Agricultural intensification, declining stream health and angler use: a case example from a brown trout stream in Southland, New Zealand

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Abstract

The Otapiri Stream brown trout (*Salmo trutta*) fishery (Southland, New Zealand) has undergone a dramatic decline over the past five decades. Over the same period, agriculture has intensified in the catchment, switching from low intensity sheep and beef grazing to dairy support and forage crop. We compared historic (1960's) and recent (2016) benthic invertebrate and electric fishing data and demonstrate substantial deterioration of the invertebrate community and reduced trout abundance. Compared with the baseline data, Ephemeroptera, Plecoptera and Trichoptera (EPT) abundance declined by 84% in riffles. The greatest decline (98%) occurred in pool habitat. Disproportionately high decline of EPT abundance in pool habitat highlights a potential issue with standard invertebrate sampling methodologies used to collect data to inform national-scale stream health assessments. By sampling only faster water habitat types (i.e., riffle and runs), the impacts of land use intensification (e.g., sedimentation) could be being underestimated.

In line with the observed decline in %EPT abundance, brown trout density has declined by approximately 71% and angler use of the fishery declined by 76% between 1994 and 2016. We contend that the decline in angler use of the Otapiri Stream is a result of land use intensification within the catchment, driving changes in the trout invertebrate food-base (EPT abundance) leading to reductions in adult trout density.

Key words: Angling, brown trout, *Salmo trutta*, macroinvertebrates, water quality, land use intensification

Introduction

Intensive agriculture is increasing in extent in New Zealand, particularly in Southland (Statistics NZ, 2017). In 1990, there were 37,772 dairy cows in Southland whilst in 2016 there were 708,895 (Statistics NZ, 2017). There is now overwhelming evidence that intensifying agricultural land use leads to degraded water and stream habitat quality (Matthaei et al. 2006; McDowell & Wilcock 2008). In New Zealand, stream invertebrates are commonly used by regional councils to monitor the health of streams. However, the State of Environment Reporting programme (SoE) which includes the collection of stream invertebrate samples, was not initiated in Southland until 1997. Prior to this period, agriculture was intensifying in Southland (Statistics NZ, 2017). Consequently, there is little pre-intensification baseline invertebrate data for many Southland streams. However, in the early 1960's the Marine Department and Southland Acclimatisation Society (now Southland Fish & Game), undertook benthic invertebrate sampling and electric fishing surveys in the Otapiri Stream, a hill country stream that flows through the Southland Plains. These data provide a valuable resource for investigating the historical ecological state of a 'typical' hill country/lowland stream prior to the conversion of much of the catchment from low intensity sheep and beef to dairy support and forage crop land uses.

From 1960 through to the 1980's, both formal and anecdotal records show the Otapiri Stream was highly valued amongst anglers. The Otapiri had the highest angler catch rate of any Southland waterbody and was identified as the most important Makarewa River tributary for anglers (Graynoth & Skrzynski 1974). Mark Sutton, former Southland Acclimatisation Society Field Officer, recalls frequent angler use of the Otapiri when undertaking angler compliance activities in the 1980's. Expert Southland angler Len Prentice recalls the Otapiri Stream to be of exceptional fishing quality during the 1970's and 80's, with the Otapiri offering mayfly hatches throughout the day and excellent dry fly fishing. More recently (1994-2016), angler use of the Otapiri fishery has declined substantially (Unwin 2016), and local anglers have regularly expressed concern about reduced trout abundance and loss of mayflies in the stream. Reduced recreational value of the Otapiri Stream is concerning for fisheries managers because the Otapiri fishery is valued by anglers for ease of access and its proximity to Southland's main population centres (Unwin 2013). To investigate how the Otapiri Stream invertebrate community has changed over the last 60 years, we resurveyed the invertebrate and brown trout population and compared these survey results with historical Southland Acclimatisation Society data. Our aim was to observe whether substantial changes in the macroinvertebrate communities had occurred in parallel with agricultural intensification within the catchment, and if changes to the trout invertebrate food-base are a plausible explanation for the observed decline in the quality and usage of the Otapiri fishery.

Methods

Study site and survey timing

The Otapiri Stream is a 5th order, rain-fed hill country stream with a stony bottom and natural flow regime. The Otapiri stream has its origins in the Hokonui Hills and flows into the Makarewa River, a major tributary of the Oreti River. The median Otapiri Stream flow is 1.08 m^3/s and the catchment land use is predominantly agricultural - sheep and dairy pasture and forage crop with pockets of native podocarp and exotic pine (*Pinus sp.*) forest. The Otapiri catchment is situated in a hill country/bedrock physiographic zone and features of this land type include: rolling/steep land, high rainfall and a dense network of branching streams that flow to neighbouring lowland areas which are a potential source of nutrients and sediment (Environment Southland, 2017).

In 1963-64, Boud & Cudby (1966) collected benthic invertebrate samples from five distinct sites in the Otapiri Stream, ranging from the upper reaches (above the Otapiri Gorge) to the lowermost reaches (near the Makarewa River confluence). At each site invertebrate samples were collected from pools (n = 9) and riffles (n = 9)in February, May and August of 1963 and January 1964. Average invertebrate species abundance over the four sampling periods was determined for each site and habitat type (riffle/pool). For the current study, we sampled benthic invertebrates at a single site during February 2016, in the lower Otapiri Gorge area. This site was chosen because it is of most interest to anglers and was also a survey location used by Boud & Cudby (1966) (46° 2'3.18"S, 168°26'47.49"E).

Benthic invertebrate sampling

At the lower Otapiri Gorge site, we selected one pool and one riffle to conduct benthic invertebrate surveys. Six benthic invertebrate samples were collected using a Surber sampler (0.25 m^2, 0.5 mm mesh) at each habitat type (i.e., pool and riffle) (see Stark et al. 2001, Protocol C3). A transect line was placed along the length and width of the pool and riffle, and sampling locations selected using a random number generator.

Following collection, the invertebrate samples were placed in labelled containers and preserved with ethanol. In the laboratory the invertebrate samples were sorted and identified to the lowest taxonomic level using the keys of Winterbourn et al. (2006) and Chapman et al (2011).. Chironomids were subsampled where abundances were very high using a volumetric approach whereby a 500 ml invertebrate sample was evenly mixed then 100 ml was removed for processing.

Invertebrate health metrics calculated included: the Macroinvertebrate Community Index (MCI), Quantitative Macroinvertebrate Community Index (QMCI) (Stark & Maxted 2007), %EPT (by taxa and abundance) and invertebrate density.

Brown trout density

To survey the brown trout population at the Otapiri Gorge site, Boud & Cudby (1966) undertook summer (January 1964) electric fishing surveys (pack-set machine). Boud & Cudby (1966) did not specify the number of electric fishing passes performed. In February 2012, we surveyed the brown trout population of a single reach (pool, riffle, run) using a three-pass electric fishing survey (Temple and Pearsons 2007) and determined brown trout density in the selected Otapiri Stream reach (46° 2'42.21"S, 168°26'50.37"E). Our electric fishing survey was conducted as part of an earlier study and was not the reach surveyed by Boud & Cudby (1966). However, our electric fishing survey site was within 150m of the site used by Boud & Cudby (1966) and involved electric fishing in a comparable section of river which included pool, riffle and run habitat.

Angler use

We used the Fish and Game National Angler Survey (Unwin 2016) to assess how angler use of the Otapiri has changed over time. Unwin (2016) provides information on angler usage of New Zealand fisheries between 1994-2016.

Results

Benthic Invertebrates

Boud & Cudby (1966) did not include raw invertebrate data in their report but did provide the average abundance for each invertebrate species over the four sampling periods for each habitat type (pool and riffle). As such, we could not statistically compare the differences in stream health metrics by sampling period. However, we are able to compare changes in species composition and abundance.

The average 2016 MCI score for the Otapiri Stream riffle and pool data was 88 and 76 respectively (Table 1), which suggest the Otapiri falls into the fair and poor water quality categories (Stark & Maxted 2007). The average QMCI scores were 2.8 and 3.2 for riffles and pools respectively (Table 1). These QMCI scores suggest that the Otapiri falls into the poor water quality category (Stark & Maxted 2007).

Historically, the Otapiri benthic invertebrate population consisted predominantly of mayflies and caddisflies (Figure 1). However, the invertebrate community in the 2016 survey was dominated by Diptera (chironomids) in the riffles and Mollusca (*Potamopyrgus* sp.) in the pools (Figure 1). In 1963-64, EPT taxa (by abundance) made up 60% and 55% of the invertebrate population in the riffles and pools respectively (Boud & Cudby 1966). In 2016, EPT taxa were only 9.4% and 1.3% of the invertebrate population in riffles and pools respectively (Table 1). In most cases, the abundance of EPT invertebrate taxa were substantially lower in 2016 than 1963-64, particularly in the pool habitat (Figure 2A). In the riffle habitat, the abundance of the mayfly *Deleatidium* sp. and caddisfly *Pycnocentria* sp. decreased by 83% and 42%, respectively. In pool habitat, *Deleatidium* abundance decreased by 97% and *Pycnocentria* abundance by 99%.

In both riffles and pools, the abundance of pollution tolerant taxa was substantially higher in 2016 compared to 1963-64 (Figure 2B). In riffle habitat, oligochaete, chironomid and *Potamopyrgus* abundance increased by 84%, 98% and 73% respectively. In pool habitat, oligochaete and *Potamopyrgus* abundance increased by 88%

Table 1. 2016 Otapiri Stream (Southland, New Zealand) stream health metrics.

Invertebrate metric	Riffle			Pool		
	Average	SD	±95%CI	Average	SD	95%CI
Taxa Richness	21.8	1.5	1.2	20.2	2.8	2.2
Abundance	1937.3	707.5	566.1	1350.5	1063.0	850.6
Density (m^2)	30996	11320	9058	21608	17008	13609
MCI	88.7	2.4	1.9	76.0	5.5	4.4
QMCI	2.8	0.1	0.1	3.2	0.5	0.4
$\%EPT_{Taxa}$	37.5	3.7	3.0	23.1	6.5	5.2
$\%EPT_{Abundance}$	9.4	2.0	1.6	1.3	0.2	0.2

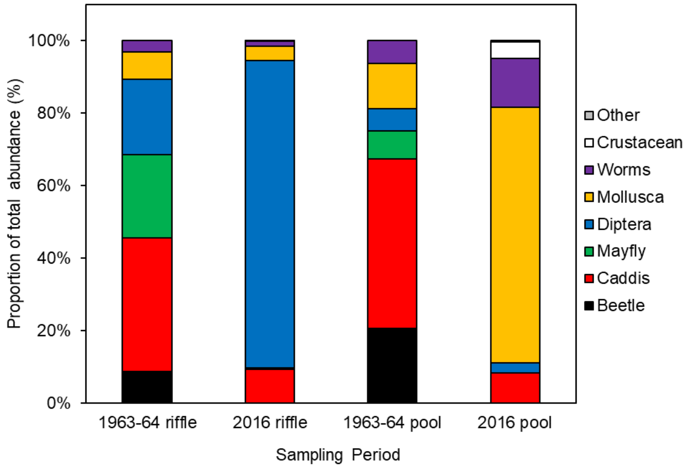
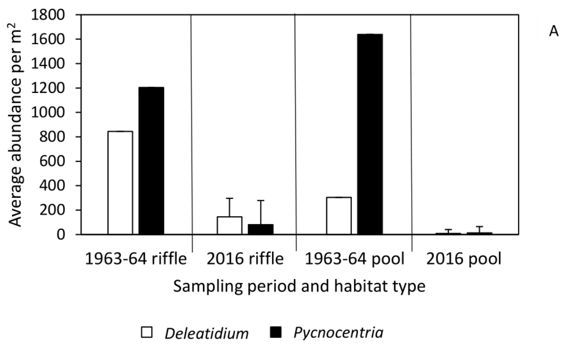


Figure 1. The proportion of total abundance that each taxa category contributes to the Otapiri Stream's benthic invertebrate community during 1963-64 and 2016. 'Other' category includes: Coelenterata, Acarina, Nematoda, Odonata, Hemiptera, Megaloptera, Platyhelminthes. 1963-64 data taken from Boud & Cudby (1966).



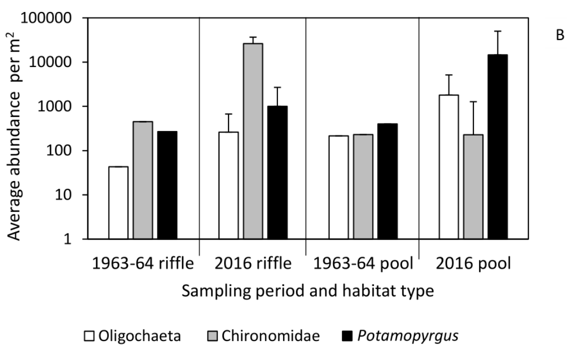


Figure 2. Average abundance (per m^2) of selected (A) pollution sensitive and (B) pollution tolerant benthic invertebrate taxa in the Otapiri Stream, over two time periods (1963-64 and 2016). n = 9 in 1963-64 and n= 6 in 2016 for both riffles and pools. Error bars are ±1 SEM. Error bars are not available for 1963-64 data because Boud & Cudby (1966) did not provide raw data or a measure of variability in their report.

and 97% respectively.

Brown trout density

In 2012, brown trout density for the surveyed reach was 1.19 per 100m^2 whereas in 1963-64, brown trout density was 4.15 per 100m^2, a decline in the order of 71%.

Angler use

The angler use survey conducted by Unwin (2016) has shown that between 1994 and 2016 there has been a substantial decline in the angler use of the Otapiri Stream (Table 2). For example, in the 1994/95 fishing season there were 950 (±220) angler visits to the Otapiri whereas in the 2015/16 season there were only 230 (±110) angler visits.

Discussion

Our investigation has confirmed there has been dramatic decline in %EPT abundance in the Otapiri Stream and an increase in the abundance of pollution tolerant taxa which suggests there has been water and / or habitat quality decline in the Otapiri Stream (*sensu* Stark & Maxted 2007). Declining %EPT abundance and increased chironomid and snail abundance has occurred in parallel with intensification of the catchment and this is a likely explanation for the decline in fishery values because other known stream stressors (point source discharges, urban stormwater and hydro regime modifications) are not present in the Otapiri. We do acknowledge that seasonal differences in sample timing may explain some of the variation in species taxa and abundances (e.g., Stark & Phillips 2009), however it is unlikely that differences in seasonality alone could explain the magnitude of the decline in the abundance of EPT taxa and changes in invertebrate community structure.

In New Zealand streams, the relationship between the declining abundance of EPT taxa and agricultural intensification has been well documented (Quinn & Hickey 1990; Harding et al. 1999; Matthaei et al. 2006; Niyogi et al. 2007). Agricultural intensification within a stream's catchment typically results in elevated nutrient (nitrogen, phosphorus) concentrations, temperature and sedimentation which can negatively affect sensitive invertebrate species (Quinn et al. 1997; Matthaei et al. 2006; Niyogi et al. 2007; McDowell & Wilcock 2008). These stressors can both directly affect invertebrate communities and interact to exacerbate the effect on invertebrate communities (Matthaei et al. 2010).

Historically, the Otapiri catchment land use was mostly low intensity sheep

Table 2. The estimated number of angler days spent on the Otapiri Stream during the trout fishing season, over four time periods. Estimates are taken from the Fish and Game National Angler Survey (Unwin 2016). Values are averages with 95% confidence intervals.

Season	Number of angler days
1994/95	950 ± 220
2001/02	990 ± 260
2007/08	250 ± 110
2015/16	230 ± 110

farming. In the last 20 years, forage crop grazing has become an increasingly prominent feature of the Otapiri catchment. In 2014 there was 851ha of forage crop in the Otapiri catchment (pers. comm., Lisa Pearson, Environment Southland). Higher intensity forage crop grazing results in greater production of overland flow, sediment and nutrients relative to grazed pasture (McDowell et al. 2003; McDowell & Houlbrooke 2008). The Otapiri Stream is particularly susceptible to inputs of sediment and nutrients because of the steep land within the catchment and the dense network of branching streams/gullies acting as mechanisms for pollutant transport. Consequently, the reduced EPT abundance and corresponding increase in the abundance of pollution tolerant species we observed is likely to be a result of increasing agricultural intensification in the Otapiri Stream.

The low %EPT abundance and the near absence of pollution sensitive invertebrate species (e.g., *Deleatidium* and *Pycnocentria*) was particularly evident in the Otapiri pool habitat. Current SoE monitoring practice involves the monitoring of benthic invertebrates in riffles/runs only (Stark et al. 2001). Relative to pools, riffle and run habitat is not as vulnerable to sedimentation because of greater water velocity. In pool habitat, water velocities are slower and consequently there is increased potential for deposition of fine sediment. Our work suggests that SoE monitoring of riffle or run habitat only (according to the Stark et al. 2001 protocols) may not be sampling the most vulnerable habitats to the impacts of land use derived fine sediment. Our results suggest that macroinvertebrate monitoring programs should include benthic invertebrate monitoring in pool habitat. Failure to sample pool habitat means sampling programs may be conservative in terms of their ability to detect an impact of land use intensification.

Substantially reduced EPT taxa abundance and density could explain the reduced trout density observed in the Otapiri. EPT taxa are often large invertebrates that frequently enter the invertebrate drift and are typically of high caloric content, making them ideal food sources for drift feeding fish (Cadwallader 1975; Shearer et al. 2003; Akbaripasand et al. 2014). In contrast, the small size of chironomids and oligochaetes precludes them from being an energetically profitable food for large drift-feeding fish such as adult trout. However, reductions in trout density could also be due to reduced spawning habitat quality and therefore recruitment limitation. For example, sedimentation has been found to adversity affect the survival of salmonid ova (Greig et al. 2005; Heywood & Walling 2007).

Because this study was based on historical data, there were some necessary limitations associated with this work , namely, having only two points in time for macroinvertebrate and trout comparison and no replication at the site level This meant we were unable to apply statistical tests to our data. However, the primary intent of this study was to make use of historical data to describe general observations with respect to changes in the invertebrate community and trout density in the Otapiri Stream. Our analysis captured a broad time scale (>50 years) which would not have been possible using conventional data sets. We demonstrated substantial declines in both %EPT abundance (from 55-60% to 9.4-1.3%, depending on habitat type) and trout density (from 4.15 per 100m^2 to 1.19 per 100m^2) over this time. Moreover, our observations fit with the scientific consensus on the effects of intensive agriculture on streams (Quinn et al. 1997; Matthaei et al. 2006; Niyogi et al. 2007; McDowell & Wilcock 2008). Future studies could investigate changes in the Otapiri Stream's invertebrate community and trout population over a longer time period and with greater spatial replication, to conclusively demonstrate deterioration in stream health.

In Southland, reduced angling pressure has been observed for several historically important lowland and hill country stream fisheries, all of which have experienced agricultural intensification within their catchments (Legard 2013). For example, angler use of the Otamita, Mokoreta, Waikaka and Waimatuku has declined by 66-90% over the last 20 years (1994-2016) (Unwin 2016). Angler use of the Otapiri has declined by 76% over the same time period (Unwin 2016). Our results suggest that habitat and / or water quality-induced changes in the Otapiri Stream benthic invertebrate community has negatively affected brown trout populations. In response, we deduce that anglers are 'voting with their feet' and selecting to fish elsewhere, specifically, rivers and lakes with less modified/pristine catchments (Unwin 2016). Continued agricultural intensification in the Otapiri and other similar streams is expected to further reduce angling amenity values. To reverse and prevent further degradation of the Otapiri Stream fishery, it is crucial that appropriate land management techniques (i.e., stream fencing (Holmes et al. 2016) and use of appropriate riparian vegetation buffers, particularly on sloping land (Zhang et al. 2010) are adopted to reduce overland flow and associated nutrient and sediment inputs.

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References

Akbaripasand, A., Ramezani, J., Lokman, P.M. & Closs, G.P. (2014). Can drifting invertebrates meet the energy requirements of drift-feeding fish? A case study on *Galaxias fasciatus*. *Freshwater Science* 33: 904–914.

Boud, R. & Cudby, R. (1966). A survey of the Otapiri Stream. Freshwater Fisheries Advisory Service. Marine Department. Job No. 55.

Cadwallader, P.L. (1975). Feeding habits of two fish species in relation to invertebrate drift in a New Zealand river. *New Zealand Journal of Marine and Freshwater Research* 9: 11–26.

Chapman, M.A., Lewis, M.H. & Winterbourn, M.J. (2011). *Guide to the freshwater Crustacea of New Zealand*. New Zealand Freshwater Sciences Society, Christchurch.

Environment Southland. (2017). *Physiographic zone: Bedrock/ Hill Country*. Retrieved 21st July 2017 from http://waterandland.es.govt.nz/repository/libraries/id:1tkqd22dp17q9stkk8gh/hierarchy/Physiographic%20zone%20factsheets/bedrock-hillcountry.pdf.

Graynoth, E. & Skrzynski, W. (1974). The Southland Trout Fishery. New Zealand Ministry of Agriculture and Fisheries. Fisheries Technical Report No. 99. Wellington, New Zealand.

Greig, S. M., Sear, D. A., & Carling,

P. A. (2005). The impact of fine sediment accumulation on the survival of incubating salmon progeny: implications for sediment management. *Science of the Total Environment* 344: 241–258.

Harding, J., Young, R.G., Hayes, J., Shearer, K.A. & Stark, J. (1999). Changes in agricultural intensity and river health along a river continuum. *Freshwater Biology* 42: 345–357.

Heywood, M. J. T., & Walling, D. E. (2007). The sedimentation of salmonid spawning gravels in the Hampshire Avon catchment, UK: implications for the dissolved oxygen content of intragravel water and embryo survival. *Hydrological Processes* 21: 770–788.

Holmes, R., Hayes, J., Matthaei, C., Closs, G., Williams, M. & Goodwin, E. (2016). Riparian management affects instream habitat condition in a dairy stream catchment. *New Zealand Journal of Marine and Freshwater Research* 50: 581–599.

Ledgard, G. (2013) Land Use Change in the Southland region. Environment Southland Technical Report No 2013-13.

Matthaei, C.D., Piggott, J.J. & Townsend, C.R. (2010). Multiple stressors in agricultural streams: interactions among sediment addition, nutrient enrichment and water abstraction. *Journal of Applied Ecology* 47: 639–649.

Matthaei, C.D., Weller, F., Kelly, D.W. & Townsend, C.R. (2006). Impacts of fine sediment addition to tussock, pasture, dairy and deer farming streams in New Zealand. *Freshwater Biology* 51: 2154–2172.

McDowell, R.W., Drewry, J.J., Muirhead, R.W. & Paton, R.J. (2003). Cattle treading and phosphorus and sediment loss in overland flow from grazed cropland. *Soil Research* 41: 1521–1532.

McDowell, R.W. & Houlbrooke, D.J. (2008). Management options to decrease phosphorus and sediment losses from irrigated cropland grazed by cattle and sheep. *Soil Use and Management* 25: 224–233.

McDowell, R.W. & Wilcock, R.J. (2008). Water quality and the effects of different pastoral animals. *The New Zealand Veterinary Journal* 56: 289–296.

Niyogi, D.K., Koren, M., Arbuckle, C.J. & Townsend, C.R. (2007). Longitudinal changes in biota along four New Zealand streams: declines and improvements in stream health related to land use. *New Zealand Journal of Marine and Freshwater Research* 41: 63–75.

Quinn, J.M., Cooper, A.B., Davies-Colley, R.J., Rutherford, J.C. & Williamson, R.B. (1997). Land use effects on habitat, water quality, periphyton, and benthic invertebrates in Waikato, New Zealand, hill-country streams. *New Zealand Journal of Marine and Freshwater Research* 31: 579–597.

Quinn, J.M. & Hickey, C.W. (1990). The magnitude of the effects of substrate particle size, recent flooding, and catchment development on benthic invertebrates in 88 *New Zealand rivers. New Zealand Journal of Marine and Freshwater Research* 24: 411–427.

Shearer, K.A., Stark, J.D., Hayes, J.W. & Young, R.G. (2003). Relationships between drifting and benthic invertebrates in three New Zealand rivers: implications for drift-feeding fish. *New Zealand Journal of Marine* *and Freshwater Research* 37: 809–820.

Stark, J.D, Boothroyd, I.K.G., Harding, J.S., Maxted, J.R. & Scarsbrook, M.R. (2001). Protocols for sampling macroinvertebrates in wadeable streams. New Zealand Macroinvertebrate Working Group Report 1, Ministry for the Environment, Wellington, New Zealand.

Stark, J.D. & Phillips, N. (2009). Seasonal variability in the Macroinvertebrate Community Index: are seasonal correction factors required? *New Zealand Journal of Marine and Freshwater Research* 43: 867–882.

Stark, J.D. & Maxted, J.R. (2007). A user guide for the macroinvertebrate community index Prepared for the Ministry for the Environment, Wellington, Cawthron report no. 1166.

Statistics New Zealand. (2017). *Infoshare*. Retrieved 21st July 2017 from http://archive.stats.govt.nz/infoshare/ViewTable.aspx?pxID=af222460-5d39-4d13-8afe-579e0a56fc9a

Temple, G.M. & Pearsons, T.N. (2007). Electrofishing: backpack and drift boat. In *Salmonid Field Protocols Handbook: Techniques for Assessing Status and Trends in Salmon and Trout Populations*. pp. 105–106. American Fisheries Society, Maryland.

Unwin, M.J. (2013) Values of New Zealand angling rivers: results of the 2013 National Angling Survey. National Institute of Water and Atmospheric research. NIWA Client Report CHC2013-120.

Unwin, M. (2016). Angler usage of New Zealand lake and river fisheries: results from the 2014/15 National Angling Survey. National Institute of Water and Atmospheric Research. NIWA Client report 2016021CH.

Winterbourn, M.J., Gregson, K.L.D., & Dolphin, C.L. (2006). *Guide to the Aquatic Insects of New Zealand*, Bulletin 14. Entomological Society of New Zealand, Christchurch.

Zhang, X., Liu, X., Zhang, M., Dahlgren, R.A. & Eitzel, M. (2010). A review of vegetated buffers and a meta-analysis of their mitigation efficacy in reducing nonpoint source pollution. *Journal of Environmental Quality* 39: 76–84.