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High country spring-fed streams: effects of adjacent land use

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Summary

Background

Spring-fed streams in the Canterbury High country are hotspots of indigenous biodiversity and critical spawning sites for Chinook salmon. Macroinvertebrate communities within these streams are a useful indicator of the overall health of streams and their potential to support salmonid populations.

The Problem

Over the last 20 years there has been a significant increase in the intensity of farming adjacent to many spring-fed streams and wetlands. As a result there is concern about the health of these waterways and their ability to provide salmon spawning opportunities. This change appears to be the result of changes in tenure status and farming technology.

What we did

We undertook a four-year study to determine the effects of adjacent land use change on the water quality, habitat and aquatic health of spring-fed streams. Water and habitat quality was measured monthly, while macroinvertebrates were sampled annually in the spring/early summer. Twelve streams were included in the study ranging from a reference site with no adjacent agriculture to streams surrounded by improved pasture including some irrigation.

What we found

Streams varied widely in terms of water and habitat quality. Instream nitrogen concentrations ranged across an order of magnitude between the reference stream and those affected by agricultural development. Similarly, fine sediment cover of the stream bed was negligible in some streams, but clearly exceeded established thresholds of ecosystem impacts in other streams. Periphyton communities were typically indicative of healthy streams although some potentially nutrient driven nuisance growths were observed, along with the occurrence of *Didymosphenia geminata*.

Macroinvertebrate communities showed distinct differences at sites with elevated nitrogen and high cover of deposited fine sediment. Impacted sites had macroinvertebrate communities indicative of poor water quality and variably dominated by aquatic snails or worms, whereas reference and low impact sites were dominated by mayflies and caddisflies. Although analyses indicated that elevated nitrogen had an over-riding influence on macroinvertebrate communities, it is likely that various contaminants had synergistic effects. The gradients in stream health are thus the result of a general land use signal rather than being indicative of a single causal pathway.

What does it mean

Spring-fed high country streams appear to be highly sensitive to relatively low levels of development within their catchments that result in a reduction in biodiversity, ecosystem health and their potential value as Chinook salmon spawning streams. These results suggest that a catchment approach to managing land use change is needed to protect these ecosystems. One option would be to map spring-fed stream catchments and establish conservative rules to regulate further development. Such an addition to the planning framework would be analogous to the LWRP sensitive lake zones and complementary to the schedule of significant salmon spawning sites.

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1 Introduction

The purpose of this report is to examine the influence of increasing land use intensity on the ecosystem health of high country spring-fed streams and make recommendations for the ongoing management of these systems. The work is part of an agreed joint work programme between Environment Canterbury and Fish and Game (both North Canterbury and Central South Island regions) and this report gives the results from joint monitoring of high country spring-fed streams.

The impacts of adjacent agricultural land use on stream communities and ecosystem function have been extensively studied throughout the world and in New Zealand (Allan and Castillo, 2007; Quinn, 2000). Effects may derive from changes in water quality, habitat quality and stream flow, but vary greatly depending on the characteristics of the stream ecosystem (Allan and Castillo, 2007). Understanding the specific effects of land use development on different stream types is vital to informing management tools which can protect ecological values, fisheries and water quality.

The Canterbury high country has historically been an area of extensive, low intensity and low impact grazing. Sheep and cattle were spread across vast tracts of predominantly un-improved land that was owned by the crown and managed under long term leases with strict conditions about land development (Brower, 2008). However, several complementary mechanisms have resulted in considerable intensification of the flat and rolling lands in the high country.

Tenure review is a voluntary process that gives pastoral lessees an opportunity to buy some of their leasehold land, while the balance returns to crown ownership usually for conservation purposes (LINZ, 2018). The subsequent owner of freehold land has greater options to develop land and intensify farming than the previous lessee albeit within the bounds stipulated by the regional and district council plans. In addition, for high country farms purchased by overseas owners the Overseas Investment Office (OIO) may require an increase in farm productivity as a condition of sale. New owners may be compelled to develop land, although the OIO is also mindful that adequate environmental mitigations occur alongside developments. Commensurately, over the last 25 years there have been considerable advances in farm technology and farm systems which have allowed a greater intensity of farming to occur in environments previously considered too harsh. In particular, efficient irrigation systems have allowed farmers to expand the footprint of their developed paddocks despite limited water supplies. A further factor is the increase in the national dairy herd. Some High Country farms have developed a full dairy milking platform while others have intensified to provide dairy support grazing or ‘cut and carry’ operations. The net result has been the progressive land development of high country valley floors and flat areas. This in turn has impacted upon many of the sensitive aquatic environments, fisheries and unique species extant in the High Country.

Some of the most sensitive aquatic environments are also the most often overlooked areas in large alpine river systems. Springs and wetlands fed by alluvial or hill slope aquifers are common in alpine and sub-montane valleys. These environments are highly oligotrophic (low nutrients) and often very stable in terms of flow or water level (Johnson and Gerbeaux, 2004; Gray, 2005). These habitats are oases of stability and moisture in an often arid landscape and surveys have found springs to be hotspots of both invertebrate and fish biodiversity (Gray, Hicks, and Greenwood, 2016). When several springs coalesce, large spring-fed streams may form only a short distance from the upwelling points of origin (Figure 1-1). Many of these streams are hotspots of indigenous biodiversity and critical habitat for introduced salmonids, providing the stable flows, cool oxygenated water and substrate required for spawning (Deans, Unwin and Maurice, 2004). In the Rakaia and Rangitata rivers 90 and 70%, respectively, of salmon spawning occurs in the spring-fed streams.

Figure 1-1: At its mouth, the Hydra waters, a spring-fed stream in the Rakaia River, attains a discharge in the order of 1 cubic metre per second

By virtue of their naturally low nutrient status and adaptation to low levels of disturbance from flooding, spring-fed wetlands and stream ecosystems may be substantially altered by adjacent land development. Land use development will inevitably result in some increase to the contaminant load of a waterway (Quinn, 2000). Nutrients, primarily nitrogen and phosphorus, bacteria and sediment may enter waterways via overland runoff and through leaching to groundwater. Elevated nutrients can have a profound effect on periphyton (algae) and macrophyte (aquatic plant) communities (Larned, Kilroy and Biggs, 2016) and consequently on fish and invertebrates. Fine sediment may carry significant phosphorus to a stream as well as smothering biota and substrates when it settles. Fine sediment settling on the stream bed is particularly problematic for spawning salmonids which excavate redds in the stream bed for spawning. Eggs and larvae require a good supply of clean oxygenated water to develop, which may become limiting under high sediment deposition as the stream bed clogs. Bacterial contaminants are not directly linked to impacts on stream biota, but are important for the health of stock and humans coming into contact with water. Bacteria and faecal matter may enter a stream via overland runoff, but also via direct deposition from stock within the waterway. Such deposition is associated with trampling/pugging by stock that has a major impact on riparian and spring head vegetation communities and causes damage to fish and invertebrate habitat.

High country spring-fed streams are also unusual in terms of their hydrological context. They attain considerable volume over a very short length, and therefore they have a limited surface catchment for their volume of water. Accordingly, they may be resilient to some degree to adjacent land use intensification because there is not adequate stream length for contaminants to accumulate. Conversely, because the groundwater from which they derive flow comes from large, pristine alpine rivers and their tributaries, and the springs themselves are naturally highly oligotrophic, a small addition of contaminants may result in a marked impact. In addition, due to their stable flow regimes these spring streams may be particularly sensitive to the addition of fine sediments which are not flushed out by occasional high flows.

The objectives of this study were to explore differences in stream habitat, water quality and macroinvertebrate communities across gradients of land use intensification to infer impacts upon biodiversity, ecosystem health and potential for Chinook Salmon spawning and rearing. Accordingly, it was attempted to find reference streams, streams within extensive grazing farm systems and streams adjacent to land with more intensive grazing and potentially some irrigation. The intent was to inform the management of land use development for the protection of the ecological health of streams and the viability of salmonid populations.

2 Methods

2.1 Site selection

Spring-fed stream site selection was based upon the current or historic value of streams for the spawning of introduced Chinook salmon, *Oncorhynchus tshawytscha,* and to represent a gradient in land use intensity. Sampling sites were chosen based on the degree of adjacent land use impact and access (Table 2-1 and Figure 2-1). Only a single site, Klondyke, was considered a true reference site being located within a national park. Other sites such as Deep Creek, Hydra Waters and Black mountain have limited stock access or are within extensively grazed farming systems, while others, such as the Glenarriffe and Deep stream sites, are surrounded by intensifying agricultural systems. All streams were predominantly spring-fed although Winding Creek intermittently originates in Lake Pearson during high lake levels. Sites such as Cora Lyn and the Glenariffe Mainstem occasionally receive overland pulses of flow from their parent rivers, the Waimakariri and Rakaia, respectively. However, all spring-fed streams may receive overland flow from hill side tributaries or water otherwise accumulating on surrounding flat ground.

Table 2-1: Site name, location and descriptions of adjacent land use

Site	Valley	Coords. (NZTM)	Land use
Klondyke	Waimakariri	1485408; 5236423	National Park, no land use, but Canada geese common
Cora Lynn	Waimakariri	1493097; 5235370	Extensive grazing of adjacent riverbed and improved pasture on the upstream tributary fan. Cattle and sheep access to spring-fed wetlands during study. Occasionally receives Waimakariri River water during high flows.
Winding Creek	Waimakariri	1504506; 5220750	Intermittently drains Lake Pearson. Fenced and unfenced reaches flow through or adjacent to improved pasture. Substantial proportion of flat catchment in improved pasture. Some headwater springs within improved pasture. Large fenced wetland directly upstream of the sampling site.
Hydra Waters	Rakaia	1463694; 5208865	Flats and tributary fan predominantly extensively grazed, some pasture improvement adjacent to wetlands. Wetlands and streams predominantly fenced.
Glenarrife East Branch	Rakaia	1467669; 5203053	Flat land and adjacent terraces improved or being improved. Stream partially fenced, but stock given access during the study period
Glenarrife South Branch	Rakaia	1465907; 5202665	Flat land primarily extensive grazing, but undergoing improvement. Some stock access and pasture improvement around headwater wetlands.
Glenarrife Main Stem	Rakaia	1465883; 5202803	Mixture of fenced and unfenced, improved pasture and extensive grazing. Receives Rakaia River water during high flows
Black Mountain Stream	Rangitata	1424840: 5176361	Extensively grazed, unimproved pasture, but full stock access
Deep Creek	Rangitata	1430156; 5176433	Extensive riverbed grazing with some stream fencing at the sampling site, but not the headwaters. Evidence of occasional stock damage throughout.
Deep Stream North Branch	Rangitata	1432899; 5163853	Predominantly within improved pasture. Main stem fenced but headwaters and some cut drains and tributaries have stock access
Deep Stream Mid. Branch	Rangitata	1432510; 5164333	Predominantly within improved pasture. Main stem fenced but headwaters and some cut drains and tributaries have stock access
Deep Stream South Branch	Rangitata	1433639; 5164197	Predominantly within improved pasture. Main stem fenced but headwaters and some cut drains and tributaries have stock access

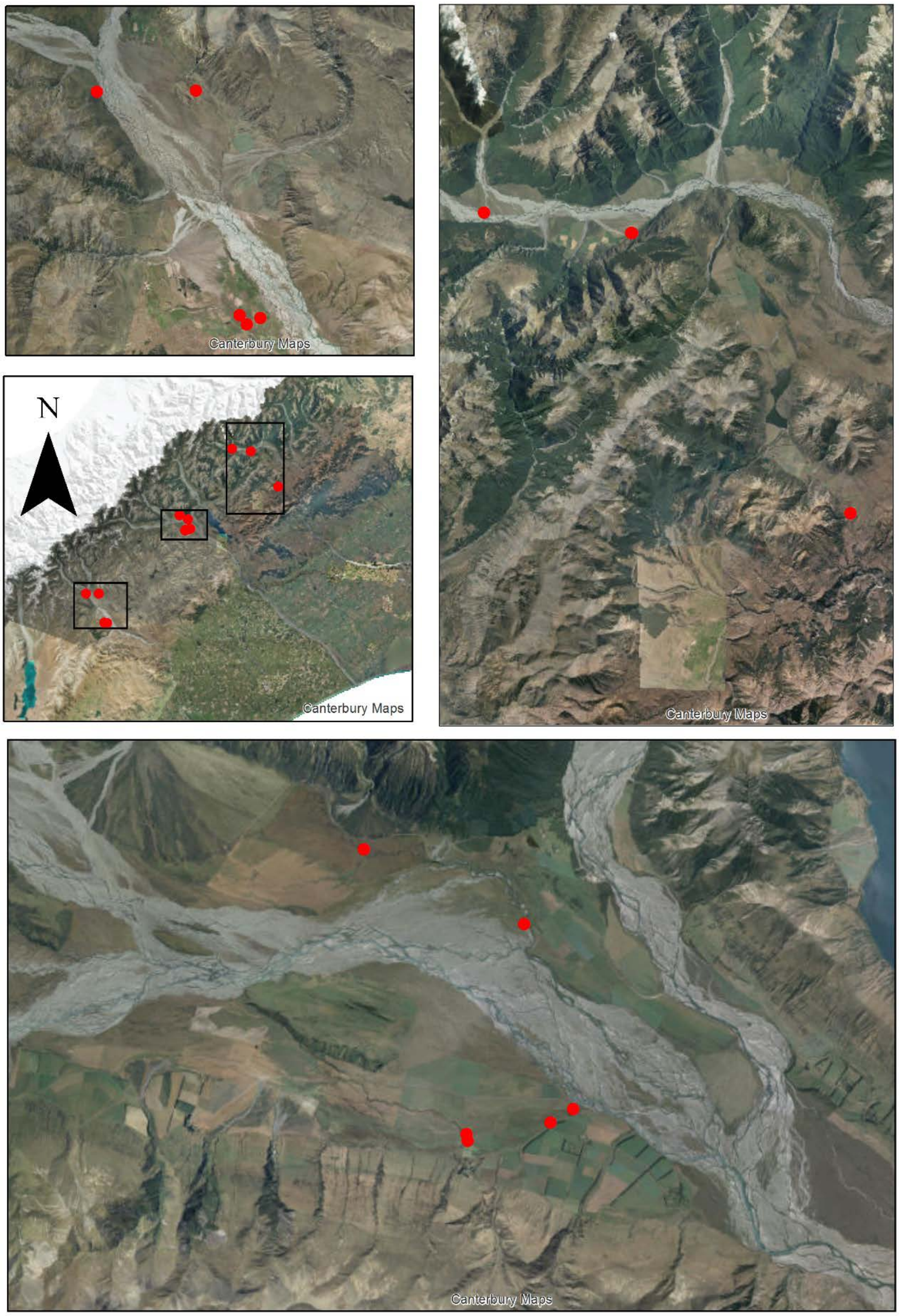

Figure 2-1: The location of monitored salmon spawning streams within three inland basins of Canterbury. Clockwise from Top left; Rangitata, Waimakariri, Rakaia, regional image

2.2 Data collection

2.2.1 Water quality and habitat condition

All monthly field data was collected by Fish and Game or Environment Canterbury officers from run habitat within the chosen sampling reaches. Water quality samples were collected using standard Environment Canterbury protocols, chilled and transported to Hill Laboratories for analysis. Samples were analysed for Nitrate+Nitrite Nitrogen (NNN), Ammonia, Dissolved Reactive Phosphorus (DRP), *E. coli* and Turbidity. Dissolved Inorganic Nitrogen (DIN) was derived as the sum of Nitrate+Nitrite Nitrogen (NNN) and Ammonia. Periphyton and fine sediment cover were assessed within the same run habitat using modifications of the RAM 2 (Biggs and Kilroy, 2000) and SAM 2 (Clapcott *et al.,* 2011). Therein, percentage cover of both fine sediment and periphyton (according to RAM protocols) were made down 25 views of the stream bed using a bathymeter. Periphyton was assessed independently of fine sediment such that a stream may score 100 % for long green filaments, but also 100 % for sediment if the bed was entirely composed of silts and covered in filaments.

2.2.2 Macroinvertebrate communities

Macroinvertebrate communities were sampled annually from 2014 to 2017 between December and February. Five replicate macroinvertebrate Surber samples were collected on each occasion from the run habitat where water quality and habitat condition were assessed. The Surber sampler had an area 0.01 m^2 and a mesh size of 500 µm. Samples were preserved in 70 % ethanol and transported to Environment Canterbury for processing. Processing followed the fully quantitative protocol P3 from Stark *et al.* (2001).

2.3 Assessment approach

2.3.1 Nutrients

Nitrogen and phosphorus may both control the growth rate and taxonomic composition of algae and macrophytes in streams. Therefore, both nutrients are routinely measured in order to gauge the potential effects of land use on stream ecosystems. A recent review by Keck & Lepori (2012) suggests considerable uncertainty in predictions of growth limitation except at extreme N:P ratios, e.g. <1 : 1 and >100 : 1. In addition, recent research has suggested that the assumption of phosphorus limitation on algal communities in rivers does not account for the ability of algal mats to derive phosphorus from a source other than dissolved in the water column (Woods *et al.,* 2015). This report includes an assessment of both the absolute and relative concentrations of both nitrogen and phosphorus.

Various nitrogen species are measured in freshwaters to infer effects on different aspects of water quality and ecosystem function. Total nitrogen in a stream is composed of ammonia nitrogen, nitrate-nitrite nitrogen and organic nitrogen. The proportion of each nitrogen species may vary widely and components are interchangeable depending on the source of contamination and processes within the stream. At low to moderate levels elevated nitrogen concentrations are associated with an increase in the growth rate of algae and macrophytes (Matheson *et al*., 2012). Dissolved inorganic nitrogen (DIN) species (ammonia + nitrite-nitrogen + nitrate-nitrogen) are the most plant available and as such DIN is most often presented when considering implications for plant growth. Alternatively, at moderate to high levels, both nitrate-nitrogen and ammonia may become toxic to aquatic life and as such nitrate-nitrogen and ammonia are often presented separately.

Ammonia and nitrate levels in this study were well below toxicity guidelines (ANZECC, 2000; Hickey, 2013a) and as such only DIN is presented and discussed in relation to algal and macrophyte growth. There is currently a lack of suitable guidance around maximum nitrogen or phosphorus concentrations to guard against nuisance growths of plants for spring-fed streams, although relationships do exist for hill-fed rivers (Biggs, 2000b). Matheson (2012) used Bayesian Belief Network analysis (BBN) to derive guidelines values for the management of macrophyte growth, presented in Table 2-2. To provide a regional context, this report also compares nutrient concentrations to summary statistics for upland Spring-fed streams as presented in Stevenson *et al.* (2010).

Table 2-2: Annual mean nutrient categories for macrophytes and the probability of occurrence of nuisance growths of macrophytes (Matheson *et al.,* 2012)

Category	Water column nutrients	Probability of nuisance growths
High	>1 mg/L DIN and/or 0.01 mg/L DRP	0.90
Adequate	0.1-1mg/L DIN and/or 0.001-0.01 mg/L DRP	0.70
Limiting	<0.1 mg/L DIN and/or <0.001 mg/L DRP	0.30

2.3.2 Bacteria

Faecal contamination of waterways may occur from direct stock and wildfowl defecation in streams and/or runoff from the land. The bacteria *Escherichia coli* is commonly found in the lower intestine of warm bodied animals and used as a general indicator of the presence of faecal matter. While the presence of *E. coli*, or any other form of faecal matter, is not typically linked to ecosystem health, elevated levels are indicative of stock access to streams or poor riparian management, both of which have associated impacts on stream habitat and communities. However, typically *E. coli* is measured to inform on the suitability for human recreational contact with water. There are various standards and guidelines available with which to compare *E. coli* levels (MfE, 2017; 2003) depending on the activity being undertaken and the degree of contact with contaminated water. The salmon spawning streams in this study are typically small and shallow and as such not considered likely sites for primary contact recreation involving full immersion. Rather the most likely human interaction is secondary contact such as wading or fishing. Accordingly, data are compared to median concentrations deemed suitable for secondary contact in the NPS-FM (2014).

2.3.3 Suspended sediments

The suspended solids (SS) or turbidity in a waterway may derive from the mobilisation of sediments already within the stream bed, bank erosion or run-off from the land. High suspended solids are consequently often associated with high flow events and may be common and entirely natural in rivers which contain glacial flour. However, a number of studies have highlighted the effects of elevated SS on ecological values. Boubee *et al.* (1997) described the avoidance of elevated suspended sediments by migratory native New Zealand fish species. Although behavioural responses varied considerably between species, Boubee *et al.* (1997) suggested a turbidity limit of 15 NTU in otherwise clear flowing water would prevent any impact on the movements of native fish. Salmonids, such as brown and rainbow trout, are also known to be sensitive to elevated SS (Bilotta and Brazier, 2008). Salmonids suffer direct effects through gill clogging and impaired vision, but are also affected through the smothering of invertebrate food resources. Invertebrates similarly suffer from clogging of respiratory apparatus and a reduction in available food resources as biofilm layers are smothered. In addition, because trout are visual feeders, increased turbidity has an adverse effect on foraging behaviour and feeding radius (Hay *et al.,* 2006). Accordingly, Hay *et al.* (2006) suggested that 0.5 NTU would be a suitable standard to maintain optimal conditions for trout feeding. We have used this guideline to compare with turbidity from salmon spawning streams because it is the most conservative and applicable to typically clear water spring-fed streams.

2.3.4 Algal growth

Algae forms a part of the stone surface slime layer known as periphyton, a primary food resource for macroinvertebrates and hence the base of the stream food web. Other components of periphyton include fungi and bacteria. While an important food resource, excessive growths of periphyton can be detrimental to streams ecosystems through smothering of the substrate, alteration to habitat quality and effects on dissolved oxygen availability (Biggs, 2000a & b). Algae and periphyton communities take many different forms determined by the dominant algal species.

2.3.5 Deposited sediment

Deposited sediments are those which have fallen out of suspension in the water column. Deposited fine sediments and the provision of guidelines have been the topic of considerable recent study in New Zealand (Clapcott *et al.,* 2011; Greenwood *et al.,* 2011; Burdon *et al.,* 2013). In a study of 64 lowland Canterbury streams, Greenwood *et al.* (2011) found that the cover of fine sediment on the stream bed was the single most influential factor in regulating the invertebrate community. Subsequently, Burdon *et al.* (2012) identified a 'tipping point' of 20 % fine sediment cover below which there were marked declines in metrics of invertebrate health. Clapcott *et al.* (2011) also recommended a guideline value of 20 % fine sediment cover to protect stream biodiversity and fish (both native and exotic), whereas 25 % fine sediment cover was deemed adequate to protect the amenity value of streams. The Canterbury LWRP outcomes for freshwater include fine deposited sediment cover thresholds of 10 % in spring, lake and alpine-fed rivers, whereas 15 % cover was deemed appropriate in hill-fed rivers. This report compares observed fine sediment cover to the 20 % threshold identified by Burdon *et al.* (2013).

2.4 Statistical analyses

In some cases contaminant concentrations in spring-fed streams were very low (Table 2-3) and the proportion of values below detection limit was too large to apply standard imputation methods to censored data (Helsel, 2012; Larned *et al.,* 2015). Therefore half detection limit values were applied to censored data, although such methods have been shown to reduce accuracy of correlation coefficient estimates and regression slopes in trend analysis (Helsel, 2012).

Table 2-3: Proportion (%) of samples below the detection limit for water quality variables

	NNN	Ammonium Nitrogen	DRP	*E. coli*	Turbidity
Detection limit	**0.002**	**0.01**	**0.001**	**1**	**0.05**
Klondyke	0	100	0	96	0
Cora Lynn	0	100	0	40	0
Winding Creek	0	100	17	7	0
Hydra waters	0	95	14	55	0
Glenarrife East	0	96	33	0	0
Glenarrife Main	0	96	54	4	0
Glenarrife South	0	100	23	0	0
Black Mountain Stream	0	97	6	33	0
Deep Creek	0	97	14	37	0
Deep Stream Mid.	3	100	8	28	0
Deep Stream North	0	97	17	50	14
Deep Stream South	0	97	6	14	6

Summary statistics of water quality data were compared to guidelines and thresholds found in statutory plans or the ecological literature discussed in section 2.3. Trends in water quality over time were assessed with seasonal Kendall trend tests using the software package TimeTrends Vs.5. Periphyton morphological type cover was summarised using the periphyton score of Biggs and Kilroy (2000). Relationships between macroinvertebrate communities, water quality, substrate and periphyton growth were assessed using multivariate ordination techniques. The cover of periphyton morphological types was decomposed into orthogonal axes describing the strongest gradients in the data using Principle Components Analysis in the r package "prcomp" (Quinn and Keough, 2002). The first two axes of the PCA were retained and used to generate variables that represented periphyton communities prior to each macroinvertebrate sampling occasion. Environmental variables representing water quality, periphyton communities (post PCA) and substrate were summarised to represent conditions over the preceding month (_1), six months (_6) and twelve months (_12) prior to macroinvertebrate sampling. This resulted in a total of 22 environmental variables. Variables were made positive with the addition of a constant where necessary and subject to an automated Box-Cox transformation routine using the r package “transformTukey” that minimises the Shapiro-Wilks W statistic and produces a variable as normally distributed as possible with a power transformation (Appendix 1).

Prior to multivariate analysis macroinvertebrate abundance data from five Surber samples were averaged and Hellinger-transformed to reduce the influence of occasional high densities in some samples, and to control for the effect of rare taxa (Rao, 1995; Legendre and Gallagher, 2001). The Hellinger distance measure also effectively deals with the “species abundance paradox” associated with Euclidean distance, where the distance between two sites sharing no species can be smaller than that between two sites that share species (Laliberte *et al.,* 2009).

We used Redundancy analysis (RDA) to relate patterns in macroinvertebrate communities to environmental variables (Ter Braak and Smilauer, 1998). In order to address the repeated measures structure of the data all RDA analyses were conditioned using a third matrix representing the time series within each site. Furthermore, permutations within RDA were restricted within sites and accounted for time ordering of macroinvertebrate sampling. The possibility of type 1 errors due to the large number of variables and occurrence of collinearity between variables was controlled by using a forward selection procedure to reduce the number of variables. Classical forward selection procedures may inflate type 1 errors and overinflate the estimate of the variance explained. Therefore, we used the procedure of Blanchet, Legendre, and Borcard (2008). An initial global model, incorporating all predictor variables, was produced. The adjusted r^2 of the global model was used as a stopping criterion for a subsequent forward selection, along with an alpha level of $p < 0.1$. If the addition of any variable into the model exceeded either threshold value, the selection procedure was stopped. During this analysis I accepted variables at $p<0.1$ to reduce the likelihood of rejecting biologically relevant variables (Legendre and Legendre, 1998). RDA analyses were done using the r package “Vegan” while forward selection was performed using package “Packfor”. To separate the independent effects of water quality, substrate and periphyton growth on macroinvertebrate communities I used the r package “Varpart.” Area proportional Venn diagrams were produced in google charts (2018).

3 Results

3.1 Water quality

3.1.1 Nitrogen

Ammonium values were consistently low and often below the laboratory detection limit, consequently reported DIN was composed primarily of nitrate and nitrite. Median DIN concentrations over the ~3 year period ranged across an order of magnitude from 0.026 mg/l at Klondyke Corner to 0.405 mg/l in the East Branch of the Glenarrife Stream (Figure 3-1). The Glenarrife South Branch and Winding Creek also showed DIN concentrations elevated above that which might be expected under natural circumstances (Morgenstern and Daughney, 2012) and would be adequate to support the growth of nuisance macrophytes (Matheson, Quinn and Hickey, 2012). However, only the Glenarrife East Branch exceeded the regional median for spring-fed, upland streams.

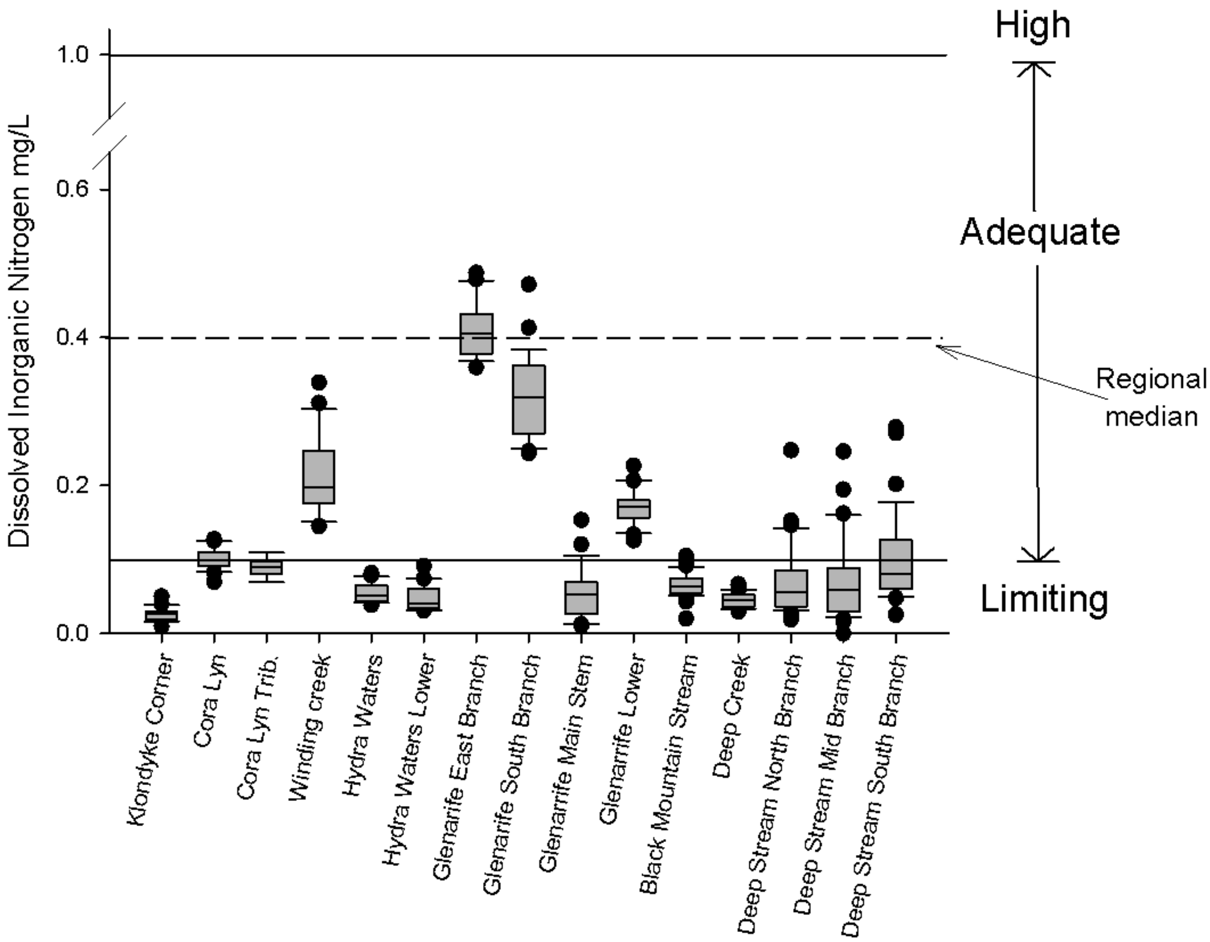

Figure 3-1: DIN in salmon spawning streams between Nov 2013 - Jan 2017. DIN provisional guidelines for the probability of nuisance macrophyte growths from Matheson (2012) and the regional median for spring-fed upland streams are shown on the right

DIN at a number of sites showed a distinct seasonal pattern of being elevated during winter and having a lower concentration during summer (Appendix 2). The relative magnitude of seasonal shifts and the absolute concentrations can provide insight into the source of DIN to a stream. For example, seasonal shifts in DIN within Deep Stream Middle Branch were of considerable magnitude, ranging from low absolute values in summer to relatively elevated concentrations in winter (Figure 3-2). This sort of pattern is indicative of elevated nitrogen coming from surface run-off and shallow fast flow groundwater in the winter, while during summer there is little runoff/local rain and high uptake by aquatic plants and algae. Conversely, DIN in the Glenarrife East Branch, while showing some seasonal patterns is elevated year round. Such a pattern is suggestive of nitrogen being accumulated in deeper slower flowing groundwater with elevated average concentrations.

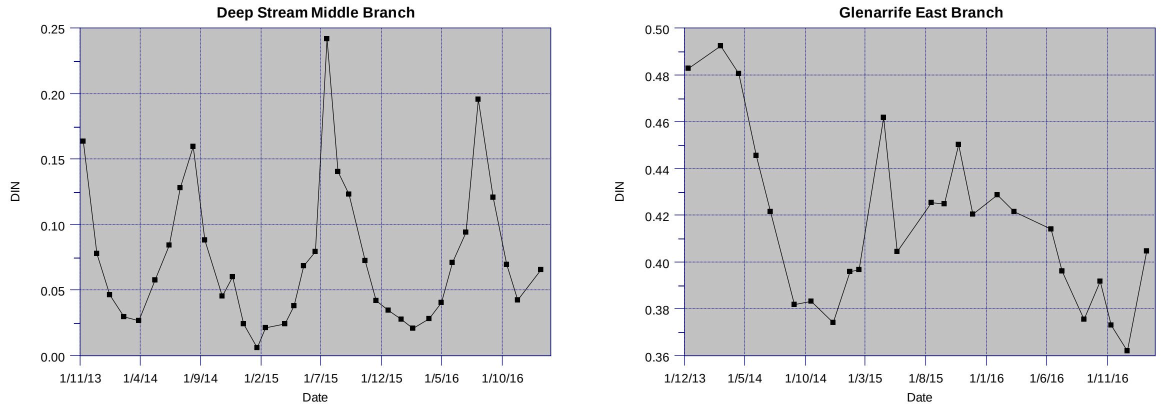

Figure 3-2: Longitudinal plots of DIN in the Deep Stream Middle Branch and Glenarrife East Branch

Although <4 years of monthly sampling is a short period of time over which to test for trends in water quality, tentative results may be informative. Only two sites showed a significant trend ($p<0.05$), both of which were negative. Winding Creek ($p=0.009$) showed a 13.4 % annual decrease while the East Branch of the Glenarrife Stream ($p=0.016$) had a 5.3 % annual decrease.

3.1.2 Phosphorus

Median dissolved reactive phosphorus ranged from 0.0005 mg/L (half the detection limit) in the Glenarrife Lower to 0.0046 mg/L in the Deep Stream South Branch (Figure 3-3). The majority of sites had adequate phosphorus to support the growth of nuisance macrophytes, but only the Deep Stream South Branch DRP median exceeded the regional median for spring-fed upland streams. Some streams had occasional elevated DRP concentrations, but overall concentrations were typically low.

It is of note that the lowest DRP values were observed in streams with relatively elevated nitrogen and /or high algal abundances. This pattern is assumed to be due to the uptake of DRP by aquatic algae and/or macrophytes when not limited by the availability of nitrogen. Sites such as Klondyke Corner, the reference site, typically had a greater concentration of DRP than other sites with farming present by virtue of the absence of nitrogen to stimulate algal growth.

Time series plots of DRP in the monitored streams (Appendix 3) were highly dominated by occasional high values, particularly in Deep Stream Middle and South branches. Otherwise, plots showed typical seasonal variation related to changes in the relative inflow of surface run-off and uptake by aquatic plants. Two sites showed a trend in DRP over the monitoring period. Both the Glenarrife South Branch ($p=0.028$) and the Hydra Waters ($p=0.045$) had an approximately 10 % annual decline.

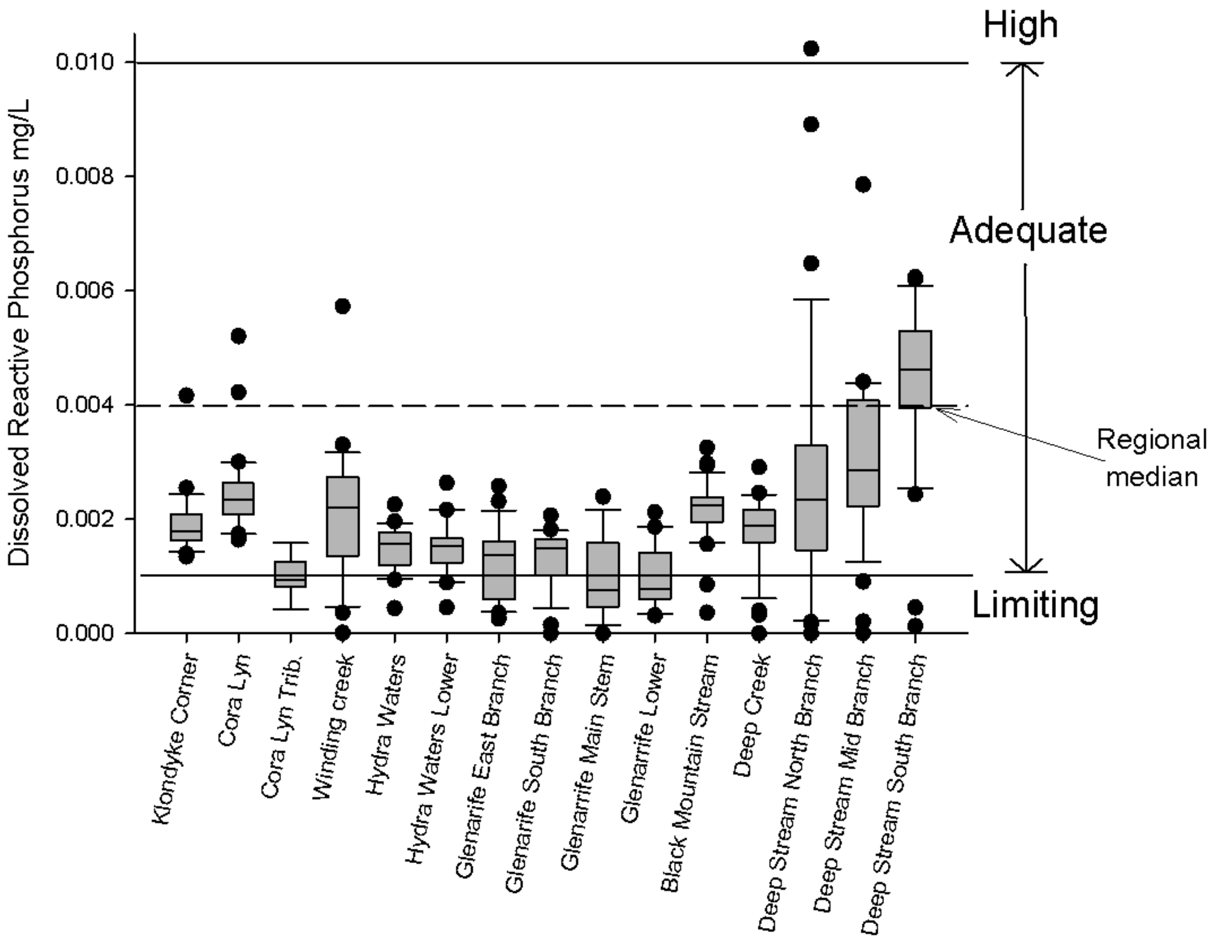

Figure 3-3: DRP in salmon spawning streams between Nov 2013 - Jan 2017. DRP provisional guidelines for the probability of nuisance periphyton growths from Matheson (2012) and the regional median for spring-fed upland streams are shown on the right

The ratio of plant-available nitrogen to phosphorus (DIN:DRP) is often used to indicate the potential for a water body to produce nuisance growths of algae (Figure 3-4). Comparisons of DIN:DRP in some streams, primarily those with elevated DIN, showed they are likely to be phosphorus limited such that increases in biomass are prevented by the availability of phosphorus. In streams where phosphorus is low, such as the Glenarrife East Branch, the likelihood of nuisance growths is therefore low provided phosphorus inputs do not increase. However, the majority of streams showed a DIN:DRP ratio indicative of co-limitation (<100), whereby an increase in either nitrogen or phosphorus would result in an increase in periphyton growth, provided nutrients are not saturated (Keck and Lepori, 2012).

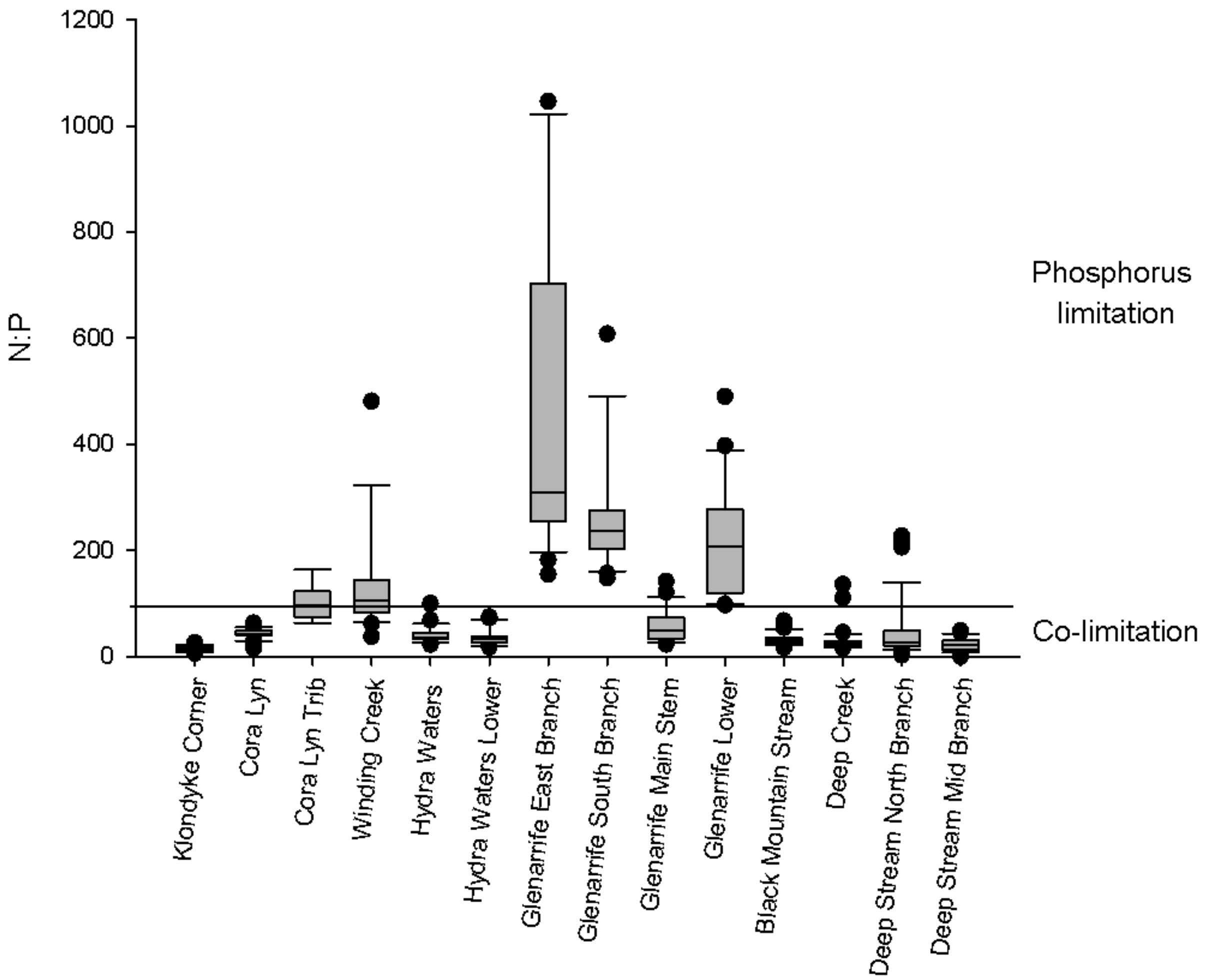

Figure 3-4: DIN:DRP ratio showing zone of nutrient limitation suggested by Keck & Lepori (2012)

3.1.3 Bacteria

E. coli counts were highly variable between streams and often between sampling occasions within streams (Figure 3-5; Appendix 4). The majority of sites, including those with some development in their catchments, had low median and maximum counts (Figure 3-5). However, the Glenarrife East Branch and Mainstem had elevated median values and some very high maximum values (>1000 *E. coli* MPN/100 ml). Deep Stream North Branch and Middle Branch had relatively low median values, but occasional very high values.

Only a single stream showed a trend in *E. coli* values. Deep Creek (p=0.043) showed a 55 % decrease in *E. coli* values over three years.

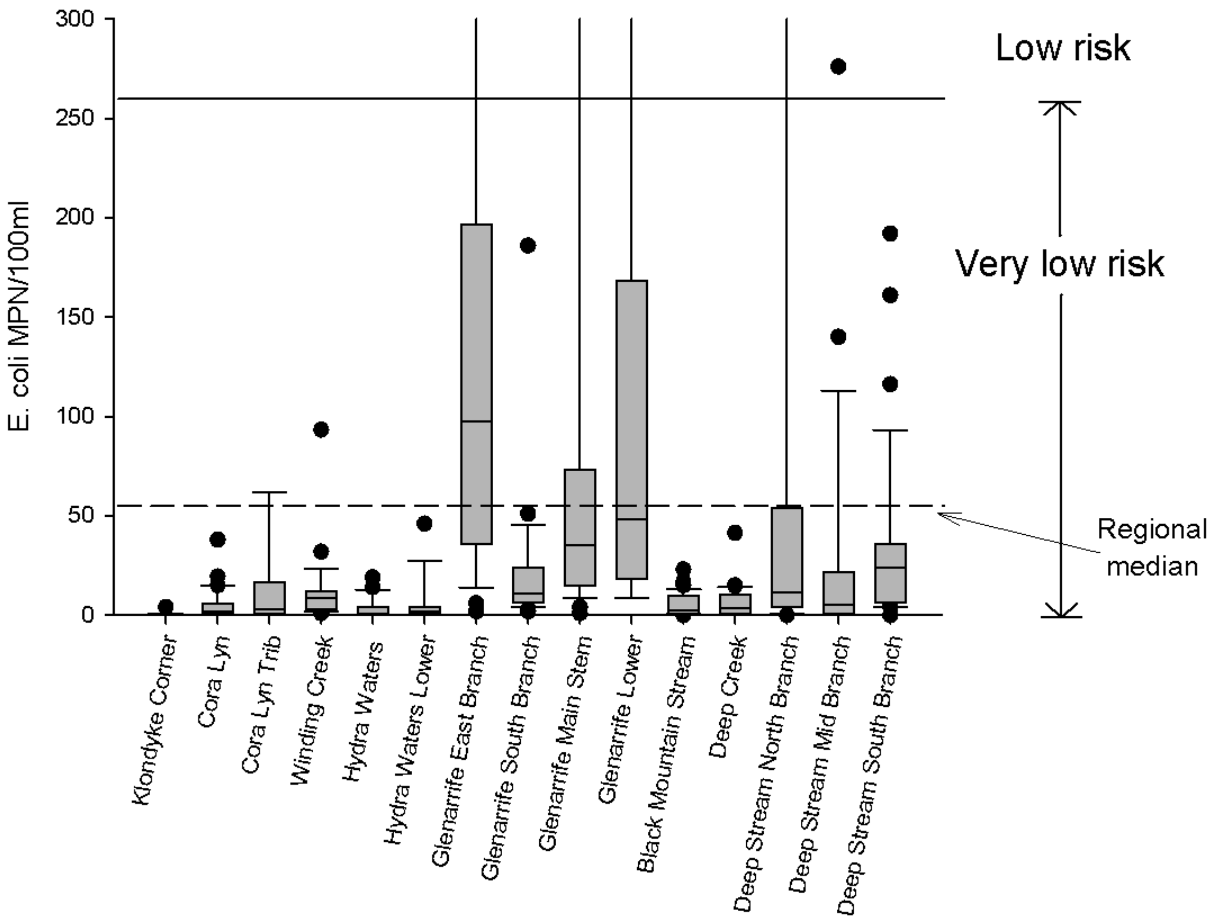

Figure 3-5: *E. coli* in salmon spawning streams between Nov 2013 - Jan 2017. Guidelines for secondary contact recreation and the regional median for spring-fed upland streams are shown on the right

3.1.4 Turbidity

The turbidity of water was variable between streams (Figure 3-6; Appendix 5). Median values at the majority of sites marginally exceeded the trout feeding optimum of 0.5 NTU (Hay *et al.,* 2006), but only the Glenarrife Mainstem and lower sites exceeded the regional median for spring-fed upland streams. Occasional elevated turbidity occurred in a number of streams. These may be associated with high flow events due to rainfall or overbank flooding of adjacent large rivers or stock access to banks and the bed of streams. The Glenarrife Stream and Cora Lyn in particular experience overflow from the Rakaia and Waimakariri rivers, respectively during flood events.

Trends in turbidity were observed in two sites. Turbidity increased in Deep Stream North (p=0.044) by 17.7 % per annum, but fell in Black Mountain Creek (p=0.025) by 16.3 % per annum.

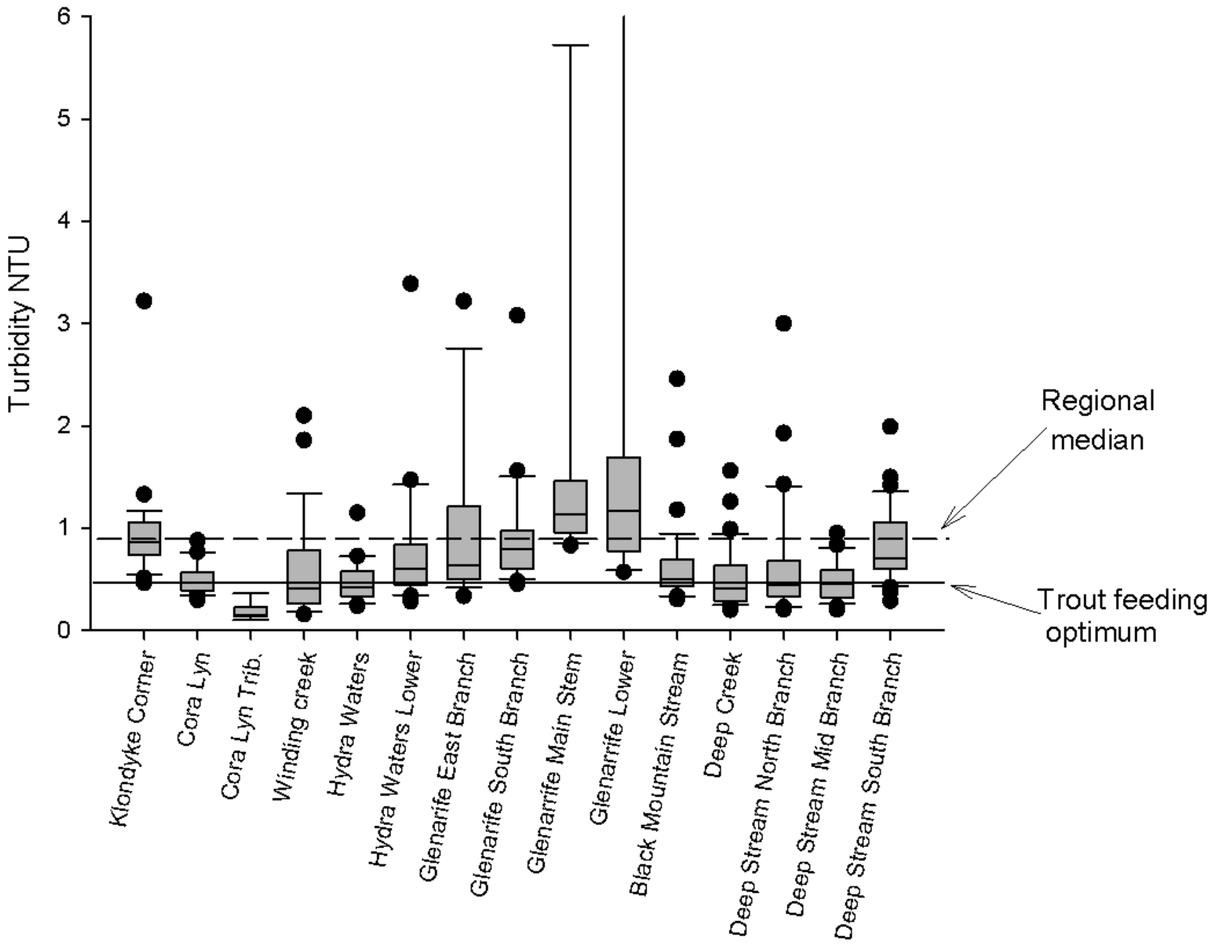

Figure 3-6: Turbidity in salmon spawning streams between Nov 2013 - Jan 2017. The regional median for spring-fed Upland streams and the trout feeding optimum of Hay *et al.* (2006) are shown on the right

3.2 Habitat characteristics

3.2.1 Riparian zone

Klondyke Corner Stream had an average width of ~9 m and an average depth of 0.24 m. Habitat was run (~65 %) and riffle (~35 %) flowing over a bed of cobbles and gravel. There were no macrophytes observed, but bryophytes on occasion covered 40 % of the bed. Banks were mostly stable and clothed in tussocks and Russel lupins with the occasional Matagouri (*Discaria toumatou*) and Sweet Briar (*Rosa rubiginosa*).

Cora Lyn Stream had an average width of ~12 m and an average depth of ~0.35 m. The flow type was dominated by run habitat (~90%) with 10 % riffle over a substrate dominated by gravels with ~20 % cobbles and 10 % fine sediment. The sampling reach had a broad riparian zone with limited stock access except for some of the headwater wetlands on Cora Lyn Station and small springs subject to sheep grazing in the bed of the Waimakariri River. The riparian vegetation was dominated by native and exotic grasses as well as an abundance of Russel lupins (*Lupinus polyphylus*) and the occasional Willow on the true right bank. The true left bank had some unstable, unvegetated sections of river gravels, while the true right bank was entirely vegetated.

Winding Creek had an average width of ~7 m and an average depth of ~0.4 m. The habitat was dominated by run with <10 % riffle or pool flowing over a bed dominated by gravels, but with ~35 % fine sediment and some cobbles (< 10 %). There were occasional macrophyte growths, covering up to 10 % of the bed and bryophytes (<5 %). Banks were mostly stable although there was some erosion due to the confluence with a flashy tributary. Some stock damage occurred downstream of the immediate sampling reach. Riparian vegetation consisted of exotic grasses and tussocks.

Hydra waters had an average width of 10 m and depth of 0.3 m. Habitat was 50 % run and 50 % riffle flowing over a bed of gravel and cobbles. There were no macrophytes observed and only occasional bryophyte growths (< 5 %). The banks were stable and no stock damage was observed. Riparian vegetation was dominated by tussocks along with Matagouri.

Glenariffe Stream East Branch has an average width of 5 m and average depth of 0.5 m. The habitat is 100 % run flowing over a bed of mixed gravels and fine sediment. Macrophyte cover averages ~ 40 % of the stream bed. The banks were stable and the riparian vegetation dominated by exotic grasses with <15 % tussocks. Some severe stock damage was observed to the banks in May of 2014, otherwise stock damage was limited.

Glenarrife Stream South Branch has an average width of 4 m and average depth of ~0.5 m. The habitat was dominated by fast flowing run over a substrate of gravels and cobbles with < 10 % cover of fine sediment. There were limited (<5 %) macrophyte growths, but bryophyte cover was typically > 10 %. The banks were stable, but showed evidence of severe stock damage on occasion. The riparian vegetation was dominated by exotic grasses and tussock.

Glenarrife Stream Main Stem had an average width of ~6 m and an average depth of 0.3 m. The habitat was 90 % run and 10 % riffle flowing over a bed dominated by gravels with some cobble (~10 %) but also fine sediment (~10 %). Occasional macrophytes grew in the margins (<10 %), but there were no bryophytes recorded. The banks were mostly stable, but subject to some erosion from stock access. Riparian vegetation was composed of exotic grasses and tussock.

Black Mountain Stream had an average width of ~7 m and depth of ~0.5 m, was dominated by run habitats, but 10 % pool and 10 % riffle was present in the sampling reach. Inorganic substrates were dominated by cobbles and gravels with occasional boulders and very little fine sediment. There were no macrophytes present and ~ 10% cover of bryophytes. The sampling reach had an extensively grazed riparian zone dominated by native red tussock (*Chionochloa rubra*) and exotic grasses with some shrub growth of Matagouri. Banks where stable and there was some bank damage from cattle.

Deep Creek had an average width of 9 m and average depth of ~0.3 m. The reach was comprised entirely of run habitat flowing over a gravel and cobble bed. There was <5 % fine sediments and the occasional (<5 %) macrophyte or moss growth. The sampling reach has recently been retired from grazing although evidence of continued stock access have been observed. The riparian vegetation is dominated by red tussock and exotic grasses. The banks are stable with grass and tussock vegetation.

Deep Stream North Branch had an average width of 4.5 m and an average depth of ~0.2 m. The habitat was dominated by riffle (~60 %) with 30 % run and 10 % pool flowing over a predominantly gravel (~60 %) and cobble (~25 %) bed. Fine sediments covered ~15 % of the bed. Macrophyte and bryophyte growths both averaged ~ 5 % cover of the bed. Banks were stable and covered in exotic grasses, tussock and occasional thistles.

Deep Stream Middle Branch had an average width of ~6.7 m and an average depth of 0.48 m. The habitat is composed of ~40 % run and pool habitat and ~ 20 % riffle flowing over a bed dominated by fine sediment (65 %) with some gravels and occasional cobbles. No macrophytes or bryophytes were recorded. Riparian vegetation was dominated by exotic grasses and some tussock. Banks were stable and minor stock damage was only observed in 2013. Thereafter, there was no observed stock access to the riparian zone.

Deep Stream South Branch had an average width of 5.5 m and an average depth of ~0.5 m. Habitat was dominated by runs (~70 %) with 15 % of both riffle and pools. Bed substrate was equally dominated by gravels and fine sediment (~45 %) with occasional boulders. Bryophytes were not observed, but 5 % of the bed was covered by macrophytes. Banks were stable and dominated by a mix or exotic grasses and tussock.

3.2.2 Fine sediment

The majority of streams were found to have low levels of fine sediment cover (<20 %) unlikely to have any detrimental effect of macroinvertebrate communities (Figure 3-7). However, other sites, in particular the Glenarrife East Branch, had high cover of fine sediment (~65 %) likely to have a significant negative impact. Fine sediment cover was variable between years at some sites possibly due to changes in land use activities or the effects of flood events.

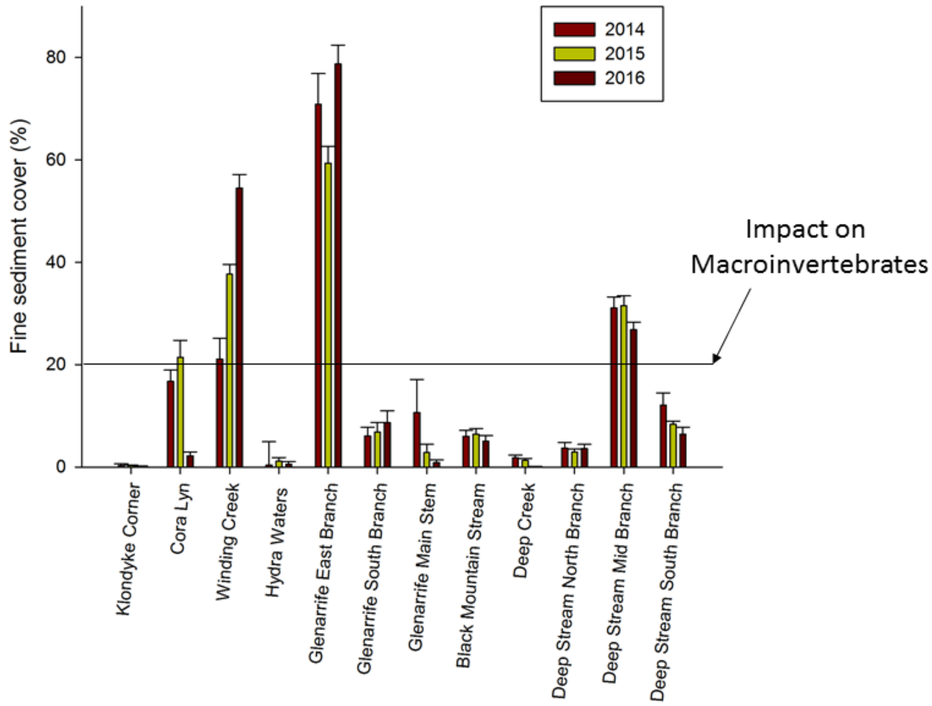

Figure 3-7: Mean fine sediment cover over three calendar years of approximately monthly monitoring

3.2.3 Periphyton

Periphyton data were summarised using the PeriScore of Biggs & Kilroy (Figure 3-8). PeriScores range from 1-10; a high score indicates a periphyton community dominated by thin films, whereas lower scores represent greater cover of mats and filaments. The majority of sites were high scoring and dominated by thin films. However, Cora Lyn had substantial growths of brown filaments at times and the Glenarrife Mainstem contained *Didymospenia geminata* which constitutes a mat.

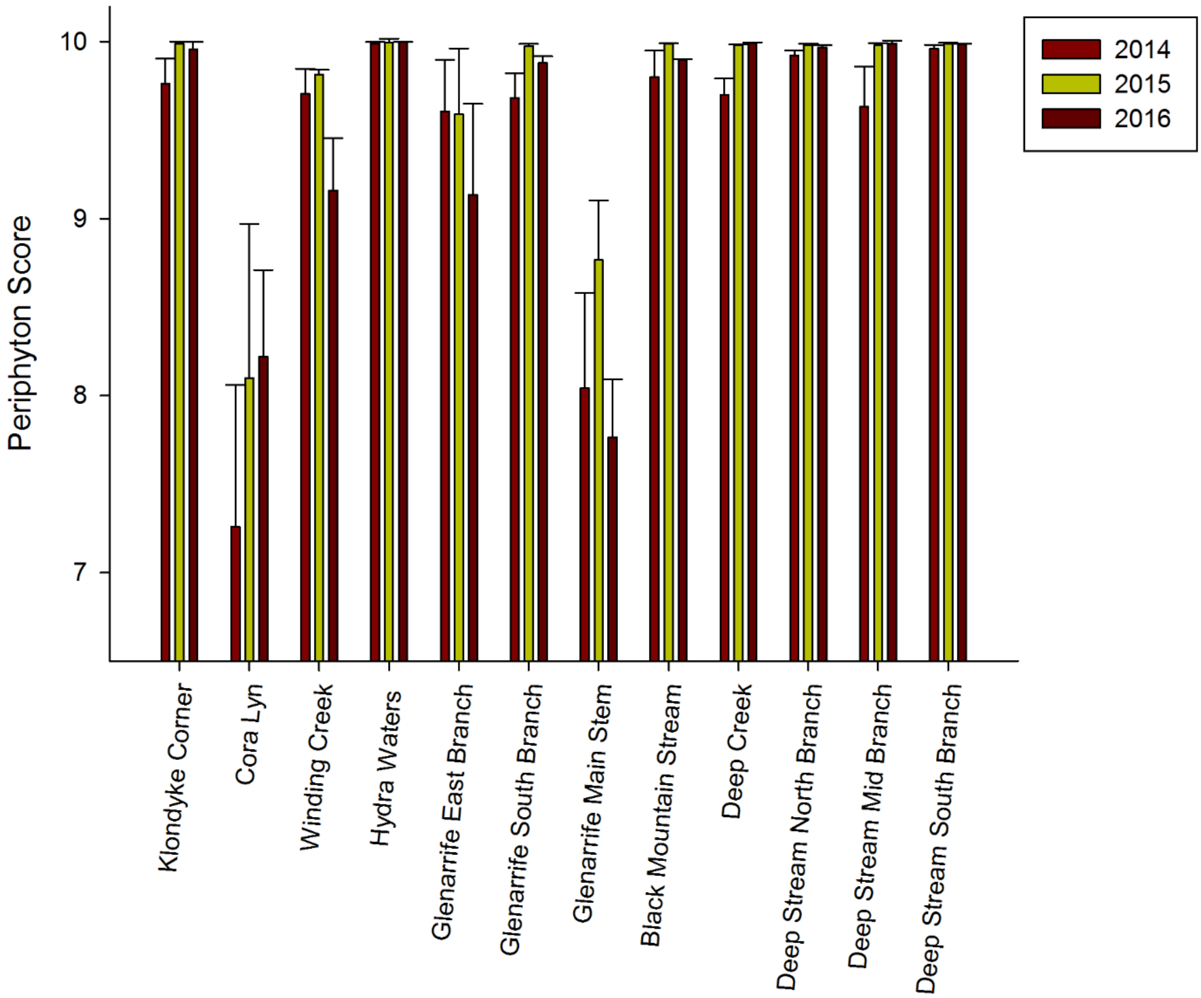

Figure 3-8: Mean periphyton score over three calendar years of approximately monthly monitoring

3.3 Macroinvertebrate communities

Overall, eighty-seven macroinvertebrate taxa were identified from 157,766 individuals over 4 years. Twenty-one percent of all individuals identified were the New Zealand mud snail, *Potamopyrgus antipodarum*, while in combination the caddisfly, *Pycnocentrodes* spp. and the mayfly *Deleatidium* spp. represented ~16 % of all individuals. Mean taxonomic richness ranged from 9.4 taxa at Cora Lyn in January 2016 to 25.2 taxa in the Hydra Waters in February 2015. Taxonomic richness was variable between years and in the majority of sites was greatest in 2015 (Figure 3-9).

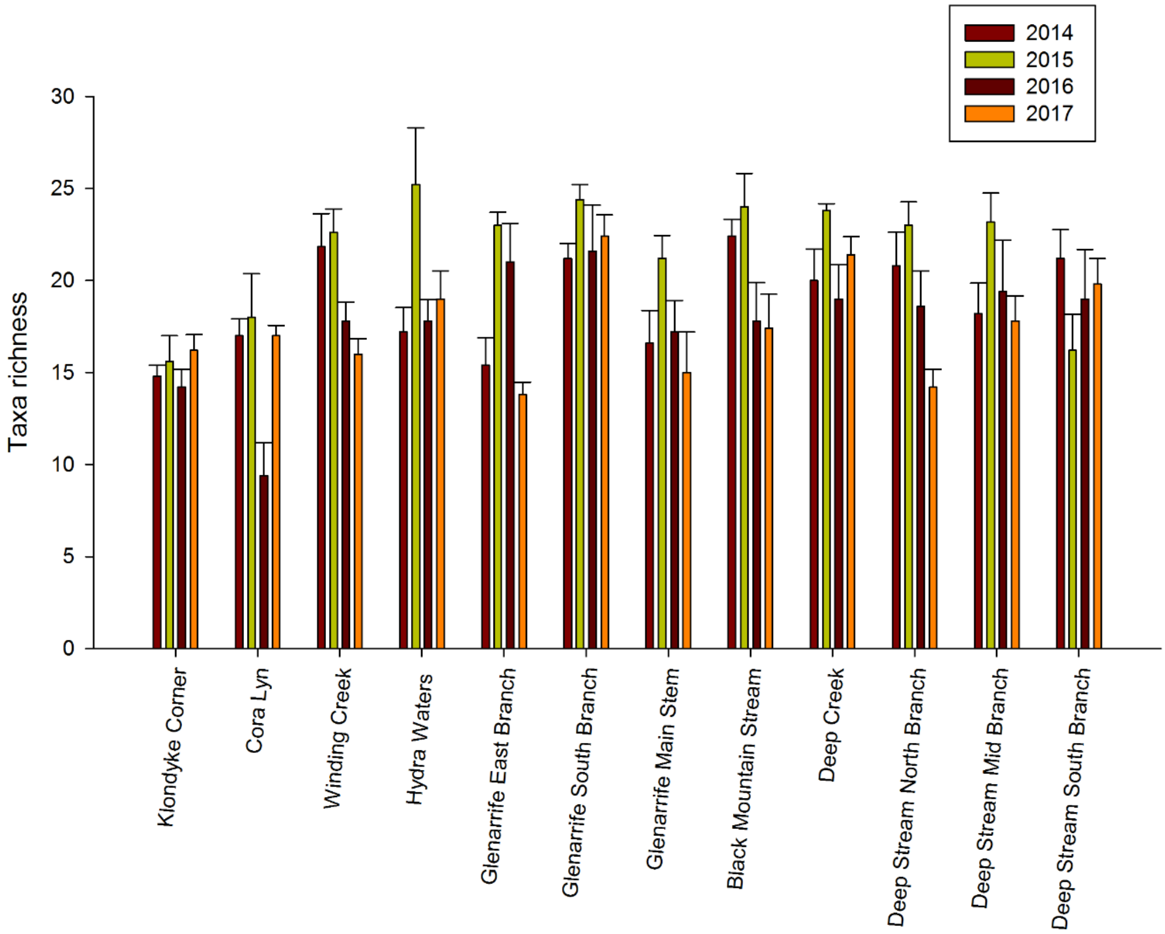

Figure 3-9: Mean ± 1 SE Taxonomic richness across four years

Average macroinvertebrate density (/0.1m²) ranged from a maximum of 2333 individuals in the Glenarrife East Branch (2015) to 133 individuals in Cora Lyn (2016) (Figure 3-10). The density of individuals in the Glenariffe East Branch was considerably greater than at the majority of other sites in each year. Other sites such as Klondyke Corner, Black Mountain and Hydra Waters had consistently lower densities of macroinvertebrates.

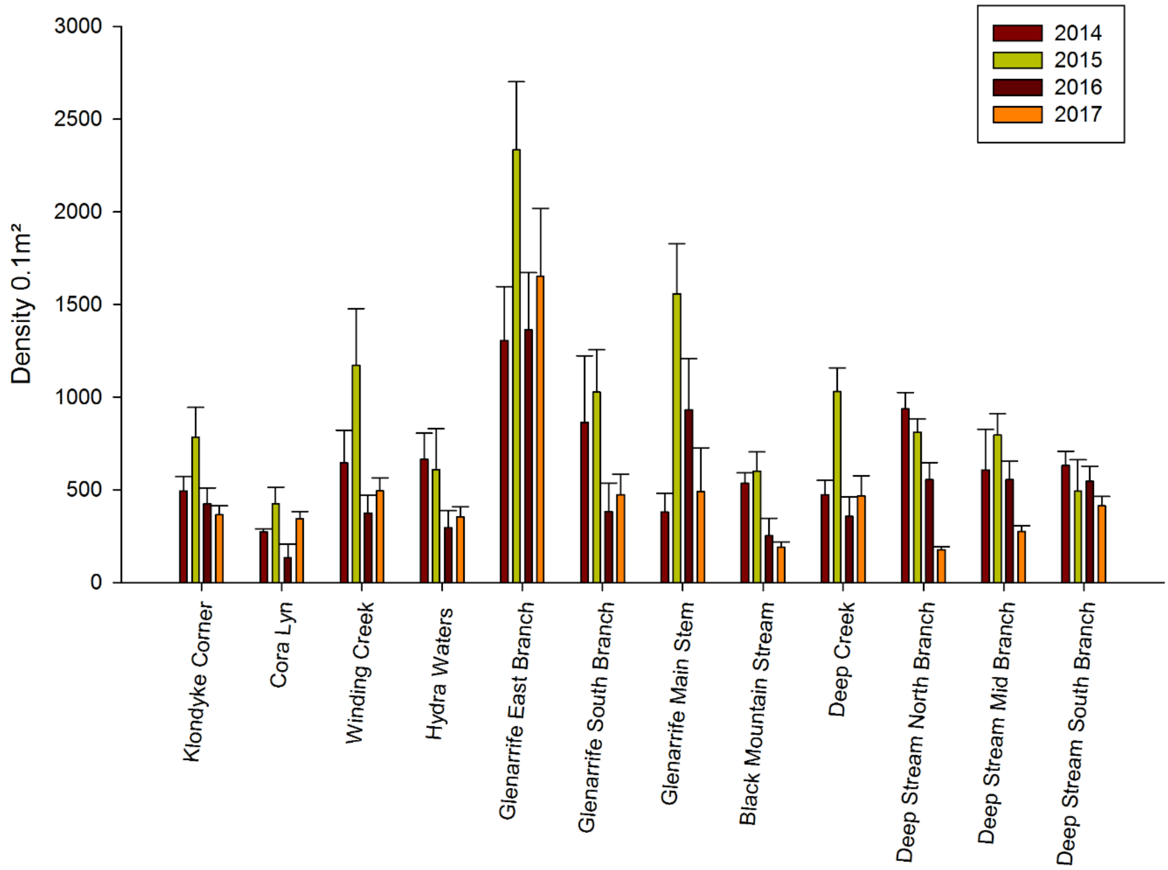

Figure 3-10: Average macroinvertebrate density (/0.1m²) across four years

The Quantitative Macroinvertebrate Community Index (QMCI) is an index of water quality that uses both the taxa present and their relative abundances (Stark and Maxted, 2007). The QMCI indicated that water quality in the majority of sites was at least good. However, the Glenarrife Mainstem and East Branch had macroinvertebrate communities of consistently poor quality and below the putative bottom line for ecosystem health set by the NPS-FM (2017) of four.

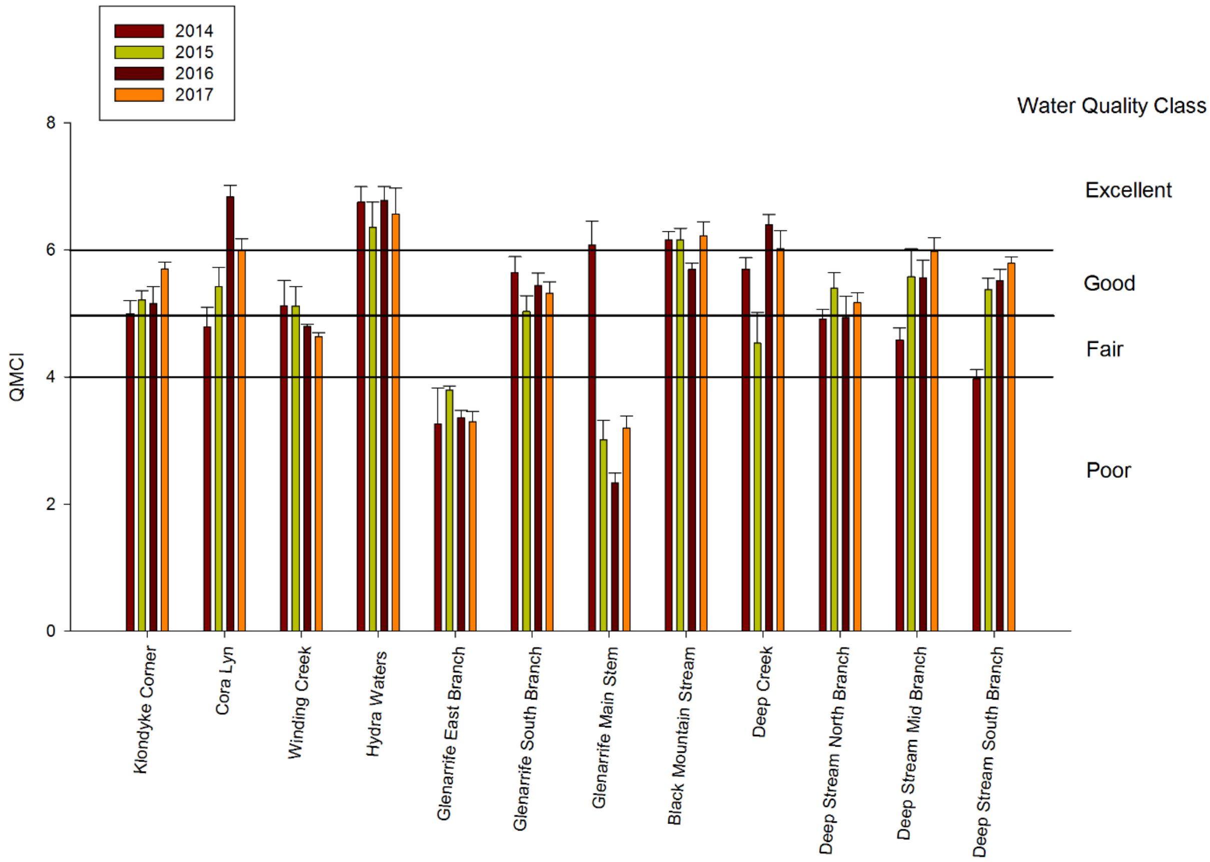

Figure 3-11: Average Quantitative Macroinvertebrate Community Index (QMCI) scores across four years

The relative abundance of the major groupings of macroinvertebrate types is shown in Figure 3-12. The majority of sites were dominated by Ephemeroptera and Trichoptera taxa, although typically Diptera, primarily chironomid larvae, make up a considerable proportion of the community. However, the Glenarrife East Branch and Winding Creek were highly dominated by Mollusc taxa, primarily *Potamopyrgus antipodarum*. The Glenarrife East Branch and Main Stem communities also contained a large proportion of oligochaete worms. Coleoptera and Crustacea were relatively uncommon except for large numbers of Ostracoda in the Glenarrife East Branch and Elmidae, or riffle beetles, in Cora Lyn, Winding Creek and Deep Stream Mid Branch.

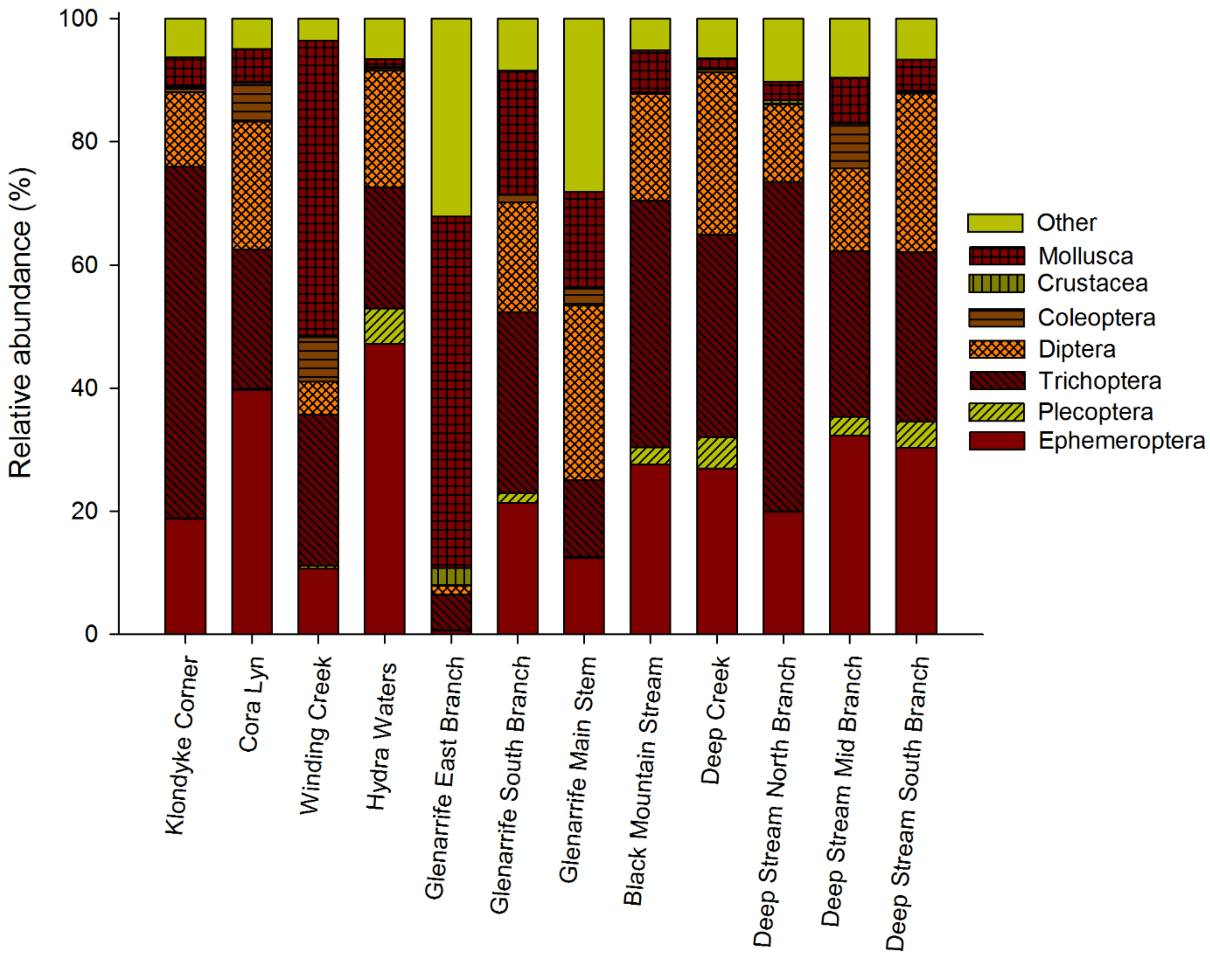

Figure 3-12: Relative abundance of macroinvertebrate types combined over four years

3.4 Environmental control of macroinvertebrates

The influence of environmental variables on macroinvertebrate communities was inferred using RDA. An initial PCA of periphyton morphological types provided two orthogonal axes that characterised communities, although they only explained 15.3 and 10 % of total variation, respectively (Figure 3-13). The primary gradients in periphyton community lay between thin brown films, "no algae" and various mat and filament growths. Observations of "no algae" were due primarily to smothering of the substrate by fine sediment, but also to occasional flooding and abrasion of algal growths in some streams. Filament and mat growths were uncommon except for the occurrence of brown filaments in Cora Lyn Stream and Winding Creek and the growth of *Didymospenia geminata* in the Glenarrife Main Stem (Figure 3-8).

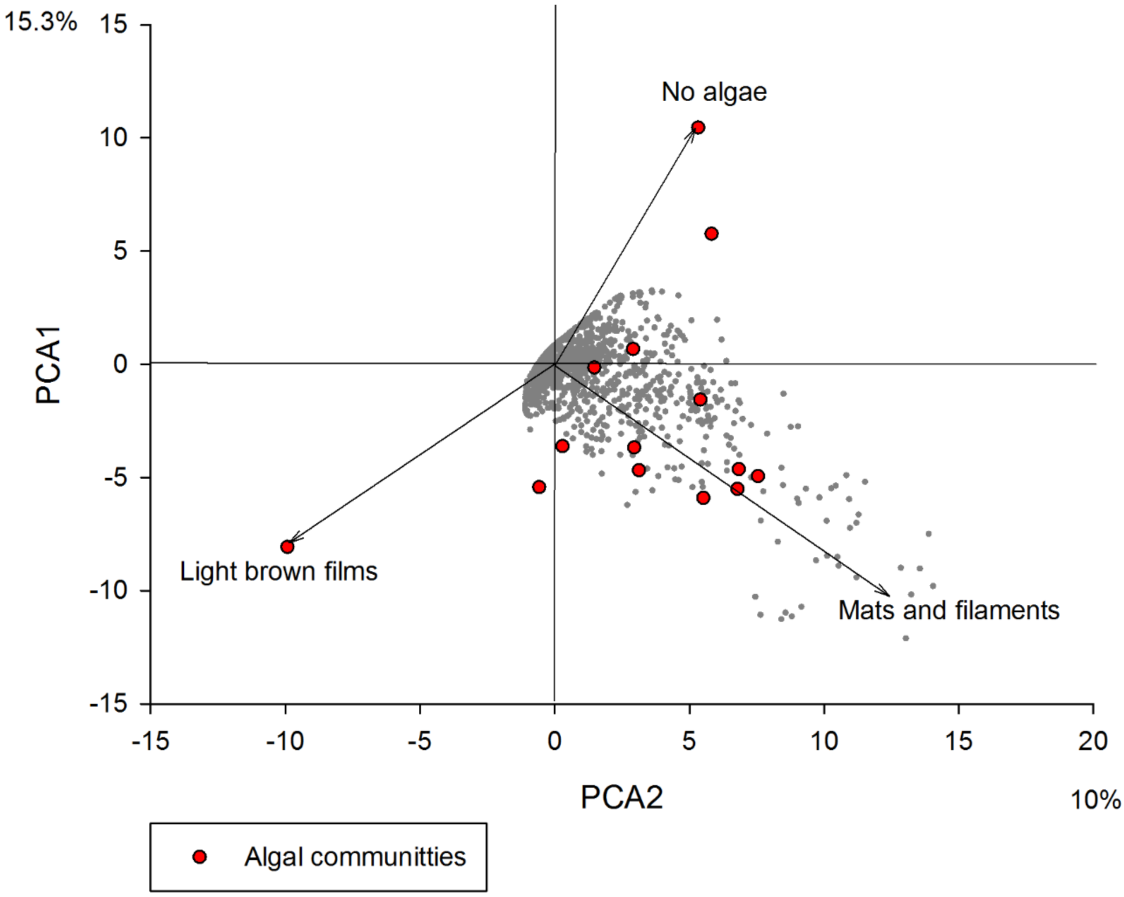

Figure 3-13: Principle Components Analysis (PCA) of periphyton communities (log+1 transformed)

Patterns in macroinvertebrate communities were compared to patterns in environmental variables after conditioning with a matrix representing the structure of temporal sampling within sites. Forward selection identified water quality, sedimentation and periphyton variables as being significantly related to patterns in macroinvertebrate communities (Table 3-1). In terms of water quality, the strongest relationships occurred between DIN over the preceding month, DRP over the preceding 6 months and *E. coli* over the preceding year. In terms of sedimentation, the cover of fine sediment over the preceding month appeared to be the most influential. Periphyton growth over the preceding year was the most influential periphyton variable on macroinvertebrate communities. Both PCA2, representing a gradient of algal films to no algae, and PCA1, nuisance growths of mats and filaments, had significant relationships with gradients in macroinvertebrate communities.

Table 3-1: Results of forward selection of environmental variables on Hellinger transformed macroinvertebrate community data. Selection criteria were a cumulative adjusted r² value of 0.57 and p value of <0.1

Variable type	Variable	r²	P value
Water quality	DIN_1m	0.24	0.001
	DRP_6m	0.08	0.001
	Ecoli_12m	0.06	0.001
	NTU_6m	0.03	0.018
	Ecoli_1m	0.02	0.057
	NTU_12m	0.02	0.095
Sedimentation	Sed _1m	0.03	0.036
Periphyton	PCA2_12m	0.05	0.001
	PCA1_12m	0.05	0.001

A final RDA using all significant variables derived from forward selection was found to be significant (p=0.008) after 999 permutations and was plotted to illustrate the relationships between sites, environmental variables and macroinvertebrate communities (Figure 3-14). Sites with limited land use intensification, low levels of contamination, low sedimentation, good habitat and macroinvertebrate communities within the good or excellent water quality class clustered to the left of RDA axis 1 and the centre of RDA axis 2. Sites with lower quality class macroinvertebrate communities, elevated nutrients, turbidity and bacterial counts or high sediment cover or algal growth were clustered to the right of RDA axis 1, but separated along RDA axis 2 depending on the particular stressor impacting macroinvertebrate communities.

Macroinvertebrate communities to the left of RDA axis 1 were typified by the mayfly *Deleatidium* and caddisfly *Pycnocentrodes,* which are taxa typical of a healthy stream. To the right of RDA axis 1 and lower half of RDA axis 2 macroinvertebrate communities where typified by the snail *Potamopyrgus antipodarum,* which was particularly abundant in Winding Creek and the Glenarrife East Branch. However, in the upper right quadrant of the RDA plot, primarily in the Glenarrife Main Stem, macroinvertebrate communities were typified by Oligochaete worms and chironomid (midge) larva.

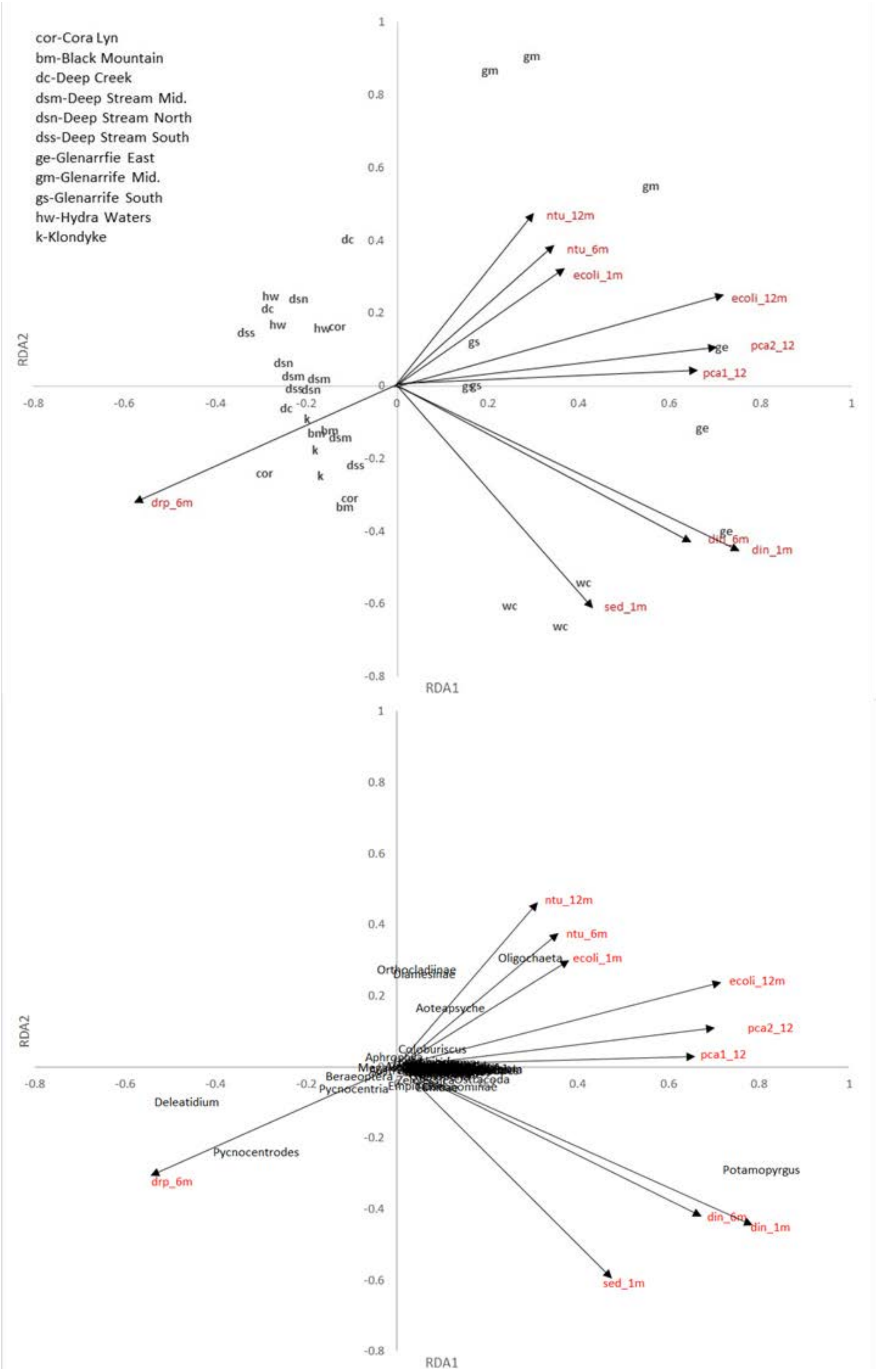

Figure 3-14: Redundancy analysis (RDA) of Hellinger transformed macroinvertebrate data and environmental variables from forward-selection analyses of environmental data. Overall model ANOVA adjusted r² = 0.58, p=0.012 The length of vector arrows indicates the strength of the relationship between the variable and gradients in macroinvertebrate communities. The top plot shows the graph location of sites while the lower plot shows the macroinvertebrate taxa

The relative shared and independent influence of different sets of variable types can provide further insight into the primary stressors affecting a macroinvertebrate community. An area proportional Venn diagram showing the shared and independent variance explained within the final RDA model suggested that water quality, in particular DIN concentration, had the over-riding influence in terms of total and independent variance explained (Figure 3-15). The independent effects of both sedimentation and periphyton growth were relatively minor when compared with that of water quality.

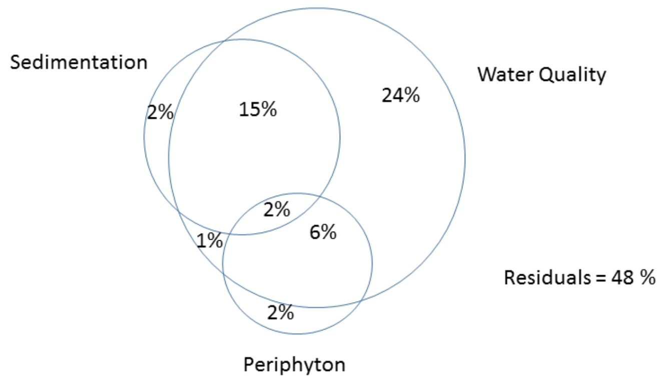

Figure 3-15: Variance decomposition of the influence on Hellinger transformed macroinvertebrate communities of water quality, sedimentation and periphyton communities

4 Discussion

A distinct land use signal was observed in the macroinvertebrate communities of spring-fed streams such that some streams had communities indicative of poor quality while others were excellent. The effects of land use intensification on water quality, aquatic habitat quality and aquatic communities are well understood (Allan and Castillo, 2007; Greenwood *et al.,* 2011; Quinn, 2000). However, specific impacts will depend upon the interactions between the land use effect or stressor, the physico-chemical characteristics of a stream and the ecological communities present. Commensurately, an appropriate management response or mitigation suite for any stream and landscape context will require a bespoke solution.

In this study streams were predominantly fed by groundwater sourced from large alpine rivers or steep eroding valley sides. As such, the true extent of the 'catchment', and the proportion of the catchment affected by land use intensification is not simply defined. However, due to the location of study sites at the upper limit of developed farming in alpine valleys, it can be assumed that any alteration in water quality from the natural state is attributable to activities in the vicinity of spring-fed creeks and over the shallow aquifers that feed them. The degree to which this land use may alter water quality will be determined by the volume of water relative to the practises, degree and area of land use intensification.

Land use contaminants follow different broad pathways to surface water. Nitrogen, particularly in the form of nitrate, is readily dissolved in water and thereby accumulates in groundwater. Phosphorus, fine sediment and *E. coli* are more likely to be transported to surface water via overland flow or direct deposition than via groundwater (Quinn, 2000). Accordingly, the relative concentrations of contaminants provide insight into the land use characteristics that are impacting water quality.

Water quality in the majority of streams in this study was high. However, relatively elevated nitrogen (DIN) was apparent in Winding Creek and the Glenarrife East and South branches. The observed concentrations were 'at' (Winding Creek) or 'in excess of' (Glenarrife) the putative natural baseline level for groundwater (0.25 mg/l) suggested by Morgenstern & Daughney (2012). These sites contrasted with Klondyke Corner, the single site with no agricultural development in the vicinity, that had very low concentrations (median 0.026 mg/l). The Glenarrife East Branch had less seasonal fluctuation in concentrations than streams with lower absolute values. This pattern is indicative of nitrogen concentrations maintained at an elevated level within shallow groundwater. However, the Glenarrife South Branch did show a regular seasonal fluctuation in DIN. This difference is likely to be a combination of greater runoff derived nitrogen sources to the South Branch and lower uptake occurring in the macrophyte dominated East Branch compared to the periphyton communities in the South Branch.

In terms of the impact of nitrogen on aquatic communities, the observed levels of DIN, even in the Glenarriffe and Winding Creek, remain relatively low such that there is no possibility of toxicity effects on macroinvertebrates or fish (Hickey, 2013b). However, there is the potential for nitrogen in both the Winding Creek and Glenarrife streams to promote nuisance growths of both periphyton and macrophytes (Biggs, 2000b; Matheson, Quinn and Hickey, 2012). Biggs (2000a) provided soluble inorganic nitrogen concentrations predicted to prevent nuisance growths of periphyton under different accrual periods (time since 3 X median flood). However, due to the highly stable nature of flow in spring creeks, accrual period is unlikely to be a good predictor of periphyton biomass. Instead, periphyton growth in such streams will be regulated by shading of the stream bed and grazing by aquatic invertebrates (Larned, Kilroy and Biggs, 2016). There is limited information on suitable nutrient criteria to avoid nuisance periphyton growth in spring-fed streams and it is commonly assumed that macrophytes are the plant form that require management in these waterways. However, the majority of the streams in this study were dominated by hard stony substrates coated with periphyton. Further investigations are required to determine a suitable nitrogen threshold for periphyton dominated spring-fed creeks. However, the results of this study provisionally suggest that elevation above 0.25 mg/l, in combination with other stressors, may begin to have negative impacts on macroinvertebrate communities.

Dissolved Reactive Phosphorus levels in streams were typically low despite occasional high values in the Deep Stream Middle and South branches. DRP was not associated with any inferred land use effect in terms of macroinvertebrate communities. Aside from an important role in promoting the growth of periphyton, DRP has no known direct impacts upon macroinvertebrates. However, elevated phosphorus concentrations are often associated with elevated *E. coli* and turbidity during rain events due to surface run-off or defecation of stock within waterways. As such, the occurrence of spikes in all three of these contaminants suggests that land use practises could be altered to the benefit of the streams. *E. coli* itself is of concern only for the potability and recreational suitability of a waterway. However, *E. coli* is also used as an indicator of faecal matter in a stream, and may be indicative of associated issues, such as trampling by stock of stream beds and margins or the addition of fine sediments.

The Glenarrife Main Stem had notably poor macroinvertebrate communities despite having low DIN and limited fine sediment cover. This stream receives occasional flooding from the Rakaia River which may result in flows adequate to cause mortality of some macroinvertebrate species and elevated turbidity. However, the Glenarrife Main Stem also has a substantial biomass of *Didymosphenia geminate* that is known to alter the community structure of macroinvertebrates with subsequent effects on fish communities (Jellyman and Harding, 2016).

Interestingly, the cover of fine sediment was not the strongest predictor of macroinvertebrate communities, although the effect may have been masked by co-linearity with other stressors, notably DIN. Stressors such as fine sediment, elevated nutrients or nuisance periphyton growths are known to interact with one another and in some instances effects are only observed due to a combination of stressors (Wagenhof, Townsend and Matthaei 2012; Piggott, Townsend and Matthaei, 2015). Given the limited number of sites involved in this study it would not be appropriate to infer causative pathways for the observed effects on macroinvertebrate communities. Rather, this study illustrates that land use intensification has the potential for negative impacts upon spring-fed stream ecosystems that should be considered in the context of the ecological values of these streams.

The Land and Water Regional Plan for Canterbury identifies the catchments of small lakes as being particularly sensitive to degradation due to their tendency to accumulate and re-cycle nutrients for an indefinite period of time (Meredith *et. al.,* 2012). As a result the plan provides maps of ‘sensitive lake zones’ within which there are specific rules about land use development intended to protect these environments. This study suggests that spring-fed streams are also highly sensitive to relatively low levels of nutrient enrichment. An appropriate planning response to the findings of this study would be to identify the spring-fed streams and wetlands with existing or potential for land use development and enact conservative policies and rules to protect water and habitat quality.

5 Conclusion

Various mechanisms have promoted/permitted the intensification of land use in the High Country, in particular areas of flat land adjacent to spring-fed streams and wetlands. These locations are hot spots of indigenous biodiversity and important for the integrity of Chinook salmon fisheries. Macroinvertebrate communities are a useful indicator of the overall health of streams and their potential to support salmonid populations. This study indicates that land use intensification can negatively impact upon macroinvertebrate communities in spring-fed salmon spawning streams. It is likely that stressors resulting from adjacent land use activities, in particular elevated nitrogen concentrations and fine sediment deposition, occur and act synergistically. In order to prevent or regulate these impacts resource managers must consider multiple contaminant pathways. Surface runoff and stock access impacts may be effectively mitigated by appropriate riparian management. However, this study found elevated nitrogen, even at relatively low concentrations, was associated with a significant impact upon stream communities. Determining the appropriate land use practises to prevent negative impacts from nitrogen loss to streams will require a site specific assessment of soils, hydrology and proposed farm systems. However, given the highly permeable, thin soils and shallow groundwater adjacent to some spring-fed streams, it seems likely that even limited land use intensification has the potential to elevate nitrogen concentrations and development should accordingly take a conservative approach. The identification and mapping of sensitive high country spring-fed streams would allow an amendment to the planning framework to protect these waterways.

6 Acknowledgements

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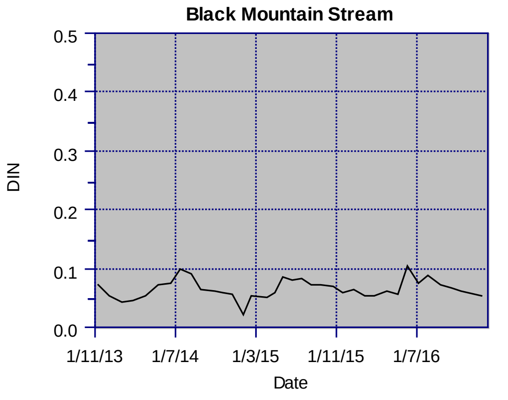
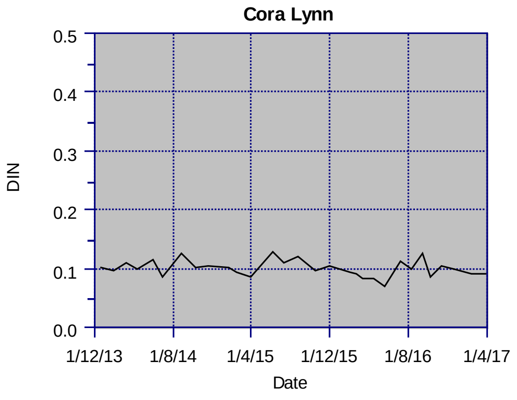
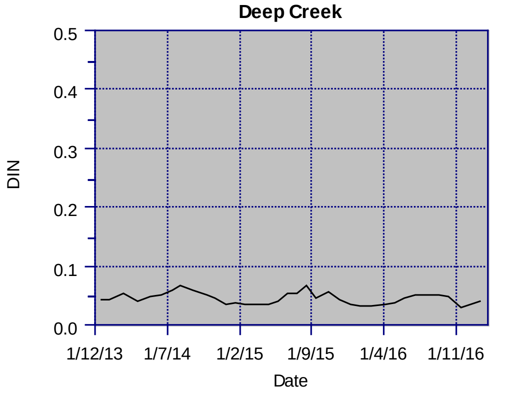
Appendix 1: TransformTukey Lambda and transformations of environmental variables

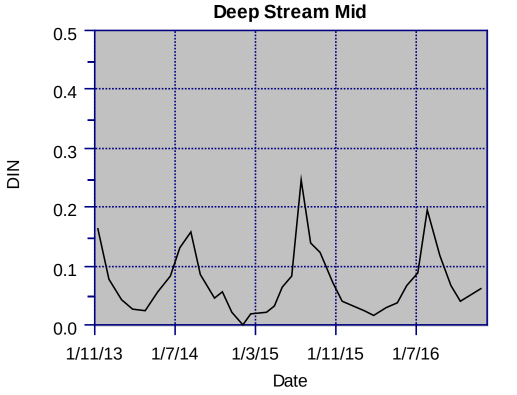
Variable	Lambda	W	Transformation
sed_12m	-0.48	0.9232	-1 * x ^ lambda
sed_6m	-0.33	0.9522	-1 * x ^ lambda
sed_12m	-0.30	0.9491	-1 * x ^ lambda
din_1m	-10.00	0.8152	-1 * x ^ lambda
din_6m	-10.00	0.8794	-1 * x ^ lambda
din_12m	-10.00	0.8044	-1 * x ^ lambda
ecoli_1m	-0.23	0.9709	-1 * x ^ lambda
ecoli_6m	-0.40	0.9673	-1 * x ^ lambda
ecoli_12m	-0.33	0.9712	-1 * x ^ lambda
ntu_1m	-3.95	0.9644	-1 * x ^ lambda
ntu_6m	-7.43	0.9743	-1 * x ^ lambda
ntu_12m	-4.93	0.9557	-1 * x ^ lambda
drp_1m	-10.00	0.3678	-1 * x ^ lambda
drp_6m	-10.00	0.9377	-1 * x ^ lambda
drp_12m	-10.00	0.9059	-1 * x ^ lambda
Substrate	3.63	0.9685	x ^ lambda
pca1_1	-1.33	0.9572	-1 * x ^ lambda
pca1_6	-1.18	0.9601	-1 * x ^ lambda
pca1_12	-1.35	0.9558	-1 * x ^ lambda
pca2_1	-0.65	0.9779	-1 * x ^ lambda
pca2_6	-0.35	0.9791	-1 * x ^ lambda
pca2_12	0.63	0.9555	x ^ lambda

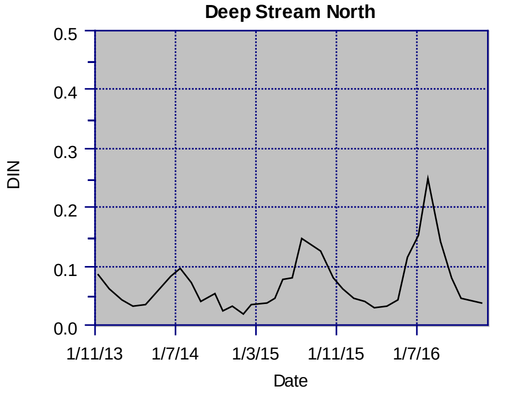
Appendix 2: DIN plots over time for each monitored site

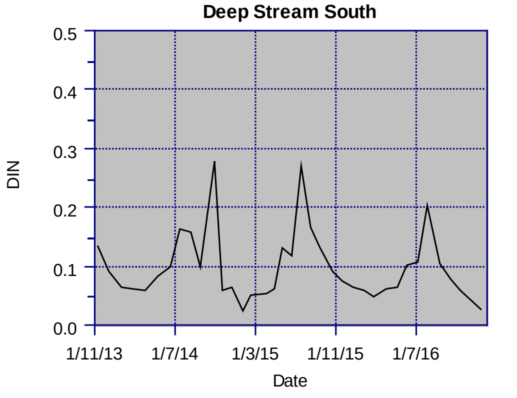


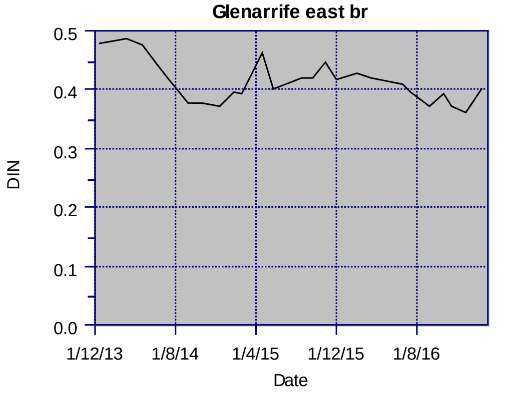


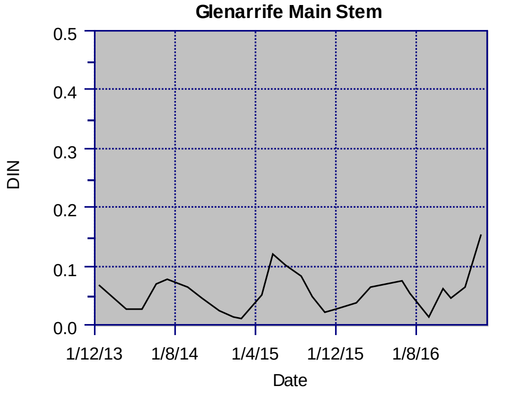


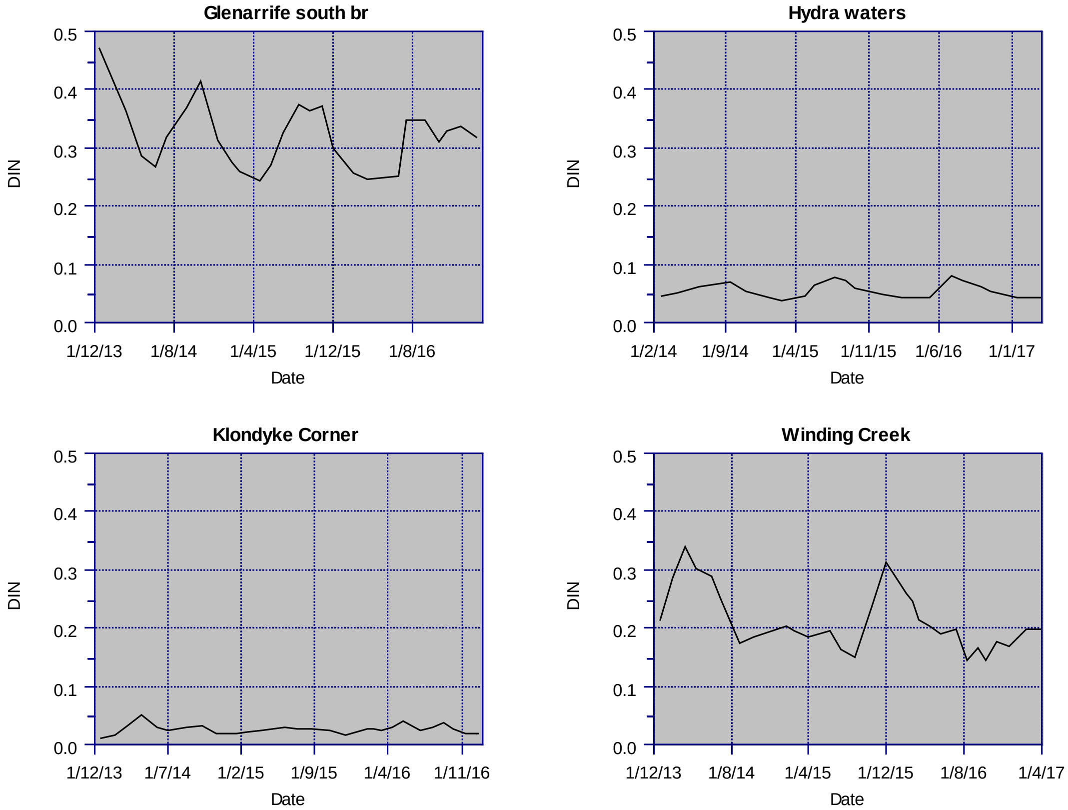






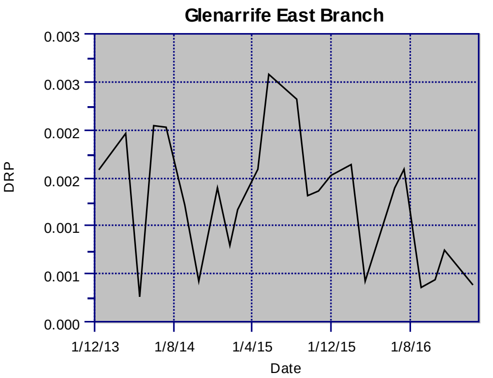


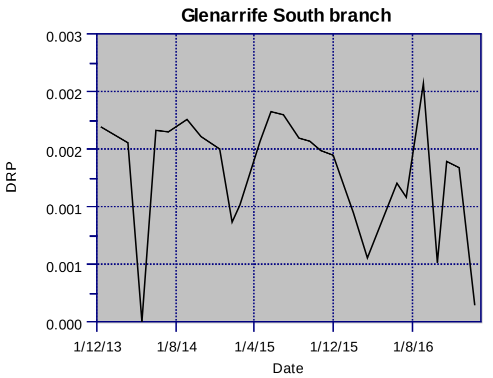


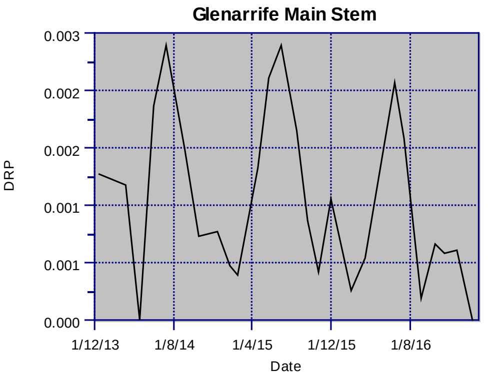

Glenarrife south br
DIN
0.5
0.4
0.3
0.2
0.1
0.0
1/12/13
1/8/14
1/4/15
1/12/15
1/8/16
Date
Hydra waters
DIN
0.5
0.4
0.3
0.2
0.1
0.0
1/2/14
1/9/14
1/4/15
1/11/15
1/6/16
1/1/17
Date
Klondyke Corner
DIN
0.5
0.4
0.3
0.2
0.1
0.0
1/12/13
1/7/14
1/2/15
1/9/15
1/4/16
1/11/16
Date
Winding Creek
DIN
0.5
0.4
0.3
0.2
0.1
0.0
1/12/13
1/8/14
1/4/15
1/12/15
1/8/16
1/4/17
Date

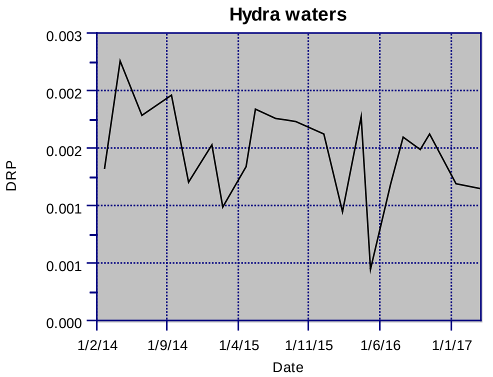
Appendix 3: DRP plots over time at monitored sites

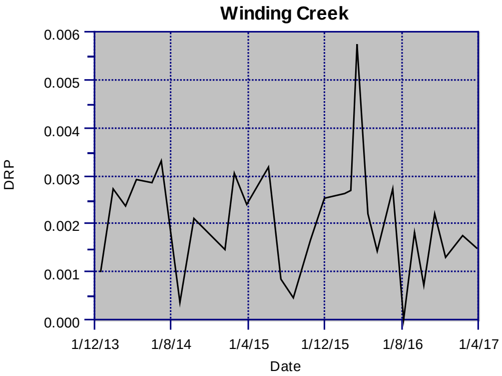
Note axes are not consistently scaled

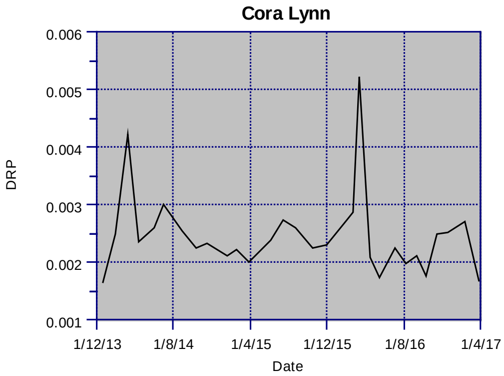


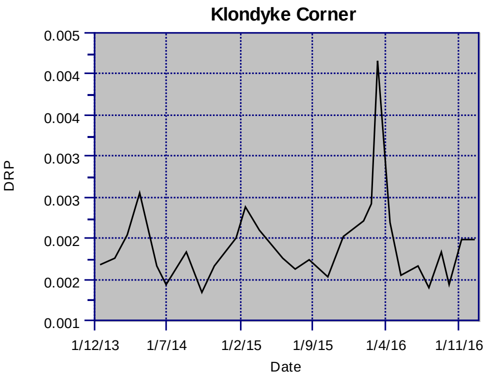


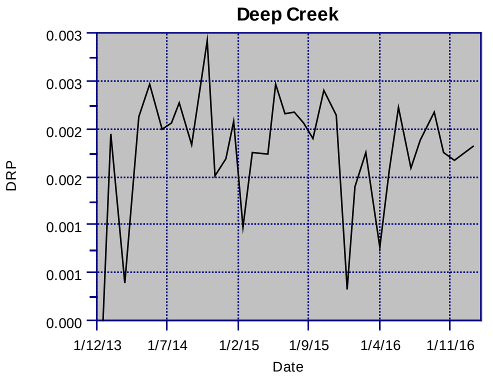


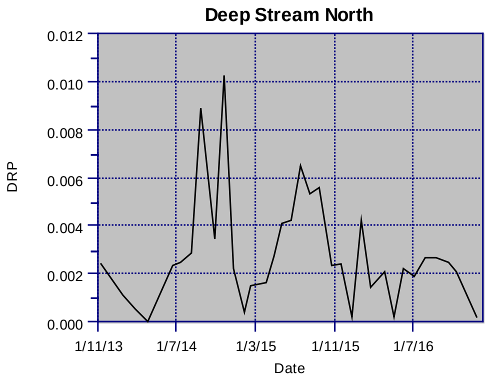


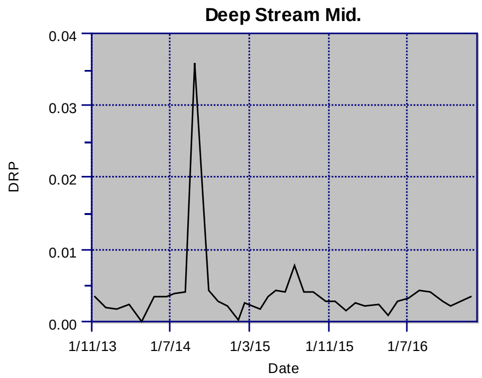


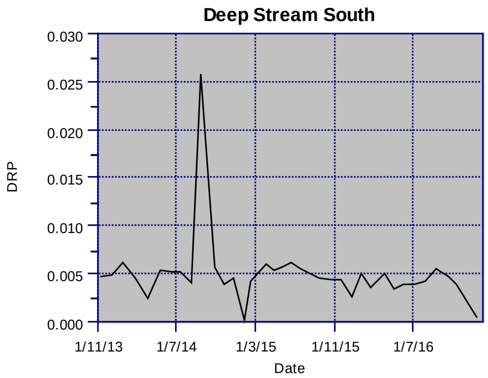


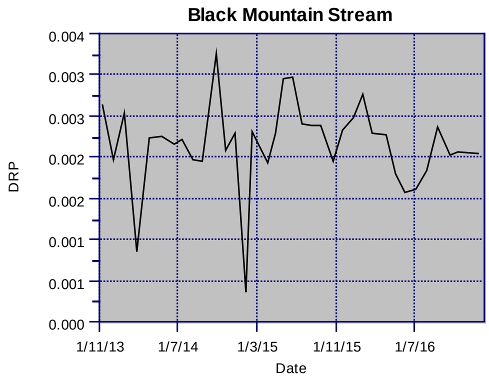





Deep Stream North
0.012
0.010
0.008
0.006
0.004
0.002
0.000
DRP
1/11/13
1/7/14
1/3/15
1/11/15
1/7/16
Date


Deep Stream Mid.
0.04
0.03
0.02
0.01
0.00
DRP
1/11/13
1/7/14
1/3/15
1/11/15
1/7/16
Date

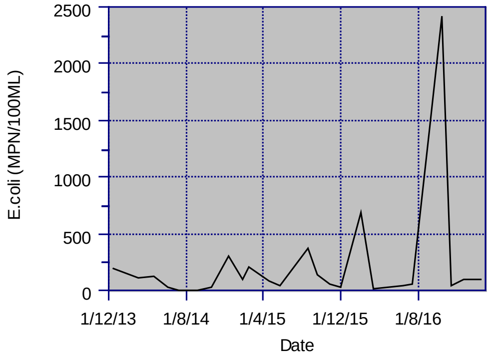

Deep Stream South
0.030
0.025
0.020
0.015
0.010
0.005
0.000
DRP
1/11/13
1/7/14
1/3/15
1/11/15
1/7/16
Date


Black Mountain Stream
0.004
0.003
0.003
0.002
0.002
0.001
0.001
0.000
DRP
1/11/13
1/7/14
1/3/15
1/11/15
1/7/16
Date

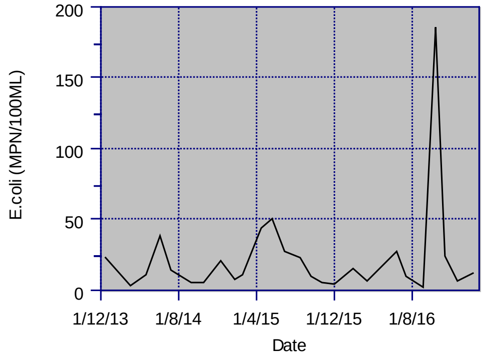
Appendix 4: *E. coli* plots over time at monitored sites

Note axes are not consistently scaled

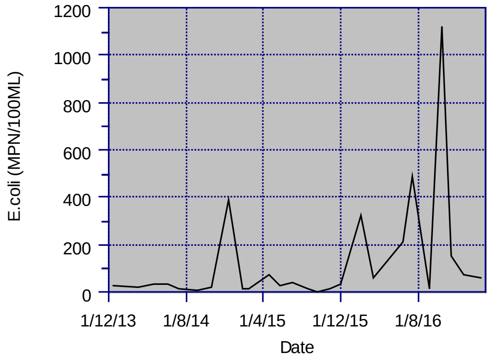
Glenarrife East Branch



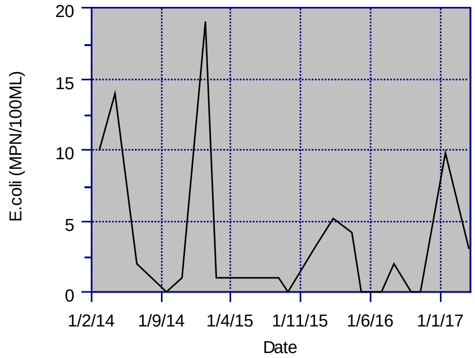
Glenarrife South Branch



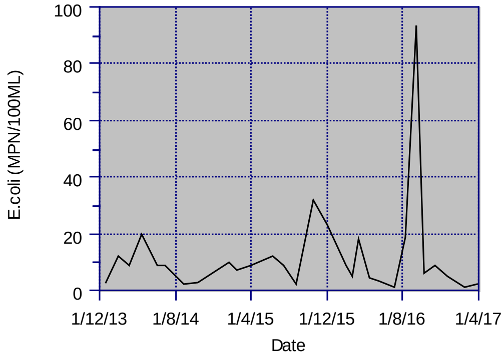
Glenarrife Main Stem



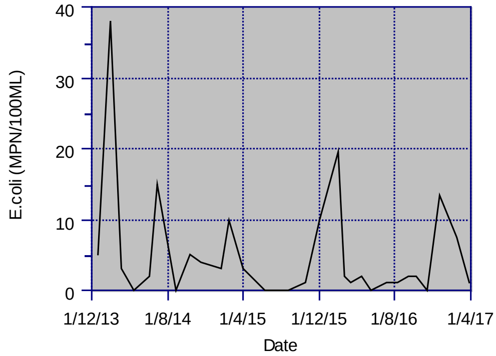
Hydra waters



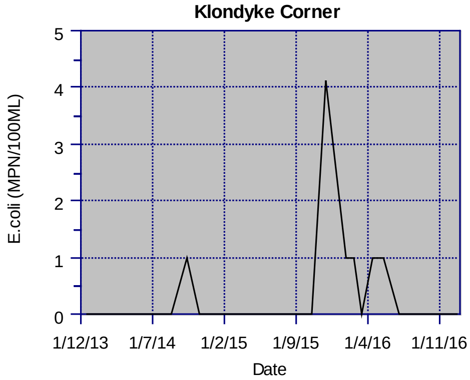
Winding Creek



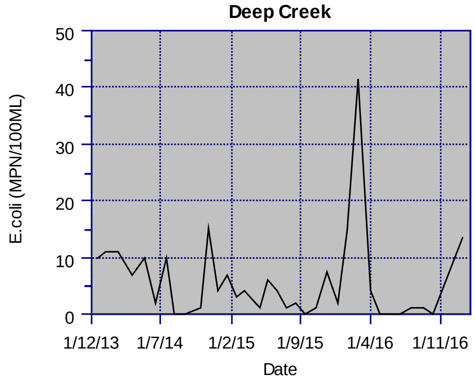
Cora Lynn

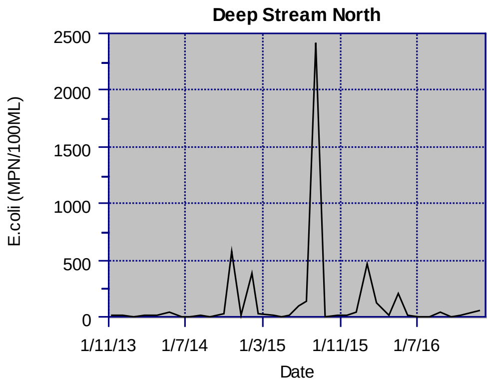


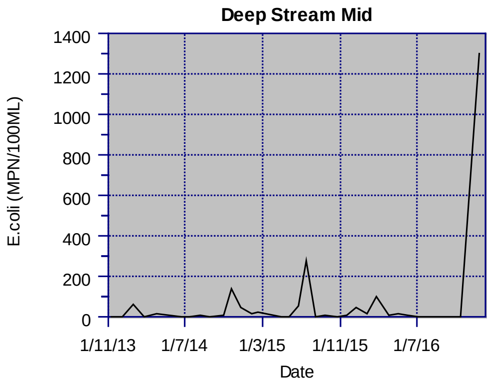
Klondyke Corner

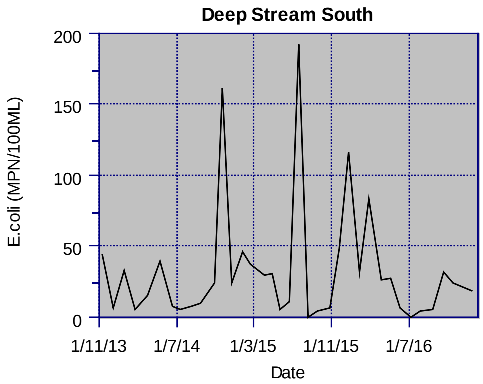


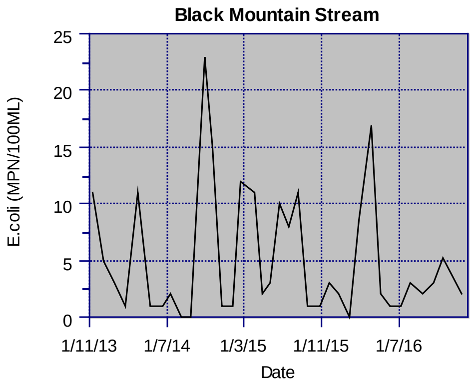
Deep Creek




Deep Stream North
2500
2000
1500
1000
500
0
E.coli (MPN/100ML)
1/11/13
1/7/14
1/3/15
1/11/15
1/7/16
Date

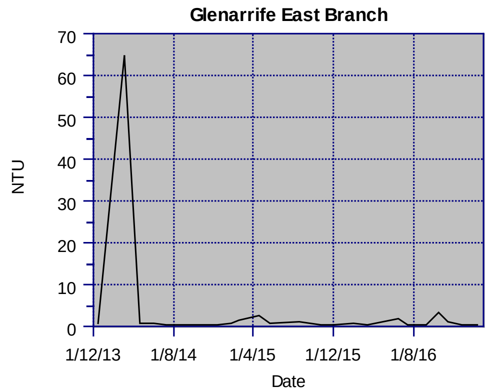

Deep Stream Mid
1400
1200
1000
800
600
400
200
0
E.coli (MPN/100ML)
1/11/13
1/7/14
1/3/15
1/11/15
1/7/16
Date

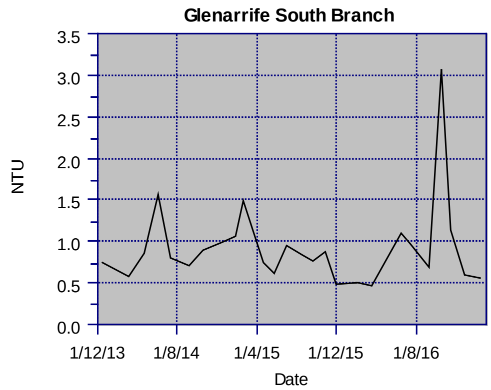

Deep Stream South
200
150
100
50
0
E.coli (MPN/100ML)
1/11/13
1/7/14
1/3/15
1/11/15
1/7/16
Date

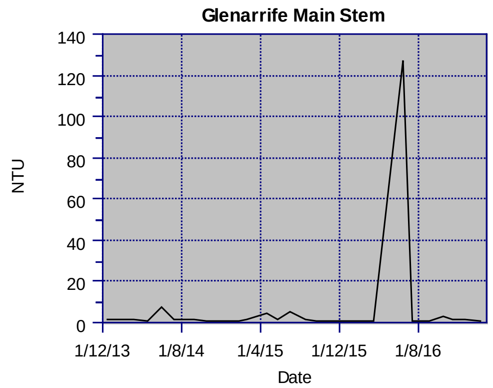

Black Mountain Stream
25
20
15
10
5
0
E.coli (MPN/100ML)
1/11/13
1/7/14
1/3/15
1/11/15
1/7/16
Date

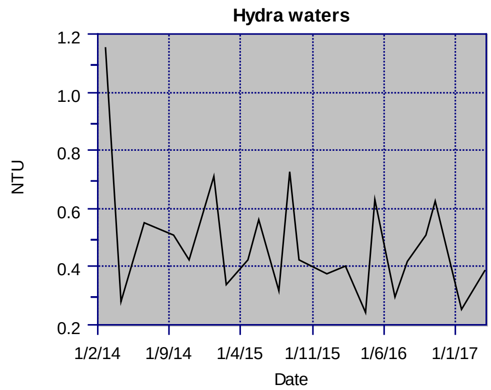
Appendix 5: Turbidity plots over time at monitored sites

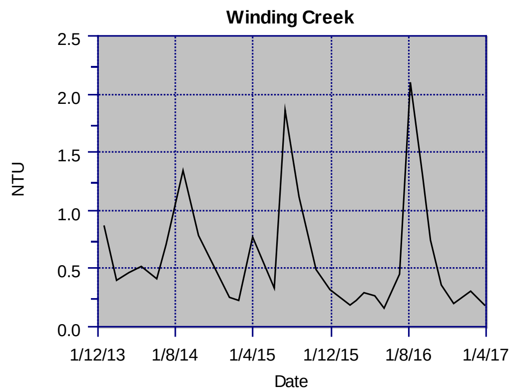
Note axes are not consistently scaled

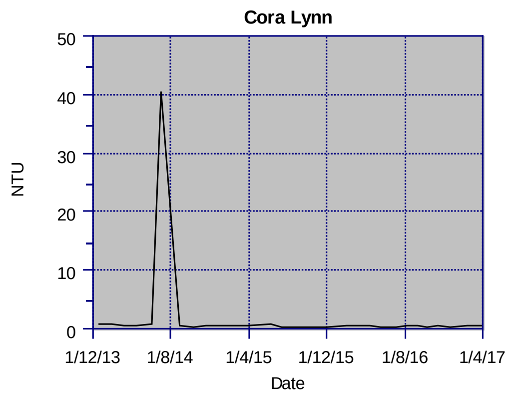


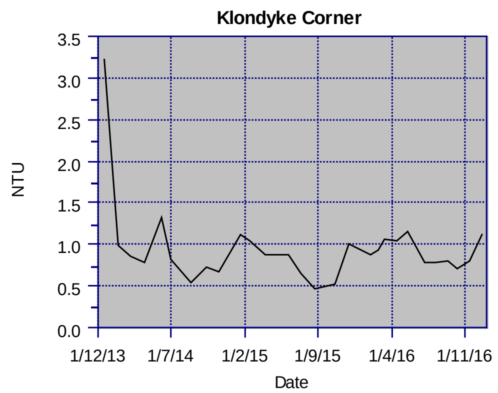


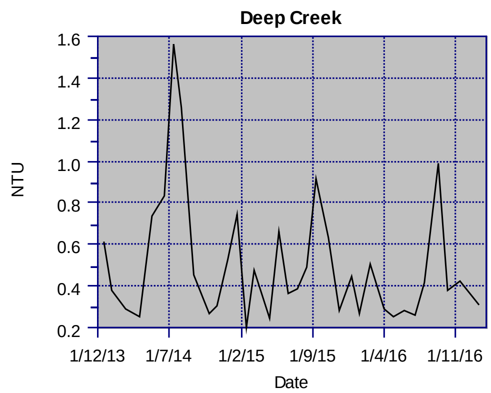


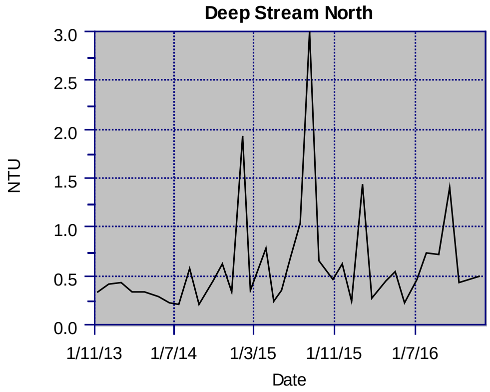


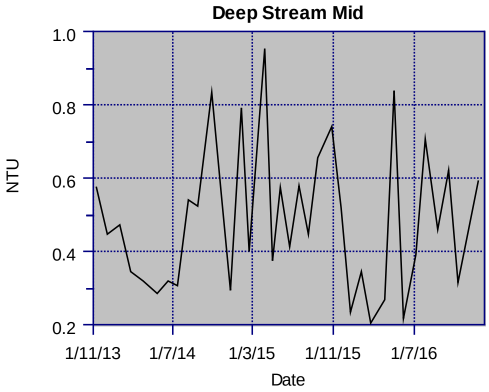


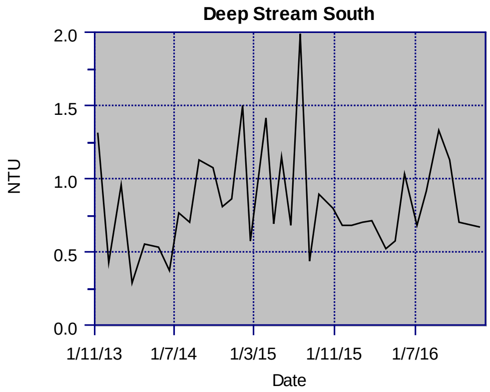


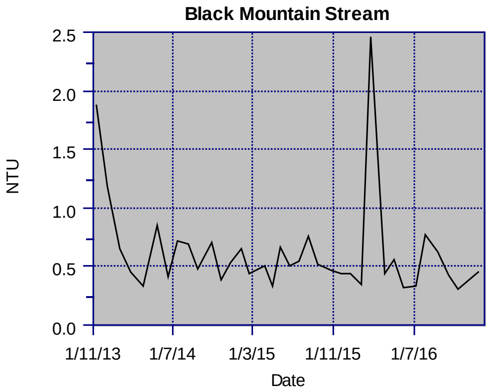





Deep Stream North
NTU
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1/11/13
1/7/14
1/3/15
1/11/15
1/7/16
Date


Deep Stream Mid
NTU
1.0
0.8
0.6
0.4
0.2
1/11/13
1/7/14
1/3/15
1/11/15
1/7/16
Date


Deep Stream South
NTU
2.0
1.5
1.0
0.5
0.0
1/11/13
1/7/14
1/3/15
1/11/15
1/7/16
Date


Black Mountain Stream
NTU
2.5
2.0
1.5
1.0
0.5
0.0
1/11/13
1/7/14
1/3/15
1/11/15
1/7/16
Date

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

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