Water abstraction impacts on non-migratory galaxiids of Otago streams

SCIENCE FOR CONSERVATION 147

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Published by
Department of Conservation
P.O. Box 10-420
Wellington, New Zealand

Science for Conservation presents the results of investigations by DOC staff, and by contracted science providers outside the Department of Conservation. Publications in this series are internally and externally peer reviewed.
Publication was approved by the Manager, Science & Research Unit, Science Technology and Information Services, Department of Conservation, Wellington.

ISSN 1173-2946
ISBN 0-478-21951-2

Cataloguing-in-Publication data

Allibone, Richard Mark, 1966-
Water abstraction impacts on non-migratory galaxiids of Otago streams / Richard M. Allibone. Wellington, N.Z. : Dept. of Conservation, 2000.
1 v. ; 30 cm. (Science for conservation, 1173-2946 ; 147)
Includes bibliographicalreferences.
Contents: Assessment techniques for water abstraction impacts on non-migratory galaxiids of Otago streams. - Water abstratction impacts on the non-migratory galaxiids of Totara Creek.
1. Water use—New Zealand—Otago Region. 2. Galaxiidae—New Zealand—Otago Region—Effect of water abstraction on. I. Title. II. Assessment techniques for water abstraction impacts on non-migratory galaxiids of Otago streams. III. Water abstraction impacts on the non-migratory galaxiids of Totara Creek. Series: Science for conservation (Wellington, N.Z.) ; 147.

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ASSESSMENT TECHNIQUES FOR WATER ABSTRACTION IMPACTS ON NON-MIGRATORY GALAXIIDS OF OTAGO STREAMS

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WATER ABSTRACTION IMPACTS ON THE NON-MIGRATORY GALAXIIDS OF TOTARA CREEK

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Assessment techniques for water abstraction impacts on non-migratory galaxiids of Otago streams

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ABSTRACT

Water abstractions for irrigation and consumption are common in Otago. Many take water from streams that are also habitat for species of endangered non-migratory galaxiids, but investigations of the impact of water abstraction on these fish populations have not been carried out. This report identifies potential impacts and provides methods to assess these impacts. Water abstractions are divided into two classes, permanent and intermittent. The two forms of abstraction, while likely to cause similar impacts, are likely to vary in the magnitude and frequency of any impacts. Three major categories of impacts are identified: fish invasion, the lack of fish passage around abstraction structures and increased fish mortality and depressed fish populations. Three categories of fish invasion via water abstraction water ways are identified: invasion by salmonids; invasion by koaro; and invasion by another non-migratory galaxiid species. The first two forms of invasion commonly lead to displacement of the resident non-migratory galaxiid. Invasion by another non-migratory galaxiid may lead to displacement or hybridization. Determining if the abstraction allows fish passage is a simple process. For permanent abstractions removing all water in the stream, passage is impossible. For intermittent abstractions or abstractions that draw only a proportion of the flow, fish passage is possible if velocity and gradient barriers are not present. It is recommended that fish passage be assessed with regard to the movement ability of the resident galaxiid population. Assessment techniques for impacts associated with fish mortality and chronic population depression are given. These include assessment of acute mortality and refuge areas following changes to intermittent abstraction regimes. Assessment of the chronic impacts on population density, biomass, fish condition and reproductive output are discussed.

Keywords: non-migratory galaxiids, water abstraction, impacts, assessment, fish passage, fish invasion.

This paper may be cited as:

Allibone, R.M. 2000: Assessment techniques for water abstraction impacts on non-migratory galaxiids of Otago streams. *Science for conservation 147A*: 5–23.

or in full as:

Allibone, R.M. 2000: Assessment techniques for water abstraction impacts on non-migratory galaxiids of Otago streams. Pp. 5–23 in: Allibone, R.M. 2000: Water abstraction impacts on non-migratory galaxiids of Otago streams. *Science for Conservation 147*, 45p.

1. Introduction

Water abstractions for irrigation and industrial purposes are common world-wide. The impacts of such abstractions on fisheries values are usually associated with important recreational and commercial fisheries in large river systems. However, there is increasing concern over the impact of abstractions from small streams on fish, not of recreational or commercial importance, but of conservation concern. These concerns often centre on the protection of fish species with limited distributions in drought prone or at least water short regions of the world. Examples of conflicts between water for irrigation and retention instream for fish conservation are numerous, although not often documented. Possibly the most famous examples centre around the efforts to protect the Devils Hole pupfish and other desert fishes of the western United States (Minckley & Deacon 1991).

In Otago, fish conservation efforts are focussed on the protection of populations of eight non-migratory galaxiids. Five species belong to a group referred to as the Otago galaxiids or the Otago galaxiid complex (roundhead galaxias *Galaxias anomalus*, flathead galaxias *G. depressiceps*, Eldons galaxias *G. eldoni*, dusky galaxias *G. pullus* and *Galaxias* sp.). These fish are either restricted to Otago or the Otago-Southland region. The other three species are galaxiids more common in the Canterbury region: alpine galaxias (*G. paucispondylus*), longjaw galaxias (G. *prognathus*) and Canterbury galaxias (*G. vulgaris*). The latter two occur in Otago only in the often water short region of North Otago, while a single alpine galaxias population occurs in the Lochy River, a tributary of Lake Wakatipu. Of these eight species only two, the alpine and Canterbury galaxias, are not classified as threatened by the Department of Conservation (Tisdal 1994).

The Otago galaxiids are found in a wide variety of rivers and streams (Allibone 1997) and occur throughout much of eastern and central Otago. Populations are absent from tributaries of all but one of the southern lakes and are also uncommon in the large rivers of coastal Otago. These galaxiids rarely coexist with other fish species. Salmonids and koaro (*G. brevipinnis*) have been implicated in the decline of these species (Townsend & Crowl 1991, McDowall & Allibone 1994, Townsend 1996, Allibone & McDowall 1997).

The impacts of water abstraction on non-migratory galaxiid populations have not been investigated. Populations of non-migratory galaxiids exist in small streams of semi-arid to arid regions of inland Otago. These streams are also often the source of water for irrigation, stock and domestic use. Multiple abstraction sites or multiple users may be present on individual streams. Abstracted water is generally transported from abstraction sites along water races to irrigation sites or reservoirs. The water abstractions can be divided into two categories: permanent abstractions that remove water year round and intermittent abstractions that draw water only when required. Intermittent abstractions can be highly variable in volume and duration. Both forms of water abstractions decrease the downstream water volume. This reduction may simply decrease habitat for fish, thereby reducing the carrying capacity of the stream. This is the most likely impact of permanent abstractions. Intermittent abstractions can produce further impacts, as the availability of habitats varies with the volume of water being abstracted. Fish strandings, spawning site exposures and declines in instream production are all likely results of the operation of intermittent abstractions. This report discusses the potential impacts on galaxiid populations associated with water abstractions and describes methods to assess these impacts.

Each abstraction presents a series of potential impacts that need to be considered. Potential impacts are:

1. The abstraction water race becomes an invasion pathway for fish species to enter the abstraction stream, or any stream the abstraction connects to.
2. The intake structure for the abstraction can prevent fish passage.
3. Permanent abstraction decreases the downstream water level and may prevent access to critical habitats such as spawning, juvenile or feeding habitats, causing chronic population declines.
4. Intermittent abstractions cause acute impacts during periods of flow alteration including fish mortality and disruption to phases of the life cycle. These impacts are in addition to any chronic population declines.
5. The changes in flow volumes lead to physical and environmental alterations in the abstracted stream and any stream receiving the abstracted water.

Both forms of abstraction can cause reductions in fish population size exceeding that expected from the loss of water volume alone. If instream habitats are not evenly distributed, abstractions can lead to changes in the proportion of available habitats or prevent access to required habitat. The fish population size may then be limited by the availability of the rarest habitat. Fish that utilise distinctly different habitats at different life history stages are vulnerable to changing proportions or availability of habitat. Many galaxiid species have spawning and juvenile rearing habitats that are distinct from adult fish habitat. This makes the species vulnerable if rare but critical habitats are lost.

2. Impacts

2.1 INVASIVE SPECIES AND THEIR IMPACTS

Invasions of fish into new areas are of considerable concern and this can occur in three ways: direct introduction, natural range expansion or an accidental introduction via an artificial pathway. Within Otago, introductions of native and introduced species have occurred when water races have provided pathways for fish passage. Two introduced salmonids, brook char (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*), and the native koaro (McDowall & Allibone 1994, Allibone & McDowall 1997) have been observed to invade new waterways in this manner. Furthermore, numerous water races contain permanent reproducing populations of salmonids, usually brown trout or brook char (New Zealand Freshwater Fish Database). Invasions by salmonids and koaro are of concern as they have been shown, or implicated, in the decline of non-migratory galaxiids (Townsend & Crowl 1991, McDowall & Allibone 1994, Allibone & McDowall 1997). The exact nature of these negative interactions has not been demonstrated, but predation is the most often suspected cause of the decline and extinction of galaxiid populations.

Undesirable interactions between species of non-migratory galaxiids are also possible. There is the potential for dispersal of non-migratory galaxiids, via water races, to streams containing other non-migratory species. Contact among the usually allopatric non-migratory galaxiids poses two threats: displacement of one species or hybridization between the species. The potential for displacement is unknown, however hybridization is known to occur. Low-level hybridization has been found between flathead galaxias and roundhead galaxias in the one stream where they coexist (Healy Creek, a Taieri River tributary, Allibone et al. 1996). Flathead galaxias are also known to have hybridised with an undescribed galaxiid species in Totara Creek (G.P. Wallis & J.M. Waters unpub. data).

2.2 FISH PASSAGE

All abstraction points divert water from the stream into an abstraction pipeline or water race. The design and positioning of the flow deflection and abstraction structures will determine whether fish passage is still possible in upstream and downstream directions. Obviously, any permanent abstraction that diverts the whole stream flow will not provide fish passage around the abstraction. Such abstractions have permanent sections of dry streambed immediately downstream of the intake making fish passage impossible. Intermittent abstractions and abstraction removing a proportion of the water can allow fish passage, but abstraction structures may or may not prevent fish passage.

The prevention of fish passage at an abstraction site may have two impacts. The lack of passage may simply split the fish population into two fragments. This can lead to increased extinction probabilities for the populations as smaller populations are more vulnerable to extinction. The alteration to fish passage may also prevent fish completing movement associated with life history phases. Almost nothing is known about movements by non-migratory galaxiids. It is possible that fish passage barriers can prevent adult galaxiids moving to areas of abundant spawning habitat, or restrict the movement of juvenile recruits.

2.3 ABSTRACTION IMPACTS

The major impact of a permanent abstraction will be the loss of habitat downstream of the abstraction. This will produce a corresponding decline in the fish population size in downstream areas. More detrimental impacts may occur if important habitats (e.g. spawning habitat) were abundant in the reaches directly below the abstraction. This is possible for some spawning habitats that are associated with specific streambed characteristics. For example, roundhead galaxias and dusky galaxias spawn along stream margins. Alterations to the availability of this habitat may reduce spawning success (Table 1).

TABLE 1. SPAWNING CHARACTERISTICS OF NON-MIGRATORY GALAXIIDS IN THE OTAGO CONSERVANCY.

GALAXIID SPECIES	SPAWNING SITES	NUMBER OF SPAWNING SITES FOUND	SPAWNING SEASON*	VULNERABILITY OF SPAWNING SITES TO FLOW CHANGES
Roundhead galaxias	Shallow water habitats in side braids, riffle edges, occasionally deeper water riffles. All sites in porous gravel and cobble substrates.	30+	Spawning generally between August and October, hatching in November.	Highly vulnerable once eggs are laid, even a small reduction in water height will expose spawning sites.
Flathead galaxias	Under boulders in riffle zones.	50+	Spawning generally between July and November depending on stream and hatching from September to December.	Not vulnerable, all eggs on the streambed and substantial exposure possible only if the stream is completely dewatered.
Eldons galaxias	Amongst cobbles and boulders in a riffle.	1	Spawning generally around October, hatching in late November.	Unknown.
Alpine galaxias	Unknown.	0	Mid to late winter	Unknown.
Longjaw galaxias	Unknown.	0	Two spawning seasons suggested (Bonnett 1992) spring and autumn, hatching assumed approximately one month after spawning.	Unknown.
Dusky galaxias	Under overhanging banks and vegetation.	4	Spawning generally around October hatching late November.	Highly vulnerable once eggs are laid, even a small reduction in water height will expose spawning sites.
Canterbury galaxias	In gravel depressions in riffles.	Numerous.	Spawning from August to October hatching from September to November.	Not vulnerable, all eggs on the streambed and substantial exposure possible only if the stream is completely dewatered.
Galaxias sp. Pool Burn	Unknown.	0	Spring, probably October	Unknown.
Galaxias sp. Totara Creek hybrids.	Under overhanging banks and vegetation.	3	Spawning in October hatching in late November.	Highly vulnerable once eggs are laid, even a small reduction in water height will expose spawning sites.

*Spawning season will vary among streams due either to temperatures or local spawning behaviours. Spawning timings given here for roundhead, flathead, Eldons, dusky galaxias and *Galaxias* sp. hybrids from observations in the Taieri and Shag River catchments, are from Allibone & Townsend (1997b), Allibone & McDowell (1997), Moore et al. (1999) and for longjaw and alpine galaxias from the Rangitata River (Bonnett 1992) and Canterbury galaxias from Cass River (Benzie 1968) and Glentui River (Cadwallader 1976).

Intermittent abstraction impacts will include the loss of instream habitats, but other impacts are likely. When intermittent abstractions that take the whole stream flow are halted, fish in the abstraction channel are likely to be stranded, producing acute mortality events. Similarly, when abstraction commences fish can be stranded in the stream channel below the abstraction. When abstraction volumes are altered during the spawning season there is also the likelihood of stranding spawning sites in either the stream or abstraction water race. Intermittent abstractions that take a small proportion of the instream flow are likely to have a limited impact. Such abstractions are likely to be within the normal range of instream fluctuations. It is, however, unclear at what size an intermittent abstraction will begin having a detectable effect. This will vary with stream size, duration and timing of the abstraction and the fish species present.

Water abstraction may also alter the timing of environmental cues that initiate spawning. Little is known about these cues for non-migratory galaxiids. Moore et al. (1999) showed water temperature appeared to influence the onset of spawning for roundhead galaxias populations but could not find such a link for flathead galaxias populations. Cadwallader (1976) also suggested that temperature controlled the onset of spawning for Canterbury galaxias. If abstractions alter stream temperature regimes then spawning timing could also be altered. The temperature regime will also influence fish growth rates and egg development rates.

Abstraction may also result in a continuous loss of fish if entry to the abstraction water races (or pipeline) is possible. Such fish may simply be exported along the water races and become permanently separated from the stream population, or die in the water race or at its end point. Conversely, if suitable habitat is present in the water races, permanent self-sustaining fish populations may become established. Populations of salmonids are known to occur in some Otago water races, and non-migratory galaxiids may also be capable of establishing populations in water races. This could provide a nett benefit to the population if the water race habitat is larger than the habitat lost in the stream.

3. Assessment of impacts

3.1 INVASION ASSESSMENT

Assessment of fish passage barriers associated with water abstractions should be regularly carried out, especially in areas of conservation concern. Natural and artificial barriers to fish passage are prone to failure, especially following flood events. Range expansion by fish species by other mechanisms (e.g. introductions) may also by-pass barriers.

3.1.1 Salmonid risk assessment

Salmonids are common and widespread throughout Otago and all abstractions should be examined to assess the distribution of salmonids locally and the invasion risk to salmonid-free areas. To assess the risk of salmonid invasion via a water abstraction the following steps are recommended:

A. Locate all salmonid populations resident in water bodies connected to the water race of concern. This includes any small stream connected to the water race between the abstraction point and the outlet. Care must be taken at this stage to allow for seasonal fluctuations in the distribution of salmonids. For instance, salmonids will avoid high water temperatures (22°C and above) and may abandon high temperature reaches in the summer only to return as the water temperature drops. Therefore absence of salmonids at one time of year cannot guarantee absence all year.

B. Locate all barriers preventing migration of salmonids into salmonid-free streams. It is recommended that barriers be distinguished by height for waterfalls, into categories under 3 m and over 3 m, and length of dry streambed section. Waterfall barriers over 3 m in height are generally complete barriers to salmonids passage, whereas lower barriers can potentially be negotiated (Townsend & Crowl 1991). Furthermore, the nature of the barriers should be distinguished, i.e. is the barrier artificial, a bedrock waterfall, boulder waterfall or dry riverbed section. Risk of salmonid invasion increases as the number and size of the barriers declines or if the barriers are not present all year round.

C. If the abstraction stream contains salmonids and this connects to other water bodies downstream via the water abstraction pathway, fish passage is harder to prevent. Waterfall barriers are not effective at preventing downstream passage and fish passage prevention will rely on fish screens at the abstraction point.

D. To complete a successful invasion salmonids require spawning habitat. Stream assessment should therefore determine the availability of salmonid spawning habitat. Limited or no spawning habitat will prevent the establishment of a self-reproducing population. It is important to distinguish between self-sustaining salmonid populations and those supported by continuing immigration via the water race. Salmonid distributions in Otago indicate that brook char are the salmonid least restricted by spawning habitat availability, followed by brown trout, then rainbow trout and chinook salmon.

3.1.2 Koaro risk assessment

Areas at risk to koaro invasion in Otago are regions around the landlocked populations at Lakes Hawea, Wanaka, Wakatipu, Dunstan, Roxburgh and Mahinerangi. The migratory koaro juveniles move from the lake upstream to adult habitats. Therefore, abstractions at risk to invasion are those that deliver water to these lakes, either directly or via lake tributaries. Abstractions that draw water from a lake or downstream area are unlikely to attract migrant fish, but may attract occasional stray koaro when pelagic juvenile fish are swept downstream from lakes. To assess the risk of koaro invasion via a water abstraction the following steps are recommended:

A. Determine if koaro populations are resident in water bodies connected to the water race of concern. Then locate the lake source of recruiting koaro juveniles.

B. Locate all waterfall barriers between the lake source and the areas of concern. Given that juvenile koaro are capable of scaling waterfalls up to 60 m in height (McDowall 1990) simple waterfall barriers are not likely to be barriers. Possible waterfall barriers to koaro are inverted V- or U-shaped overhangs that extend across the entire wetted surface. Long stretches of salmonid-inhabited water or dry stream sections during the migration period may be other effective barriers.

C. Removal of present day koaro populations is possible by the construction of a koaro barrier preventing the upstream migrations of juvenile. Successful removal operations of this nature may take up to twenty years before all adult koaro die.

3.1.3 Non-migratory galaxiid risk assessment

Contact between isolated non-migratory galaxiid populations should be prevented. Abstractions linking any populations of non-migratory galaxiids are of concern. The wide distribution of non-migratory galaxiids in Otago means most areas are at risk. A major difficulty with this situation is that movement has to be prevented in both up and downstream directions. Waterfall barriers will reduce or prevent upstream movement, but will do nothing to prevent downstream movement. Fish screens are also unlikely to prevent the downstream movement of larval, juvenile and small adult fishes. To assess this risk the following steps are recommended:

A. Investigate all waterways connected to the abstraction water race for the presence of non-migratory galaxiids.

B. Determine if any waterfall barriers are present between galaxiid populations. This step presents some difficulties. The climbing ability of the different non-migratory galaxiids is varied, and may also reflect local stream conditions. However, bedrock waterfalls greater than 3 m high are likely to be barriers to upstream movement by all species.

C. Determine if any salmonid population separates the non-migratory galaxiid populations. A well-confined salmonid population could reduce or eliminate the potential for galaxiid movement in either up or downstream directions. However, this form of barrier is untested and even occasional non-migratory galaxiid movements through the salmonid area could compromise the conservation objective of maintaining separate galaxiid populations.

D. Investigate all streams occupied by galaxiids for the spawning habitat of the other galaxiid species in the connected catchment. The lack of spawning habitat could prevent the establishment of a galaxiid species, but not the possibility of hybridization. Again caution needs to be exercised when considering the potential spawning habitat as some non-migratory galaxiid species have relatively flexible spawning habitat requirements.

3.1.4 Detecting invasion events after the event

It is likely that in some abstraction streams invasions have already occurred and galaxiid populations have been displaced. Detection of these events requires evidence that the invasive species could only have arrived in the stream via the water abstraction path and not by another route. For salmonids there is always the possibility that their presence is a result of an introduction, but for the native species this is unlikely.

Detection initially centres on the availability of fish passage, both via the water race and from downstream populations. Examine the abstracted stream, the water race and any waterways receiving the abstracted water for fish passage barriers and compare with the distribution of fish populations. Determine whether any fish populations occur in areas where access can only gained via the water race. Fish distributions at permanent abstractions, drawing 100% of the flow, may also indicate whether the water abstraction route is the invasion pathway. The lack of flow in the stream below the abstraction prevents up and downstream fish movement. Invasive species that arrived via the water race will then only reside in stream sections above the abstraction. The presence of salmonids and koaro upstream of water abstractions in Shepherd Stream and Broad Stream (McDowall & Allibone 1994) provide examples of invasion via water races.

Detecting invasions of non-migratory galaxiid species will be difficult. If two species have been linked, distinguishing between naturally occurring sympatry and an invasion is difficult. The distribution of fish passage barriers and species within the streams may show whether invasions have occurred. If one species is restricted to areas around the water abstraction and not found upstream of any barriers above the abstraction then it may be an invader. Given that sympatry between Otago galaxiids is very rare, any cases of sympatry in streams with abstractions should be viewed with caution and investigated.

A confounding factor for investigating after the event invasions is invasions resulting from the goldmining era. Many of the water races of that era are now disused and hard to detect, but these could still have led to fish transfers.

3.1.5 Minimising the potential for undesired fish movement via water abstractions

Ideally, invasion prevention should utilise as many mechanisms as possible to prevent water abstractions becoming pathways for fish movement. Prevention can include the use of structures or timing of water take.

Structural methods for the prevention of fish passage are best at preventing upstream movement. Natural or artificial barriers made of bedrock or concrete and greater than 3 m in height are most likely to prevent salmonid invasions. Artificial barriers with koaro exclusion structures will also prevent koaro invasion.

If barriers are not possible then modification of the abstraction timing and duration has the potential to reduce invasion risk. Abstractions that take water all year are most likely to lead to the transfer of fish species, as passage is always available. The risk of species transfer can be decreased if abstractions avoid water removal during periods when fish are migrating. Even changes in the time of day water is abstracted may reduce the movement of fish; for example, whitebait species migrate at much higher rates during daylight hours than at night. If landlocked koaro follow the same migratory behaviour then night-time abstractions would reduce the potential for koaro invasion.

Abstractors that store water in ponds, for summer irrigation, could be encouraged not to stock ponds with sports fish. This would reduce the potential for upstream migration from the storage ponds to abstraction sources.

3.2 FISH PASSAGE REQUIREMENT

3.2.1 Passage requirement for non-migratory galaxiids

The object of any fish passage structure (e.g. a fish ladder) is to allow free and easy movement of fish through the abstraction site. No studies have investigated fish passage designs for non-migratory galaxiids. King & Wallis (1998) showed that though non-migratory galaxiid populations occur upstream of large waterfalls, upstream movements can be limited to less than one individual per generation. Allibone & Townsend (1997a) carried out an experiment testing the climbing ability of four species of Otago galaxiids. Their results indicated that slopes greater than 45° presented ascent difficulties for fish of all sizes during 30-minute test periods. Passage success was improved when rock-lined guttering rather than plastic guttering was used, indicating a need for a roughened surface for traction when climbing. Water depth and velocity, passage gradient and substrate nature and structure appear to be important influences on fish passage.

3.2.2 Assessment and design recommendations to maintain fish passage

Any assessment of abstraction structures for fish passage should investigate a number of factors. Sections of dry stream bed obviously prevent fish passage and, similarly, any free-fall waterfalls will almost certainly prevent fish passage for all but the best climbing species. The slope of any fish passage structure for non-migratory galaxiids should not exceed 30°. Allibone & Townsend (1997a) found most galaxiid species could freely ascend slopes of this gradient if the pass was lined with rock substrata. Further investigation may determine species-specific slopes. Resting sections at corners on the pass are recommended. Water volume and depth do not have to be great. A fish pass could consist of rock-lined guttering or drainage pipe less than 50 cm in width with a water depth up to 5 cm in the centre of the channel and shallower towards the edges. The most important feature of the pass is, possibly, its downstream positioning so that upstream-moving fish encounter the pass entrance. The passage area may also require a cover to prevent predation of fish by birds and small mammals.

3.3 FISH POPULATION ASSESSMENT

3.3.1 Introduction

Water abstraction can cause acute and/or chronic impacts. Acute impacts will generally involve fish mortality associated with dewatering of habitat when an abstraction commences or terminates. These impacts are relatively easy to detect a simple count of fish stranded in dry streams or water races will determine the acute impact. Chronic impacts occur over long time periods and are associated with a decline in habitat quality and quantity. Chronic impacts on a fish population will be hard to detect and separate from the natural variability in population parameters. To prove a chronic impact is occurring, the impact will have to be shown to be present over an extended time period, not just at a single sampling. Reference sites in unmodified streams can be used for comparisons with the populations in abstracted streams. The reference sites should, however, have the similar climatic and physical conditions to the potentially impacted streams, otherwise differences in the population parameters measured may simply result from naturally occurring differences among the streams. The establishment of a database recording galaxiid densities, condition factor and size frequency distributions will assist in comparing and categorising populations. Such a database should include samples from populations expected to be healthy and populations thought to be in decline. Additional sampling could include sites that have suffered drought or flood impacts. The usefulness of database comparisons of population parameters will decrease for galaxiid species that have few populations, due to the limited comparisons available.

3.3.2 Permanent abstraction assessment

At permanent abstractions the simplest form of assessment is to determine the area of stream lost as a result of the reduction in water volume below the abstraction. The area of dry streambed should be measured or estimated. Fish densities from either upstream or downstream of the abstraction can then be used to determine the decline in population size below the abstraction. Fish density multiplied by stream area gives an estimate of the population reduction.

Assessment of a permanent abstraction should also determine if galaxiids are present in the water race. It is possible that fish losses in the stream are offset by the presence of fish in the water race. The fish density in the water race can be determined, at a number of sites, and total fish numbers calculated once the water race area has been determined. Some caution must be applied to this assessment, as fish may be present in the water race but habitat quality may be poor. This may also be compounded by water race maintenance. Condition factor, growth etc. can be assessed for the water race population and compared with other populations to determine if the fish are in good condition. It is also important to determine whether the fish in the water race have spawning habitat and are reproducing successfully. If the water race fish are not reproducing successfully then they play no part in sustaining the population.

3.3.3 Intermittent abstraction assessment

Assessment of intermittent abstractions should investigate mortality following commencement and closure of the abstraction. Areas of dry stream bed or water race should be examined for dead fish and remnant pools fished to estimate the numbers of trapped fish. Investigation of fish mortality in dry areas should be carried out immediately after the change in abstraction regime. Stranded fish can become food items for scavengers. As a result mortality can be under-estimated if scavengers consume fish bodies prior to the investigation. Further mortalities are likely to occur if remnant pools are not permanent. During the initial investigation of a site all remnant pools should be located and the presence or absence of fish determined. Subsequent site visits can determine if remnant pools are permanent, and for the temporary pools determine the fish mortalities occurring as these pools dry up.

If the abstraction alteration coincides with the spawning season, investigations can search for stranded spawning sites. The known spawning habitats for non-migratory galaxiids are quite specific (Table 1) and can be located relatively easily for some species. However, spawning habitat for other species has yet to be identified. Assessment of spawning site stranding can be carried out once an alteration to the abstraction regime has occurred. Areas of suitable spawning habitat that have emerged from the water can be surveyed for spawning sites. Alternatively, if spawning habitat can be located at submerged sites these can be marked. Marked sites can then be revisited when abstraction is altered and the number of sites now emergent can be determined.

3.3.4 Methods to assess fish population parameters

The following procedure is recommended at all sites surveyed for data on population structure, fish density, fish biomass, recruitment and fish condition. It is highly likely that only relatively large impacts will be detected when monitoring these population parameters. Care must be taken not to interpret yearly variation in population parameters as impacts of water abstraction.

A. Select stream reaches (30–50 m long) that contain riffle and pool habitats. Sampling should not be restricted to single sample sites above and below an abstraction, rather a number of sites should be examined. If the stream habitats up and downstream of the abstraction are significantly different, then site comparisons are likely to be flawed. Comparisons with fish data from similar habitats in other streams may be carried out with some degree of confidence. In water races, the habitat is likely to be more uniform and randomly located sample reaches may have to be selected. Site length can be varied among galaxiid species depending on fish density. The objective of the fishing operation is to obtain a large sample of fish. Small streams may require longer sections than larger streams to obtain a fish sample of at least 30 or more fish. If the fish are sparse, fishing can be restricted to 100 m^2 of stream. Larger site areas provide better fish density estimates because small scale patchiness in fish distribution can bias samples from small areas.

B. Place stop nets at the top and bottom of the section.

C. Stream widths are measured at each end of the sample site and at number of places within the site and total area is determined by the addition of the area of each segment.

D. The site is divided into habitat sections (when possible) and each section is stop-netted before fishing. It is recommended that fishing commences in the upstream section and progresses down through the site. The uppermost stop net can be shifted following the fishing of the uppermost habitat section. Fishing the reach then requires only three stop nets. The bottom-most net remains in position throughout the fishing operation. The uppermost net is shifted downstream to bottom of the next habitat section to be fished after each section is completed.

E. Electric fishing operations should fish each habitat section at least twice and preferably three times. Two sweeps are sufficient if the second catch is less than 10% of the first sweep. If catches have not declined in the first three sweeps, continue fishing until the catch declines to less than 25% of the initial sweep's catch, to a maximum of five sweeps.

F. All fish captured are measured (to the nearest mm) and weighed (to the nearest 0.1 g). Recorded in conjunction with these measurements should be information about which habitat section the fish came from, (i.e. riffle or pool) and the spawning status of fish (i.e. ripe, partially spent, or spent).

3.3.5 Data analysis for assessment of chronic impacts

Determine the average density and biomass of fish for the whole site and for each habitat unit (riffles, runs and pools). Density estimates can be based on actual fish captured and on estimated fish numbers using the repeated runs fishing data according to the methods of Carle & Strub (1978) and Zippin (1956) or other calculations (Cowx 1983).

Biomass can be directly calculated from the total biomass of fish caught or alternatively the biomass can be adjusted to match the estimated fish numbers using the equation:

$$\text{Estimated biomass} = \text{biomass of caught fish} \times (N_{estimated\ fish}/N_{fish\ caught})$$

Comparison of biomass and densities caught among sites up and downstream from the intake may indicate chronic declines in population health. If biomass and/or density are significantly lower in downstream sites this could indicate an impact. Similarly, comparisons of biomass and density can be carried out among streams in the same fashion as within a stream. Data used for comparisons should be from the same time of year. There is likely to be significant variation in fish density and biomass among different seasons. The data can be graphed with plots comparing sites or variation through time (Figs A1.1 and A1.2). Comparisons of the fish density and biomass can be carried using analysis of variance (ANOVAs) or non-parametric tests such as the Kruskal-Wallis test (Zar 1984).

Condition factors should be determined using Fulton's Condition factor (Schreck & Moyle 1990):

$$\text{Condition factor (K)} = \text{weight/length}^3 \times 1000$$

Condition factors can be directly compared among sites up and downstream of the abstraction initially by simple visual comparisons of length verses condition factor plots (Fig. A1.3) or statistically using ANOVAs. The analysis should only compare samples taken in the same season, preferably from dates as close as possible to one another. Condition factor will vary considerably among seasons as fish gain weight prior to spawning and subsequently loose weight during spawning. Condition factor and biomass comparisons during the spawning season should divide samples into spent, ripe and partially spent fish. This categorisation of the samples will allow any analysis to avoid the pitfalls of differing percentages of ripe and spent fish at different sites.

In stressed populations the fish may respond by reducing their reproductive outputs. To test this, measurements of the gonad production of the fish can be made and fecundity and egg size estimated. Samples of ripe male and female fish can be taken from the population and egg and milt production compared from sites above and below abstraction sites or from similar streams. A gonadosomatic index (GSI) can be calculated for male and female fish from the following formula:

$$\text{GSI} = \text{gonad weight (g)} / \text{total body weight (g)}$$

For good comparisons among impacted and unimpacted sites, samples of 20 fish and probably up to 50 would be required of each sex. This unfortunately requires the sacrificing of fish to obtain gonad weights and is not recommended for populations with few spawning adults.

Reproductive limitations may also be detected in length frequency analyses of the fish collection data. Fish collections measured in autumn should contain a distinct cohort of juvenile fish usually between 30–50 mm in length. These are the juvenile fish recruiting to the population. The absence of recruits at some sites may indicate reproductive limitations and/or the absence of spawning habitat (Fig. A1.4). However, care must be taken when assessing recruitment data, as environmental and historical factors may be influencing recruitment, not the abstraction. Comparison of recruitment in the abstracted stream with that in unimpacted streams could distinguish the effects of the abstraction from natural variability.

3.3.6 Environmental factors leading to chronic declines in galaxiid population

If galaxiid populations downstream of abstractions show reductions in the measures of population health (e.g. density, biomass, or condition factor) it is likely that interest will focus on the causes of the decline. Potential causative factors that could be assessed are temperature regime, dissolved oxygen levels, food availability, operating frequency of water abstraction, and sediment inputs. Monitoring programmes can be initiated to investigate temperature and oxygen level using the appropriate monitors and data loggers. Temperature and oxygen monitoring sites up and downstream of the abstraction point can be compared against one another and with environmental tolerance data for a species of concern if this data is available. The difficulty with monitoring programmes investigating environmental factors is not the implementation, but linking any changes in the monitored conditions to changes in the fish population. Therefore it is recommended that investigations be initiated to determine lethal temperature and oxygen levels for non-migratory galaxiids.

Food availability, both the abundance of preferred prey items and overall prey abundance, can decline when instream conditions are harsh. For example, many mayfly species do not tolerate high temperatures (Quinn et al. 1994, Cox & Rutherford 1998). *Deleatidium* mayfly nymphs are a common prey of galaxiid species (Glova & Sagar 1989, Bonnet et al. 1989, Allibone & Townsend 1998) and a decline in their abundance has the potential to reduce prey availability. However, diets of non-migratory galaxiids (Allibone & Townsend 1998) are variable and prey species may vary without the galaxiids being limited nutritionally.

A further area of investigation is the rate of fine sediment accumulation in low-flow areas downstream of abstractions. Where abstractions remove a high proportion of the instream water it is likely that the stream immediately below the abstraction will have reduced sediment transport ability, leading to accumulation of fine sediments. Fine sediment accumulation can reduce habitat quality by clogging interstitial spaces, reducing cover for fish and invertebrates, and smothering spawning habitats. Initial assessment of sedimentation can be made visually after a period of abstraction and comparison made with either upstream areas or the same areas below the abstraction when the abstraction is not operating.

Invertebrate communities provide another abstraction assessment possibility. Collection of invertebrates from similar habitats up and downstream of the abstraction point can be assessed. The MCI or other invertebrate assessment methods can be used to determine whether sensitive taxa are present in the abstraction impact reaches (Stark 1985, 1993). In conjunction with this assessment, density comparisons can be made of the invertebrate numbers at different sites. This may be especially valuable when prominent diet species are compared. If common species such as mayflies are absent, dietary restrictions may be limiting the fish populations. Studies on such limitations have not been carried out and it is possible that substantial declines in invertebrate numbers are required for there to be noticeable decline in fish density and condition. This is because the galaxiid diets are often very broad and include terrestrial items (Allibone & Townsend 1998) and galaxiids populations are generally not food limited but recruit limited (Huryn 1998)

3.4 LIMITATIONS OF DETECTION METHODOLOGIES

The comparison sites used in the analysis will also limit the assessment of chronic impacts. For ideal comparisons the impacted and non-impacted sites should be the same in all respects apart from the abstraction. This condition is usually very hard to satisfy as prior history of the fish populations may differ, instream habitat can vary and catchment features (e.g. landuse, altitude, runoff and gradient) may all influence the outcome of comparisons. Similarly, even comparisons within the abstraction stream, up and down stream from the abstraction point can be influenced by the above factors weakening any analysis. The best method for minimising this problem is to obtain accurate, large and long term data sets for the best available comparisons. Consistent long-term depression of a monitored population or slow continuous decline should be detected by such studies.

4. Acknowledgements

This research was funded by the Department of Conservation (Investigation No. 2506).

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Appendix 1

EXAMPLE PLOTS OF FISH DENSITY, FISH BIOMASS, FISH CONDITION AND FISH LENGTH FREQUENCIES PLOTS FOR SITE COMPARISONS

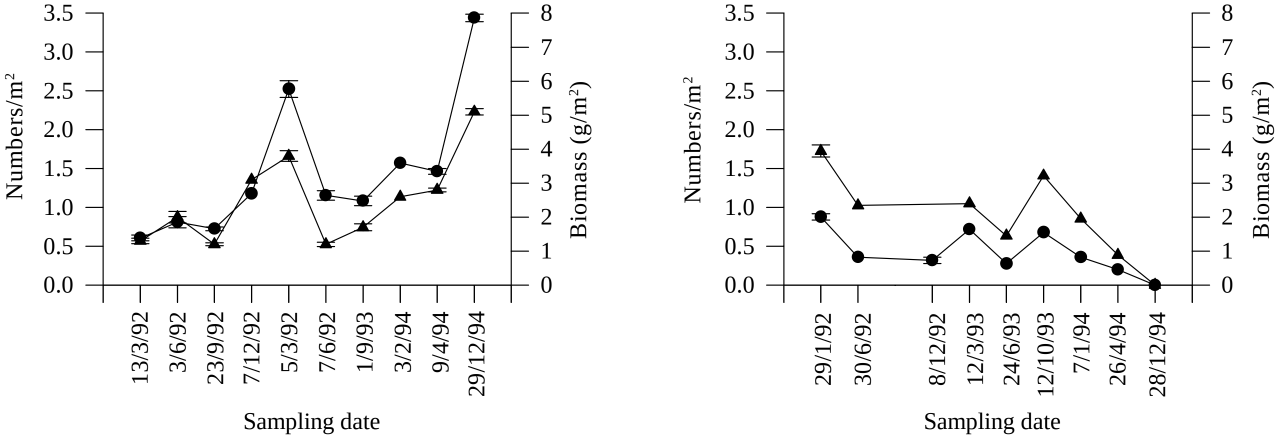
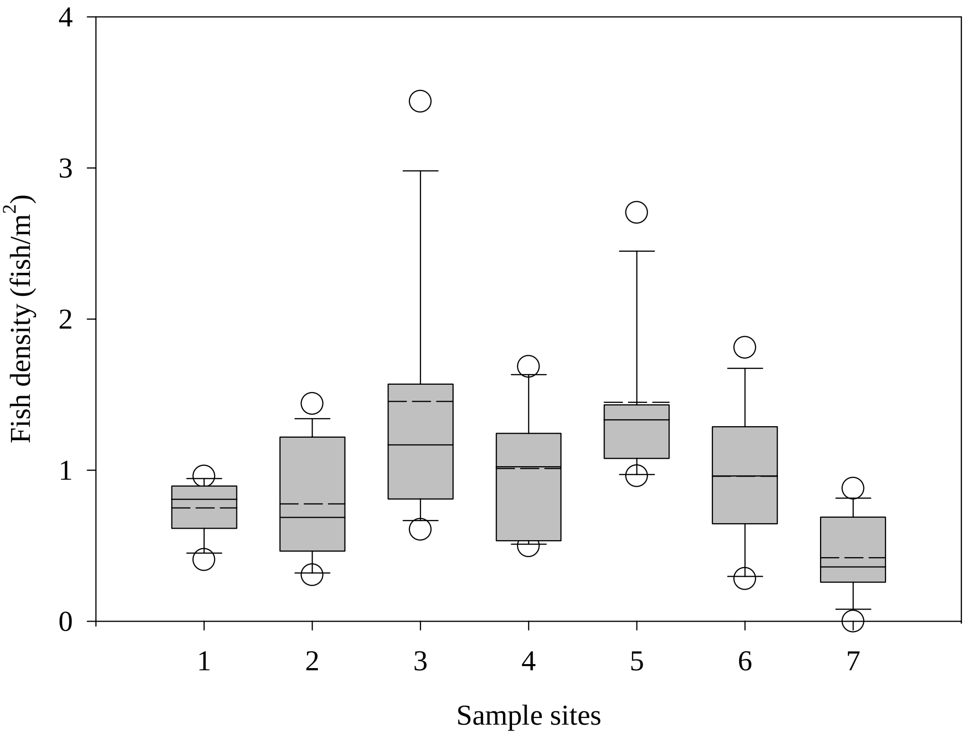


Figure A1.1. Plots of the variation in density and biomass of *G. depressiceps* through time at two sites.

Figure A1.2. Box plots of *G. depressiceps* densities at seven sites. The box plot whisker bars display the range between 10th and 90th percentiles, the shaded boxes enclose the 25th to 75th percentiles and the line with the boxes indicate the 50th percentile. Mean density at each site is indicated by the dashed lines. Open circles outside the range of the whisker bars are density samples greater or less than the 10th and 90th percentiles. These plots are useful for comparing the variation among sites, and visualising the variability at a site. For instance, density varies very little at site 1 compared with all the other sites and the density at site 5 is almost always higher than the density at site 7.



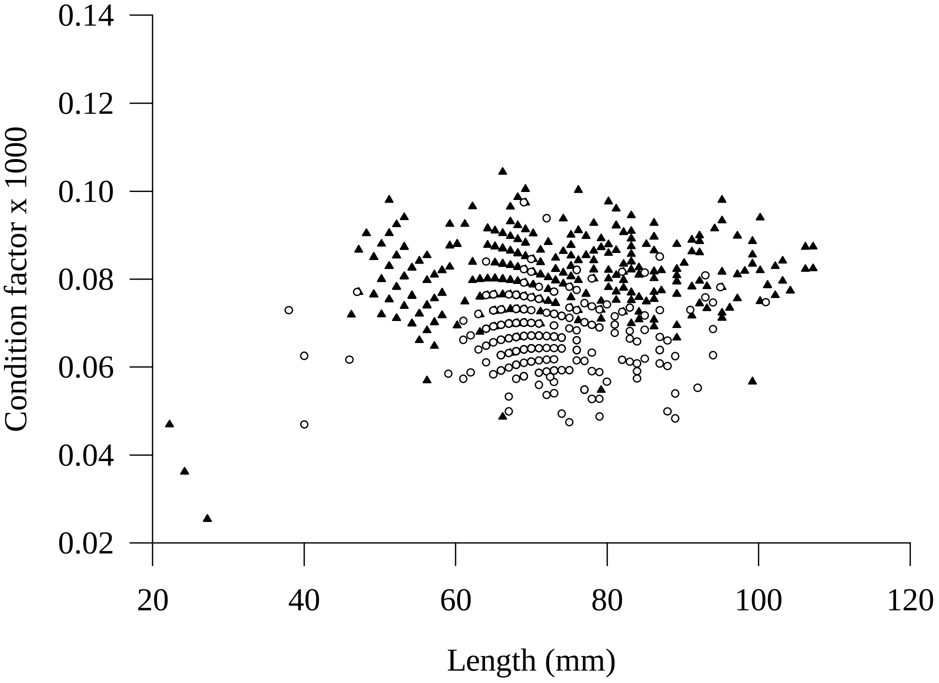


Figure A1.3. Length verses condition factor plot for two *G. depressiceps* populations, Healy Creek (circles) and Three O'clock Stream (triangles). Healy Creek has a consistently lower condition factor than Three O'clock Stream and the condition factor of Healy Creek fish over 80 mm also declines. This plot illustrates that differences in condition factor can be determined from condition factor plots, but also reinforces the requirement that comparison sites among control streams and potentially impacted abstraction streams are carefully selected.

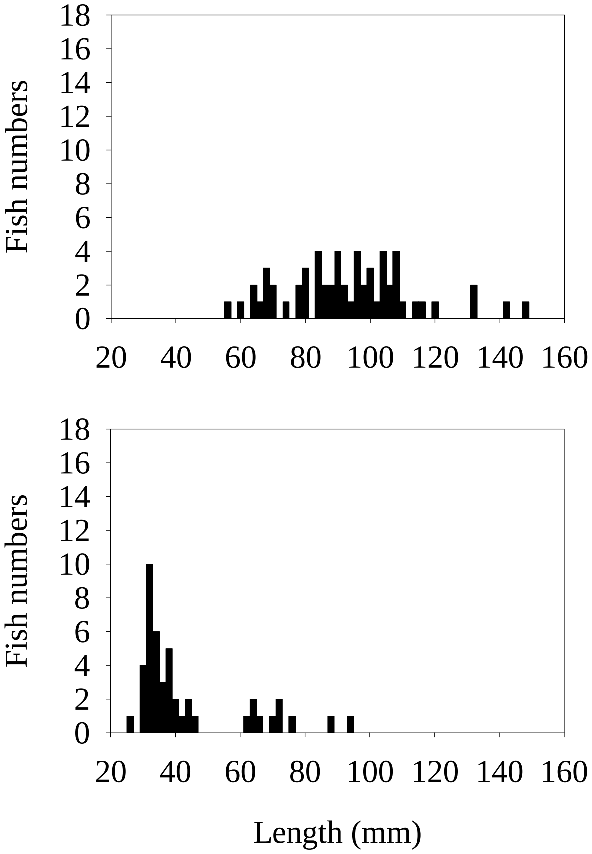


Figure A1.4. Plots of fish length frequencies from two sites in Totara Creek, February 1999. The upper plot is from a site within a water race and has no recruits (30–50 mm fish) at the time of sampling, whereas the lower plot from a site in Totara Creek above the abstraction has high recruit numbers. However, adult numbers display the opposite trend, with more adults at the site in the upper plot.

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

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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.

This paper may be cited as:

Allibone, R.M. 2000: Water abstraction impacts on the non-migratory galaxiids of Totara Creek. *Science for conservation 147B*: 25–45.

or in full as:

Allibone, R.M. 2000: Water abstraction impacts on the non-migratory galaxiids of Totara Creek. Pp. 25–45 in: Allibone, R.M. 2000: Water abstraction impacts on non-migratory galaxiids of Otago streams. *Science for Conservation 147*, 45p.

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.

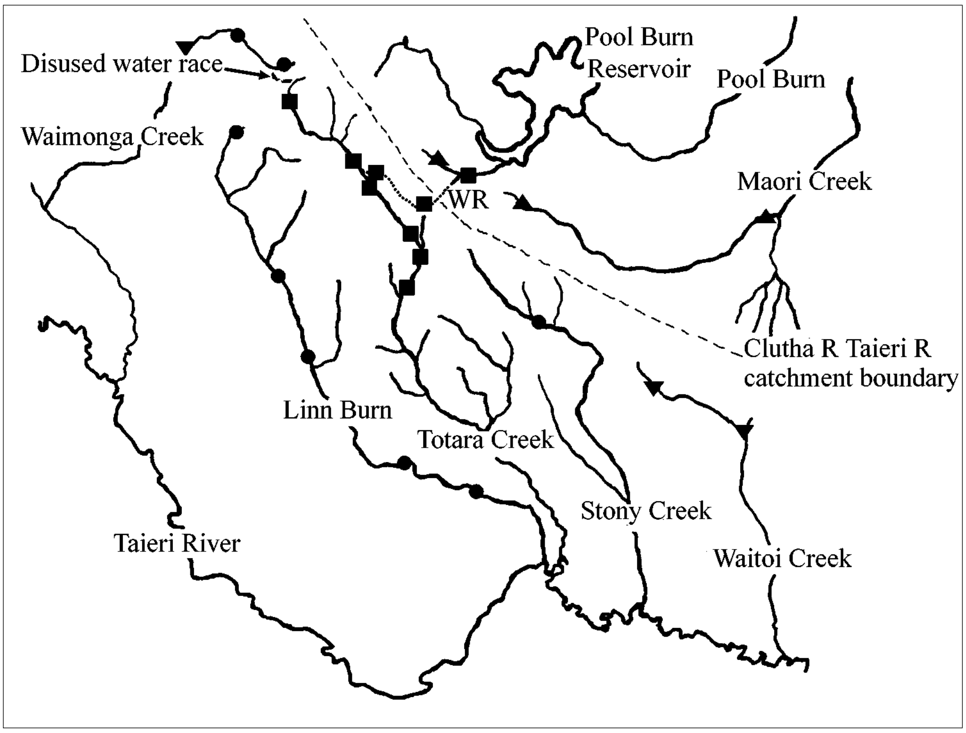
Totara Creek has two water abstraction sites, one in the upper low gradient reach and one at the base of the descent off Rough Ridge. The upper abstraction site is constructed at the site of an old dam, assumed to be a relic of the goldmining era. Water is transported from the reconstructed dam along 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)

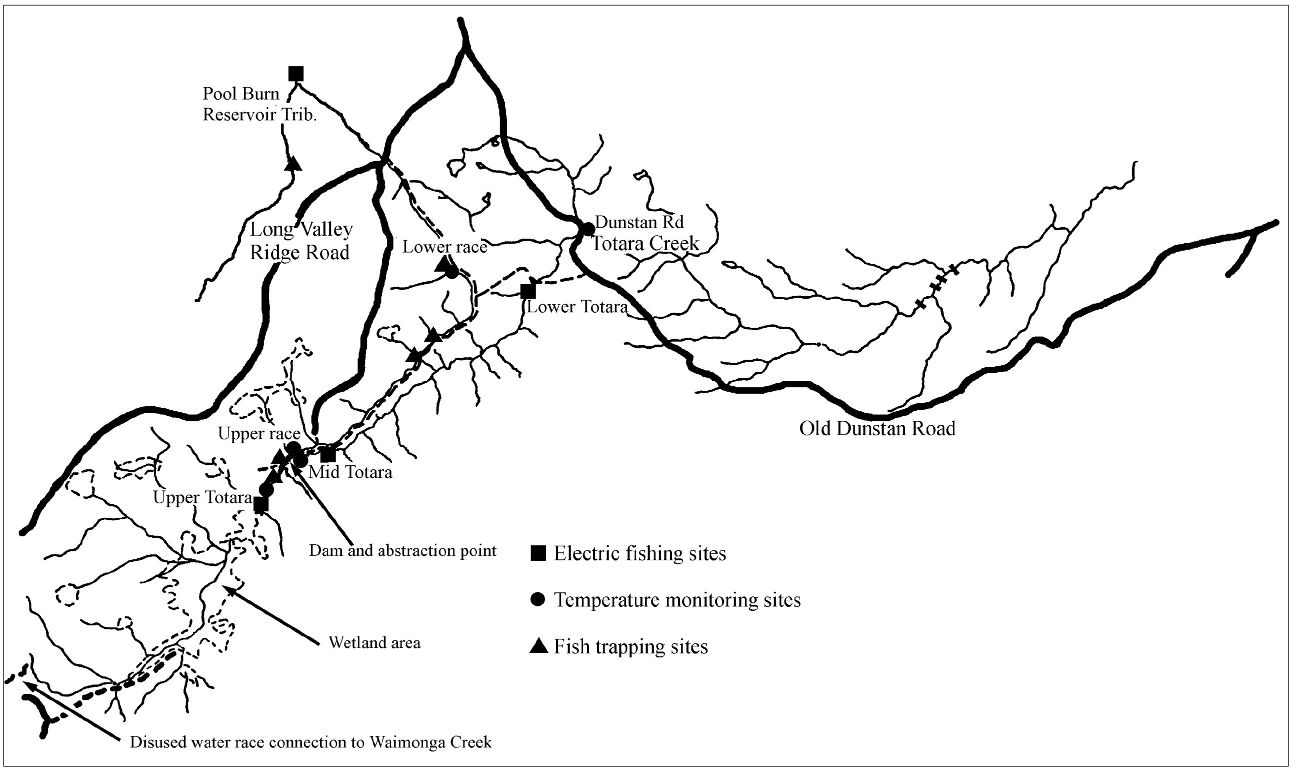


Figure 2. Sampling sites for fish and instream water temperatures in Totara Creek and the Pool Burn Reservoir tributary.

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.

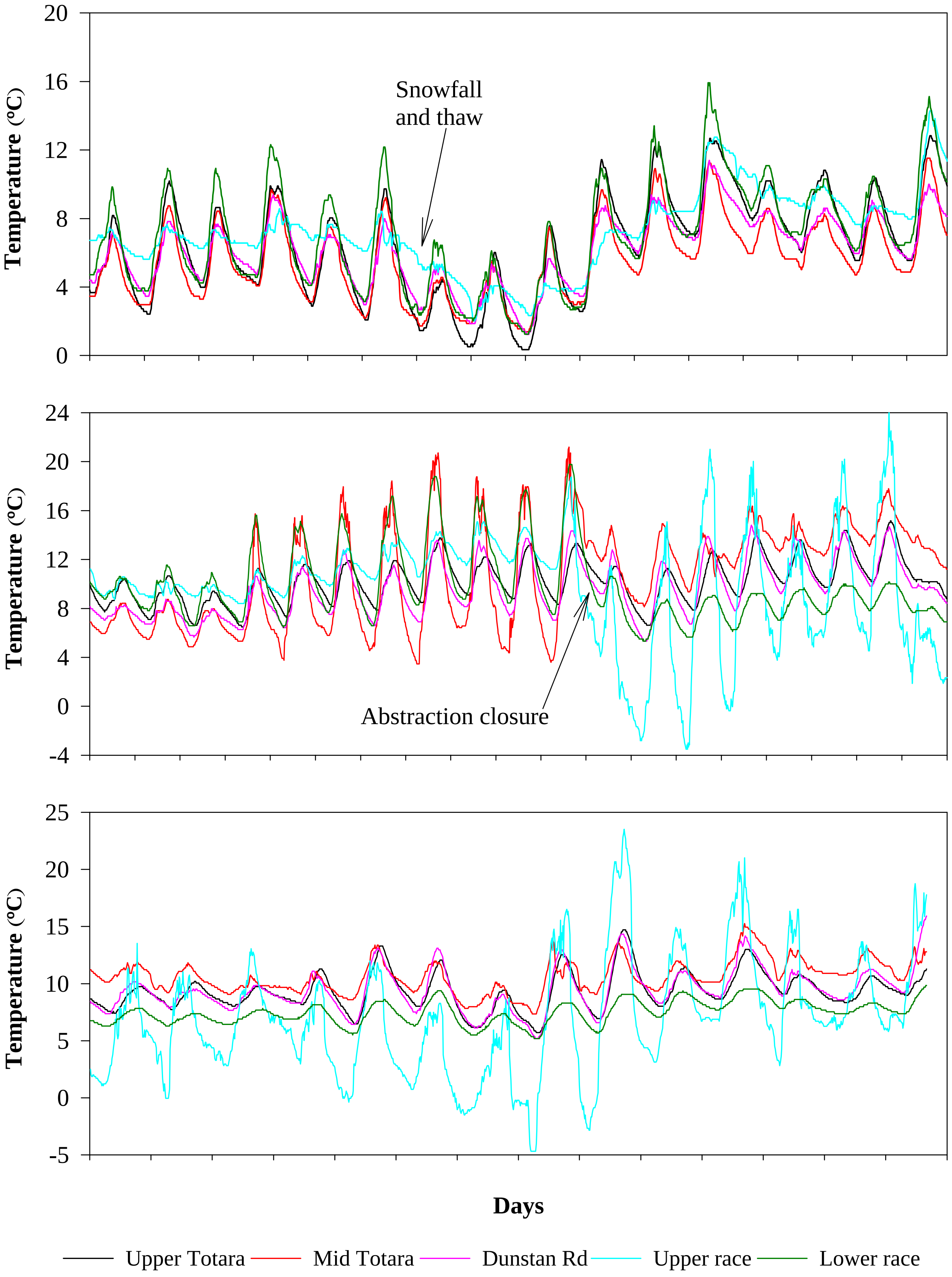


Figure 3. Instream water temperature records at five sites in Totara Creek; 16–31 October 1998 (top), 1–19 November (middle) and 20 November to 3 December (bottom).

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).

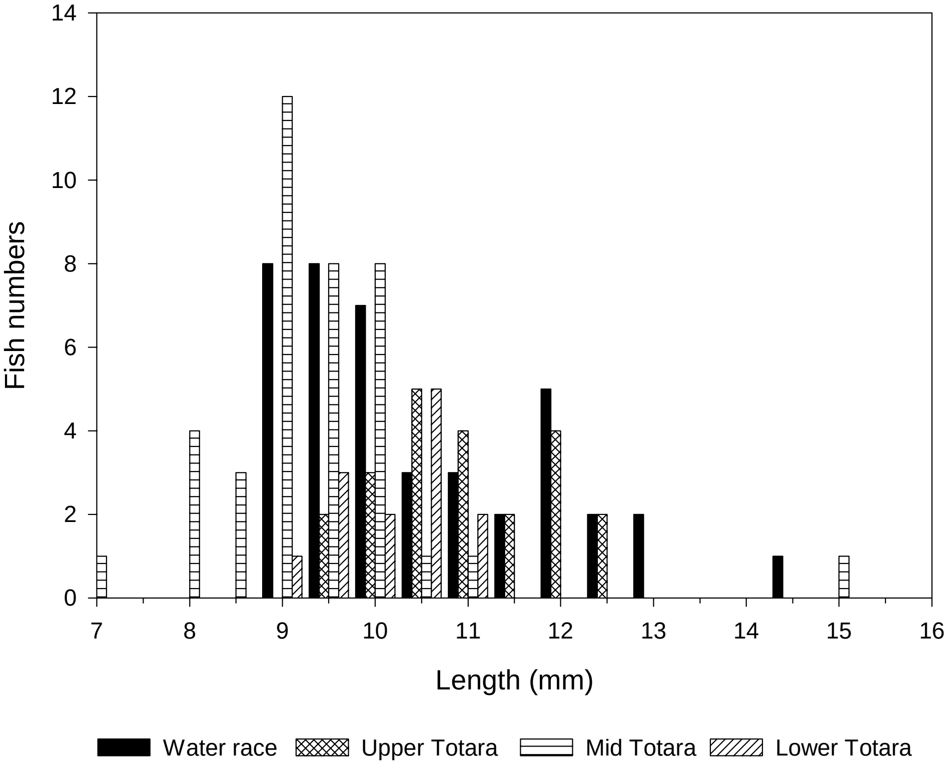
4.7 SPAWNING TIMING AND LARVAL FISH GROWTH

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.

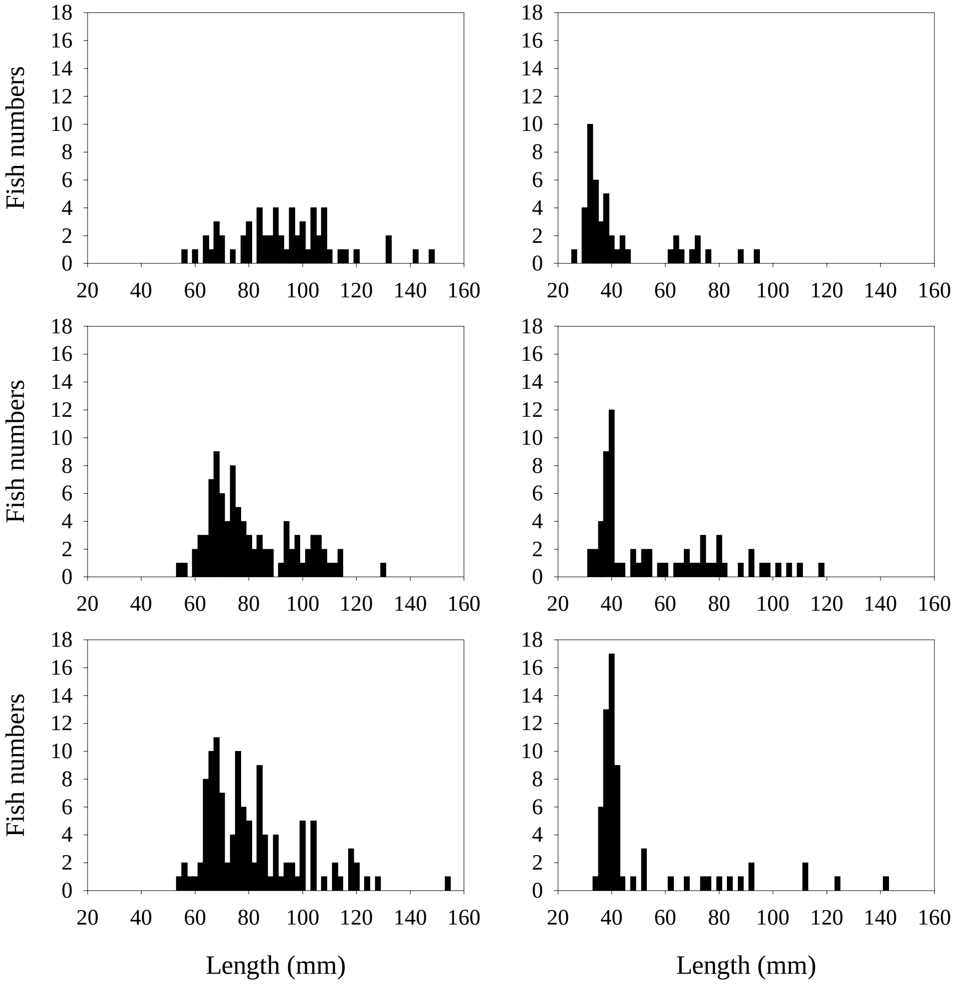


4.8 THE WATER RACE GALAXIIDS

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

This research was funded by the Department of Conservation (Investigation No. 2506). The assistance of Murray Neilson, Mike Tubbs and Tony Eldon with the field work for this project was much appreciated.

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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.

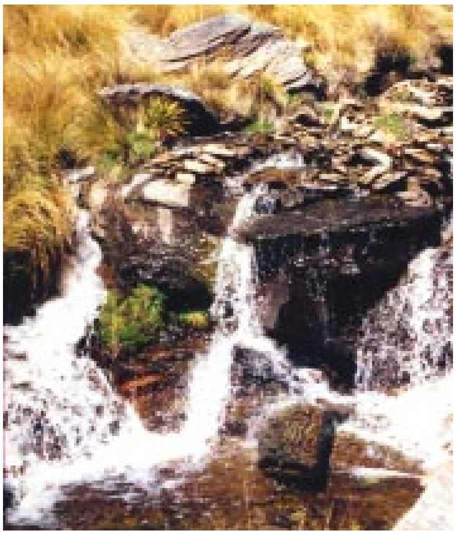

Photo 3. The Pool Burn Reservoir tributary section undergoing erosion of the streambed and margins.

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.

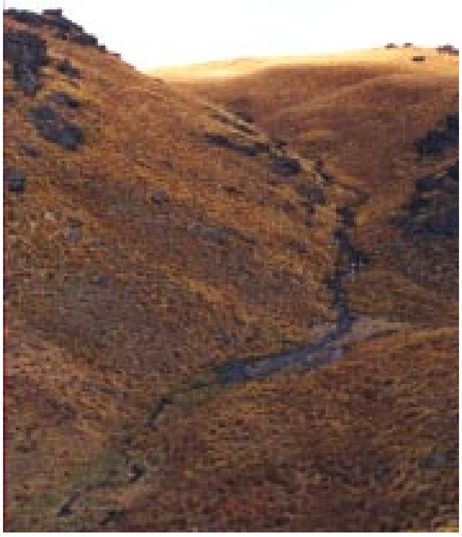

Photo 7. The alluvial fan developing in the Pool Burn Reservoir tributary as a result of headwater erosion.

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.