BEFORE THE MINISTER FOR THE ENVIRONMENT
SPECIAL TRIBUNAL

IN THE MATTER of an Application by New Zealand and North Canterbury Fish & Game Councils for Hurunui River Water Conservation Order

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STATEMENT OF EVIDENCE OF ROGER GRAEME YOUNG ON BEHALF OF NEW ZEALAND AND NORTH CANTERBURY FISH & GAME COUNCILS

DATED this 6th day of March.2009

Introduction – Qualifications and Experience

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 11 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 North American Benthological Society.
2. My areas of expertise include freshwater fisheries, river health assessment, water quality, and river ecosystem ecology.
3. Over the last 11 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 & 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 20 scientific papers and more than 40 reports relating to this work.

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

   - Otago Regional Council's Water Plan Environment Court Hearing

   - Natural Gas Corporation's hearing relating to the proposed expansion of the Stratford Power Station

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

   - Meridian Energy's lower Waitaki North Branch Tunnel Concept Water Resource Consents Hearing

5. 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.

6. I confirm that I have read and agree to comply with the Code of Conduct for Expert Witnesses (Environment Court Practice Note 2006). 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.

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

   · Habitat and trout abundance data from the '100 Rivers' study (Jowett 1990; Teirney & Jowett 1990)

   · Data on trout size from the headwater trout study (Jellyman & Graynoth 1994)

   · Water quality data from NIWA and Environment Canterbury

   · A report on trout growth modelling in the Hurunui Catchment (Hayes &

Quarterman 2003)

- A report on otolith microchemistry of trout from the Hurunui Catchment (Bickel & Olley 2009)

- A report on the effects on didymo on invertebrate drift and trout growth potential (Shearer et al. 2007).

- The evidence of Mr Stewart, Dr Jellyman, Mr Unwin, and Mr Greenaway

Scope of Evidence

8. I have been asked by the North Canterbury Fish and Game Council to provide evidence to this hearing on the following:
   a. The in-stream habitat in the Upper Hurunui Catchment
   b. The outstanding trout population in the Upper Hurunui River
   c. Catchment-wide movements by trout in the Hurunui River
   d. The importance of free passage for maintaining the Hurunui River's outstanding trout population
   e. The likely effects of didymo on the Hurunui River trout population

Executive summary

9. 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.

10. 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.

11. 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 special values

12. 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.

13. In contrast, water quality in the lower Hurunui River at SH1 is relatively poor with high concentrations of nutrient levels 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.

14. 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.

15. 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.

16. 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.

17. 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 trophy trout in the Upper Hurunui and most of the large trout in the South Branch.

18. The otolith microchemistry study indicated that there was no evidence of trout migration to and from the ocean. However, there was strong evidence that a substantial 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

19. 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 often 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.

20. Didymo is an exotic benthic diatom which forms dense mats over riverbeds and has the potential to alter water quality, aquatic invertebrate communities, trout growth and carrying capacity, angling success, and aesthetic values. However, the results from limited studies to date have shown no noticeable negative effect on invertebrate drift density and biomass, or predicted trout growth potential that can be attributed to didymo. However, the study did not include spring and summer, the most critical seasons for trout growth and therefore must be considered provisional. More research is needed before we can ascertain the effects of didymo on trout growth with any certainty.

Upper Hurunui River instream habitat

21. The Hurunui River upstream of the confluence with the Mandamus River (hereafter referred to as the Upper Hurunui River) is composed of 3 main river sections – the mainstem below Lake Sumner, the South Branch, and the North Branch above Lake Sumner. There are also numerous tributaries including Seaward River, Jollie Brook, Sisters Stream, and Glenrae River. 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.

22. 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) through to the Mandamus confluence. 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.

23. 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). 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 which I will refer to later.

24. 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.

25. The interconnections between 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.

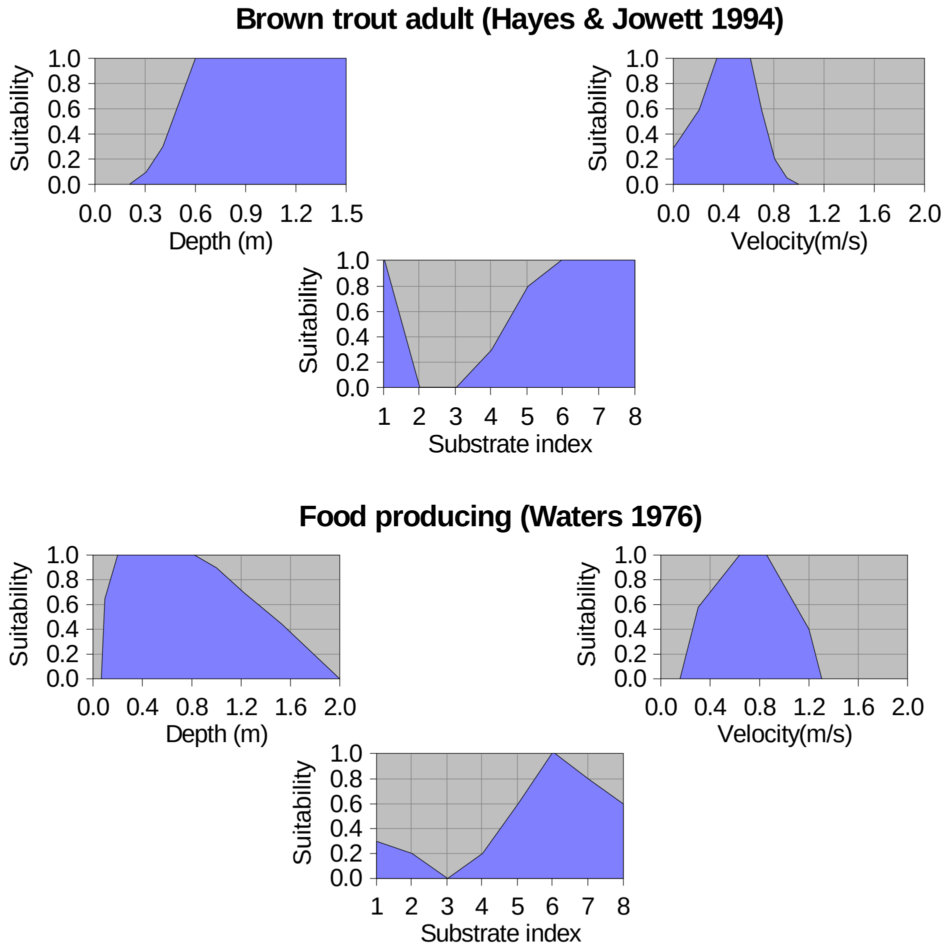

Figure 1. Habitat preference curves for drift feeding adult brown trout (Hayes & Jowett 1994) and trout food production (Waters 1976). Substrate indices are 1 = Vegetation, 2 = Silt, 3 = Sand, 4 = Fine Gravel, 5 = Gravel, 6 = Cobbles, 7 = Boulders, 8 = Bedrock.

The special characteristics of the Hurunui River Mainstem below Lake Sumner

26. 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).

27. 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.

28. 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.

29. 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).

30. 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.

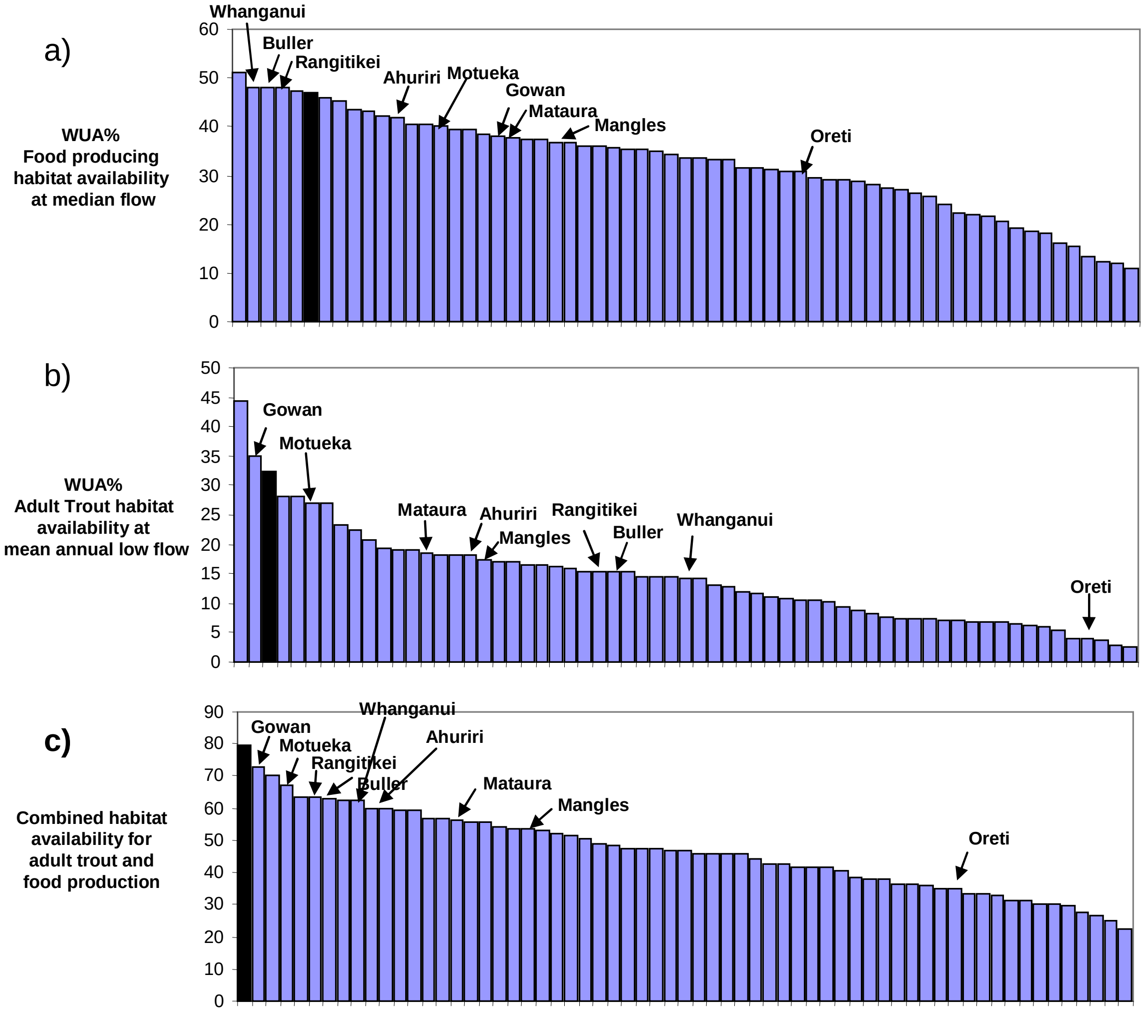

Figure 2. A comparison of habitat availability in the Hurunui River below Lake Sumner with other notable rivers around New Zealand for a) food production, b) adult trout, and c) the combination of food production and adult trout. The Hurunui River is marked as the black bars.

31. 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.

32. 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 more indigestible (Richardson 1984).

33. 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

Upper Hurunui River water quality

34. 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 2006 is shown in Figure 3.

35. Dissolved oxygen is close to 100% saturation at both sites most of the time and never below levels expected to cause problems for ecosystem health (Figure 3).

36. 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 high 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).

37. The pH at the Mandamus site is also 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.

38. Faecal indicator bacteria (*E. coli*) concentrations 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).

39. 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.

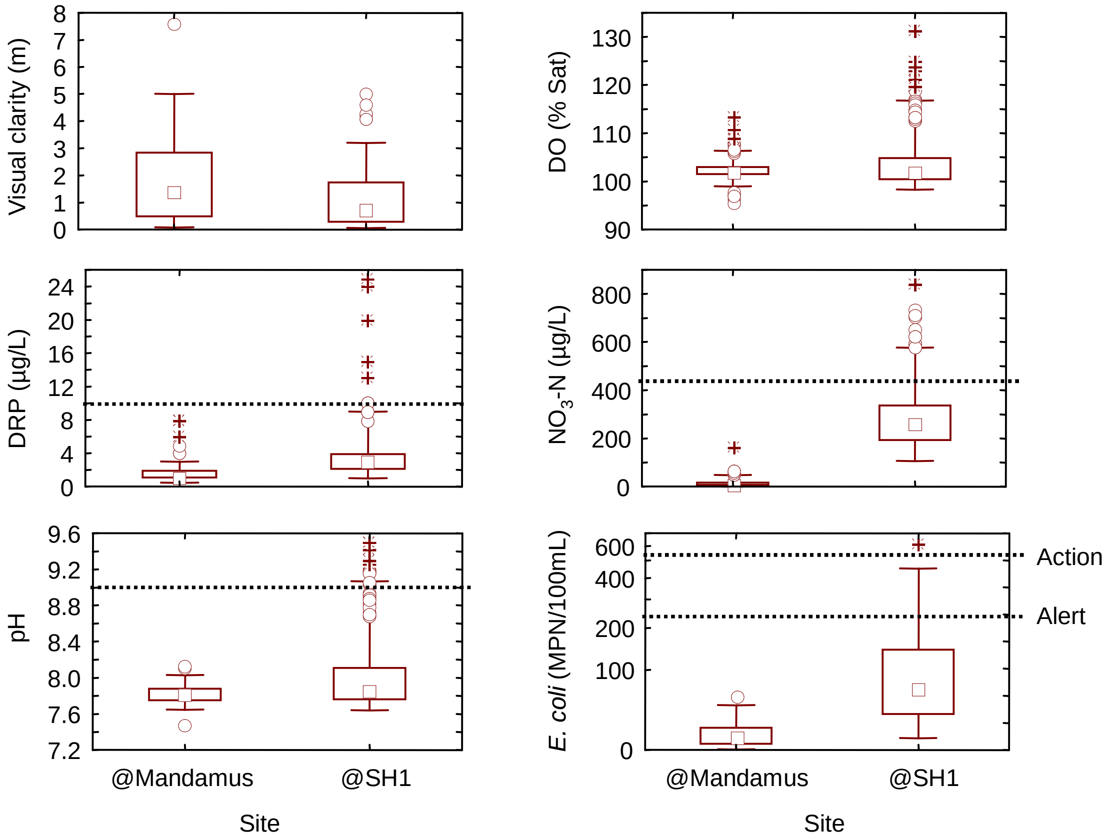

Figure 3. A comparison of water quality data from the Hurunui River at Mandamus and the Hurunui River downstream at SH1. The box plots show median values, while the bottom and top of the boxes represent 25th and 75th percentiles, respectively. The whiskers represent 5th and 95th percentiles. Outliers 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)).

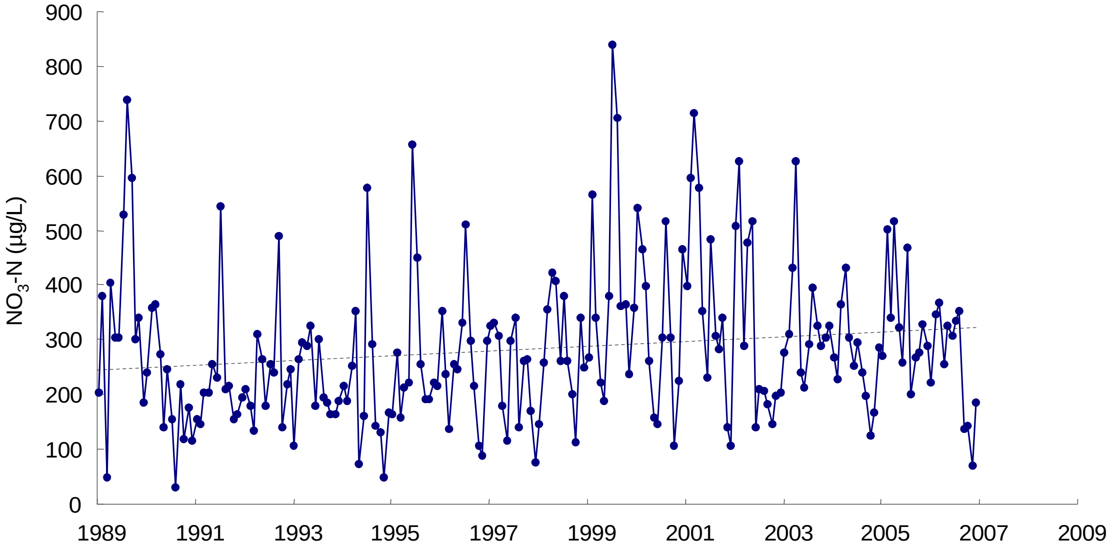

Figure 4. Increase in nitrate nitrogen concentration in the Hurunui River at the SH1 sampling site (Slope of trend 4.6, Relative slope 1.8%, P = 0.27%).

40. Environment Canterbury has also measured water quality at 3 additional sites in the Hurunui Catchment; the Mainstem upstream of the Jollie Brook confluence, the South Branch upstream of the confluence with the Mainstem, and at SH7 upstream of the confluence of the Pahau and Waitohi rivers (Hayward 2001). The two upstream sites generally had very high water quality with low concentrations of nutrients and faecal indicator bacteria (Hayward 2001). No long-term trends in water quality were observed in the upper catchment sites (Hayward 2001).

41. 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).

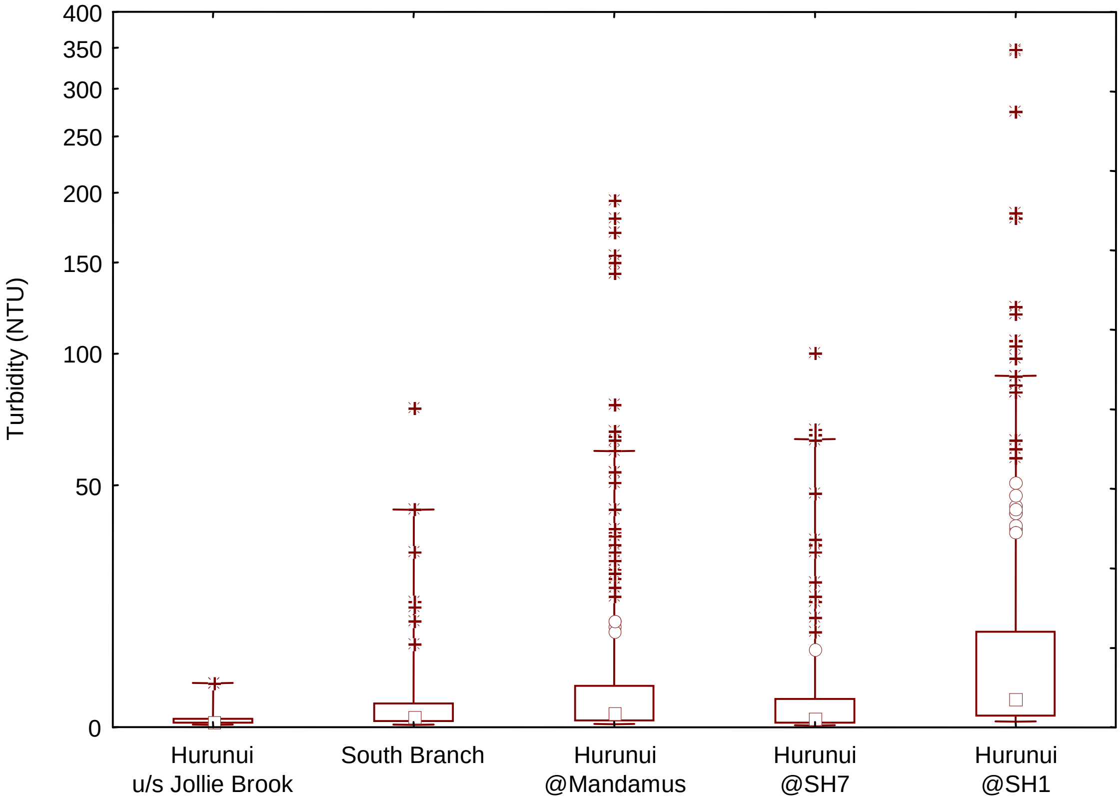

Figure 5. A comparison of turbidity from the three Environment Canterbury sites with the NIWA national river water quality network sites. The box plots show median values, while the bottom and top of the boxes represent 25th and 75th percentiles, respectively. The whiskers represent 5th and 95th percentiles.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

42. 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).

43. 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.

Upper Hurunui River water temperature

44. 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.

45. 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).

46. Water temperature in the Upper Hurunui River was in the ideal range for brown trout growth 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).

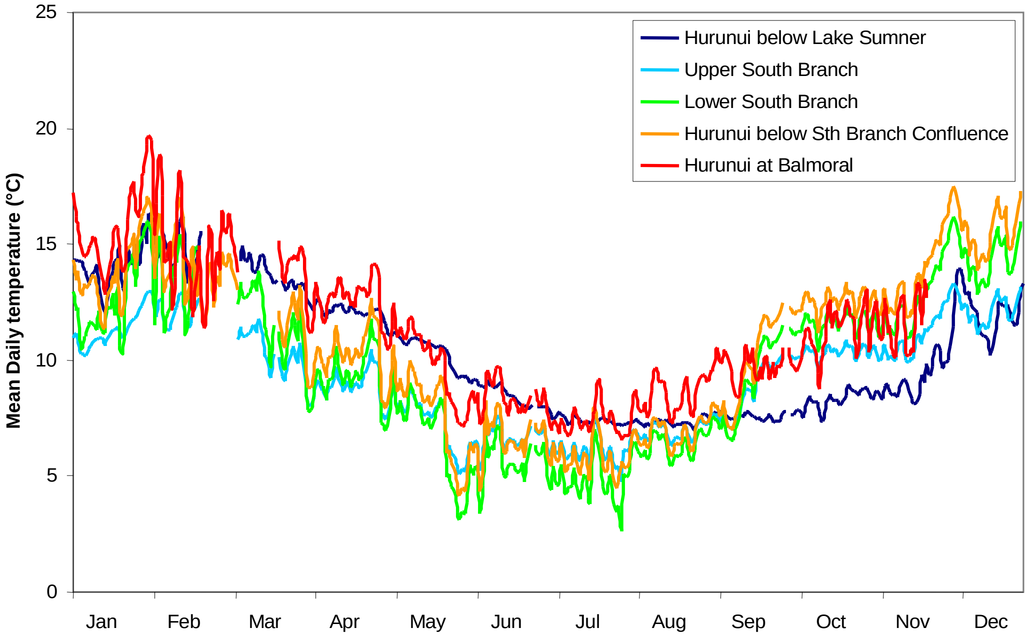

Figure 6. Annual changes in mean daily water temperature at sites in the Upper Hurunui Catchment and also at Balmoral.

Stream invertebrate communities of the Upper Hurunui

47. 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).

48. The invertebrate community at Mandamus is typical of other mountain-fed rivers that drain largely unmodified land with MCI scores often greater than 120 (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).

49. 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.

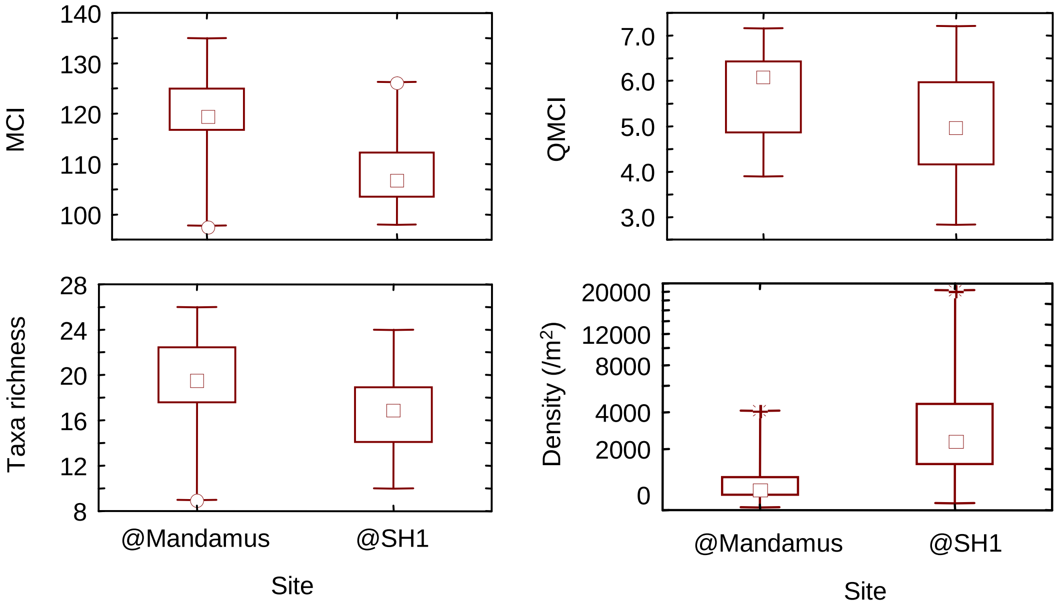

Figure 7. Box and whisker plots of macroinvertebrate community scores (MCI), quantitative MCI (QMCI) scores, taxa richness, and density for the Hurunui River at Mandamus and SH1 from 1989 to 2006. The box plots show median values, while the bottom and top of the boxes represent 25th and 75th percentiles, respectively. The whiskers represent 5th and 95th percentiles. Outliers are shown with stars and circles.

The Upper Hurunui River's outstanding trout population - density

50. 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.

51. 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. However, the proportion of trout that are detected by divers appears to remain relatively constant over time within river reaches (Young & Hayes 2001).

52. 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.

53. 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).

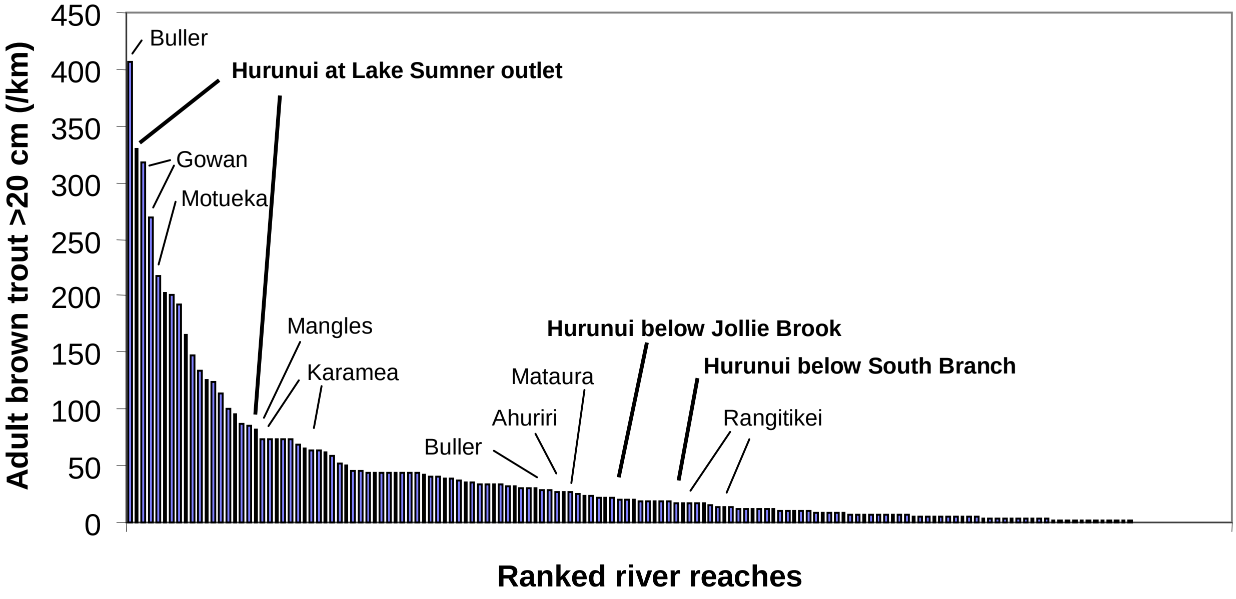

Figure 8. A comparison of the abundance of adult brown trout in 158 river reaches from throughout the country (data from Teirney & Jowett 1990).

54. Trout abundances can fluctuate substantially over time with variations from year to year typically ranging between 1.6 and 11 times (Platts & Nelson 1988; Jowett 1995; Zorn & Nuhfer 2007).

55. 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 68 and 376 large and medium trout per km in the Lake Sumner Outlet reach, and between 41 and 158 large and medium trout per km in the reach downstream of Jollie Brook (Figure 9). The level of annual variability since 1988 (3.9 to 5.5 times) is consistent with that reported elsewhere (Platts & Nelson 1988; Jowett 1995; Zorn & Nuhfer 2007).

56. 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 32).

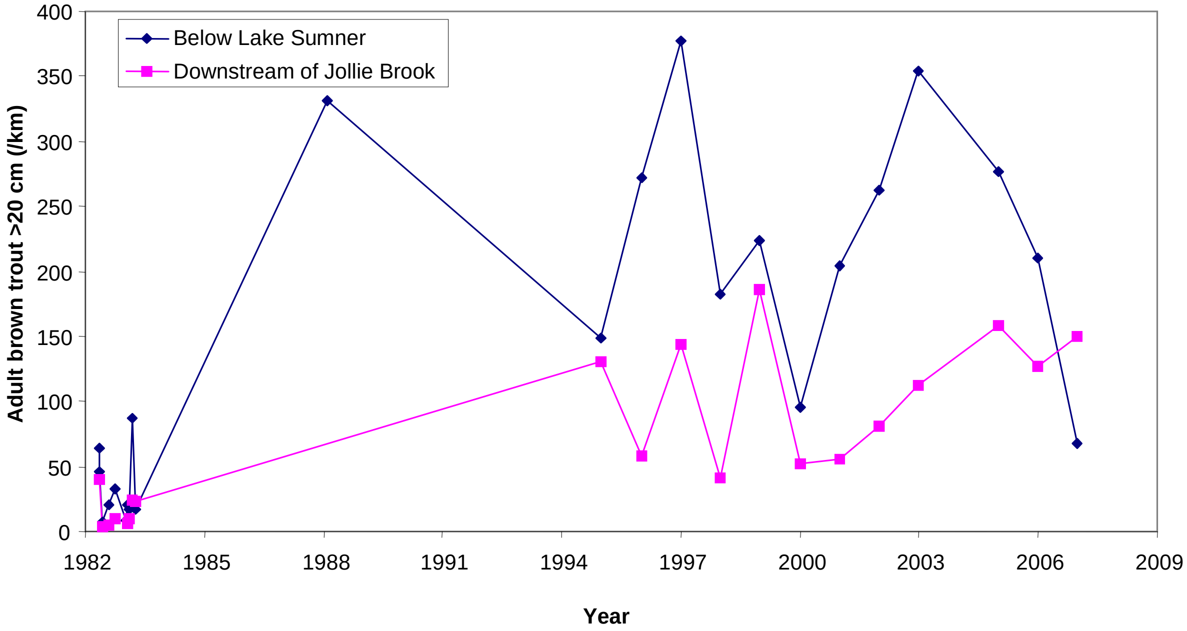

Figure 9. Changes in trout counts over time in the Hurunui River below Lake Sumner and downstream of Jollie Brook.

57. Long-term drift dive records for brown trout populations with more than 6 records over a period of >10 years up to 2007 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 (3rd highest average, Figure 10).

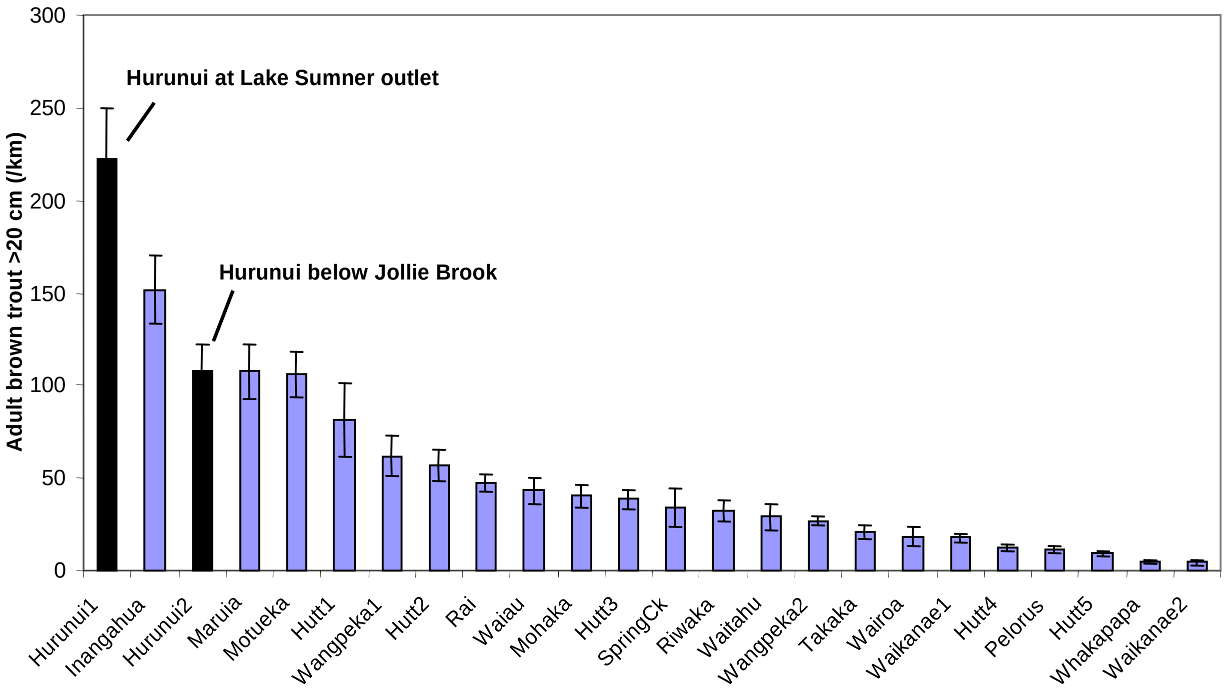

Figure 10. A comparison of brown trout abundance (±SE) in rivers throughout New Zealand where long-term drift dive records are available (Data from Fish & Game New Zealand).

The Upper Hurunui River's outstanding trout population - size

58. 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).

59. 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), and an expert angler (127 trout, Chappie Chapman). In most cases the capture location was available along with fish length and weight.

60. 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.

61. 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).

62. The proportion of large (>2.7 kg) trout in the anglers catch from the North Branch above Lake Sumner (33%) and the South Branch (31%) 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.

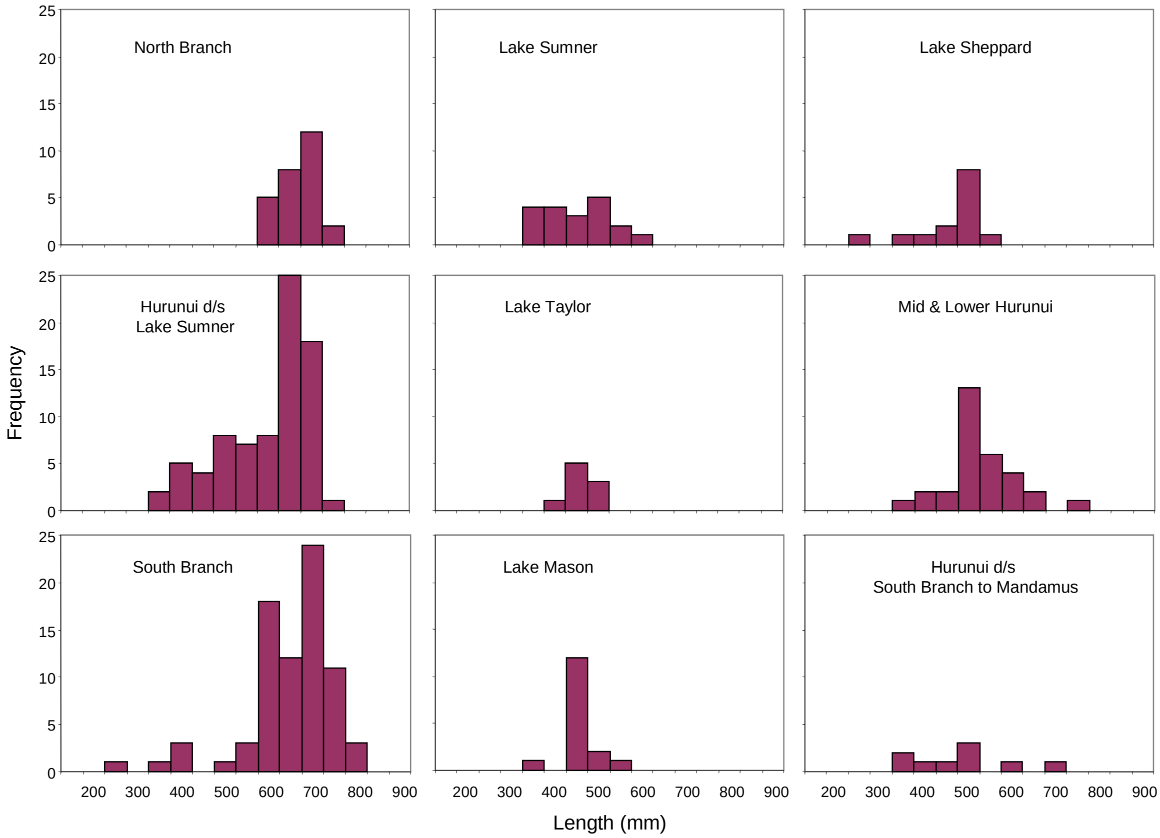

Figure 11. Length distribution of trout caught in different parts of the Hurunui Catchment.

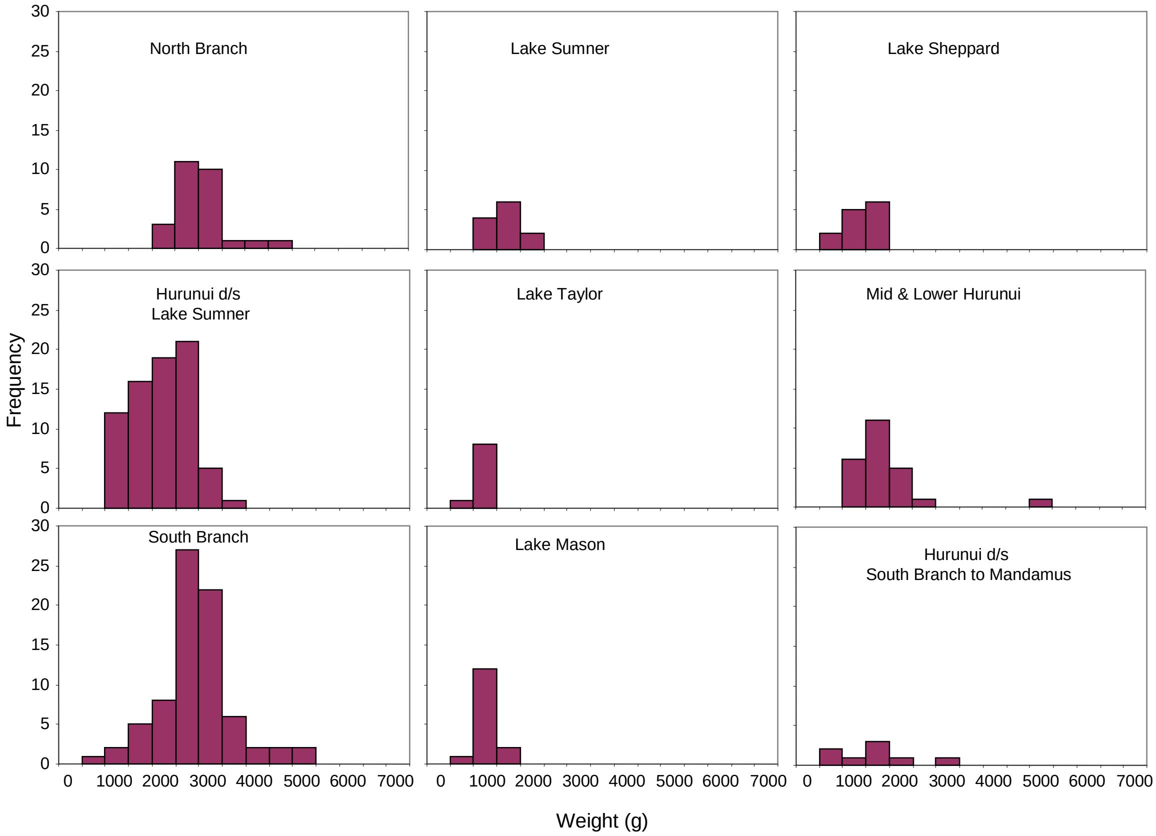

Figure 12. Weight distribution of trout caught in different parts of the Hurunui Catchment.

63. 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).

64. 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.

65. 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).

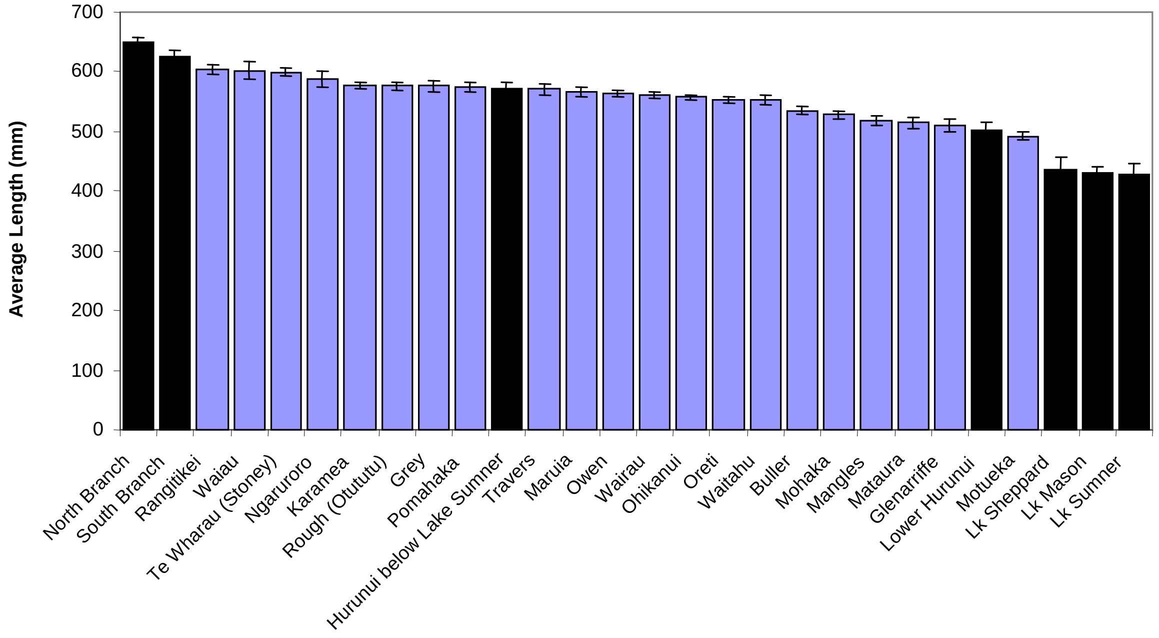

Figure 13. Average length of trout from different parts of the Hurunui Catchment (black bars) compared with data collected from other rivers in the headwater trout fisheries study (data from Dr Don Jellyman).

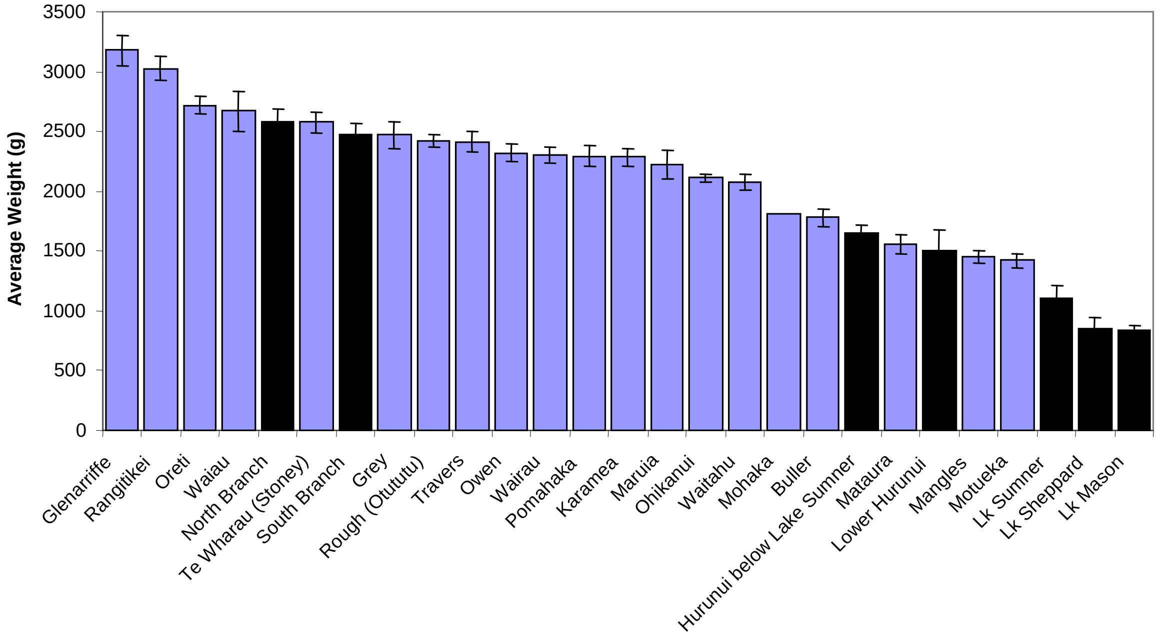

Figure 14. Average weight of trout from different parts of the Hurunui Catchment (black bars) compared with data collected from other rivers in the headwater trout fisheries study (data from Dr Don Jellyman).

66. 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 a 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).

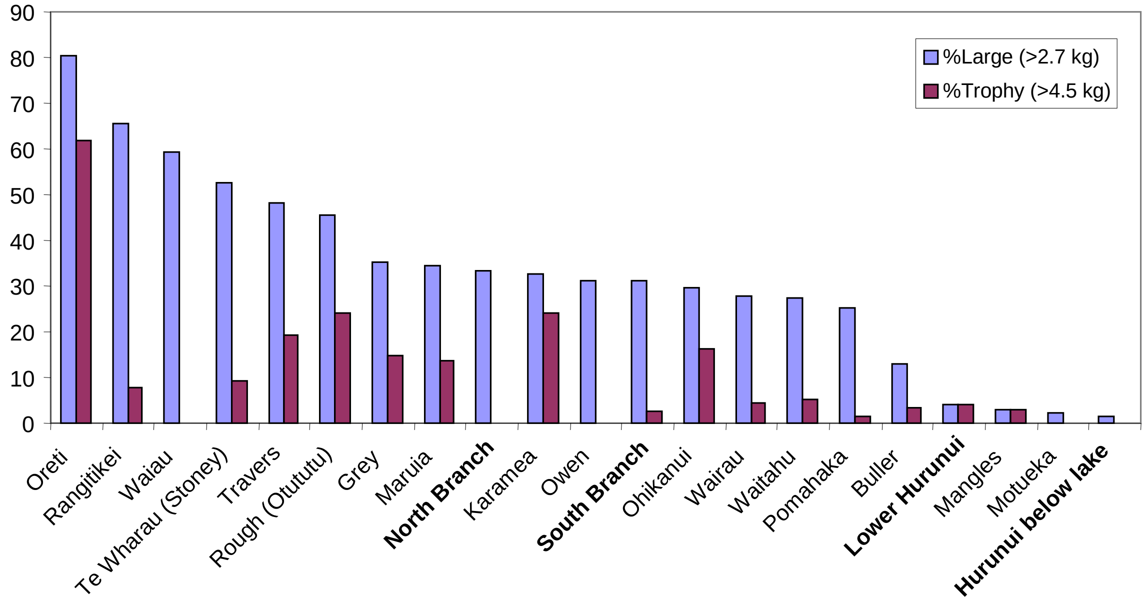

Figure 15. The percentage of large (>2,7 kg) and trophy (>4.5 kg) trout in anglers catch from different parts of the Hurunui Catchment compared with data collected from other rivers in the headwater trout fisheries study (data from Dr Don Jellyman).

67. In summary, the large size of fish from 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 such as the Rangitikei, Buller, Oreti, Travers, Maruia, Owen, Mohaka, Mangles, Mataura, and Motueka.

Catchment-wide movements by trout in the Hurunui River

68. 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).

69. 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.

70. 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. in review).

71. 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).

72. 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.

73. 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.

74. 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

75. 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.

76. 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.

77. 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.

78. 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.

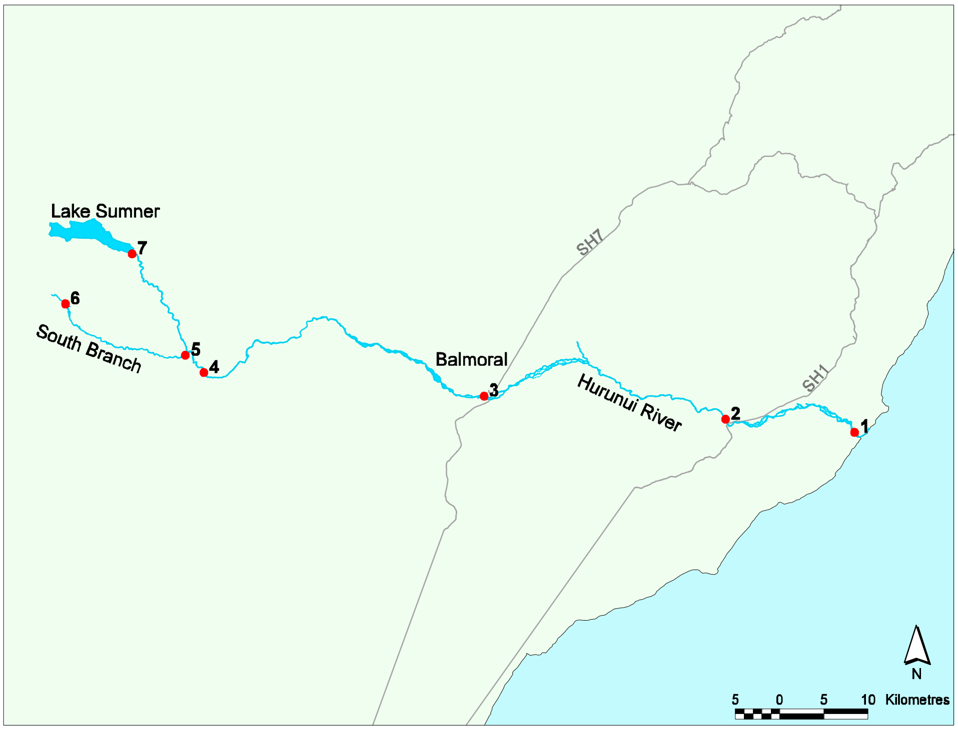

Figure 16. Map of the Hurunui River showing location of the seven water temperature loggers.

79. 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.

80. 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.

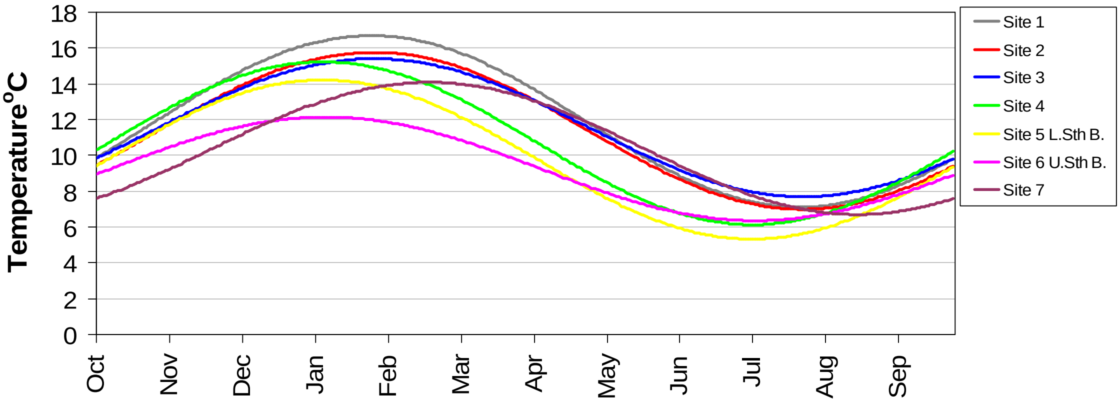

Figure 17. Modelled mean daily temperature records for the seven logger sites (site 5 = lower South Branch, site 6 = upper South Branch).

81. 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).

82. 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.

83. 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).

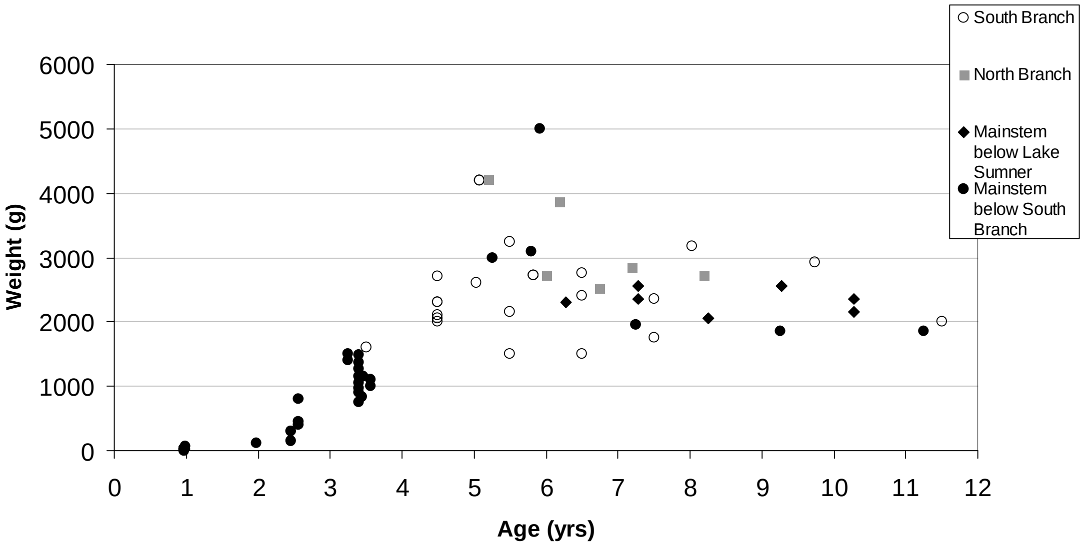

Figure 18. Observed weight at age for trout from different locations within the Hurunui River. Note that this figure contains more data than that presented originally in Hayes & Quarterman (2003).

84. 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).

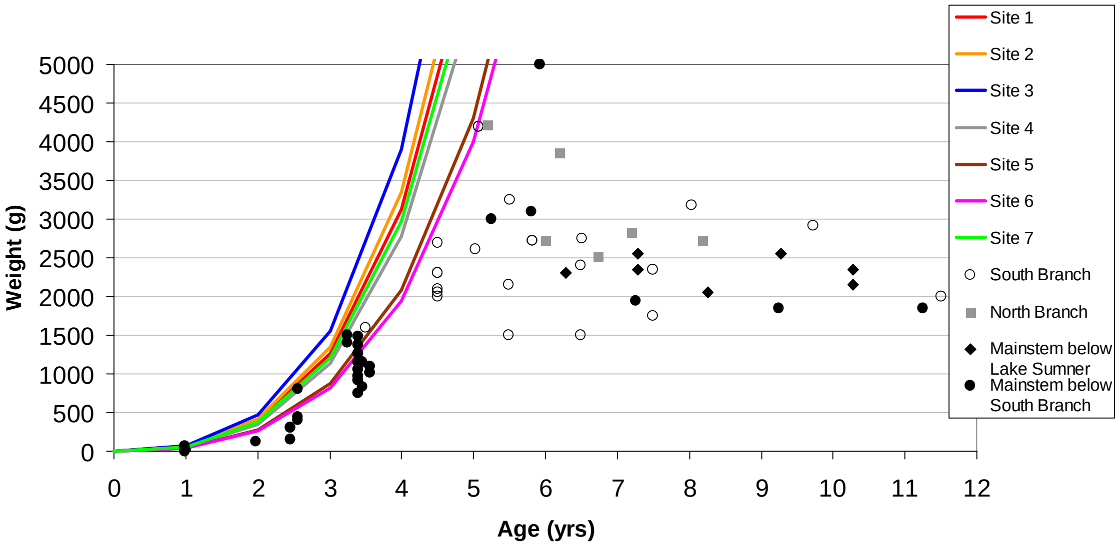

Figure 19. Observed weight at age versus predicted weight at age from growth modelling for trout on an unlimited invertebrate diet and with no reproduction or foraging costs for the seven water temperature logger sites (Site 5 = lower South Branch, Site 6 = upper South Branch). Note that this figure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

85. 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.

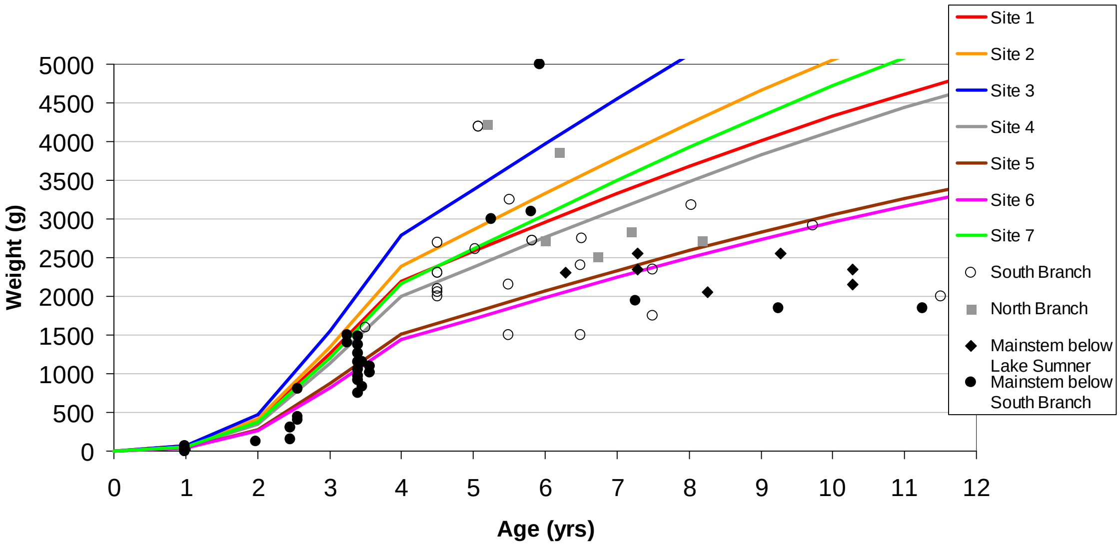

Figure 20. Observed versus predicted weight at age for trout on an unlimited invertebrate diet, and applying reproduction and drift foraging costs in consecutive years after maturity at age 4 (Site 5 = lower South Branch, Site 6 = upper South Branch). Note that this figure contains more data than that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

86. 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.

87. 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.

88. 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.

89. 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 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.

90. 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).

91. 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.

92. 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

93. 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).

94. 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.

95. 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.

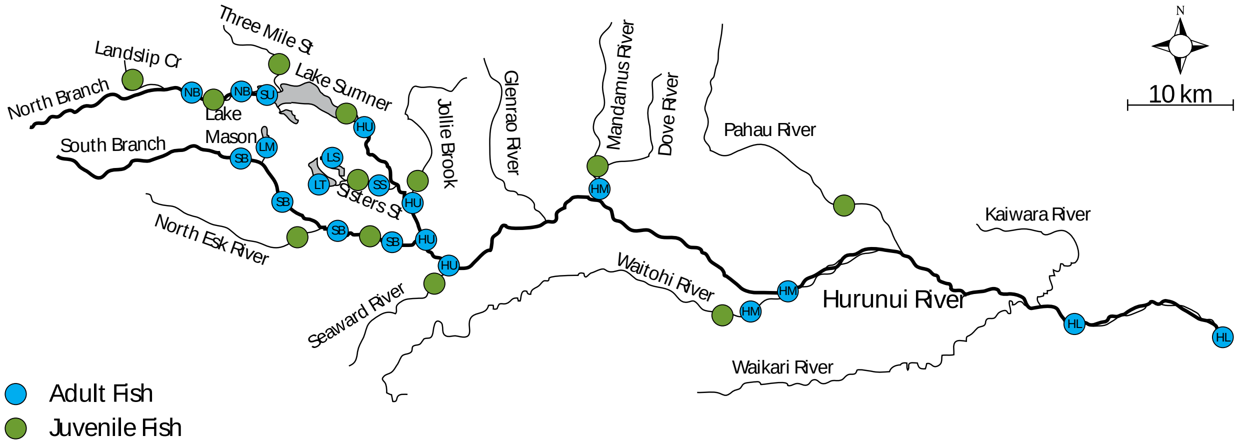

Figure 21. Map showing the Hurunui River and locations (blue circles) where adult brown trout were sampled. The major tributaries where juvenile brown trout were collected are shown with green circles.

96. 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).

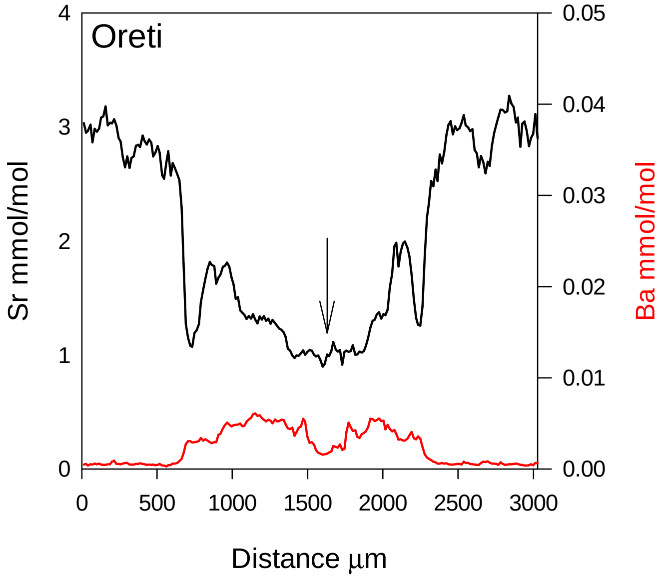

Figure 22. Concentrations of strontium and barium (measured as element:calcium ratios) in an otolith from a trout collected in the Oreti Estuary as an example of an estuarine reared fish; the Sr;Ca levels exceed 2 for much of the life history and there is a simultaneous drop in Ba:Ca ratios. The graph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

97. 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.

98. 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).

99. 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).

100. 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 (SS)	3		2 (67%)	1 (33%)
Total	113	24 (21%)	75 (66%)	13 (12%)

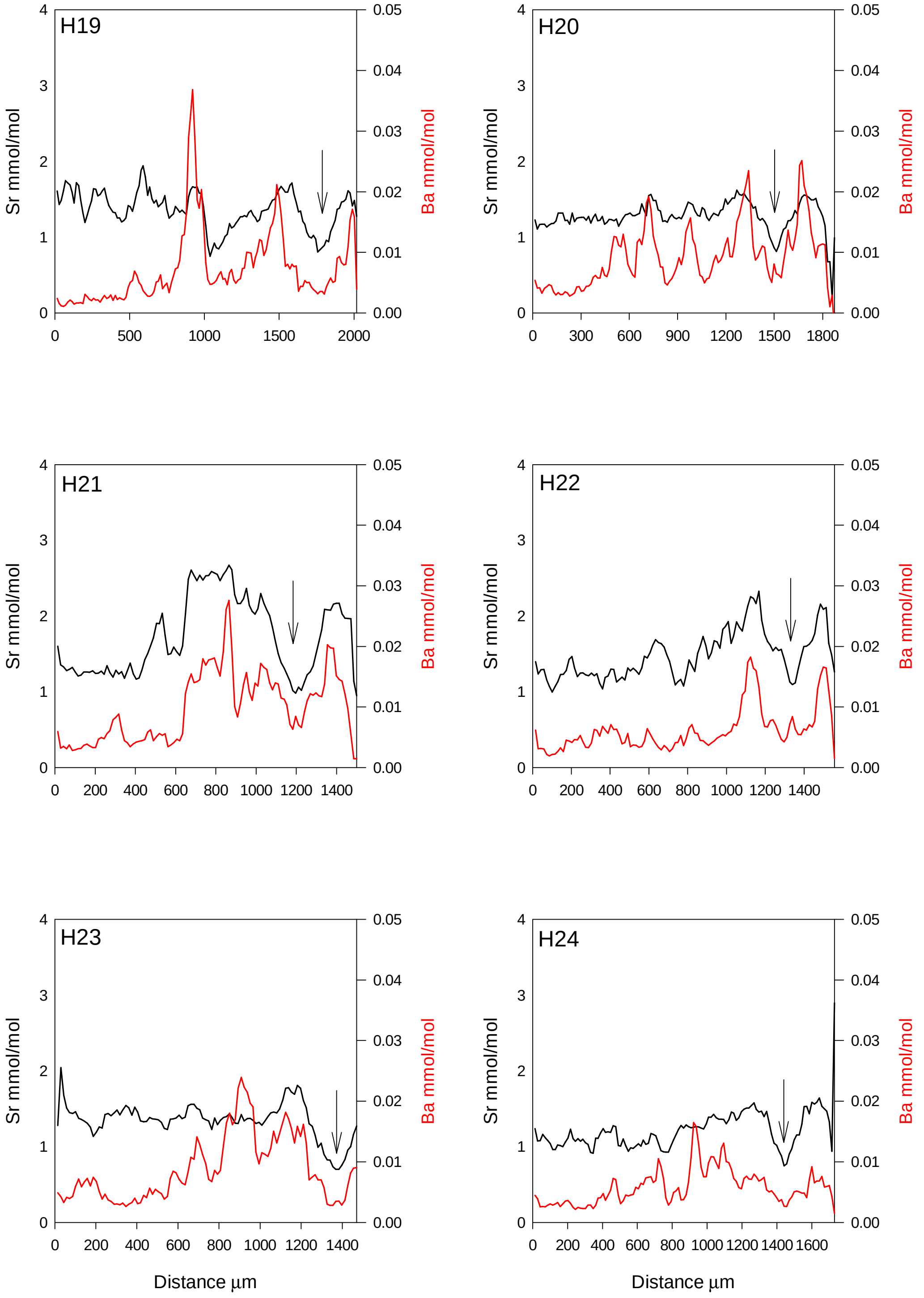

Figure 23. Concentrations of strontium and barium (measured as element:calcium ratios) in otoliths from six trout collected in lower Hurunui River. Each graph represents a full life-history transect running from edge to the core of the otoliths. The arrows indicate the location of the core of the otoliths.

101. 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).

102. 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).

103. In summary, the otolith microchemistry study indicated that there was no evidence of trout migration to and from the ocean. However, there was 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 importance of free passage for maintaining the Hurunui River's outstanding trout population

104. 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.

105. 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.

106. 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).

107. Fish ladders 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 exception to this that I am aware of is the fish pass on the Mararoa Weir in Southland where trout have been observed negotiating the pass (Maurice Rodway, Fish & Game Southland, pers. comm, Figure 24), There is anecdotal evidence that fish passes on the Opuiaki and Omanawa rivers (Tauranga) and the fish pass on the Branch River weir (Marlborough) allow some trout passage (Jowett 1987, Young 2000). However,

more recent data from these passes has failed to confirm successful passage (Rob Pitkethley, Eastern Fish & Game; Lawson Davey, Nelson/Marborough Fish & Game, pers. comm.). In none of these cases is it 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.

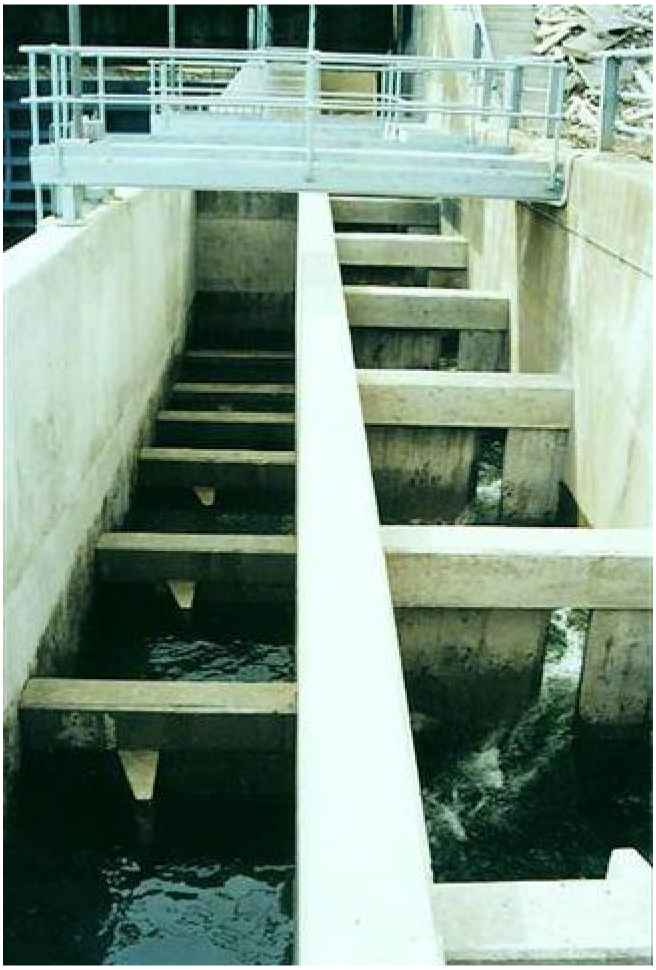

Figure 24. The fish pass on the Mararoa Weir in Southland where trout have been trapped negotiating the pass.

108. Dam construction can also potentially result in the inundation of important habitat, including productive feeding areas and spawning areas upstream of the dam wall. Changes in flow variability downstream of dams can also have adverse effects on habitat quality and algal proliferation.

Effects of Didymo

109. Didymo (*Didymosphenia geminata*) is an exotic benthic diatom which can cover riverbeds in dense mats up to 20 cm thick. Didymo was first discovered in the Mararoa and Waiau rivers in Southland in 2004 and spread to the Hurunui River by 2007.

110. There is concern that proliferations of this alga have the potential to alter the aquatic invertebrate food base for trout with negative consequences for growth and carrying capacity, and affect angling success and satisfaction by fouling anglers' lures and reducing aesthetic value. Didymo could also affect water quality parameters such as pH and dissolved oxygen concentrations to a degree that could be harmful for trout (Bickel & Closs 2008).

111. Didymo forms substantial mats in the mainstem downstream of Lake Sumner due to the lack of bed moving floods. Therefore any impacts will be most apparent there. The more flashy flow regimes elsewhere in the catchment, as shown in Mr Stewart's evidence, will mean that didymo will only become a potential problem after prolonged periods of low flow. My observations during informal drift dives of three sites downstream of Lake Sumner indicate that didymo is much more patchy downstream of the South Branch confluence.

112. Drift dive counts from the Waiau River in Southland, where didymo was first detected, indicate a possible reduction in the numbers of medium-sized brown and rainbow trout in the two years after the discovery of didymo (Figure 25). However, there is a gap in the drift dive record from 2003 to 2005 and the large amount of variability in the record prior to 2002 makes it impossible to confirm if there was a real change.

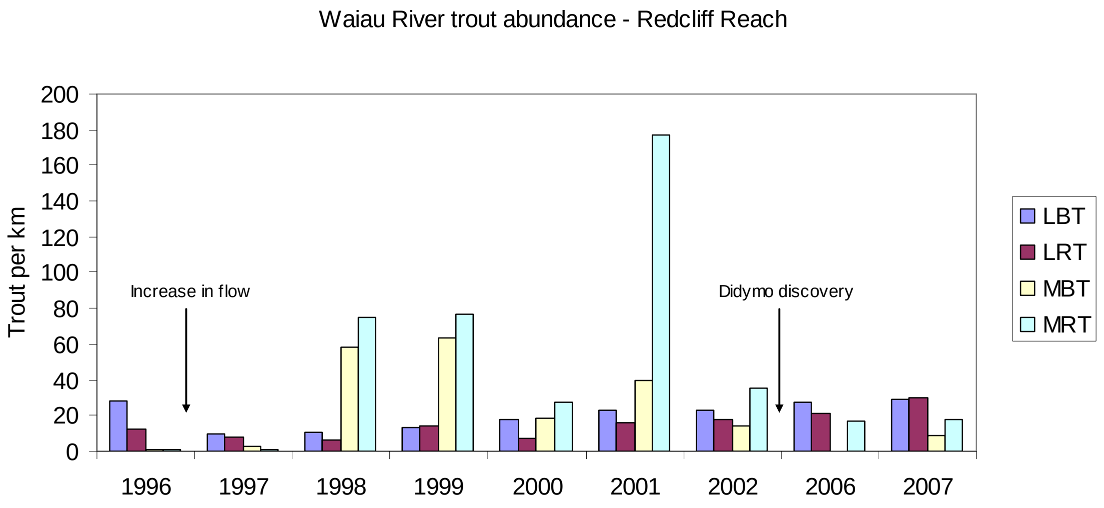

Figure 25. The abundance of large and medium-sized brown and rainbow trout in the Waiau River in Southland associated with increasing minimum flows downstream of the Mararoa Weir and the discovery of didymo (data from Fish & Game Southland).

113. Proliferations of periphyton (biofilm and algae on the river bed) commonly result in a change in aquatic invertebrate community composition, with large, drift-prone, EPT taxa (that is mayflies, caddisflies and stoneflies) being replaced by small (chironomids, algal piercing caddis) or non drifting taxa (oligochaete worms, snails). Such altered benthic invertebrate communities have been found in association with didymo proliferations in the Mararoa River (Kilroy et al. 2006). On the other hand, the same study found that total biomass of benthic invertebrates, including large EPT taxa that trout prefer, was higher in didymo affected sites than in unaffected sites. A similar result was reported by Shearer et al. (2003) but for native algal proliferations in the Pomahaka River, and in that case even the common mayfly *Deleatidium* spp. (a favoured trout prey) occurred at higher densities at sites with high algal biomass. However, in that study the higher densities of mayflies on the riverbed were offset by reduced densities (no./m^3) of mayflies in the drift (that is to say high algal biomass may have been inhibiting drift by mayflies).

114. Didymo proliferations have the potential to impair drift-foraging energetics and reduce trout growth rate and maximum size of trout by reducing the abundance of large drift-prone invertebrates which promote fast growth rate of trout in New Zealand rivers.

115. Colleagues at Cawthron conducted research for Biosecurity New Zealand focusing on the impacts of didymo on invertebrate drift and trout growth in two Southland rivers (Shearer et al. 2007). The results of the study showed no noticeable negative

effect attributable to didymo on invertebrate drift density and biomass, or predicted trout growth potential. However, the study did not include spring and summer, the most critical seasons for trout growth. Therefore, the results must be considered provisional. More research is needed before we can ascertain the effects of didymo on trout growth with any certainty.

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