Water abstraction impacts on the non-migratory galaxiids of Totara Creek

Richard M. Allibone

National Institute of Water & Atmospheric Research Ltd, PO Box 11-115, Hamilton, New Zealand. Email: r.allibone@niwa.cri.nz

ABSTRACT

Totara Creek, a third-order stream in the Taieri River catchment, was investigated to determine what impacts water abstraction from this stream was having on the resident non-migratory galaxiid population. The water abstraction regime varies, either 100% of the water is abstracted or no water is abstracted. Either condition can be in operation for long periods although periods of abstraction are usually greater than non-abstraction periods. Impact assessment centred on impacts to the fish populations, but also investigated physical habitat alterations. The most critical impact appears to be the linking of two galaxiid species via the water abstraction water race. This linkage has led to hybridisation occurring between the two species and a galaxiid hybrid swarm now occupies Totara Creek. This impact is irreversible and should be considered a major environmental concern associated with water abstraction. Other impacts were also numerous and on-going. These include: a lack of fish passage in an upstream direction at the abstraction site; spawning habitat disruption downstream from the abstraction; alterations to the stream's water temperature regime; significant fish mortalities in the water abstraction water race when abstractions are halted; increased erosion in the stream receiving water from Totara Creek and reductions in juvenile recruitment rate.

Keywords: non-migratory galaxiids, water abstraction, fish passage, hybridisation, invasion, deformaties, population impacts, spawning habitat.

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1. Introduction

Totara Creek is a third-order tributary of the Taieri River. The stream drains part of South Rough Ridge in the Maniototo region of Central Otago. It flows from its source for approximately 11 km northward along Rough Ridge before descending steeply to the Maniototo Plains. In the upper reaches the stream has a gentle gradient, descending from 1100 m to 940 m in those first 11 km. The gradient increases when the stream descends from 940 m to 440 m in 7 km as it flows off Rough Ridge to the Maniototo Plains.

Totara Creek has two water abstraction sites, one in the upper low gradient reach and one at the base of the descent off Rough Ridge. The upper abstraction site is constructed at the site of an old dam, assumed to be a relic of the goldmining era. Water is transported from the reconstructed dam along a restored goldminer's water race from Totara Creek to a Pool Burn Reservoir tributary (Fig. 1). This abstraction, when operating, generally takes all the water in Totara Creek at the abstraction site. Upstream of this abstraction the stream flows through a large upland wetland that has numerous small tributaries. Below the abstraction the stream is confined within a valley and has few tributaries. The lower abstraction removes water for use by Linn Burn Station and was not part of this study.

This investigation in Totara Creek commenced in September 1998 and continued through to February 1999 and aimed to determine if the water abstraction was impacting or has impacted upon the resident galaxiid population. Fish mortality associated with the abstraction, fish population parameters, stream habitat alterations, water temperature, fish invasion probability and fish passage were all studied.

2. Fish species in the Totara Creek region

The upper reaches of Totara Creek are occupied by a single fish species, a non-migratory galaxiid. Investigations of the species status of this population are still on-going. Following isozyme genetics studies of non-migratory galaxiids in the Taieri River, Allibone et al. (1996) recognised this population as distinct. G.P. Wallis & J.M. Waters (pers. comm.), using DNA studies, have found that a hybridisation event between an undescribed galaxiid and *Galaxias depressiceps* (flathead galaxias) has occurred in Totara Creek, in the relatively recent past. The extent of hybridisation and the distribution of hybrids are, as yet, not fully determined; but it appears that Totara Creek contains a hybrid galaxiid population. Pure strain populations of the undescribed galaxiid have been located in the upper parts of the Pool Burn Reservoir tributary and Maori Creek (Fig. 1). Further hybrid individuals have been detected in the lower parts of the Pool Burn Reservoir tributary and the water race connecting Totara Creek to the

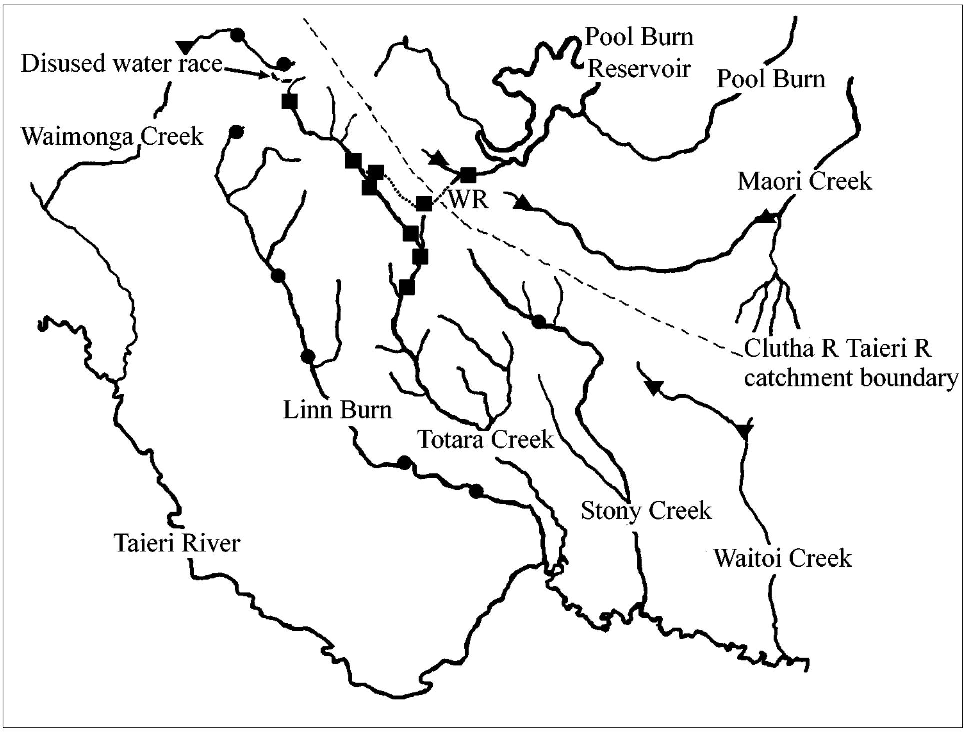

Figure 1. A map showing Totara Creek and adjacent streams with the distributions of galaxiid species indicated, hybrid galaxias (■), flathead galaxias (●), and undescribed galaxias (▲), sites where no fish are present (▼). The upper Totara Creek abstraction water race is indicated by dotted line (WR).

Pool Burn catchment. Populations of *G. depressiceps* are present in Stony Creek, Linn Burn and Waimonga Creek, all streams adjacent to Totara Creek (Fig. 1). It is unclear which galaxiid—the undescribed galaxiid or *G. depressiceps*—was the original resident species in Totara Creek. A disused goldminers water race appears to have provided fish passage for *G. depressiceps* between Waimonga and Totara Creeks. Similarly, fish passage is available for the undescribed species from the Pool Burn Reservoir tributary to Totara Creek via the present-day water race. Therefore, either species could have invaded Totara Creek and hybridisation could have resulted from movement mediated by human activities.

The biology of the Totara Creek fish has been investigated in conjunction with other Taieri River non-migratory galaxiids. Allibone (1997) described the population structure and monitored fish abundance at three sites in Totara Creek. Allibone (1997) recorded fish up to 157 mm in Totara Creek. This maximum size is greater than that for any other non-migratory galaxiid in New Zealand. Abundance fluctuated at all sites due to spawning movements and flood disruptions. Fish densities ranged from 0.4 to 3.4 fish/m^2. High densities were found at the very upper part of the stream and at a site 300 m downstream from the dam (Fig. 2). The high densities at the site below the dam occurred after water race reconstruction and flood events. At times, fish densities in Totara Creek were substantially higher than those found for other Otago galaxiids (*Galaxias anomalus* and *G. eldoni*) but similar to *G. depressiceps* (Allibone 1997).

Allibone (1997) also investigated growth and age of the Totara Creek fish. These results were not conclusive, but indications were that growth rates were low and hence maximum age for the large fish was high. Allibone (1997) considered it possible that some fish were more than ten years old.

Allibone & Townsend (1997) investigated the spawning biology of the Totara Creek galaxias. They found two spawning sites for the fish, both at the head of riffles under over-hanging vegetation (tussock roots). Spawning occurred in October with spawning aggregations of fish appearing at spawning sites. These aggregations produced fish distributions characteristically different from fish distributions at other times of year. Allibone (unpubl. data) found that fish at spawning sites were not generally fish resident in the immediate area, indicating that fish travelled to areas of preferred spawning habitat.

Allibone & Townsend (1998) reported on the diet of Totara Creek fish and concluded that they had a generalist invertebrate diet. The diet samples were collected from a site just downstream of the dam site on two occasions, in November 1992 and January 1993. Dietary items included a very broad range of aquatic and terrestrial invertebrates.

3. Deformed fish occurrences

Deformed fish have been located at all sites in Totara Creek (R. Allibone pers. obs.). Deformities appear to be more pronounced in larger fish, but they also occur in fish as small as 59 mm. The nature of the deformities is varied, but generally involves the head and jaw structure and, occasionally, the fin structure (Photos 1 & 2, end of report). The distribution of deformed fish and cause(s) of the deformities were investigated during this study

Deformed fish were most numerous at the mid-Totara site, immediately downstream of the dam (Table 1, Fig. 2), and at sites in the water race. This was, in part, due to the general abundance of fish at these sites. Fish from Waimonga Creek were also deformed, although only rarely. No deformed fish were located in Linn Burn or the Pool Burn Reservoir tributary.

The cause(s) of the deformities was not identified. Deformities that occur with increasing severity as organisms grow are often the result of organophosphate insecticide residues (C. Hickey pers. comm.). Enquiries among the landowners and leasees in the Totara Creek catchment indicated that insecticide use has never occurred in the Totara Creek catchment. A second possibility is heavy metal poisoning, resulting from leaching at old gold mining areas. However,

TABLE 1. THE PERCENTAGE AND NUMBER (IN BRACKETS) OF DEFORMED FISH OCCURRING AT SITES IN TOTARA CREEK AND THE ABSTRACTION WATER RACE.

SAMPLE DATE	TOTARA CREEK			WATER RACE		
	Lower	Mid	Upper	Site 1	Site 2	Site 3
Nov 1998	9.4%(3)	40.6% (13)	0%			
Dec 1998			20% (3)	6.1% (6)	18.9%(7)	12.0% (3)
Feb 1999	1.5% (1)	14.0% (9)	2.2% (1)	15.2% (9)	17.2% (16)	5.9% (7)

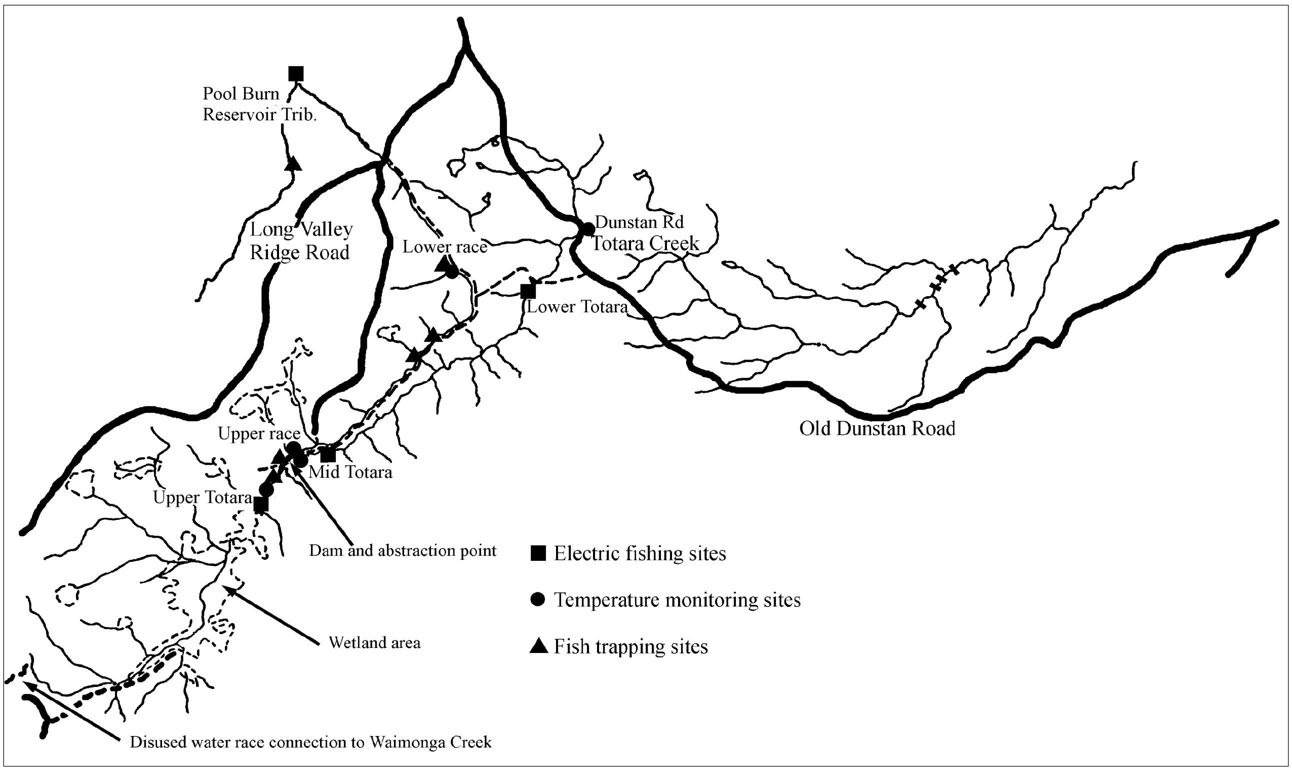

Figure 2. Sampling sites for fish and instream water temperatures in Totara Creek and the Pool Burn Reservoir tributary.

heavy-metal poisoning usually effects fish during early embryonic development. Initial tests for arsenic, a common heavy metal leached from Otago mine sites, failed to detect any in the water at any sites in Totara Creek or the water race. Furthermore, while Totara Creek is close to the Serpentine gold field there is no visual evidence of mining in the Totara Creek catchment. A further possibility considered was that the waters of Totara Creek are calcium deficient and the fish are unable to form bone tissue normally. However, snorkel and Surber sample surveys of the stream and the dam found abundant snails indicating calcium levels are sufficient for shell construction and hence likely to be sufficient for bone growth requirements.

A final untested possibility is that the deformities are caused by the hybridisation between the undescribed galaxiid and *G. depressiceps*. If hybrid fish have conflicting genomic instructions for the development of jaw and general head structure then developmental deformities may be the result. The pure strain undescribed galaxiids from the Pool Burn Reservoir tributary and *G. depressiceps* from the Linn Burn were examined and show no sign of the deformities observed in Totara Creek or hybridisation. However, very occasional *G. depressiceps* in Waimonga Creek do display the jaw deformities common in Totara Creek and genetic studies (G.P. Wallis & J.M. Waters pers. comm.) shows this population also contains hybrids.

4. Water abstraction assessment

4.1 FISH INVASION PROBABILITY

A potential invasion pathway to Totara Creek exists from the Pool Burn Reservoir tributary via the water race. A single high-gradient cascade occurs in the water race that may prevent upstream salmonid movement, but this will not prevent upstream movement of all galaxiid or other native species. The Pool Burn Reservoir tributary into which the water race discharges has a high-gradient section and a series of cascades which will again prevent salmonid invasion. Movement by galaxiids capable of climbing is not prevented. Furthermore, this high-gradient stream is incurring significantly increased stream bed erosion as a result of the high water flows and the long-term stability of any barriers is not guaranteed (Photo 3).

The risk of a fish invasion into Totara Creek via the water race is reduced by the near absence of fish in the Pool Burn Reservoir tributary. Fish sampling in this stream located larval galaxiids, but no salmonids. Visual surveys of the lower reaches of this stream noted the presence of a series of waterfalls that, although not of great height, should prevent upstream movement by salmonids from the Pool Burn Reservoir. However, movement of fish from Totara Creek into the Pool Burn Reservoir tributary is not prevented at any time the water race is flowing. A series of waterfalls on the Pool Burn Reservoir tributary upstream of the water race inflow does prevent movement and mixing of the Totara Creek hybrids with galaxiids in the upper section of the Pool Burn Reservoir tributary (Fig. 1, Photo 4).

Spawning habitat for salmonids was not investigated systematically in Totara Creek but observations noted that patches of gravel suitable for brook char and brown trout spawning are available in the upper sections of Totara Creek. Spawning habitat in areas of Totara Creek downstream of the abstraction are far more limited due to the bedrock nature of the streambed. Therefore, in the unlikely event of salmonids colonising Totara Creek, a self-reproducing population would certainly become established in the upper reaches and possibly downstream of the abstraction.

4.2 FISH PASSAGE AT THE ABSTRACTION SITE

Upstream fish passage at the abstraction is impossible at all times. When the water is abstracted there is no connecting water flow between the sections of Totara Creek above and below the abstraction. When water is not being abstracted, a connection exists between the upper and lower sections of Totara Creek, but fish passage in an upstream direction is still impossible. Water flows from the water race to the lower stream over an approximately 2 m high free-fall preventing passage (Photo 5). This does not however, prevent fish passage in a downstream direction as long as fish survive the fall.

This lack of fish passage has two detrimental impacts on the galaxiids. Firstly, upstream movement is prevented and larval fish that drift downstream after hatching are prevented from moving back upstream at the abstraction. Similarly, after flood events displaced fish are also prevented from returning to the upstream area. This was evident during investigations in 1994 (Allibone 1997) when fish numbers immediately below the abstraction were very high following a major flood event. A second impact was the prevention of upstream dispersal of surplus juvenile fish production from the lower reaches. This can lead to crowding and growth rate depression below the abstraction and depress the population size above the abstraction.

4.3 POOL BURN RESERVOIR TRIBUTARY IMPACTS

Visual surveys of the Pool Burn Reservoir tributary determined that it is undergoing significant erosion in many areas. In the very upper section (a low-gradient wetland) scour pools are forming, impacting on wetland structure and possibly water retention (Photo 6). In the next 700 m of high gradient stream the increased water volume is leading to erosion of the streambed and channel widening. Particles up to small boulder size (30 cm at the widest diameter) are being moved down slope. This eroded material is then being deposited in a low-gradient section of stream, where coarse sediments are forming an alluvial fan (Photo 7). The alluvial fan is progressively burying the original meandering channel. This deposition of material produces shallow stream habitats that are more vulnerable to drying out during low flow periods. The finer sediments are being flushed further downstream filling interstitial space in the streambed substrata. The end result is a substantial alteration to the instream habitat in both high- and low-gradient sections of the Pool Burn Reservoir tributary.

With no prior data on the fish population of this stream available, it is unclear whether these alterations to the fish habitat have led to a decline in fish abundance downstream of the water race inflow. However, the apparent absence of adult fish is unusual and the flow variability and habitat alteration are probable causes for this absence.

4.4 CRITICAL HABITAT AVAILABILITY

The critical habitat within Totara Creek for the galaxiid is most probably the spawning habitat. Unfortunately, the cryptic nature of this habitat makes assessment of availability and use difficult. Searches for spawning habitat found spawning at one of the sites identified by Allibone & Townsend (1997) but at no other sites. Fish were found at the site, prior to spawning, and all the ripe fish (22 fish) were dye marked. Only three marked fish were recaptured (13.6%) in sampling after spawning. This indicates (as previously mentioned) that fish are searching out these sites. Interestingly, the spawning site is within a set of riffles, and on both the occasions that spawning has been observed in this area it has been in exactly the same area of the riffles and not other sections, indicating very strong site selection for spawning. Spawning sites may also have been rare, as water levels were low during spring while the abstraction was operating. Many potential spawning riffle areas near the abstraction site were above the water level. Spawning site searches were also conducted around the upper Totara site. These failed to locate any spawning sites and habitat similar to the observed spawning habitat was absent. Observations of the distribution of larval fish around the upper Totara site in December found that they were not widely dispersed. This would indicate spawning habitat is not widely available in the upstream areas. Therefore the abstraction appears to dewater potential spawning habitat downstream of the abstraction and the lack of fish passage prevents upstream resident fish gaining access to this potentially rich spawning habitat zone.

Spawning habitat of a similar nature to that observed in Totara Creek was not available in the water race. Overhanging vegetation and banks are absent from riffle areas as a result of maintenance work. Despite this, spawning did occur within the race at one riffle site, approximately 2 km from the race intake. Although the spawning site was not observed, larval galaxiids were collected at this point in the water race. These fish were not considered to be larval fish that had drifted into the race from upstream because at the time the race was not carrying water. It was also likely that the majority of eggs laid at this site failed to hatch. Less than 50 larvae were observed at the head of a remnant pool in the water race. These fish were just downstream of a long dry riffle section, and it was likely that these few larvae had successfully hatched before the spawning site emerged from the water following the closure of the abstraction. Certainly, the timing of the water race closure was such that it would have occurred close too or during the initial stages of larval fish hatching.

4.5 CHRONIC IMPACT ASSESSMENT

Fish were captured at three sites (upper, mid and lower Totara) in October, November and February (Table 2), using multiple-pass electric fishing in stop-netted sections to estimate fish density. At the mid and lower Totara sites fish density in spring was lower than at upper Totara (above the abstraction). At lower Totara there was a major decline in density between October and November as the spawning fish left the site, then a major increase by February when large numbers of 0+ fish were present. Conversely, at mid Totara there was an increase in fish density between October and November. This was possibly due to fish returning to the reach after spawning elsewhere. There was

TABLE 2. FISH DENSITY AT THREE SITES IN TOTARA CREEK.

SITE	FISH DENSITY (FISH /m^2)			
	October	November	February	February, 0+ fish only
upper Totara	0.625	0.675	0.675	0.425
mid Totara	0.375	0.571	1.143	0.589
lower Totara	0.345	0.239	1.390	1.022

a further increase by February, again due to large number of 0+ fish being present. At upper Totara, fish density was high in spring, but it had not increased by February when the 0+ fish were present. The stable spring density possibly indicates that spawning was almost completed and fish were at their feeding habitats rather than spawning habitats when surveys were carried out. Recruit density was the lowest at upper Totara and this would support the hypothesis that this area is recruit limited due either to little available spawning habitat and/or loss of recruits downstream to the water race and Totara Creek below the abstraction.

Temperature monitors (Onset Optic StowAway® monitors) were placed in Totara Creek to monitor water temperatures up and downstream of the water race and in the water race. These monitors measured the water temperature every 15 minutes and were in place at five sites (Fig. 2) from 15 October to 4 December 1998.

The monitoring showed that the abstraction substantially alters the temperature regime of Totara Creek below the abstraction (Fig. 3). The most obvious alteration was the reduction in daily temperature variation just downstream from the abstraction as a result of water storage in the dam.

The temperatures at the mid Totara site immediately downstream from the abstraction show the greatest variability during the monitoring period. In October this site generally had the coolest overnight temperatures. However, by mid November the daily maximum and minimum were extremely high compared with the other sites. At this time it is thought that water levels were low and this section responded very rapidly to the daily heating and cooling. Within the water race temperatures also increased and just prior to the abstraction closure the abstraction was exporting relatively high temperature water to the Pool Burn Reservoir tributary. The relatively unshaded nature of much of the water race certainly allows for considerable heating on sunny days.

The abstraction closure rapidly altered the temperature regime. The upper race site became dry within a day and monitored the air temperature from that point. This was apparent from the very high temperature variation at the site including below 0°C nights and >20°C days. The lower race site became a remnant pool and the temperatures were relatively stable and cool. The cool nature of this pool probably came about because it had some tussock shading and also a small wetland seepage flowing into it. This pool retained fish through to the last sampling in February. All but one of the long-term refuge pools had similar shading and seepage inflows. This would reduce evaporation rates, provide cool water for the fish and recharge oxygen levels.

Following abstraction termination, water temperatures at mid Totara became less variable and generally warmer. Daily temperature variation was reduced and the area had the highest night time temperatures. This was a substantial change from the temperature regime while the abstraction was operating. The Dunstan Rd temperature monitoring showed, however, that the warm water released by the dam did not reach this site. The stream below the dam was heavily shaded by tussock. This probably induces significant cooling between mid Totara and Dunstan Rd.

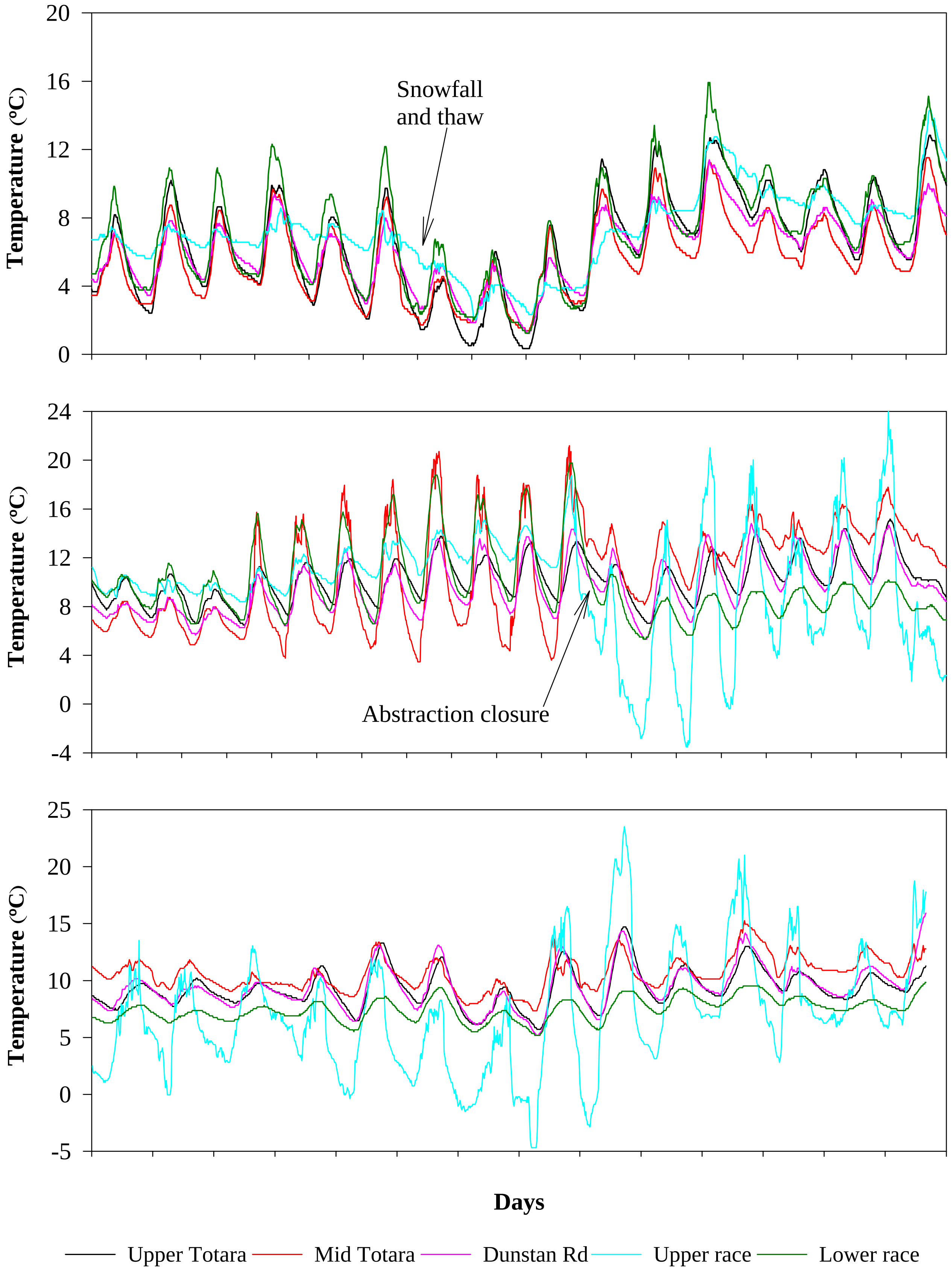

Figure 3. Instream water temperature records at five sites in Totara Creek; 16–31 October 1998 (top), 1–19 November (middle) and 20 November to 3 December (bottom).

The impact of the temperature alteration was mixed. When the abstraction operates, the wide temperature fluctuations at mid Totara were likely to cause some impacts. Egg and larval fish development appeared to be slowest at mid Totara and such development is temperature dependent. However, this must be balanced against fish growth in the period after abstraction stopped. The relatively warmer temperatures monitored at mid Totara would promote juvenile and adult fish growth. Therefore, it is likely that temperature regime impacts will vary from year to year depending on the timing and duration of the abstraction operation. The longer the abstraction operates, the greater the negative impacts will be on egg, larval and adult fish development and growth in the mid Totara section of the stream.

4.6 IMPACTS FOLLOWING WATER RACE CLOSURE

Temperature monitors indicated that the water race was closed on 11 November 1998 to allow the full flow of Totara Creek to proceed downstream to Linn Burn Station. The stream and water race were visited on 3–4 December 1998. At this time the water race had become a series of isolated pools with the connecting riffle areas waterless. Searches were made at eight random sites along the water race to determine whether fish had been stranded in the dry sections of the water race. Desiccated fish were collected at two sites, at one site 116 fish were found and at the second a single fish. Fish size was estimated from the bodies to be between 50 and 120 mm. At all sites surveyed there were numerous aquatic invertebrates that had also been stranded and desiccated.

Fish traps were set in seven remnant refuge pools along the water race on 3 December. A total of 241 fish were collected in 16 traps set (average per trap, 15 fish). Visual observations made while the traps were being retrieved showed that not all fish in these pools were captured by the traps. Fish collected in the water race traps had a wide size range from 57–162 mm. The 162 mm fish is the largest Totara Creek galaxiid ever collected and is, in fact, the largest non-migratory galaxiid collected in New Zealand. Three traps were set in similar pool habitat in the stream above the water race intake and 15 fish were collected (average per trap, 5 fish) and two traps set in the dam collected two fish. The high capture rates in the water race pools would indicate that fish densities shortly after water race closure were substantial higher than in other natural pool habitats. This would indicate crowding was occurring as fish retreated from the dried up riffle areas to the pools.

During this initial overnight fish trapping a falling water level was observed in one of the remnant pools fished. Traps set at approximately 6.00 pm did collect fish during the night, but when they were collected at 10.00 am the following day, the trap entrances were approximately 5 cm out of the water. This falling water level indicated that some remnant pools were not permanent.

Trapping was repeated in three remnant pools on 11 February (Photo 8). Other remnant pools trapped in December no longer existed by this time, confirming that not all pools persist for the entire period the water race is without flow. A total of 270 fish were collected in six traps (average per trap, 45 fish). The increased capture rate probably reflects the crowding of fish in these remnant pools and, possibly, a better response to the baited traps due to food limitation. Emaciated fish were collected in all pools indicating depleted food resources (Photo 9). A further indication of fish stress was an increase in parasites cysts observed in fish in one refuge pool. Emaciated fish or fish with high cyst numbers were not observed in the December sampling. A further impact of the reduced food availability in these remnant pools will be on egg production. Without sufficient food female fish will produce fewer eggs, or poorer quality eggs or no eggs at all. This reduces the likelihood the water race population is self-sustaining.

Surveys of dry areas of the water race where remnant pools were present in December failed to detect any fish bodies. This was despite trapping 97 fish in these pools in December. It is unlikely that these fish somehow moved to the remaining pools. It was observed that scavengers (ferrets, cats and skinks) were removing fish bodies from the water race and other near-by dried up streams. Therefore it is likely that the stranded fish were scavenged, and that all observations of fish mortality are under-estimates as the bodies may often be rapidly removed. Stranded and dead fish were also observed in the scour pools at the head of the Pool Burn Reservoir tributary (Photo 10).

4.7 SPAWNING TIMING AND LARVAL FISH GROWTH

Sampling on 14 October found fish about to start spawning or already spawning. At upper Totara all but one fish was spent (80% of the females spent); however, at mid Totara only two females were spent (16.7% of the females spent), and at lower Totara there was only a single spent female (11.1% of the females spent). This indicated that spawning commenced first in the areas upstream of the abstraction and was nearly finished before spawning began in the downstream sections. Stream temperature has often been suggested as a spawning cue for non-migratory galaxiids, with spawning occurring when water temperatures become warm enough. The distribution of spent fish correlated with the maximum instream temperatures measured from 15 October. At upper Totara, above the abstraction, the daily maximums were generally higher than those at the other Totara Creek sites (Fig. 3).

Not only is spawning related to water temperature but also egg development. Higher water temperatures lead to faster embryo development and earlier hatching. Larval fish were captured on the 5 December at the three Totara Creek sites and at one site in the water race. There were significant differences in the lengths of the larval fish (ANOVA $P < 0.0001$, Fig. 4) and larval fish were significantly smaller at mid Totara than in the water race and at upper Totara (Tukeys test $p = 0.05$). Given the assumption that length indicates older fish, then hatching dates were different, with the larger fish from upper Totara and the water race hatching earlier.

The single very large larval fish collected at the site below the abstraction was interesting (Fig. 4). This had either hatched very early compared with others at this site or, possibly, drifted downstream from upstream of the abstraction.

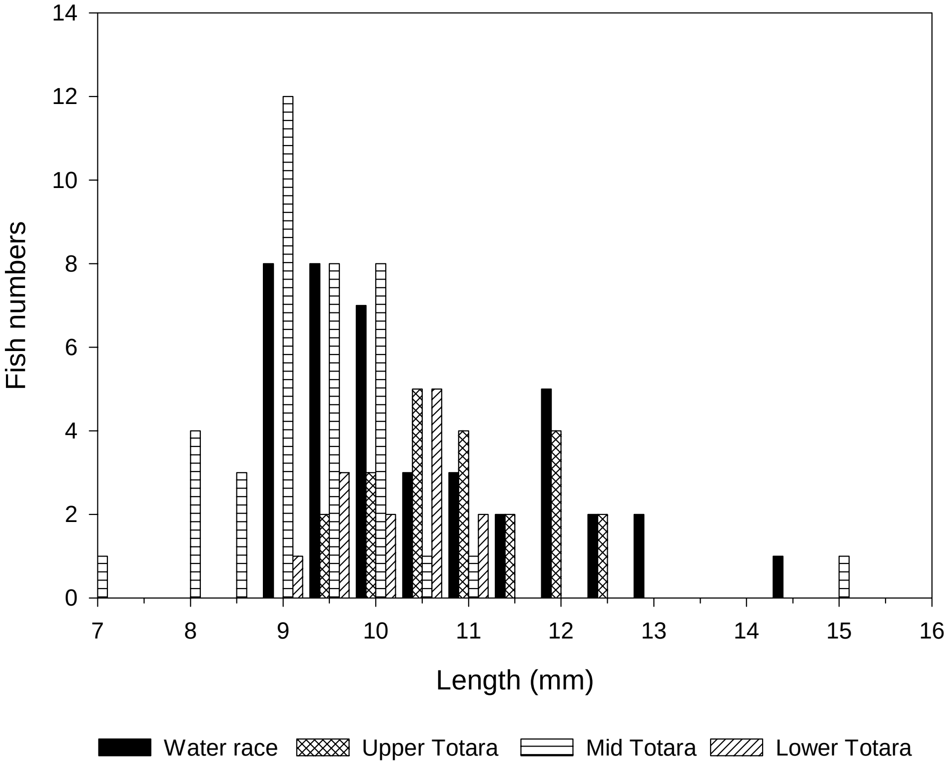

Figure 4. Length frequency distribution of larval galaxiids collected from four sites in Totara Creek on 5 December 1998.

4.8 THE WATER RACE GALAXIIDS

Trapping operations, dead fish surveys and visual observations showed that the water race contains a sizeable population of galaxiids, possibly numbering, at times, in the 1000s. The population undergoes fluctuations in size associated with the changes in abstraction volume. Substantial fish losses occurred following the water race closure in November, and losses continued as remnant pools dried out during the summer. However, trapping in late February indicated many fish, although stressed, were surviving in the remaining, probably permanent, pools. Therefore a permanent population of galaxiids is likely to reside in the water race. The capture of a galaxiid 162 mm long supports this assertion, as a fish this size would be of considerable age.

Nevertheless, the water race has a chronic detrimental impact upon the Totara Creek galaxiid population. During this study year, in spite of a successful spawning in the water race, no juvenile fish were observed or captured in any remnant pools in February. The single pool that larval galaxiids were captured from in December was dry by February. The lack of recruitment is evident when the length frequency distribution of fish collected in the water race and from stream habitats are compared (Fig. 5). Without successful spawning and recruitment within the water race, the resident fish in the water race play no part in the maintaining the galaxiid population. In fact, the water race population is a sink population, its survival is dependent on recruitment of individuals from upstream of the abstraction. The loss of these recruits from the upstream areas to the water race may be reducing fish densities upstream of the abstraction.

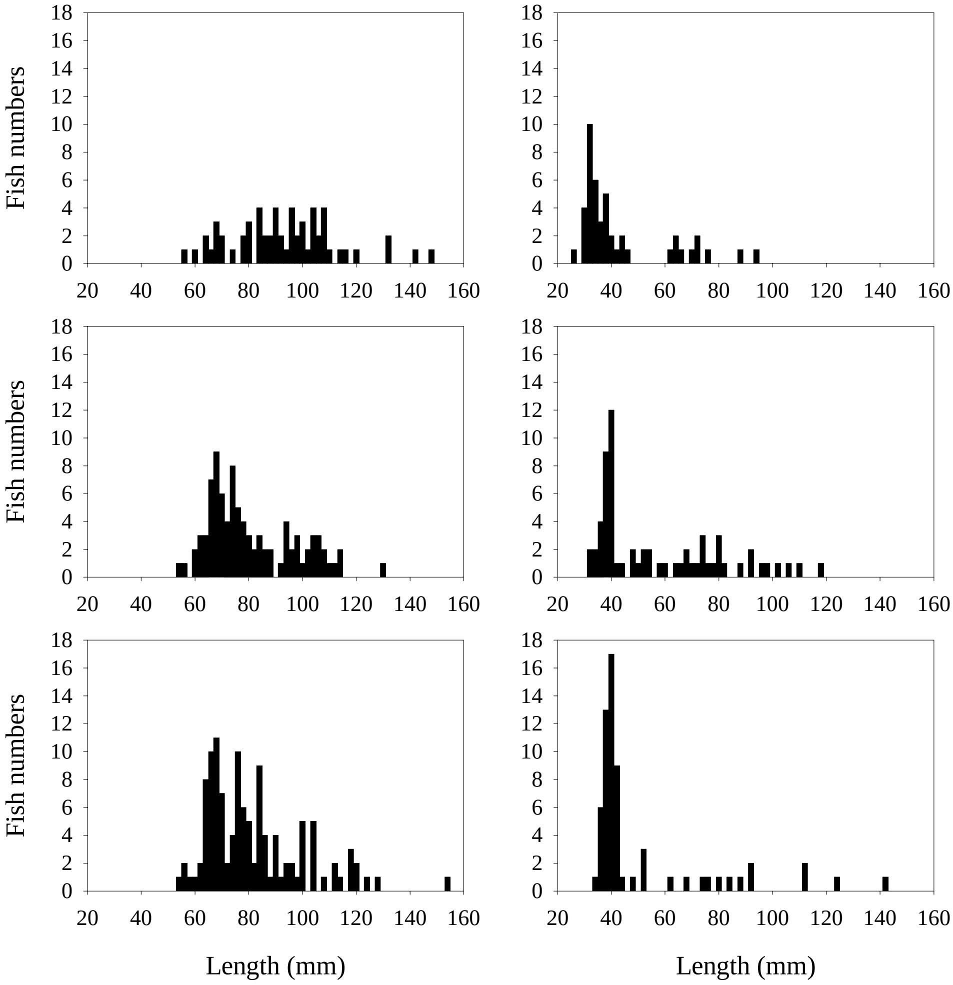

Figure 5. Histograms displaying the length frequencies of fish caught in three remnant pools in the water races (left column) and at upper Totara, mid Totara and lower Totara sites (right column, in descending order).

4.9 SEDIMENTATION

Observations of instream sediment levels were carried out during electric fishing operations. It was noticeable that at sites downstream of the abstraction there was a considerable accumulation of fine brown sediment. This sediment was easily resuspended when disturbed. Following the closure of the abstraction, increased water flows at the mid Totara site, flushed this sediment from most areas of riffles and pools. Therefore, sediment accumulation appears to be the result of low water flows when the abstraction is operating. The impact of this accumulation is unknown, but smothering of a streambed by sediment is generally considered a sign of habitat degradation.

5. Conclusions

The water abstraction from Totara Creek is having a number of impacts on the galaxiid population. The hybrid nature of the population appears almost certainly related to fish transfer through the existing water race and the disused goldminer's race. This impact is the most serious and appears irreversible.

In Totara Creek the abstraction has several effects. It has modified the temperature regime of the stream with probable impacts on spawning timing and development rates of eggs and larval fish. The movement of fish into the water race is reducing the recruits available to the upstream section of Totara Creek. The lack of fish passage at the abstraction also prevents downstream-resident fish moving upstream. The combination of these two factors is possibly leading to recruitment limitation of the galaxiid population in the unimpacted waters. The abstraction is also reducing the downstream population's access to spawning habitat and limiting overall habitat availability when operating. The galaxiids resident in the water race are a sink population and therefore of little (if any) value to the source population in Totara Creek. Their lack of reproductive success and reliance on recruitment from the upper section of Totara Creek represent a continuing chronic impact.

Impacts are also occurring in the receiving Pool Burn Reservoir tributary. Hybrid fish occupy areas of this stream and there is a risk (as yet undetermined) that the pure strain population will come into contact with these hybrids. Erosion and sediment deposition in this stream is altering instream habitats. Habitat quality is also likely to be declining as a result of the substantial alterations to the flow and temperature regimes that the stream experiences.

Brown trout from the Pool Burn Reservoir are prevented from gaining access to Totara Creek by waterfalls on the Pool Burn Reservoir tributary. However, if these barriers fail and trout move into Totara Creek, then salmonid habitat is plentiful.

6. Acknowledgements

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7. References

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Photo 1. A normal (upper) and deformed (lower) fish with the common lower jaw deformity.

Photo 2. A normal (upper) and deformed (lower) fish with reduced fin development.

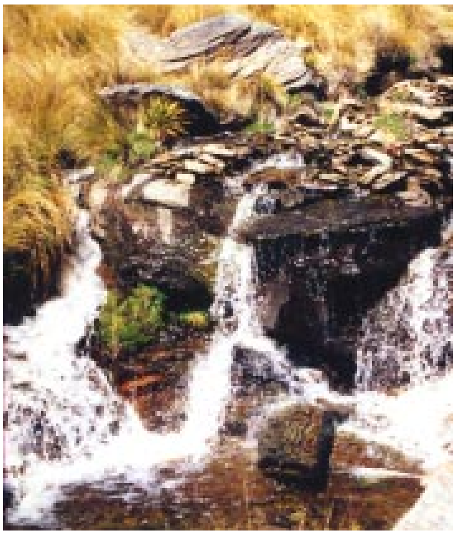

Photo 3. The Pool Burn Reservoir tributary section undergoing erosion of the streambed and margins.

Photo 4. The waterfalls separating hybrid from pure strain galaxiids in the Pool Burn tributary.

Photo 5. Water flow from the water race to Totara Creek, the waterfall prevents upstream fish passage.

Photo 6. A scour pool in the headwater of the Pool Burn Reservoir tributary receiving water from the abstraction.

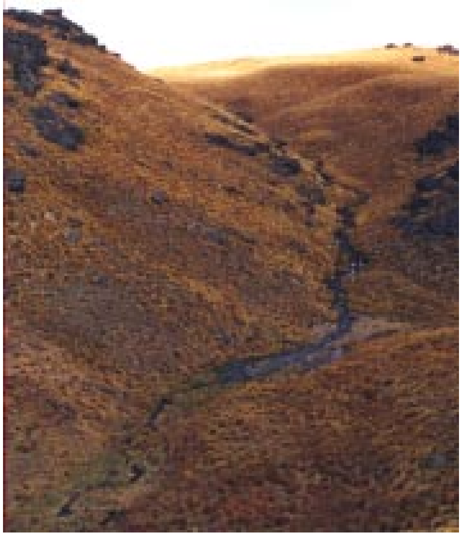

Photo 7. The alluvial fan developing in the Pool Burn Reservoir tributary as a result of headwater erosion.

Photo 8. A remnant pool in the water race with vegetation shading and inflowing seepage.

Photo 9. An emaciated fish from a remnant pool in the water race.

Photo 10. Stranded fish in mud at the bottom of a nearly dry remnant pool.