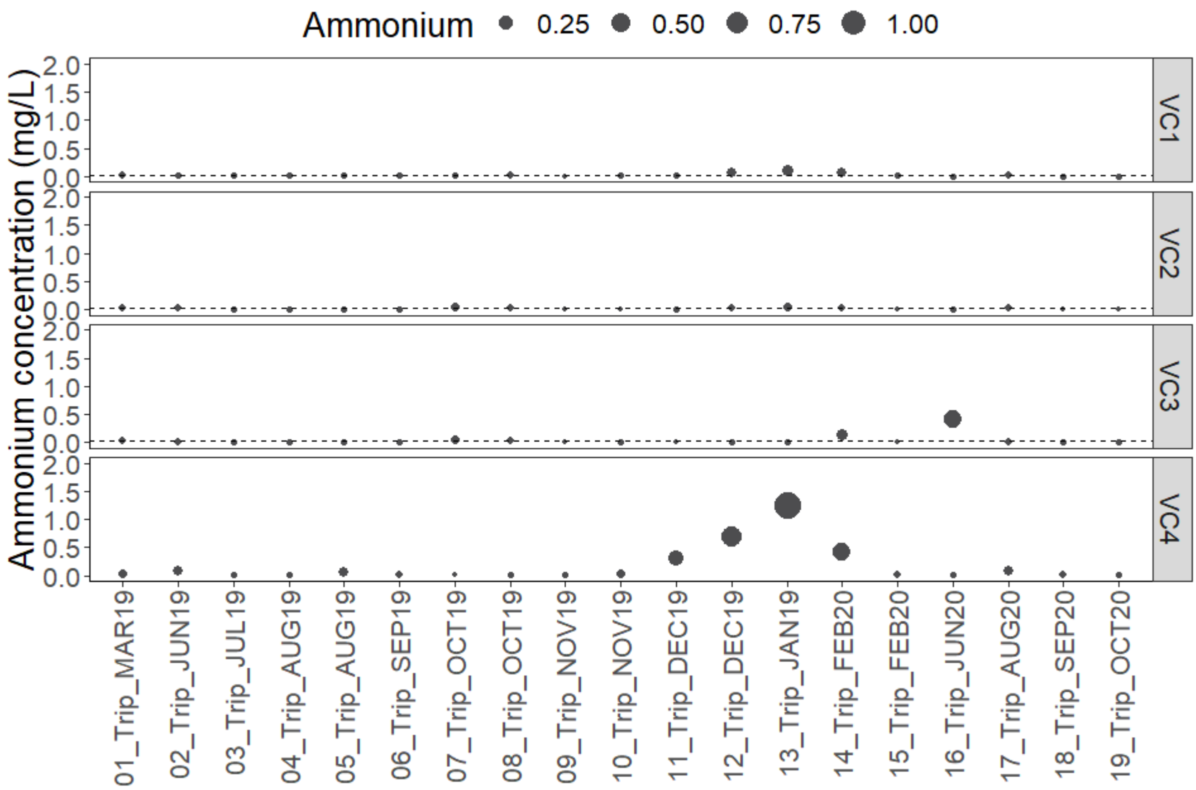
Cf. Total nitrogen



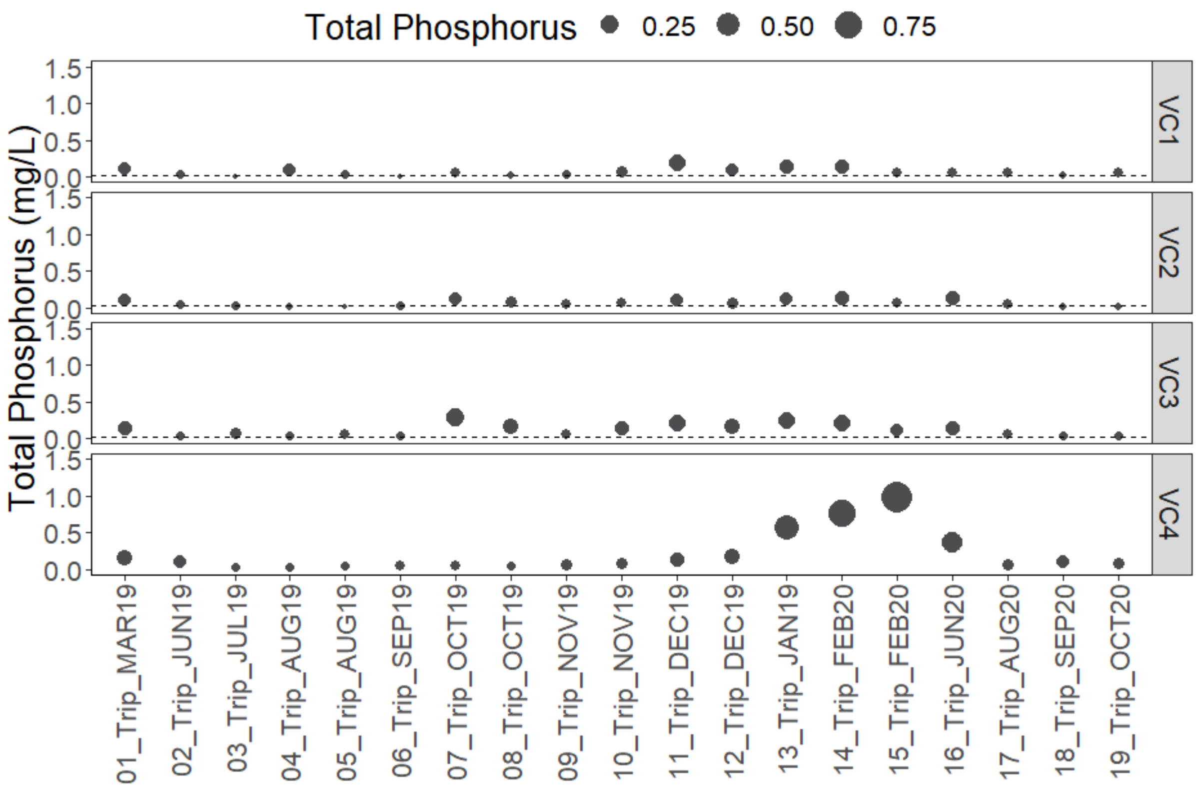
Cg. NOx concentration



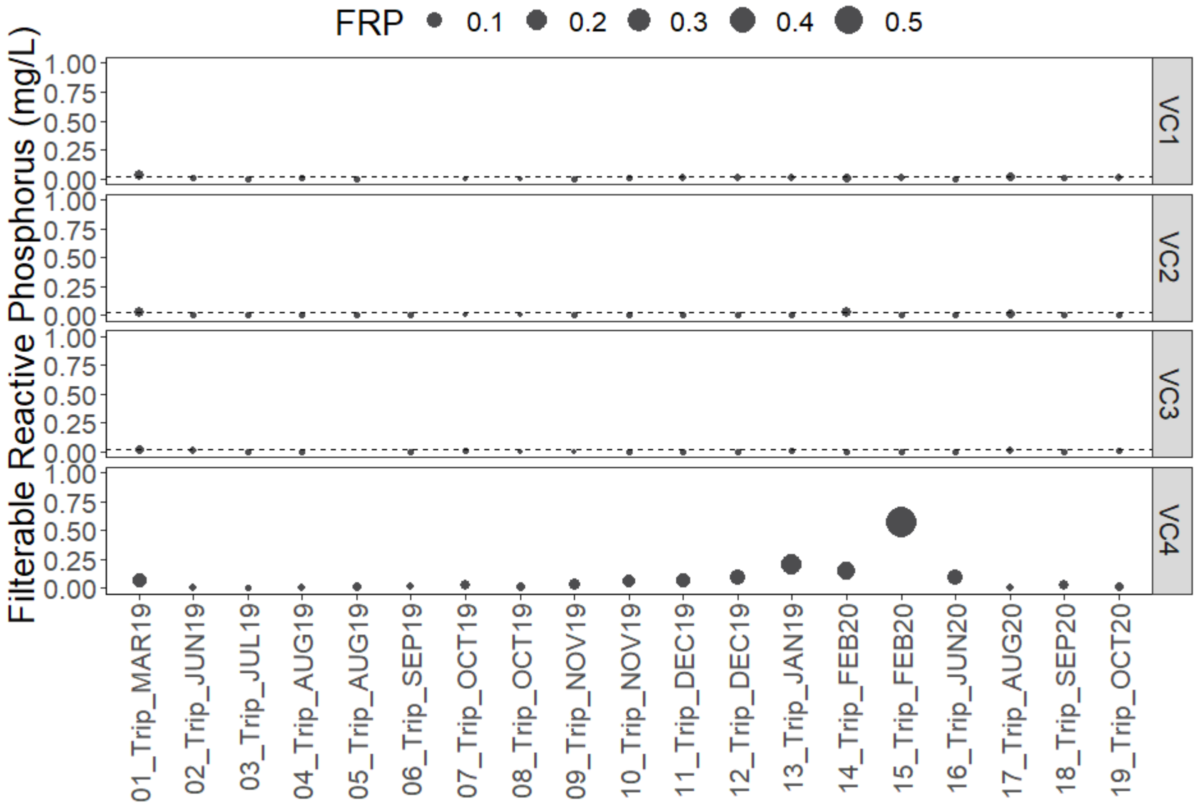
Ch. Ammonium concentration



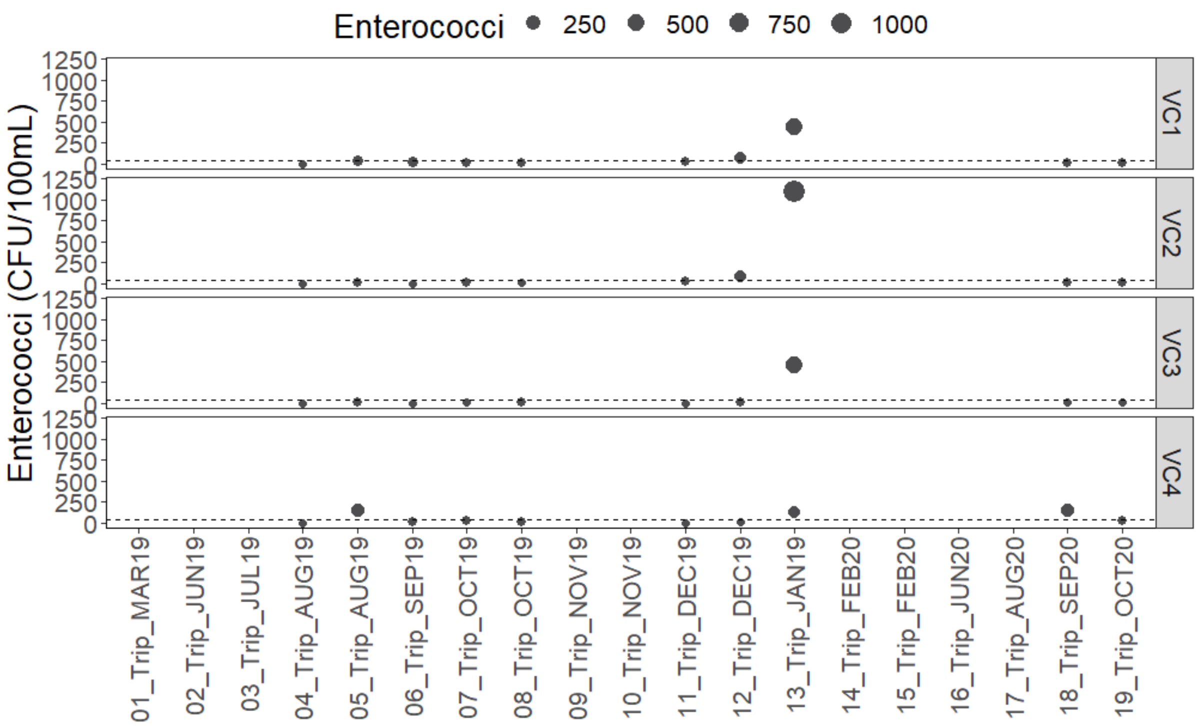
Ci. Total phosphorus concentration



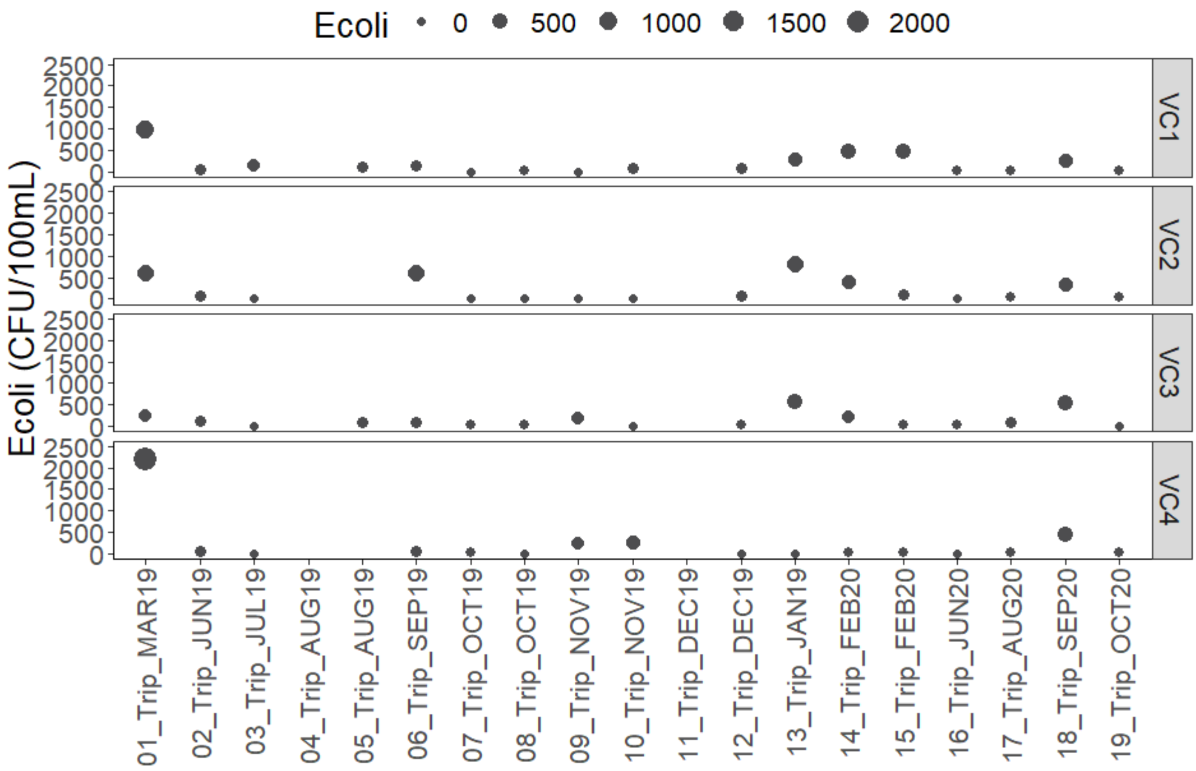
Cj. Filterable reactive phosphorus



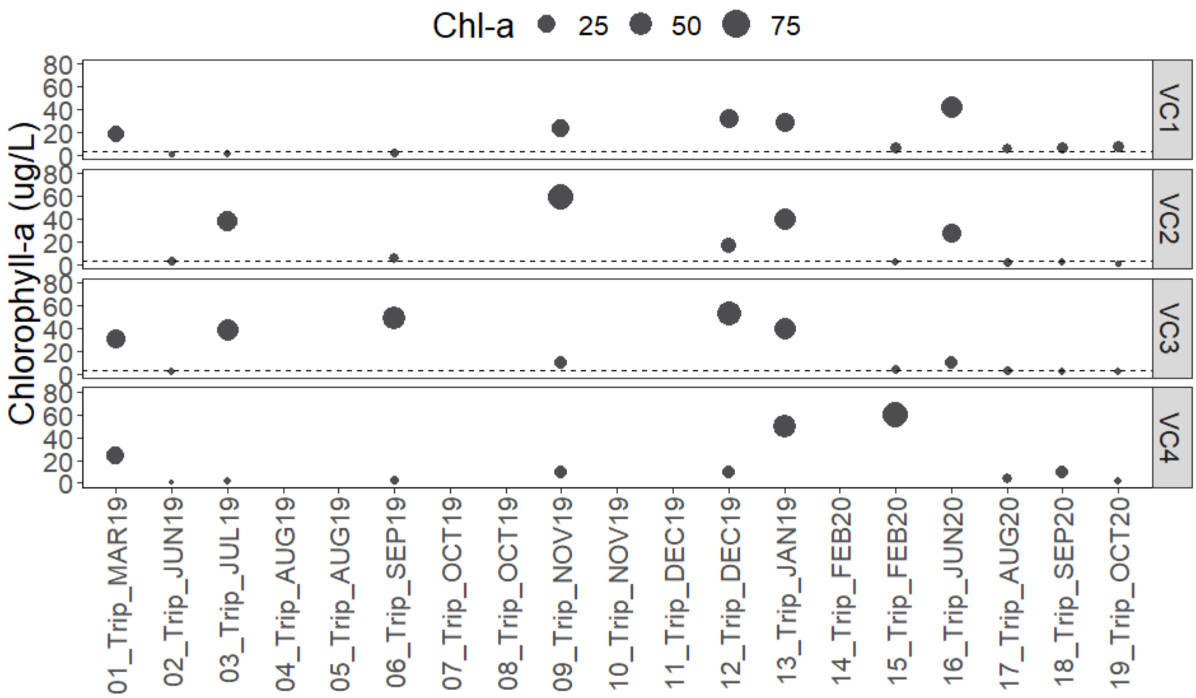
Ck. Enterococci



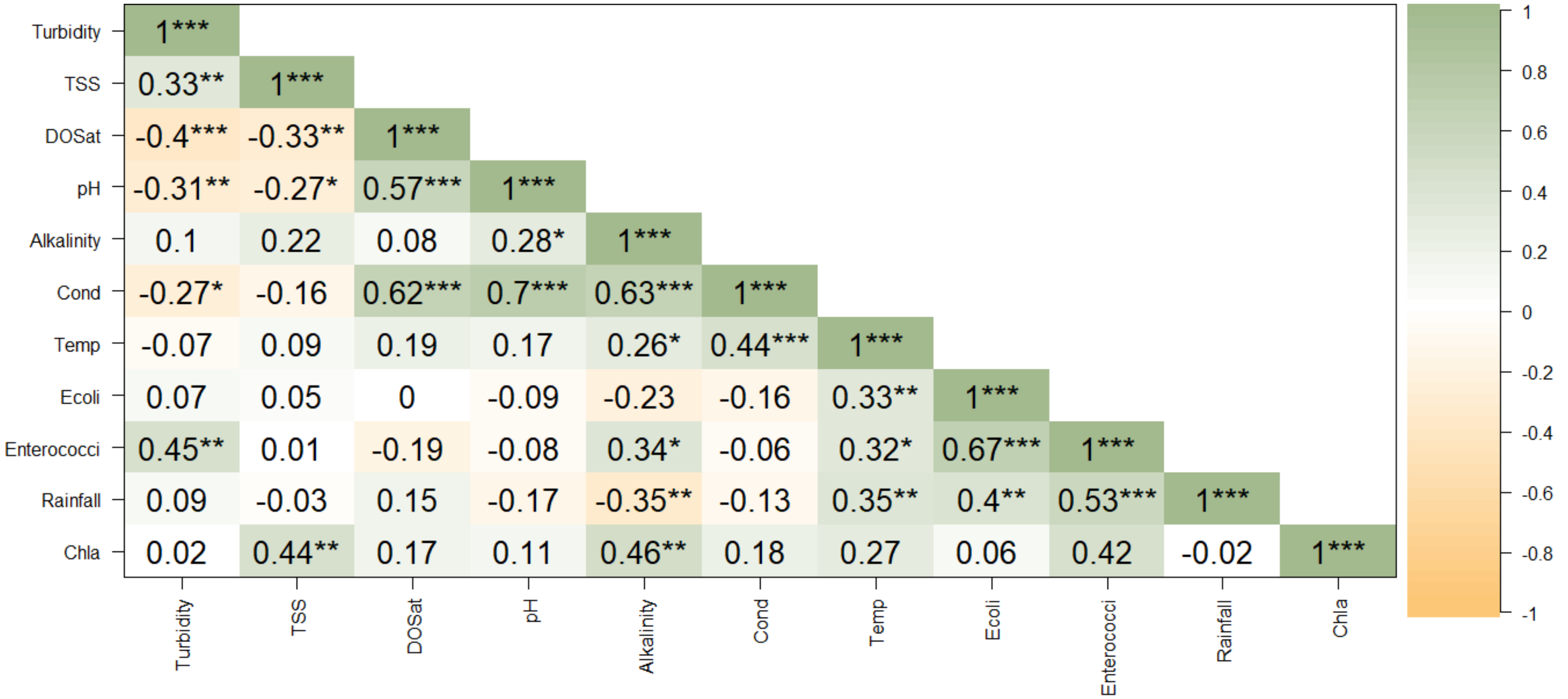
Cl. E. coli



Cm. Phytoplankton

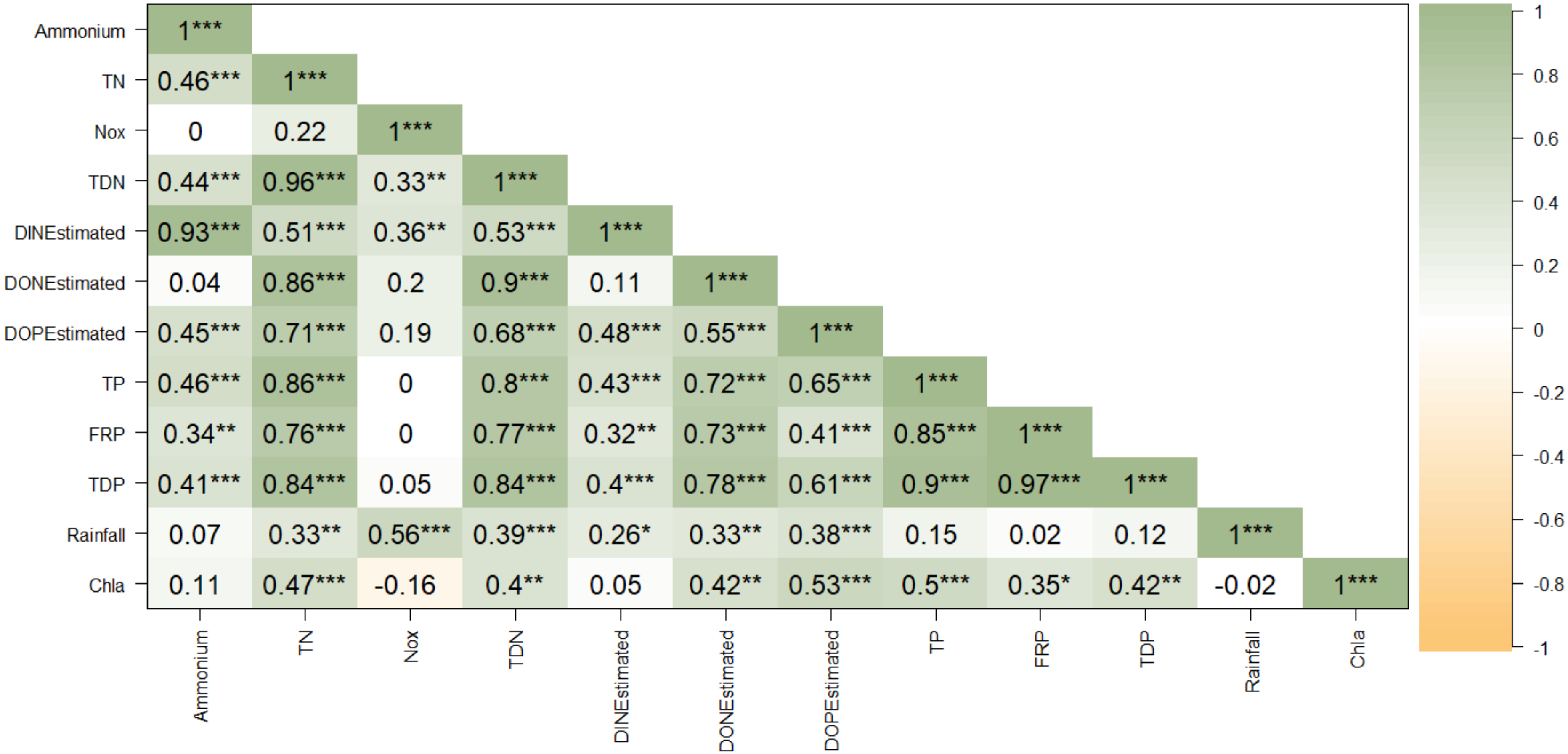


Appendix D. Relationships between physico-chemical-biological indicators and rainfall



Pearson correlations between physico-chemical-biological indicators and rainfall. Asterisks indicate significance level: * at p<0.1, ** at p<0.01, *** at p<0.001.

Appendix E. Relationships between nutrient indicators, chlorophyll-a and rainfall



Pearson correlations between nutrient indicators, chlorophyll-a and rainfall. Asterisks indicate significance level: * at p<0.1, ** at p<0.01, *** at p<0.001.TDN = total dissolved nitrogen, DIN= dissolved inorganic nitrogen, DON= dissolved organic nitrogen, TDP = total dissolved phosphorus, DOP = dissolved organic phosphorus.

Appendix F. Plant species recorded from 20 x 20 metre plots from five sites on Victoria Creek in September 2019, February and October 2020, and from Corunna State Forest in October 2020

WPFG (water plant functional groups) and WPIL (water plant indicator list) codes from Ling et al. (2019).

* Non-native species.

† Water plant functional group abbreviations are Sk, k-selected; Se, perennial – emergent; ARf, amphibious fluctuation-responders – floating; ARp, amphibious fluctuation-responders – morphologically plastic; ATe, amphibious fluctuation-tolerators – emergent; ATl, amphibious fluctuation-tolerators – low growing; ATw, amphibious fluctuation-tolerators – woody; Tda, terrestrial – damp places; Tdr, terrestrial – dry places.

‡ WPIL codes: 1–2.99, wetland indicator species; 3–3.99, discretional wetland indicator; 4–5, non-wetland indicator species

Family	Scientific name	Common name	Site						Growth form	WPIL code	WPFG
			VC1	VC2	VC3	VCR1	VCR2	VCR3			
Acanthaceae	*Brunoniella pumilio* (R.Br.) Bremek	Dwarf brunoniella		X					Forb (FG)	5	
Aizoaceae	*Tetragonia tetragonioides* (Pall.) Kuntze	New Zealand spinach, native spinach, warrigal greens		X					Forb (FG)	2	
Alismataceae	*Alisma plantago-aquatica* L	Water plantain	X	X	X	X	X		Forb (FG)	1.33	ARf
Alliaceae	*Allium triquetrum* * L	Three-corned garlic, angled onion		X					Forb (FG)	5	
Amaranthaceae	*Alternanthera denticulata* R.Br.	Lesser joyweed	X						Forb (FG)	3.17	Tda
Apiaceae	*Daucus carota* * L	Wild carrot	X						Forb (FG)	5	
Araceae	*Lemna disperma* Hegelm.	Common duckweed	X	X	X	X	X		Forb (FG)	1.33	ARf
Araliaceae	*Hydrocotyle bonariensis** Lam.	Largeleaf pennywort				X			Forb (FG)	5	
Arecaceae	*Livistona australis*	Cabbage fan palm						X	Shrub (SG)	2.65	ATw

Family	Scientific name	Common name	Site						Growth form	WPIL code	WPFG
			VC1	VC2	VC3	VCR1	VCR2	VCR3			
Asteraceae	*Brachyscome graminea* (Labill.) F.Muell.	Grass daisy			X				Forb (FG)	5	
Asteraceae	*Cirsium vulgare* (Savi)* Ten.	Swamp thistle	X	X	X				Forb (FG)	5	
Asteraceae	*Conyza sumatrensis* (Retz.) E.Walker	Tall fleabane	X	X	X				Forb (FG)	5	
Asteraceae	*Cotula coronopifolia** L.	Water buttons	X	X			X		Forb (FG)	1.76	ARp
Asteraceae	*Delairea odorata* Lem. *	Cape Ivy	X						Other (OG)	4.5	
Asteraceae	*Gamochaeta purpurea*	Purple cudweed			X				Forb (FG)	5	
Asteraceae	*Hypochaeris radicata** L.	Catsear		X	X	X			Forb (FG)	5	
Asteraceae	*Ozothamnus diosmifolius*	Rice flower						X	Forb (FG)	5	
Asteraceae	*Senecio linearifolius* A.Rich.	Fireweed groundsel, native fireweed	X	X	X				Forb (FG)	5	
Asteraceae	*Senecio madagascariensis* Poir *	Fireweed	X	X	X	X	X		Forb (FG)	5	
Asteraceae	*Sonchus asper* (L.) Hill *	Prickly sowthistle		X	X				Forb (FG)	5	
Asteraceae	*Taraxacum officinale** Weber	Dandelion	X	X	X	X			Forb (FG)	5	
Blechnaceae	*Blechnum nudum* (Labill.) Mett. ex Luerss.	Fishbone water fern	X	X	X	X			Forb (FG)	2.58	ATe
Brassicaceae	*Nasturtium officinale* W.T.Aiton*	Water cress	X	X	X	X			Forb (FG)	1.33	ATe
Bryophyta	*Bryophyta*	Moss	X					X	Other (OG)		
Callitrichaceae	*Callitriche stagnalis**	Common starwort	X		X		X		Forb (FG)	1	ATl
Campanulaceae	*Wahlenbergia gracilis*	Australian bluebell			X				Forb (FG)	5	

Family	Scientific name	Common name	Site						Growth form	WPIL code	WPFG
			VC1	VC2	VC3	VCR1	VCR2	VCR3			
Caryophyllaceae	*Cerastium glomeratum* Thuill.*	Mouse-ear chickweed			X				Forb (FG)	5	
Caryophyllaceae	*Cerastium vulgare* * Hartm.	Mouse-ear chickweed	X	X	X	X			Forb (FG)	5	
Caryophyllaceae	*Lobelia anceps* L.f.			X					Forb (FG)	5	
Caryophyllaceae	*Stellaria media** (L.) ill.	Common chickweed			X				Forb (FG)	5	
Chenopodiaceae	*Chenopodium murale* L.*	Nettle-leaf goosefoot	X						Forb (FG)	5	
Chenopodiaceae	*Dysphania ambrosioides* (L.) Mosyakin & Clemants*	Mexican tea, wormseed		X					Forb (FG)	5	
Commelinaceae	*Tradescantia fluminensis** ell.	Wandering jew	X	X	X	X			Forb (FG)	5	
Conolulaceae	*Dichondra repens* J.R.Forst. & G.Forst.	Kidney weed		X		X			Forb (FG)	5	
Crassulaceae	*Crassula helmsii* (Kirk) Cockayne	Swamp crassula	X	X	X				Forb (FG)	1.33	ARp
Cyperaceae	*Carex appressa* R.Br.	Tall sedge, tussock sedge	X	X				X	Grass & grass-like (GG)	2.17	ATe
Cyperaceae	*Carex fascicularius*	Tassel sedge	X	X					Grass & grass-like (GG)	1.68	ATe
Cyperaceae	*Carex longebrachiata* Boeckeler	A tassel sedge		X					Grass & grass-like (GG)	1.68	ATe
Cyperaceae	*Cyperus brevifolius* (Rottb.) Endl. ex Hassk.	Mullumbimby couch		X					Grass & grass-like (GG)	5	
Cyperaceae	*Cyperus gracilis* R.Br.	Slender flat-sedge		X	X	X			Grass & grass-like (GG)	5	
Cyperaceae	*Cyperus imbecillis* R.Br.	A sedge		X					Grass & grass-like (GG)	3.17	Tda

Family	Scientific name	Common name	Site						Growth form	WPIL code	WPFG
			VC1	VC2	VC3	VCR1	VCR2	VCR3			
Cyperaceae	*Cyperus sp.*	A sedge				X			Grass & grass-like (GG)	3	ATe
Cyperaceae	*Eleocharis acuta* R.Br.	Common spike-sedge				X			Grass & grass-like (GG)	1.3	ATe
Cyperaceae	*Eleocharis sphacelata* R.Br.	Tall spike rush	X	X	X	X			Grass & grass-like (GG)	1.33	ATe
Cyperaceae	*Gahnia radula* (R.Br.) Benth.	Thatch saw-sedge						X	Grass & grass-like (GG)	5	
Cyperaceae	*Isolepis cernua* (Vahl) Roem. & Schult.	Nodding club-rush			X				Grass & grass-like (GG)	2.66	ATl
Cyperaceae	*Isolepis fluitans*	Floating club-rush		X					Grass & grass-like (GG)	1.65	Sk
Cyperaceae	*Isolepis inundata* R.Br.	Club-rush, swamp club-rush	X	X	X				Grass & grass-like (GG)	1.97	ATl
Cyperaceae	*Isolepis marginata** (Thunb.) A.Dietr.	Coarse club-rush			X				Grass & grass-like (GG)	3	
Cyperaceae	*Isolepis prolifera** (Rottb.) R.Br.		X	X	X	X			Grass & grass-like (GG)	2	
Cyperaceae	*Schoenoplectus validus* (Vahl) A.Löe & D.Löe		X	X	X	X			Grass & grass-like (GG)	1.33	Se
Dennstaedtiaceae	*Hypolepis muelleri* N.A.Wakef.	Harsh ground fern	X	X					Fern (EG)	2.99	Tda
Dennstaedtiaceae	*Pteridium esculentum* (G.Forst.) Cockayne	Common bracken	X	X					Fern (EG)	5	
Dilleniaceae	*Hibbertia aspera* DC.	Rough guinea flower						X	Shrub (SG)	5	
Dilleniaceae	*Hibbertia scandens* (Willd.) Dryand.	Climbing guinea flower		X				X	Shrub (SG)	5	

Family	Scientific name	Common name	Site						Growth form	WPIL code	WPFG
			VC1	VC2	VC3	VCR1	VCR2	VCR3			
Fabaceae (Faboideae)	*Glycine microphylla* (Benth.) Tindale	Small-leaf glycine						X	Fern (EG)	5	
Fabaceae (Faboideae)	*Kennedia rubicunda*	Dusky coral pea						X	Shrub (SG)	5	
Fabaceae (Faboideae)	*Lotus corniculatus**	Birds-foot trefoil	X						Forb (FG)	5	
Fabaceae (Faboideae)	*Medicago polymorpha* L*	Burr medic		X					Forb (FG)	5	
Fabaceae (Faboideae)	*Oxalis articulata Savigny**		X						Forb (FG)	5	
Fabaceae (Faboideae)	*Pultenaea daphnoides* J.C.Wendl.	Large-leaf bush-pea						X	Shrub (SG)	5	
Fabaceae (Faboideae)	*Trifolium repens** L.	White clover	X	X	X	X	X		Shrub (SG)	5	
Fabaceae (Faboideae)	*Vicia sativa**	Common vetch		X					Forb (FG)	5	
Fabaceae (Mimosoideae)	*Acacia cognata* Domin	Narrow-leaf bower wattle						X	Shrub (SG)	5	
Fabaceae (Mimosoideae)	*Acacia falcata* Willd.	Hickory wattle		X					Shrub (SG)	5	
Fabaceae (Mimosoideae)	*Acacia irrorata* Sieber ex Spreng.	Green wattle						X	Shrub (SG)	3.67	Tdr
Fabaceae (Mimosoideae)	*Acacia maidenii* F.Muell.	Maiden's wattles						X	Shrub (SG)	5	
Fabaceae (Mimosoideae)	*Acacia mearnsii* De Wild	Black wattle	X	X	X				Tree (TG)	3.92	Tdr
Geraniaceae	*Geranium gardneri* de Lange	Rough cranes-bill	X	X	X				Forb (FG)	5	

Family	Scientific name	Common name	Site						Growth form	WPIL code	WPFG
			VC1	VC2	VC3	VCR1	VCR2	VCR3			
Geraniaceae	*Geranium homeanum* Turcz.	A cranes-bill			X				Forb (FG)	5	
Geraniaceae	*Pelargonium inodorum* Willd.	Native blackthorn	X						Forb (FG)	5	
Goodeniaceae	*Goodenia ovata*	Hop goodenia						X	Shrub (SG)	5	
Haloragaceae	*Gonocarpus teucrioides* DC.	A raspwort						X	Forb (FG)	5	
Iridaceae	*Romulea rosea var. australis**	Onion grass			X				Forb (FG)	5	
Juncaceae	*Juncus articulatus** L.	Jointed rush			X				Grass & grass-like (GG)	1.82	ATe
Juncaceae	*Juncus prismatocarpus*	Branching rush	X		X	X			Grass & grass-like (GG)	2.15	ATe
Juncaceae	*Juncus usitatus* L.A.S.Johnson	Common rush	X	X	X	X	X	X	Grass & grass-like (GG)	1.67	ATe
Juncaceae	*Juncus vaginatus*					X			Grass & grass-like (GG)	1.94	ATe
Juncaginaceae	*Cycnogeton microtuberosum* (Aston) Mering & Kadereit	Water ribbons		X	X	X	X		Grass & grass-like (GG)	1.33	Se
Lamiaceae	*Plectranthus parviflorus* Willd.	Cockspur flower		X					Forb (FG)	5	
Lobeliaceae	*Lobelia anceps* L.f.	Angled lobelia		X		X			Forb (FG)	2.15	Tda
Lomandraceae	*Lomandra longifolia Labill.*	Spiny-headed mat-rush, honey reed	X	X		X			Forb (FG)	5	
Malvaceae	*Modiola caroliniana* (L.) G.Don	Red-flowered mallow	X	X	X	X			Forb (FG)	5	

Family	Scientific name	Common name	Site						Growth form	WPIL code	WPFG
			VC1	VC2	VC3	VCR1	VCR2	VCR3			
Malvaceae	*Modiola caroliniana** (L.) G.Don	Red-flowered mallow	X						Forb (FG)	5	
Malvaceae	*Sida rhombifolia** L.	Paddy's lucerne		X		X			Forb (FG)	5	
Moraceae	*Ficus sp.*	Fig						X	Tree (TG)	5	
Myrtaceae	*Corymbia maculata*	Spotted gum		X				X	Tree (TG)	5	
Myrtaceae	*Eucalyptus botryoides* Sm.	Bangalay, southern mahogany	X	X					Tree (TG)	5	
Myrtaceae	*Eucalyptus globoidea* Blakely	White stringybark						X	Tree (TG)	5	
Myrtaceae	*Syncarpia glomulifera* (Sm.) Nied.	Turpentine						X	Tree (TG)	5	
Oleaceae	*Ligustrum sinense**	Small-leaved privet		X					Shrub (SG)	5	
Oleaceae	*Notelaea venosa* F.Muell.	Veined mock-olive, smooth mock-olive, large-leaved mock-olive						X	Shrub (SG)	5	
Onagraceae	*Epilobium sp.*			X					Forb (FG)	5	
Onagraceae	*Ludwigia peploides subsp. monteidensis* (Spreng.) P.H.Raen	Water primrose, cloe-strip	X	X	X	X			Forb (FG)	1.48	ARp
Orchidaceae	*Cryptostylis sp.*							X	Forb (FG)	5	
Oxalidaceae	*Oxalis corniculata** L.	Creeping oxalis	X	X	X				Forb (FG)	5	
Oxalidaceae	*Oxalis debilis var. corymbosa** (DC.) Lourteig			X		X			Forb (FG)	5	
Oxalidaceae	*Oxalis exilis*							X	Forb (FG)	5	
Papaveraceae	*Fumaria officinalis* L.*	Common fumitory	X						Forb (FG)	5	
Phormiaceae	*Dianella revoluta* R.Br.	Blueberry lily, blue flax-lily						X	Forb (FG)		

Family	Scientific name	Common name	Site						Growth form	WPIL code	WPFG
			VC1	VC2	VC3	VCR1	VCR2	VCR3			
Phyllanthaceae	*Breynia oblongifolia* Müll.Arg.	Coffee bush		X					Shrub (SG)	5	
Pittosporaceae	*Billardiera mutabilis* Salisb.	Climbing apple berry						X	Shrub (SG)		
Pittosporaceae	*Pittosporum undulatum* Vent.	Sweet pittosporum						X	Shrub (SG)	5	
Plantaginaceae	*Plantago lanceolata* *L.	Lamb's tongues, plantain	X		X	X			Forb (FG)	5	
Plantaginaceae	*Plantago major* L. *	Large plantain			X	X			Forb (FG)	5	
Plantaginaceae	*Veronica anagallis-aquatica** L.	Blue water speedwell		X	X	X			Shrub (SG)	2.65	ATe
Poacaeae	*Agrostis capillaris* L.*	Browntop bent			X				Grass & grass-like (GG)	5	
Poacaeae	*Anthoxanthum oderata** L.	Sweet vernal grass	X	X	X				Grass & grass-like (GG)	5	
Poacaeae	*Entolasia stricta* (R.Br.) Hughes	Wiry panic						X	Grass & grass-like (GG)	5	
Poaceae	*Bromus catharticus** Vahl	Prairie grass, rescue grass	X	X	X		X		Grass & grass-like (GG)	5	
Poaceae	*Cenchrus clandestinus** (Hochst. ex Chio.) Morrone	Kikuyu	X	X	X	X	X		Grass & grass-like (GG)	5	
Poaceae	*Cynodon dactylon* (L.) Pers	Couch, Bermudagrass		X	X	X			Grass & grass-like (GG)	5	
Poaceae	*Echinochloa crus-pavonis** (Kunth) Schult.	South American barnyard grass		X	X				Grass & grass-like (GG)	5	
Poaceae	*Festuca pratensis* Huds.	Meadow fescue		X					Grass & grass-like (GG)	5	
Poaceae	*Glyceria australis*	Australian sweetgrass				X			Grass & grass-like (GG)	1.97	

Family	Scientific name	Common name	Site						Growth form	WPIL code	WPFG
			VC1	VC2	VC3	VCR1	VCR2	VCR3			
Poaceae	*Holcus lanatus** L.	Yorkshire fog		X	X	X			Grass & grass-like (GG)	5	
Poaceae	*Lolium perenne* L.	Perennial ryegrass		X		X	X		Grass & grass-like (GG)	5	
Poaceae	*Paspalum dilatatum** Poir.	Paspalum	X	X	X	X			Grass & grass-like (GG)	5	
Poaceae	*Paspalum distichum* L.	Water couch	X	X	X	X	X		Grass & grass-like (GG)	1.34	ATe
Poaceae	*Phragmites australis*	Common reed				X			Grass & grass-like (GG)	1.33	ATe
Poaceae	*Poa annua* *L.	Winter grass		X					Grass & grass-like (GG)	5	
Poaceae	*Poa pratensis**	Kentucky bluegrass	X		X				Grass & grass-like (GG)	5	
Poaceae	*Poa sieberiana* Spreng.							X	Grass & grass-like (GG)	5	
Poaceae	*Sporobolus africanus** (Poir.) Robyns & Tournay	Parramatta grass		X	X	X	X		Grass & grass-like (GG)	5	
Poaceae	*Stenotaphrum secundatum** (Walter) Kuntze	Buffalo grass		X					Grass & grass-like (GG)	5	
Poaceae	*Tetrarrhena juncea** R.Br.			X					Grass & grass-like (GG)	5	
Polygonaceae	*Acetosa sagittata** (Thunb.) L.A.S Johnson & B.G.Briggs	Rambling dock, turkey rhubarb, arrow dock	X	X	X				Forb (FG)	5	
Polygonaceae	*Persicaria decipiens* (R.Br.) K.L.Wilson	Slender knotweed	X	X	X	X			Forb (FG)	2.27	ATe

Family	Scientific name	Common name	Site						Growth form	WPIL code	WPFG
			VC1	VC2	VC3	VCR1	VCR2	VCR3			
Polygonaceae	*Persicaria hydropiper* (L.) Delarbre	Water pepper	X						Forb (FG)	1.92	ATe
Polygonaceae	*Persicaria strigosa* (R.Br.) H.Gross	Spotted knotweed	X	X	X	X			Forb (FG)	1.65	ATe
Polygonaceae	*Rumex acetosa* L.*	Sheep sorrel	X	X					Forb (FG)	5	
Polygonaceae	*Rumex brownii* Campd.	Swamp dock		X					Forb (FG)	2	
Polygonaceae	*Rumex conglomeratus* Murray *	Clustered dock	X	X	X		X		Forb (FG)	5	
Polygonaceae	*Rumex crispus** L.	Curled docks	X	X	X	X			Forb (FG)	3	
Polygonaceae	*Rumex sagittatus* Thunb*	Sheep sorrel	X	X					Forb (FG)	5	
Polygonaceae	*Rumex sp.*	Docks	X	X	X	X			Forb (FG)	5	
Potamogetonaceae	*Potamogeton ochreatus* Raoul	Blunt pondweed	X				X		Forb (FG)	1.33	Sk
Primulaceae	*Lysimachia arensis** (L.) U.Manns & Anderb	Scarlet pimpernel	X	X	X	X			Forb (FG)	5	
Primulaceae	*Samolus valerandi** L.	Common brookweed, water pimpernel	X	X	X				Forb (FG)	3.65	Tda
Pteridaceae	*Adiantum aethiopicum* L.	Common maidenhair		X				X	Fern (EG)	2.92	Tda
Ranunculaceae	*Ranunculus amphitrichus* Colenso	Small river buttercup		X					Forb (FG)	1.33	ATl
Ranunculaceae	*Ranunculus inundatus* R.Br. ex DC.	River buttercup	X	X					Forb (FG)	1.33	ATl
Ranunculaceae	*Ranunculus lappaceus* Sm.	Common buttercup	X		X				Forb (FG)	5	
Ranunculaceae	*Ranunculus repens* L.	Creeping buttercup	X						Forb (FG)	5	
Ranunculaceae	*Ranunculus sceleratus**	Celery buttercup			X				Forb (FG)	1.88	ATe

Family	Scientific name	Common name	Site						Growth form	WPIL code	WPFG
			VC1	VC2	VC3	VCR1	VCR2	VCR3			
Rosaceae	*Rubus anglocandicans* A.Newton *	Blackberry	X	X	X				Shrub (SG)	5	
Rosaceae	*Rubus parvifolius* L.	Native raspberry			X				Shrub (SG)	5	
Rutaceae	*Correa lawrenceana var. cordifolia* Paul G.Wilson	Mountain correa						X	Shrub (SG)	5	
Rutaceae	*Zieria smithii*	Sandfly zieria						X	Shrub (SG)		
Salicaceae	*Salix sp.* *	Willows			X	X			Tree (TG)	3	
Saliniaceae	*Azolla filiculoides* Lam.	Pacific azolla	X	X	X	X			Fern (EG)	1.33	ARf
Santalaceae	*Exocarpus cupressifolia* Labill.	Cherry ballart						X	Shrub (SG)	5	
Scrophulariaceae	*Verbascum virgatum** Stokes	Twiggy mullein			X				Forb (FG)	5	
Solanaceae	*Solanum americanum*	Glossy nightshade		X					Shrub (SG)	5	
Solanaceae	*Solanum chenopodioides**		X						Forb (FG)	5	
Solanaceae	*Solanum laxum** Spreng.	Potato climber	X						Forb (FG)	5	
Sparganiaceae	*Sparganium subglobosum* Morong	Floating bur-reed			X				Forb (FG)	1.65	Se
Thymelaeaceae	*Pimelea linifolia*	Pale fan-flower						X	Shrub (SG)	5	
Typhaceae	*Typha domingensis* Pers.	Narrow-leaved cumbungi, cattails	X	X	X	X	X		Grass & grass-like (GG)	1.33	Se
Urticaceae	*Urtica incisa* Poir.	Stinging nettle	X	X		X			Forb (FG)	5	
Uvulariaceae	*Schelhammera undulata*							X	Forb (FG)	5	
Verbenaceae	*Verbena bonariensis** L.	Purpletop	X	X	X	X			Forb (FG)	5	
Viscaceae	*Notothixos subaureus*	Golden mistletoe	X						Other (OG)	5	

Appendix G. Photos of seed bank experiments for replicates of four sites: VC1, VC2, VC3, VCR1

This appendix has been provided as a separate document due to its large download size.

Appendix H. Map of Victoria Creek Catchment and woody (woodland and forest) vegetation extent (2019)