Using otolith micro-chemistry to track migration and recruitment of brown trout in the Nevis River

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1. Introduction

1.1 This report has been produced by Tobias Oliver Bickel (TOB) and Rickey Olley (RO). TOB has completed a Ph.D. in freshwater ecology at University of Otago in 2006. TOB has researched brown trout migration and recruitment pattern using otoliths microchemistry in several South Island river catchments (Oreti River, Clutha River and Mokihinui River) and took part in the development of the otolith micro-chemical methods. RO has completed a Bachelor of Science degree majoring in Ecology from the University of Otago and is currently nearing the completion of a Masters degree in Ecology, specifically examining and developing the use of element fingerprinting to establish trout movement in the Motueka River catchment. RO also participated in the Oreti River project. Taken together, TOB and RO therefore have substantial experience in brown trout ecology and the application of otolith micro-chemistry to investigate trout migration and recruitment.

1.2 Both authors confirm to have read and agree to comply with the Code of Conduct Expert Witnesses (July 2006).

2. Evidence Summary

2.1 In summary, this report provides evidence that migrations along the main stem of the Nevis River are common among brown trout in this system and that fish recruit from a variety of locations in the catchment and will include:

- The focus of this study.
- The theory and background to otoliths and micro-chemistry.
- A short explanation of the methods.
- Presentation of the results.
- Concluding remarks.
- Implications for brown trout populations in the Nevis River.
- Closing summary.
- Acknowledgements.
- References

3. Research Focus

3.1 The focus of this research was to determine the extent of migration by individual brown trout along the length of the Nevis River main stem and to identify key spawning areas. Specifically, the study aimed to determine (i) whether adult brown trout moved between the reaches above the lower Nevis gorge and the lower reaches including the Kawarau catchment, (ii) the contribution of various tributaries in the Nevis River catchment to the adult stock of brown trout, and (iii) patterns of whole-life patterns of movement of adult brown trout between tributaries and various reaches of the Nevis River

4. Theory and Background

4.1 Understanding the life-history and migration patterns within and among brown trout populations is crucial for effective management of fisheries. Brown trout display remarkable plasticity and variability in life history strategies and are known to be both migratory and resident (Klemetsen *et al.*, 2003). Resident populations are isolated river populations where the fish 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. The most familiar situation 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.

4.2 Otoliths are small calcium carbonate structures found within the inner ear of teleost fish and are used to investigate migration of fish for several reasons (Campana and Tharrold, 2001). Otoliths grow continuously throughout the entire life of the fish, and once material is deposited in the otolith it is not remobilised. Material at the core of the otolith is formed when the fish begins to grow in the egg, and outermost layer is material that has been deposited most recently. Although primarily made up of calcium carbonate, certain trace elements are incorporated into the crystal lattice of the otolith as a substitute for calcium. Different environments will 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 therefore also change, 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 Tharrold, 2001; Wells *et al.*, 2003).

5. Methods

5.1 To investigate migration of adult fish in the Nevis River main stem up- and downstream of the lower Nevis River Gorge, two approaches were taken. Firstly, the Nevis River was divided into four different sections (Fig 1). Otoliths from adult brown trout caught in the mid Nevis (the area with highest angling usage) were analysed for life long variations in trace element signatures indicating migratory behaviour. Secondly, juvenile trout (1 – 2 years old) were collected from the four main stem sections, the Kawarau River, and from major tributaries of the system to establish elemental habitat signatures for all these reaches (main stem sections and tributaries). Migration of adult fish from the mid-Nevis River was then traced through the reaches. Finally, we identified the hatch origin of the adult fish by comparing the micro-chemical habitat fingerprints with the micro chemical composition around the centre of adult otoliths that represent the time of hatch.

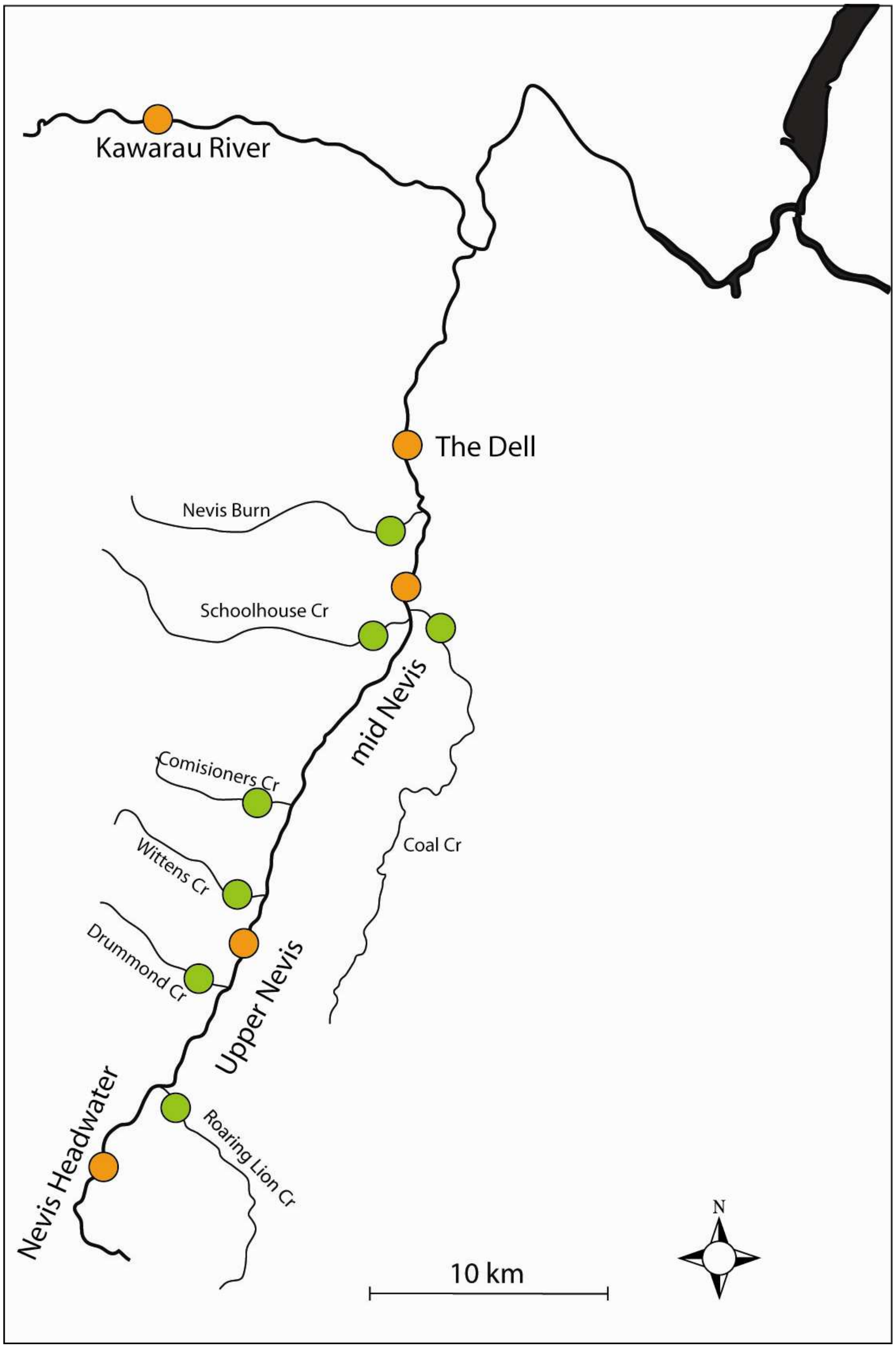

Fig. 1: Map showing the Nevis River and location of the five main stem sections; The Dell located within the lower gorge (1), mid Nevis above the lower gorge (2), the upper Nevis above the upper gorge (3), the Headwaters (4) and the Kawarau River above Nevis confluence (5) and the major tributaries where juvenile brown trout were collected.

5.2 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 glued 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.

5.3 Estuarine signatures in adult fish of all sections

To analyse otoliths from adult brown trout collected in the mid Nevis for variations in trace elements, scans across the entire otoliths were completed. This was done by reducing the otoliths to a thin section and then running the laser across from edge to core producing in a trace element life history transect. The life history transects were then inspected for changes in concentrations of strontium and barium which indicate habitat shifts and therefore, migration between reaches and/or tributaries.

5.4 Migration along the main stem of the Nevis River and recruitment

We determined trace element habitat signatures for four main stem sections (the Dell, mid Nevis, upper Nevis and Headwater), the Kawarau River and the sampled tributaries by analysing the edge area of juvenile otoliths. This material represents the otolith material deposited most recently and is hence representative of the trace element signature of the location where the fish have spent time just before they were caught. Therefore, instead of scanning the laser across the entire otolith, only the material at the edge was ablated. The otoliths were analysed for six different elements, strontium, barium, manganese, magnesium, cadmium and rubidium which have previously been found to be useful in discriminating between sites within river catchments. To investigate possible differences in trace element signatures between river reaches and tributaries, the trace element data were then entered into a linear discriminant function analysis.

After the trace element signatures were determined, the next step was to track migration of adult fish through the different habitats in the Nevis River catchment. For this, the otoliths of adult fish were scanned with the laser from otolith edge to core to obtain full trace element life-history transects. From these transects we identified the natal elemental habitat signature of the adult fish (ca. 300 μm from the core as previously determined). The core of the otolith can be determined not only by symmetry in the transect, but also by a distinct spike of manganese which is thought to be physiologically derived (Rutenberg *et al.*, 2005). Additionally we obtained yearly habitat signatures for individual fish from to be able to track migration of adult fish.

The elemental habitat signatures of the natal and yearly habitat signatures could then be directly compared to the previously established elemental habitat signatures of the main river section and tributaries. This allowed the tracking of fish migration through out the entire life span of individual fish and the identification of recruitment from the natal fingerprints.

6. Results

6.1 Variation in element signatures of adult trout from the mid Nevis

From a total of 10 large (>5 years) and 7 medium (>3 years) sized adult brown trout (trout1-10, and medium1-7, respectively) that were collected from the mid Nevis River, we constructed 17 life history transects.

Of the ten large fish that were collected in the mid Nevis River, all showed pronounced variations in Sr and Ba levels throughout their life history (Fig. 2a & b). These variations in Sr and Ba levels indicate migration between river sections and/or tributaries which differ in Sr and Ba concentrations in their respective water. Additionally, some of the fish showed quite abrupt changes in Sr levels after more stationary early life stages (first 1-2 years), indicating a habitat shift from spawning and nursery habitats to the adult habitat in the river catchment (see for example trout 3).

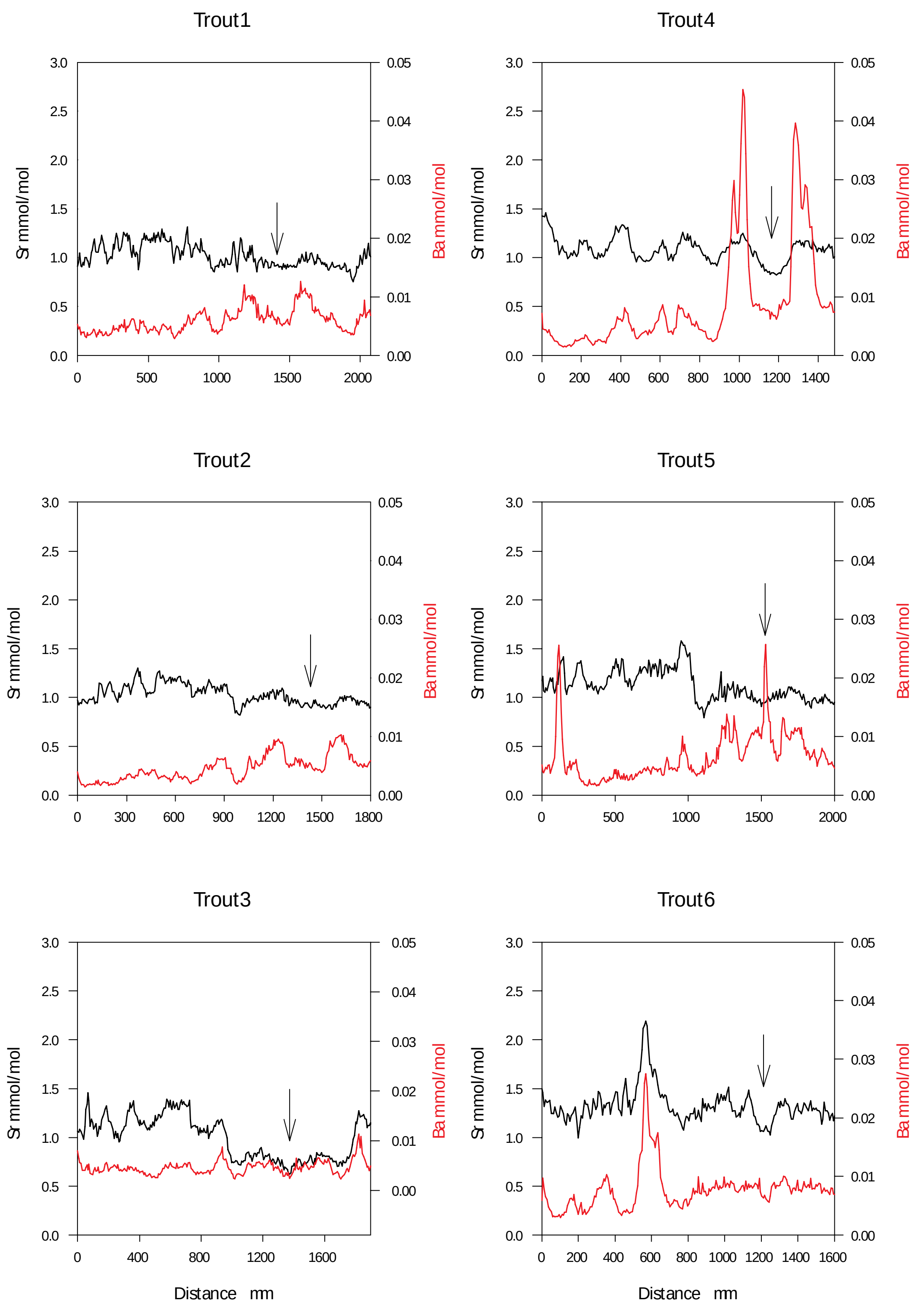

Fig. 2a: Concentrations of strontium and barium (measured as element:calcium ratios) in otoliths from six large trout collected in mid Nevis River. Each graph represents a full life-history transect running from edge to the core of the otoliths. The arrows indicate the location of the core of the otoliths.

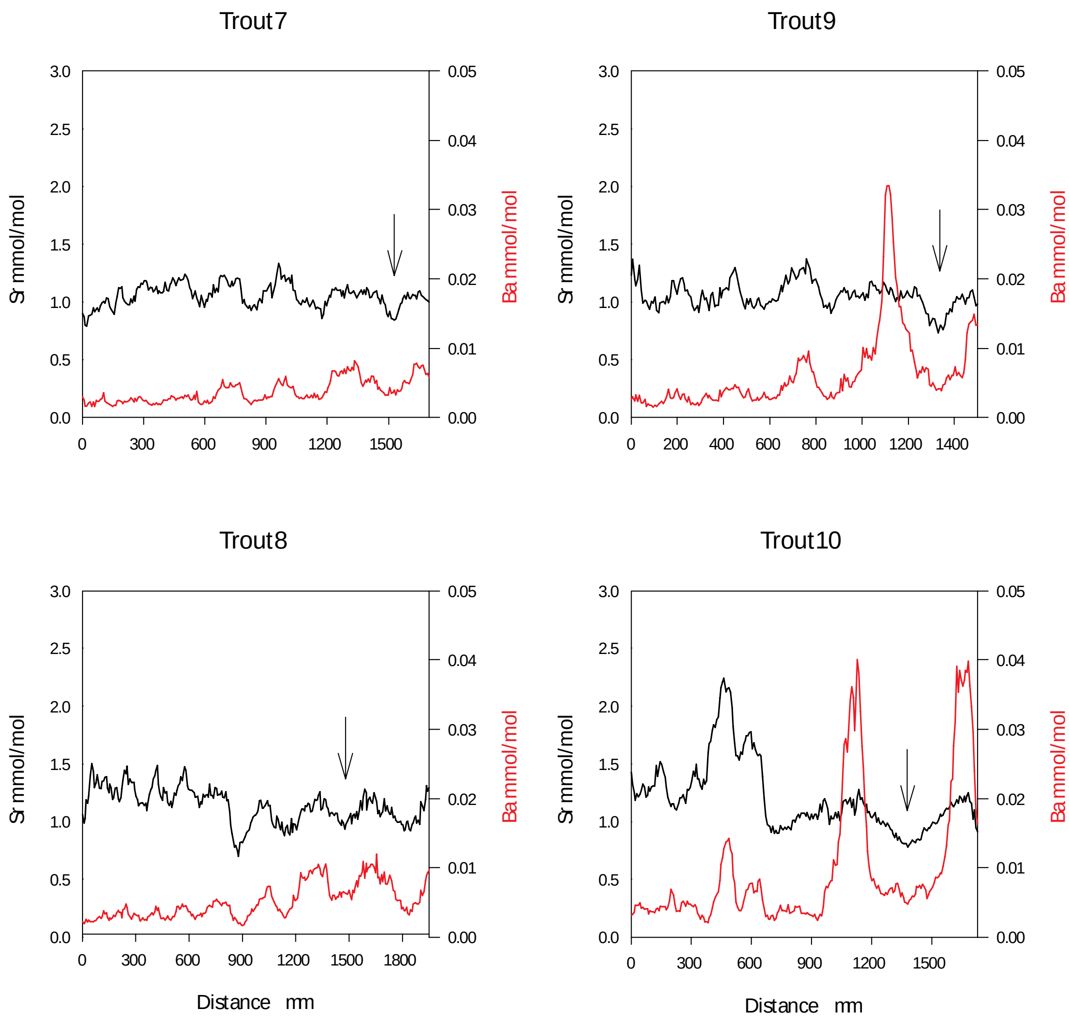

Fig. 2b: Concentrations of strontium and barium (measured as element:calcium ratios) in otoliths from four large trout collected in mid Nevis River. Each graph represents a full life-history transect running from edge to the core of the otoliths. The arrows indicate the location of the core of the otoliths.

As seen in large trout, the medium sized trout (>3 years) showed variations in Sr and Ba levels throughout their (shorter) live history, indicating movement between river sections and tributaries (Fig 3a & b). Variation in element concentrations were less pronounced as with large fish, presumably due to less pronounced migratory behaviour in earlier live stages (see stationary early life stage in some of the large trout).

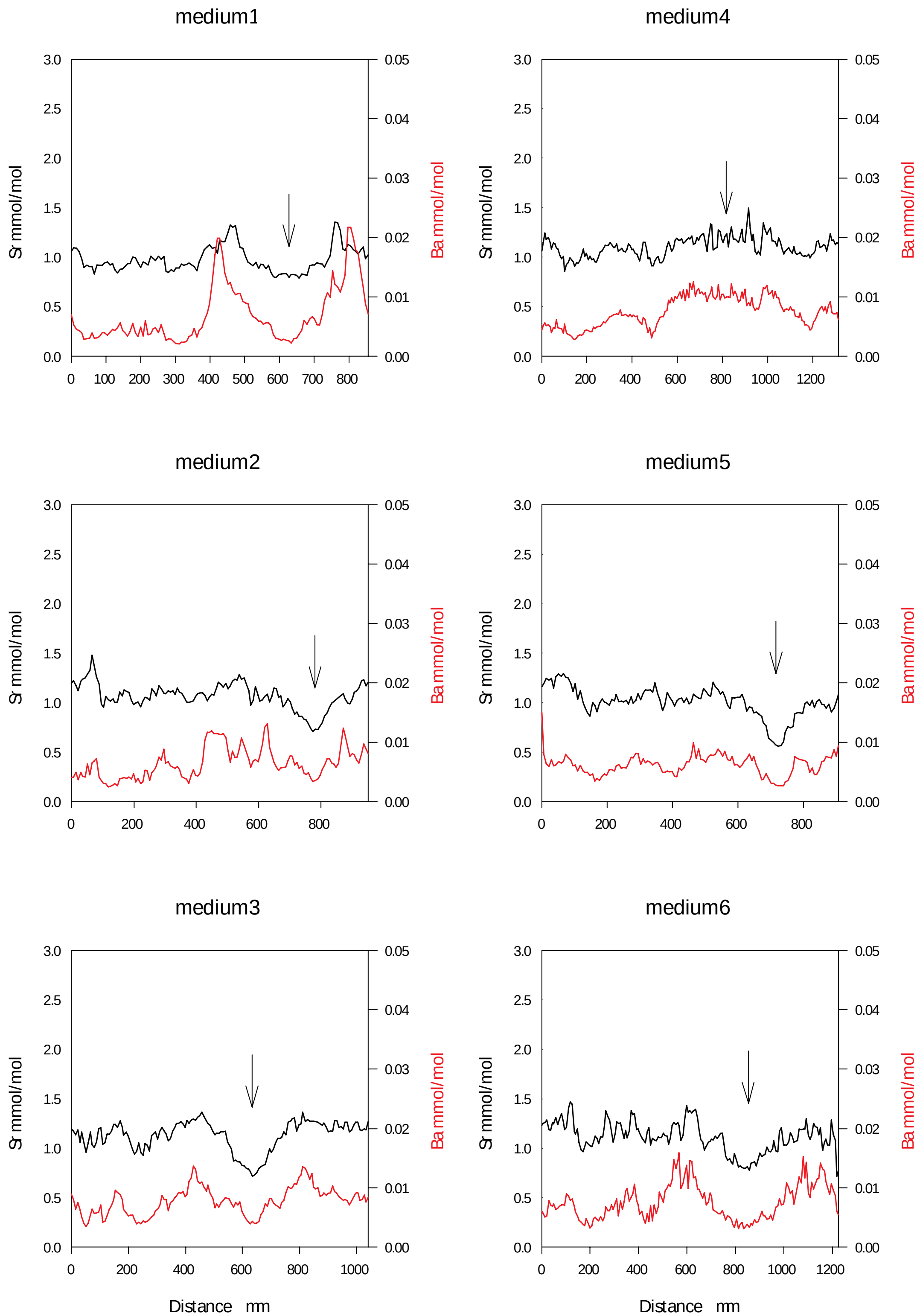

Fig. 3a: Concentrations of strontium and barium (measured as element:calcium ratios) in otoliths from six medium sized trout collected in mid Nevis River. Each graph represents a full life-history transect running from edge to the core of the otoliths. The arrows indicate the location of the core of the otoliths.

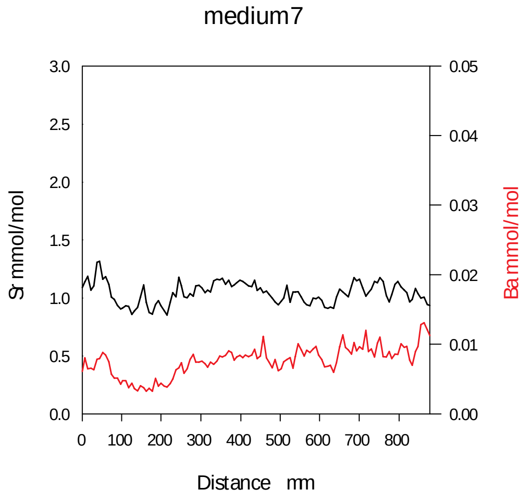

Fig. 3b: Concentrations of strontium and barium (measured as element:calcium ratios) in otoliths of one medium sized trout collected from the mid Nevis River.

6.2 Migration along the main stem of the Nevis River

As there was considerable overlap in habitat signatures of the headwater, upper and mid Nevis, these Nevis River sections were grouped together into a single section in the following analysis (Nevis River, above lower gorge). Additionally, this simplifies analysis and helps interpretation of the data.

The construction of habitat trace element signatures for the grouped Nevis River, Kawarau River and tributaries showed that habitat trace element signatures were significantly different (Pillai's trace = 1.763, df = 45, $P < 0.0001$). Overall, 50% of the fish were classified correctly into the area where they were caught (Fig. 4). There was a perfect (100%) classification of the fish collected from the Nevis Burn, a 80% classification success for Schoolhouse Cr and 70% success for Roaring Lion Cr, Schoolhouse Cr and the Nevis River in the lower Gorge (the Dell), respectively. However, the Kawarau River could not be distinguished from the Nevis River by this analysis due to similarities in element signatures. The overall classification success allows the tracking of fish and the identification of recruitment areas to a certain degree. However, the overlap between some of the habitats will limit the predictability of exact migration routes and recruitment areas.

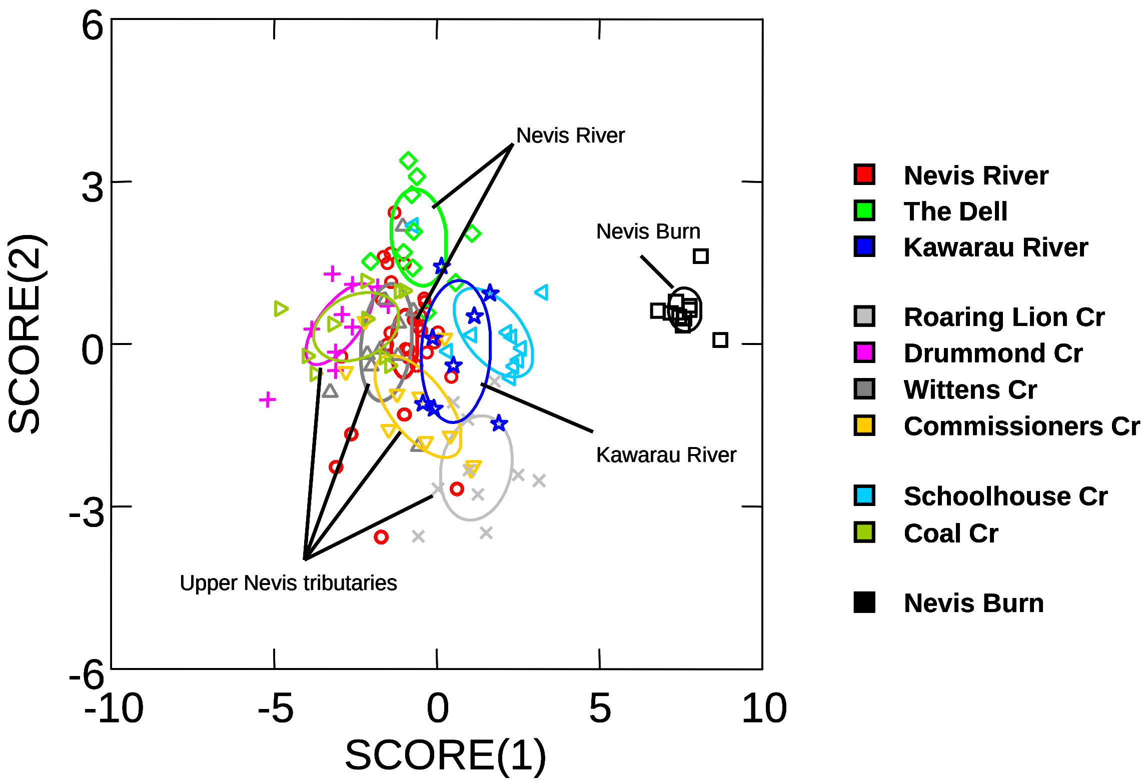

Fig. 4: Plot from the discriminant function analysis showing grouping of individual fish into elemental habitats. Ellipses represent 95% confidence intervals.

Migration routes by large trout from the mid Nevis

The trace element signatures obtained from juvenile fish otoliths (Fig. 4) allowed the tracking of long term migration by adult trout within the Nevis River catchment to a certain degree. The tracking of individual large fish caught in the mid Nevis is presented in Figures 5a & b. The origin of most adult trout seemed to be from outside the Nevis River main stem itself as fish recruited from tributaries. After rearing in tributaries fish drop downstream into the main river and appear to undertake migrations within the main stem itself (see for example t4 which most likely recruited from Schoolhouse Cr). Other fish originated from downstream sources (t1; the Dell area) before moving into the Nevis River. Note that the confidence ellipse of the Nevis River is very small due to the high sample number from this habitat, after merging fish from the upper and mid Nevis sections as explained in the previous section. Fish that appear to move out of the system (as for example t1) most likely moved within the Nevis River as the spread of the Nevis river sample extend further to the lower part of the graph (compare with Fig. 4). However, there was one fish (t6) that possibly migrated into the Nevis River from beyond the Nevis/Kawarau River system. We can only speculate that this fish might be from the Clutha system that is only a few kilometres downstream of the Nevis/Kawarau River confluence.

In general, most large adult fish recruited from a variety of sources in the River system and most fish seem to undertake life long migrations within the Nevis River system. For the overlap between the Nevis and Kawarau River habitat signatures, we can't predict if fish migrate between these two systems (that is move upstream from the Kawarau, through the lower gorge and into the mid Nevis). However, as most of the adult migration routes are grouped into the lower part of the graph (that is separated from the Kawarau confidence ellipse) it is more likely that most of the movement is confined to the Nevis River itself. Nevertheless, one of the adult fish apparently moved into the Nevis River from beyond the gorge.

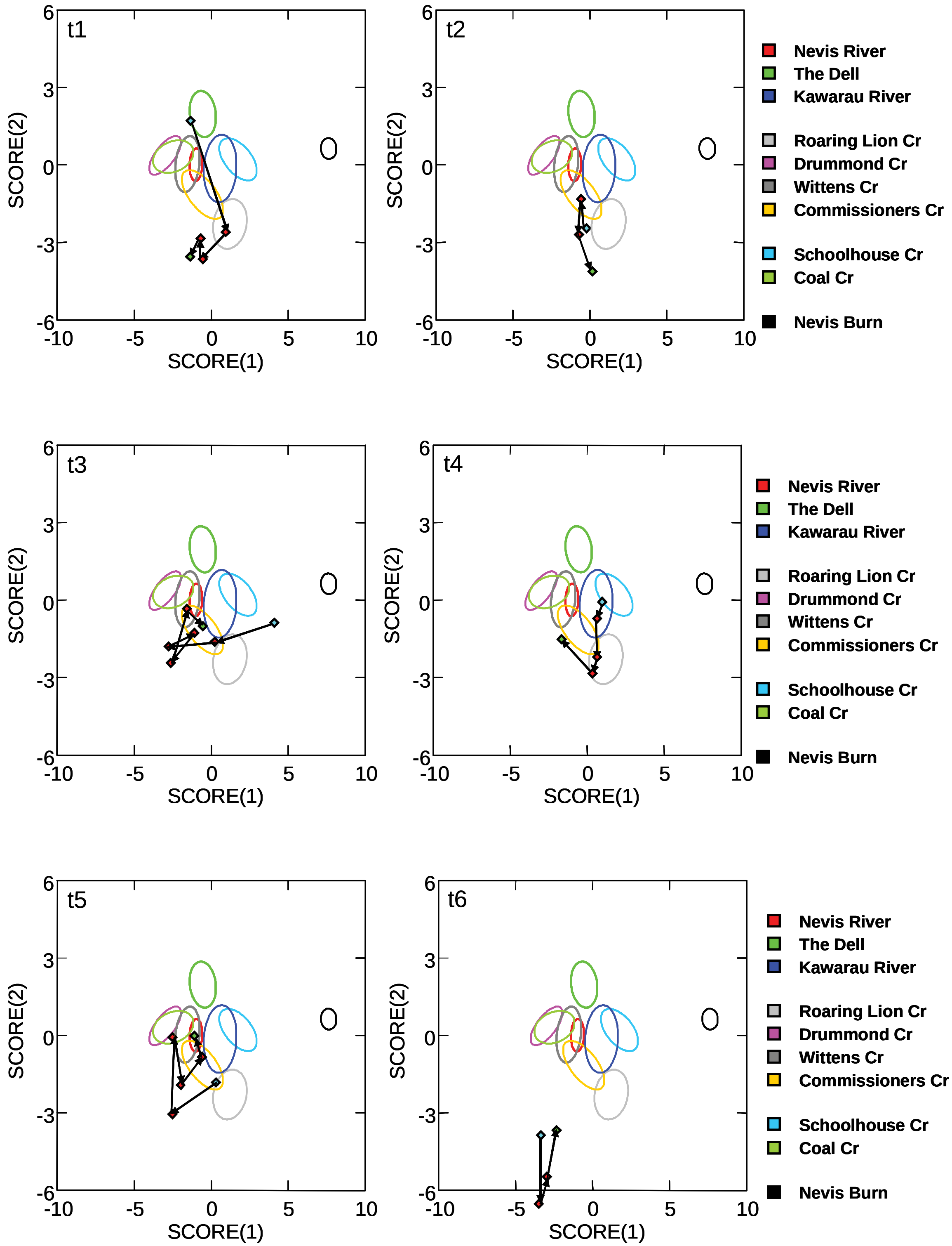

Fig. 5a: Tracking of life-long migration routes by six large brown trout collected in the mid Nevis overlaid over the elemental habitat signatures for the different areas of the Nevis River. First point of each track represent the habitat where fish were spawned, the following points each represent subsequent years that are connected by arrows in a chronological order. See text or further explanation. For clarity, only the 95% confidence ellipses are shown for the elemental habitat signatures for each area.

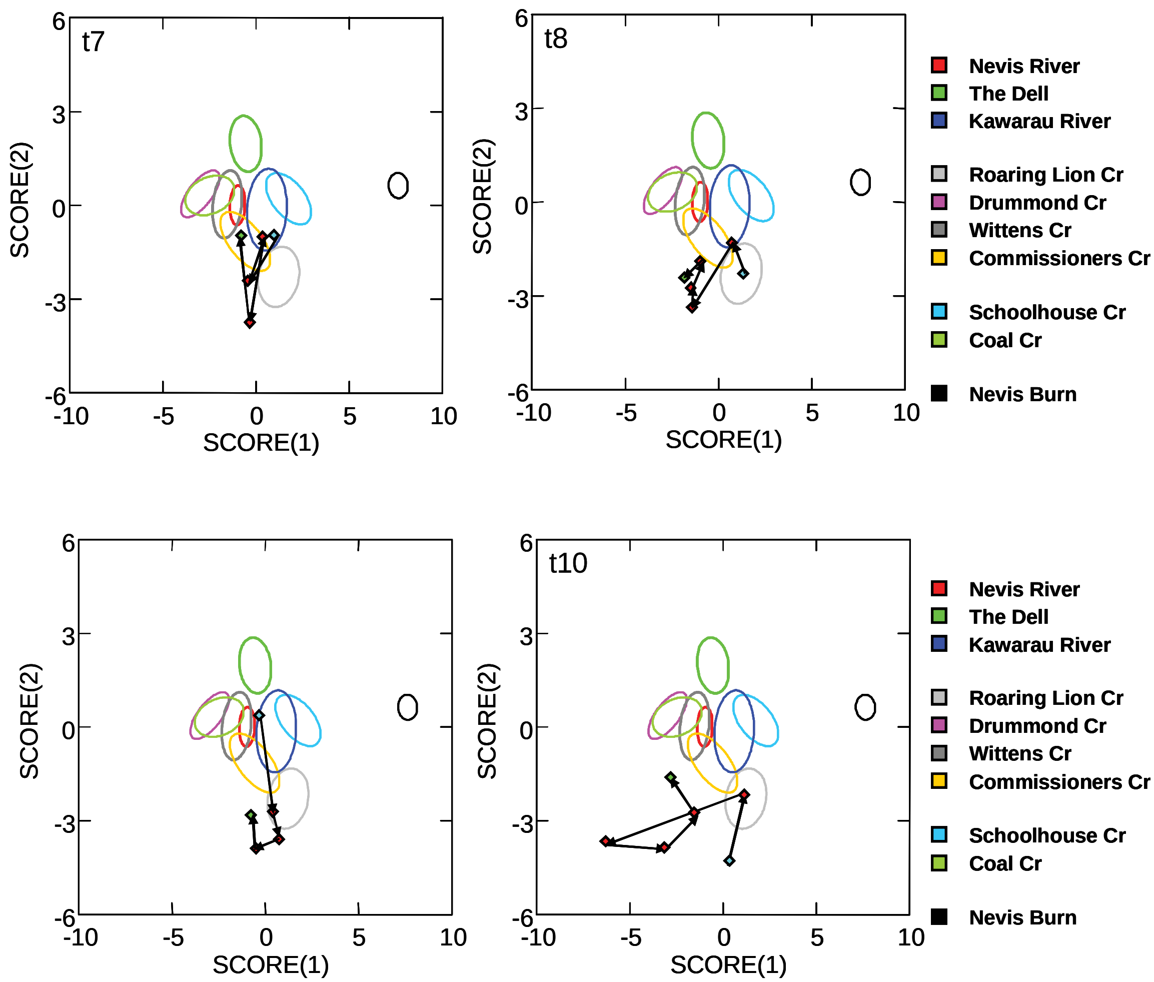

Fig. 5b: Tracking of life-long migration routes of four large brown trout collected in the mid Nevis overlaid over the elemental habitat signatures for the different areas of the Nevis River. First point of each track represent the habitat where fish were spawned, the following points each represent subsequent years that are connected by arrows in a chronological order. See text or further explanation. For clarity, only the 95% confidence ellipses are shown for the elemental habitat signatures for each area.

Migration routes by medium sized fish from the mid Nevis

As seen with the large adult fish, medium sized trout recruited from a variety of sources before migrating into the Nevis River (Fig. 6). As these fish were mostly about 3 years old, the migration routes are much shorter than the previous ones presented. However, one can still see that even this medium sized fish undertake migrations within the Nevis River. Of the six fish that we analysed, none appeared to come from outside the river system. As discussed above, due to the overlap of Nevis and Kawarau River habitat signatures we can’t determine if fish migrated between these two river systems.

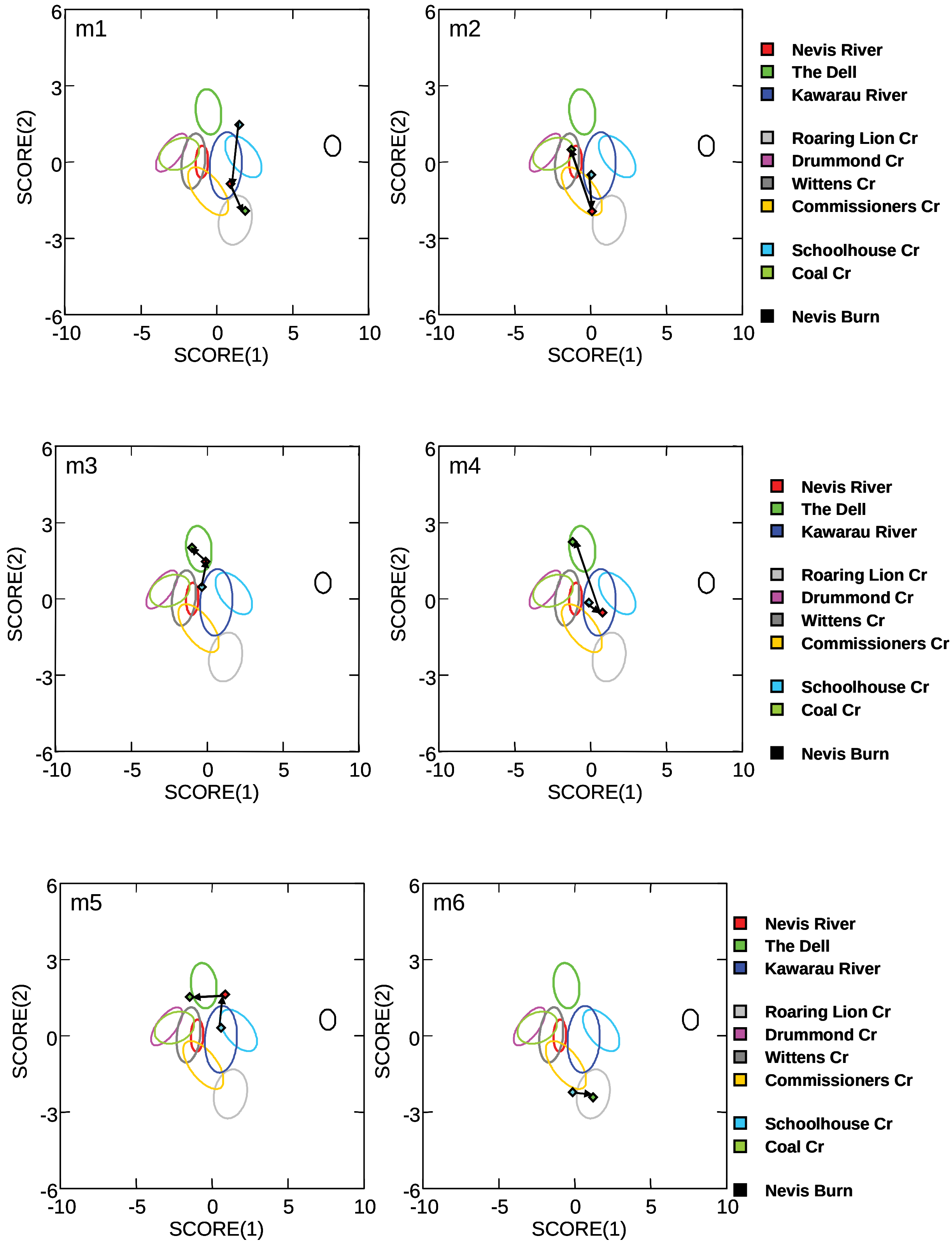

Fig 6: Tracking of life-long migration routes of six medium sized brown trout collected in the mid Nevis overlaid over the elemental habitat signatures for the different areas of the Nevis River. First point of each track represent the habitat where fish were spawned, the following points each represent subsequent years that are connected by arrows in a chronological order. See text or further explanation. For clarity, only the 95% confidence ellipses are shown for the elemental habitat signatures for each area.

6.3 **Recruitment**

Previously the migration routes of selected adult fish were presented including the inferred origin of these fish. In this section we will summarize the origin of all the adults collected for the study.

As can be seen from Figure 7a & 7b, adult fish collected in mid Nevis originate from a variety of location, with equal proportions (41% each) recruiting from the upper Nevis system (above upper gorge) and mid Nevis (Schoolhouse flat and tributaries). However, there was still a considerable recruitment from the lower gorge (18%), i.e. the Nevis Burn and the Dell area of the lower Nevis (Table 1). The Roaring Lion Creek from the upper Nevis River system was the single most important habitat in terms of the number of adult trout that originate from this tributary.

Table 1: The most likely origin of ten large and seven medium sized fish caught in the mid Nevis River as predicted by discriminant function analysis using the micro-chemical signatures.

Reach	large fish	medium fish	all fish
Nevis River	2	-	2
Roaring Lion Cr	4	3	7
Drummond Cr	-	-	
Wittens Cr	-	-	
Commissioners Cr	-	3	3
Schoolhouse Cr	-	1	1
Coal Cr	1	-	1
Nevis Burn	2	-	2
The Dell	1	-	1
Kawarau R	-	-	-
total	10	7	17

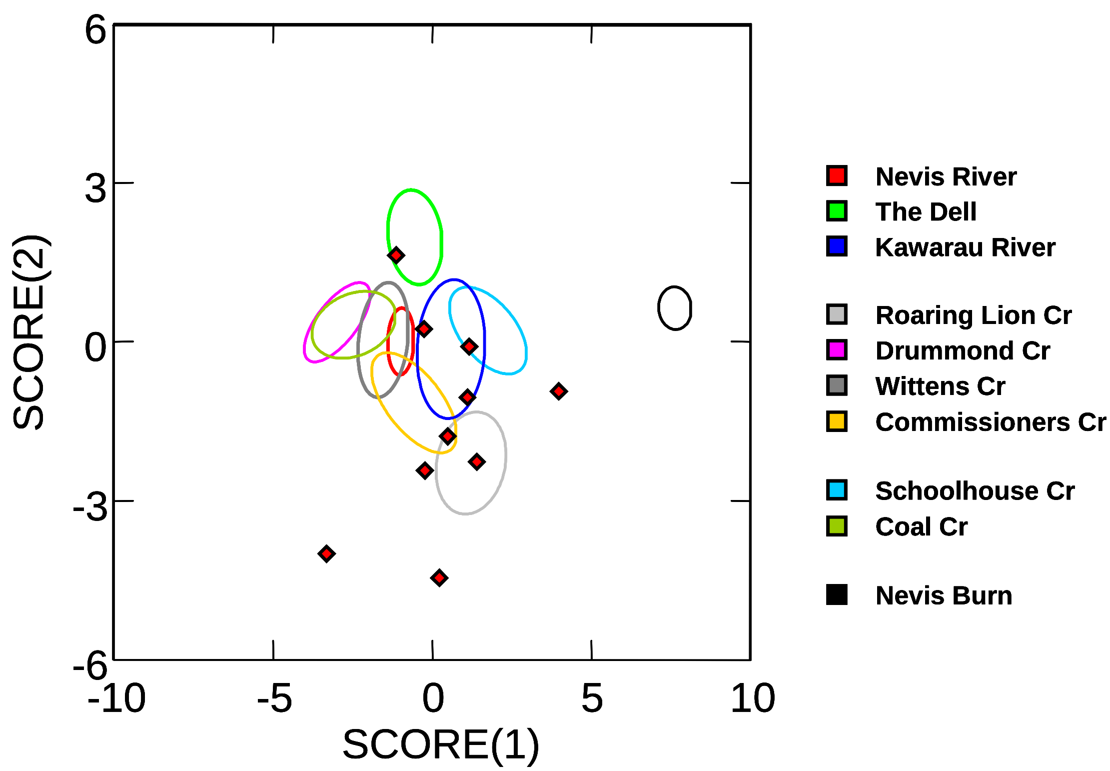

Fig 7a: The origin of all the large adult fish collected from the mid Nevis River. Each of the points represent the likely location of hatch as predicted from habitat signatures of individual adult trout. For clarity, only the 95% confidence ellipses are shown for the trace element signatures for each area.

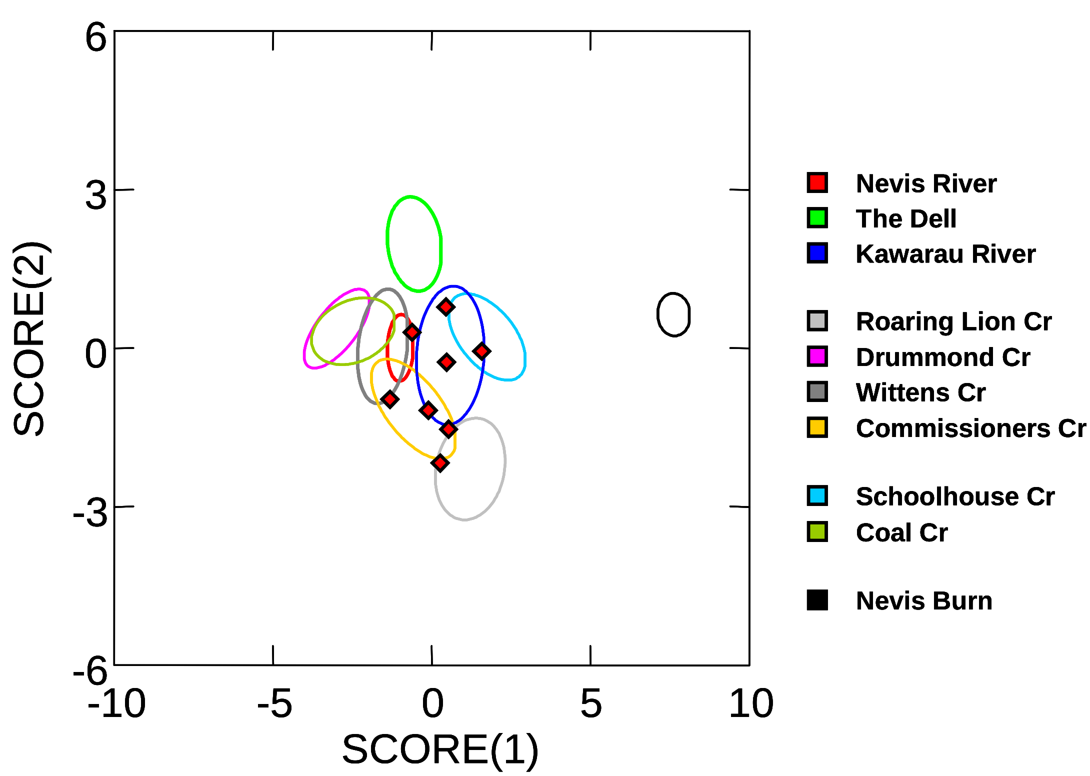

Fig 7b: The origin of all the medium adult fish collected from the mid Nevis River.

7. Conclusions

7.1 The results do indicate that life long migrations within the catchment are a common feature of the life history of brown trout in the Nevis River. Juvenile fish recruited from a variety of sources in the upper, mid and gorge section of the Nevis River. These recruitment patterns and the migratory behaviour of adult fish therefore effectively link the trout populations of the different river sections.

7.2 Construction of trace element habitat signatures of different sections of the main stem and tributaries and the subsequent tracking of life-long migration by individual brown trout revealed that life long migratory behaviour is a common feature among brown trout from the Nevis River. Due to the overlap of habitat signatures of Nevis and Kawarau Rivers, we could not determine if trout migrate between these to Rivers; that is through the lower Nevis River Gorge. However, most likely, most of the adult trout migration is restricted to the mid and upper Nevis River, and fish extensively migrate within and between these river sections. One of the large fish possibly migrated into the Nevis River from beyond the Kawarau River system.

7.3 We were able to identify the recruitment areas of the Nevis River sections. The upper and mid Nevis River sections, including the tributaries, were the most important recruitment areas for the adult fish investigated in this study. However, nearly 20% of the adult fish caught in the mid Nevis originated from the lower gorge itself (the Dell) or from the Nevis Burn which flows in the Nevis near the Dell area. Therefore, recruitment in the mid Nevis partly depends on fish movement from the lower gorge.

7.4 These results are mirrored by similar studies performed other South Island River systems, including the Taieri River, the Motueka River, the upper Clutha River, the Mokihinui River, and the Oreti River. In all these systems juvenile and adult brown trout also complete migrations over large distances and often span the entire catchment. The results presented here add to the growing body of evidence suggesting that the ecology of the brown trout within New Zealand includes life history strategies involving large scale movements.

8 Implications for management of brown trout in the Nevis River

8.1 Given the long distance migrations along the main stem performed by brown trout in the Nevis River, it is clear that any barrier preventing migration throughout the catchment could have negative impacts on the brown trout population in the river, particularly in the mid reaches which are most important from a fisheries perspective. Adult brown trout from the mid Nevis recruited from a wide variety of sources, including downstream ones. These recruitment patterns and the migration of adult fish effectively link trout populations in the different Nevis River sections. As we could not distinguish the micro chemical habitat signatures of the Kawarau and Nevis River we can not fully quantify the possible impact of a possible artificial barrier that would inundate large parts of the mid Nevis River sections. However, regarding the recruitment from this area of the River (41%) and from below a proposed dam site at Nevis River crossing (18%) a barrier could impact trout recruitment in a future impounded Nevis River.

9 Summary

9.1 In summary, this research on brown trout migrations provides information suggesting that brown trout in the Nevis River migrate within the Nevis River system and spawn in several of the tributaries of the entire river system. This would appear to be a life history strategy particular to brown trout as a species, given the similar results obtained from other New Zealand rivers. Construction of barriers preventing these migrations might therefore have negative impacts on the brown trout populations. Additionally, barriers also have the potential to interfere with recruitment of fish populations.

10 Acknowledgements

10.1 We wish to thank Aaron Horrel for tireless and ingenious effort in collecting the adult trout under extremely difficult circumstances. Fish&Game Otago granted permission for fish sampling and provided an electro fishing machine and other support (including fish samples gathered by Morgan Trotter). We would also like to thank Greg Yaxley and Charlotte Allen from the Research School of Earth Sciences at Australia National University for help with analysis of otoliths.

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