BEFORE THE CANTERBURY REGIONAL COUNCIL

UNDER	the Environment Canterbury (Temporary Commissioners and Improved Water Management) Act 2010
IN THE MATTER	of the proposed Hurunui and Waiau River Regional Plan

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STATEMENT OF EVIDENCE OF ROGER GRAEME YOUNG
ON BEHALF OF
THE NORTH CANTERBURY FISH AND GAME COUNCIL

12 October 2012

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1. INTRODUCTION

Qualifications and experience

1.1 My name is Roger Graeme Young. I am a freshwater ecologist and have been employed at the Cawthron Institute in Nelson for the last 14 years. I have the following qualifications: BSc Honours and PhD in Zoology from the University of Otago. I am a member of the New Zealand Freshwater Sciences Society and the Society for Freshwater Science (formerly North American Benthological Society).

1.2 My areas of expertise include freshwater fisheries, river health assessment, water quality, and river ecosystem ecology.

1.3 Over the last 14 years I have undertaken freshwater ecological work throughout New Zealand for clients including power companies, regional councils, Ministry for the Environment, Department of Conservation and Fish and Game New Zealand. I have also been involved with research investigating the behavioural response of back country trout to anglers, factors affecting trout abundance, accuracy of drift dive assessments of trout abundance, catchment-wide patterns of fish movement (including supervising a MSc student's work on the use of otolith microchemistry as a tool for understanding fish movements), integrated catchment management, new tools for river health assessment, and links between human pressure indicators and aquatic ecosystem integrity. I have written 38 scientific papers and more than 60 reports relating to this work.

1.4 Examples of recent hearings in which I have presented water quality, freshwater fisheries, river ecology and instream habitat evidence include:

a. The special tribunal hearing related to the application to amend the National Water Conservation (Rakaia River) Order 1988;

b. Environment Court hearing on Horizons Regional Council One Plan;

c. Environment Canterbury's hearing on their proposed Canterbury Regional Policy Statement;

d. Horizons Regional Council hearing on their proposed One Plan;

e. Meridian Energy's lower Waitaki North Branch Tunnel Concept Water Resource Consents Hearing;

f. Trustpower's hearing relating to re-consenting the Cobb Power Scheme;

g. Natural Gas Corporation's hearing relating to the proposed expansion of the Stratford Power Station;

h. Environment Court hearing on Otago Regional Council's Water Plan.

1.5 I also presented evidence at the Special Tribunal hearing of the application for a Water Conservation Order for the Hurunui River.

1.6 In January 2009 I spent two days visiting the Upper Hurunui Catchment and conducted an informal drift dive down three sections of the Hurunui downstream of Lake Sumner. In February 2010 I assisted with a formal drift dive of the South Branch of the Hurunui.

1.7 I have not had any work-related visits to the Waiau Catchment, but as a result of multiple road trips from Nelson to Christchurch I am familiar with the parts of the Catchment that border SH7.

1.8 I was a co-author of a report on the effects of the proposed Amuri Hydro Project on the Waiau River (Olsen et al. 2011).

1.9 I have recently been appointed to a science panel to assist with the development of a national objectives framework to help with limit setting, as required under the National Policy Statement for Freshwater Management.

1.10 I confirm that I have read and agree to comply with the Code of Conduct for Expert Witnesses (November 2011). This evidence is within my area of expertise, except where I state that I am relying on what I have been told by another person. I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

1.11 In preparing my evidence I have drawn on the information from the following reports and evidence of others:

a. Habitat and trout abundance data from the ‘100 Rivers’ study (Jowett 1990; Teirney & Jowett 1990);
b. Data on trout size from the headwater trout study (Jellyman & Graynoth 1994);
c. Water quality and invertebrate data from the Hurunui and Waiau Catchments provided by NIWA and Environment Canterbury;
d. Water temperature data for the Waiau Catchment provided by Meridian Energy;
e. A report on trout growth modelling in the Hurunui Catchment (Hayes & Quarterman 2003);
f. A report on otolith microchemistry of trout from the Hurunui Catchment (Bickel & Olley 2009);
g. Reports on water quality and invertebrate communities in the Waiau River (Olsen et al. 2011; Hayes et al. 2012);
h. Reports on Hurunui Water quality (Hayward 2001, Ausseil 2010, Norton & Kelly 2010);
i. The evidence of David Stewart and Les Hill.

Scope of evidence

1.12 I have been asked by the North Canterbury Fish and Game Council (**Fish and Game**) to provide evidence to this hearing on the following:

a. The characteristics of headwater fisheries;
b. The in-stream habitat and water quality in the Upper Hurunui Catchment;
c. The outstanding trout population in the Upper Hurunui River;
d. Catchment-wide movements by trout in the Hurunui River;
e. The importance of free passage for maintaining the Hurunui River’s outstanding trout population;
f. Water quality limits proposed in the Hurunui Catchment;
g. The Waiau catchment in-stream habitat and fishery values;

h. The importance of fish passage for maintaining the Waiau River's outstanding trout population;

i. Water quality limits in the Waiau Catchment.

2. EXECUTIVE SUMMARY

2.1 New Zealand's headwater trout fisheries are internationally unique and provide one of the most sought after experiences in the trout fishing world. The upper reaches of the Hurunui and Waiau Catchments support classic headwater fisheries, with eight parts of these catchments specifically identified in a national headwater fisheries study.

Hurunui catchment

2.2 The Upper Hurunui River is renowned for its trout fishery. There are a number of factors required to maintain this fishery, including good water quality and habitat, a moderate temperature regime, and unimpeded passage to food resources, thermal regimes, and refuges in other parts of the catchment as required.

2.3 The Upper Hurunui consists of an interconnected set of waterways that provide excellent habitat for brown trout. The smaller streams provide spawning and rearing habitat, while the lakes and main river sections provide good habitat for adult trout. The lakes and some of the smaller streams will act as refuges from floods. Free passage among the different waterbodies is required to maintain the resilience of the system. The rivers are dominated by coarse substrate and have water depths and velocities that are in the preferred range for brown trout. Quantitative habitat assessments in the reach of the Upper Hurunui downstream of Lake Sumner conducted as part of the '100 Rivers' study indicate that habitat availability for adult brown trout and for invertebrates in this reach is among the top 5-10% of rivers in the country and when looking at these two measures combined, the Hurunui was the top ranked river in the country. This ranks it equivalent to or above other rivers recognised as having outstanding trout habitat and/or fisheries in existing Water Conservation Orders such as the Buller, Gowan, Oreti, Motueka, Mangles, Ahuriri, Rangitikei and Mataura.

2.4 Lake outlets, like the Hurunui River below Lake Sumner, are typically characterised by high densities of benthic invertebrates and also support the highest densities of trout in New Zealand. Unmodified lake outlets are a rare feature nationally - only six deep lakes greater than 10 km^2 in the South Island, including Lake Sumner, retain an unmodified outlet. Modification of the Lake Sumner outlet and natural flow regime has the potential to damage some of its relatively rare values.

2.5 Water quality in the Upper Hurunui is generally excellent with low concentrations of nutrients and faecal bacteria and relatively high water clarity. Clarity in the Hurunui River below Lake Sumner is particularly high, which will promote faster fish growth and allows angling opportunities when conditions elsewhere in the catchment and in neighbouring rivers will be unsuitable because of turbid water. Water temperature throughout the Upper Hurunui River is within the ideal range for brown trout growth and always below guidelines for the protection of ecosystem health. Invertebrate communities in the Upper Hurunui are typical of other mountain-fed rivers that drain largely unmodified land.

2.6 In contrast, water quality in the lower Hurunui River at SH1 is relatively poor with high concentrations of nutrients and faecal bacteria which compromise the recreational value of the river. Invertebrate communities in the lower Hurunui River are indicative of sites experiencing mild or moderate pollution. Trend analyses indicate that water quality at this site is deteriorating over time, presumably reflecting the intensification of agriculture in the mid and lower parts of the catchment.

2.7 Trout abundance in the mainstem of the Hurunui River downstream of Lake Sumner is consistently high and equivalent to or above other rivers recognised as having outstanding trout habitat and/or fisheries in existing Water Conservation Orders such as the Buller, Gowan, Oreti, Motueka, Mohaka, Mangles, Maruia, Ahuriri, Rangitikei and Mataura.

2.8 The average length of trout from the North and South Branches of the Hurunui River was higher than in any of the other rivers with 10 or more records included in a national study of headwater trout fisheries. Large trout greater than 2.7 kg (6 lbs) are highly sought after by anglers and make up a substantial proportion of the catch in the North and South Branches of the Hurunui. Trophy-sized trout (>4.5 kg; 10 lbs) are also a feature of these waterways.

2.9 Trout growth modelling and trout otolith microchemistry are useful tools for inferring patterns of fish migration. These two approaches complement each other well with the otolith microchemistry providing information on broad scale movement patterns of trout, while the growth modelling provides information on whether trout need to migrate in order to grow to the size that anglers are used to catching.

2.10 The modelling analysis indicated that only the largest three trout (5% of the sample of angler caught fish) would have required a period of growth in the ocean, or would have needed to have fed significantly on fish, to have attained the size-at-age observed. However, approximately 70% of the angler-caught fish from the South Branch would have had to migrate elsewhere within the freshwater part of the catchment or fed significantly on fish, to have attained the size observed. Maintaining unimpeded passage throughout the catchment appears critical for sustaining the largest trout in the Upper Hurunui Catchment and most of the large trout in the South Branch.

2.11 The otolith microchemistry study provided strong evidence that a large proportion of the trout population in the Upper Hurunui undergo substantial migrations within the Hurunui Catchment. Trout caught in the river appear to originate from a variety of rearing areas emphasising the interconnections between the different waterbodies of the catchment. Otolith microchemistry provided no evidence of trout migration to and from the ocean, although it appears that some large trout are able to take advantage of the abundant food near the river mouth without incorporating a marine signature into their otoliths.

2.12 Any barrier preventing upstream or downstream migration throughout the catchment could have an adverse impact on the brown trout population in the catchment, particularly in the North Branch and South Branch. Fish ladders designed to allow trout and salmon movement past dams in New Zealand have more often than not been failures. Even in the few situations that are considered a success, it is not known what proportion of the potential migrating population is successfully negotiating the fish passes. Therefore, there is substantial risk involved in relying on a fish pass to maintain fish passage.

2.13 Nitrate nitrogen concentrations have increased significantly over the last 20 years at the SH1 sampling site on the lower Hurunui River and concentrations are sometimes above guidelines. During low flow periods, nuisance periphyton growths can occur. Therefore, efforts should be made to maintain or improve the health of the lower Hurunui River.

2.14 I support the approach that is signalled in the proposed Hurunui & Waiau River Regional Plan (**HWRRP**) where a catchment nutrient load limit is proposed to maintain the values identified in the Hurunui Catchment. However, I recommend that these nutrient load limits are applied immediately, rather than further increases being allowed until 2017. I also recommend that numeric periphyton objectives are included in the HWRRP so the purpose of the nutrient load limits is clear.

2.15 Maintaining the 2005-2010 dissolved inorganic nitrogen and dissolved reactive phosphorus concentrations at both SH1 and Mandamus, as proposed in the HWRRP will only ‘possibly’ meet the water quality outcomes relating to nuisance periphyton growth identified in the current NRRP (Norton & Kelly 2010). Therefore, emphasis should be given to **at least** maintaining 2005-2010 concentrations of both nitrogen and phosphorus and ideally reducing these loads, rather than allowing a further increase in nutrient loads.

Waiau catchment

2.16 The Upper Waiau Catchment includes many kilometres of waterways that provide excellent habitat for large trout and support valuable headwater fisheries. The water quality and invertebrate community of the upper Catchment are indicative of a healthy ecosystem.

2.17 The upper Waiau Catchment is particularly notable for the size of the trout that are available to anglers. Large trout, greater than 4.5 kg, are regularly caught and in a national survey of headwater fisheries the average size of trout from the Waiau Catchment was ranked 4^{th} for both length and weight.

2.18 Water temperature patterns throughout the catchment indicate that there is a strong incentive for trout to move downstream during the winter to take advantage of the more benign thermal regime of the lower reaches, but return upstream during summer when the lower reaches can become dangerously warm.

2.19 There is evidence for a downstream decline in water quality in the Waiau River. A nutrient load limit needs to be set for the Waiau Catchment to help control nuisance periphyton accumulations, protect aquatic organisms from nitrate toxicity and ensure that concentrations of nitrogen do not result in water becoming unsuitable for human consumption. Therefore, I support the current Policy 5.4 of the HWRRP which calls for nutrient limits to be set in the Waiau River catchment. However, I recommend that these limits are set as soon as possible. I also recommend that numeric periphyton objectives for the Waiau River are included in the HWRRP so the purpose of the nutrient load limits is clear.

3. HEADWATER FISHERIES

3.1 The combination of large trout, clear water and scenic surroundings that is available in the upper reaches of New Zealand's backcountry rivers provides an experience that is unique internationally. Anglers from New Zealand and overseas rate these 'headwater fisheries' very highly, with some claiming that they offer the most prestigious and sought after experience available in the trout fishing world.

3.2 Challenges associated with managing angling pressure and fish stocks, along with concerns about the effects of hydro-power development and land use change led to a study of these headwater fisheries in the early 1990's (Jellyman & Graynoth 1994).

3.3 The study identified 94 rivers (North Island 20; South Island 74) that support headwater fisheries throughout the fishing season and 43 rivers (North Island 3; South Island 40) that provide headwater fisheries in the early part of the angling season (Jellyman & Graynoth 1994).

3.4 These headwater fisheries are maintained by a regular influx of adult fish from downstream reaches that usually coincides with the spawning migration of fish to the upper reaches. After spawning male trout often take up residence and dominate the catch in headwater fisheries. In contrast, the majority of females migrate back downstream where the presence of abundant forage fish, such as inanga and smelt, along with a more favourable temperature regime allows them to replenish the energy reserves lost during spawning.

3.5 The upper reaches of the Hurunui and Waiau rivers support classic headwater fisheries with the South Branch and North Branch of the Hurunui River, Boyle River, Hope River, Doubtful River, Nina River, Lewis River and the upper Waiau River specifically identified in the national headwater fisheries study (Jellyman & Graynoth 1994).

PART A – HURUNUI RIVER

4. UPPER HURUNUI RIVER INSTREAM HABITAT

4.1 The Hurunui River upstream of the confluence with Surveyors Stream (hereafter referred to as the Upper Hurunui River) is composed of 3 main river sections – the section of the mainstem below Lake Sumner, the South Branch, and the section of the mainstem referred to as "North Branch" above Lake Sumner. There are also numerous tributaries including Seaward River, Jollie Brook and Sisters Stream. These waterways are connected to and drain a series of lakes including Lake Sumner, Lake Mason, Lake Taylor, Lake Sheppard, Loch Katrine, Lake Marion, Lake Mary and the Raupo Lagoon. Apart from the latter two waterbodies, this interconnected set of waterways provide excellent habitat for brown trout.

4.2 The North Branch above Lake Sumner and the South Branch drain the Main Divide and flow over a bed of cobble and gravel. Flows are not affected by upstream lakes to any extent and therefore fluctuate widely. Habitat is dominated by riffles and runs with occasional pools. In the mainstem below Lake Sumner the river has a more stable boulder/cobble/gravel bed with some rock outcrops and has a relatively stable flow regime courtesy of the upstream lake. Below the confluence with the South Branch, the river flows through a narrow valley with several substantial gorges (Maori Gully, Hawarden Gorge). Bedrock, boulders and cobbles dominate the riverbed with a series of rapids and fast runs interspersed with deep pools. Flow fluctuates more widely in this section of the river reflecting the contribution of the South Branch.

4.3 Information on habitat preferences for brown trout indicate that they prefer areas with gravel or coarser substrate, water depths greater than 0.6 m and water velocity between 0.3 - 0.6 m/s (Figure 1; Hayes & Jowett 1994). Similarly, studies on a variety of stream invertebrates that are commonly included in trout diets have shown that these invertebrates generally prefer areas with a substrate dominated by gravels, cobbles, and boulders, water depths between

0.1 - 0.8 m, and water velocities between 0.6 – 0.9 m/s (Figure 1, Waters 1976). Observations during my visits to the Upper Hurunui Catchment indicate that the three main river sections provide a substantial amount of habitat with these hydraulic characteristics and support abundant adult trout populations, although quantitative analysis of habitat availability has only been conducted in the Mainstem below Lake Sumner to which I will refer later.

4.4 The smaller rivers and streams in the upper catchment are also important for the maintenance of the trout population in the Hurunui River as they provide many kilometres of important spawning and juvenile rearing habitat. Adult trout are also present and targeted by anglers in some of these smaller systems (e.g. Seaward River, Jollie Brook, Sisters Stream). In 2007 Fish & Game staff collected juvenile trout using an electric fishing machine from many tributaries around the catchment as part of the otolith microchemistry study that I will describe later. The number of trout collected is indicative of juvenile trout densities and ranged from 20 collected in just a 50 m reach of a tributary of Sisters Stream through to none seen in a 300 m reach of Jollie Brook. Juvenile trout were successfully collected from the Seaward River, South Branch of the Hurunui, North Esk River, Sisters Stream, a tributary of Sisters Stream, Three Mile Stream, North Branch Hurunui River above the lake, and Landslip Stream.

4.5 The interconnections among the waterbodies in the Upper Hurunui Catchment are important for maintaining the resilience of the system. As already mentioned, the smaller streams provide spawning and rearing habitat, while the lakes and main river sections provide good habitat for adult trout. The lakes and some of the smaller streams will act as refuges from floods, while the diversity of spawning habitats makes it unlikely that a flood or other disturbance will affect all recruitment areas. Free passage among the different waterbodies is required to maintain the resilience of the system.

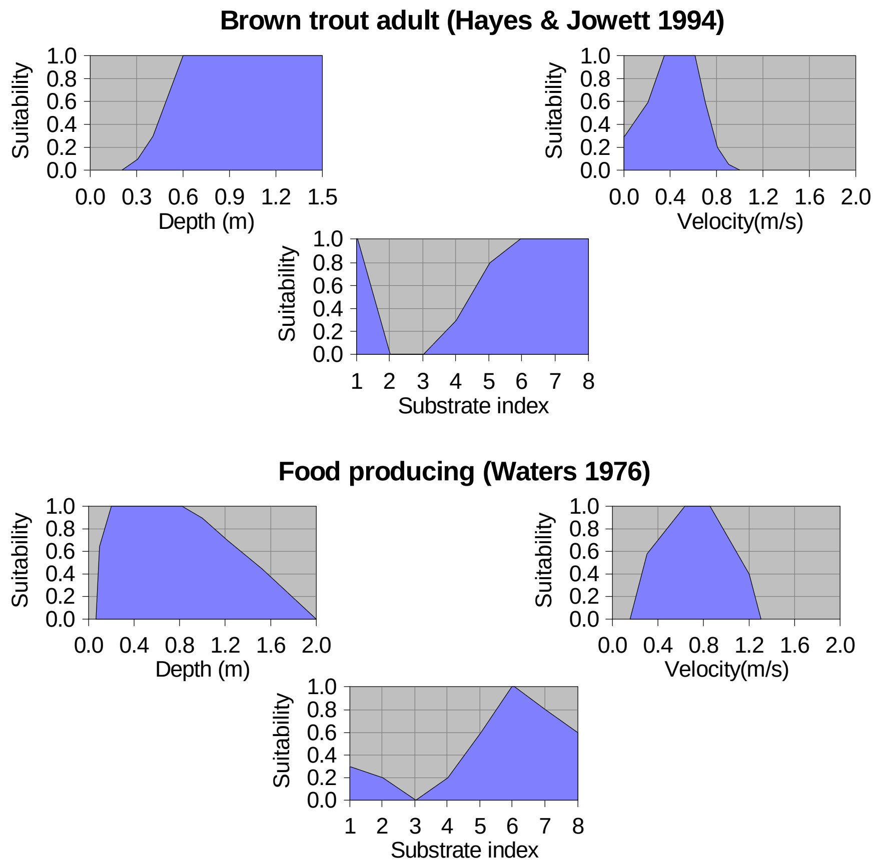

Figure 1. Habitat preference curves for drift feeding adult brown trout (Hayes & Jowett 1994) and trout food production (Waters 1976). Substrate indices are 1 = Vegetation, 2 = Silt, 3 = Sand, 4 = Fine Gravel, 5 = Gravel, 6 = Cobbles, 7 = Boulders, 8 = Bedrock.

The special characteristics of the Hurunui River Mainstem below Lake Sumner

4.6 Lake outlets like the Hurunui River below Lake Sumner are typically characterised by high densities of benthic invertebrates (Wotton 1979; Bronmark & Malmqvist 1984; Harding 1994) and also support the highest densities of trout in New Zealand (Tierney & Jowett 1990).

4.7 The high densities of trout and invertebrates at lake outlets probably are related to the combination of stable flows, abundant food resources, good physical habitat, good water quality, and suitable water temperatures that are typical of these locations. All information that is available indicates that the Hurunui River below Lake Sumner is typical of other lake outlets in these regards and therefore compared to other fisheries generally, has a high density of trout.

4.8 An instream habitat survey of the Hurunui River below Lake Sumner was carried out as part of the '100 Rivers' survey (Jowett 1990). The instream habitat survey involved measuring depth, water velocity and substrate composition at regular intervals across a series of river cross-sections. The water level is measured during the survey and again at several contrasting flows to determine the relationships between water level and flow on each cross section (these are commonly referred to by hydrologists as rating curves). A hydraulic model (RHYHABSIM, Jowett et al. 2008) is then used to predict how water depths and velocities will change with flow across the cross-sections. The model then uses a series of preference curves like those I've just described to relate changes in flow (and thus depth and velocity) with changes in habitat availability for particular species or life stages of a particular species.

4.9 The '100 Rivers' study showed that the percentage of adult trout drift feeding habitat at the mean annual low flow (MALF) and the percentage of food producing habitat at the median flow were important factors affecting trout population abundance in New Zealand rivers (Jowett 1992).

4.10 A comparison of these values among the 63 sites where data was collected placed the Hurunui River as the 6th ranking site (top 10%) in terms of food producing habitat (Figure 2a) and the 3rd (top 5%) best site in terms of adult brown trout drift feeding habitat (Figure 2b). When looking at these two measures combined together, the Hurunui was the top ranked river in the country (Figure 2c). This ranks it equivalent to or above other rivers recognised as having outstanding trout habitat and/or fisheries in existing Water Conservation Orders such as the Buller, Gowan, Oreti, Motueka, Mangles, Ahuriri, Rangitikei and Mataura.

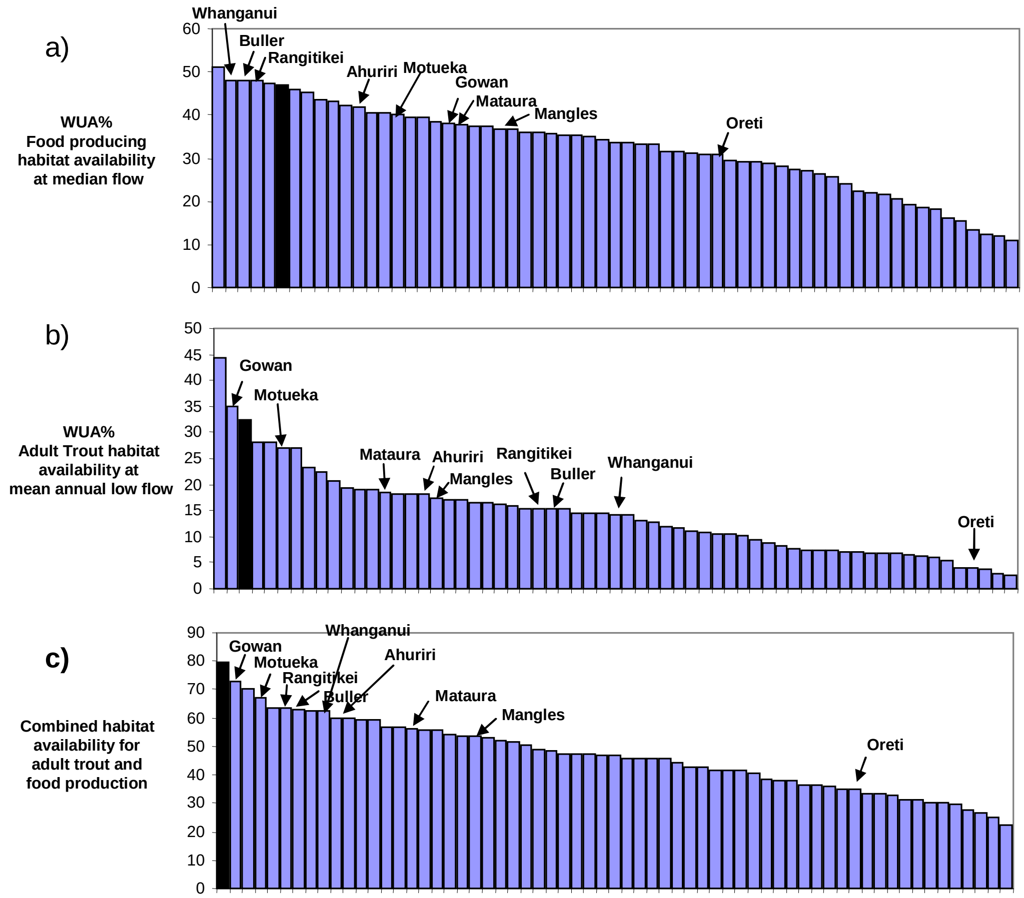

Figure 2. A comparison of habitat availability in the Hurunui River below Lake Sumner with other notable rivers around New Zealand for a) food production, b) adult trout, and c) the combination of food production and adult trout. The Hurunui River is marked as the black bars.

4.11 Filter-feeding invertebrates, such as hydropsychid caddisflies typically dominate lake outlet invertebrate communities and feed on seston (live and dead organic matter suspended in the water column) that is derived from the lake upstream. Seston in lake outflow water generally is a richer food resource for benthic invertebrates than seston in non-lake outlet rivers because it contains a much higher proportion of live organisms. The live organisms common in lake outlet seston include zooplankton (planktonic 'animals') and phytoplankton (planktonic plants). Lakes also act as sediment traps and therefore lake derived seston has a lower proportion of inorganic material than river-derived seston.

4.12 Invertebrate densities typically are highest close to the lake outlet and then decline downstream. This decline has been attributed to gradients in a range of environmental variables, but the strongest evidence explaining their downstream decline is the associated gradient in seston, their food supply (Richardson & Mackay 1991). As the lake-derived seston moves downstream the large lake-derived zooplankton are quickly lost from the water column reducing the average size and food value of seston particles remaining in suspension. The lake-derived seston is also diluted as it travels downstream by increasing quantities of river-derived material that typically has a lower organic content and/or is less digestible (Richardson 1984).

4.13 Unmodified lake outlets are a rare feature nationally and there are currently only six deep lakes greater than 10 km^2 in the South Island, including Lake Sumner, that retain an unmodified outlet (Table 1). Modification of the outlet and natural flow regime has the potential to damage some of the special values associated with lake outlets (Young et al. 2004). Large flow fluctuations will reduce the availability of high quality habitat for fish and invertebrates, while damming associated with water diversion can interrupt or reduce the supply of high quality seston to lake outlet ecosystems. Fish movements to and from the upstream lake will also be affected by flow control structures as I will discuss later in my evidence.

Table 1. Outlet modification of New Zealand's deep lakes greater than 10 km^2 in surface area.

Lake	Size (km^2)	Modified Outlet
Taupo	623	Yes
Te Anau	348	Yes
Wakatipu	289	Yes
Wanaka	180	No
Manapouri	143	Yes
Hawea	138	Yes
Pukaki	99	Yes
Tekapo	87	Yes
Rotorua	80	No
Hauroko	68	No
Waikaremoana	56	Yes
Ohau	54	Yes
Poteriteri	43	No
Tarawera	41	No
Brunner	36	Yes
Rotoiti (NI)	35	No
Coleridge	33	Yes
Monowai	33	Yes
Rotoroa	21	No
McKerrow	18	No
Rotoaira	15	Yes
Kaniere	15	Yes
Sumner	**14**	**No**
Rotoma	11	No
Okataina	11	No

5. HURUNUI RIVER WATER QUALITY

5.1 Water quality is measured monthly in the Hurunui River at the Mandamus flow recorder and SH1 by NIWA as part of the New Zealand National River Water Quality Network. The Mandamus site was chosen to represent a 'baseline' site where there is likely to be little or no influence of diffuse or point source pollution, while the SH1 site is an ‘impact’ site downstream of present and future areas of agriculture, exotic plantation forestry, industry, and urbanisation (Scarsbrook et al. 2000). A summary of the data collected from these two sites over the period from 1989 to 2011 is shown in Figure 3.

5.2 Dissolved oxygen is critical for supporting aquatic life and low concentrations can cause death for fish and other aquatic organisms. Spot measurements of daytime dissolved oxygen were close to 100% saturation at both sites most of the time and never below levels expected to cause problems for ecosystem health (Figure 3). Dissolved oxygen concentrations vary on a daily basis and it is likely that dissolved oxygen concentrations would be lower at dawn than was measured with these spot day time measurements. However, I consider it unlikely that DO concentrations at these sites would drop to levels sufficiently low to cause problems for ecosystem health.

5.3 Nutrients stimulate the growth of algae and other aquatic plants. Algal blooms can degrade aesthetic and recreational values and have potential health implications for humans and animals. High algal densities can also cause large fluctuations in pH, smother habitat for stream invertebrates, cause taste and odour problems for water supplies, and cause problems with low dissolved oxygen when the algal mats mature and decompose. Nutrient concentrations (dissolved reactive phosphorus and nitrate nitrogen) are relatively low at the Mandamus site and always below guidelines for protection of river ecosystem health (Figure 3). In contrast, nutrient levels are higher at the SH1 site (Figure 3) and a trend analysis has indicated that water quality at this site is deteriorating over time (e.g. Figure 4).

5.4 Measurements of pH indicate whether water is acidic, neutral or alkaline. Most aquatic organisms prefer water that is close to neutral pH (7) and may die if the water is highly acidic (<5) or alkaline (>9). The pH at the Mandamus site is within guideline levels, whereas the pH at SH1 sometimes exceeds the upper pH guideline (Figure 3), which is likely to be related to extensive algal blooms, because algal photosynthesis creates daily swings in pH.

5.5 Faecal indicator bacteria (*E. coli*) concentrations are used to indicate the likelihood of faecal contamination of waterways and the potential risk for humans if they drink, swim or contact the water. Faecal indicator bacteria have only been monitored from 2005 and again indicate good water quality in the upper Hurunui at Mandamus with concentrations never exceeding the ‘Alert’ guideline level. In contrast, faecal indicator levels in the lower river at SH1 have exceeded the ‘Action’ guideline level, and are commonly above the ‘Alert’ level (Figure 3).

5.6 Water clarity potentially affects aesthetic and recreational values and also affects the ability of fish to see their food. Poor water clarity is also associated with high concentrations of particles in the water which may clog fish gills and smother habitat when it deposits on the river bed. Water clarity at the Mandamus site is generally higher than further downstream with a median value of 1.5 m and water clarity exceeding 5 m for 5% of the time (Figure 3). Water clarity is strongly inversely related to river flows, with the clearest water during low flow conditions.

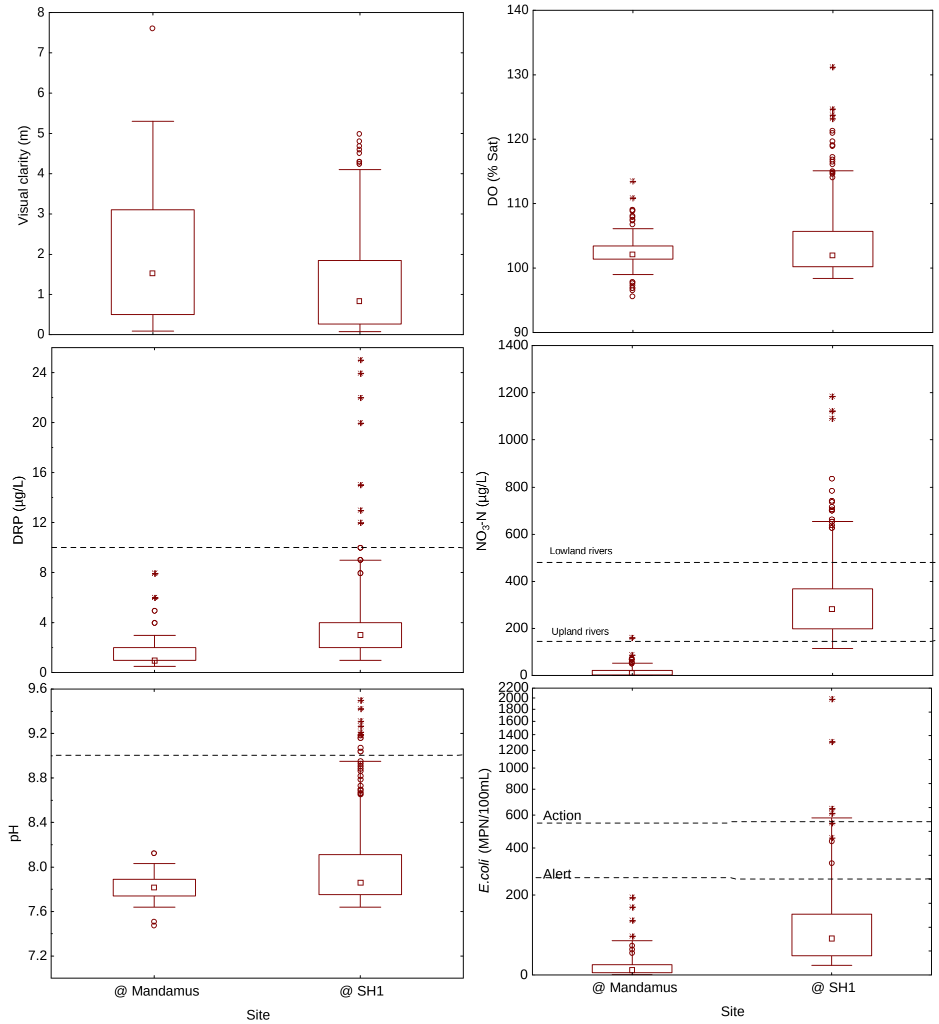

Figure 3. A comparison of water quality data from the Hurunui River at Mandamus and the Hurunui River downstream at SH1. The box plots show median values, while the bottom and top of the boxes represent 25th and 75th percentiles, respectively. The whiskers represent 5th and 95th percentiles. Outliers are shown with stars and circles. Appropriate guidelines for the different parameters are shown with the dotted lines (NO_3-N, DRP, ANZECC & ARMCANZ (2000); pH, CCREM (1987); *E. coli*, MfE & MoH (2003)). Data provided by NIWA.

5.7 This water quality data indicates that the Upper Hurunui Catchment above Mandamus is in a healthy state and provides good quality water that will support a range of aesthetic and recreational values and not restrict the types of aquatic organisms that live there. In contrast, water quality in the Lower Hurunui River is degraded and has deteriorated over the last 20 years, potentially affecting some of the aesthetic, recreational and ecological values of the lower river (Norton & Kelly 2010).

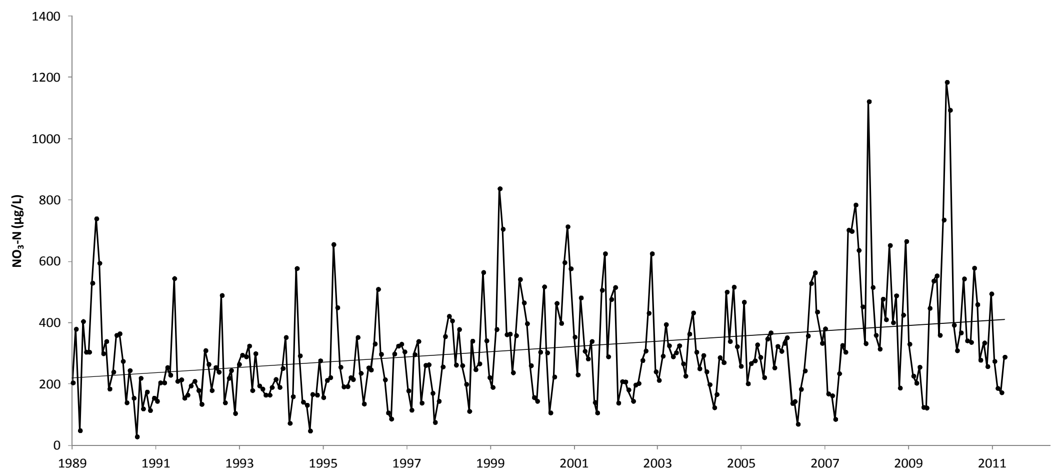

Figure 4. Increase in nitrate nitrogen concentration in the Hurunui River at the SH1 sampling site (Slope of trend 7.3 µg/L/yr, Relative slope 2.6%, $P < 0.001$). Data from NIWA.

5.8 Environment Canterbury has measured water quality at additional sites in the Hurunui Catchment, including the Mainstem upstream of the Jollie Brook confluence, the South Branch upstream of the confluence with the Mainstem, and at SH7 (Hayward 2001). The two upstream sites generally had very high water quality with low concentrations of nutrients and faecal indicator bacteria (Hayward 2001).

5.9 More recent monitoring has also been conducted by Environment Canterbury on several of the tributaries draining the middle of the catchment, including the Waitohi River, Pahau River, St Leonards Drain and Dry Stream. Most of these tributaries have elevated concentrations of DRP, nitrate nitrogen and faecal indicator bacteria and make a major contribution to the contaminant load to the lower Hurunui River (Ausseil 2010).

5.10 Turbidity, which is essentially the opposite of clarity, is considerably lower at the site upstream of Jollie Brook (median 0.64 NTU, which is equivalent to a clarity of about 5 m), than in the South Branch (median 1.4 NTU, equivalent to a clarity of about 2 m) reflecting the trapping of sediment within Lake Sumner resulting in clearer water below Lake Sumner for a larger proportion of the time (Figure 5).

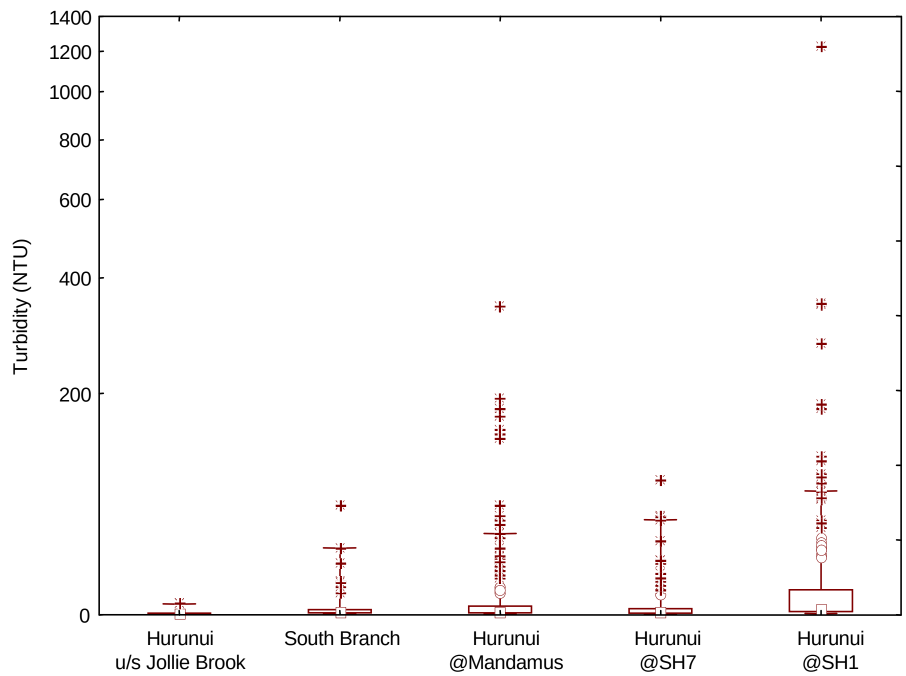

Figure 5. A comparison of turbidity from three Environment Canterbury sites with the NIWA national river water quality network sites. The box plots show median values, while the bottom and top of the boxes represent 25^{th} and 75^{th} percentiles, respectively. The whiskers represent 5^{th} and 95^{th} percentiles. Outliers are shown with stars and circles. Data from Environment Canterbury and NIWA.

5.11 Since trout are visual predators and drift feeding is the predominant foraging behaviour in most rivers (especially those of moderate to steep gradient), lower water clarity is expected to have an adverse effect on trout because it reduces their ability to detect and intercept drifting prey (Gregory & Northcote 1993). The strength of this effect depends on trout size and prey size, but will start to have an effect once water clarity drops below 4 m and becomes more pronounced once clarity drops below 1.4 m (Hayes 2007).

5.12 The high water clarity in the Hurunui River between Lake Sumner and the South Branch confluence will be one factor contributing to the outstanding abundance of trout in this reach. Many anglers also prefer to spot fish before fishing to them, so water clarity is also an important feature contributing to angling values. The consistently high water clarity in the Hurunui below Lake Sumner will allow angling opportunities when conditions elsewhere in the catchment and in neighbouring rivers will be unsuitable because of turbid water.

6. HURUNUI RIVER WATER TEMPERATURE

6.1 Water temperature loggers were deployed at 7 sites throughout the Hurunui River Catchment in 2002 as part of the trout growth study that I will describe later.

6.2 The main concerns with water temperature are the effects of high temperatures on aquatic life. Some species will only tolerate relatively cool water and may become stressed or die if temperatures become too high. For example, laboratory studies have found that brown trout ceased feeding once temperatures climbed above 19 °C and they will die if temperatures climb above 25 °C for a sustained period (Elliott 1994). Trout deaths have been reported in New Zealand rivers when water temperatures have equalled or exceeded 26 °C (Jowett 1997). Similarly, 50 % of *Deleatidum* mayflies will die after 4 days in water at 22.6 °C (Quinn et al. 1994).

6.3 Water temperature in the Upper Hurunui River was in the ideal range for brown trout growth for much of the year and always below guidelines for the protection of ecosystem health (average of daily mean and maximum < 20 °C; Cox & Rutherford 2000). The highest daily mean temperature in the upper Hurunui (17.3 °C) was recorded below the confluence with the South Branch (Figure 6). Even downstream at Balmoral, temperatures were below levels of concern for most of the time, although the daily mean temperature reached 19.5 °C (instantaneous peak of 21.8 °C) in late January (Figure 6).

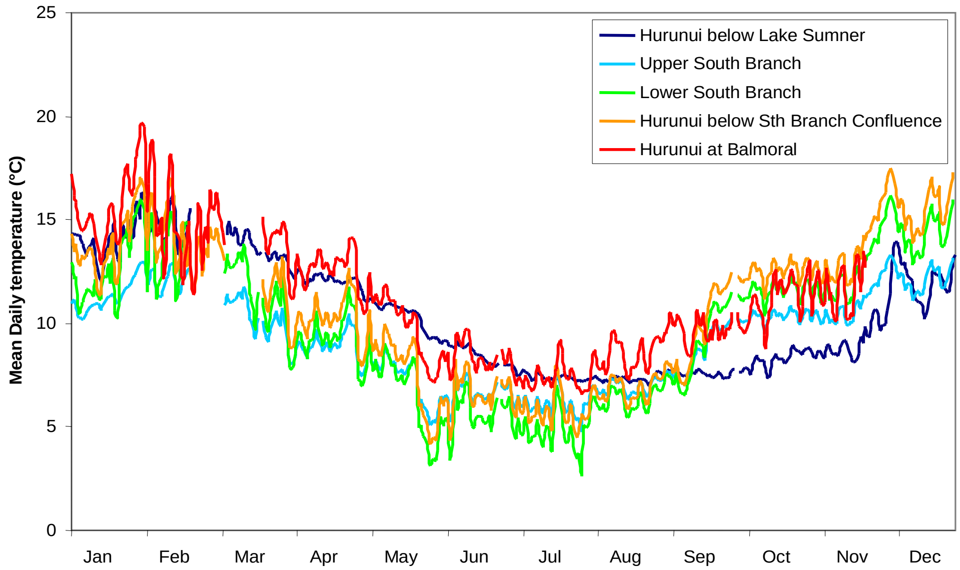

Figure 6. Annual changes in mean daily water temperature at sites in the Upper Hurunui Catchment and also at Balmoral.

7. STREAM INVERTEBRATE COMMUNITIES OF THE HURUNUI RIVER

7.1 As part of the New Zealand National River Water Quality Network, stream invertebrates have been collected annually since 1989 at the same two sites where water quality is measured (Mandamus and SH1). As I've already mentioned, the Mandamus site was chosen to represent a 'baseline' site where there is likely to be little or no influence of diffuse or point source pollution (Scarsbrook et al. 2000).

7.2 The invertebrate community at Mandamus is typical of other mountain-fed rivers that drain largely unmodified land with MCI scores often greater than 120, which is indicative of clean water and a healthy river ecosystem (Stark 1993) (Figure 7). In contrast, the invertebrate community at the SH1 site is indicative of possible mild pollution with MCI scores generally between 100-120 (Figure 7). A similar conclusion is apparent from the QMCI scores with values at Mandamus often greater than 6 (indicating clean water), while values at SH1 are often between 4 and 6 indicating either mild or moderate pollution (Figure 7; Stark 1993).

7.3 The number of types of invertebrates (Invertebrate taxa richness) was higher at the Mandamus site than the SH1 site, while invertebrate densities (often chironomids and snails) were higher at the SH1 site than the Mandamus site (Figure 7). No rare or unusual types of invertebrates were found at either site, although the relatively coarse level of taxonomic identification (mostly Genus level) would make the detection of rare species unlikely. The higher MCI and QMCI scores at the Mandamus site indicate that relatively large species like mayflies, stoneflies and caddisflies dominate the invertebrate fauna. These types of invertebrates provide great trout food and trout prefer them to small organisms like chironomids.

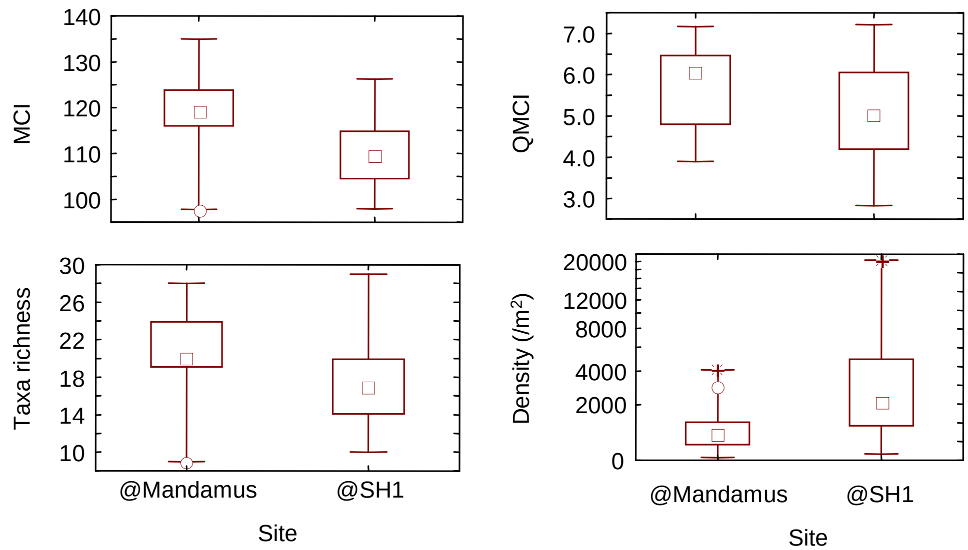

Figure 7. Box and whisker plots of macroinvertebrate community scores (MCI), quantitative MCI (QMCI) scores, taxa richness, and density for the Hurunui River at Mandamus and SH1 from 1990 to 2009. The box plots show median values, while the bottom and top of the boxes represent 25th and 75th percentiles, respectively. The whiskers represent 5th and 95th percentiles. Outliers are shown with stars and circles. Data from NIWA.

8. THE UPPER HURUNUI RIVER'S OUTSTANDING TROUT POPULATION

Density

8.1 Trout fisheries are normally recognised as outstanding based on the abundance of trout and/or the size of the trout available. Both of these features are apparent in the Upper Hurunui Catchment which is relatively unusual.

8.2 Trout abundance in rivers throughout New Zealand was assessed by drift diving as part of the '100 Rivers' study that I mentioned earlier (Teirney & Jowett 1990). Drift dive counts are considered to be underestimates of the total trout population (Teirney & Jowett 1990; Young & Hayes 2001). The degree of underestimation varies from river to river and is probably dependent on the amount of physical cover that is available. Some specific work on the Hurunui River found that only 60% of the trout population are observed by divers (Terry 2002). However, the proportion of trout that are detected by divers appears to remain relatively constant over time within river reaches (Young & Hayes 2001).

8.3 A comparison of the abundance of large (> 40 cm) and medium (20 – 40 cm) brown trout among 158 dive records from the 152 river reaches surveyed during the '100 Rivers' study shows that the mainstem of the Hurunui River just downstream of Lake Sumner had a very high abundance of trout >20 cm (Figure 8). Trout densities during one dive in 1988 (329 per km) were the second highest recorded among New Zealand rivers, while an earlier dive in 1983 found 86 medium and large trout per km (18th highest recorded). This ranks it equivalent to or above other rivers recognised as having outstanding trout habitat and/or fisheries in existing Water Conservation Orders such as the Buller, Gowan, Oreti, Motueka, Mohaka, Mangles, Maruia, Ahuriri, Rangitikei and Mataura.

8.4 Two other reaches of the Hurunui River were also included in the '100 Rivers' survey. The mainstem below Jollie Brook had 22 large and medium trout per km in 1983 (70th highest recorded), while a reach of the Hurunui just below the South Branch confluence had a density of 17 large and medium trout per km in 1983 (80th highest recorded; Figure 8).

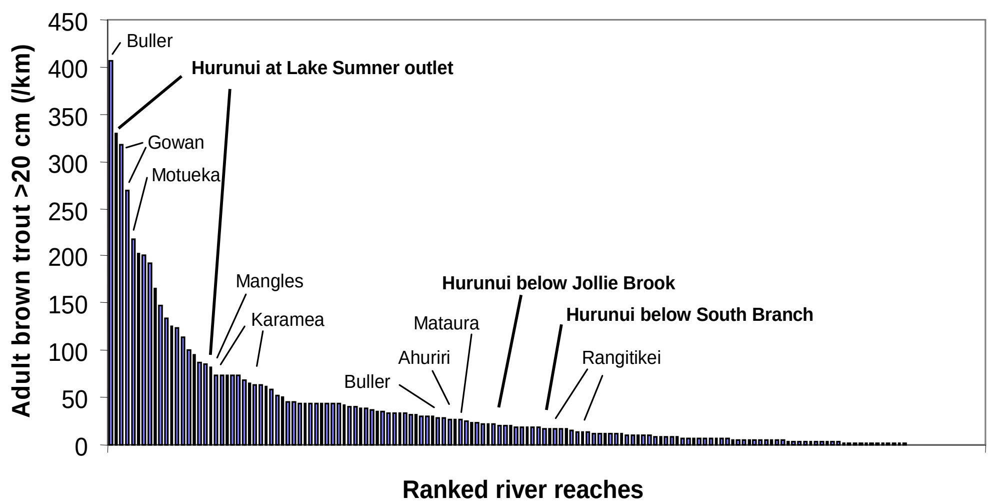

Figure 8. A comparison of the abundance of adult brown trout in 158 river reaches from throughout the country (data from Teirney & Jowett 1990).

8.5 Drift dives have been conducted relatively regularly since the 1980's at two sites in the Upper Hurunui Catchment (Figure 9). Trout counts in both reaches were relatively low in 1982/83 which may reflect the fact that drift diving techniques were in their infancy at that time. Trout counts since 1988 have consistently ranged between 30 and 376 large and medium trout per km in the Lake Sumner Outlet reach, and between 41 and 208 large and medium trout per km in the reach downstream of Jollie Brook (Figure 9).

8.6 Trout abundance was typically higher in the reach near the lake outlet than further downstream at Jollie Brook (Figure 9), which is consistent with my earlier statements regarding the decline in high quality seston with distance downstream of lake outlets (Paragraph 4.12).

8.7 The level of annual variability in trout numbers since 1988 (3.9 to 12.5 times) is consistent with that reported elsewhere (Platts & Nelson 1988; Jowett 1995; Zorn & Nuhfer 2007; Dauwalter et al. 2009).

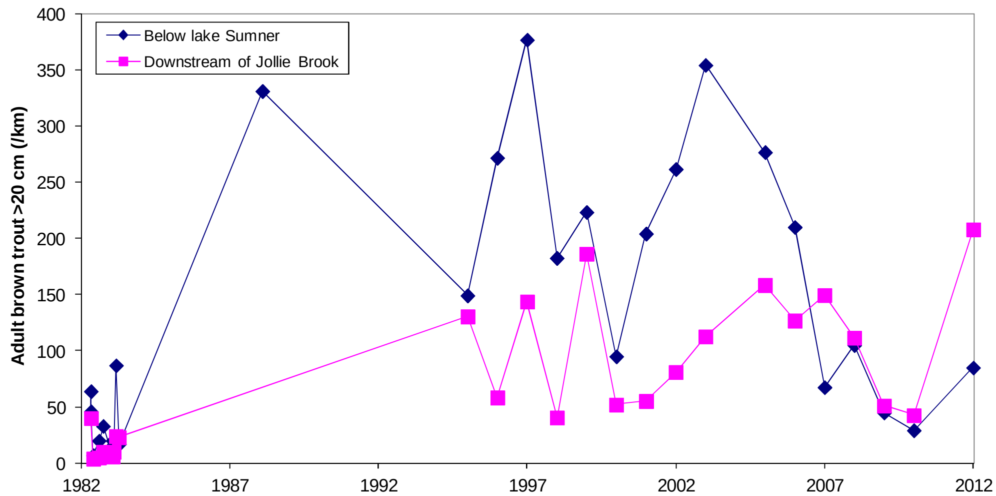

Figure 9. Changes in trout counts over time in the Hurunui River below Lake Sumner and downstream of Jollie Brook.

8.8 Long-term drift dive records for brown trout populations with more than 6 records over a period of >10 years up to 2010 are available for 24 river reaches in New Zealand, including the Hurunui River at the Lake Sumner Outlet and the Hurunui River below Jollie Brook (Figure 10). The Hurunui River at the Lake Sumner Outlet has consistently had the highest trout abundance of any of these rivers. The Hurunui River below Jollie Brook also has consistently high trout abundance compared to the other rivers (5th highest average, Figure 10).

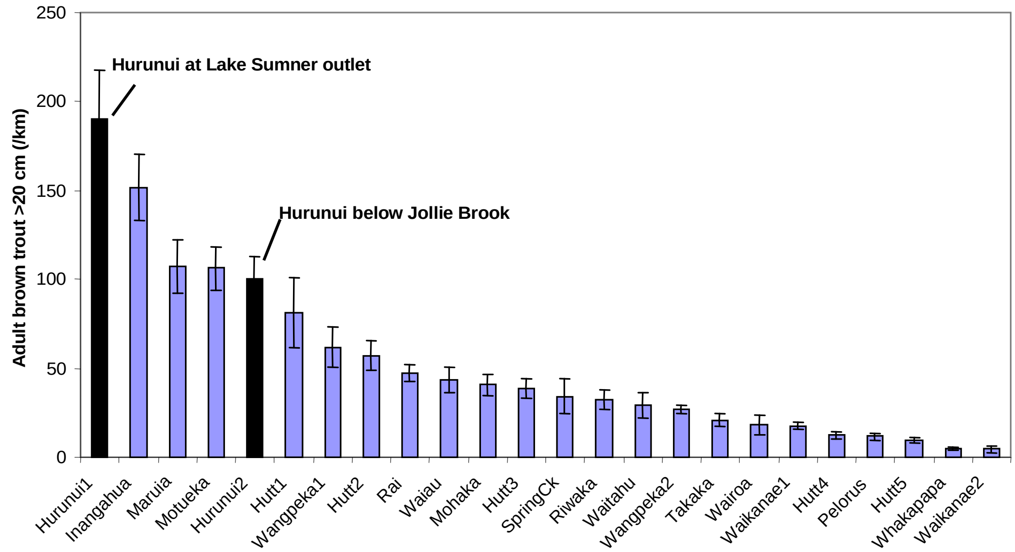

Figure 10. A comparison of brown trout abundance (±SE) in rivers throughout New Zealand where long-term drift dive records are available (Data from Fish & Game New Zealand).

8.9 Trout abundance in the South Branch has been assumed to be low-moderate and typical of most backcountry fisheries. A drift dive carried out in February 2010 along a 1.2 km reach of the South Branch using 4 divers supported this assumption with 9 large trout seen (7.5 adult trout per km). Water clarity was 4.6 m during this dive. Trout counts via helicopter conducted during salmon spawning surveys in May 2009, May 2010 and May 2012 found 84-115 large trout in the reach of the South Branch between the Homestead Stream confluence to the top of the short gorge created by the Stony Stream fan (i.e. 7.2-9.9 trout per km, Tony Hawker pers. comm.)

Size

8.10 Anglers generally consider trout greater than 2.7 kg (6 lb) to be 'large' while trout in excess of 4.5 kg (10 lb) are considered to be 'trophy' fish. A well-conditioned fish of 600 mm is likely to weigh more than 2.7 kg (6 lb).

8.11 Information on trout size in the Hurunui Catchment is available from samples collected by anglers for the growth modelling (45 trout, mentioned further below), otolith microchemistry study (120 trout; also mentioned below), a study of headwater trout fisheries throughout NZ (7 trout, Jellyman & Graynoth 1994), catch records of Tony Hawker for 2009/10 (29 trout), and an expert angler (127 trout, Chappie Chapman). In most cases the capture location was available along with fish length and/or weight.

8.12 The largest recorded trout caught in the Upper Hurunui Catchment was 813 mm long with a weight of 8.2 kg (18 lbs) and caught in February 1992. This record is from the headwater trout study and was recorded as being caught in the Upper Catchment of the Hurunui River. However, not surprisingly the exact capture location was not provided.

8.13 Within the Hurunui Catchment, the largest fish were generally captured in the North Branch above Lake Sumner (mean length 649 mm, mean weight 2.6kg; Figures 11 & 12), followed closely by the South Branch (mean length 625 mm, mean weight 2.5kg; Figures 11 & 12). Trout from the Hurunui River below Lake Sumner covered a broader size distribution and on average were somewhat smaller than in the North Branch and South Branch (mean length 571 mm, mean weight 1.7kg; Figures 11 & 12). Nevertheless, there were still large numbers of large trout caught in the mainstem below Lake Sumner (Figures 11 & 12). Trout caught in the Hurunui between the South Branch confluence and Mandamus (mean length of 459 mm and mean weight 1.3 kg; Figures 11 & 12) were generally smaller than those caught further upstream, but similar to that caught in the middle (Balmoral) and lower reaches (SH1) of the river (mean length 502 mm, mean weight 1.5 kg; Figures 11 & 12). Trout captured from the Hurunui Lakes were generally smaller than from the rivers (Figures 11 & 12).

8.14 The proportion of large (>2.7 kg) trout in the anglers catch from the North Branch above Lake Sumner (33%) and the South Branch (30%) is very high compared to other parts of the catchment (all <7%). The South Branch is also notable for the presence of trophy trout (>4.5 kg). One trophy trout was also captured in the lower reaches near the river mouth.

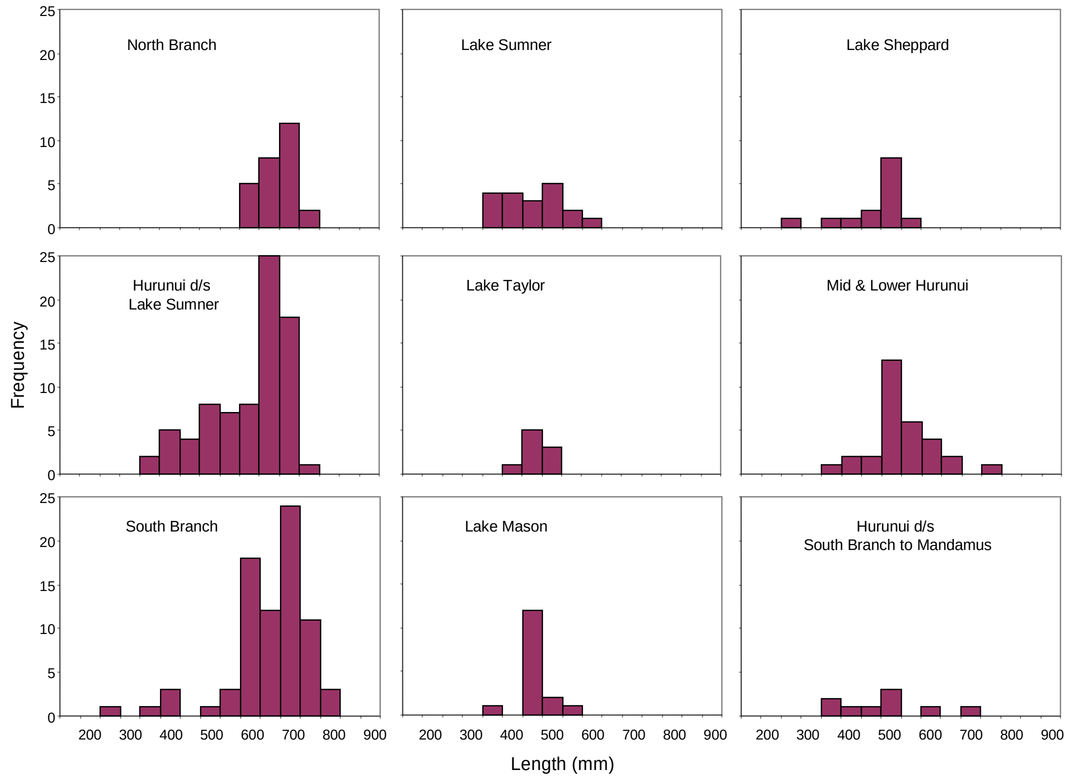

Figure 11. Length distribution of trout caught in different parts of the Hurunui Catchment.

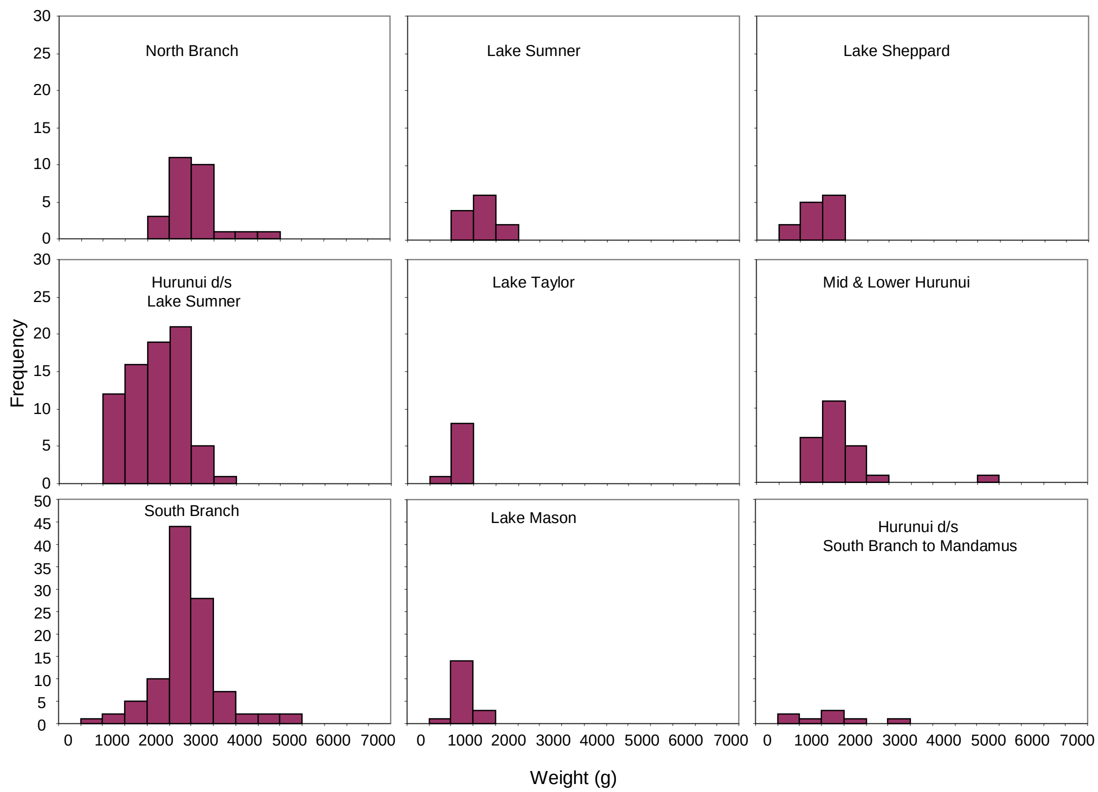

Figure 12. Weight distribution of trout caught in different parts of the Hurunui Catchment.

8.15 The average size of trout from different parts of the Hurunui Catchment can be compared with trout size data collated by Jellyman & Graynoth (1994) in their New Zealand headwater trout fisheries study. The mean length of brown trout recorded in this study was 556 mm with a mean weight of 2.2 kg (Jellyman & Graynoth 1994).

8.16 The average length of trout from the North and South Branches of the Hurunui River was higher than in any of the other rivers with 10 or more records included in the headwater trout study (Figure 13). Average length of trout from the mainstem downstream of Lake Sumner was comparable to many of the other headwater fisheries while the mean length of trout from the lower reaches of the Hurunui was smaller than most headwater fisheries (Figure 13). As I've already mentioned, fish from the Hurunui Lakes are generally smaller than from the rivers.

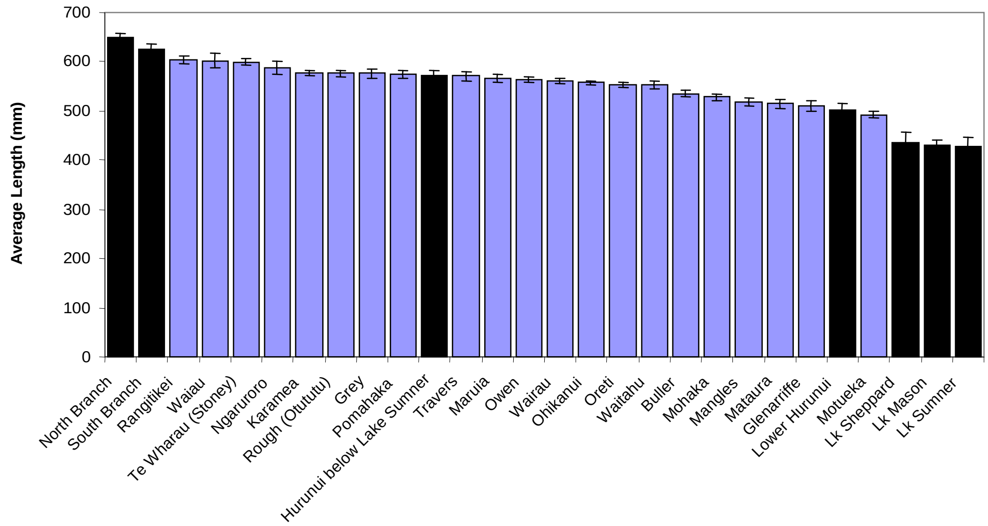

Figure 13. Average length of trout from different parts of the Hurunui Catchment (black bars) compared with data collected from other rivers in the headwater trout fisheries study (data from Dr Don Jellyman).

8.17 The average weight of trout from the North Branch above Lake Sumner and the South Branch of the Hurunui River was also high compared to many other headwater fisheries, while the weight of trout in other parts of the Hurunui Catchment are less remarkable (Figure 14).

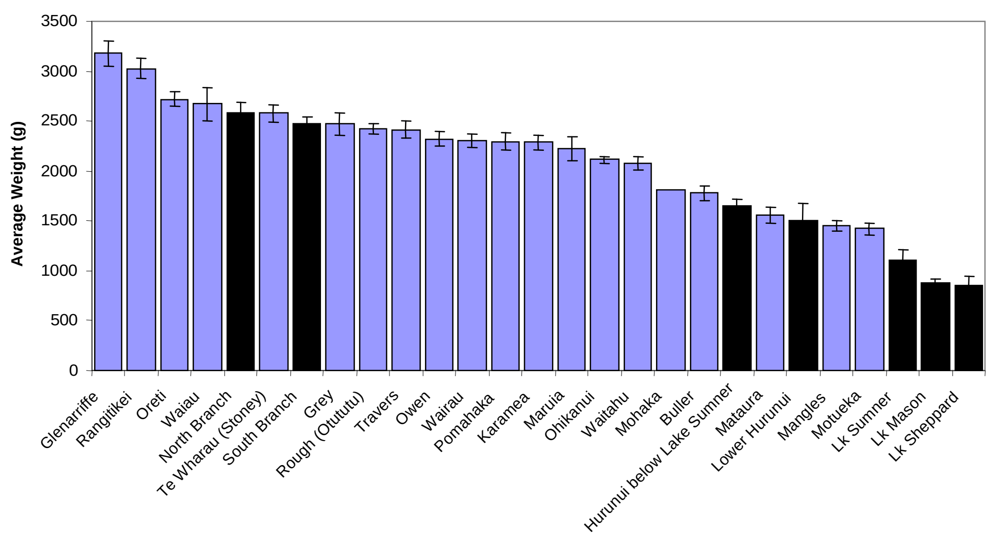

Figure 14. Average weight of trout from different parts of the Hurunui Catchment (black bars) compared with data collected from other rivers in the headwater trout fisheries study (data from Dr Don Jellyman).

8.18 The percentage of large (>2.7 kg) trout in anglers catch from the North Branch and the South Branch compare favourably with other rivers in the headwater trout study that are noted for their large trout (Figure 15). Large trout make up a smaller proportion of the anglers' catch in the Lower Hurunui and in the mainstem below Lake Sumner (Figure 15), although there are still relatively high numbers of large fish caught from this latter reach (Figures 11 & 12). In contrast, the percentage of trophy (>4.5 kg) trout in any sections of the Hurunui River does not appear to be exceptional compared to other rivers examined in the headwater trout study (Figure 15).

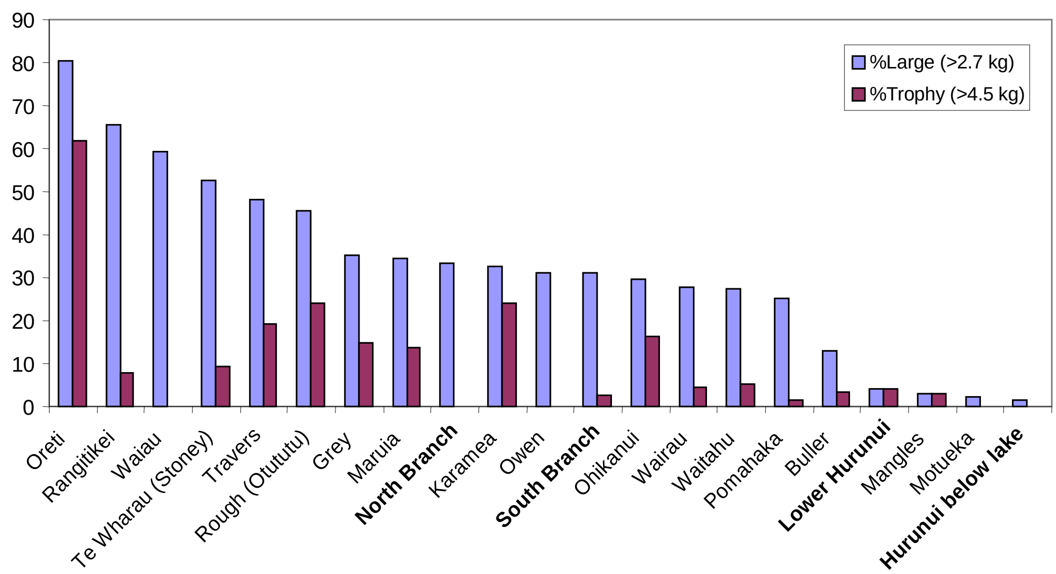

Figure 15. The percentage of large (>2,7 kg) and trophy (>4.5 kg) trout in anglers catch from different parts of the Hurunui Catchment compared with data collected from other rivers in the headwater trout fisheries study (data from Dr Don Jellyman).

8.19 In summary, the large size of fish from the North Branch, South Branch, and Hurunui below Lake Sumner ranks them each equivalent to or above other rivers recognised as having outstanding trout habitat and/or fisheries in existing Water Conservation Orders such as the Rangitikei, Buller, Oreti, Travers, Maruia, Owen, Mohaka, Mangles, Mataura, and Motueka.

8.20 The average weight and length of trout from the North Branch was slightly higher than from the South Branch, but the difference was not statistically significant. Both of these rivers are nationally outstanding in terms of trout size.

9. CATCHMENT-WIDE MOVEMENTS BY TROUT IN THE HURUNUI RIVER

9.1 The annual migration of salmon to their spawning grounds in North America and Europe is a phenomenon that humans have observed and relied on for thousands of years. Despite their similarity to salmon, the migration and movement of trout is less well documented. Brown trout display remarkable variability in life history strategies and are known to be both migratory and resident (Klemetsen et al., 2003). Resident populations do not migrate to another habitat and are often characterised by temporally stable populations consisting of small individuals (Rincon and Lobon-Cervia, 2002). In migratory populations the life history of the fish includes one or more habitat shifts. One migratory strategy is where adult fish live in the sea and migrate to natal rivers for spawning (anadromous fish). The juvenile brown trout then spend between 1-8 years in freshwater, before migrating to the sea, where they grow to large size before returning for spawning (Klemetsen et al., 2003). Other migratory life histories include migrating from a rearing habitat to either a lake (Naslund, 1993), estuary or a larger river (Klemetsen et al., 2003), and using these habitats for feeding before returning to natal rivers to spawn. In some New Zealand rivers, migratory 'sea-run' trout are thought to be common and comprise an important part of the anglers' catch, while in other rivers the amount of movement by trout is largely unknown (Jellyman & Graynoth 1994; Fox et al. 2003).

9.2 Up until recently the majority of scientific studies of trout movement have concluded that most trout show restricted movement and tend to occupy a relatively small home range. However, these studies have relied on recapturing tagged trout and only small proportions of the tagged trout are usually recaptured. Therefore it is impossible to determine whether tagged trout that are not recaptured have died, as is often assumed, been missed by recapture efforts, or moved out of the study reach.

9.3 More recent studies using radiotracking equipment have shown that trout are much more mobile than originally thought (Gowan et al. 1994). In New Zealand, brown trout have been tracked from the tidal reaches of the Waikato River for over 200 km upstream to the headwaters of the Waipa River system and back again (Wilson & Boubee 1996). Brown trout from the Wairau River have been found to move up to 70 km, either upstream or downstream, from their original tagging locations (Strickland et al. 1999). Similarly, some trout in the Motueka Catchment have been found to move up to 40 km downstream from their original tagging locations (Young et al. 2010).

9.4 Other examples of extreme movements by tagged trout have been recorded. A brown trout tagged in the Manganuiateao River was recaptured in the Kaupokonui River 230 km away -- requiring movement down the Manganuiateao and Wanganui rivers, out to sea, and up the Taranaki coast to the Kaupokonui. A brown trout tagged in the Owen River moved 4 km down the Owen River and into the Buller River, then 23 km down the Buller, and finally 46 km up the Matakitaki – a total of at least 73 km from where he was tagged. The most impressive movement recorded by a trout in New Zealand was from a brown trout tagged in the Selwyn River that eventually turned up in the Mataura River, a movement of about 500 km (Young 2002).

9.5 Although these movements are impressive, a more important question relates to whether movement occurs in a substantial proportion of the trout population such that if movement was restricted the stock would decline noticeably.

9.6 Three trout trapping and tagging projects have been conducted in Glenariffe Stream, a spawning tributary of the Rakaia River, over the period from 1965 to 1993 (Fox et al. 2003). A large number (1437) of trout were tagged during these studies and 289 were subsequently recaptured. Approximately 17% of the recaptures occurred 100 km downstream near the mouth of the Rakaia River, or outside the catchment (Fox et al. 2003). The majority of juvenile trout hatched within Glenariffe Stream tended to emigrate downstream to the mainstem of the Rakaia River shortly after emergence, although some juveniles remained with the Glenariffe Stream for more than 1 year (Fox et al. 2003). The authors of this study concluded that the mainstem of the Rakaia River appears to be an important conduit for brown trout moving between spawning grounds and the lower river and therefore obstruction of fish passage between these two areas would have a detrimental effect on the fishery.

9.7 Ideally, movement of fish in rivers is best determined from direct observation by means of trapping, acoustics, and/or tagging like the study I've just described. However, these methods are time demanding and expensive. No direct measurements of trout movement have been conducted in the Hurunui Catchment. While not as definitive, cost effective alternatives are now available that use indirect evidence from which movement is inferred. These are trout growth modelling (Hayes & Quarterman 2003) and trout otolith microchemistry (Bickel & Olley 2009). These two approaches complement each other well with the otolith microchemistry providing information on broad scale movement patterns of trout, while the growth modelling provides information on whether trout need to migrate in order to grow to the size that anglers are used to catching.

Inferring trout movements from growth predictions

9.8 Trout are cold blooded so water temperature influences their metabolism and growth. Hayes (2000) constructed growth models for brown trout based on energetics equations developed by Elliott & Hurley (1999, 2000). These models are driven by water temperature, or by both temperature and food when data on food availability and foraging behaviour of trout are available. Brown trout predominantly eat aquatic invertebrates in rivers, but larger trout will supplement their diet with fish – even switching entirely to fish prey in some circumstances. The growth models allow prediction of growth of brown trout on invertebrate and fish diets. Growth is about three times faster on a fish diet.

9.9 Brown trout have an optimal temperature for growth of 13.9°C when feeding at maximum consumption rates on invertebrates, increasing to 17°C on a fish diet (Elliott & Hurley 1999, 2000). Where trout occur in habitats that are colder or warmer than these temperatures they grow more slowly. Trout grow slowly in cold water headwaters and tributaries, or at high latitude, even when invertebrate food is abundant because the rate at which they can digest their food is severely limited by cold conditions. In these situations migration to warmer habitats downstream, and even to the ocean, at an early age allows trout to escape these temperature limitations to growth. By migrating to the lower reaches of rivers, or to the ocean, trout also have access to abundant fish prey. The abundance of native forage fish, such as bullies, smelt and whitebait, declines with distance upstream because many of these species are diadromous (sea migratory) and most only penetrate a short distance upstream in most rivers.

9.10 The trout growth models are useful for predicting and monitoring environmental impacts to rivers – or the effects of longitudinal temperature gradients down rivers. They can show how growth is affected by change in water temperature and by changes in aquatic invertebrate communities. Inferences can be made about whether trout need to migrate in order to grow to the sizes observed in the anglers catch (Young & Hayes 1999). Such information can be useful for assessing whether disruption to trout migration by dams might result in an isolated upstream population having reduced growth and maximum size.

9.11 Colleagues at Cawthron have used this modelling approach in the Hurunui River to determine the influence of the longitudinal water temperature gradient down the river on trout growth potential (Hayes & Quarterman 2003). Brown trout growth on invertebrate and fish diets was modelled for the Hurunui River using the bioenergetics growth model "Trout_Energetics 2" developed by Hayes (2000 - with recent updates). The model was based on Elliott & Hurley's (1999, 2000) bioenergetics equations for brown trout. Data input to the model was in the form of mean daily water temperature calculated from 15 minute continuously logged data recorded at seven sites in the catchment over the period 7 September 2001 – 14 January 2003 (Figure 16). An annual mean daily temperature record was predicted from sine curve models for each logger site and this was used for growth modelling.

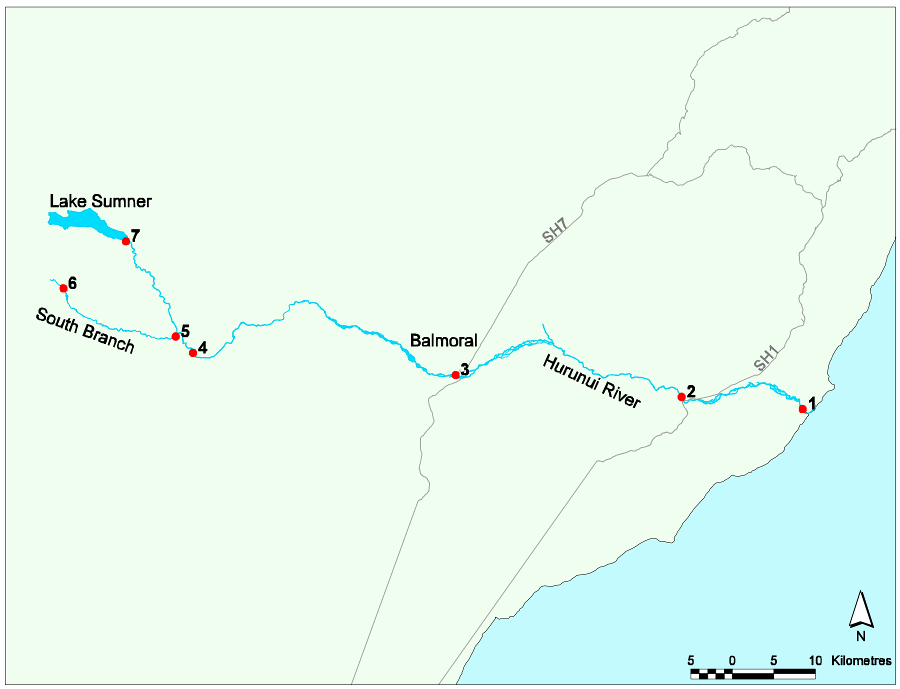

Figure 16. Map of the Hurunui River showing location of the seven water temperature loggers.

9.12 Predicted growth was compared with observed growth, the latter based on size at age data collected from 56 angler-caught fish and from 27 juvenile trout collected by electrofishing. Some of these trout have been collected subsequent to Hayes & Quarterman's initial 2003 analysis. Age was estimated from thin-sectioned otoliths and scales.

9.13 Annual water temperature regimes for the various sites showed the expected pattern of increasing water temperature with distance downstream (Figure 17). The one anomaly was Site 7 at the Lake

Sumner outlet. Here the average annual temperature was higher than at Site 5, in the lower South Branch, and average winter temperature was higher than Sites 4 – 6. This was presumably due to the buffering effect of Lake Sumner.

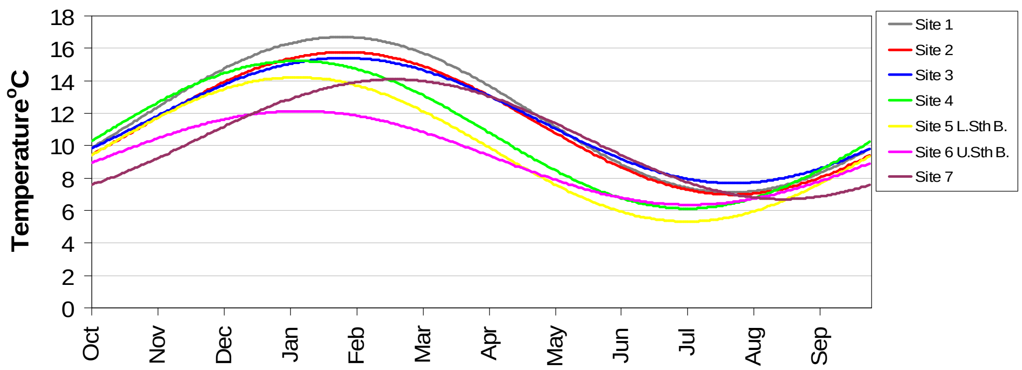

Figure 17. Modelled mean daily temperature records for the seven logger sites (site 5 = lower South Branch, site 6 = upper South Branch).

9.14 Observed size at age data indicated that the majority of trout grow rapidly in the Hurunui River until about age 4 – 5 at which point they cease growing and size levels off at about a mean of 2250 g (640 mm) (Figure 18). The asymptotic growth pattern results largely from energy being diverted into reproduction after maturity (Hayes *et al*. 2000; Hayes 2002a). This typically commences at between ages 3 – 5 in New Zealand rivers (Hayes *et al*. 2000; Fox *et al*. 2003; Hayes 2002a). Increasing costs of foraging on invertebrate drift with increasing size also contributes, but to a lesser extent, to the reduction in growth rate and asymptotic growth pattern after maturity (Hayes *et al*. 2000).

9.15 The majority of mature trout (> 4 years old) in the anglers' sample ranged between 1500 g and 2900 g (520 – 655 mm) with ages between 4 and 11. The remainder followed a faster growth trajectory, being larger (2900 - 5000 g), and young (5 - 8 years old). Three of these fish were caught in the South Branch, 3 in the mainstem, and two in the North Branch (Figure 18). The 5 kg trout was caught at the river mouth. There was no evidence of older very large fish.

9.16 This mix of a fast and slower growth trajectory pattern has also been recorded from other large rivers which have free access for trout through their length and to the ocean including: the Pomahaka, Wairau, and Motueka rivers (Hayes 2002a). The fast growing trout from these rivers are thought to be either sea-running or have grown large in warmer downstream river reaches (Young & Hayes 1999; Hayes 2002a).

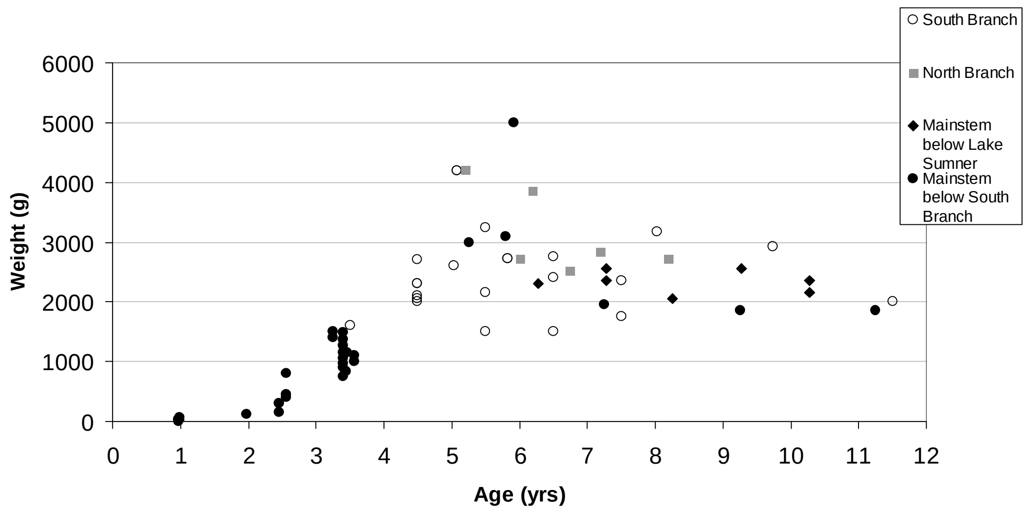

Figure 18. Observed weight at age for trout from different locations within the Hurunui River. Note that this figure contains more data than that presented originally in Hayes & Quarterman (2003).

9.17 The growth predictions from the model based on water temperature for the seven sites are shown in Figures 19 & 20. In the interpretations that follow a key point to understand is that if observed growth substantially exceeds predicted maximum growth (based on temperature) then this suggests trout have grown larger than expected elsewhere (i.e., under better temperature conditions for growth). The type of food (invertebrates versus fish) can also have a role to play but this will be addressed later. Modelling for Figure 19 assumed unlimited invertebrate food and no spawning or foraging costs. The results suggest that water temperatures are sufficient for trout to match or exceed the sizes observed at every site. Predicted growth rate is highest for Site 3 (Balmoral). Growth potential does not continue increasing with distance downstream below Site 3 because summer water temperature more often exceeds the optimum for growth (13.9°C) (Figure 19).

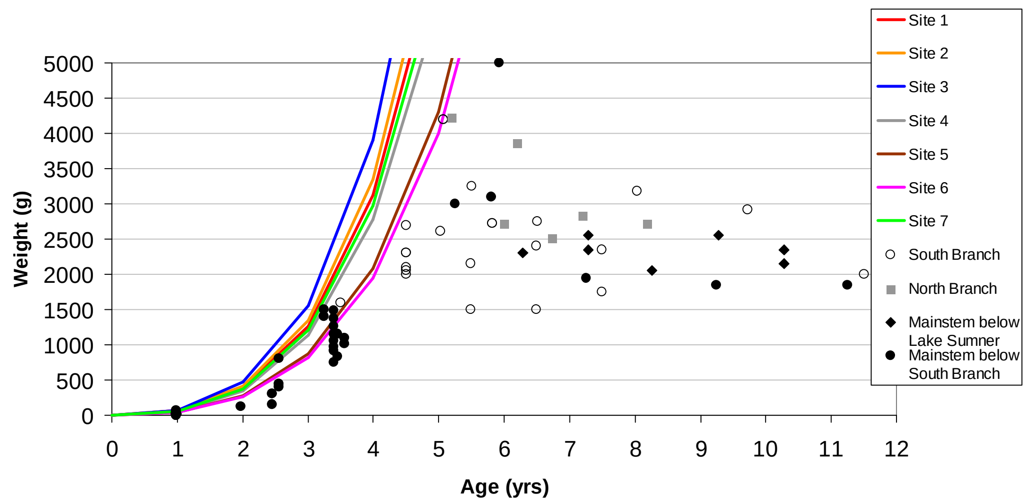

Figure 19. Observed weight at age versus predicted weight at age from growth modelling for trout on an unlimited invertebrate diet and with no reproduction or foraging costs for the seven water temperature logger sites (Site 5 = lower South Branch, Site 6 = upper South Branch). Note that this figure contains more data than that presented originally in Hayes & Quarterman (2003).

9.18 Clearly though, the predictions shown in Figure 19 are unrealistic since reproduction and foraging costs are not included. Foraging and reproduction costs substantially reduce predicted growth rate. Figure 20 shows predicted growth on an unlimited diet where foraging costs and reproduction costs are applied.

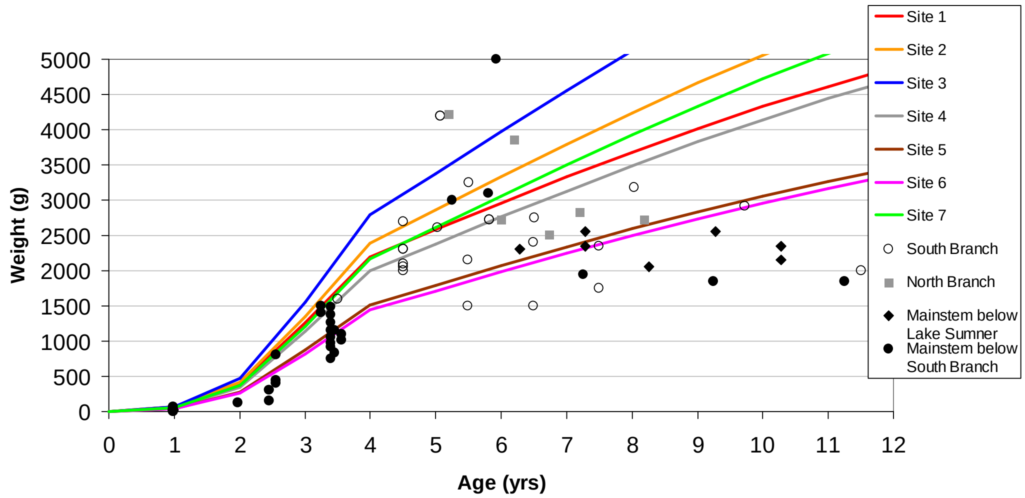

Figure 20. Observed versus predicted weight at age for trout on an unlimited invertebrate diet, and applying reproduction and drift foraging costs in consecutive years after maturity at age 4 (Site 5 = lower South Branch, Site 6 = upper South Branch). Note that this figure contains more data than that presented originally in Hayes & Quarterman (2003).

9.19 The fact that predicted growth for all sites except the South Branch equalled or exceeded observed growth for most fish is evidence that many trout caught in the upper Hurunui mainstem would not have needed to migrate downstream to grow to the size observed (Figure 20). The buffering effect of Lake Sumner on water temperature regime enhances trout growth potential, reducing the need for fish to migrate to achieve observed size.

9.20 By contrast, predicted growth for the South Branch was substantially lower than the observed size of fish between 4 and 8 years of age caught in the South Branch and North Branch above Lake Sumner (Figure 20). The inference from this result is that these fish must have migrated from the Hurunui mainstem below Lake Sumner. Three trout exceeded the fastest predicted growth trajectory possible in freshwater suggesting that they may have been to the ocean and/or supplemented their diet by feeding on fish prey. One of these trout (the 5 kg one) was caught at the river mouth.

9.21 The upper South Branch (site 6) had the coldest summer water temperature regime and this may make it attractive to large trout. When trout are food limited (i.e. not attaining maximum rations) their optimum temperature for food energy conversion and growth declines. Food limitation is more likely in large, than in small, trout because they outgrow their optimal prey size. Large migratory trout, therefore, are most likely to be found in the coldest tributaries or headwaters over summer where they can minimise their metabolic costs.

9.22 In summary, the modelling analysis indicates that only the larger trout (> 3kg) are likely to have migrated from the ocean or lower river, although these fish are highly prized by anglers. Only three trout (5% of the sample of angler caught fish) would have required a period of growth in the ocean, or would have needed to have fed significantly on fish, to have attained the size-at-age observed. However, approximately 70% of the angler-caught fish from the South Branch would have had to migrate elsewhere within the freshwater part of the catchment or fed significantly on fish, to have attained the size observed. The results do not preclude other, smaller, Hurunui trout also making substantial movements within the catchment. Maintaining unimpeded passage throughout the catchment appears critical for sustaining the trophy trout in the entire Upper Hurunui and most of the large trout in the South Branch and probably the North Branch too, although we do not have a temperature record from there.

9.23 A key assumption underlying the interpretation of the growth modelling data is that migration to better growing conditions is responsible for observed growth exceeding predicted growth (Hayes & Quarterman 2003). Alternative explanations are 1/ the growth model underestimates growth of some trout, 2/ the fish that have grown faster than expected based on an invertebrate diet were piscivorous (fish eaters). The authors of the study considered the first alternative to be unlikely for the following reasons. The growth model, or variants of it, have accurately predicted growth in the majority of applications overseas (Elliott 1994) and it has performed well in most applications on New Zealand rivers and lakes to date. Its predictions have either matched or exceeded observed growth in all applications except one, the Nevis River (Hayes *et al*. 2000; Hayes 2002b; Young *et al*. 2000). All of the applications in which observed growth exceeded predicted growth have been on rivers which have had free access to the ocean, i.e., in which migration is possible (Hayes 2002a; Young 2000; Young & Hayes 1999).

9.24 The second alternative, that the very large fish in the Hurunui sample were piscivorous, is possible but migration is likely to accompany this behaviour. The greatest densities of prey fish occur in the ocean and, in New Zealand rivers near the ocean owing to the fact that many native fishes are diadromous. Prey fish densities reduce fairly rapidly with distance inland. Drifting invertebrates are the most common prey available in large trout habitat in the headwaters of New Zealand rivers. South Island upland lakes (e.g. Lake Sumner) offer greater opportunities for piscivory because they can support seasonally abundant populations of upland bullies and koaro. That said the model has under-predicted the size of a few large resident trout in the Nevis River, Central Otago, where a downstream falls apparently prevents upstream migration. A possible explanation is that these fish supplement their diet with fish – probably resident galaxiids which are known to occur in the Nevis catchment.

9.25 Hayes & Quarterman's (2003) analysis indicated that trout which migrate to the ocean are probably uncommon in the upper Hurunui (5% of angler-caught fish). Nevertheless these fish grow to trophy size (> 3 kg) and are highly sought after by anglers. Other large trout from the South Branch (and probably North Branch too) appear to require access to the mainstem downstream of Lake Sumner to grow to observed sizes. Free passage to downstream reaches and the ocean is necessary to sustain opportunities to catch these large fish. It is unlikely that these large trout are resident and grow large by preying on other fish.

Inferring trout movements from otolith microchemistry

9.26 Another approach to inferring the importance of migration for trout is to analyse the microchemistry of their otoliths. Otoliths are small calcium carbonate structures found within the inner ear of bony fishes that grow continuously throughout the entire life of the fish. Once material is deposited in the otolith it is not remobilised (Campana and Thorrold, 2001). Material at the core of the otolith is formed when the fish begins to grow in the egg, and the outermost layer is material that has been deposited most recently. Although primarily made up of calcium carbonate, some trace elements are incorporated into the crystal lattice of the otolith as a substitute for calcium. Different environments have different levels of trace elements as a result of varying basement geology or land use. If a fish moves between these different chemical environments, the trace element composition of respective layers within the otolith will change accordingly, thus reflecting movement between environments. Therefore, by analyzing levels of trace elements across layers in the matrix of the otolith, we can infer patterns of movement if the trace element signature of the different habitats in which a fish may have been resident can be identified (Campana and Thorrold, 2001; Wells et al., 2003).

9.27 A study of the microchemistry of otoliths from trout collected in the Hurunui Catchment has recently been completed (Bickel & Olley 2009). This study involved three main approaches – firstly trace element signatures from the edge to the core of adult trout otoliths were analysed to determine if any trout collected from the Hurunui River had spent time in the ocean. Secondly, variability in trace element signatures across individual otoliths was used to determine the likely amount of movement within the river system by individual trout. An additional analysis compared the trace element signatures near the core of otoliths from adult trout, which would have been deposited when they were juveniles, with trace element signatures from juvenile trout collected from various potential rearing areas. This final analysis gives an indication of the likely importance of different rearing areas within the catchment.

9.28 Trout were collected from the locations shown in Figure 21. The elemental signature of brown trout otoliths was measured using a spectrometry technique known as laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS). Here, the otolith is cleaned, and mounted onto a slide which is placed in a sealed, purged chamber. A laser beam is then fired at the otolith. As the otolith material is ablated off, the ejecta are transferred via a carrier gas into a mass spectrometer which then determines the trace elemental composition of the ablated material.

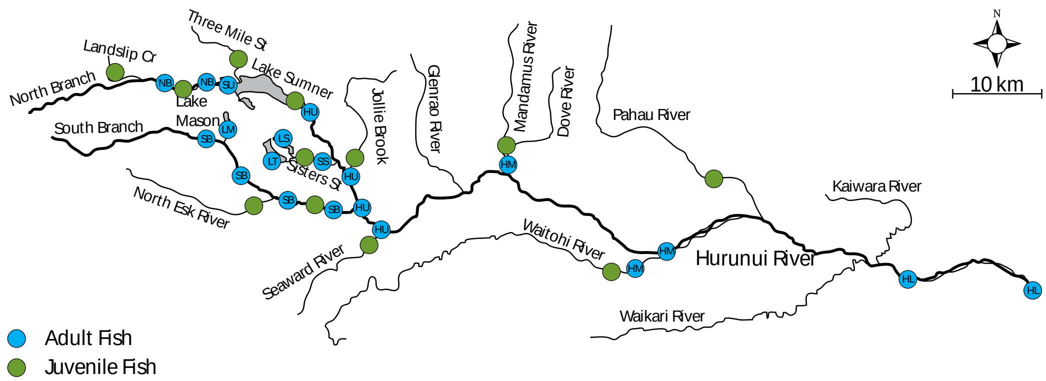

Figure 21. Map showing the Hurunui River and locations (blue circles) where adult brown trout were sampled. The major tributaries where juvenile brown trout were collected are shown with green circles.

9.29 To determine if there was a marine signature in any otoliths, scans from the edge to the core were completed to produce a trace element life history transect for each trout. The life history transects were then inspected for any areas with relatively high concentrations of strontium and low concentrations of barium which are indicative of estuarine/marine life history stages (Arai et al., 2002). A reference sample from a brown trout collected from the Oreti River estuary was used to develop criteria to distinguish between freshwater and estuarine/marine signatures. The fish collected from the Oreti estuary demonstrated the high levels of strontium and simultaneous low levels of barium that can be expected in fish entering a marine influenced estuarine environment for a sustained period (Figure 22). A Sr:Ca ratio > 2 was considered to be indicative of estuarine conditions (Bickel & Olley 2009).

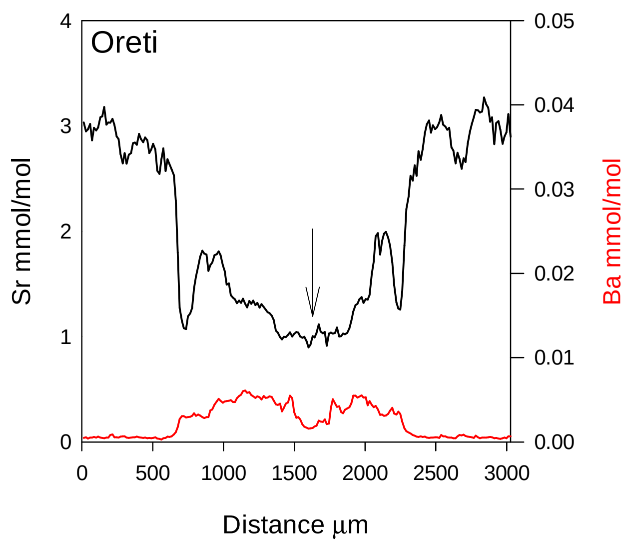

Figure 22. Concentrations of strontium and barium (measured as element:calcium ratios) in an otolith from a trout collected in the Oreti Estuary as an example of an estuarine reared fish; the Sr:Ca levels exceed 2 for much of the life history and there is a simultaneous drop in Ba:Ca ratios. The graph represents a full life-history transect running from opposite edges to the core of the otolith. The arrow indicates the location of the core of the otolith.

9.30 Additionally, analysis of the Sr and Ba transects allowed the degree of migratory or resident behaviour of individual fish to be determined (Bickel & Olley 2009). Changes in Sr or Ba levels along the life history transect, beyond background noise, were assumed to reflect a movement into a habitat with a different trace element composition. Fish were grouped into resident individuals showing stable Sr and Ba levels throughout their life, and migratory individuals showing varying Sr and Ba levels with at least one habitat shift. Fish that could not be classified (e.g. high background noise) were denoted as indeterminate. As sections in a river catchment do not always differ in Sr or Ba concentrations (similar basement geology), this method may underestimate the frequency of migratory behaviour in some individuals.

9.31 Life history transects from 113 adult trout were examined and included samples from throughout the catchment including Lakes Sumner, Taylor, Sheppard, and Mason (Table 2).

9.32 None of the adult trout collected from the Hurunui Catchment showed elevated Sr:Ca ratios (Sr:Ca > 2) and a simultaneous drop in Ba:Ca levels that are indicative of time spent in an estuarine/marine environment (Bickel & Olley 2009). One adult fish collected in the lower river (H21) showed elevated Sr levels in its early life (close to the core), however, there was no corresponding drop in Ba levels (Figure 23). Therefore, the high Sr levels in this individual were not considered to be the result of an estuarine life stage (Bickel & Olley 2009). Surprisingly, the 5 kg trout caught at the Hurunui River mouth that exceeded the growth modelling predictions (H19) also did not display elevated Sr:Ca levels (Figure 23). Perhaps this fish was able to take advantage of abundant forage fish resources near the river mouth without actually spending much time in Sr-rich salt water.

9.33 There were pronounced changes in Sr levels during the life history of most (75) of the sampled fish (e.g. H19, Figure 23) suggesting movement between freshwater habitats within the Hurunui catchment that differ in Sr levels (Table 2). Other fish (24) showed relatively stable Sr levels throughout their life (e.g. H20, Fig. 20) indicating limited migratory behaviour (i.e. resident fish). Life history transects from thirteen fish had higher levels of background noise and were classified as indeterminate (Table 2; Bickel & Olley 2009).

Table 2. Overview of the sample effort of adult fish analysed from different sections of the Hurunui catchment and the classification of fish into resident, migratory or indeterminate groups.

Habitat	N	Resident	Migratory	Indeterminate
Lower Hurunui	15	2 (13%)	10 (63%)	3 (19%)
Mid Hurunui (Balmoral)	8	2 (25%)	5 (63%)	1 (13%)
Hurunui above Seaward	13	1 (8%)	10 (77%)	2 (15%)
North Branch	6	4 (67%)	2 (33%)	
South Branch	21	7 (33%)	13 (62%)	1 (5%)
Lake Sumner	11	1 (9%)	9 (82%)	1 (9%)
Lake Mason	7		4 (57%)	3 (43%)
Lake Sheppard	17	1 (6%)	15 (88%)	1 (6%)
Lake Taylor	11	6 (55%)	5 (45%)	
Sisters Stream	3		2 (67%)	1 (33%)
Total	112	24 (21%)	75 (67%)	13 (12%)

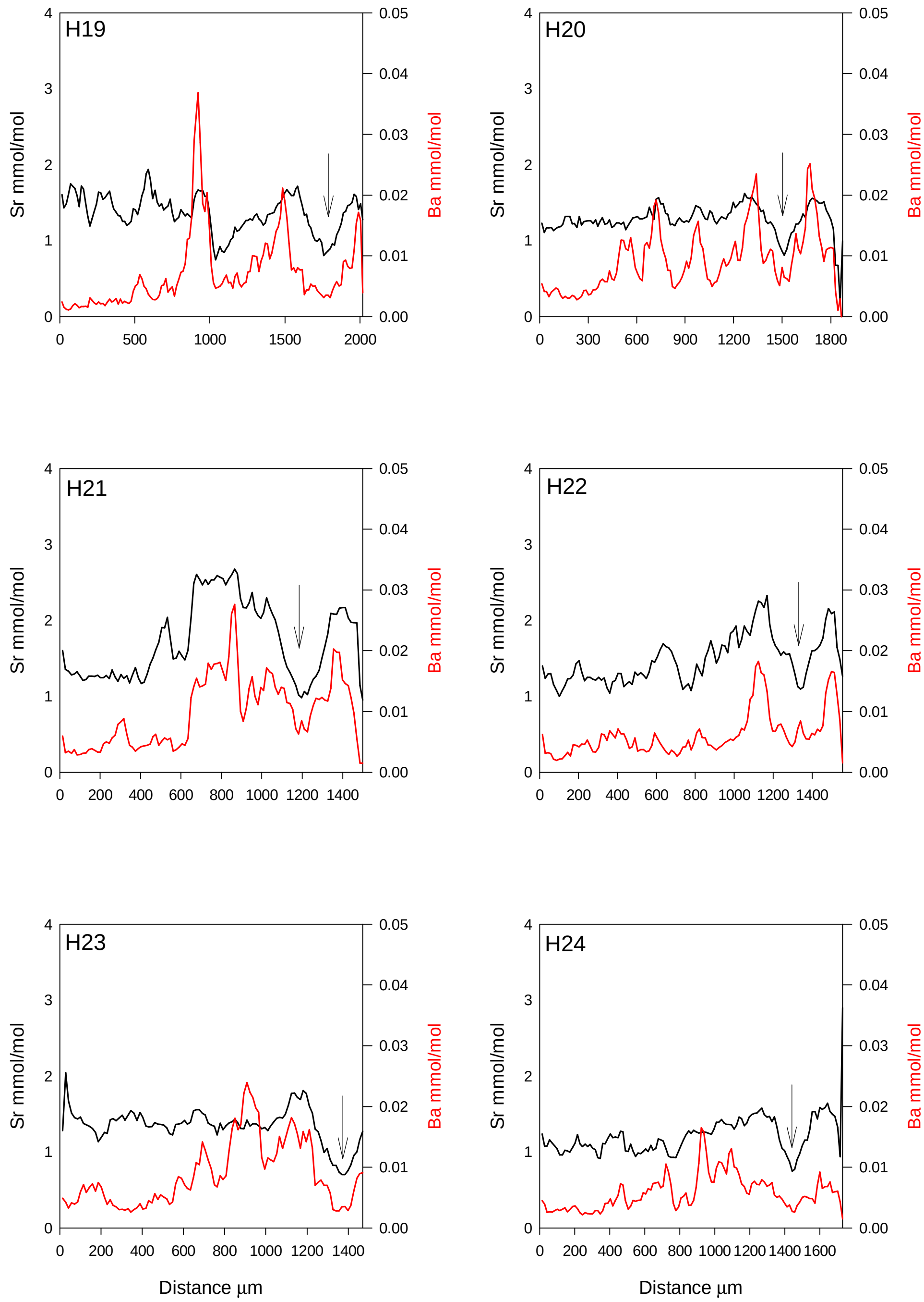

Figure 23. Concentrations of strontium and barium (measured as element:calcium ratios) in otoliths from six trout collected from the lower Hurunui River. Each graph represents a full life-history transect running from edge to the core of the otoliths. The arrows indicate the location of the core of the otoliths.

9.34 The majority of fish collected from the Hurunui Catchment show life history transects that indicate migratory behaviour within the freshwater part of the catchment. Many of these trout move multiple times during their life. Fish collected from the North Branch were predominantly resident, while fish from the South Branch had more variable life history transects (Table 2). A large number of the fish sampled from the Hurunui Lakes also showed signs of migratory behaviour. Brown trout reproduce mainly in running waters, therefore, fish resident in lakes must recruit from elsewhere in the system. Analysis of the Sr/Ba transects from lake fish generally supports this with a single habitat shift presumably from recruitment/juvenile rearing habitat to the adult (lake) habitat (Bickel & Olley 2009).

9.35 Trace element signatures from juvenile trout otoliths collected from potential rearing habitats showed relatively good separation among habitats. Overall, 65% of the fish were classified correctly into the area where they were sampled (Bickel & Olley 2009). The most likely origin for trout caught in the river was determined and included, in order of importance, the Hurunui mainstem, Lake Sheppard, South Branch, Waitohi River, Sisters Stream, Mandamus River, Lake Sumner, Lake Mason, Pahau River, and Landslip Creek (Bickel & Olley 2009). Trout caught in the South and North Branches (and the Hurunui Lakes) appear to depend on recruitment from elsewhere in the system, particularly the Hurunui main stem. This shows that the trout populations in the entire Hurunui catchment are linked by movement of adult fish within the freshwater part and by recruitment of juveniles from often distant parts within the catchment (Bickel & Olley 2009).

9.36 In summary, the otolith microchemistry study provided strong evidence that a substantial proportion of the trout population in the Hurunui River move throughout the river during their lifetime. Trout caught in the river appear to originate from a variety of rearing areas emphasising the interconnections between the different waterbodies of the catchment. The otolith microchemistry study provided no evidence of trout migration to and from the ocean, although it appears that at least some fish take advantage of the abundant food resources at the river mouth without incorporating high levels of strontium in their otoliths.

10. THE IMPORTANCE OF FREE PASSAGE FOR MAINTAINING THE HURUNUI RIVER'S OUTSTANDING TROUT POPULATION

10.1 As I have mentioned, the Hurunui River is renowned for its trout fishery with a combination of high trout densities and an abundance of large trout. There are several factors that are required to maintain this fishery, including good water quality and habitat, a moderate temperature regime, and unimpeded passage to food resources, thermal regimes, and refuges in other parts of the catchment as required.

10.2 The evidence that I have presented indicates that brown trout undergo substantial migrations within the Hurunui Catchment. Any barrier preventing upstream or downstream migration could have an adverse impact on the brown trout population in the catchment, particularly in the North and South Branches which probably are dependent on the influx of large trout that have grown fast in the more benign thermal regime downstream of Lake Sumner or in the Lower Hurunui River where access to forage fish is more likely.

10.3 The construction of a dam or weir on the Upper Hurunui River is very likely to restrict passage for trout throughout the catchment, and salmon. For example, dams built on the Clutha and Waitaki rivers had devastating effects on the Chinook salmon populations in these rivers with accounts of large numbers of upstream migrants subsequently congregating below the dams for the first few years after construction was completed. Data on the salmon runs in these rivers prior to damming is very limited, but are thought to have declined from runs of 50,000-100,000 down to levels between 6,000-36,000 currently in the Waitaki River, and to between a few hundred and a few thousand fish post-Roxburgh Dam in the Clutha River (McDowall 1990).

10.4 Fish passes have been designed to enable passage for salmon and sea trout past dams and can be classified into three main types – pool and weir fish passes, fish locks, and fish elevators (Clay 1995).

10.5 Pool and weir fish passes consist of a series of pools in steps leading from the river below the dam to the reservoir upstream. Water flows from pool to pool, either over the weir, through a vertical slot in the weir, or through submerged holes/orifices in the weir. Fish are able to burst swim through the slot/hole, or jump, from pool to pool. Each pool provides a resting opportunity. This design is not considered appropriate for dams greater than 30-35 m in height (Jowett 1987).

10.6 Fish locks are a device that raises fish over dams by attracting fish into a chamber at the bottom of the dam, closing the entrance to the chamber and filling it with water until the water level reaches the reservoir level enabling fish to swim into the reservoir above the dam. After a certain period the chamber is emptied and the process is repeated. Fish locks have been built on dams of up to 60 m in height and are considered to operate successfully maintaining runs of salmon and trout (Clay 1995). Fish locks are not considered suitable for large runs of fish, which has deterred their use in western North America. There have also been problems reported with clearing the fish from the chamber once it is full, resulting in fish being washed back downstream and injured when the chamber is emptied.

10.7 Fish elevators take a variety of forms but all involve the collection of fish at the bottom of a dam, followed by mechanical transport of the fish upstream of the dam. This can be conducted via cable and bucket systems associated with the dam, or more independent trap and transfer systems involving trucking fish upstream. Fish elevators are used extensively on rivers in North America, France and Russia and can cope with large numbers of fish (Clay 1995). However, fish can be stressed/injured during capture, transport and release and ongoing costs associated with this method are very high.

10.8 Fish pass design has traditionally concentrated on facilitating upstream passage past dams. However, facilitating downstream passage of juvenile trout and salmon (and adult eels) is at least as big a problem. Downstream movement of juvenile salmonids is delayed due to the lack of current in reservoirs and significant mortality can occur if fish pass through turbines or over spillways. Downstream passage of juvenile trout and salmon has been reported with some fish locks (Clay 1995), while trap and transfer systems are used to transport juvenile salmon downstream past dams on several North American rivers.

10.9 Fish passes designed to allow trout and salmon movement past dams have been incorporated into only 15% of the major diversion structures and weirs throughout New Zealand. Almost all of the fish passes that have been constructed have been failures (e.g. Waitaki, Monowai, Ohau, Manganui). The only confirmed exception to this that I am aware of is the fish pass on the Manapouri Lake Control structure (otherwise known as the Mararoa Weir), which was retro-fitted to the structure in 1998 after the previous fish pass was considered a failure (Figure 24). The fish pass is a vertical slot pool and weir fish pass with three entrance gates at the bottom of the weir. The height of the Mararoa Weir is dependent on the level of Lake Manapouri and can range from 4.3 m under normal lake levels up to 6.2 m (Zane Moss, Fish & Game NZ – Southland Region, personal communication).

Figure 24. The fish pass on the Mararoa Weir in Southland where trout have been trapped negotiating the pass.

10.10 In 1999/2000 Fish & Game NZ, Southland region undertook a trapping and tagging programme to assess the effectiveness of the pass. From April 1999 to June 2000 1645 trout (889 brown and 756 rainbow) were caught in a trap at the upper end of the fish pass. Movement was most pronounced during May for brown trout and December for rainbow trout. There were also indications that increased flows stimulated fish movement, and movement was greatest during periods when the moon was close to New Moon phase, rather than a full moon phase (Maurice Rodway, Fish & Game NZ – Southland Region, personal communication).

10.11 Fish & Game also conducted a radiotagging study from March to November 2001 to determine the behaviour of trout as they approached the Weir, success of passage, and their subsequent movements upstream. Fifty seven brown trout were implanted with radiotransmitters as part of that study. Fifty five of these trout were initially caught in a trap within the fish pass before being tagged and therefore had some knowledge of how to locate and ascend the pass. Forty four trout were released downstream of the weir and 14 of these subsequently passed through the fish pass and were located in the Mararoa and Whitestone rivers upstream. Some of these fish spent a considerable amount of time (up to 46 days) below the weir before ascending the fish pass. Thirteen trout were recorded immediately downstream of the Weir but did not ascend the pass, suggesting that they had difficulty locating the pass, were not seeking passage at the time, or the trapping/handling/tagging procedure stressed the fish and impaired their migratory behaviour. These trout spent 1 to 25 days downstream of the Weir (Maurice Rodway, Fish & Game NZ – Southland Region, personal communication). This study provides some information, but it does not provide a definitive estimate of the proportion of the trout population negotiating the pass.

10.12 There are also reports of lamprey and elvers using the fish pass at the Mararoa Weir (Zane Moss, Fish & Game NZ – Southland Region, personal communication).

10.13 Dam construction can also potentially result in the inundation of important habitat, including productive feeding areas and spawning areas upstream of the dam wall. If these habitats are inundated, or access to them is restricted, trout and salmon can not simply move to alternative spawning areas because the characteristics of these areas, in terms of water velocity, depth, substrate size and lack of flood disturbance, are quite specific and relatively rare. In addition, it is likely that other areas with these characteristics will already be heavily utilised by existing populations of fish.

10.14 Changes in flow variability downstream of dams can also have adverse effects on habitat quality and algal proliferation. Rapid flow fluctuations downstream of dams may mean that the depth and velocity at a particular location may provide ideal habitat at one flow, but be too shallow or slow during the low flow phase of the cycle and/or too fast during high flows. Mobile fish species may be able to deal with these flow fluctuations by moving, but their food resources are not so well equipped and may be exposed during low flows, or dislodged by high flows. Reductions in the frequency of bed-moving flows downstream of dams may allow accumulations of algal mats that are unsightly and can smother habitat.

11. THE IMPORTANCE OF WATER QUALITY THROUGHOUT THE HURUNUI MAINSTEM

11.1 Nutrient concentrations and pH in the lower Hurunui River at SH1 are currently elevated and sometimes above guidelines. Nitrate nitrogen concentrations have increased significantly over the last 20 years at the SH1 sampling site. During low flow periods, nuisance periphyton growths can occur in the lower reaches (Hayward 2001). Therefore, efforts should be made to maintain or improve the health of the lower Hurunui River.

11.2 In this regard I support the approach that is signalled in the Proposed Hurunui & Waiau River Regional Plan (HWRRP) where a catchment nutrient load limit based on current nutrient concentrations is proposed to maintain the values identified in the Hurunui Catchment. Setting appropriate nutrient load limits will help to control nuisance periphyton accumulations, protect aquatic organisms from nitrate toxicity and ensure that concentrations of nitrogen do not result in water becoming unsuitable for human consumption.

11.3 However, I note that there is no numeric detail in any of the current Policies within the HWRRP about the level of periphyton growth that is considered to adversely affect recreational, cultural and amenity values. This potentially results in considerable ambiguity about what the objective is for periphyton growth.

11.4 I recommend that a numeric objective for periphyton growth in the mainstem is included in the HWRRP and is something like "The 95th percentile of monthly periphyton biomass measurements in the mainstem of the lower Hurunui River (below Pahau R confluence) does not exceed 120 mg/m^2 or 20% cover of filamentous algae."

11.5 Similarly, I recommend a numeric objective for the tributaries of the Hurunui River that could be something like "The 95th percentile of monthly periphyton biomass measurements in the Pahau and Waitohi rivers does not exceed 200 mg/m^2 or 30% cover of filamentous algae.

11.6 I also note that the current Policy 5.3 provides for the dissolved inorganic nitrogen load limit at SH1 to increase by 20% prior to 2017, followed by a requirement to return to 2005-2010 levels, or better, post 2017.

11.7 Experience has shown that rehabilitation of river ecosystems can be difficult and take a long time. In addition, ecosystem recovery may not follow the expected trajectory (Bernhardt et al. 2005; Lake et al. 2007). Therefore, I recommend that the nutrient load limits are applied immediately.

11.8 I also note that the maintenance of the 2005-2010 dissolved inorganic nitrogen and dissolved reactive phosphorus concentrations at both SH1 and Mandamus, as proposed in the HWRRP, is not expected to be sufficient to limit periphyton growth to low levels and will thus only 'possibly' meet the water quality outcomes relating to periphyton biomass and cover identified in the current NRRP (Norton & Kelly 2010). Therefore, emphasis should be given to at least maintaining 2005-2010 concentrations of nitrogen and phosphorus and ideally reducing these loads, rather than allowing a further increase in nutrient loads.

11.9 Periphyton growth can potentially be limited by nitrogen, phosphorus, or co-limited by both nitrogen and phosphorus. Therefore, at a regional planning level it is appropriate to manage both nitrogen and phosphorus to control periphyton growth (Wilcock et al. 2007). In some situations, such as the lower Hurunui River, it is likely that phosphorus is the main limiting nutrient, and it is tempting to focus on phosphorus management alone. However, this is a risky strategy since nutrient limitation can switch between nitrogen and phosphorus over time, and downstream waterways may have a different limiting nutrient. There is also growing evidence that potentially toxic cyanobacteria (*Phormidium*) blooms are stimulated by high nitrogen concentrations (Wood & Young 2012). Therefore, I recommend that controls on both nitrogen and phosphorus are included in the HWRRP.

11.10 Hickey & Martin (2009) provided guidelines to protect aquatic species from chronic nitrate toxicity effects. I understand that these guidelines are currently being revised for Hawkes Bay Regional Council (HBRC) based on additional overseas information and new studies on inanga and *Deleatidium* mayflies. However, the guidelines are not expected to change dramatically.

11.11 There are also concerns with high nitrate concentrations for human drinking water supplies. The maximum acceptable value for drinking water is 11.3 mg N/L (MoH 2008).

11.12 Nitrate concentrations in the mainstem of the Hurunui River are currently well below levels which will result in toxicity effects on aquatic organisms, or result in water becoming unsuitable for human consumption (Figure 3; Hayward 2001, Ausseil 2010). Setting nitrogen loads based on these objectives would potentially allow for a significant perceived deterioration in water quality and risk an increase in nuisance periphyton growth. Therefore, maintaining nitrate concentrations and loads similar to that currently observed in the Hurunui River seems a more appropriate objective and I support the nitrogen load limit in the HWRRP. The addition of N and P concentrations in the HWRRP that are related to the load limits, as suggested by Fish & Game, would also be helpful, especially if alterations to the flow regime are expected that will require recalculation of the load limits.

11.13 Nitrate concentrations in some tributaries within the middle parts of the Hurunui Catchment are currently close to the 99% protection levels (Waitohi), 95% protection limits (Pahau) and beyond the 90%

protection limits (St Leonards) for chronic nitrate toxicity (Table 3, Ausseil 2010).

11.14 I believe that a 95% protection limit for chronic nitrate toxicity (i.e. mean annual nitrate concentration <1.7 mg N/L,Table 3) would be appropriate in these and other tributaries joining the Hurunui downstream of the Mandamus River.

Table 3. Adaptation of Hickey & Martin's (2009) guideline values.

Guideline type	**Annual average mg NO_3-N/L (NOEC)**
Chronic– high conservation value systems (99% protection)	1.0
Chronic – slightly to moderately disturbed systems (95% protection)	1.7
Chronic – disturbed systems (90% protection)	2.4
Chronic – highly disturbed systems (80 % protection)	3.6

12. **CONCLUSION - HURUNUI**

12.1 The Upper Hurunui Catchment includes a range of waterways that provide excellent habitat and support a renowned trout fishery. Water quality is generally excellent and suitable for sustaining a wide range of aquatic organisms. Invertebrate communities in the Upper Catchment are indicative of a healthy river ecosystem and are dominated by relatively large species that constitute the preferred food for trout. A quantitative habitat survey of the Hurunui River downstream of Lake Sumner found that habitat availability for adult brown trout and invertebrates (combined) was the highest ranked river in the country.

12.2 Unmodified lake outlets like the Hurunui River below Lake Sumner are a rare feature nationally and are typically characterised by high densities of invertebrates and support the highest densities of trout in New Zealand. Modification of the Lake Sumner outlet has the potential to damage some of its special values.

12.3 The trout fishery in the Hurunui Catchment is outstanding based on both the abundance and size of the trout available. In a national study of trout densities, the Hurunui River downstream of Lake Sumner had the second highest density of adult trout recorded. Information on trout size from headwater fisheries throughout New Zealand indicated that the average size of trout from the North Branch above Lake Sumner and the South Branch were among the highest recorded in the country.

12.4 The availability of habitat, abundance of trout and size of trout in the Upper Hurunui Catchment ranks it equivalent to, or above, other rivers recognised as having outstanding trout habitat and/or fisheries in existing Water Conservation Orders.

12.5 Trout growth modelling and otolith microchemistry provided strong evidence that a large proportion of the trout population undergo substantial migrations within the Hurunui Catchment. Any barrier preventing upstream or downstream migration throughout the catchment could have an adverse impact on the brown trout population.

12.6 While water quality in the upper Hurunui River is excellent, concentrations of nutrient and faecal indicator bacteria are elevated in the lower river and nitrate concentrations have increased significantly over the last 20 years. Efforts should be made to maintain or improve the health of the lower Hurunui River.

12.7 I support the approach that is signalled in the Proposed Hurunui & Waiau River Regional Plan (HWRRP) where a catchment nutrient load limit is proposed to maintain the values identified in the Hurunui Catchment. However, I recommend that a numeric periphyton limit is included in the plan for the mainstem and specified tributaries and that the nutrient load limits are applied immediately, rather than allowing further increases until 2017.

12.8 Maintaining the 2005-2010 dissolved inorganic nitrogen and dissolved reactive phosphorus concentrations at both SH1 and Mandamus, as proposed in the HWRRP will only 'possibly' meet the water quality outcomes relating to nuisance periphyton growth identified in the current NRRP (Norton & Kelly 2010). Therefore, emphasis should be given to **at least** maintaining 2005-2010 concentrations of both nitrogen and phosphorus and ideally reducing these loads, rather than allowing a further increase in nutrient loads.

PART B – WAIAU RIVER CATCHMENT

13. UPPER WAIAU RIVER INSTREAM HABITAT

13.1 The Upper Waiau River and its major tributaries the Hope River and Boyle River drain the Spencer Mountains and Main Divide. These rivers and their tributaries, such as the Doubtful, Lewis, Nina, Henry, Ada, Stanley and Edwards rivers provide a large network of relatively unmodified waterways that provide excellent habitat for brown trout. In contrast to the Upper Hurunui, the only lake of any size in the upper Waiau Catchment is Lake Guyon (approx 64 ha).

13.2 In most of the Upper Waiau Catchment the river beds are dominated by cobbles and gravel forming a mix of riffles and runs with occasional deeper pools. Immediately upstream from the Hope River confluence, the Waiau River flows through a 9 km gorge section and I imagine that bedrock and boulders will dominate the substrate in this reach of the river forming rapids and deep pools.

13.3 From what I have seen, the Upper Waiau, Boyle and Hope rivers provide a substantial amount of habitat with depths and velocities that are suitable for adult brown trout and the invertebrates that they eat (Figure 1) and therefore should support abundant adult brown trout populations. However, quantitative analysis of habitat availability has not been conducted within any parts of the Waiau Catchment upstream of the Hope confluence.

13.4 The Upper Waiau, Boyle and Hope rivers, and particularly their smaller tributaries, will also provide many kilometres of important spawning and juvenile rearing areas for brown trout.

14. WAIAU CATCHMENT WATER QUALITY

14.1 Water quality monitoring has been conducted quarterly since 2004/5 at five sites in the Waiau Catchment as part of Environment Canterbury's State of the Environment water quality monitoring programme. These sites are Waiau River at Leslie Hills Bridge, Waiau River at Waiau township bridge, Waiau River at SH1, Mason River at SH70 and Leader River at SH1, so only cover the middle and bottom of the catchment (Figure 26).

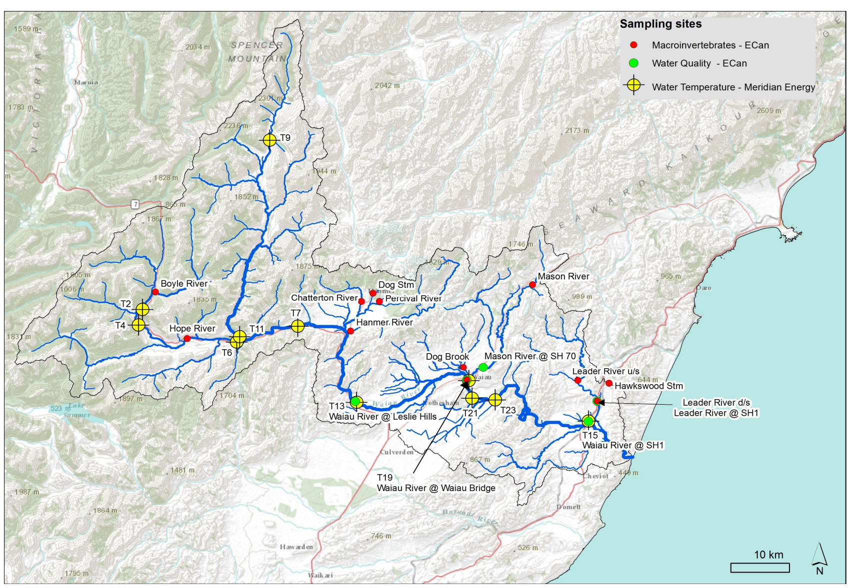

Figure 26. Map of the Waiau Catchment showing the location of water quality, invertebrate and water temperature monitoring sites.

14.2 Data provided by Environment Canterbury shows that the most upstream site at Leslie Hills Bridge has the best water quality, but there is evidence for a decline in water quality downstream with higher concentrations of nitrate-nitrogen and faecal indicator bacteria at the Waiau township bridge and SH1 sites (Figure 27). Concentrations of faecal indicator bacteria at the two tributary sites (Leader River, Mason River) are also occasionally elevated and above guidelines for contact recreation (Figure 27).

14.3 Turbidity (the opposite of water clarity) is often relatively high at all sites (Figure 27). However, this is probably due to natural inputs of glacial flour in the headwaters, rather than any indication of poor river health.

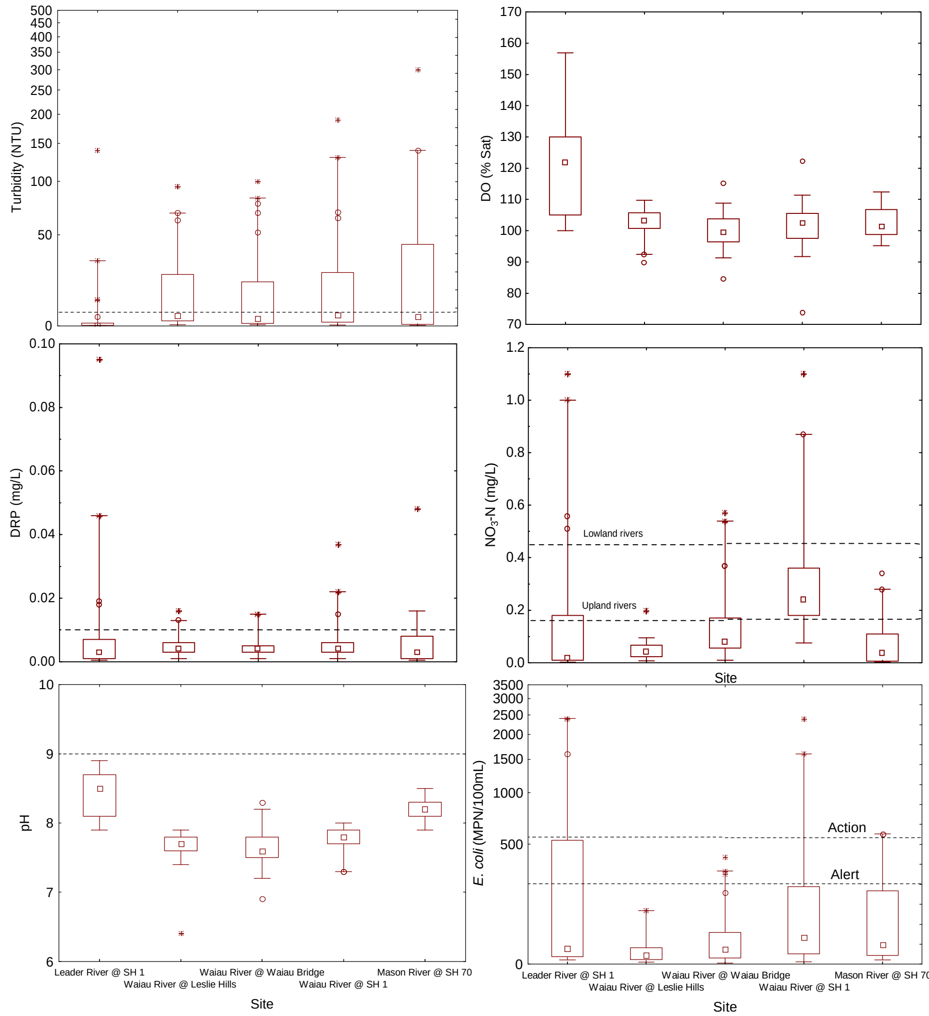

Figure 27. A comparison of water quality data from sites in the Waiau Catchment. The box plots show median values, while the bottom and top of the boxes represent 25th and 75th percentiles, respectively. The whiskers represent 5th and 95th percentiles. Outliers are shown with stars and circles. Appropriate guidelines for the different parameters are shown with the dotted lines (NO_3-N, DRP, ANZECC & ARMCANZ (2000); pH, CCREM (1987); *E. coli*, MfE & MoH (2003)). Data provided by Environment Canterbury.

15. WAIAU CATCHMENT WATER TEMPERATURE

15.1 As part of Meridian Energy's assessment of environmental effects of their proposed Amuri Project, water temperature has been logged continuously at 11 sites throughout the Waiau Catchment over the period from April 2011 to March 2012 (Figure 26).

15.2 Data provided by Meridian Energy indicate that water temperature in the upper reaches of the Waiau Catchment was always below guidelines for the protection of ecosystem health (average of daily mean and maximum < 20°C; Cox & Rutherford 2000). However, further downstream near the Waiau township and at SH1 water temperatures during January and February exceeded these guidelines with daily mean values up to 22°C and instantaneous temperatures peaking at 26.3°C in late January 2012 (Figure 28). Despite only occurring for a relatively short period, trout deaths have been reported in New Zealand rivers when water temperatures have equalled or exceeded 26 °C (Jowett 1997) and temperature sensitive invertebrates such as stoneflies and mayflies are unlikely to survive such high temperatures.

15.3 During winter, water temperatures in the upper Waiau Catchment are low and well below the optimum for brown trout growth (13.9°C, Elliott & Hurley 1999, 2000) that I mentioned earlier. In fact, once water temperatures drop below 4°C, trout will lose weight even with an abundance of food, because they are not able to digest it at such low temperatures. However, water temperatures at SH1 during the winter are much more benign with mean daily temperatures >10 °C for much of the winter (Figure 28). Therefore, there is a strong incentive for trout to migrate downstream to the lower reaches of the river during winter so they can continue to feed and grow.

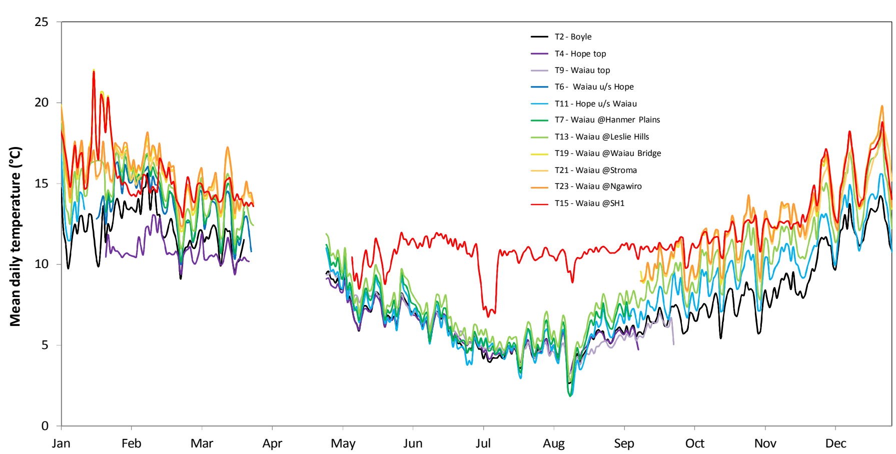

Figure 28. Annual changes in water temperature at 11 sites throughout the Waiau Catchment. Data provided by Meridian Energy.

16. STREAM INVERTEBRATE COMMUNITIES OF THE WAIAU CATCHMENT

16.1 Environment Canterbury has sampled invertebrate communities at 12 sites in the Waiau Catchment (Figure 26). Some sites have been sampled twice per year since 1999, while others have only been sampled 2-3 times.

16.2 The invertebrate communities in the Boyle and Hope rivers are typical of other mountain-fed rivers that drain largely unmodified land with MCI scores often greater than 120, and QMCI values greater than 6 which are indicative of clean water and a healthy river ecosystem (Stark 1993) (Figure 29). The invertebrate communities in the Chatterton River, Hanmer River, Mason River and Dog Stream are also indicative of good ecosystem health (Figure 29). In contrast, invertebrate communities in the downstream site on the Leader River, Hawkswood Stream, Percival River, and Dog Brook are indicative of fair to poor ecosystem health (Figure 29). Data from the Waiau River at Waiau township bridge is indicative of a healthy river ecosystem based on QMCI scores, but only fair-good ecosystem health based on MCI scores (Figure 29).

16.3 A comprehensive invertebrate survey was conducted in the braided Amuri and Hanmer Plains reaches of the Waiau River in conjunction with Meridian Energy's AEE for their Amuri Project (Hayes et al. 2012). Invertebrate diversity and density was low in these reaches reflecting the recent floods, and dominated by *Deleatidium* mayflies, free living caddis (*Hydrobiosis*) and chironomid larvae. The invertebrate community found at these sites were indicative of good to excellent ecosystem health using the QMCI score (5.0-7.8), but only fair to good health using the MCI score (80-103) (Hayes et al. 2012).

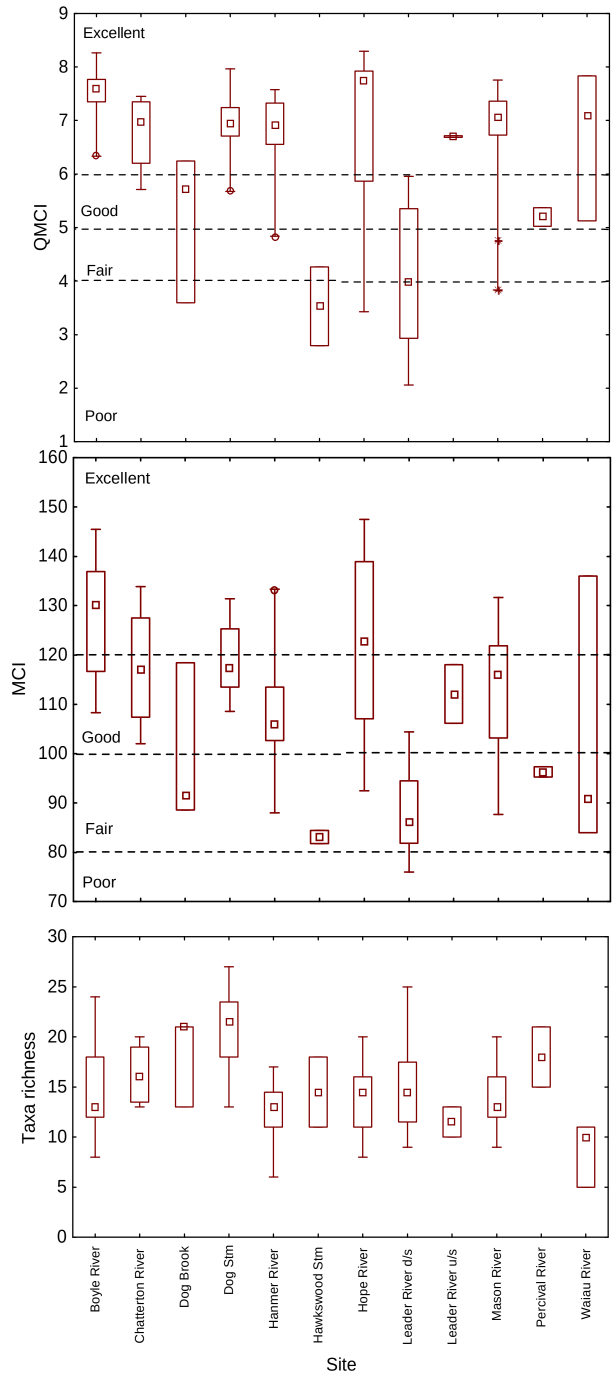

Figure 29. Box and whisker plots of macroinvertebrate community scores (MCI), quantitative MCI (QMCI) scores and taxa richness for 12 sites in the Waiau Catchment. The box plots show median values, while the bottom and top of the boxes represent 25th and 75th percentiles, respectively. The whiskers represent 5th and 95th percentiles. Outliers are shown with stars and circles. Data provided by Environment Canterbury.

17. UPPER WAIAU RIVER TROUT POPULATION

17.1 As mentioned earlier the upper Waiau River and its tributaries (Hope, Boyle, Doubtful, Nina, Lewis) were all specifically identified in the national study of headwater fisheries as providing the opportunity to catch large fish in scenic surroundings throughout the whole fishing season (Jellyman & Graynoth 1994).

17.2 Fish & Game have conducted 3 drift dive surveys in 2 reaches of the Waiau River above the Hope confluence over the last 3 years. Trout abundance ranged from 2 – 25 large trout per kilometre, which is within the range seen for headwater fisheries elsewhere (Jellyman & Graynoth 1994). However, the divers reported that many of the trout seen were trophy-sized (>4 kg – Tony Hawker pers. comm.).

17.3 Large trout seem to be a feature of the upper Waiau Catchment. Using data collated for the national headwater fisheries study (Jellyman & Graynoth 1994) the average length (601 mm) and weight (2.7 kg) of Waiau trout was greater than the national average (556 mm and 2.2 kg). In fact, the Waiau was ranked 4th for both length and weight among the rivers in the national headwater fisheries study where 10 or more records were available (Figures 13 & 14).

17.4 Les Hill's evidence clearly shows that large trout, including trophy fish, are an important feature of the upper Waiau River fishery.

18. THE IMPORTANCE OF FREE PASSAGE FOR MAINTAINING THE WAIAU RIVER'S TROUT POPULATION

18.1 As already mentioned for the Hurunui, there are several factors that are required to maintain headwater fisheries, including good water quality and habitat, a moderate temperature regime, and unimpeded passage to food resources, thermal regimes, and refuges in other parts of the catchment as required.

18.2 Given the strong incentive for migration offered by the benign downstream temperatures in the winter, it is very likely that brown trout undergo substantial migrations within the Waiau Catchment, in a similar way to what I described earlier for the Hurunui Catchment. Similarly, any barrier preventing upstream or downstream migration could have an adverse impact on the brown trout population in the upper Waiau Catchment. The construction of a dam or weir on the Waiau River is very likely to restrict passage for trout throughout the catchment.

19. THE IMPORTANCE OF WATER QUALITY THROUGHOUT THE WAIAU MAINSTEM

19.1 As indicated, trout are very likely to move throughout the Waiau Catchment to take advantage of the spawning habitat and cool summer temperatures offered by the upper river, and the abundant food supplies and relatively warm winter water temperatures available in the lower river. Therefore, maintenance of suitable water quality throughout the Waiau mainstem is important so fish passage is not restricted.

19.2 Very warm water temperatures have been measured in the lower reaches of the Waiau River in summer, and there is evidence of a degradation in water quality within the lower reaches of the Waiau River. Therefore, efforts should be made to maintain or improve the current status of the lower Waiau River.

19.3 I believe that a nutrient load limit needs to be set for the Waiau Catchment to help control nuisance periphyton accumulations, protect aquatic organisms from nitrate toxicity and ensure that concentrations of nitrogen do not result in water becoming unsuitable for human consumption

19.4 Therefore, I support the Policy 5.3 of the HWRRP as proposed by Fish and Game, which calls for nutrient limits to be set in the Waiau River catchment. However, I recommend a numeric periphyton objective is included within the plan and that the nutrient limits are set as soon as possible. The numeric periphyton objective for the Waiau River could be something like "The 95th percentile of monthly periphyton biomass measurements in the mainstem of the Waiau River does not exceed 120 mg/m^2 or 20% cover of filamentous algae.

19.5 I believe that a 95% protection limit for chronic nitrate toxicity (i.e. mean annual nitrate concentration <1.7 mg N/L,Table 3) would be appropriate in these and other tributaries joining the Waiau downstream of the Hope River.

20. **CONCLUSION - WAIAU**

20.1 The Upper Waiau Catchment includes many kilometres of waterways that provide excellent habitat for large trout and support valuable headwater fisheries. The water quality and invertebrate community of the upper Catchment are indicative of a healthy ecosystem.

20.2 The upper Waiau Catchment is particularly notable for the size of the trout that are available to anglers. Large trout greater than 4.5 kg are regularly caught and in a national survey of headwater fisheries the average size of trout from the Waiau Catchment was ranked 4th for both length and weight (Figures 13 & 14).

20.3 Water temperature patterns throughout the catchment indicate that there is a strong incentive for trout to move downstream during the winter to take advantage of the more benign thermal regime of the lower reaches, but return upstream during summer when the lower reaches can become dangerously warm.

20.4 A nutrient load limit needs to be set for the Waiau Catchment to help control nuisance periphyton accumulations, protect aquatic organisms from nitrate toxicity and ensure that concentrations of nitrogen do not result in water becoming unsuitable for human consumption. Therefore, I support the current Policy 5.4 of the HWRRP which calls for nutrient limits to be set in the Waiau River catchment. However, I recommend that these limits are set as soon as possible. I also recommend that numeric periphyton objectives for the Waiau River are included in the HWRRP so the purpose of the nutrient load limits is clear.

21. ENVIRONMENT CANTERBURY SECTION 42A REPORTS

21.1 I have read the Section 42A reports prepared by Mr Ned Norton, Mr Ian Brown, Dr Ton Snelder and Dr Don Jellyman.

21.2 I agree with most of the material presented in these reports. Mr Norton's report, in particular, provides a useful analysis of how different flow scenarios and land use intensification with and without mitigation measures may influence the ability to meet appropriate water quality outcomes. His analysis is at a relatively high level and doesn't incorporate potential seasonal variations in nutrient load and flow. However, I agree with Mr Norton that this level of analysis is appropriate for a plan hearing.

21.3 Mr Norton's results are particularly helpful because they consider the effects of both land use intensification and flow regime change. The need to alter the proposed catchment load limits in response to significant changes in the flow regime is an important point. He concludes that it is not possible at this time to take the full A, B and C Block allocations under the HWRRP for intensified agricultural land use and stay within the water quality limits designed to achieve Objectives 5.1 and 5.2.

21.4 In paragraph 43 Mr Norton points out that the load limits for the tributaries that he used for his analysis were based on nitrate toxicity and there was no clear link with controlling nuisance periphyton in these tributaries. This concern is potentially addressed by incorporating a numeric periphyton objective for the tributaries that have identified values (Pahau, Waitohi), as suggested in the Fish & Game submission and my paragraph 11.5.

21.5 Mr Norton's discussion regarding managing one or both nutrients is detailed and helpful. I agree with his conclusion that there are environmental risks in focussing on just one nutrient and management of both nitrogen and phosphorus is appropriate in the HWRRP.

21.6 Mr Norton's comments on using load limits in management and planning are also important and I support his suggestion that the HWRRP should signal a move towards nutrient discharge allowances at a farm or enterprise level, so the responsibility for achieving the overall catchment load limits is allocated to individual landowners.

R Young
12 October 2012

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