The Ecology of Koaro (*Galaxias brevipinnis*) in Manson Creek, North Canterbury

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The secret of Life is…

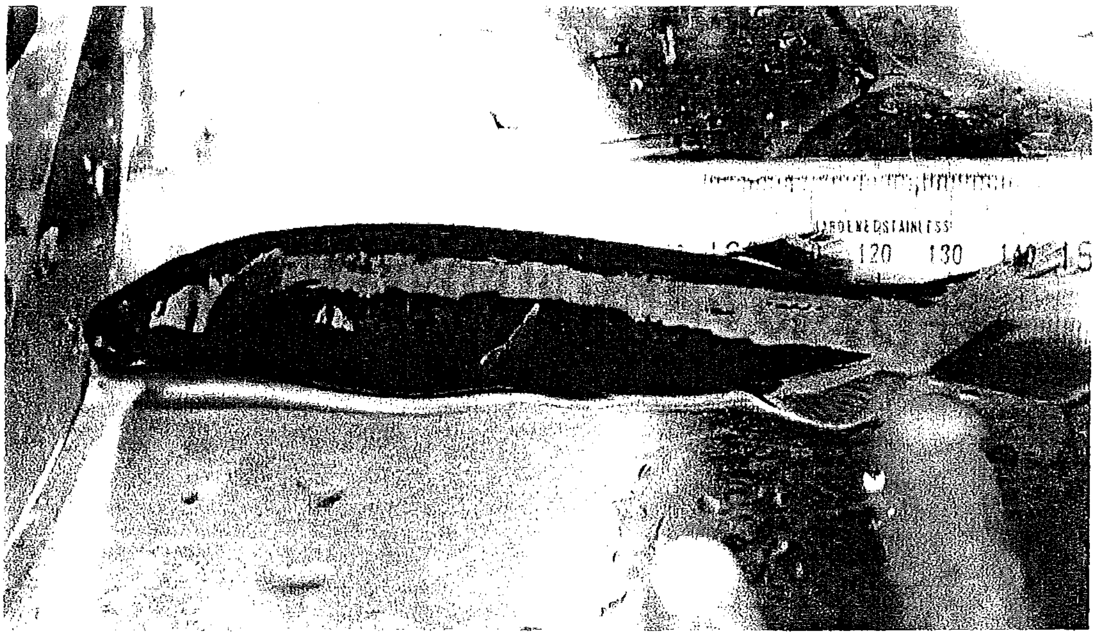
Not to do what you like,

But to like what you do.

The words that inspired me to pursue a thesis in the field of freshwater fish ecology.

FRONTPIECE: *The study animal.*

A: a small adult koaro captured from Mansons Creek.



B: a larger adult koaro swollen with eggs.

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Abstract

The koaro (*Galaxias brevipinnis*) is important in New Zealand's whitebait fishery but aspects of its ecology and life-history are poorly understood. Factors affecting koaro distribution and life-history were investigated in Manson Creek, a lake tributary stream. Six 20 metre sites were electrofished during the summers of 1999/2000 and 2000/01. All koaro > 90mm (FL) captured were tagged. Mean koaro size and density were higher at upstream sites. Brown trout (*Salmo trutta*) abundance was significantly lower upstream, but trout were larger upstream. Koaro distribution can be partly attributed to abiotic factors (more riparian forest and pools upstream). However, interactions with brown trout could also affect their distribution. All koaro were recaptured at the site of initial tagging indicating they utilised a well defined home-range. Mean growth of recaptured koaro was greatest at upstream sites, where koaro density was lowest. Juvenile koaro captured during autumn were the result of spring spawning. Koaro interactions with juvenile brown trout and habitat preferences (shade and velocity) were tested in stream channels. Koaro showed no microhabitat preference even in the presence of trout. However, koaro spent significantly more time alone in trout treatments compared to troutless treatments. Thus, trout affected koaro microhabitat choice more strongly than the microhabitat type. The influence of small and medium sized brown trout on the growth and mortality of small and large koaro was investigated during a one month growth experiment. Mean growth of small koaro was less in trout treatments and least in treatments containing the largest trout, suggesting that trout negatively affect growth of small koaro, possibly through competitive interactions. Less koaro survived in the largest trout treatments, suggesting that larger trout may have preyed upon smaller koaro. This study was undertaken to expand on the knowledge of koaro ecology and life-history in a land-locked population, and how the introduced brown trout may affect distribution, growth and survival of koaro.

CHAPTER 1

Introduction

THE GALAXIID FISHES OF NEW ZEALAND

The Galaxiidae is a southern hemisphere family of freshwater fish in the order Salmoniformes and incorporates the majority (presently 20 of the 36 species) of the indigenous New Zealand freshwater fish fauna (McDowall, 1990a, 2000). The 20 species of New Zealand Galaxiidae are divided into two genera, *Galaxias* and *Neochanna*, having sixteen and four species, respectively (McDowall, 2000). Within the whole family Galaxiidae there are seven diadromous or marine migratory species, four in Australia (two shared with New Zealand) and five in New Zealand (McDowall, 1988).

During spring, throughout New Zealand juveniles of five different galaxiid fishes migrate into freshwater where they are often harvested and eaten as a culinary delicacy know as whitebait. Juvenile galaxiids of the giant kokopu *(Galaxias argenteus*), banded kokopu (*Galaxias fasciatus*), shortjaw kokopu (*Galaxias postvectis*), koaro (*Galaxias brevipinnis*) and inanga (*Galaxias maculatus*) comprise the whitebait catch (McDowall, 1984). Because of its economic importance as the most abundant whitebait species, the biology of the inanga is relatively well known. However, in comparison the remaining species have been poorly researched (McDowall, 1990a).

With the arrival of the Polynesian and European people to New Zealand there came introductions of exotic species and the removal of vast stands of native forest, creating open land suitable for cultivating crops and grazing stock. The resulting changes had serious effects on the fish and invertebrate fauna inhabiting nearby rivers, streams and water ways, by both changing the surrounding riparian habitat and introducing new predators and competitors into the existing system (McDowall, 1990a).

Several researchers have discussed the influence of habitat destruction and modification on galaxiid declines (Hanchet, 1990; Main, 1988; Main *et al*, 1985; McDowall, 1980, 1984; Minns, 1990). Some galaxiid fishes which are sensitive to forest removal and thus are largely absent from streams beyond the forest margin are the banded kokopu, shortjaw kokopu and koaro (McDowall, 1990a). The removal of riparian forest by early settlers would have certainly affected the distribution of these galaxiid species.

While the climbing ability of the various galaxiids may influence the upstream limits of their distributions, downstream limits may be set by other factors (Allibone & Townsend, 1997). Much circumstantial evidence indicates that introduced trout have deleterious effects on the native freshwater fish fauna (Crowl *et al*, 1992). These effects are being studied, but still remain poorly documented (McIntosh, 1990; McIntosh, 2000a).

Several papers consider the introduction of brown trout to be a principle cause of the recorded galaxiid declines, citing the competition for space (Cadwallader, 1975; McIntosh *et al*, 1992), competition for food (Cadwallader, 1975; Tilzey, 1976; Sagar & Eldon, 1983) and direct predation (McDowall, 1968a; Tilzey, 1976; McIntosh, 2000a) as mechanisms likely to cause declines in vulnerable galaxiids. As galaxiid and salmonid habitat overlap is often considerable (Glova & Sagar, 1991b; McDowall, 1990b) and as trout are highly aggressive and territorial (Allen, 1951; Hearn, 1987), interactions between trout and galaxiids could occur regularly and may explain some declines in galaxiid populations (Crowl *et al*, 1992). McDowall (1968a) explained how New Zealand's native freshwater fishes have not evolved with salmonid fishes, and thus have not developed the predator escape mechanisms necessary to escape the introduced trout. He further pointed out that in order for them to survive they will need a degree of protection from salmonids.

Koaro are a galaxiid species that have declined in number since the introduction of trout into New Zealand (McDowall, 1990a). As little is know about their interactions with trout it is important that these interactions be studied so that they can be fully understood. For this reason I have chosen to study certain aspects of koaro ecology including their interactions with brown trout.

THE BIOLOGY OF KOARO

The koaro *Galaxias brevipinnis* Günther (1866), is the second most common, and the most widespread, of the five diadromous galaxiid species that have a whitebait migratory stage (McDowall, 1990a). The species name *brevipinnis,* comes from brevis, latin for short and pinna, latin for fin (referring to the short based dorsal and anal fins). Koaro have also been called the mountain trout, *Galaxias lynx*, mountain whitebait (Otago), *Galaxias koaro* (Rotorua lakes area) and the lowland galaxiid (Stokell, 1955). Their large pectoral fins have given rise to common names like elephant ears and broad-finned galaxias (McDowall 1988). In fact there have been 11 different scientific names given to koaro from different areas since the first *brevipinnis* was first described in 1866 by A. Günther (McDowall, 1990a). Studies have shown that all the differently named populations belong to the species *Galaxias brevipinnis*, although two life history types, lake and sea going, exist. The Maori name, koaro, was used for fish of this species from the volcanic plateau, so in the absence of any regularly used common name, koaro is now almost always used in the naming of this species (McDowall, 1990a).

Koaro are a relatively large (typically 160-180 mm mature adult size, but up to 280 mm) galaxiid fish found mainly in the faster flowing bouldery streams of forested catchments throughout the whole of New Zealand, including Stewart Island (McDowall, 1984, 1990a). Although indigenous to New Zealand, koaro are also found in south eastern Australia, Tasmania, and on some of New Zealand's more remote islands including the Chatham, Auckland and Campbell Islands (McDowall, 1990a).

Koaro are negatively buoyant, slender, and almost tubular in body form (McDowall, 1990a). They have a short flattened head allowing them access to small insect refuges among rocks and boulders (Eldon, 1969). They have no scales, instead they are covered in a tough leathery skin and protective mucus layer. The koaro is a beautiful fish with almost tiger-like skin markings of irregularly patterned olive/brown/green pigmentation, that varies between habitats. They often have gold flecks pigmenting their head and anterior dorsal surface and usually have a lighter fawn coloration on their ventral surface (McDowall 1984).

Koaro reach sexual maturity at 2 years of age, almost certainly surviving spawning several times [at least 4 years (Eldon, 1969)], and probably living for up to 6-8 years, perhaps longer (McDowall, 1990a). They are usually found in water of pH >6.6 and most often where the pH is between 7 and 7.4, however they have been found in waters down to pH 3.8 in the Lake Mapourika area (Main, 1988).

As shall be discussed, adult koaro spawn among adult habitat, usually in headwater rivers and streams during autumn and early winter (McDowall, 1990a). Once larvae hatch they are swept downstream where they enter the marine environment. Here they grow quickly due to an abundance of food. During spring, at approximately 50mm in length and 6 months old (McDowall & Eldon, 1980), juveniles migrate from the sea back into rivermouths where they are often harvested as part of the whitebait catch (Woods, 1963, McDowall & Allibone, 1994; McDowall & Suren, 1995). Juvenile koaro whitebait are most abundantly caught during September, declining thereafter (McDowall & Eldon, 1980).

The koaro's importance as the second most abundant species in New Zealand's whitebait catch results in the capture of large numbers of juvenile koaro by recreational and commercial fishers during spring each season (McDowall, 1984). However in a recent newspaper article Bob McDowall discussed how there is no evidence that the recent poor catches of whitebait on the South Island's west coast were the result of over fishing (Henzell, 2000). He did, however, provide support that stock declines over time are due to the continued devastation of the wetland habitats on which native freshwater fish rely.

An earlier report relating to the management of the whitebait fishery supported the influence of human impacts on New Zealand's whitebait fishery (McDowall, 1996b). This report outlined how large areas of the fish and fishery remain poorly understood and that the fishery has always fluctuated and is likely to continue to do so. McDowall (1996b) discussed that there may be a slow decline occurring and that this may be the result of many factors including deforestation, swamp drainage, encroachment by human populations and industry into indigenous habitats, as well as the introduction of exotic predatory fish. Cumulatively these influences are considered likely to have made significant contributions to a decline in the productivity of the fishery. However, these damaging impacts cannot be distinguished from the possibility that declines may be the result of over harvesting (McDowall, 1996b).

Although rarely seen koaro are an important part of New Zealand's freshwater communities. As discussed, increasing urbanisation and development resulting in habitat loss, potential over fishing and competition/predation by trout may all be contributing to a decline in koaro numbers. As with many other species, if the numbers continue to decline it may some day be necessary to conserve or enhance koaro populations so as to prevent another of New Zealand's wonderful, uniquely beautiful species, from disappearing. To be able to accomplish this successfully it is necessary to have a good understanding of many aspects of their ecology as well as biology, two areas where knowledge is presently lacking.

Distribution

Despite having been called the lowland galaxiid, koaro are really the least lowland of all the New Zealand freshwater fishes as they are found great distances inland in bouldery headwater streams of many large rivers. Koaro have been reported to live in the headwaters of the Wanganui approximately 250km from the ocean (McDowall 1990a), and in some South Island tarns, some approaching 1,500m in altitude (McDowall, 1988). How koaro got into these small alpine tarns without stream connections at more than 1000m in the southern alps, is unknown (McDowall, 1990a).

Their widespread distribution can largely be attributed to their legendary climbing abilities. They have been known to climb 20-30m waterfalls (Moffat & Davison, 1986; McDowall, 1990a; Rowe, 1993).

The juvenile fish, 50-70mm in length, climb waterfalls by adhering to damp surfaces through surface tension. Using surface tension they can climb wet glass with little evident difficulty (Woods, 1963). In many of the galaxiids, climbing is also assisted by their quite expansive and ventrally flared pectoral and pelvic fins which both increases the ventral surface area of the fish and also offers some purchase against irregularities in the surface being climbed.

It is widely accepted that koaro distribution is in some way dependent on the presence of native forest (Main *et al*, 1985; McDowall, 1990a; R. Strickland, *personal communication*). As a result, the largest populations of adult fish occur in regions like Westland where extensive areas of native forest occur (Main, 1988). Examples of koaro populations being significantly reduced or completely disappearing after the removal of native bush from stream margins exist (McDowall, 1980). Logging of native bush has almost certainly resulted in the destruction of native fish habitat. A change in riparian vegetation can eliminate or markedly reduce the invertebrate fauna both in and outside the stream, resulting in changes in food available to fish (Cadwallader *et al*, 1980; Edwards & Huryn, 1996). Cadwallader *et al* (1980) found that terrestrial organisms formed a substantial part of the diet of *Galaxias olidus* taken from sites surrounded by overhanging vegetation. In addition, detrital matter which may be extremely important to the overall productivity of streams (Cummins, 1975) is reduced when forest is reduced (Cadwallader *et al*, 1980). There can also be accompanying changes in flow, sedimentation, cover, light penetration, temperature, and dissolved nutrient levels, all of which may also directly or indirectly affect the existing fish fauna (Lynch *et al*, 1977, Morgan & Graynoth, 1978). With human development being increasingly more common in even remote areas of New Zealand, the resulting habitat alteration is a current threat to many of our native fishes. It is presently unclear as to the extent these fish will be able to tolerate further changes.

Koaro sometimes occur outside forested areas but in such areas (e.g., in the braided rivers of Canterbury) are usually rare (Main, 1988). During a twelve month sampling period Sagar & Eldon (1983) collected only seven koaro from Canterbury's Rakia River. However, there is a record of a large number of koaro being captured from a stream with little riparian forest in Canterbury's Lake Coleridge region (Glova & Sagar, 1989). Koaro movements within these different habitats are relatively undocumented.

Being a headwater stream inhabitant, koaro are affected by barriers in streams that prevent access to desired headwater habitats. Although juveniles are able to climb many obstacles, some culverts or barriers constructed in streams prevent the upstream migration of many of New Zealand's migratory species including koaro (McDowall, 1990a). There are probably thousands of kilometres of small stream affected by careless construction of culverts, which could seriously affect the available habitat for migrating koaro (McDowall, 1990a). Dam construction also affects the upstream migration of juvenile koaro, however, fish ladders constructed on some dams allow the passage of migrating fish.

Diet

Koaro are often described as non selective feeders (Sagar & Eldon, 1983). Being a benthic fish, koaro predominantly feed on benthic invertebrates (Kusabs & Swales, 1991; Eldon 1969). As a result terrestrial prey is of less importance, however they do take terrestrial prey in moderate numbers, particularly when drift feeding in riffles (Main, 1988; Main & Winterbourn, 1987). Kusabs (1989) found koaro diet to contain 5% terrestrial prey. A study by Main (1988) found that terrestrial organisms were taken more frequently by larger koaro. This is supported by Hayes (1996), who observed visual surface feeding of large adult koaro during daylight in Northwest Nelson. This behaviour could be considered unusual as these fish are benthic and nocturnal in habit.

Koaro diet varies depending on their size (Naylor, 1983). Naylor (1983) found that larger koaro in lakes maximised energy uptake by feeding predominantly on gastropods, whereas young koaro fed mainly on *Daphnia* and plankton. A change from planktonic feeding as a pelagic larvae to benthic feeding as the fish matures is also found in bully species (Stephens, 1982). A study of another lake population in Lake Chalice found that koaro consumed manuka beetles, caddis, various beetles, wetas and smaller koaro (Meredyth-Young & Pullan, 1977). In stream populations from South Westland, stomach analysis of summer feeding koaro found that adults mainly fed on Trichoptera larvae (34.6%), aquatic Diptera (24.6%) and Ephemeroptera (13.8%), whereas in winter fish consumed mayflies (24.2%) and caddis larvae (23.1%) (Main & Winterbourn, 1987). Main and Winterbourn (1987) found that the invertebrates were taken approximately in proportion to their presence in the drift and benthos. Kusabs & Swales (1991) also found koaro diet to be dominated by Ephemeroptera, Trichoptera and Diptera larvae. Although Main & Winterbourn (1987) and Kusabs & Swales (1991) found terrestrial invertebrates in koaro stomachs, Sagar & Eldon (1983) and Rounick & Hicks (1985) found only benthic invertebrates in koaro stomachs. Adult koaro have also been found to sometimes feed on juvenile koaro, rainbow trout and koaro ova (Kusabs & Swales, 1991). Information on koaro diets in McIntosh (2000b) showed that koaro feed on a wide variety of invertebrate taxa. Thus, koaro have varied diets that are most likely dependent on the local environment, supporting the theory that they are a non-selective feeder.

Spawning

Generally, little is know about the breeding ecology of koaro (McDowall & Suren, 1995). It is very desirable that their life-history be fully understood as such knowledge would be very important to help in the enhancement of endangered koaro populations.

In diadromous populations, adults usually spawn in headwater streams among adult habitat, in streamside cobble substrate (O'Connor & Koehn, 1992, 1998) during a fresh in autumn and early winter (McDowall, 1990a; McDowall & Suren, 1995).

In Australia koaro have been found to spawn in streamside cobble with egg masses being found up to 7m from the stream edge at normal flows (O'Connor & Koehn, 1998). Once laid, eggs mature until mid April or early June when the next large fresh engulfs the eggs, stimulating hatching (O'Connor & Koehn, 1998). Newly hatched larvae are probably then swept downstream to the sea where they feed and grow. Up until recently no koaro spawning sites had been found in New Zealand. A koaro nest was recently discovered in a stream on the slopes of Mt Taranaki (Allibone & Caskey, 2000). These eggs, likely deposited between late April and early May, were found partially submerged and in habitat similar to that described for spawning in Australia by O'Connor & Koehn (1998). The position of the nest at the stream edge also indicated that koaro spawning occurred at higher flows.

Not all koaro are diadromous. Land-locked lacustrine populations inhabit many high altitude lakes in New Zealand (McDowall, 1990a). It is believed that these lake populations have a life-history pattern similar to the sea going populations (McDowall, 1990a), but may spawn during spring rather than autumn or winter. Although undocumented, it is thought that spawning of land-locked populations occurs in the tributary streams of these lakes with the juvenile koaro migrating back into the tributary streams when they are approximately 50 mm in length. Here the pelagic larvae become cryptic bottom dwellers amongst the rocks and gravel of the swiftly flowing streams (McDowall, 1990a; Naylor, 1983). The lakes therefore act as an "inland sea" in which the larval koaro develop (McDowell & Suren, 1995). However, little evidence exists to support these suggestions and it is entirely possible that lake dwelling adults remain among, and spawn within lake habitats (Young, *personal communication*). The size at which lacustrine koaro leave the plankton and enter lake tributary streams seems to be less than the size that the marine diadromous fish enter freshwater, although adult koaro from both populations grow just as large and as fast as each other (McDowall, 1988). Whether these anecdotal reports reflect the general biology of the species is yet to be confirmed.

Despite the recent discovery of a koaro nest in New Zealand, information about spawning habitat, time and spawning cues in different diadromous and non diadromous populations is not well known.

Knowledge of spawning habitat, time and cues can help in the species conservation by assisting managers to identify and protect existing spawning habitat and select suitable release sites if translocation ever becomes necessary (Allibone & Townsend, 1999).

FACTORS INFLUENCING KOARO POPULATIONS

There are a large number of factors that potentially affect the presence or abundance of species in local assemblages (Matthews, 1998). Behavioural interactions, competition, foraging mutualisms, patch choice, presence of predators or prey, population variation, and random variance in the structure of assemblages all influence the presence or abundance of a species (Matthews, 1998).

Reasons for koaro spatial distribution and microhabitat choice in streams have been discussed by several researchers (McDowall, 1980, 1990a; Main, 1988) however, few studies have experimentally tested which physical factors most strongly influence habitat selection. If we know why these fish are limited in distribution then it should be possible to use the information in the wise management and conservation of the species (Main, 1988).

There is a huge literature based on field and laboratory studies to suggests that gradients of temperature, oxygen, or pH can be strong cues to fish in habitat selection or avoidance. Physical characteristics including water chemistry, light intensity and thermal regime can all influence habitat choice (Matthews, 1998). The presence of spawning habitat, forest cover, presence of refuge, access to suitable food resources and vulnerability to competition/predation by trout are all likely to affect koaro distribution.

What happens to dwindling koaro stocks as they penetrate through trout populations when moving long distances upstream to find adult habitats is not known (McDowall 1990b). The nature of the interactions between the introduced salmonids and galaxiids are not well understood (McIntosh *et al*, 1994). Even with the significant increase in research effort, there has been little study of the relationships between indigenous and exotic fish faunas, particularly large galaxiids in New Zealand.

The introduction of both brown and rainbow trout into New Zealand waters to establish a recreational fishery coincided with a dramatic decrease in stocks of koaro in some central North Island lakes (McDowall, 1987). Koaro were once abundant in Lake Taupo, until the introduction of trout into the lake during the late 1800's when dramatic declines in koaro numbers were observed (Fletcher, 1919). Today, with high densities of trout existing in the lake, only remnant populations of koaro remain in the Lake Taupo and its tributaries. Although the significant reduction in koaro populations has not been critically examined, the association between trout introduction into lake Taupo and the subsequent koaro decline suggests that the reduction in koaro was largely caused by trout predation (Stephens, 1983). Added to this, is the relative importance of koaro in trout diets (Phillips, 1924). Although few data from the time of trout introduction exist, the koaro were the only abundant and readily available food resource that trout could have taken advantage of in the lake (McDowall, 1987). Their decline in the years after the trout establishment can be attributed, with little doubt, to trout predation (McDowall, 1987).

Competition for food resources between native fish and trout are also likely to be an important factor contributing to the decline of some native fish populations (McDowall, 1990b, Crowl *et al*, 1992). An example of koaro decline after trout introduction was discussed by Frankenberg (1966). He documented how koaro are no longer found in Lake Tarli Karng in Australia as brown trout numbers are now high. A more recent review by Rowe (1993) discussed the complex shift in abundance between introduced brown trout and koaro in Lake Rotorua. Like the koaro population of Lake Taupo, koaro declines were observed immediately after the introduction of brown trout to the lake in 1888. The same pattern of decline was also observed in nearby Lakes Rotoiti, Waikaremoana and Okaitaina after the introduction of rainbow trout. However, whether the introduction of trout was the only reason for the reduction in koaro numbers in unclear due to the further introduction of the common southern smelt (*Retropinna retropinna*) to the lakes occurring shortly after. As these pelagic fish compete for plankton required by koaro larvae, few koaro were found following the introduction of the smelt, while some galaxiids were still found in the lakes up to 20 years after trout introduction (Rowe, 1993).

McDowall (1968a, 1984, 1987, 1990b) discussed how streams habitable by trout generally contain high trout numbers and low, or non existent, galaxiid densities. In comparison, streams less suitable to trout usually contain low trout densities and often high galaxiid densities. A survey of South Westland streams by Main *et al* (1985) found that koaro did not occur at any site where brown trout were present. This was supported by a later study by Main (1988) which found no overlap of larger galaxiid and brown trout distributions. A survey by Jackson & Williams (1980) in Australia's Otway ranges also found koaro were absent from sites where trout were present.

Galaxiids have been found to be more vulnerable to trout predation than bullies (Glova, 1990). Juvenile koaro were once very important in the diet of trout (Phillips, 1924). Koaro juveniles are likely to be especially vulnerable to predation due to their small size. Large adults probably experience a size refuge against predation from most trout, however, large trout could most likely consume even the largest koaro. My personal observation of a large trout (500mm) consuming a whole giant kokopu (approximately 250mm) supports this theory. McIntosh (1990) discussed how the threat of further introductions, planned or accidental, makes understanding the effects of the present introductions even more important.

Predation by eels would certainly occur as the diet of large eels is dominated by various fish including galaxiids (McDowall, 1990a). Other native predators of koaro probably include herons, shags and rats. Introduced predators probably include cats, ferrets, stoats and possibly possums.

As discussed, little is known about the basic biology of koaro. Many aspects of its life-history and ecology including size distributions, age of sexual maturity, when and where fish spawn (McDowall & Suren, 1995) and their movements as adults are all uncertain. In particular, the habitat requirements of large galaxiids are poorly understood, although all appear to depend to some extent on the presence of forests for their existence (Main & Winterbourn, 1987). Interactions between koaro and other fish are also not well understood.

To conserve and perhaps enhance our dwindling native galaxiid populations we must first obtain a better understanding of the ecology of these fish. If we know why these fish are limited in distribution then it should be possible to use the information in the wise management and conservation of the resource (Main, 1988).

Koaro and trout size may vary longitudinally up a stream from its lake/sea outlet in the lower reaches to its origin in its headwaters. Factors that may influence the size distribution of koaro are the presence of preferred habitats and the resulting food supply, as well as fish (koaro/trout) density and the resulting intra/inter-specific competition and predation. Water depth and velocity are also likely to affect the size distribution of trout. The relationships between habitat and koaro abundance, koaro size and longitudinal distribution in a stream and the importance and reasons for their selection of forested habitats are relatively uncertain.

The objective of my study was to investigate some of these unknown aspects of koaro ecology, more specifically focussing on their longitudinal distribution, interactions with the introduced brown trout (*Salmo trutta*), growth in different habitats, movement and their time and choice of spawning sites.

The galaxiids are secretive fishes with the ability to exist in large numbers undetected. Researchers once considered the possibility of koaro extinction as the clearing of forests and opening of stream gullies had caused substantial koaro declines (Stokell, 1955). For this reason it is essential that the koaro's life history and behaviour be fully understood to allow any necessary measures to preserve the species to be taken (Eldon, 1969).

Reductions in koaro recruitment would have clear implications for the New Zealand whitebait industry (Eldon, 1969). More importantly, such a beautiful fish species is seen by the Department of Conservation as important part of New Zealand's bio-diversity and further declines in another of New Zealand's endemic species would be extremely sad indeed.

THESIS STRUCTURE

In Chapter One, I have discussed much of the information already known about koaro ecology, biology and life-history and have emphasised why they are important and in which areas knowledge of this species is currently lacking.

In Chapter Two, I report on investigations of the spatial distribution of both koaro and brown trout with respect to their density and size moving longitudinally up Manson Creek. Biotic and abiotic factors (Section 1.3) may vary with proximity to Lake Pearson as the surrounding riparian habitat and other physical characteristics of the stream, as well as the density and size of co-existing brown trout, changes with distance upstream. To assess how koaro and trout spatial distribution in Manson Creek varied with proximity to Lake Pearson, electrofishing was used to capture fish at six 20 metre sites situated longitudinally up the stream. I have discussed how fish size distribution varies with proximity to Lake Pearson and have related my findings to the abiotic/biotic factors that may affect each fish species distribution.

Chapter Three assesses aspects of koaro life-history in Manson Creek. Koaro growth at different sites in Manson Creek, the movements and the presence of a home-range of tagged adult fish are all discussed. Factors likely to affect such processes are also described. Comments on koaro spawning are also included.

In Chapter Four, I investigated how koaro of different sizes interacted with trout of different sizes and how these interactions affected their habitat utilisation, growth rate and condition. Using a variety of different tank and in-stream behavioural, growth and interaction experiments it was possible to access how different sized trout affect the growth, habitat utilisation and behaviour of different sized koaro. This is an important aspect of my research as trout impacts on galaxiid fishes are not only likely to play an important role in the distribution of koaro in a stream via competition, but also represent a more serious threat to koaro survival through predation. More knowledge of trout impacts on koaro are required so that if ever necessary, in the future, appropriate steps can be taken to reduce any negative impacts caused by trout, resulting in the enhancement of koaro populations.

Chapter Five is a general conclusion to my thesis and summarises information regarding threats to koaro populations and advice for conservation, management and enhancement of koaro populations.

CHAPTER 2

Spatial distribution of koaro in Manson Creek

INTRODUCTION

Koaro typically inhabit smaller, steep-gradient streams, two to three metres wide, often having cool, clear water and swift bouldery rapids (McDowall, 1990a). Their distribution is to some extent dependent on forests (McDowall, 1980; Main *et al*, 1985; Main, 1988) as they are rare or absent in poorly forested regions. As a result, the clearing of forests and opening of stream gullies has led to koaro decline (McDowall, 1990a). There have almost certainly been dramatic reductions in the distribution of koaro populations since the arrival of the European and the subsequent removal of riparian forest cover along rivers and streams. The largest populations of adult fish now occur in regions such as Westland with the most extensive areas of native forest and are rare, or absent, in poorly forested regions such as Canterbury (Main, 1988).

While the climbing ability of galaxiids may influence the upstream limits of their spatial distributions, downstream limits may be set by other factors (Allibone & Townsend, 1997). Exotic trout may have been responsible for altering galaxiid distributions through competition and predation (McDowall, 1987), and have been found to actively deter galaxiids from occupying certain microhabitats (McIntosh *et al* 1992). This is reflected in many galaxiid and trout distributions that are largely allopatric (e.g., *G. brevipinnis*, Main, 1988; *G. vulgaris*, Townsend & Crowl,1991; *G. anomalus* and *G. depressiceps*, Allibone & Townsend, 1999). Distributional studies in Australia imply that trout have reduced koaro numbers, and in some more extreme cases have completely eliminated koaro from streams (Tilzey,1976; Jackson & Williams, 1980). In New Zealand, numbers of *G. vulgaris*, a galaxiid species very similar to the koaro, have been found to be reduced by trout (McIntosh *et al*, 1994). McDowall (1987) discussed how in New Zealand, the native Maori people became concerned with the trout feeding voraciously on small koaro in lakes as these fish were an important part of their food supply.

Another New Zealand study concluded that predation by trout was most likely to be the cause of disjunct galaxiid distributions in Otago (Townsend & Crowl, 1991). In the mainstems of a medium sized forth order stream on Stewart Island, koaro have been found to occupy diverse habitats including pools and backwaters, habitats they would not usually be found occupying when trout are present (Chadderton & Allibone, 2000). The wide habitat usage and extensive distribution of koaro on Stewart Island have been attributed to several factors including the presence of intact catchment vegetation, unmodified stream channels and the absence of introduced salmonid fishes. This result implies that some native species have been excluded from mainstem habitats elsewhere in New Zealand by trout and land use change. Koaro distribution has also been found to be affected by other galaxiids. On Stewart Island, koaro were found to avoid backwaters, runs, and pools in reaches occupied by *Galaxias fasciatus* and *Anguilla dieffenbachii* (Chadderton & Allibone, 2000).

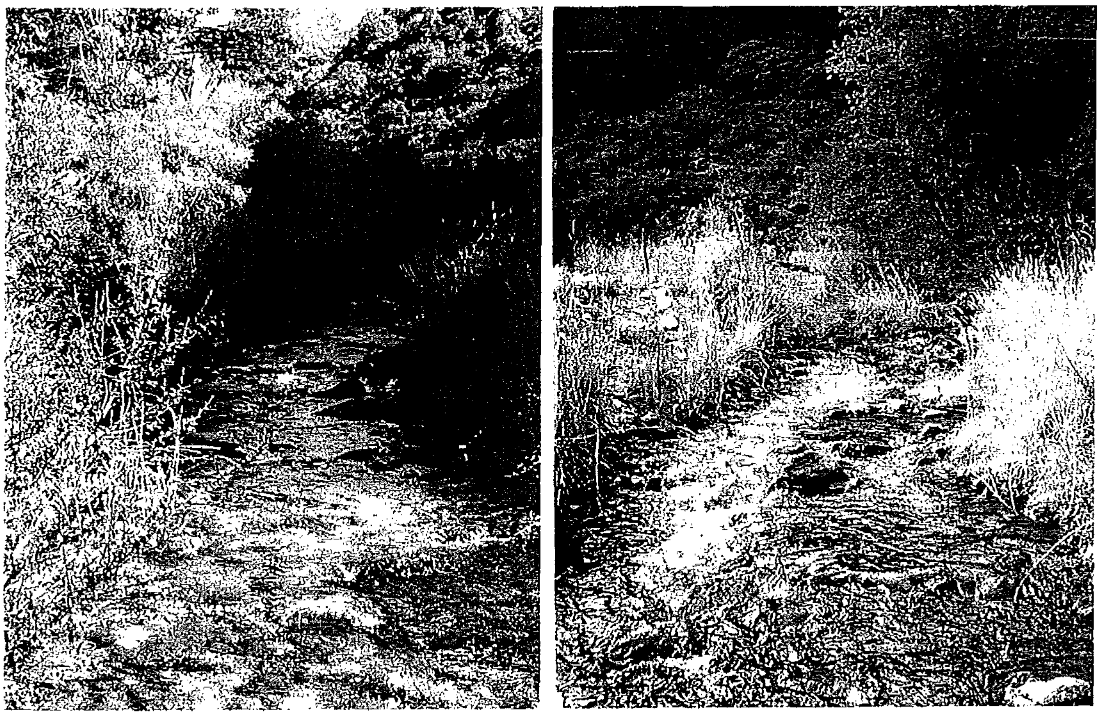
In certain rivers and streams koaro have been found to inhabit riffles as often as they do pools (Main, 1988). Chadderton & Allibone (2000) found that koaro occupied diverse habitats including pools and backwaters in a Stewart Island stream where trout were absent. I predict that as trout prefer pools, slower water velocities would most often be selected by trout. However, as koaro rarely inhabit the same habitat as trout, when trout are present I predict that koaro should occupy faster water including riffles and cascades.

In this chapter I evaluate the factors that are most important in explaining the distribution of koaro in Manson Creek. This stream was chosen because it contained a relatively large population of adult koaro, it was relatively close to the Cass field station and was accessible through to its upper most reaches by an overgrown walking track. Specifically, I evaluated their distribution patterns with respect to habitat variables, their size and the presence and absence of different sized brown trout.

METHODS

Study sites

Manson Creek is a small to medium sized, fast flowing bouldary stream which originates in the Beech clad hills surrounding Flock Hill Station, central North Canterbury. It flows for some distance from its mountain origin close to Craigieburn Ski Field before entering Craigieburn Stream, the only significant Lake Pearson tributary, less than two kilometres prior to entering the lake (Fig. 2.3). Comparing the lower and upper reaches of Manson Creek, there is a dramatic change from low gradient, open, shingle riffles containing few pools and occasional riparian vegetation in the lower reaches, to higher gradient, bouldery riffles and cascades with increasing numbers of pools bounded by riparian beech forest in the upper sites (Figs. 2.1 & 2.2).



Manson Creek (Site 1) **Manson Creek (Site 2)**

Figure 2.1. Manson Creek Sites 1 and 2 showing the open riffle habitats utilised mainly by smaller brown trout in the lower reaches. Note the cobble-dominated substrate and the relative lack of riparian forest close to the stream.

Manson Creek (Site 5) **Manson Creek (Site 6)**

Figure 2.2. Sites 5 and 6 in the upper reaches of Manson Creek showing the tumbling cascades and pools. The large boulders and nearby riparian beech forest are also obvious.

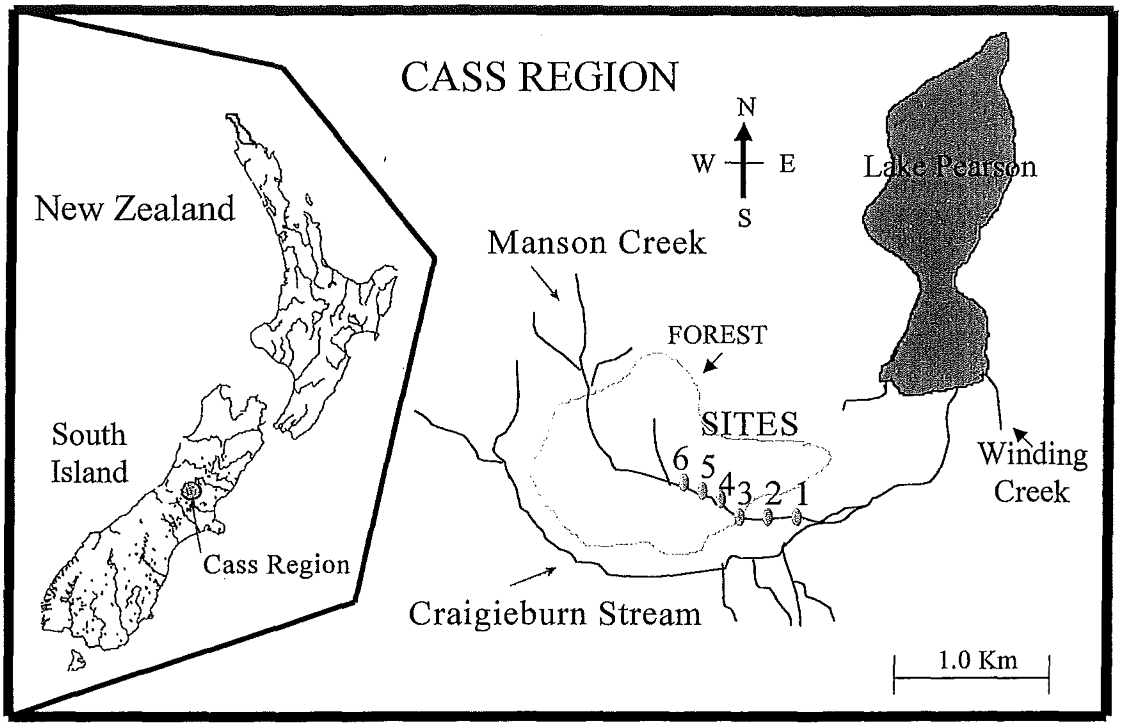


Figure 2.3. The location of Manson Creek, the main study stream and associated study sites in the South Island of New Zealand.

The longitudinal distribution of fish in Manson Creek was determined by electrofishing six sites in the summers of 1999-00 and 2000-01. The six sites were spread longitudinally up Manson Creek covering one kilometre of water consisting of different instream and riparian habitats (Fig. 2.4). The transition from open gently sloping terrain to beech covered steeper habitat was the most obvious visual change that occurred when moving from downstream to upstream sites (Figs. 2.1 & 2.2).

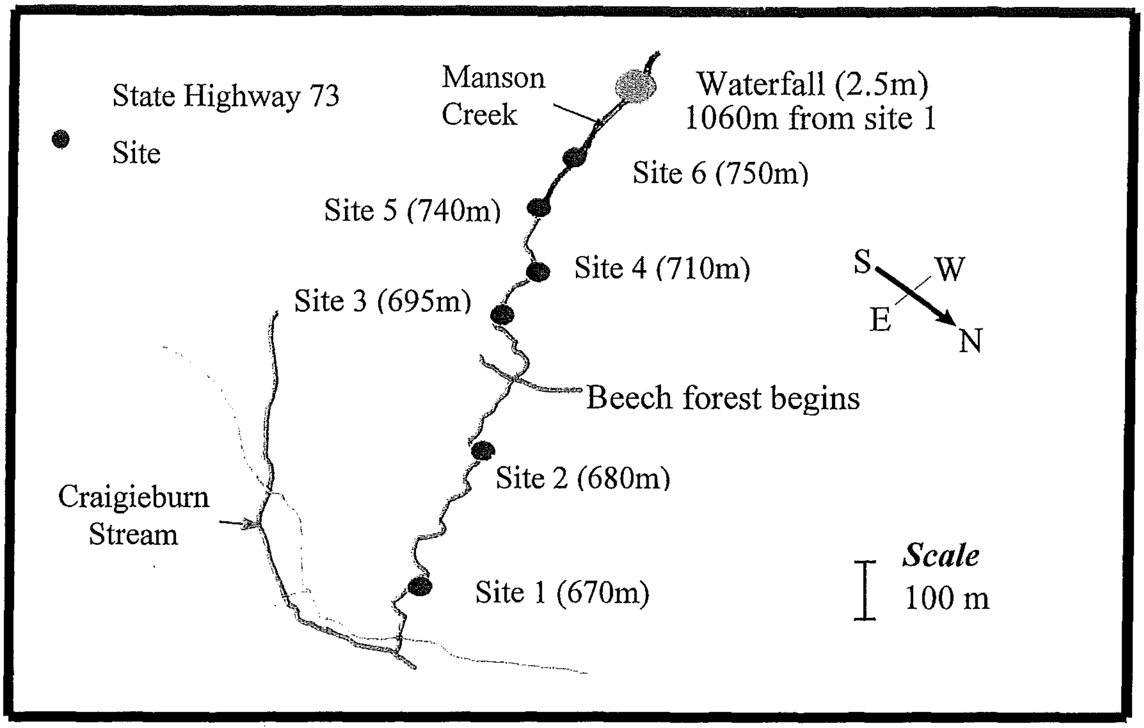


Figure 2.4. The position of the six study sites in Manson Creek. The nearby state highway, beech forest transition zone and location and altitudes of each of the six study sites are shown.

A Kainga EFM 300 backpack electrofishing machine (NIWA Instrument Systems, N.Z.) was used to capture fish. This equipment produced 400 - 600 volts pulsed D.C. (pulse width = 3ms, 60 pulses/s). As many researchers have utilised electrofishing methods as an efficient means of successfully capturing unharmed fish, it was decided that this method would be used in an attempt to capture all fish at each 20m site. Kusabs (1989) found electrofishing an effective method of capturing koaro in small streams and found little koaro mortality resulted from using this method. It has also been used as an effective method of catching other galaxiids including *G. vulgaris* (Cadwallader, 1976).

Figure 2.5. Electrofishing a section of water between Manson Creek Site 5 and Site 6. Note the movement from upstream to downstream and the use of a hand-held stop-net by an assistant.

All sites were fished between the 10 December 1999 and the 31 March 2000 and again between the 20 December 2000 and the 16 March 2001 the following year. Upon arrival top and bottom stop nets were immediately placed in the stream to prevent any fish from entering or leaving the 20m site. The 20m site was then electrofished with three downstream passes (Fig 2.5). Using handheld stop and handheld capture nets any stunned/disturbed fish were captured.

All captured fish were measured and weighed after being anaesthetised using 2-phenoxyethanol. The fish species, length (fork length, FL to the nearest mm) and weight (+/- 0.1g), plus any comments on condition or morphology of the fish were recorded.

Koaro were identified using the criteria in McDowall (1990a). There is a small possibility that some galaxiids captured in lower Manson Creek could have been Canterbury galaxiids (*Galaxias vulgaris*). *G. vulgaris* have very similar markings to koaro. Even in the laboratory, analysis of the jaw (koaro have their lower jaw more obviously shorter than upper jaw compared to *G. vulgaris*), and numbers of fin rays are required to distinguish between the two species (McDowall, 2000).

In some populations fin ray numbers can be similar between the two species (McDowall, 1990a). This overlap can make identification even more difficult. Due to regularly capturing koaro at upstream sites, I became familiar with identifying this species. Gold flecks present on the head and dorsal region were one of the most deterministic features of the koaro. I am confident that all the fish identified as koaro in my study were indeed koaro.

Fish density calculations

Fish densities at each Manson Creek site were calculated using the maximum weighted likelihood formulae of Carle & Strub (1978). This method uses the reduction in catch per run to calculate the likely number of fish remaining after electrofishing has finished, the "capture probability" or the likelihood of capturing a certain percentage of fish on a single pass through a site, as well as the standard error (S.E.) and 95 percent confidence interval (95% C.I.) for the total number of fish at each site.

Statistical analysis of fish distributions

Two-way ANOVAs were used to test year to year and site differences in mean koaro and trout density. Koaro density was Log_{10} transformed. Mean density at Sites 1, 2 and 3 represented replicates for lower sites and Sites 4, 5 and 6 were replicates for upper sites. Two-way ANOVAs were also used to test for differences in mean koaro and trout length, and total koaro and trout biomass between lower and upper sites over the two summers sampled (Independent variables: year & up/down, dependent variables: (A) mean koaro length & (B) mean trout length).

Habitat assessment

At each 20m site habitat variables were measured. Depth was measured using a meter ruler. The ruler was placed in the stream 0.25, 0.5 and 0.75 of the distance across the stream at 5 m, 10 m and 15 m up each site and the average calculated. At the 5, 10 and 15 m marks, 10 rocks were randomly chosen at regular intervals across the stream and measured to the nearest 0.5 cm. The mean rock size for each site was calculated as the average of these 30 rocks. A 10 m measuring tape was used to measure the width of the stream at each of the 5, 10 and 15 m marks.

At each of the 5, 10 and 15 m marks, a 100m measuring tape was used to measure the distance to the nearest beech foliage on both banks, parallel with that mark. Negative values were obtained if foliage overhung the stream. Overhang was recorded at each of the 5, 10 and 15 m marks by estimating the percentage of the stream width that had vegetation overhanging the stream, one metre either side of the mark on each bank. At each site the number of pools was counted. A pool was considered any area where water velocity slowed (< 0.2 m/s $^{-1}$) and water depth increased (> 0.5 m/s $^{-1}$). Pools were easily identified as they were usually at the tail of a riffle, rapid or cascade.

Statistical analysis of habitat variables

One-way ANOVAs were used to assess whether there were significant differences in each habitat variable between lower (Sites 1, 2 and 3) and upper (Sites 4, 5 and 6) Manson Creek sites. One-way ANOVAs were also used to determine whether the abundance of each invertebrate species was significantly different between lower Manson Creek Sites (1, 2 and 3) and upper Sites (4, 5 and 6).

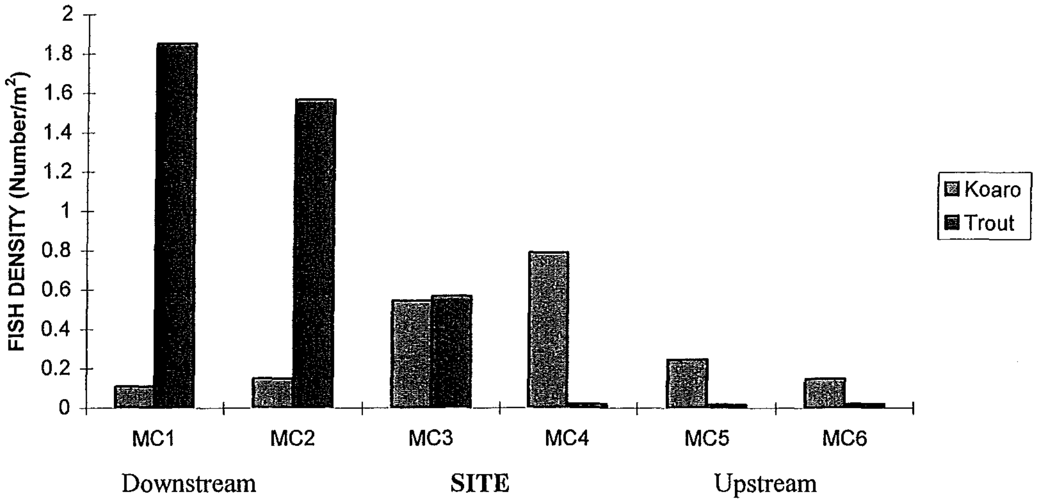
RESULTS

Fish populations

During 1999-00 summer, brown trout density was higher at lower sites and low at upstream sites (Fig. 2.6). In the following summer, brown trout density was found to have reduced at lower Sites 1- 2, but still remained a lot higher than at upper sites. No trout were captured at upstream Sites 5 and 6 during the second summer. However, a large trout was spotted at Site 5 but was not captured. In the first summer, total trout numbers captured in each 20 m site ranged from 1 in Sites 4, 5 and 6 to 84 at Site 1. During the second summer, total trout numbers captured per 20m site were noticeably lower ranging from 2 at Site 4, to 40 at Site 3.

During the first summer of electrofishing I found that koaro densities were generally higher at upstream sites compared to downstream sites. Koaro density increased from Site 1 to Site 4, but then reduced again through to Site 6. Although 2000-01 site densities were mainly less than those recorded during 1999-01, the same trends were found for both sampling years (Fig. 2.6). Total koaro number ranged from 5 at Site 1, to 38 at Site 4 during 1999-00, and from 2 at Site 1, to 25 at Site 4 during the following summer. Two-way ANOVA (Table 2.1) showed that koaro density was significantly greater at upstream sites in Manson Creek. Koaro densities were not found to be significantly different between years and the interaction between year and upstream/downstream was also not significant. Trout density was found to be significantly greater at lower sites (Table 2.1). No year or interaction effect was significant for trout.

(A) 1999-00 summer



(B) 2000-01 summer

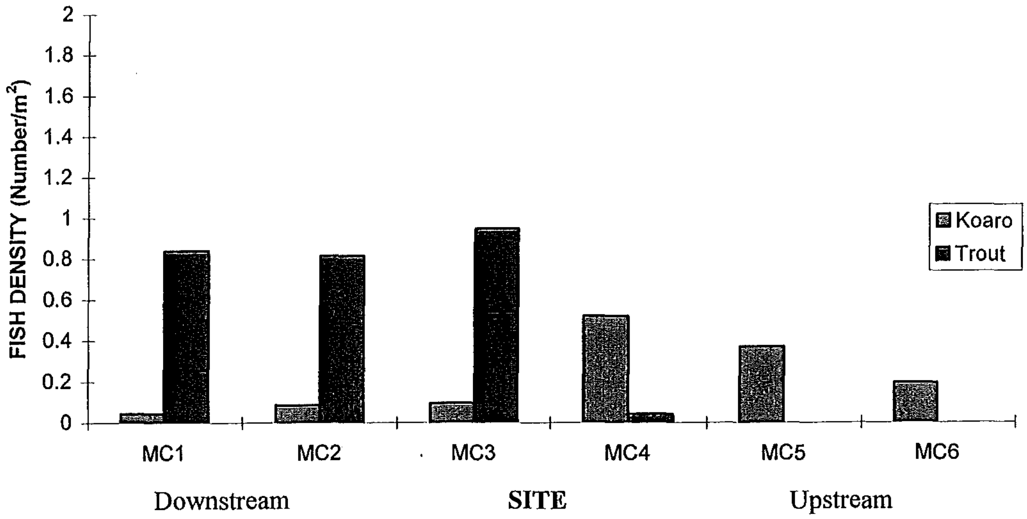


Figure 2.6. Koaro and trout density measured at the six Manson Creek sites during the 1999-00 (A) and 2000-01 (B) summers. Site 1 was located downstream and Site 6 was furthest upstream.

Table 2.1. Two-way ANOVAs of koaro (A) and trout (B) density at upstream and downstream sites during the summers of 1999-00 and 2000-01.

A

Source	df	ms	F- ratio	p-value
Year	1	0.14	1.58	0.24
Up/down	1	0.53	6.00	0.04
Year x Up/down	1	0.19	2.13	0.18
Error	8	0.12		

B

Source	df	ms	F- ratio	p-value
Year	1	0.16	1.41	0.27
Up/down	1	3.50	30.56	0.0006
Year x Up/down	1	0.16	1.36	0.28
Error	8	0.09		

Overall, as a percentage of the total fish captured, the proportion of koaro to trout increased when moving upstream in both years. Highest koaro densities were found at sites containing the lowest trout densities (Fig. 2.7). The exception during 1999-00 summer occurred at Site 3, where similar densities of koaro and trout existed at the same site. This site represented the transition zone above which, few trout were found. However, there was not a complete negative correlation between trout and koaro because Sites 5 and 6 contained low koaro densities and low trout densities. Therefore, trout density had a weak negative effect on koaro density.

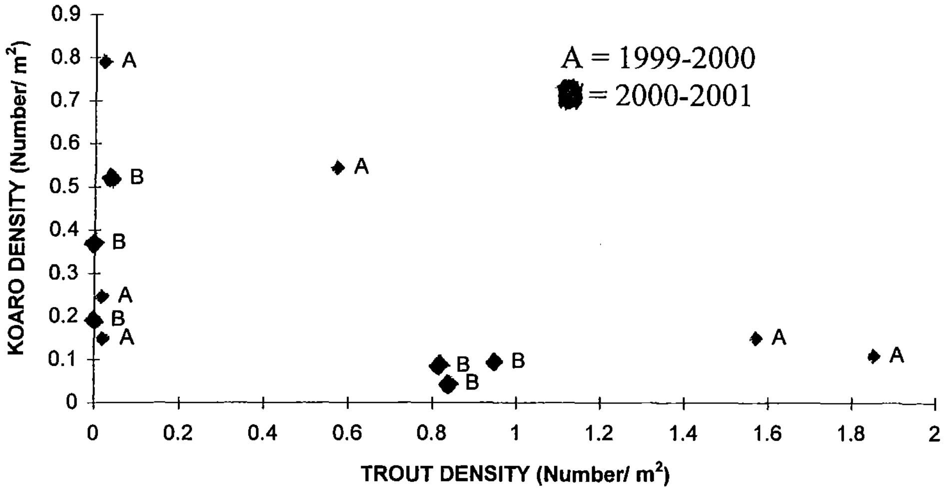
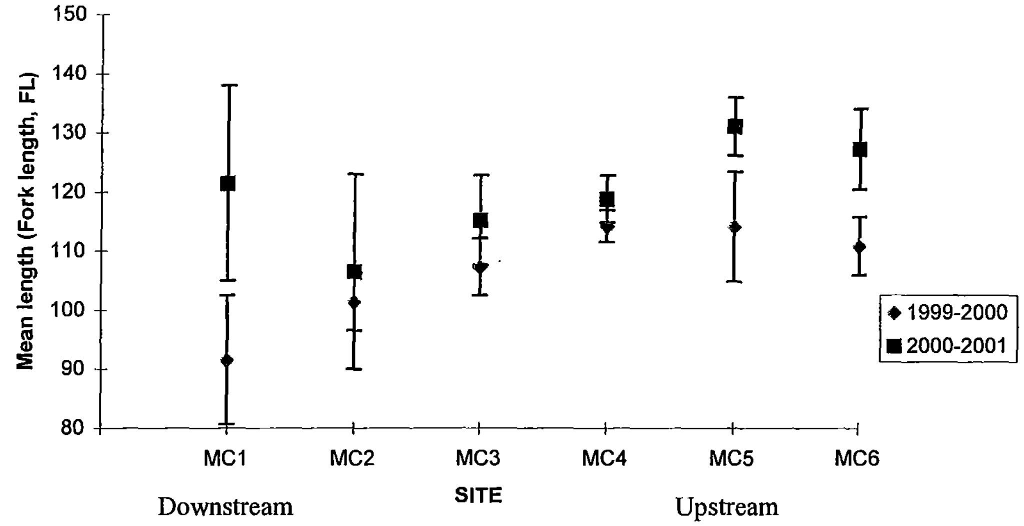


Figure 2.7. The relationship between trout and koaro density in Manson Creek during 1999-00 (A) and 2000-01 (B).

During the first summer (1999-00) koaro length was found to be larger at upstream sites compared to downstream sites. Generally, mean koaro size increased upstream from Site 1 to Site 4, but was similar at Sites 4-6 (Fig. 2.8). The same trends occurred during the summer of 2000-01, with the only difference being the capture of one larger koaro at Site 1. Two-way ANOVA showed that koaro length was significantly larger at the upper (top three) sites compared to lower Sites 1, 2 and 3 (Table 2.2). The mean lengths were greater during the 2000-01 summer. Mean koaro length ranged from 91.6 mm to 114.2 mm during 1999-00 and from 106.5 mm to 131.1 mm the following summer (2000-01). Two-way ANOVA showed that in comparison to the first summer, koaro lengths were significantly larger during the second summer (Table 2.2). Total koaro biomass was greater at upstream sites. Two-way ANOVA showed that total koaro biomass was significantly greater at Sites 4, 5 and 6 (Table 2.2). No year or interaction effects were significant.

A



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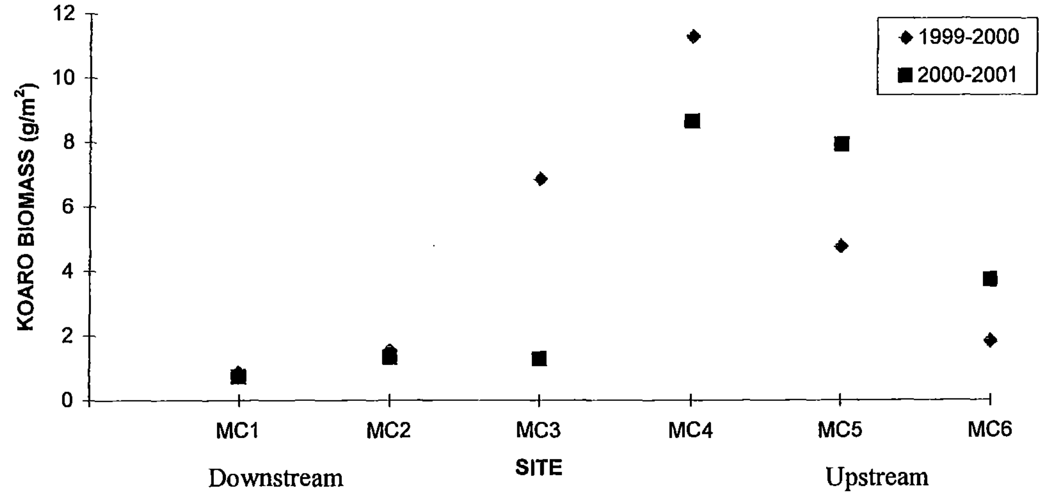


Figure 2.8. Plot of mean (+/- SE) koaro fork length (FL) in Manson Creek during 1999-00 + 2000-01 (A) and plot of total koaro biomass (g/m^2) at each site during both summers (1999-00 and 2000-01)(B).

Table 2.2. Two way ANOVA's of mean koaro length (A) and total koaro biomass (B) at upstream and downstream sites during the summers of 1999-00 and 2000-01.

A

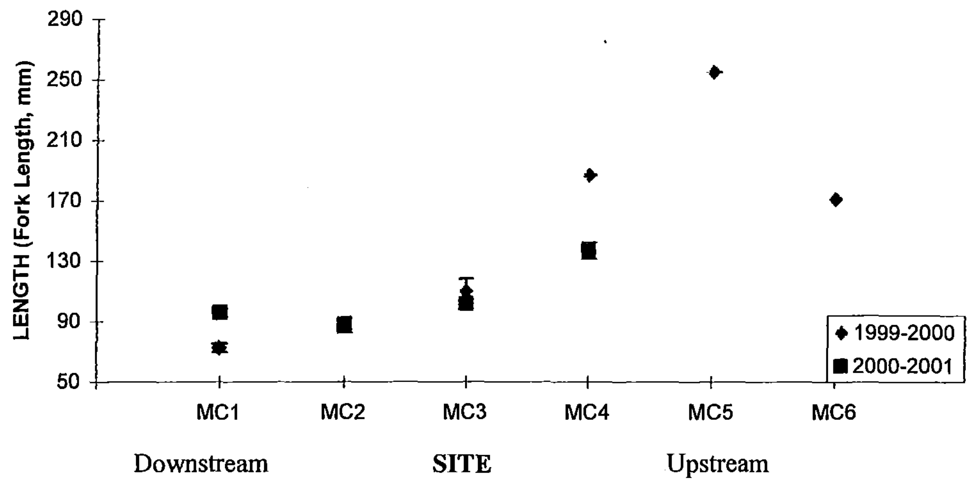
Source	df	ms	F- ratio	p-value
Year	1	549.28	13.41	0.006
Up/down	1	445.75	10.881	0.01
Year x Up/down	1	1.73	0.04	0.84
Error	8	40.97		

B

Source	df	ms	F- ratio	p-value
Year	1	1.01	0.10	0.76
Up/down	1	54.53	5.27	0.05
Year x Up/down	1	5.76	0.56	0.48
Error	8	10.29		

During 1999-00, mean trout length was greater at upstream sites 4, 5 and 6 compared to downstream Sites 1, 2 and 3 (Fig. 2.9). Mean trout length ranged from 72.5 mm to 255 mm. The next summer, trout size was similar at Sites 1 to 3, but slightly higher at Site 4 (Fig. 2.9). No trout were captured at Sites 5 and 6 in 2000/01 although a large trout was spotted while electrofishing Site 5. Average trout length ranged from 87.5 mm to 137 mm. Despite the absence of values for Sites 5 and 6 during the second summer, two-way ANOVA showed that mean trout length was significantly larger at upstream sites (Table 2.3). No year or interaction effect was found. Total trout biomass in Manson Creek was greater at Sites 1, 2 and 3. Two-way ANOVA showed that total trout biomass was significantly greater at downstream sites (Table 2.3). No Year or interaction effects were found.

A



B

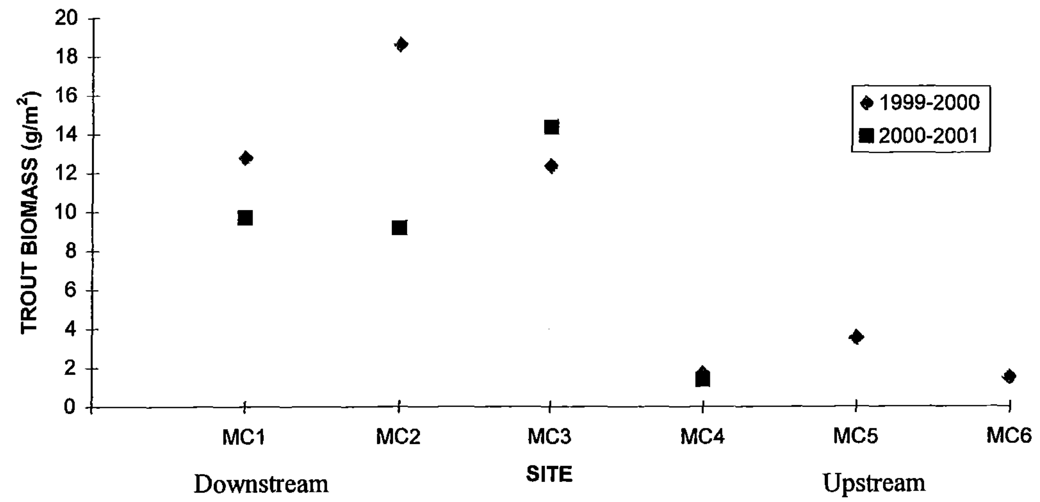


Figure 2.9. Average (+/- SE) trout fork length (mm) at the six Manson Creek sites during 1999-00 and 2000-01 summers. During 2000-01 Sites 4, 5 and 6 contained only one trout (A) and plot of total trout biomass (grams/square metre) at each site during both summers (1999-00 and 2000-01) (B).

Table 2.3. Two way ANOVA's of mean trout length (A) and total trout biomass (B) at upstream and downstream sites during the summers of 1999-00 and 2000-01.

A

Source	df	ms	F- ratio	p-value
Year	1	1962.00	2.46	0.17
Up/down	1	12186.00	15.27	0.008
Year x Up/down	1	2594.00	3.25	0.12
Error	6	798.26		

B

Source	df	ms	F- ratio	p-value
Year	1	9.71	1.36	0.29
Up/down	1	242.73	33.99	0.001
Year x Up/down	1	3.54	0.50	0.51
Error	8	7.08		

Stream Habitat

Changes in mean values of selected habitat variables (Table 2.4) between lower Sites 1, 2 and 3 and upper Sites 3, 4 and 5 were assessed using one-way ANOVAs (Table 2.5). Of the eight variables measured, only the number of pools and in-stream logs/roots and slope at each site were found to be significantly different between upstream and downstream sites. The number of pools, in-stream logs/roots and slope were all significantly greater at upstream sites. The distance to the nearest beech tree was found to be weakly significant as beech trees were closer to the stream edge at upstream sites.

Table 2.4. Mean value for each habitat variable assessed during the study for each Manson Creek site.

	LOWER			UPPER		
Habitat variable	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**
Stream Depth (cm)	15.3	11.5	14.8	16.2	17.3	15.3
Nearest Beech tree (m)	52.1	38.3	10.0	1.7	3.2	-3.4
Rock Size (cm)	9.6	8.9	19.2	23.8	15.6	21.4
Stream width (m)	2.3	2.3	2.1	2.4	2.8	2.3
Number of pools/20m site	1	1	3	5	4	5
% riparian overhang	4	8.1	17.2	1.8	2.8	0
Water velocity (m/s)	0.6	0.9	0.9	0.9	0.7	0.7
Slope (degrees)	1	1	2	3	3	5
Instream Logs/roots	1	1	1	5	5	3

Table 2.5. ANOVA table for habitat variables in Manson Creek. Spearman rank values, probability (significance) and degrees of freedom are listed. (N.S., Non significant; *, $p < 0.1$; **, $p < 0.05$).

Habitat variable	**d.f**	**ms**	**F-ratio**	**p-value**
Stream depth (cm)	4	2.63	3.28	0.14 N.S.
Nearest Beech tree (m)	4	236.30	6.90	0.06 *
Rock size (cm)	4	25.44	3.49	0.14 N.S.
Stream width (m)	4	0.04	2.56	0.19 N.S.
Number of pools/20m site	4	0.83	16.20	0.02 **
% riparian overhang	4	23.83	4.27	0.11 N.S.
Water velocity (m/s)	4	0.02	0.08	0.80 N.S.
Slope (degrees)	4	0.83	9.80	0.04 **
Instream logs/roots	4	0.67	25.00	0.008 **

Average koaro length was larger at sites where beech foliage was close to the edge of the stream (Fig. 2.10, $r_s = -0.95, p < 0.01$).

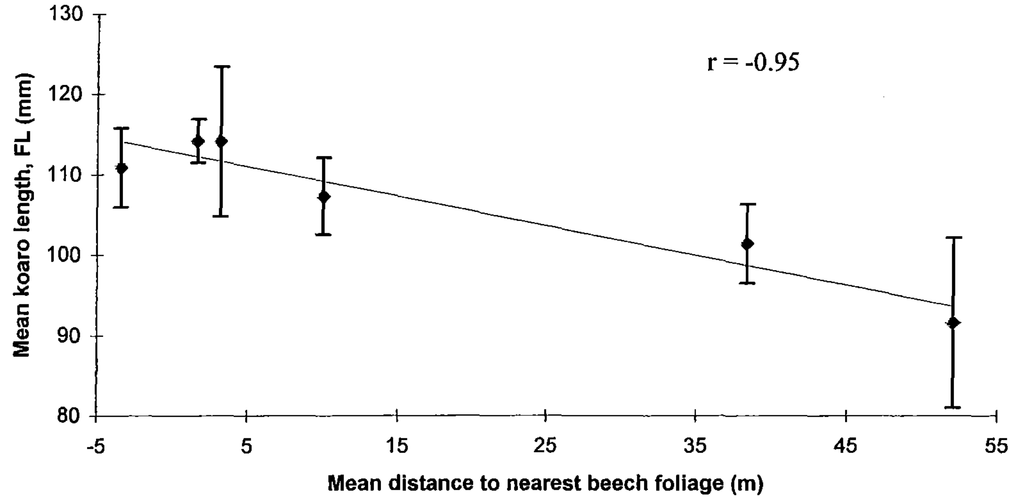


Figure 2.10. Average koaro fork length (+/- SE) verses mean distance to the nearest beech foliage at the six Manson Creek sites.

Smaller trout were found at sites with few pools and larger trout were found at sites containing greater numbers of pools (Fig. 2.11, $r_s = 0.78, p < 0.05$).

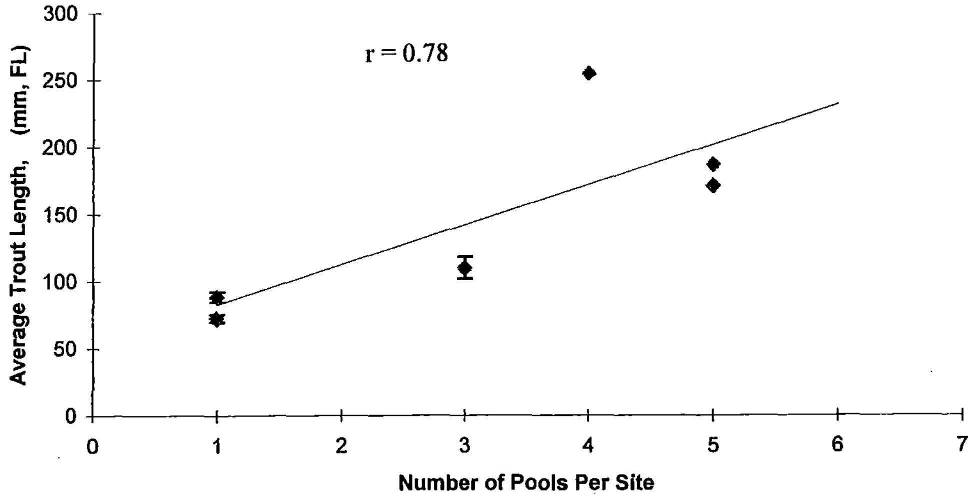


Figure 2.11. Graph of average trout fork length (+/- SE) verses the number of pools found at each site.

Invertebrate fauna

Although some invertebrates (flatworms, water beetles, *Coloburiseus humeralis*, oligochaete worms and *Aoteapsyche* spp) were only found in either the lower or upper three Manson Creek sites, one-way ANOVAs indicated no significant difference in the abundance of any invertebrate species, between lower and upper sites (Table 2.6).

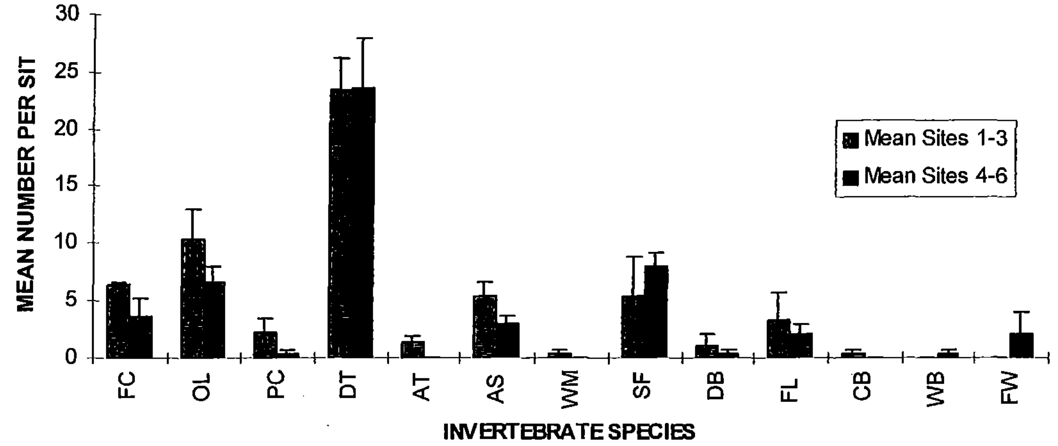


Figure 2.12. Mean number (+/- SE) of each invertebrate species captured at the six Manson Creek sites.

KEY: FC = *Hydrobiosidae* , OL = *Olinga feredayi*, PC = *Pycnocentrodes* spp, DT = *Deleatidium* spp, AT = *Aoteapsyche* spp, AS = *Austrosimilium* spp, WM = Worm (oligochaete), SF = *Stenoperla*, DB = Dobsonfly larvae, FL = Fly larvae, CB = *Coloburiscus humeralis*, WB = Water Beetles, FW = Flatworms.

Table 2.6. Results of one-way ANOVAs used to assess whether there was a significant difference in the abundance of each invertebrate species at upstream Sites 4, 5 and 6 and downstream Sites 1, 2 and 3.

SPECIES	d.f.	F-ratio	P-value
Hydrobiosidae	4	3.20	0.15
Olinga feredayi	4	1.46	0.29
Pycnocentrodes spp	4	2.60	0.18
Deleatidium spp	4	0.01	0.95
Aoteapsyche spp	4	4.00	0.12
Austrosimilium spp	4	3.06	0.16
Worm (oligochaete)	4	1.00	0.37
Stenoperla	4	0.52	0.51
Dobsonfly larvae	4	0.40	0.56
Fly larvae	4	0.26	0.64
Coloburiscus humeralis	4	1.00	0.37
Water Beetles	4	1.00	0.37
Flatworms	4	1.00	0.37

Fish density estimates

During both summers, electrofishing proved to be successful at obtaining accurate estimates of fish densities at the six Manson Creek sites. Calculated estimates of fish numbers at each site were in almost all cases very similar to actual observed numbers (Table 2.7). This suggests that electrofishing is an effective means of capturing adult koaro and juvenile trout in small mountain streams. However, while electrofishing some sites, fish were observed escaping under large boulders, and despite careful/persistent electrofishing, some of these fish could not be extracted from the refuges. On other occasions, certain sized or coloured koaro were flushed from cover and could not be accounted for among those fish captured in the hand held or bottom stop nets. Although effective, this suggests that electrofishing in small streams is not 100% successful at capturing all fish.

Table 2.7. Total fish numbers captured and calculated estimates of fish number at each Manson Creek site during A: 1999-00 and B: 2000-01 summer's electrofishing.

1999-00 Summer

Site	Run 1	Run 2	Run 3	Total	Estimate	Capture probability	S.E.	95% C.I.
MC1	71	16	3	90	90	0.80	0	0
MC2	52	17	11	80	85	0.60	3.36	6
MC3	33	9	4	47	48	0.68	1.19	2
MC4	31	4	5	40	40	0.74	0	0
MC5	8	5	2	15	15	0.63	0	0
MC6	5	3	0	8	8	0.73	0	0

2000-01 Summer

Site	Run 1	Run 2	Run 3	Total	Estimate	Capture probability	S.E.	95% C.I.
MC1	30	8	2	40	40	0.77	0	0
MC2	25	7	10	42	48	0.48	4.5	8
MC3	28	13	3	44	45	0.67	1.19	2
MC4	17	7	3	27	28	0.63	1.28	2
MC5	15	3	3	20	20	0.74	0	0
MC6	7	2	0	9	9	0.82	0	0

DISCUSSION

Koaro and trout had well defined distribution patterns in Manson Creek. While koaro density increased moving up Manson Creek, trout density decreased. There are a number of possible reasons that may explain these distributions.

Native forest

Except for tributaries of upland lakes which occur above the bush line, koaro are almost exclusively found in streams bounded by riparian forest (McDowall, 1990a). In streams unmodified by forestry, koaro populations can exist at high densities, but are rarely found outside forest and then only in areas bordering forest (McDowall, 1990a). In Manson Creek highest koaro densities were found at sites among beech forest (Sites 3-6). Larger koaro were also found upstream at forested sites. Like the banded kokopu, koaro seem to disappear once the forest canopy has been removed (McDowall, 1990a). At lower Manson Creek Sites 1 and 2 where forest canopy was absent, only low densities of koaro were captured. On average, koaro were smaller than those at forested sites.

Koaro appear somehow dependent on forested habitats (McDowall,1980). The dependence has been attributed to a variety of factors including temperature regime, food availability and suitability of spawning habitat (McDowall, 1980). This dependence perhaps explains why the largest adult koaro populations exist in regions such as Westland where the most extensive areas of virgin forest occur. It also explains why there are few examples of koaro being found in areas with little native forest such as Canterbury (Main, 1988). Sagar & Eldon (1983) only captured seven koaro from Canterbury's Rakia River over a twelve month sampling period. Although some of the above accounts are taken from studies in rivers and streams quite dissimilar in location and size to Manson Creek, the findings equate well with the Manson Creek distributions.

Glova & Sagar (1989) captured smaller koaro from a non-forested tributary of Canterbury's Ryton River. In Manson Creek only small adult koaro were captured at open sites. Small adult koaro were also captured in a small unnamed stream with no riparian vegetation during my study. These findings suggest that smaller koaro do not show a strong dependence for forested habitats, and further suggests that the strong association of koaro with forest seems to be more specifically related to fish size or maturity. This may indicate a morphological or physiological change in dietary requirements as koaro mature. The requirement of suitable spawning habitat may be another significant reason for the apparent dependence of large adult on forested habitat.

Food availability

Forest undoubtedly provides cover and refuge for fish (McDowall, 1980). However, there are other potential reasons for koaro choice of native forest habitats. An increase in the availability of terrestrial invertebrates as food in forested streams compared to unforested streams is one such reason (McDowall, 1980). In Australia, terrestrial insects formed a substantial part of the diet of *G. olidus* taken from sites surrounded by overhanging vegetation but were rare in the diets of galaxiids from unforested areas (Cadwallader *et al*, 1980). As terrestrial insect abundance can be eliminated or markedly reduced when streamside vegetation is removed, so too is the food available to the fish (Cadwallader *et al*, 1980). Edwards & Huryn (1995) also showed that riparian characteristics influence the amount of invertebrate input into streams. Insect biomass entering streams in native forest was found to be significantly higher than that entering pasture streams (Edwards & Huryn, 1996). This explains why banded kokopu, which are more dependent on riparian vegetation to provide a source of food than are koaro, have less diverse habitat requirements and distributions (Main & Winterbourn, 1987).

Downstream sites in Manson Creek are probably less likely to be chosen by adult koaro as fewer terrestrial insects would be available as food. However, koaro are non selective feeders (Sagar & Eldon, 1983; Main, 1988). They often consume different types of aquatic and terrestrial invertebrates.

Therefore they are not completely dependent on terrestrial food sources. In fact, koaro being benthic forages (Glova & Sagar, 1989) probably feed mainly on benthic invertebrates. This is supported by Rounicks & Hicks (1985) who found koaro exclusively fed on non-terrestrial invertebrate forms, and Main & Winterbourn (1987) who found stomach contents of koaro captured in south Westland forested streams were numerically dominated by benthic prey. Sagar & Eldon (1983) also support the unimportance of terrestrial prey in koaro diet. Food type and abundance available will depend on habitat. It is possible that adults require more food, therefore they may need terrestrial food sources.

Stream temperature

Temperature regimes may vary inside and outside of forest (McDowall, 1980; Cadwallader *et al*, 1980; Main, 1988; Eklöv 1999). Shading from riparian forest reduces light penetration and the subsequent warming from the sun. This can result in lower temperatures inside forest. The extent of temperature change will depend on local environmental conditions as well as the water volume and distance the water flows in the open and is exposed to solar rays. Temperatures in Manson Creek only varied by one degree Celsius between the upper enclosed sites and lower open Site 1 during a warm summer day. However, extreme summer temperatures during a period of low flow may cause more substantial changes in water temperature. Graynoth (1979) found summer temperatures 6.5 degrees higher in clear felled areas compared to forested sites of a first order Nelson stream. Large koaro have little tolerance for warm temperatures (Main, 1988). Woods (1966) considered that koaro could only acclimate to water temperatures of between 17 and 20 degrees Celsius. Later experiments by another researcher obtained results that supported a higher koaro thermal maximum of 27 degrees Celsius (Main, 1988). These laboratory studies found that koaro were highly stressed at 27 degrees, but during 24 hours at 26 degrees Celsius they behaved, and fed, normally. Although this suggests that koaro can inhabit quite warm water, it is possible that as certain koaro populations inhabit rivers and streams exhibiting different temperature regimes, they acclimatise to these temperatures.

Selectivity for forested habitats may prevent exposure to warmer, potentially harmful water temperatures. It is likely that the influence of riparian forest on water temperature in Manson Creek would be minimal, however a slightly different temperature regime may have a minor contribution to selection of upstream, shaded habitats by adult koaro. It is unlikely that water temperatures at the lower sites (Sites 1 and 2) could ever be significantly greater than at upper sites and thus limit koaro distribution. Therefore, stream temperature is unlikely to be a significant factor causing adult koaro to select forested habitats.

Organic input

Perhaps more obvious would be the release of organic material from the overhanging vegetation into the stream. Such terrestrial input is important for maintaining productivity of headwater streams draining forested catchments (Cummins, 1975; Wallace *et al*, 1999). Increasing detrital input and litter retention in streams may serve to increase invertebrate productivity (Dobson *et al*, 1995). As predator production is constrained by productivity of their prey (Wallace *et al*, 1999), such input into Manson Creek may affect the fish fauna present in certain areas. Lynch *et al* (1977) discussed how different levels of dissolved nutrients can affect the invertebrate fauna inhabiting streams. This study also supported how these nutrient levels can directly or indirectly affect the fish fauna present in streams (Lynch *et al*, 1977). However, in Manson Creek invertebrate sampling showed similar insect fauna inhabited upstream and downstream sites. Therefore, the selection of upstream sites by adult koaro most likely is not due to their preference for certain invertebrates.

Water acidity is also influenced by forest. Leeching from organic material in forest can produce water of a lower pH (Main, 1988). However this is not likely to be relevant to the Manson Creek situation as water acidified by forest located a relatively small distance upstream would also flow through the lower sites. Therefore all sites would have water of the same pH. A pH of 7.0 was recorded in Manson Creek during October 1998.

Stream stability

Floods are usually confined to defined channels in forested locations as the root systems create stable banks and reduce the collapse of stream bank resulting in loss of habitat (McDowall, 1980). This also reduces the release of soil into the water decreasing sediment build up. Overall, riparian forest would create a more stable environment. In addition, logs and tree roots along stream edges provide abundant cover and create favourable mirco-habitats in forest streams for fish. Such debris would create cover and refuge for koaro. In-stream log jams and exposed tree root systems were only found in the upper Manson Creek sites, however, they were not extremely common. A maximum of five logs/tree roots were located at Sites 4 and 5. While electrofishing Manson Creek sites I had regularly observed koaro dart out from log jams but most often disturbed koaro hiding under boulders. Actual frequencies were not recorded but the difference between numbers disturbed from logs/roots and boulders was obvious. This suggests that in this stream koaro utilise log jam habitats but more commonly use boulders for refuge or cover.

Spawning habitat availability

The location of spawning habitat may also affect the distribution of galaxiids (Allibone & Townsend, 1997). Allibone & Townsend (1999) demonstrated that the distribution of *Galaxias depressiceps* in the Taieri River was partially controlled by the availability of spawning habitat. The selection of upstream habitat by koaro could be due to availability of suitable spawning habitat. The association of native forest with adult koaro habitat could suggest that leaf litter from riparian vegetation may be an important spawning substrate. In New Zealand's Otira River where koaro larvae were captured moving downstream, marginal forest litter was very sparse (McDowall & Suren, 1995). The researchers suggested that koaro inhabiting this area may use alternative substrate for spawning. In a later study O'Connor & Koehn (1998) also discovered koaro eggs that had not been deposited among riparian vegetation. Although vegetation did not seem to be important as spawning substrate, they did find that the shade from riparian vegetation seemed to be critical at maintaining a damp streamside environment, thereby preventing egg desiccation. This could be one of the main reasons why adult koaro are sparse in streams without a forest canopy cover.

Moreover, trapping and electrofishing of Manson Creek throughout a one and a half year period (Chapters 2 & 3) identified no obvious movement of larger adult koaro away from upstream sites. Others have also argued that adult koaro do not migrate, and that spawning takes place close to adult habitat (Kusabs, 1989; Duffy, 1996; O'Connor & Koehn, 1998). Thus, adult koaro probably spawn in the habitats occupied by adult fish.

Interactions between trout and koaro

Although habitat destruction and modification have contributed to galaxiid declines (McDowall, 1980, 1984; Main *et al*, 1985; Main, 1988; Minns, 1990), only a proportion of observed disjointed distributions of larger galaxiids species can be explained by habitat limitations (Main, 1988).

Fish distribution patterns can potentially be affected by other influences. There are examples of galaxiid/salmonid distributions that are largely allopatric (Main 1988). Analysis of the New Zealand Freshwater Fish Database indicated a negative relationship between exotic and native fish (Minns, 1990). Trout are frequently found in the accessible mainstreams of rivers, whereas large galaxiids are restricted to tributaries and headwaters (Main 1988). Galaxiid and trout distributions in south westland are largely allopatric (Main *et al*, 1985). No koaro were captured at sites where adult trout were present (Main *et al*, 1985). In coastal streams of south eastern Australia, O'Connor & Koehn (1988) also found koaro to be abundant when trout were absent. There are also many examples of other galaxiid species only being found above obstacles or barriers such as waterfalls, which are impassable to trout (Tilzey, 1976; Cadwallader, 1979; Townsend & Crowl, 1991).

The negative correlation between koaro and trout in Manson Creek could be the result of trout forcing koaro to occupy upstream habitats. Trout, being highly aggressive and territorial (Allen, 1951), compete for positions that provide cover and the best access to food (Hearn, 1987). Thus, trout could actively deter koaro from occupying areas of refuge or the best feeding sites.

In Australia, Tilzey (1976) found that in comparison to three other spawning streams, galaxiid biomass was highest in Boghole Creek, a stream that became inaccessible to spawning trout when the level of a lake downstream dropped below a certain level. McDowall (1990a) discussed how dwarf galaxiids (*Galaxias divergens*) tend to retreat into the hill streams and are found in areas above barriers to the upstream migration of spawning trout. The annual invasion of spawning trout into Manson Creek from Lake Pearson could affect galaxiid abundance. I spent several weeks walking up Manson Creek daily during the trout spawning season. I monitored large trout spawning movement up Manson Creek and found that trout up to 500 mm in length had travelled as far upstream as 20m above Site 3. Therefore only the bottom three sites would have been affected by the presence of large spawning trout. This distance upstream corresponded with the transition region in which smaller resident trout numbers suddenly reduced and koaro became dominant. There was no barrier or waterfall large enough to prevent smaller trout movement upstream in this area, although this was the area that consistent pool/run cascade habitat began.
This suggests that there must be a more complex interaction of factors causing the koaro/trout distribution found. The yearly influence of spawning trout may be a factor contributing to the observed reduction in koaro density below Site 4.

Trout substantially smaller than those observed spawning in Manson Creek have been found to affect galaxiid abundance (McIntosh, 2000a). Trout greater than 150 mm (FL) have likely eliminated small bodied galaxiids from many Waimakiriri streams (McIntosh, 2000a). However, the extent of their impact is limited by the availability of habitats suitable for large trout (McIntosh, 2000a). Brown trout presence is largely dependent on medium-sized substrata and intact marginal habitat with shallow, slow flowing areas representing nursery grounds for fry (Eklöv *et al*,1999). Lower Manson Creek sites contained a greater percentage of medium substrata compared to upper sites which contained more boulders. Although mean substrate size was larger upstream, the difference between combined Sites 1, 2 and 3 and upstream Sites 4, 5 and 6 was not significant.

Eklöv *et al* (1999) observed that high trout densities of >0+ fish were associated with low water temperatures and shading. Zero plus and older trout were mainly found in the open lower sites in Manson Creek. Here they would encounter potentially warmer temperatures and less shade compared to upstream sites. However, within these sites, more trout were found concentrated in microhabitats with in-stream cover creating shade.

Another factor that influences trout distribution is the availability of cover (Eklöv *et al*, 1999). My results indicate that most instream cover, in the form of submerged logs and large boulders, was present upstream in the beech forest. It is likely that lower trout densities upstream were either due to the smaller trout not liking upstream habitats, larger koaro upstream forcing smaller trout downstream or larger trout upstream excluding smaller trout. Therefore, I think that smaller trout preference for downstream habitat most likely explains the observed small trout distribution. However, exclusion by large trout located upstream may also contribute.

The "Growth Experiment" (Chapter 4) indicated that both small and medium sized trout grew well with larger koaro present and indicated that trout were better at obtaining food resources. This suggests that the large koaro were unlikely to exclude small trout from upstream habitats and that large trout were likely to be the biotic factor that would most strongly influence the selection of lower sites by smaller trout. As trout grow they shift to deeper areas with faster water velocities and larger in-stream structures (Bohlin, 1977). Usually such habitat would be found in the lower reaches of a river or stream but in Manson Creek, deeper water occurred in the bouldery pools located upstream. Therefore, selection of deeper water by larger trout could explain why large trout were only found at the upper sites in Manson Creek.

Despite common accounts of allopatric galaxiid and trout distributions, sometimes these two fish families coexist together. A study by Main *et al* (1985) found that juvenile trout sometimes co-occurred with galaxiids, but usually in marginal trout habitat. In Manson Creek koaro and trout were found coexisting together at similar densities at Site 3. In-stream substrate size and riparian beech forest increased upstream from this site.

The change in stream characteristics and the corresponding reduction in trout abundance beyond this point may suggest that Site 3 represented marginal trout habitat. As a result trout densities at this site were probably low enough to allow koaro to co-exist with the trout.

At those sites where koaro and trout co-existed, koaro were almost exclusively found inhabiting faster water microhabitats. While electrofishing, I often observed that koaro flushed from cover at lower sites always seemed to have originated from fast riffle microhabitats. In comparison, at those sites with low trout densities, koaro were often disturbed from slower pool microhabitats.

Townsend & Crowl (1991) hypothesised that habitat instability promoted the co-occurrence (at very low densities) of trout and *G. vulgaris*. Trout and koaro co-occurred at each of the six Manson Creek sites. Very low densities of koaro and high trout densities were found at the two lowest sites. Although Site 3 contained similar densities of both trout and koaro during 1999-00, it showed no evidence of instability compared to any of the other sites.

The change in fish distribution patterns during the 2000-01 electrofishing could have been caused by a significant "one in forty year" flood (Kelly, 2000) which caused a visually robust waterfall located above site six, to be destroyed and other significant damage to farmland in the Canterbury region. It is also possible that natural year to year variation caused the observed changes.

The fact that in Manson Creek koaro were captured at lower sites suggests that they are able to survive in habitats outside beech forest. Koaro are known to occur outside forest in tributaries of upland lakes which are above the bush line (McDowall, 1990a). The electrofishing of a site in Slovens Stream near where it exited Lake Hawdon (Cass region), resulted in the capture of large numbers of small koaro (50-70 mm) and several larger (100 mm) koaro. This stream flowed in the open and had no riparian forest except for willow trees several hundred metres downstream. The presence of high densities of smaller sized koaro in an open stream supports the fact that koaro of this size can survive outside native forest.

Therefore, it is likely that koaro would almost certainly occur in much higher densities in Manson Creek's lower sites if trout were absent, as many of the in-stream physical characteristics of the stream remain similar between lower and upper sites.

It is most likely that the selection of forested habitats by large koaro most significantly influenced their distribution in Manson Creek. The likely requirements associated with spawning, preference for microhabitats containing large substrate and in-stream cover, combined with a lower temperature regime are likely to be the most important influences associated with their choice of upstream sites. The extent of trout influence is somewhat more complicated. Interactions between koaro and trout are investigated further with microhabitat experiments in Chapter 4.

CHAPTER 3

Life-history of koaro

INTRODUCTION

The breeding ecology and life-history of many of New Zealand's galaxiids, including the koaro (*G. brevipinnis*), are poorly understood (McDowall & Suren, 1995; Allibone & Caskey, 2000). There appears to be considerable diversity in spawning location, habitat selection and the time of spawning within the *Galaxias* genus (McDowall, 1990a). However, the cryptic nocturnal nature and benthic habit of many of the galaxiids makes determination of such life-history processes more difficult.

In this chapter I report an investigation of the growth, longitudinal movements (home-range) and spawning of adult koaro in Manson Creek. Knowledge of these factors is important to assist managers to identify and enhance existing spawning habitat, protect certain areas during spawning time and select suitable release sites if translocation ever becomes necessary (Moore *et al*, 1999). Conservation of suitable sites/habitats may result in enhanced juvenile recruitment into existing populations and increased recruitment could increase whitebait catches and may enhance adult populations.

Until recently, no koaro spawning sites had been found in New Zealand (Allibone & Caskey, 2000). Various studies had speculated on the most likely sites and time of koaro spawning based on observations of gravid adult koaro (McDowall, 1990a; Duffy, 1996), migrating larvae and back calculation of aged juveniles (McDowall & Suren, 1995). These studies have suggested that koaro most likely spawn during autumn and early winter, possibly either in or out of water. However, no studies have been able to confirm what microhabitats are required and what cues initiate koaro spawning.

Koaro from a Taranaki (New Zealand) diadromous population were found to spawn between April and early May on the edge of riffles, with eggs found partially submerged and adhering to gravel, cobble and other eggs (Allibone & Caskey, 2000). The position of the nests suggested that spate flows were the spawning cue that allowed koaro to gain access to the bankside gravel deposits. This also matched that described for koaro spawning in Australia (O'Connor & Koehn, 1988). The almost certainly land-locked Lake Pearson koaro population may have a different spawning season. There are indications that a change in spawning season from autumn to spring may occur in land-locked galaxiid populations (McDowall, 1988).

If land-locked koaro from the Lake Pearson population spawned during autumn, as occurs in diadromous populations, then after hatching the newly hatched koaro larvae would enter a lake where the water temperature is cooling down. Because of the cooler water temperatures over the winter period, the larvae would grow more slowly due to their slower metabolism and reduced feeding opportunities. In addition, greater juvenile mortality may occur in the less favourable winter conditions. Diadromous larvae most likely enter the sea during autumn as the sea remains relatively warm and contains an abundance of food. If land-locked koaro evolve a spring spawning period then the newly hatched larvae would enter an environment where water temperature is increasing and food is becoming more abundant. Therefore the larvae would grow faster and a greater number of recruits are likely to enter the population. I therefore hypothesised that koaro in Manson Creek could either spawn during spring or autumn and that koaro in Manson Creek would deposit their eggs in the vicinity of the stream margin as observed in Taranaki.

Mature koaro may undergo a spawning migration from local adult habitat to areas more suitable to lay their eggs. Determination of spawning time could be aided by the monitoring of adult fish movements to see if spawning migrations occur. Alternatively, adult koaro may remain in adult habitat for spawning. In this chapter I also describe a study of koaro movements in Manson Creek that aimed to determine whether or not koaro occupied a defined area/space or home-range. This may help to determine when and where koaro spawn.

A home-range is considered to be the area to which individuals, pairs or family groups commonly restrict their activities (Cadwallader, 1976). Although the presence of a home-range has been studied in stream and river-dwelling fish from a variety of taxonomic groups, little is known of the home-range size and movements of lake and stream dwelling galaxiids, including the koaro (Cadwallader, 1976). Cadwallader (1976) investigated the home-range and movements of *Galaxias vulgaris* in Canterbury's Glentui River. Fish were tagged and regular electrofishing of sections of the stream allowed the distribution and movements of recaptured galaxiids to be determined. He found 97 percent of fish were recaptured in the same section of river in which they were originally marked, indicating that most *G. vulgaris* remained in the same stretch of stream.

I utilised tag and recapture methods, commonly used in fish studies (Skalski & Gilliam, 2000; Jellyman *et al*, 2000), to monitor movements of adult koaro in Manson Creek. I predicted that as other stream resident galaxiids have a small home-range, koaro in upper Manson Creek would be recaptured at the same site at which they were originally tagged. Utilisation of a limited stream area would be beneficial to koaro as they would become familiar with the location of the best feeding sites, the location of predators, competitors and mates, and the position of refuge from floods, predators or other danger.

It is possible that if fish remain in the same stretch of stream, growth may be density dependent. Fish growth rate can depend on many variables including water temperature, food availability and the extent of inter/intra-specific competition that they experience (Weatherley & Gill, 1987). These factors almost certainly vary between lower and upper Manson Creek sites as riparian vegetation and other physical stream characteristics change moving upstream. Although selection of less suitable habitats will result in lower koaro densities, I expected to find higher growth rates at sites with lower koaro densities and higher koaro growth rates at upstream sites compared to downstream sites.

METHODS

Determination of koaro spawning site and time

Manson Creek Sites 4, 5 and 6 were searched for koaro spawning sites on the 24 May 2000, 13 and 14 June 2000, 28 and 29 June 2000, 27 October 2000 and 9 November 2000 and on several other days during spring and autumn. On each occasion an assistant and myself spent approximately 15 minutes searching for eggs along the stream bank up to 1m from the waters edge at the upper three sites. Searching focussed on areas shaded by overhanging riparian vegetation. Rocks and vegetation in these areas were sometimes moved. No in-stream searching was carried out.

I had planned to determine koaro spawning time via observations of spawning sites, although none were found. However, ten juvenile galaxiids were captured from a small Lake Pearson tributary stream during autumn (28 March 2000). As the 40-45 mm fish exhibited benthic behaviour the possibility that they could have been smelt was excluded. Their prominent pectoral fins suggested that they were juvenile koaro, but to be sure they were taken back to the University of Canterbury and raised in an aquarium for six months. After six months, four surviving fish were released into Manson Creek. The six fish that had not survived were stored in 70% alcohol and were later used for identification and ageing purposes.

To determine whether the galaxiids were *G. brevipinnis* or *G. vulgaris* the juvenile koaro were identified using criteria from McDowall (1990). As koaro pyloric caeca are noticeably longer than that of *G. vulgaris* (McDowall, 2000), the first stage of identification involved the dissection of the intestinal tract to determine the length of the fish's pyloric caeca. This proved to be less accurate than expected as pyloric caeca lengths in different specimens were variable and were neither short enough to be *G. vulgaris*, nor long enough to be *G. brevipinnis*. Therefore, this method of identification was inconclusive. This left two remaining methods of species identification, these being genetic or vertebral (spinal) counts. As the genetic option was too expensive, I proceeded with preparations for spinal column counts.

The following procedure was utilised. (1) The fish were skinned and placed in 2% Potassium hydroxide (KOH) for 24 hours until most of the muscle tissue had dissolved. (2) The KOH was then removed and replaced with lizerine (a red dye) in 2% KOH to stain the bone and dissolve some of the remaining muscle tissue. (3) After approximately 24 hours the solution was removed. (4) 50 % glycerol solution was added to the fish to clear the remaining muscle tissue. (5) After 24 hours an equal amount of 100 % glycerol was added to the existing solution. (6) The skeleton was then stored in the glycerol solution. A dissection microscope with an occular (gridded) lens was used to count the number of vertebrae in the spinal column. Each spinal vertebrae was identified from the articulation of the vertebral spines. This allowed the separation of the spine and tail vertebral segments resulting in an accurate spinal count.

Otolith analysis was required to age the juvenile koaro. This allowed back calculation of spawning time. The following methods were used to age the fish. (1) Small koaro were placed in Pancreatin, an enzyme which dissolved away all muscle tissue, leaving only the skeleton and otoliths. (2) Otoliths were removed from the solution and stored in 70% alcohol for several days before being dried and stored in an air tight bottle. (3) Otoliths were mounted on glass slides using melted "Crystalbond" adhesive. (4) 1000 grit "wet & dry" sandpaper was then used to gently sand the otoliths until the daily growth rings could be viewed relatively clearly under a stereomicroscope at 400x magnification. (5) Rings could then be counted with reasonable accuracy. One day of growth is represented with reasonable accuracy by a single growth ring (J. Sykes, N.I.W.A, personal communication), so age in days was determined by counting each ring.

Electrofishing/Tagging

To individually identify any recaptured fish for the determination of movements or growth, all koaro (> 90mm fork length, n = 83) captured during the first summer of electrofishing (10 December 1999 and 12 April 2001) of the six Manson Creek sites were tagged.

Electrofishing, trapping and spotlighting are the most commonly used methods for capturing galaxiids (Allibone & Chadderton 1992; Kusabs, 1989; Main, 1988; Duffy, 1996). To follow changes in fish growth and longitudinal distribution in the stream I mainly used trapping methods to recapture tagged koaro. However, when possible electrofishing was also used.

(A) *Electrofishing* (as described in Chapter 2 "Spatial distribution of koaro").

During the initial electrofishing of Manson Creek, all koaro captured at each site were tagged. After anaesthetised fish had been weighed and measured, koaro > 90mm fork length were tagged using florescent green soft vialpha Visual In-plant Tags (V.I.T.) from Northwest Marine Technologies. As koaro proved to have very tough skin that would quickly blunt the finely sharpened point of the carbon injector, an initial skin penetrating incision was accomplished using a fine (Number 11) scalpel. This tiny 2mm cut in the koaro's skin allowed the injector to then place the tag under the fish's skin. All fish were tagged in a pale patch of skin in the caudal peduncle region (near the tail)(Fig. 3.1). After tagging, fish were placed in freshwater until they had recovered enough to be safely released in a slow section of the stream as near as possible to the centre of the site.

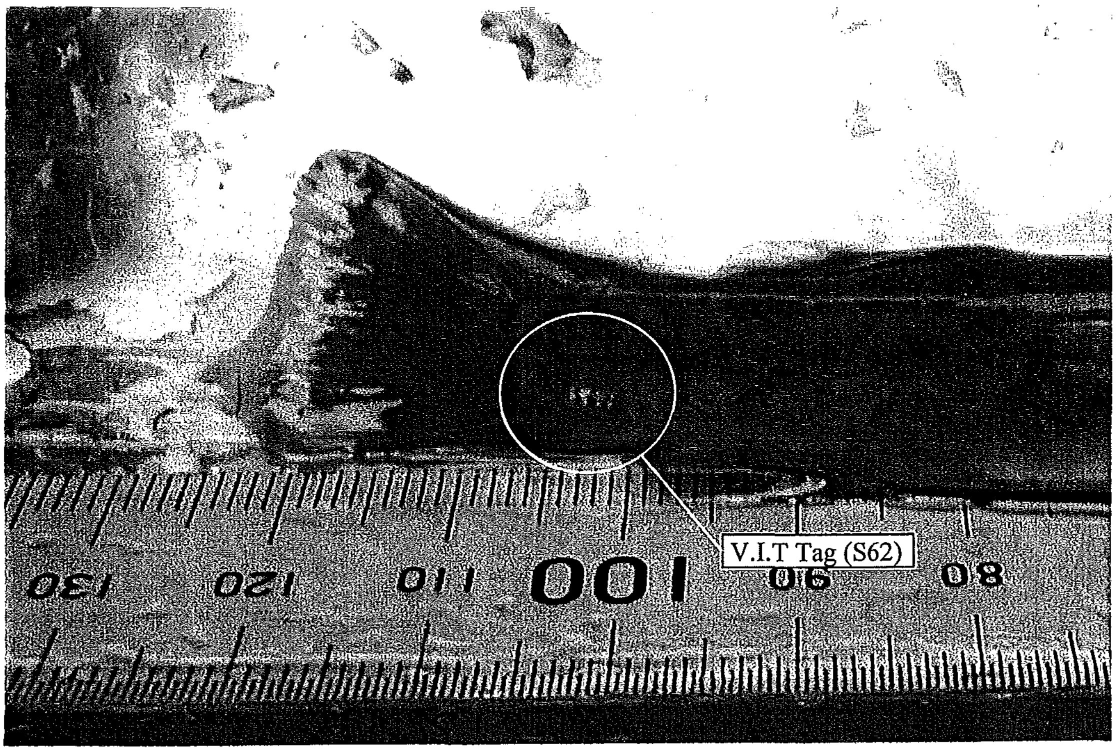


Figure 3.1. Position of V.I.T tag (S62) in the caudal peduncle region, near the koaro's tail.

(B) *Trapping*

Other capture methods also focussed on the 6 x 20m study sites in Manson Creek. Thirty steel wire "Gee-minnow" traps were used to capture koaro (Fig. 3.2). Five traps were placed at each of the six Manson Creek sites on each trap night. While three of the five traps were placed within each 20m site (top, middle and bottom), one of each of the remaining two traps was placed above and below, within 10m of the top or bottom, of the site.

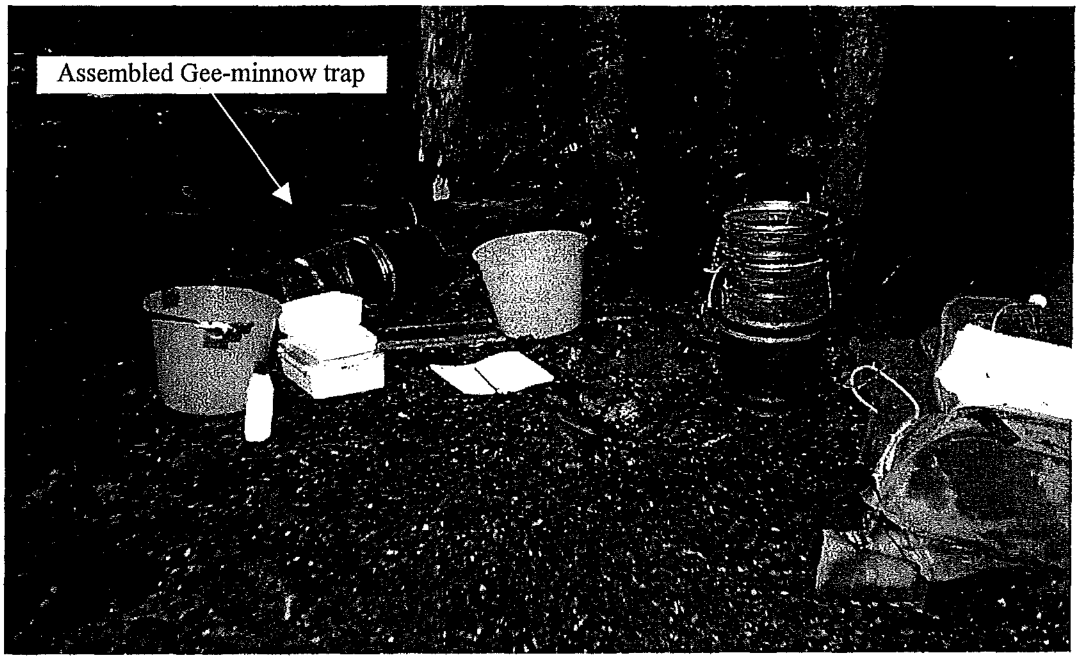


Figure 3.2. Field equipment used for trapping koaro. Note the assembled "Gee-minnow" trap at the rear of the photograph.

Each trap was positioned in water of slower velocity, usually on the slower side of a riffle/run, a glide or pool, at depths where at least 50mm of water covered the top of the entrances to the trap. Each trap was baited with "Marmite" (Allibone & Chadderton, 1992) and fish ("Ocean bounty") flavoured "Go-Cat" cat biscuits. The bait was placed in perforated film canisters attached by string to the inside of the trap.

Traps were usually set during the afternoon. They were left for approximately 24 hours (overnight) and were then checked the next morning/afternoon. All captured koaro and trout were anaesthetised using 2-phenoxyethanol and then checked for a tag. Their species, weight, length and any other distinguishing features were then recorded. After measurements were taken, captured fish were left to recover and then released. All traps were re-baited by swapping the already used bait canisters with pre-baited film canisters. The traps were then placed in the same spot for one more night. After two nights in the same spot, the trap position was changed to a different position in the same general location, i.e., above, top, middle, bottom and below the site. Trapping occurred during autumn, winter and spring on the following dates. Autumn: 23, 24 and 25 May 2000; Winter: 13, 14 and 15 June 2000 and 27, 28 and 29 June 2000; Spring: 26 and 27 October 2000, 9 and 10 November 2000. No summer trapping occurred because of very low flows.

Home-range, growth and life-history

As discussed, koaro were tagged for the purpose of future identification. Growth and distribution data obtained from recaptured fish were used to assess fish longitudinal movements and the size of their home-range, as well as any change in length and weight (growth) of the koaro in Manson Creek. Fish were recaptured using both electrofishing and trapping methods. Although electrofishing proved to be a much more effective method of recapture in terms of both time and effort, traps were most often utilised because they could be operated by one person. Additional electrofishing on the 29 June 2000 of all water from the top of Site 6 to the bottom of Site 4, and Sites 3, 2 and 1 was undertaken to recapture tagged fish. The fishing of all water from Site 6 to Site 1 was planned, but this was prevented by time constraints. This was unlikely to reduce the number of koaro recaptured as almost all koaro marked during the initial electrofishing of Manson Creek were captured above Site 3.

Tag retention trials

To estimate the tag loss rate of those fish tagged in Manson Creek, two trials were conducted. In the first trial six koaro were captured using Gee-Minnow traps, tagged, and kept in an aquarium for two weeks. In the second trial ten adult koaro were captured using electrofishing equipment, tagged, and placed in the outside flow through tanks (described in Chapter 4 "Growth experiment") containing large rocks for a two week period. During this period the fish were fed with stream invertebrates (mainly *Deleatidium* mayflies and various species of cased/free-living caddis) and checked every two to three days. After the two weeks, all koaro were removed from the tank, anaesthetised and then checked to determine whether they had retained their tag.

RESULTS

Spawning sites and estimates of spawning time

Despite several searches, no koaro spawning sites were located in the upper reaches of Manson Creek. However, the juvenile fish captured during autumn, were identified as koaro. The two fish prepared for identification using spinal counts had spinal counts of 59 and 57, respectively (Fig. 3.3).

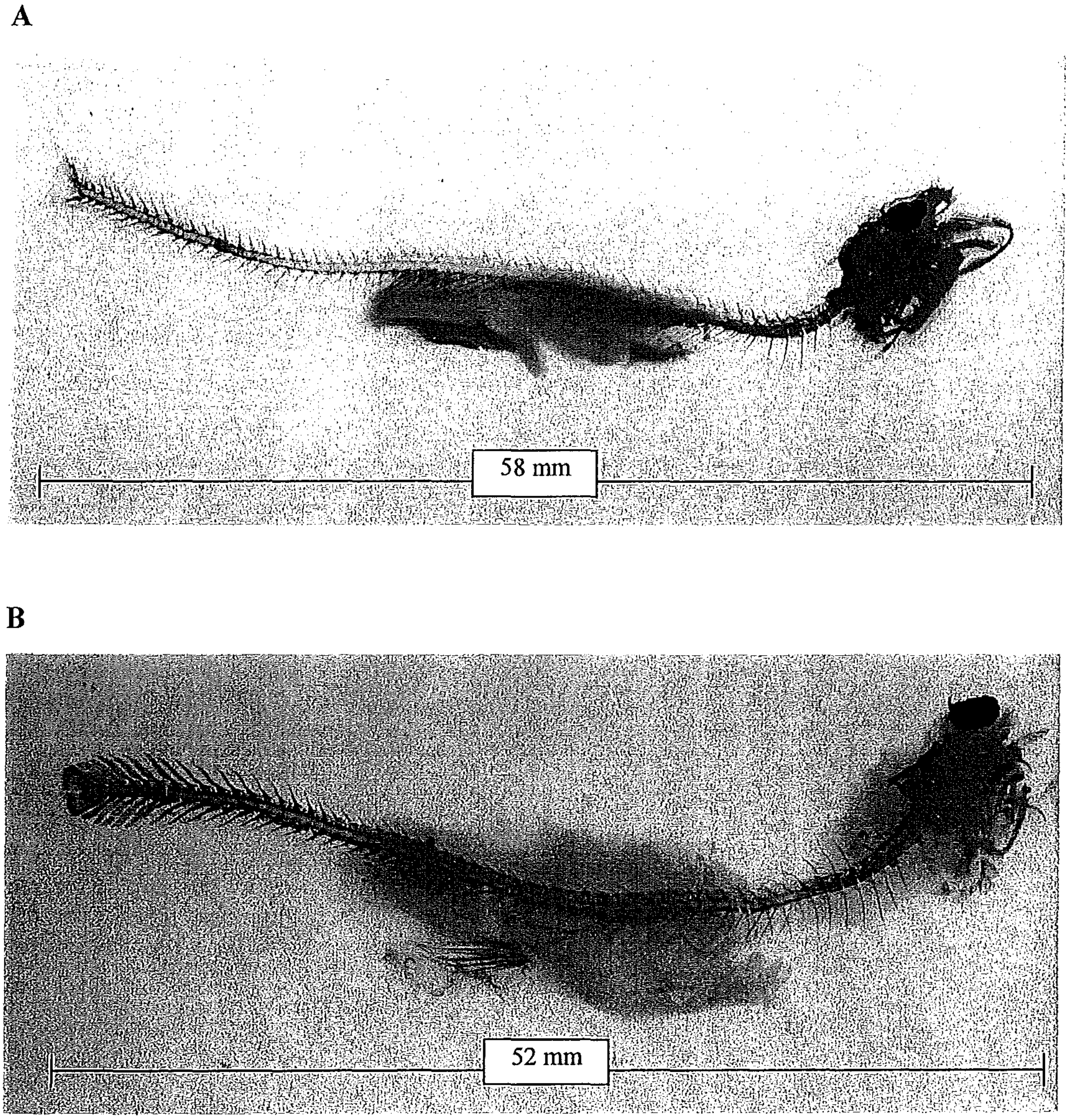


Figure 3.3. Photographs of two juvenile koaro from Lake Pearson prepared for spinal column counts. Spinal counts were A: 59 and B: 57.

Five otoliths were prepared for counts but two were damaged during the final sanding stage (Fig. 3.4). The remaining three had ring counts which when back calculated from the time they had died, indicated that they had been spawned between late September and early November (spring period). Each of the three otoliths was counted several times until a consistent range was achieved, an exact date could not be determined as otolith slide preparation provided samples which were difficult to focus under the microscope. Counts (mean +/- S.E.) of 353 +/- 8.03 days, 249.33 +/- 6.38 days and 419.33+/-8.19 days were achieved.

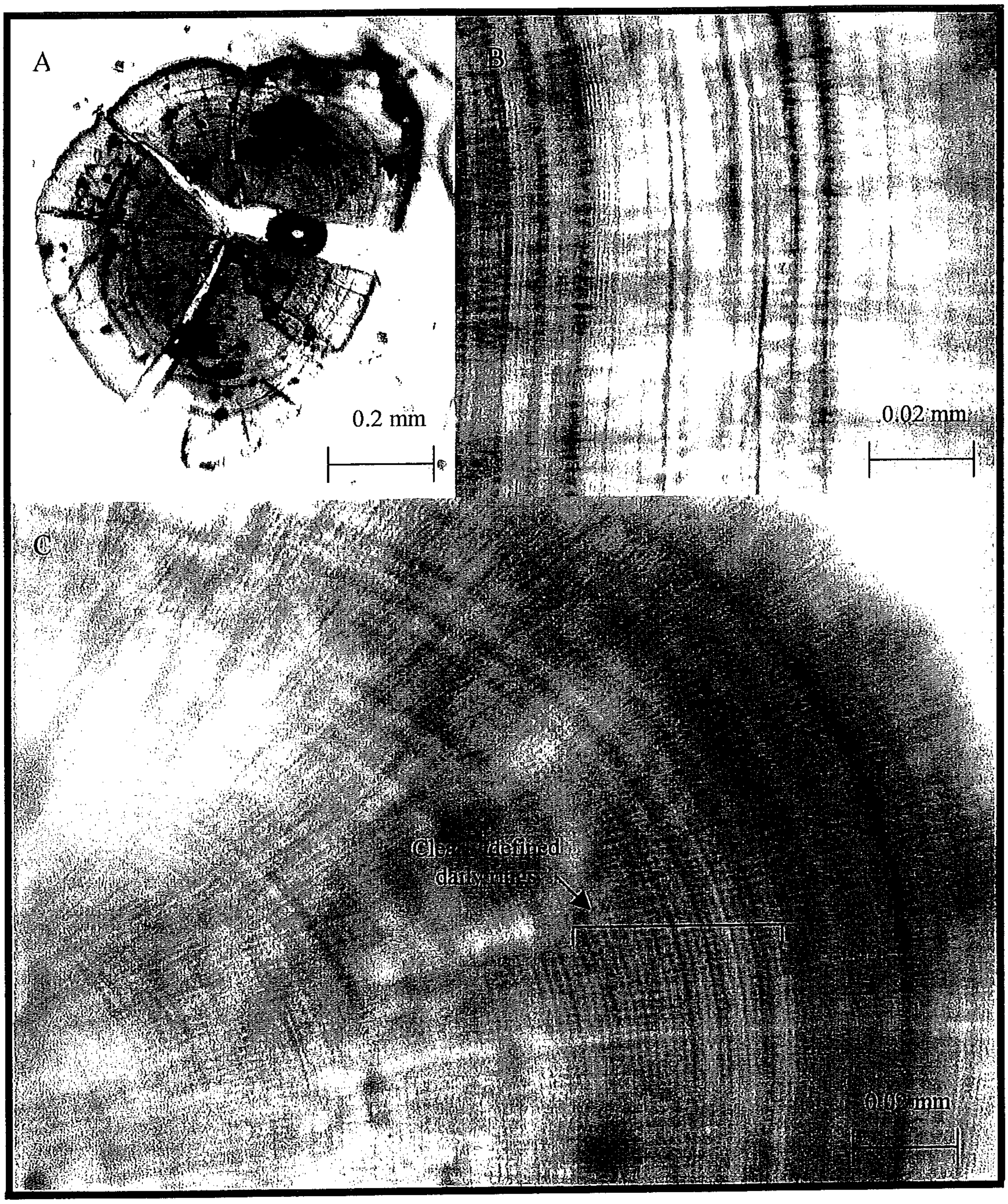


Figure 3.4. Photographs of otoliths from the juvenile koaro used to determine koaro age.
A: Whole otolith = 0.2 mm; B: Otolith segment = 0.02 mm; C: Otolith segment = 0.02 mm.

Gravid koaro were also captured in Manson Creek during spring (October 2000). However, no eggs were extruded from a probable female despite being obviously swollen with maturing eggs (Fig. 3.5).

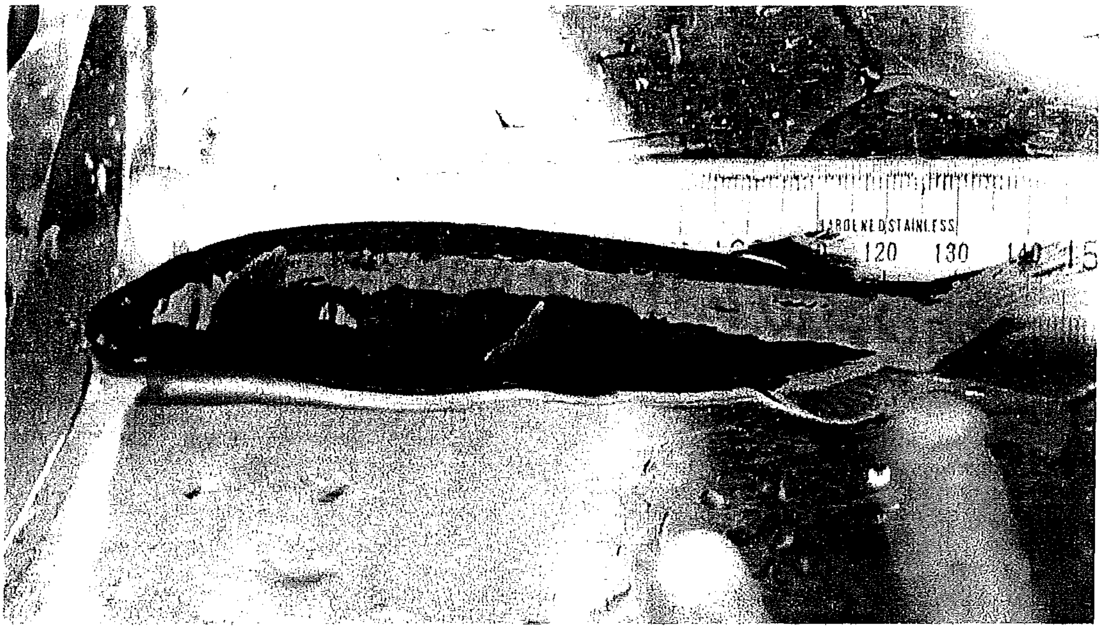


Figure 3.5. A gravid koaro (149 mm) captured from upper Manson Creek during October 2000.

Home-range

All 26 koaro recaptured from Manson Creek were found within the 20 m site at which they were originally tagged.

Growth

Koaro growth increased moving upstream from Site 4. Weight change was least at Site 4, where koaro density was greatest, and greatest at Site 6 where koaro density was lowest (Fig. 3.6). No statistical analysis was performed to test relationships between growth rates at different sites as there were too few recaptures at most sites.

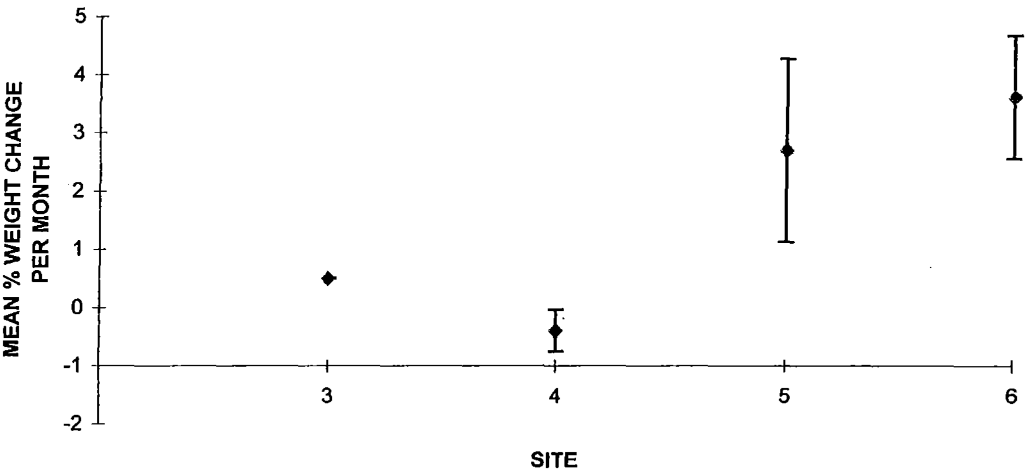


Figure 3.6. The mean percentage weight change (+/- S.E.) per month of adult koaro recaptured from Manson Creek Sites 3, 4, 5 and 6. The number of koaro recaptured at each site were Site 3: 1; Site 4: 21; Site 5: 2 and Site 6: 2.

Growth data from individual fish recaptured at Manson Creek Site 4 showed that percentage change in length rather than percentage change in wet weight gave the best estimate of growth over time (Fig.'s 3.7 & 3.8). Mean koaro growth was 0.44 mm per month.

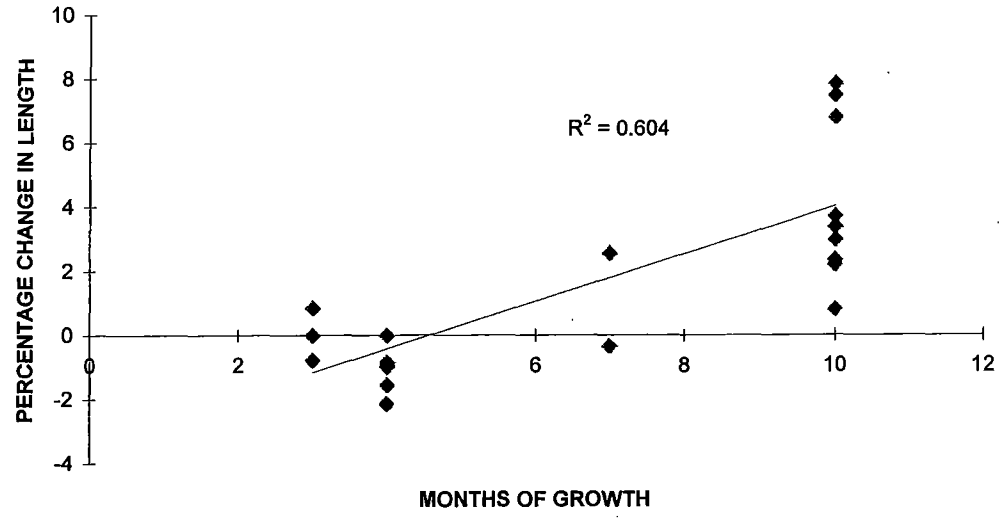


Figure 3.7. The mean percentage change in koaro length verses time for recaptured adult koaro from Site 4, (regression line equation: y = 0.7419x - 3.3924).

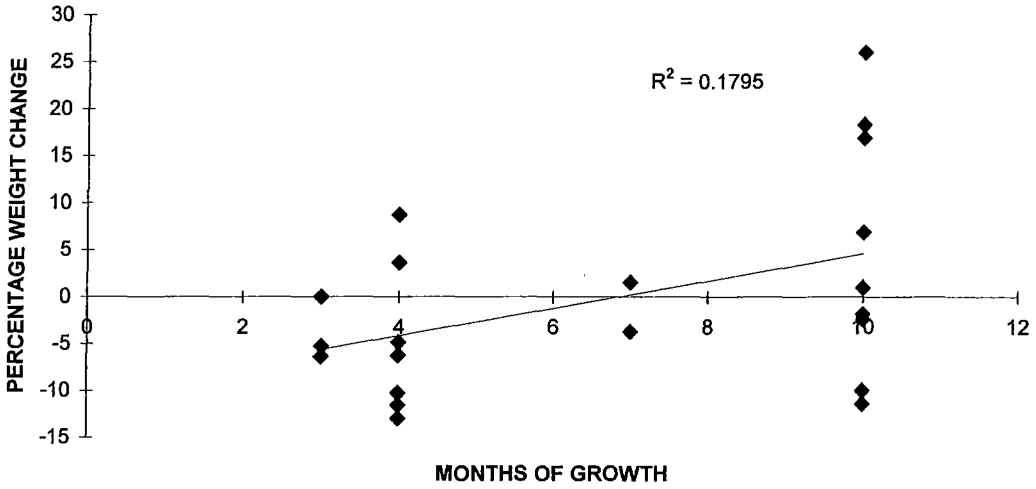


Figure 3.8. The mean percentage weight change verses time for recaptured adult koaro from Site 4, (regression line equation: y = 1.4527x - 9.9515).

Tag retention

In trial 1, five of the six koaro (5/6) retained their tags. An examination of the wound created by the injection of the tag showed that after 2 weeks the wound had healed, sealing in the tag. In trial 2, nine of the ten koaro (9/10) retained their tags after 2 weeks. The fish were retained for an experiment and after another four weeks, only seven of the remaining eight koaro retained their tag. This indicated that healing had not occurred in all fish after the initial 2 week period. An overall tag retention rate of 86.5 % was found.

DISCUSSION

Koaro are one of the most fecund galaxias species with records of up to 23,676 eggs per fish (O'Connor & Koehn, 1988). With such large egg masses you could expect that nests would be easy too find. However, as the eggs are transparent, 1.2- 2 mm in diameter, and deposited among substrate they are probably well hidden and most likely wouldn't be easily seen.

Despite a reasonable search no koaro spawning sites were found in this study. Allibone & Caskey (2000) spent substantially more time in a more intense and well organised search, and despite all this, only found one nest. As identification of spawning sites was not the main priority, and as time was often limited due to short days, overall significantly less time was spent looking in Manson Creek compared to the Taranaki streams. Therefore, we may have missed any koaro nesting sites.

As no koaro spawning sites were found it is not possible to comment on koaro choice of spawning habitat. However, the capture of juvenile koaro provided some in-site into the spawning time of some adults in the Lake Pearson population. 40-45 mm fork length juvenile galaxiids were found to be abundant at the mouth of a small Lake Pearson tributary stream during autumn 1999 and 2000. Two of the juvenile fish were found to have spinal counts of 57 and 59, respectively. Spinal counts of koaro from the Lake Pearson population donated by B. McDowall varied from 57 to 59 but were most commonly counts of 58. *Galaxias vulgaris* spinal counts from the central south Island region (Hurunui to Hinds Rivers) are consistently between 52 and 55 (McDowall, 1968b). The maximum recorded *G. vulgaris* counts of 57 occurred in Canterbury's Rakia River (McDowall, 1968b). The higher counts of the juveniles captured from Lake Pearson strongly supported the fact that the juveniles were *G. brevipinnis* rather than *G. vulgaris*.

As discussed in Chapter 1, adult koaro from diadromous populations are considered to spawn during autumn and early winter, and the migrations of juvenile koaro into rivers and streams is a spring phenomenon (McDowall, 1984). The observed difference in the timing of the migrations could reflect a difference in spawning season. For example, while diadromous populations spawn in autumn, lacustrine populations possibly spawn in spring. An alternative spawning season has been suggested for land-locked koaro populations, although there is presently little evidence for a shift in, or widening of, spawning season (McDowall, 1988, 1990a). There may just be a difference in the time that juveniles inhabiting lakes enter tributary streams. For example, it is possible that in the less productive freshwater environment, juvenile koaro need to spend more time rearing in the lakes to attain a minimum threshold size before migrating upstream to assume stream residence (Young, *personal communication*). However, using otolith ageing procedures, the koaro I captured from Lake Pearson were determined to have been spawned during the spring period. As over forty juveniles were captured in the lower 30m ($15m^2$) of the stream it is likely that a large number of juveniles were present in the stream. This suggests that spring spawning could contribute a substantial number of recruits to the Lake Pearson population.

Swollen fish were also found in the upper reaches of Manson Creek during spring. Although no milt or eggs were extruded from the fish abdomens when gently rubbed, the obvious swelling of the abdominal region was very likely due to the presence of mature eggs. This observation also supports spring spawning of some adults. It is possible that koaro in Lake Pearson and its tributaries spawn during both spring and autumn, or possibly all year round. Observations of ripe adult koaro all year round in a North Island lake supports this theory (Young, *personal communication*).

Spawning habitat was most certainly among adult habitat in upper Manson Creek. Similar koaro numbers and size distributions were captured while trapping Manson Creek throughout the year. This suggests that no upstream spawning migration of adults occurred. Young (*personal communication*) found no migration of lake dwelling koaro into tributary streams of the Rotorua lakes.

The theory that no adult spawning migration occurred away from upstream adult habitat is supported by the results of my home-range study. All koaro recaptured from Manson Creek were recaptured at the same site at which they were originally tagged. The absence of any recaptures outside the site of original tagging suggests that the adult koaro in Manson Creek do occupy a limited stream area. *G. vulgaris*, a galaxiid similar to the koaro, has been found to utilise a defined home-range (Cadwallader, 1976). Cadwallader (1976) found 97 percent of *G. vulgaris* were recaptured in the same section of the Glentui River as they were originally tagged. This suggests that adult fish remain in a small area of stream (< 20m) and most likely do not move far to spawn. Other researchers have recaptured high percentages of tagged koaro in the same area as they were originally tagged. A recent study found that male lake resident adult koaro tended to remain in a particular area, whereas some ripe females were found to move large distances (Young, *personal communication*). Of twelve tagged koaro recaptured during this study, nine were found in exactly the same, or in close proximity to, the same location. Another researcher found that most stream resident koaro tagged in Lake Taupo tributary streams were recaptured at the site they were originally tagged (Kusabs, 1989). This suggested that these koaro utilised a defined stream area. These findings support the occupancy of a limited home-range by adult koaro and further support the reduced likelihood that adult koaro undergo a spawning migration away from adult habitats to spawn.

An additional element of my tag/recapture study was the determination of koaro growth in different areas of Manson Creek. As few koaro were recaptured from sites other than Site 4 it was difficult to make any firm comparisons as to any difference in mean growth between sites. While 21 koaro were recaptured from Site 4, and two fish were recaptured from each of Sites 5 and 6, only one koaro was recaptured at Site 3. Greatest mean growth occurred at Site 6, the uppermost site containing the lowest koaro density of the four upper sites. The lowest mean growth rate occurred at Site 4, the site containing the highest koaro density. Therefore, koaro growth was inversely correlated with koaro density. The intensity of competition for food among the members of a fish population will be directly related to the population density (Weatherly, 1966).

Strong intra-specific interactions such as those most likely experienced by the high density of adult koaro at Site 4, have been found to negatively affect fish growth (Eklöv, 1999; Armstrong *et al*, 1999). Byström and Garcia-Berthou (1999) found strong intra-specific density dependent growth in perch. High fish densities were found to have strong negative effects on available food resources. Therefore, fish density most likely affected koaro growth at Site 4 as greater competition for food resources would likely occur there.

CHAPTER 4

Interactions between koaro and brown trout (*Salmo trutta*)

INTRODUCTION

Despite recent research, many of the effects of exotic fishes on the native galaxiid fishes of New Zealand are not well understood. Human impacts on the environment and aquatic habitats have long been considered a principle cause of recorded galaxiid declines (McDowall, 1990a). Negative effects of introduced brown and rainbow trout on galaxiid populations have been identified as another potential reason for the reduction of galaxiids (McDowall, 1968a; Cadwallader, 1979; Jackson & Williams, 1980; Moffat, 1984; Glova, 1989; McIntosh, 2000a). Many examples of disjunct trout and galaxiid distributions and records of significant reductions in galaxiid numbers exist (see review in Chapter 1). These negative interactions may be due to competition for space, competition for food or direct predation by trout. As trout are highly aggressive and territorial, they compete for positions that provide cover and the best access to food, and thus could actively deter galaxiids from occupying certain microhabitats (McIntosh *et al*, 1992). However, knowledge of these complex interactions, including experimental testing of possible causes of observed fish distributions are lacking. If we know why galaxiids have limited distributions, it should be possible to use the information to better manage and conserve the species.

In Chapter Two, electrofishing of Manson Creek indicated that there was a negative correlation between trout and koaro. Koaro were also smaller downstream. Koaro numbers increased from downstream to upstream and this tended to correspond to a decrease in trout numbers from downstream to upstream. In this chapter I investigate whether these patterns of koaro abundance might be due to competition between trout and koaro (forcing koaro upstream), whether larger koaro upstream might force smaller trout downstream, or whether the patterns could be explained by koaro and trout habitat preferences.

To fully understand why distributions of these fish appear restricted, it is important to further investigate interactions between these two fish families. In a tributary stream of Lake Taupo where dietary overlap between koaro and juvenile rainbow was high, koaro density was found to be low (Kusabs & Swales, 1991). In comparison, in another tributary stream where dietary overlap between the two species was less significant, koaro density was higher. Furthermore, koaro were only common in habitats where they could avoid direct competition with juvenile trout through temporal and/or spatial food resource partitioning (Kusabs & Swales, 1991).
Another New Zealand study assessing dietary and spatial overlap between koaro and brown and rainbow trout found differences in koaro and trout diel feeding patterns and microhabitat use (Glova & Sagar, 1991a). In this case, these differences were considered to lessen interactions between the galaxiid and salmoniid fishes.

Experimental testing of hypotheses relating to potential reasons for the observed distributions is the best way to identify possible causes of the distribution patterns.
McIntosh and coworkers (1992) experimentally tested the preference of an Otago galaxiid for certain microhabitats, both with and without trout. Artificial stream channels were modified so that two different microhabitats (one in each half) were available to the galaxiids. Galaxiid habitat choice was determined by the comparison of a control (no trout) and a trout treatment. Another study by Glova *et al* (1992) also assessed the interactions for food and space between a Canterbury galaxias and brown trout. A study by Hayes (1989) utilised experimental stream troughs to assess social interactions between brown and rainbow trout.

In this chapter I report the results of an investigation into the possible effects of *Salmo trutta* on koaro, *Galaxias brevipinnis*. This investigation assessed two types of potential competitive interactions between koaro and brown trout. These included possible competitive exclusion of koaro from preferred habitats by trout ("Microhabitat experiments": A: Shade, B: Velocity) and competition for food between the two species, resulting in different koaro growth in situations with and without trout present ("Growth experiment").

I hypothesised that koaro would prefer shaded conditions both with and without trout. As discussed in Chapter 1, koaro usually inhabit fast, rocky streams in close proximity to forest (Stokell, 1955, McDowall, 1990a). The shade and cover created by forest are important to koaro because these areas provide overhead cover and lower water temperature (McDowall, 1980). I predicted that because shade is closely associated with adult koaro habitat in upper Manson Creek, that the presence of shade would more strongly influence their choice of microhabitat than the presence of aggressive trout.

In some streams koaro inhabit riffles just as frequently as they do pools (Main, 1988). Chadderton and Allibone (2000) found that koaro occupied diverse habitats including pools and backwaters in a Stewart Island stream where trout were absent. In areas with low trout densities in the upper reaches of Manson Creek, I regularly captured koaro in pools. However, in lower Manson Creek, an area containing high trout densities, I never captured koaro in pools. Thus, I predict that as trout prefer pools (Bohlin, 1977), trout would select slower water velocities most often. As a result, where trout are absent (e.g. upper Manson Creek), koaro would likely inhabit a wider range of water velocities including pools and slower water velocities. I hypothesised that koaro used in microhabitat experiments would inhabit faster water velocities when trout were present because trout would aggressively exclude them from slower water velocities. I further hypothesised that when trout were absent, koaro would more regularly be found in slower velocity microhabitats.

Townsend and Crowl (1991) suggested that trout predation is the most likely mechanism explaining disjunct galaxiid distributions. Other researchers in New Zealand and Australia have also implicated trout predation as causing galaxiid declines (McDowall, 1968a; Tizley, 1976; Cadwallader, 1978, 1979; Glova, 1990). Trout size was considered the most important variable determining galaxiid density in a study by McIntosh *et al* (1994). Lower densities of galaxiids in the Shag River also occurred in areas containing large trout (McIntosh *et al*, 1994). Another study in the Waimakiriri River system revealed that galaxiids were absent from all sites containing trout greater than 150 mm fork length (McIntosh, 2000a).

An experiment conducted by the same author indicated that predation of *G. vulgaris* by large trout (>150 mm) occurred in stream tanks, and appeared not to be size selective. Therefore, even larger galaxiids (up to 120 mm FL) were vulnerable to predation by trout greater than 150mm in length. Although koaro grow much larger than 120 mm, this suggests that the extent of interaction between koaro and trout is also likely to be dependent on fish size.

To test the hypothesis that trout force koaro to occupy less preferred microhabitats (the "microhabitat experiments"), I used artificial stream channels divided into two different microhabitats to determine whether koaro habitat choice varied between trout and troutless treatments. Although an experimental environment is less natural than a real stream environment, the channels allow the variation in natural systems to be controlled so that specific hypotheses can be tested. Several researches have used various types of *in-situ* stream channel to investigate microhabitat selectivity in stream fishes (Fraser, 1983; Hayes, 1989; McIntosh, 1990).

The "growth experiment" was designed to assess whether the growth of small and large koaro was affected by the presence of different sized trout over one month. It tested whether both small and large koaro grew less when medium sized trout were present. I predicted that as trout often behave aggressively towards other fish (Kalleberg, 1958), both large and small koaro would remain in refuge while trout were active. Due to such aggressive behaviour, I also predicted that competition for food is likely to favour the trout. Therefore, I expected the koaro to grow more slowly in medium trout treatments compared to control treatments. As the extent of competition between koaro and trout is likely to be dependent on fish size, I also predicted that although small trout would have negative effects on small koaro growth, large koaro, being much larger than the small trout, should be unaffected.

METHODS

Microhabitat experiments

Twelve artificial stream channels were constructed using corrugated plastic sheets (1800 mm x 1200 mm). These channels (length x width x depth = 1800 mm x 450 mm x 300 mm, Fig. 4.1), had mesh ends (5 mm x 10 mm) large enough to allow insect drift to enter and leave the channel, without allowing any fish to escape. A fine mesh cover (3 mm x 3 mm) was used to prevent fish from escaping through the top of the channel. A mesh drop net weighted with heavy chain was located at the centre of each channel (Fig.'s 4.2 & 4.4). Pulling a string attached to a steel pin holding up the net, released the drop net blocking off each section, preventing any fish movement between halves of the channel.

The channels were placed in a section of Craigieburn Stream on Flock Hill Station that was of relatively uniform depth (150 mm - 250 mm), had a series of wide riffles and runs large enough to place the channels in the substrate, and was easily accessible by a road. Small dry stones (20 mm - 50 mm) were used to fill the bottom 50 mm of each channel creating channels with an average water depth of 148 mm. Steel warratahs were used to secure the channels in place. Small boulders (150 mm diameter) were placed in each half of the channel, to provide refuges for the fish. Before stocking with fish, the lids were placed on the channels and then left for six days to allow for natural insect colonisation via drift. The channels were placed in four sets of three across the stream. This created four replicates of three different treatments (Fig. 4.3). Each block of channels was separated by 7 m - 10 m of stream.

In each block, one channel contained two medium sized koaro (95 mm - 115 mm), the second contained a medium koaro and a large koaro (135 mm - 150 mm), and the final channel contained a medium koaro and a trout (130 mm - 145 mm). These treatments represented a control, large koaro and trout treatment, respectively (Table 4.1), and were allocated randomly within each block, creating a randomised block design. Each treatment was replicated four times.

Table 4.1. Fish species and sizes (Fork length) used in each treatment for the "Shade" and "Velocity" microhabitat experiments.

TREATMENT	Medium Koaro (95 - 115 mm)	Medium Koaro (95 - 115 mm)	Large Koaro (135 - 150 mm)	Trout (130 - 145 mm)
Control	✓	✓	✗	✗
Large Koaro	✓	✗	✓	✗
Trout	✓	✗	✗	✓

To prevent leaves blocking water flow through the channels, the mesh was cleaned once a day using a scrubbing brush. A mesh fence (25 mm x 25 mm) was also constructed in the stream approximately 10 m above the top block of channels to capture willow leaves. This was also cleaned once a day (Fig. 4.3).

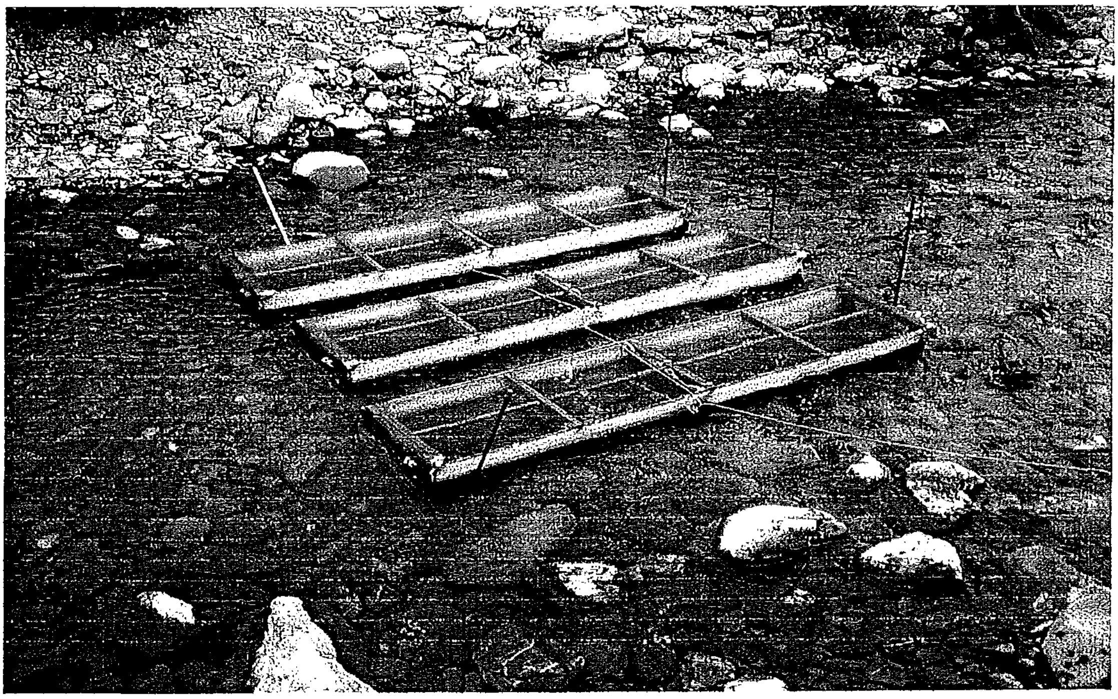


Figure 4.1. Set-up of a block of stream channels across the stream. Each block represents one replicate consisting of a control, a large koaro treatment and a medium trout treatment.

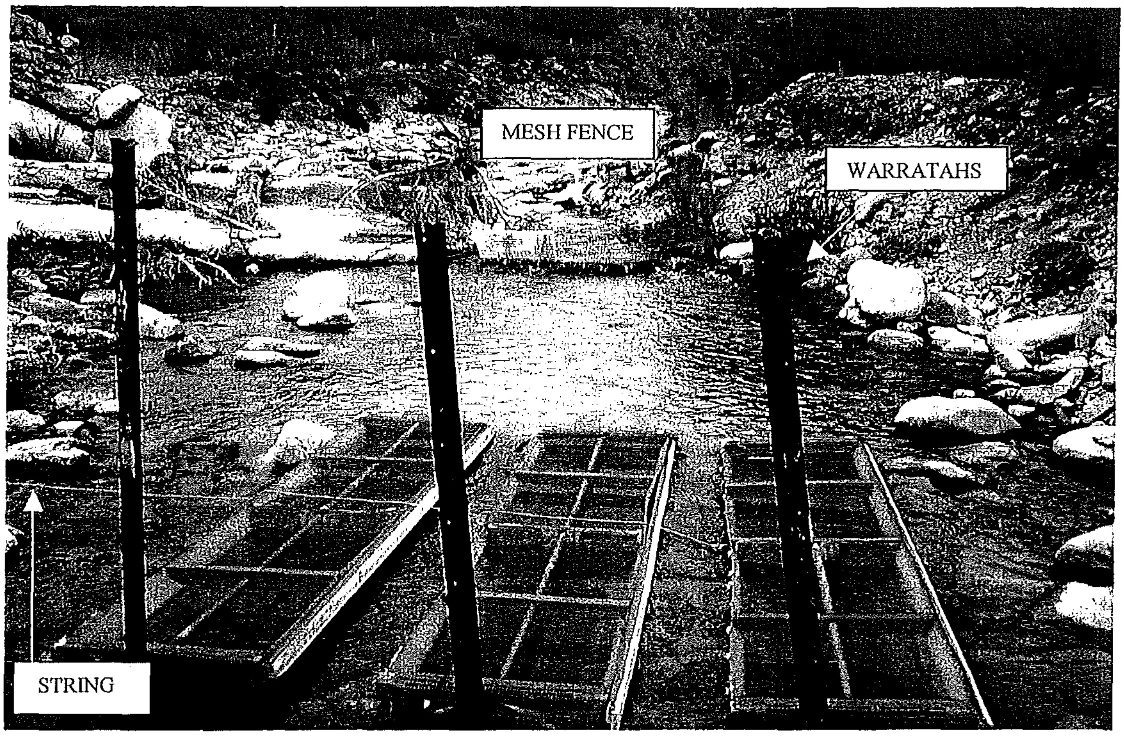


Figure 4.2. The top block of channels showing the string attached to the steel pins holding up the mesh drop nets. Above the channels, a leaf-catching barrier was constructed to reduce blocking of the channel mesh by leaves.

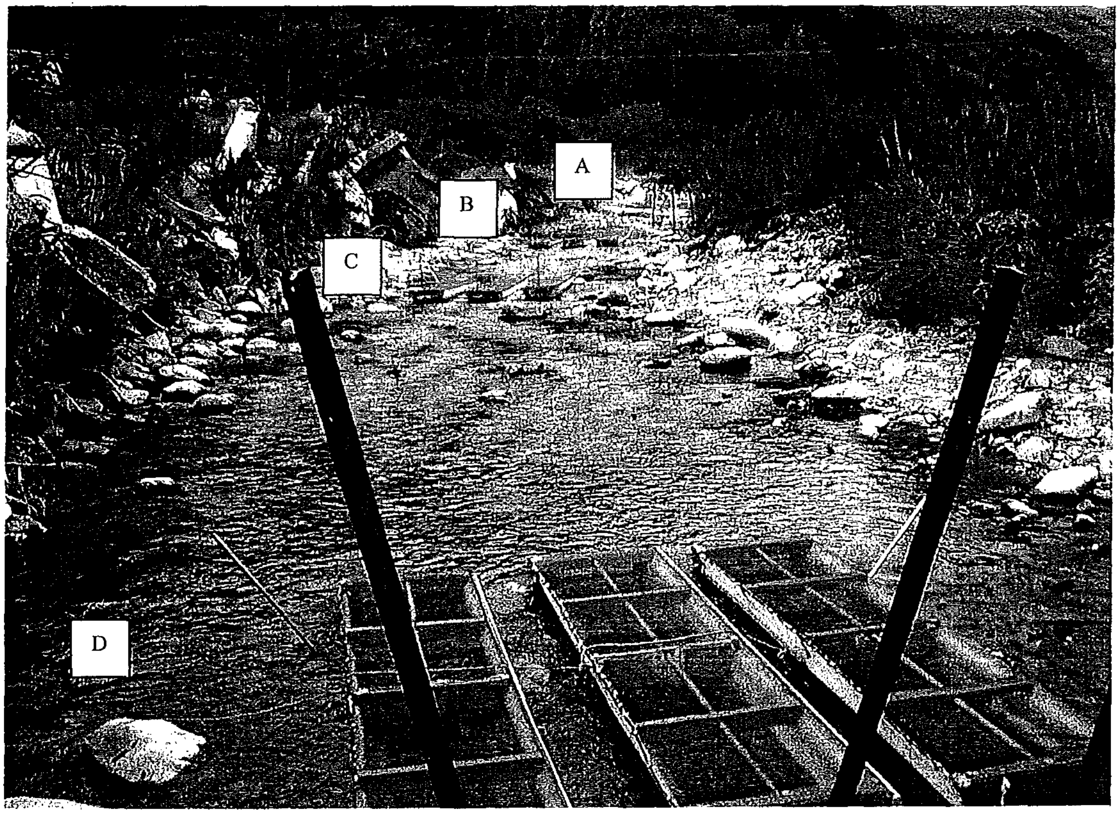


Figure 4.3. View looking upstream at the position of each of the four blocks of channels (A,B,C and D).

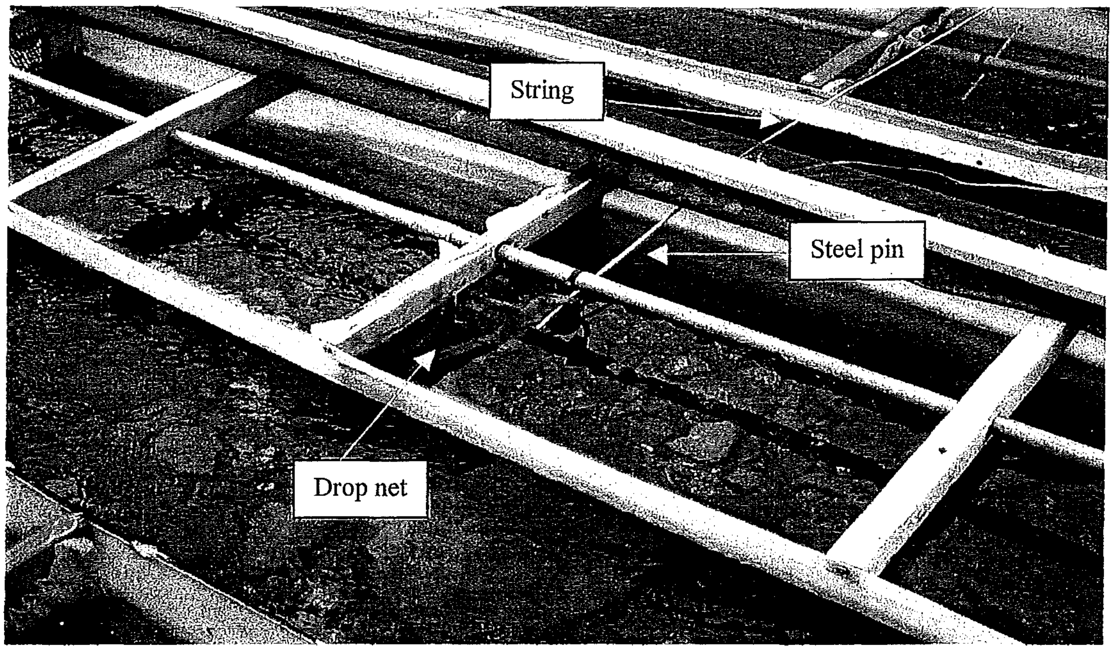


Figure 4.4. Construction of the mesh drop net used to isolate fish in half of the channel. The steel pin and string used to drop the net are also visible.

Experiment A: *Shade Experiment*

This experiment took place during low summer flows, beginning on the 11 February 2001 and running until the 14 February 2001. To determine if koaro use of shaded and non-shaded sections of the channel varied with trout presence, a piece of canvas was placed over one half of each channel, creating a shaded microhabitat (Fig. 4.5). The position of the canvas was alternated from the upstream half to the downstream half of the channels between blocks. On a bright sunny day (>20,000 Lux), light intensity inside the covered halves of the channels was reduced by approximately 90 percent to 1505 Lux.

In this stream Drinnan (2000) found significantly higher insect drift during the night compared to during the day. Her study occurred during November and December 1999, with drift sampling focussed on the dark period of the lunar cycle. Total invertebrate abundance's per drift net (size: 300 mm x 250 mm) sample were as follows. Day (began 10:00 am): 12, 13, 17 and Night (began one hour after sunset): 40, 44, 53. *Deleatidium* mayflies, *Olinga feredayi* (Cased caddis) and Chironomids were the most common invertebrate species captured.

Koaro were captured from Manson Creek and trout were captured from Craigieburn Stream using electrofishing. The fish were placed in the channels and allowed to acclimatise for twelve hours before the experiment began.

After the initial acclimatisation period (11 February 2001 and 18 February 2001 for shade and velocity experiments, respectively), the experiment ran for two day and two night samples. The channels were sampled once during the day (between 14:00 and 16:00 NZDT) and once during the night (between 22:30 and 23:30 NZDT). The channels were quietly approached from downstream. During the day it was necessary to stay low (crawl) so that the fish would not be disturbed. For each block in sequence, the string attached to the steel pin was pulled causing the drop nets to fall down, isolating the fish in one of the compartments. The channels could then be approached and checked. Checking consisted of removing the mesh lid and visually spotting the location of all fish.

At night, a Petzl Duo headtorch with the lens covered in red cellophane was used because the fish reacted more calmly. The channels were approached using low beam and fish were located using high beam.

Once the experiments were completed the fish were placed in a flow through holding tank at the University of Canterbury's Cass field station where they were fed large numbers of stream invertebrates.

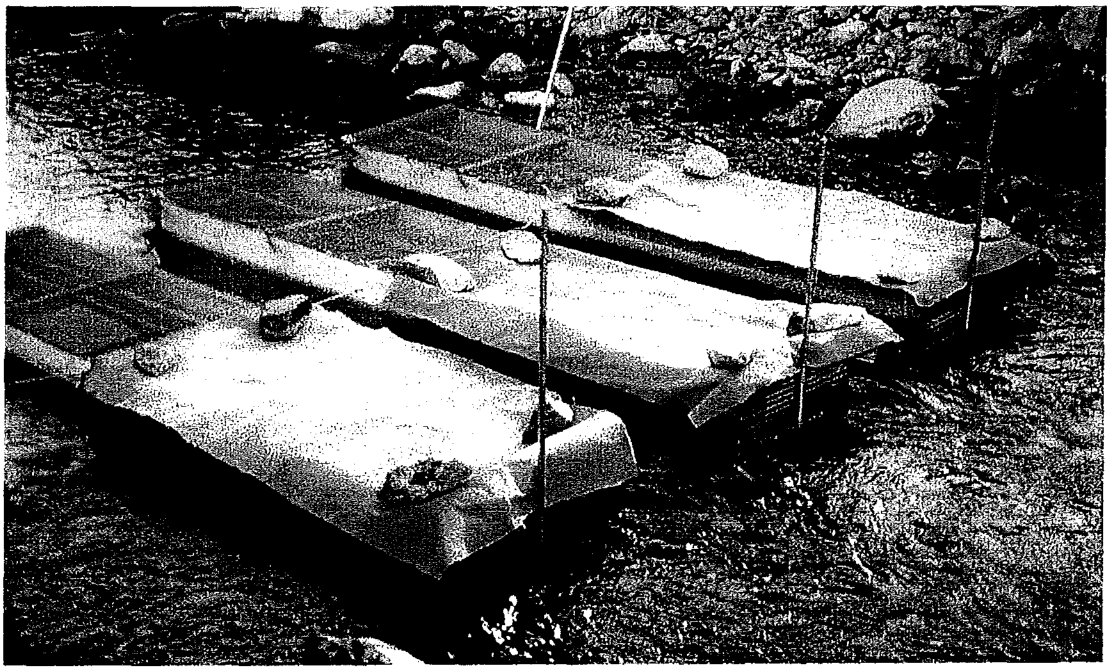


Figure 4.5. The canvas used to cover each channel creating a shaded microhabitat.

Experiment B: *Velocity Experiment*

This experiment also took place during low summer flows, beginning on the 18 February 2001 and running until the 21 February 2001. To determine if koaro use of fast (0.3 - 0.5 m/s^{-1}) and slow water velocity (0.1 - 0.2 m/s^{-1}) varied with trout presence, the water velocity in the downstream half of each channel was increased using a specially designed barrier. The barrier, positioned in the centre of each channel, consisted of two pieces of plywood shaped to the contours of the channel (Fig. 4.6). This increased water velocity in the downstream section of the channel by 0.2 - 0.3 m/s^{-1} and created a "slow" water velocity in the upstream half of the channel and a "fast" water velocity in the bottom half of the channel. A velocity meter (Hydrological Services PTY. LTD. Australia, Model: OSS.PC1) was used to test that the velocity in each channel was relatively uniform (Fig. 4.7).

Microhabitat Experiment Data analysis

Two-way ANOVAs were utilised to determine whether significant differences in microhabitat choice occurred between treatments during the day and night. Arcsine-squareroot transformations were used on percentage data before analysis proceeded. This analysis identified whether any fish species had a preference for certain microhabitats and whether the presence of other fish affected their microhabitat choice.

A Chi-square goodness-of-fit test was used to determine whether use of the upstream verses downstream part of the channel departed from an expected 50:50 ratio in the shade microhabitat experiment. This analysis identified whether any upstream or downstream channel bias existed. Chi-square goodness-of-fit tests were also used to determine whether the percentage of time medium koaro spent alone was independent of treatment. In these tests the mean of all observations was used as the expected number.

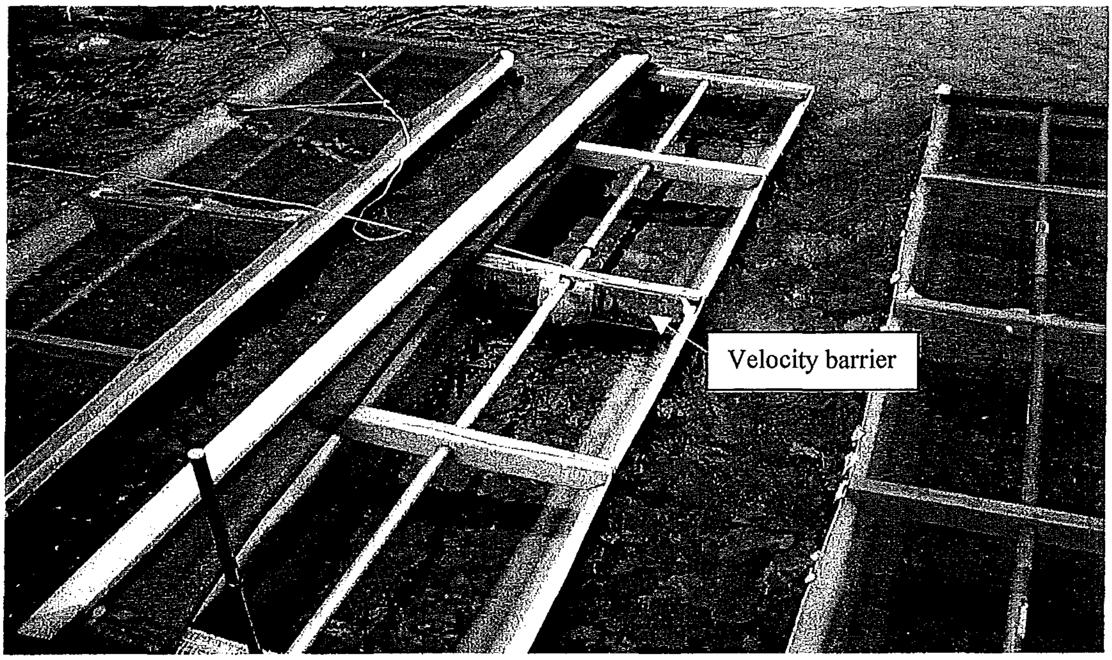


Figure 4.6. Wooden velocity barrier constructed to increase water velocity in the downstream half of each channel. Note the drop net is also in place.

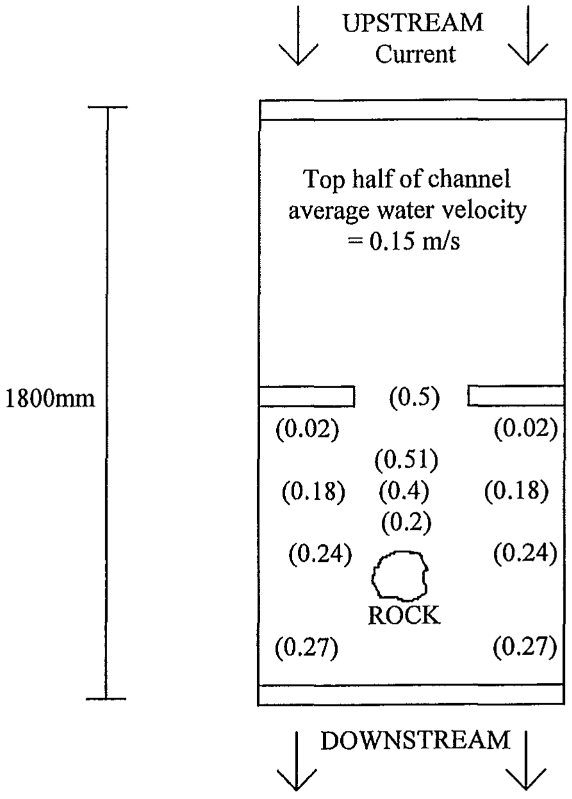


Figure 4.7. Diagram showing the average water velocity in certain sections of an experimental stream channel. Each value shown in brackets is a velocity measurement in metres per second (m/s^{-1}).

Growth experiment

This experiment utilised fifteen circulatory flow-through tanks located at the Cass field station. The tanks (Fig. 4.8) were oval in shape and constructed from plastic cattle watering tanks (width x length, 680 mm x 1210 mm). A clear perspex baffle (600 mm in length) on the tank centre line with a water jet on either side of the baffle, created a oval circulatory water current. Water in the flow through system was filled via a pump, and drained through a central standpipe with 1 mm mesh overflow windows. If the mesh windows remained unblocked an average water depth of 220 mm and water volume of $0.823m^2$ was achieved. However, if the mesh became blocked with detritus/algae, a depth up to 270 mm was possible. In the event of an overflow, the top of each central over flow standpipe was also covered with 1 mm mesh to prevent any fish from escaping. Four large rocks (200 mm - 250 mm) were placed in each tank, one in each corner. Mesh lids were placed over each tank.

After the tanks had been set up, the fish were captured from Manson Creek and Craigieburn Stream. Captured fish were separated into size classes and then weighed and measured before being placed in the appropriate tank. All koaro were weighed several times until three similar values were recorded. The mean of these values represented the fishes weight. This process made sure that the recorded value was accurate. The same method was later used to re-weigh the fish at the conclusion of the experiment.

Five of the fifteen tanks represented a control treatment containing a small koaro (60-70mm) a large koaro (120-160mm) and another larger koaro chosen to ensure fish biomass was equal in all tanks. Another five tanks represented a small trout treatment containing a small koaro, a large koaro and a small trout (70-80mm). The remaining five tanks (medium trout treatment) contained a small koaro, a large koaro and a medium trout (120-140mm). Randomisation of tanks allowed different treatments to be placed in different rows, thus reducing any row effects.

Every three days 80 - 120 stream invertebrates were placed in each tank. *Deleatidium* spp, mayflies constituted most of the diet, however cased caddis, free-living caddis and other mayflies were also present. The insects were counted into individual containers using a large suction pipette and the same number were placed in each tank.

After one month, each tank was drained and the fish were captured. The fish were weighed and measured and any fish that had died or were missing were noted.

A two-way ANOVA was used to determine whether significant differences in small and large koaro growth occurred between treatment. Arcsine-squareroot transformations were used on the percentage data before analysis proceeded.
T-tests were used to test whether there were significantly differences between the growth of large koaro and medium trout, and small koaro and small trout. A Fisher's exact test was used to examine whether the number of koaro that died or went missing in the growth experiment varied between treatments.

Figure 4.8. Experimental set-up of the sixteen tanks at the Cass field station. Water was pumped from Grasmere Stream (left) into the tanks. Fifteen tanks were used for the experiment.

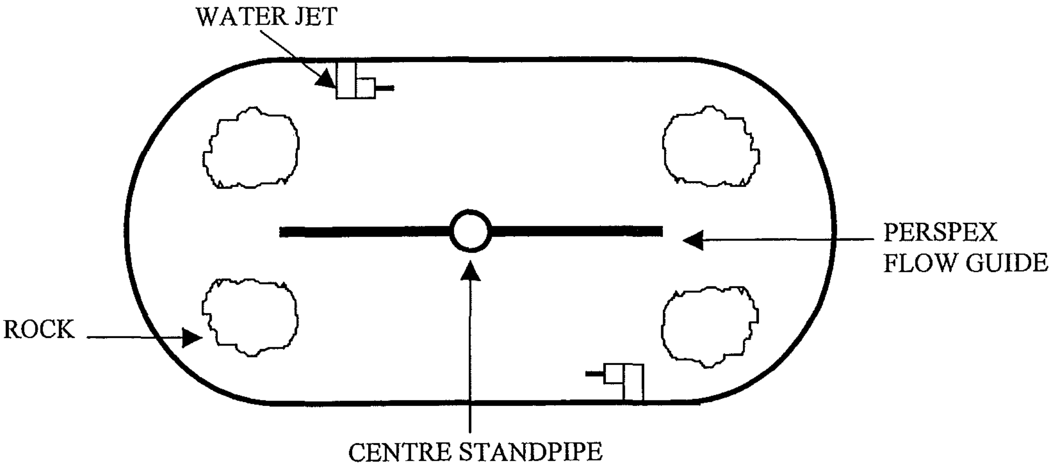


Figure 4.9. Diagram showing the set up of each tank. Rocks were placed in the same position in each of the fifteen tanks.

RESULTS

Shade selectivity

During the day, medium sized koaro showed no significant preference for shaded microhabitats within any of the three treatments (Fig. 4.10, Table 4.2). The same result occurred during the night as there was no significant effect of time on microhabitat choice (Table 4.1). In addition, a Chi-square goodness-of-fit test ($\chi^2 = 0.66$, df = 1, $p > 0.05$) indicated there was no upstream effect; koaro use of the upstream and downstream halves of the channels was not significantly different from a 50:50 ratio.

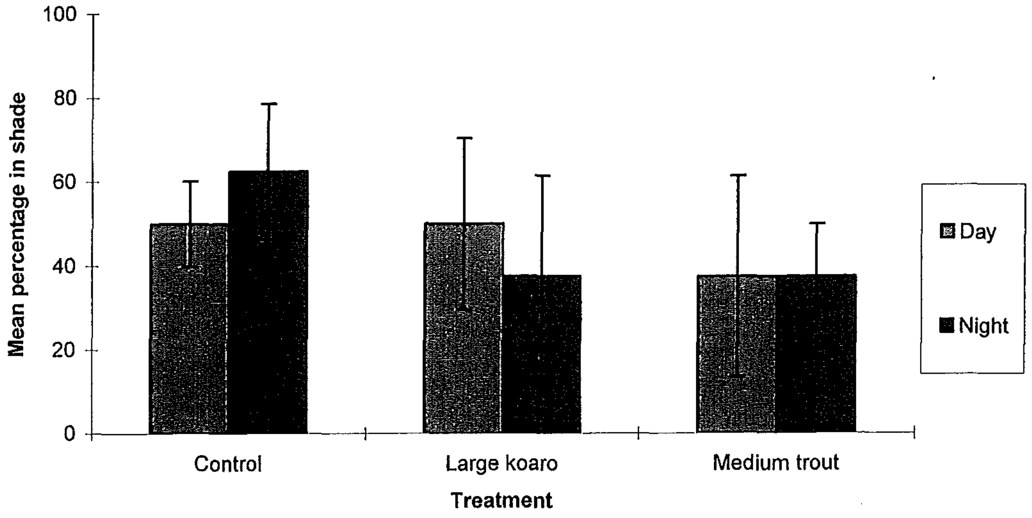


Figure 4.10. Mean percentage use of shade by medium koaro in each of the experimental treatments: control, large koaro and medium trout. Error bars indicate one standard error for the mean.

Table 4.2. Two way ANOVA testing the percentage of medium koaro present in shaded microhabitats in each of the three fish treatments during the day and night time. Note there was no variance associated with the time treatment.

Source	df	ms	F- ratio	p-value
Fish	2	0.180	0.555	0.583
Time	1	0.000	0.000	1.000
Fish x time	2	0.070	0.238	0.790
Error	18	0.323		

The percentage of time medium koaro were found alone during the shade experiment differed between control and medium trout treatments (Fig. 4.11). A Chi-square goodness-of-fit test ($\chi^2 = 20.1$, df = 1 , $p < 0.05$) indicated that time spent alone was not independent of treatment. Koaro spent more time alone in medium trout treatments than expected, and less time alone in control treatments than expected. However, a second Chi-square test including just the trout and large koaro treatments ($\chi^2 = 2.64$, df = 1, $p > 0.05$) indicated that large koaro had a similar effect to medium trout.

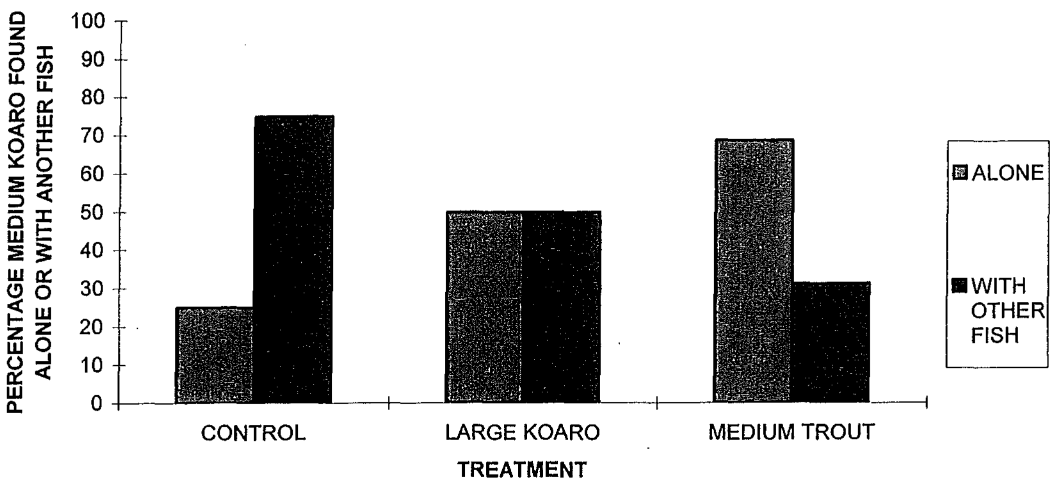


Figure 4.11. Percentage of time (day and night inclusive) during the shade experiment that the medium koaro spent alone or with another fish in each of the experimental treatments: control, large koaro and medium trout.

In the trout treatments, trout consistently occupied shaded microhabitats during the night and day (Fig. 4.12).

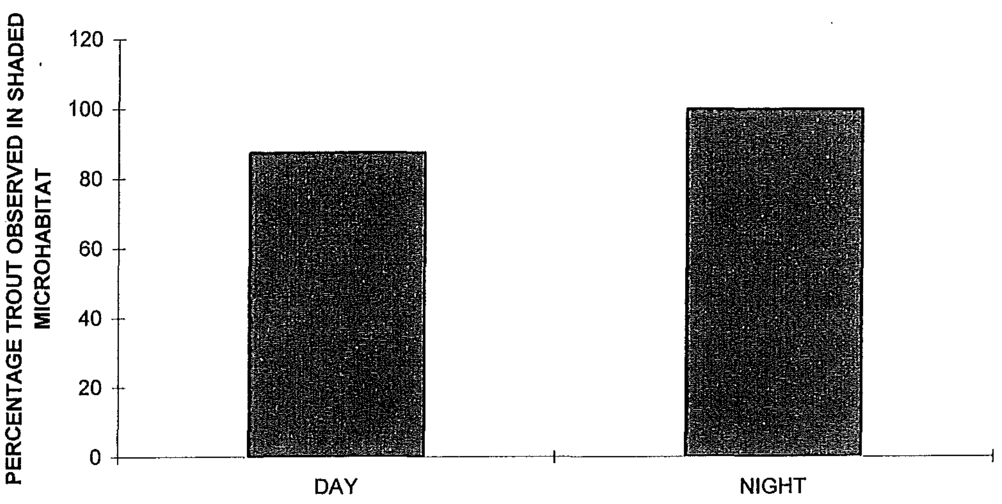


Figure 4.12. Total percentage of times trout were observed inhabiting shaded microhabitats during the day and night in trout treatments.

Velocity selectivity

Medium sized koaro showed no obvious preference for either fast or slow water velocity during the day within all treatments (Fig. 4.13), and ANOVA indicated there was no significant difference in koaro microhabitat selection between treatments (Table 4.3). When present, trout were observed in fast velocity microhabitats half the time during the day and on 25% of samples during the night (Fig 4.15).

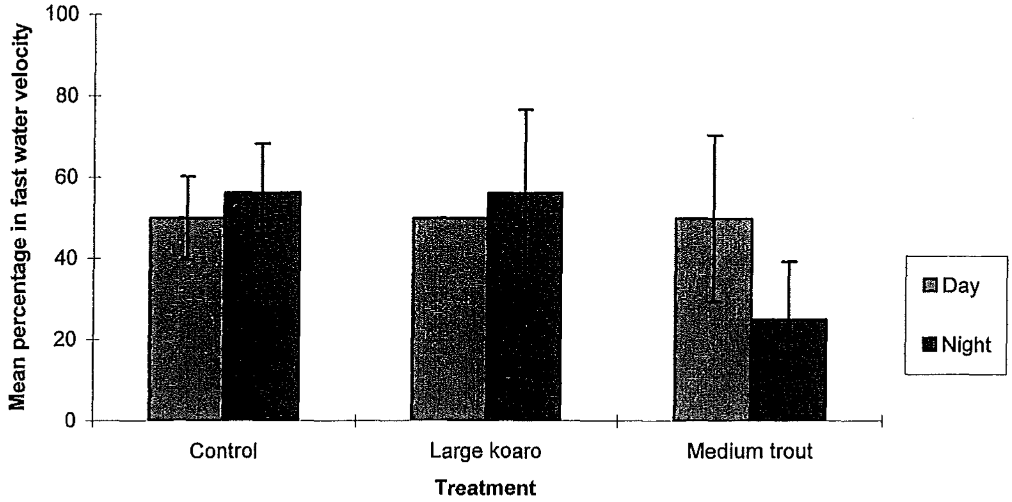


Figure 4.13. Mean percentage use of fast water velocity by medium koaro in each of the experimental treatments: control, large koaro and medium trout. Error bars indicate one standard error for the mean.

Table 4.3. Two-way ANOVA testing the percentage of medium koaro present in fast water velocity microhabitats in each of the three fish treatments during the day and night time.

Source	df	ms	F- ratio	p-value
Fish	2	0.123	0.648	0.535
Time	1	0.071	0.377	0.547
Fish x time	2	0.123	0.648	0.535
Error	18	0.243		

However, the percentage of time medium koaro were found alone during the velocity experiment differed between the large koaro and medium trout treatments (Fig. 4.14). A Chi-square goodness-of-fit test ($\chi^2 = 18.8$, df = 1, $p < 0.05$) showed that the percentage of time spent alone was not independent of treatment.

Medium koaro spent more time alone in trout treatments than expected and less time alone in the large koaro treatment than expected. Surprisingly, medium koaro spent most time with another fish in large koaro treatments and less when only medium koaro were present. A second Chi-square ($\chi^2 = 4.86$, df = 1, $p < 0.05$) considering the control and medium trout indicated that the time medium koaro spent alone was also not independent of treatment. Medium koaro spent more time alone in the medium trout treatment than in controls.

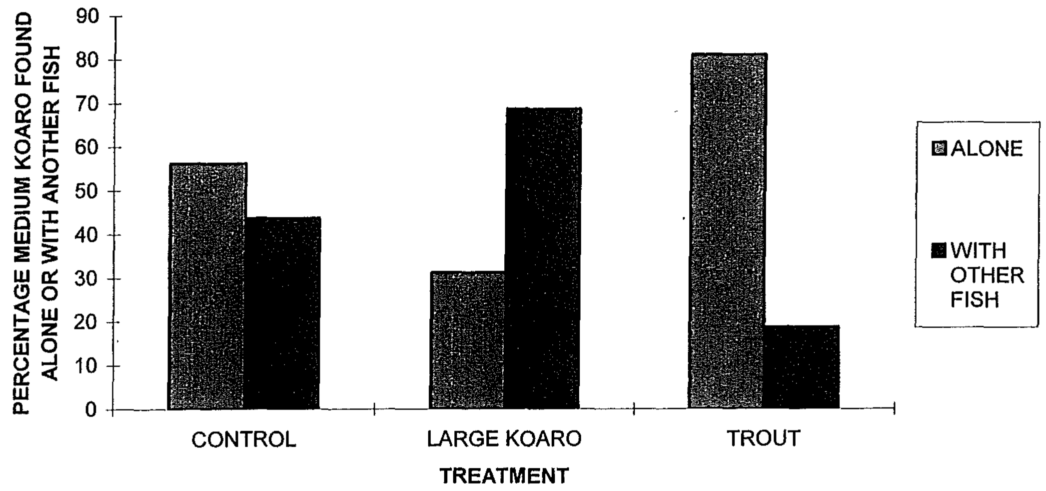


Figure 4.14. Percentage of medium koaro found alone or with another fish in each of the three experimental treatments during the velocity microhabitat experiment.

When present. Trout occupied fast water velocity microhabitats during the day at twice the frequency they did during the night (Fig. 4.15).

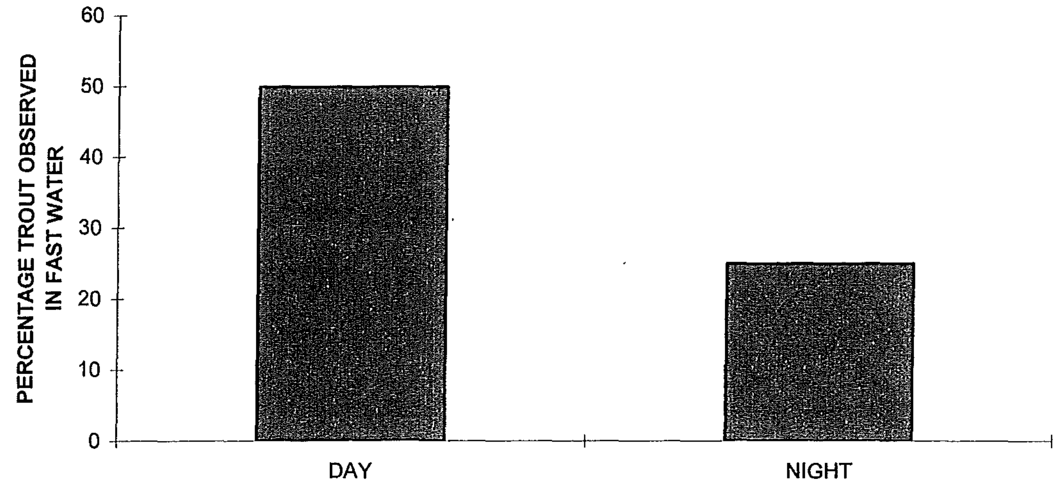


Figure 4.15. Percentage of times trout were observed in fast water velocity microhabitats during the day and night in trout treatments.

Growth Experiment

In the growth experiment, for tanks where all fish remained at the end of the experiment, all small koaro showed a positive weight change, but all large koaro lost weight over the one month period (Fig. 4.16). Small koaro grew more in the control treatments when compared to the medium trout treatments. However, a two-way ANOVA (Table 4.4) showed that there was no significant effect of the fish species present on koaro weight change between the three treatments. However, small koaro grew significantly more than large koaro indicated by a significant koaro size effect in the ANOVA (Table 4.4).

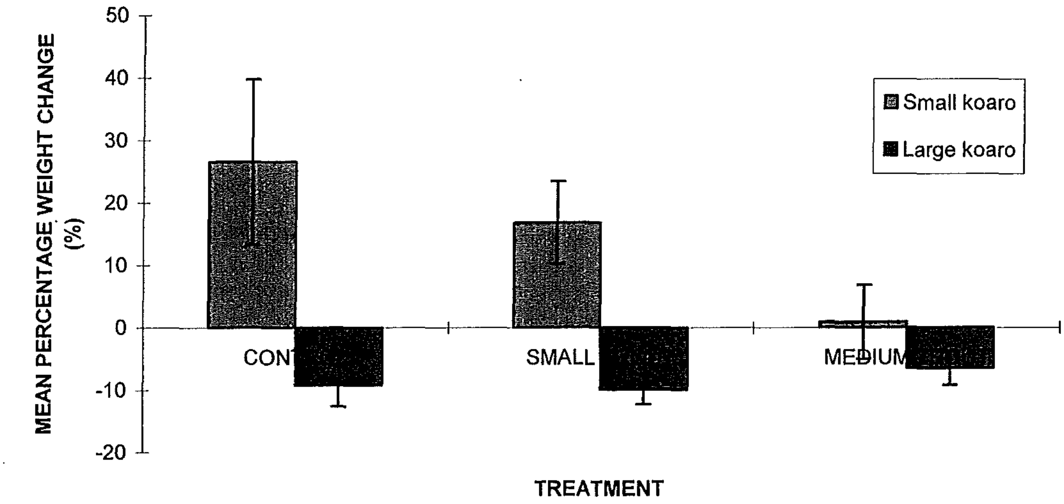


Figure 4.16. Mean percentage weight change of small and large koaro for each of the three experimental treatments from the one month growth experiment. Error bars indicate one standard error for the mean.

Table 4.4. Two way ANOVA of the log of mean percentage growth of small and large koaro in control, small trout and medium trout treatments after one month.

Source	df	ms	F-ratio	p-value
Fish	2	0.186	3.313	0.066
Koaro size	1	3.306	59.045	< 0.001
Fish x size	2	0.130	2.327	0.134
Error	14	0.056		

Comparing the growth of trout and koaro, medium trout grew more than large koaro of a similar size (Fig. 4.17; t = 7.643, df = 4, p = 0.001). A comparison of growth among small trout and small koaro indicated the trout grew more (t = 5.197, df = 4, p = 0.007).

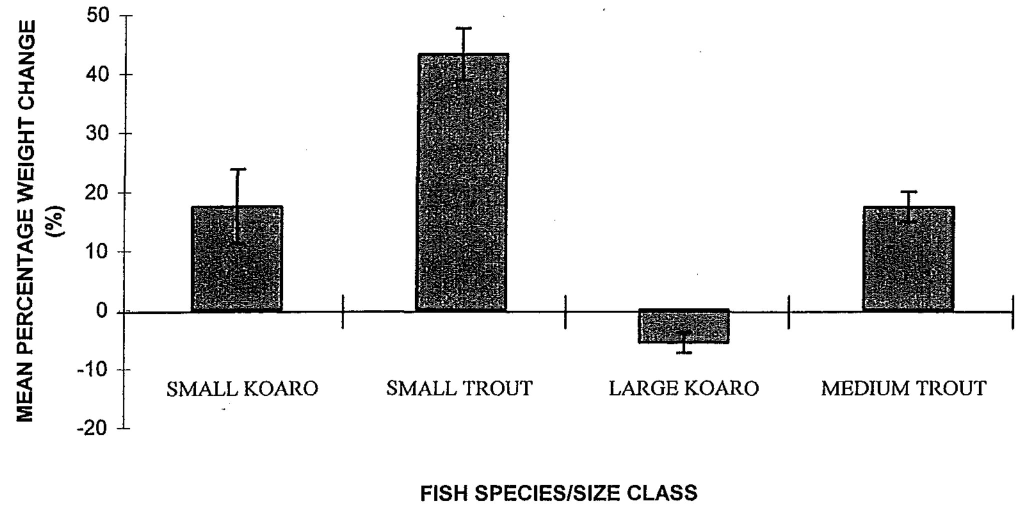


Figure 4.17. Mean (+/- SE) percentage weight change of each fish species/size class used in the growth experiment.

Comparison of fish survivorship in the growth experiment (Fig. 4.18) showed that fewer koaro remained alive in the medium trout treatment tanks compared with the other two treatments.

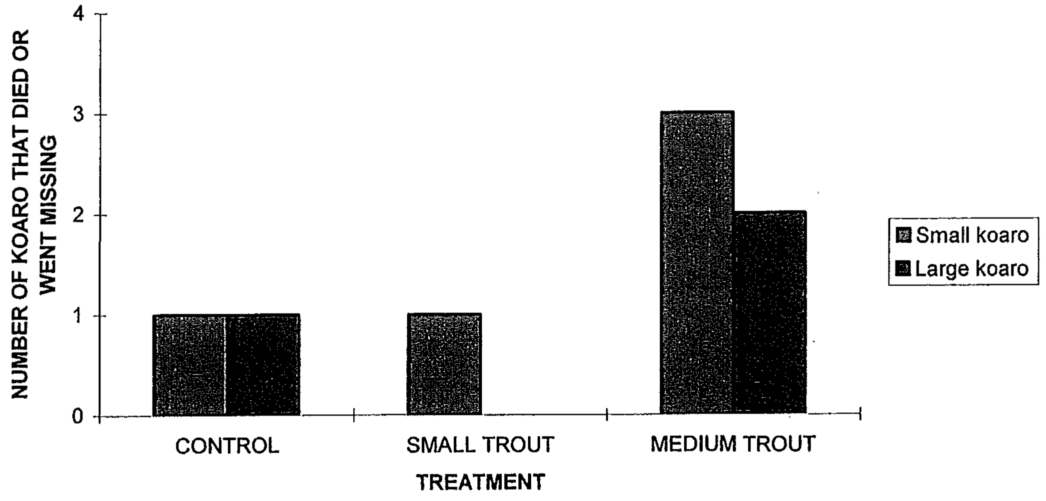


Figure 4.18. Number of small and large koaro that either died or went missing from each experimental treatment in the one month growth experiment.

DISCUSSION

Microhabitat experiments

Microhabitat refers to the local environment surrounding an organism and generally reflects the spatial resources that the organism uses. Spatial separation of fish among microhabitats has been demonstrated in many studies (Hartman, 1965; Larson, 1980; Townsend & Crowl, 1991; Chadderton & Allibone, 2000), and can be due to morphological constraints (Gatz, 1979) or species having different microhabitat preferences. However, if the resource or habitat requirements of species overlap, less competitive species may be forced to occupy less preferred microhabitats. Thus, differences in microhabitat use may also be due to species interactions.

Hartman (1965) found two morphologically similar species, the steelhead and coho salmon spatially separated within a river, with the less competitive steelhead in riffles, and dominant coho, in pools. Main (1988) suggested that in contrast to kokopu species, koaro are more able to coexist with brown trout because they can live in the riffles as well as pools. Moffat (1984) suggested that the koaro he found in water of 80 cm/s velocity held these positions to avoid competition with trout.

Trout and koaro, being morphologically dissimilar in body shape and structure, can potentially occupy different microhabitats. Trout are known to prefer pools (Bohlin, 1977). Moffat (1984) found that both brown and rainbow trout dominated deeper rocky areas with slower water velocities (pools) in the Ryton River. Koaro inhabit pools and riffles but when trout are absent they will often inhabit pools with increasing frequency (Main, 1988).

I hypothesised that koaro would prefer shaded conditions both with and without trout. I predicted that koaro association with shade in their natural forested environment would more strongly influence their choice of microhabitat than the presence of aggressive trout. However, I was surprised to obtain results that indicate biotic interactions had a stronger influence on koaro microhabitat choice than the physical factors.

Both during the day and night, in all treatments koaro showed no obvious preference for shaded over non-shaded microhabitats. The greatest mean shade utilisation by medium koaro occurred in the controls and the least occurred in the trout treatments, but overall, no significant microhabitat selection was found. Instead medium-sized koaro avoided microhabitats occupied by trout and spent significantly more time alone in trout treatments compared to control treatments. Despite these findings, I still consider that koaro prefer microhabitats that provide cover. Adult koaro in Manson Creek were consistently found in habitats with cover and I have rarely captured adult koaro in habitats providing little cover. Reasons for their association with forest and cover are discussed in Chapter 2. The lack of shade selection by medium koaro in this experiment may be because boulders located in unshaded microhabitats may have provided enough cover for the koaro. Koaro were almost always found under boulders, and boulders, regardless of their location, may have provided more accessible cover to the fish.

There was no significant difference in koaro use of fast water velocity between treatments during both the day and night. A mean 50 percent of medium koaro inhabited fast water during the day in all treatments. At night the only major change occurred in the trout treatment where the percentage of medium koaro inhabiting fast water dropped to approximately half that of the other treatments. However, no significant effects were observed in the analysis.

As trout are highly territorial and aggressive (Kalleberg, 1958; Hartman, 1965) compared to koaro (Moffat, 1984), I expected to find trout aggressively excluding koaro from habitats preferred by the trout. My observations that koaro were found alone more frequently when trout were present supports this expectation. Trout may exclude large galaxiids by competitive interference for space (Moffat, 1984). Trout often use intentional movements, chases, nips, and lateral or frontal threats towards other fish (Hartman, 1965). As galaxiids evolved without trout they have not evolved appropriate competitive and predator avoidance behaviours (McDowall, 1968a). As a result, aggressive behaviour exhibited by trout has been documented as being responsible for forcing galaxiids into areas less preferred by, or less accessible to trout (Cadwallader, 1978; McIntosh *et al*, 1992; Edge *et al*, 1993).

Trout have been observed acting aggressively towards koaro in experimental stream channels, forcing koaro from preferred substrate into shallower/faster water (Moffat, 1984). Trout were observed vigorously chasing koaro on four occasions during Moffat's experiment, with one report of a trout chasing a koaro out from under a rock.

In addition, the prediction that smaller koaro would inhabit less favourable micro-habitats when large koaro were present was not supported by the results of my experiment. In Manson Creek, koaro size increases moving upstream. I hypothesised that the reduced numbers of small koaro at the most upstream sites in Manson Creek was due to competitive exclusion of smaller koaro by larger koaro upstream. The utilisation of shaded microhabitats by medium koaro was not found to be different in control and large koaro treatments during the day and night. This suggested that large koaro did not affect medium koaro distribution in the stream channels. However, an increase in the percentage of time medium koaro spent alone in the large koaro treatments compared to controls, indicated that large koaro perhaps exhibited some aggressive behaviour towards medium koaro, forcing them into microhabitats not occupied by large koaro. As no other studies have experimentally assessed interactions between different sized koaro, it is not possible to provide any support toward the theory of aggressive exclusion of smaller koaro by larger adults.

Growth experiment

Competition between fish species exists when an interaction between two or more individuals or species causes the birth, growth or survival rate of one of the species to be depressed by the other species (Begon *et al*, 1990). Competition can be expressed in terms of its effects on a fishes growth rate when fish are consuming the same food supply (Weatherley & Gill, 1987). Therefore, growth experiments can be conducted to help determine competitive effects of fish of a certain size or species on another fish of a specific size or species.

I hypothesised that both small and large koaro would grow less when medium sized trout were present as competition for food is likely to favour the aggressive trout. As the extent of competition between koaro and trout was likely to be dependent on fish size, I predicted that although small trout will negatively affect small koaro growth, large koaro, being larger than the small trout, would be unaffected.

Results from the growth experiment indicated that in comparison to control treatments, small koaro growth was lower in channels with medium trout, although the difference was only marginally significant (p= 0.066). Although the statistical analysis did not provide definitive evidence for a trout effect, this was most likely due to the low power of the analysis associated with the small sample size.

Large koaro lost weight in all treatments so it is not possible to come to any conclusion about the effect of trout on their growth.

Koaro, being non-selective feeders (Sagar & Eldon, 1983; Main & Winterbourn, 1987; Main, 1988) show little prey selection while feeding on benthic and drifting organisms (Main & Winterbourn, 1987). Both mayfly and caddis larvae are often consumed by trout and were found to be the most abundant prey in gut samples of summer feeding koaro in south Westland (Main & Winterbourn, 1987). As these invertebrates were used as food in the growth experiment, brown trout and koaro would have shared similar food resources and therefore would compete for food.

Competition for food between trout and koaro would explain the reduced growth of koaro in trout treatments. An experiment by Fletcher (1979) found evidence for food competition between galaxiids and brown trout. In comparison to a control section lacking trout, *Galaxias olidus* declined in abundance and condition when brown trout were present. Aggression exhibited by trout may also force smaller koaro to remain in refuge while trout were out feeding during the best feeding times.

The negative effect of trout on small koaro in my experiment was most likely due to reduced feeding success of koaro. Edge *et al* (1993) found that Otago galaxiids fed less in the presence of brown trout. When trout are present, galaxiids may be forced to take up less profitable feeding positions and as a result may feed less often and be less successful in their feeding attempts (McIntosh *et al,* 1992). McIntosh *et al* (1994) discussed how interactions between trout and galaxiids vary depending on fish size. This suggests that fish size is an important factor that will most likely affect the extent of competition that exists between fish. As discussed above, my growth experiment showed that mean small koaro growth was lowest in treatments containing the largest (medium) trout. Although growth between treatments was not significantly different (e.g. < 0.05), a trend of decreasing koaro growth with increasing trout size was found. This supports trout size as an important variable affecting growth of small koaro.

The observed weight loss of large koaro in all experimental treatments suggests that either food requirements were not met or that these fish were experiencing some other form of stress. It is possible that the food resources available to the large koaro were not sufficient to sustain condition, whereas small koaro food requirements were more easily met. No significant difference in weight loss of large koaro between treatments combined with the fact that the least mean weight loss was recorded in the medium trout treatments, suggests that environmental factors or insufficient food, rather than competition with trout, were most likely responsible for large koaro weight loss. The warm conditions during the summer created water temperatures between 16.2 and 18.6 degrees Celsius. Koaro are usually found in cooler waters (McDowall, 1990a; Tilzey, 1976; McDowall & Eldon, 1980), and large galaxiids have tolerances which are among the lowest of our native fishes (Main, 1988). Therefore metabolic stresses associated with warmer temperatures and an artificial environment may have caused large koaro to lose weight.

Excluding the single large koaro missing from the controls (due to torn mesh), I found that only small koaro less than 80mm in length disappeared during the experiment. The unexplained disappearance of only small koaro suggests that these fish could have been predated by trout. McIntosh *et al* (1994) found only *G. vulgaris* less than 80mm were reduced with large trout presence.

Another study indicated that juvenile rainbow trout in Lake Taupo tributaries fed extensively on small koaro (Kusabs & Swales, 1991).

The piscivorous tendencies of salmonids are well known (Scott & Crossman, 1973), but more recently a study by McIntosh (2000a) discussed the critical size at which trout become potentially piscivorous as being approximately 150mm fork length. In an experiment, brown trout > 150mm (FL) consumed Canterbury galaxias at a much higher rate than did smaller trout. Trout predation appeared not to be size-selective, as galaxiids between 48mm and 95mm were consumed in equal proportion.

In the experiment mentioned earlier, Fletcher (1979) noticed a decline in abundance and condition of mainly small galaxiids after introducing trout to a fenced off section of Watchbow Creek, Victoria Australia. The introduction of trout to the Taupo/Rotorua lakes also resulted in very significant declines in koaro numbers. Schools of juvenile koaro once harvested by Maori were dramatically reduced. Their decline can be attributed, with little doubt, to trout predation (McDowall, 1987). Thus, it is likely that the small koaro that disappeared in my experiment were consumed by trout.

CHAPTER 5

General discussion

Koaro populations currently exist in many of New Zealand's lakes, rivers and streams. Despite being quite widespread they are undoubtably less common than they were prior to the arrival of the european settlers and the subsequent habitat changes and introductions of exotic fish (McDowall, 1990a). Their apparent dependence on native forest makes them a species vulnerable to human development, and combined with fishing pressure and competition/predation with trout, they could potentially become a threatened species in the future. Another of the five whitebait species, the Shortjaw kokopu is already considered an endangered species (McDowall, 2000). Understanding the impact of factors like habitat and predation have on koaro populations is important. Based on my research, factors that represent the greatest threat to koaro populations, and therefore should be considered for the purpose of conservation and enhancement, are described in this chapter.

This study contributed to the further understanding of certain aspects of the ecology and life-history of land-locked, stream-resident koaro populations. Several of my results supported a negative influence of brown trout on koaro. The microhabitat experiments (Chapter 4) showed that koaro were rarely found in the same microhabitat as trout and that trout presence appeared to more strongly affect koaro microhabitat choice than the type of habitat itself. Small trout negatively affected small koaro growth through competition for food. This effect was more severe with larger (medium) trout and these larger trout (120-140 mm) most likely predated several small (60-70 mm) koaro.

Negative interactions (competition/predation) between koaro and trout may cause koaro populations to become fragmented. This can make populations vulnerable to chance extinction due to natural disasters such as floods (Moore *et al*, 1999).

In Lake Pearson's tributaries, koaro are almost certainly restricted to areas also inhabited by lower trout densities (i.e. there are no troutless habitats). Therefore, if koaro numbers in an area containing both trout and koaro decline to a point that the koaro become threatened, it would be sensible to remove trout from the community. Removal of trout (all sizes) using electro-fishing methods would reduce any potential negative trout affect and thus the koaro population would have a better chance of recovery. Trout removed from Manson Creek could be used to stock Lake Pearson. If trout removal occurred during summer, fish released into the lake could not re-enter Craigieburn Stream (and then Manson Creek) as the lower reaches of the stream normally flow underground during this period.

An understanding of koaro spawning time, habitat and cues is very important as it would enable population spawning to be monitored and the resulting recruitment into populations to be better understood and managed. As no spawning sites were found during my study it is not possible to comment on the selection of spawning substrate, exact time and the cues which triggered spawning among adult koaro in Manson Creek. The lack of any apparent migration of adults does support the fact that mature adults remain among, and spawn in, adult habitats. However, the capture of juvenile koaro does allow a relatively accurate estimation of spawning time to be achieved. The approximately six month old juveniles (40-45 mm) were captured during March/April (autumn) in both 1999 and 2000. The season of capture and estimated age (otolith analysis) suggested that some adults from the Lake Pearson population spawn during spring. The additional capture of gravid adults during October (spring) further supports an alternate spawning season from their diadromous/migratory cousins. As many juvenile koaro were captured during autumn it is possible that a spring spawning event may contribute a significant number of recruits into the Lake Pearson population.

This means that spawning habitat (almost certainly in upper Manson Creek and Craigieburn Stream) would need to be protected from animal and human impacts during both the spring and autumn. Any future land-locked koaro life-history studies should also focus on spring as well as late autumn/winter as possible spawning times.

As discussed in Chapter 2, koaro dependence on native bush has been documented in many studies. Their strong association with native forest is supported by my findings as very few koaro were captured in habitats outside forest. As adult koaro most likely spawn in forested habitats and as native forest is rare in the Lake Pearson catchment, protection of the remaining forest remnants is extremely important.

Applying the above theories may prove beneficial in the struggle to further understand and improve the management of this wonderful species.

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I'd like to present the annual "Excellence in Supervisors" award to my supervisor Angus McIntosh. His enthusiasm and passion for his chosen field of science is reflected in his willingness to motivate those students who have the privilege to work with him. His advice and ideas concerning my field work were much appreciated as was his help with preliminary field work and suggestions of possible methods of statistical analysis. In addition, a very big thank you for reading drafts of my thesis (even when you were really busy) and for putting up with some more difficult or even frustrating times when I didn't quite understand certain things. A top supervisor for anyone planning to pursue postgraduate research in the field of freshwater ecology. A massive *THANK YOU* for helping me with almost certainly my biggest academic achievement in life. Bring on the Phd, Yeahhhh right !

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Appendix 1 - List of koaro in Mansons Creek

The last recorded weight of each adult koaro tagged in Manson Creek. This list has been included so that the growth rate and minimum age of any tagged koaro captured in the future can be determined.
Key : -- fish released at Site 1

Date	*Tag*	*Length(mm)*	*Weight(g)*	*Site*
2/02/00	S00	126	19.5	6
2/02/00	S01	111	11.6	6
28/06/00	S02	129.8	19.5	6
2/02/00	S03	121	16.5	6
2/02/00	S04	96	6.5	6
16/01/01	S05	119	15	6
2/02/00	S06	92	5.3	6
31/03/00	S07	168	42.9	4
31/03/00	S08	108	10.5	4
22/02/00	S09	161	36.6	5
22/02/00	S11	126	17.3	5
22/02/00	S12	129	20.5	5
22/02/00	S13	149	30.6	5
22/02/00	S14	147	26.7	5
22/02/00	S15	120	28.8	5
22/02/00	S16	107	11.3	5
22/02/00	S17	103	10.1	5
22/02/00	S18	116	15.8	5
22/02/00	S19	96	8.2	5
22/02/00	S20	78	6.2	5
22/02/00	S21	136	25.8	5
22/02/00	S22	108	12.8	5
22/02/00	S23	122	19.9	5
15/03/00	S25	101	7.7	1
15/03/00	S26	101	9.7	1
15/03/00	S27	119	15.7	1
15/03/00	S28	108	12.5	2
15/03/00	S29	112	12.5	2
15/03/00	S30	89	6.9	2
15/03/00	S31	121	17.1	2
15/03/00	S33	99	9.3	2
15/03/00	S32	98	7.4	2
31/03/00	S35	158.5	37.4	3
31/03/00	S36	121.5	20.4	3
31/03/00	S37	123	17.8	3
31/03/00	S38	103	9.8	3
31/03/00	S39	115	13.6	3
31/03/00	S40	111	12.6	3
31/03/00	S41	97	7.5	3
31/03/00	S42	106.5	10.4	3
31/03/00	S43	109.5	12.4	3
31/03/00	S44	115	12.8	3
31/03/00	S45	132	19.1	3
31/03/00	S46	118	13.7	3
31/03/00	S47	119	13.4	3
31/03/00	S48	102.5	9.4	3
15/01/01	S49	135	23.1	3
31/03/00	S50	124	17.1	3
28/04/00	24	128.5	17.8	5
25/07/00	SY1	131.5	20.7	5
26/10/00	SY5	178	48.1	4
31/03/00	S51	103.5	9.2	3
31/03/00	S52	115	13.8	4
31/03/00	S53	133	20.5	4
16/01/01	S54	122	16.1	4
16/01/01	S55	140	20.4	4
16/01/01	S56	153	31.5	4
25/07/00	S57	137	21.4	4
16/01/01	S58	112	11.6	4
25/07/00	S59	95	7.5	4
31/03/00	S60	102	8.3	4
31/03/00	S61	101.5	10.2	4
16/01/01	S62	130.5	21.4	4
16/01/01	S63	131	19.9	4
27/10/00	S64	120	13.5	4
31/03/00	S65	116.5	13.5	4
31/03/00	S66	122	18.3	4
31/03/00	S67	114	13.2	4
31/03/00	S68	100	7.8	4
16/01/01	S69	104	10.8	4
31/03/00	S70	125	17.6	4
31/03/00	S71	112	12.5	4
25/07/00	S72	108	12	4
31/03/00	S73	95	7.9	4
31/03/00	S74	102	10.3	4
31/03/00	S75	113	11.3	4
31/03/00	S76	107	10.5	4
31/03/00	S77	120	15.6	4
31/03/00	S78	119	12.9	4
31/03/00	S79	111	14.7	4
16/01/01	S80	126	16.2	4
31/03/00	S81	100	9	4
25/07/00	S82	100	8.7	4
16/01/01	S83	133.5	20.3	4
25/07/00	S84	117	13.7	4
28/04/00	S85	135	19.8	--
28/04/00	S87	111.5	13.5	--
28/04/00	S86	119	12.5	--
28/04/00	S88	116	11.7	--
28/04/00	S89	112.5	12.4	--
28/04/00	S91	178.5	54.3	--
28/04/00	S92	112.5	12.9	5
28/04/00	S93	115	11.9	5
28/04/00	S94	121	15.4	5
28/04/00	S95	117.5	13.9	5
28/04/00	S96	124	18.1	5
28/04/00	S97	109.5	11	5
28/04/00	S98	118.5	16	5
28/04/00	S99	117.5	15	5
25/07/00	SX6	159.5	40.8	5
16/01/01	SX9	146	28.2	5

Appendix 2 - List of the number of koaro and brown trout captured at each Manson Creek site

The total number of adult and juvenile koaro and brown trout captured at the six 20 metre study sites in Manson Creek using electrofishing during the summers of 1999/00 and 2000/01.

Year: 1999/00

SITE	KOARO	BROWN TROUT
1	5	84
2	7	73
3	23	24
4	38	1
5	14	1
6	7	1

Year: 2000/01

SITE	KOARO	BROWN TROUT
1	2	38
2	4	38
3	4	40
4	25	2
5	21	0
6	9	0