

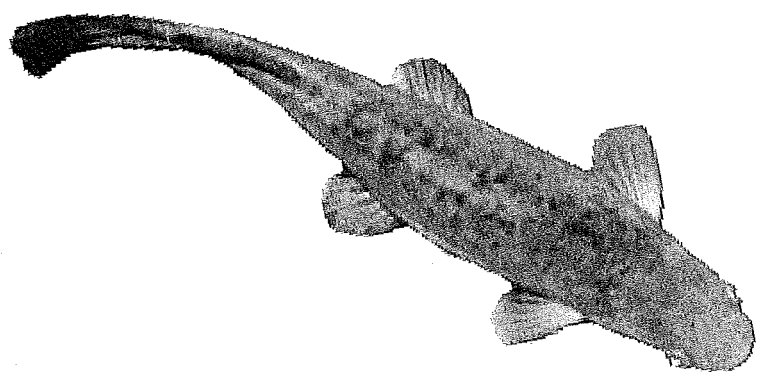
**The ecology and conservation of
shortjaw kokopu (*Galaxias postvectis*)
in Nelson and Marlborough**

A thesis
submitted in partial fulfilment
of the requirements for the Degree of
Master of Science in Zoology
in the
University of Canterbury,
Christchurch, New Zealand

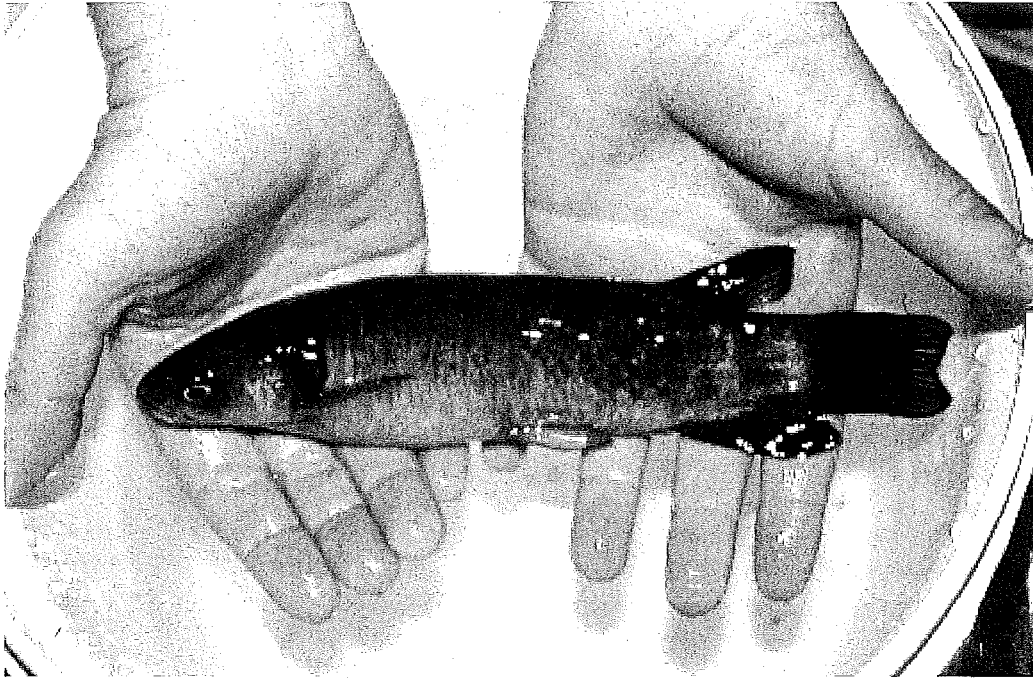
by
Jane M. Goodman

University of Canterbury

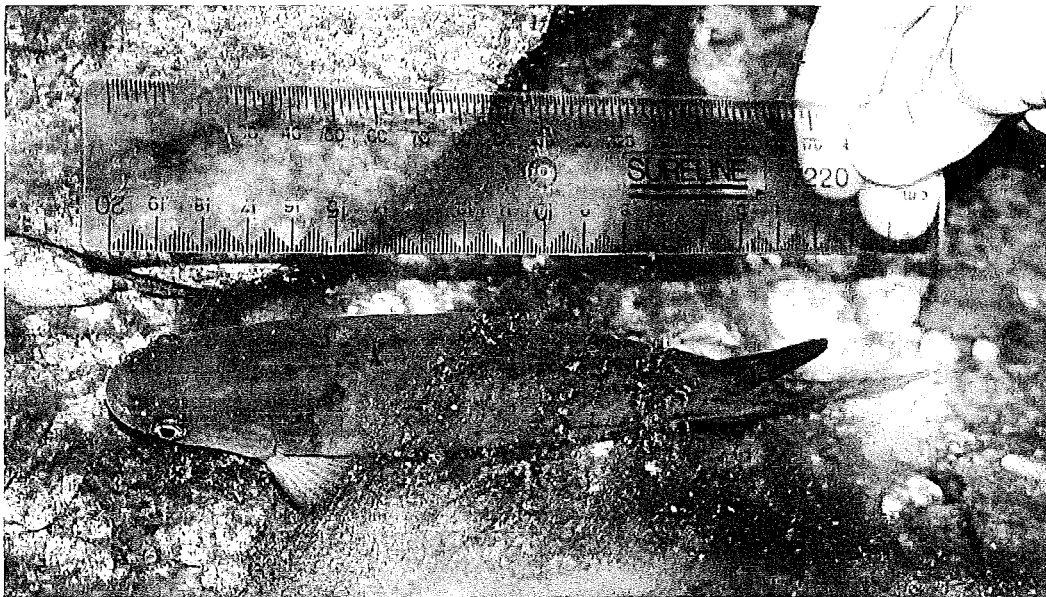
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a



b



Adult shortjaw kokopu captured from Simonet Creek, Abel Tasman National Park (**a**) and Bonny Doon Creek, Aorere River Catchment (**b**).

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Abstract

The shortjaw kokopu (*Galaxias postvectis*) is a threatened New Zealand freshwater fish (family Galaxiidae) that migrates between freshwater habitat and the marine environment during its life cycle. The influence of this diadromous life-cycle, as well as the potential effect of introduced predatory fish on the population dynamics and habitat occupancy of shortjaw kokopu were investigated in the Nelson Marlborough Department of Conservation conservancy. The distribution and abundance of shortjaw kokopu were measured using spotlighting, substantially increasing their known range in this area. Juveniles (<100 mm FL) were recorded from the same stream reaches as adults using this method. Shortjaw kokopu were positively associated with native forest, however they occupied a wide range of streams and habitat variables were not accurate predictors of their presence and absence. Diadromy had a large influence on fish communities at low- to mid- elevation sites. Shortjaw kokopu were associated with the presence of other diadromous species, in particular other migratory galaxiids. Juvenile galaxiids were able to migrate through modified stream reaches, but the density of juvenile galaxiids significantly decreased with increasing distance from the sea. The number of juveniles recruiting to the adult population was probably influenced by the biomass of piscivorous fish species (e.g. introduced trout) and the cumulative effects of habitat modifications downstream. Shortjaw kokopu and trout co-occurred at the reach scale, however shortjaw kokopu were more likely to be absent when trout abundance was high. Negative interactions between shortjaw kokopu and trout may be offset by diadromy, whereby individuals eaten or displaced are constantly replaced by juveniles returning from the marine environment. Conservation effort should be aimed at mitigating the deleterious effects of habitat degradation and migration barriers on shortjaw kokopu and other migratory fish populations. Further research is needed to properly understand the effect that introduced trout have had on native migratory fish species.

Author's Preface

The data used in this thesis was collected during a three year survey carried out by the Department of Conservation to investigate the distribution and abundance of shortjaw kokopu in the Nelson Marlborough Department of Conservation conservancy (hereafter referred to as the Nelson Marlborough conservancy). From January to June 2001, I worked for the Department of Conservation in Golden Bay and Murchison to help complete this survey. Surveys were carried out in the summers of 1999, 2000 and 2001, and I undertook additional research in association with the Department of Conservation in the summer of 2002. Some of the data used in this thesis have been published in Department of Conservation internal reports (Studholme et al. 1999, Jack and Barrier 2000, Jack et al. 2001).

“... The short jaw for which *G. postvectis* is named, however, has always suggested that this fish may be to some extent a scavenger It is a biological vacuum cleaner, although its first preference is for food drifting through the water column. I no longer have to worry about initially uneaten scraps fouling the tank because when new food ceases to materialise from above, the kokopu turns its attention to items missed earlier and picks them up, quite able to recognise static food items missed by other species ... This behaviour was not unexpected ... but its extension to random grubbing, after the manner of goldfish, was interesting ... sucking up mouthfuls of silt to extract anything edible ... and is unique in my experience of native fishes ... the shortjaw kokopu has catholic tastes – worms, slaters, minced ox heart, grass grubs and salmon pellets all go the same way ... Also, the fish sometimes casts what appears to be a wistful eye over its smaller aquarium fellows – inanga and smelt – but I have never observed a serious attempt at predation on these ... the shortjaw kokopu has a rather Friar Tuck personality.”

Tony Eldon (1984)



CHAPTER ONE

Introduction

Shortjaw kokopu (*Galaxias postvectis*) have been “something of an enigma” (Eldon 1983, p17) for naturalists and freshwater fish scientists in New Zealand for at least the past 100 years. The species was described and assigned the scientific name *Galaxias postvectis* by Clarke (1899). It was later described by Whitley and Phillipp (1939) from a single specimen as *Galaxias charlottae* and has been confused with and described as *Galaxias fasciatus* (banded kokopu) and *Galaxias argenteus* (giant kokopu) (Regan 1905, Whitley and Phillips 1939). Sixty-one years after its description by Clarke (1899), Stokell (1960) confirmed *Galaxias postvectis* was a distinct (from banded and giant kokopu) and separate species. However, in 1990, McDowall wrote that shortjaw kokopu were “probably known to relatively few people and when found often probably not distinguished from banded kokopu” (McDowall 1990a, p100). The main aim of this study was to investigate the reasons for the apparent rarity of shortjaw kokopu. There is a lack of research on shortjaw kokopu and the numerous threats to their distribution and abundance, moreover, the factors controlling the population dynamics of large galaxiid fishes in general are poorly understood.

Shortjaw kokopu have been listed by the International Union for the Conservation of Nature (IUCN), and were also listed in the New Zealand Red Data Book, as a potentially threatened species (Miller 1977, William and Given 1981). Prior to 1994, the Department of Conservation (the government agency charged with conservation in New Zealand) ranked shortjaw kokopu as a ‘Category B’ threatened species according to their classification system (Molloy and Davis 1992). In 1994 the Department of Conservation upgraded shortjaw kokopu to ‘Category A’ status, this

was the Department's highest priority for threatened species. In the Department's latest (early 2002) threatened species ranking system, shortjaw kokopu were classified as a species in "gradual decline" (Molloy et al. 2001, R. Allibone, *pers. comm.*).

Defining rarity

As early as 1859, rarity and factors that restricted the distribution of species were mentioned by Darwin (Darwin 1859). More recently Gaston (1994), and deLange and Norton (1998) discussed attributes of rare species and the variety of meanings that are attached to 'rarity'. These authors emphasised the importance of distinguishing between species that have always been uncommon due to natural influences and life-history tactics, and species that are restricted in distribution and uncommon due to anthropogenic disturbances and habitat modifications.

Rarity can be divided into three components: spatial, temporal and knowledge (Gaston 1994, deLange & Norton 1998). Some species may have always been rare because they are confined to very specific habitat. For example, the plant species *Hebe brevifolia* is rare because it grows on an uncommon substrate (deLange 1997). Distinguishing between natural fluctuations in abundance, and declines in abundance related to human impacts, is important; though not always easy (Gaston 1994, deLange and Norton 1998). Shortjaw kokopu is one of the five *Galaxias* species (along with giant kokopu, *Galaxias argenteus*; banded kokopu, *Galaxias fasciatus*; koaro, *Galaxias brevipinnis*; and inanga, *Galaxias maculatus*) that have a larva/juvenile stage that migrate between freshwater habitat and the marine environment (i.e. they are diadromous). The juveniles of these species comprise New Zealand's whitebait fishery. The abundance of juveniles (whitebait) returning to freshwater habitat fluctuates naturally. The extent to which harvesting has affected the distribution and abundance of migratory *Galaxias* species is unclear, however the quantity of whitebait captured each year has apparently been decreasing (McDowall and Eldon 1980).

Human error and sampling bias contribute to misconceptions of rarity. When classifying a species in relation to threat of extinction, accurate knowledge is crucial (Gaston 1994, deLange and Norton 1998). The classification of shortjaw kokopu as a

'Category A' threatened species reflected the relatively low number of sites from which the species was known, and the paucity of individuals (usually one or two) found at most sites (Tisdall 1994, McDowall et al. 1996a, Molloy et al. 2001). In 1996 the New Zealand Freshwater Fish Database (NZFFD) had in excess of 11 000 site records, and shortjaw kokopu were recorded at only two percent of these sites. The reasons for these patterns are unclear, but are beginning to be better understood by recent studies (Caskey 1999, Studholme 1999, Jack and Barrier 2000, Eastwood 2001, Jack et al. 2001, Bowie 2002, Charteris 2002). It is possible that shortjaw kokopu has always been rare due to very specific habitat requirements. However, the destruction of native forest, land use conversion, and the introduction of exotic predatory species may have restricted their distribution and caused a decline in their abundance (McDowall 1990a, McDowall et al. 1996a). The nocturnal behaviour of shortjaw kokopu, their ability to evade capture by fleeing to deep cover and their patchy distribution (*sensu* Townsend 1989) within streams makes them difficult to detect. Thus, past sampling techniques may have underestimated their abundance (McDowall et al. 1996a). I used spotlighting methodology to document the distribution and abundance of shortjaw kokopu in the Nelson Marlborough conservancy. This technique allowed shortjaw kokopu to be observed in their active feeding state. Factors affecting the patterns seen were evaluated and the reasons for the past and current conservation status of shortjaw kokopu are discussed in relation to my findings.

Biodiversity and the decline of fish worldwide

Many authors have discussed and theorised about extinction rates, the potential number of species that remain unidentified and the significance of these species to biodiversity and the structure and functioning of ecosystems (May 1990, Myers 1993, Smith et al. 1993, Naeem et al. 1994, Thompson 1996, Bengtsson 1998). Bruton (1995) suggested there would be a 4 % loss of all known fish species in the near future and Leidy and Moyle (1998) hypothesised that a loss in excess of 20 % of freshwater fish species is realistic. The destruction of native forest and the upsurge of intensive landuse practises, as well as modifications to freshwater habitats threatens the status of fishes as being the most diverse group of living vertebrates (Bruton 1995, Duncan & Lockwood 2001). Identification of areas where species are rare due to

anthropogenic disturbances and therefore are vulnerable to extinction is important (Angermeier 1995). By examining the factors that contribute to the rarity of shortjaw kokopu I hoped to improve the management of diadromous fish species.

The loss of freshwater fish species could have serious consequences for freshwater ecosystems. The effect of the extinction of New Zealand grayling (*Prototroctes oxyrhynchus*) on New Zealand freshwaters is unknown. The grayling was probably diadromous, and thus provided a link between the marine and freshwater environments. Furthermore, although little is known about the life-history of *P. oxyrhynchus*, it was described by naturalists as very common (McDowall 1990a). It has been shown that diadromous salmon species are a source of marine derived nutrients for terrestrial food webs (Ben-David et al. 1998). For example, they contribute to the nitrogen pool available to riparian vegetation (Ben-David et al. 1998). Migration barriers that inhibit diadromous fish species influence the composition of upstream fish communities, consequently it is possible that ecosystem processes may be altered (McDowall 1996, Pringle 1997). In some systems where disturbances are not extensive diadromy may allow natural restoration of fish stocks, however where damage is extensive and permanent the effect on diadromous fish species will be marked. In this study, I investigate factors that could potentially alter the link between freshwater habitat and the marine environment. I do this by examining factors affecting the migration of juvenile shortjaw kokopu to upstream adult habitat.

Habitat fragmentation in lotic environments

The break up of continuous habitat (fragmentation) due to human modifications is one of the greatest threats to the world's biodiversity (Didham et al. 1998, Palumbi 2001). The ability of an organism to move through unsuitable habitat affects their distribution and abundance (Wiens et al. 1997, Fraser et al. 1999, Krebs 2001). In stream environments interactions between upstream and downstream processes, as well as interactions with the terrestrial environment are important in the structure and function of stream communities (Vannote et al. 1980, Ward 1989). Fragmentation of freshwater habitat results from deforestation and land-use modifications which break up continuous in-stream habitat and inhibit migration of aquatic organisms by

degrading water quality (McDowall 1984 and 1995). Migratory fish that immigrate into, or emigrate from, the freshwater environment can be restricted by man-made structures such as weirs and fords, or they can be inhibited by natural features, for example waterfalls (McDowall 1995, Pringle 1997, Benstead et al. 1999). Furthermore, the presence of predatory fish species may also fragment the distribution of prey populations, for example by competitive exclusion, direct predation or threat of predation (Hardin 1960, Fraser et al. 1995). In-stream, riparian and catchment features are analysed in relation to the presence or absence of shortjaw kokopu. Human modifications to the land surrounding streams and the ability of shortjaw kokopu to migrate through degraded areas are discussed.

Diadromy and dispersal

Diadromy is a minority phenomenon worldwide, however it can be locally and regionally important as is the case in New Zealand (Myers 1949, Gross 1987, McDowall 1987, Magurran 1993). Over 50 % of New Zealand's freshwater fish are diadromous (McDowall 2000). Thus, its contribution to the structure of fish communities in New Zealand is considerable (McDowall 1996, McDowall 1998). In New Zealand, some diadromous species, notably koaro, shortjaw kokopu, and eel species are known for their ability to penetrate large distances inland and 'climb' high waterfalls (McDowall 1990a). Diadromous fish species often have sympatric distributions, whereas many of the non-diadromous species, in particular galaxiids, have allopatric distributions or few species are found together (McDowall 1990a, Allibone and Townsend 1997). Diadromy may offset intra- and inter-specific interactions between fish species. Individuals that are displaced are constantly being replaced by juveniles returning from the marine environment. I examine the processes influencing fish communities in low- to mid- elevation streams, in particular communities that contain shortjaw kokopu, in the Nelson Marlborough conservancy.

Exotic organisms and invasion biology

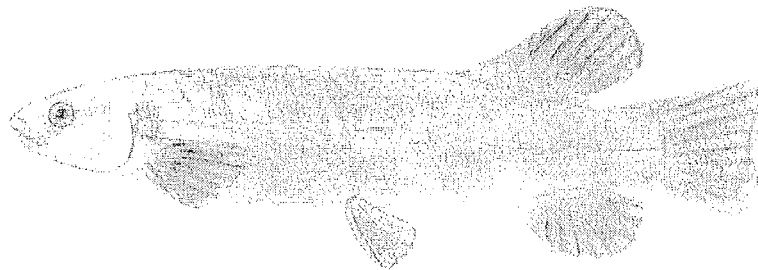
The introduction of an organism to an area can significantly affect the structure and function of native communities (Coblentz 1990, Soule 1990, Lodge 1993, Townsend

1991, Townsend 1996, Mack et al. 2000). Competition for resources (McIntosh et al. 1992, Wilson et al. 1998, Beggs and Rees 1999), predation, perhaps leading to extinction or a reduction in range and abundance (Taylor and Thomas 1993, O'Donnell 1996), modification of the surrounding environment and ecosystem processes (for example, nutrient cycling) may lead to a decrease in biodiversity (Coblentz 1990). The introduction of brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) to New Zealand in the late 1800's, and their subsequent rapid colonisation of all accessible habitat is known to have had a deleterious effect on some native fish (Crowl et al. 1992, McDowall 1990b). Trout are known to have influenced the distribution of non-migratory galaxiid populations in New Zealand and Australia (Hopkins 1971, Tilzey 1976, Jackson and Williams 1980, Townsend and Crowl 1991, Lintermans 2000, McIntosh 2000). Little research has been carried out on the interactions between New Zealand migratory galaxiids and trout (however, see Bell 2001). In this study I investigate the possible effects of introduced trout on shortjaw kokopu at the site scale. It is possible that trout predate on juvenile galaxiids as they move upstream, altering population dynamics in adult habitat.

NATURE

“There is a delight in the hardy life of the open.
There are no words that can tell the hidden spirit
of the wilderness, that can reveal its mystery its
melancholy and its charms.
The nation behaves well if it treats the natural resources
as assets which it must turn over to the next generation
increased and not impaired in value.
Conservation means development as much
as it does protection.”

Theodore Roosevelt



CHAPTER TWO

Distribution and abundance of shortjaw kokopu in Nelson and Marlborough

INTRODUCTION

Rarity and the historical distribution and abundance of shortjaw kokopu

Species that have limited or sporadic distributions and are found in low abundances, are often regarded as rare and consequently have high conservation status (Gaston 1994). There are a wide range of definitions and viewpoints on what constitutes a rare species (Gaston 1994, deLange and Norton 1998). For example, some species are regarded as rare because of their specific habitat requirements, while others are regarded as rare because they are taxonomically distinct (Gaston 1994). Gaston (1994) and deLange and Norton (1998) emphasize the importance of defining rarity in relation to these issues, especially for conservation and management purposes. They argue there is a need to distinguish between species that are naturally uncommon and those that are uncommon because of human influences. Some species may always have been rare, for example because they are confined to specific habitat (deLange and Norton 1998). The plant species *Hebe brevifolia* is rare because it grows on an uncommon substrate (deLange 1997). In this chapter I assess the distribution and abundance of shortjaw kokopu in the Nelson Marlborough conservancy, and relate my findings to the concept of 'rarity'.

Gaston (1994) and deLange and Norton (1998) emphasise the importance of referring to spatial, temporal and knowledge components, as well as scale, when classifying species according to their threat of extinction. Species may be rare on one scale but not another. For example, they may be nationally rare and locally common (Gaston 1994, deLange and Norton 1998). Shortjaw kokopu may be rare on all scales (locally

and nationally), they may be nationally rare but locally common, or they may be common throughout New Zealand.

Some species may always have been rare, while others fluctuate greatly in abundance and may be temporally rare. For example, the annual population size of the Australian grayling (*Prototroctes maraena*) fluctuates greatly depending on environmental conditions for spawning and migration of young (Allen et al. 2002).

P. maraena is listed as a threatened species, however, it is not assigned to the highest risk category in Australia (Allen et al. 2002). Shortjaw kokopu may always have been rare due to environmental constraints or specific habitat requirements.

Anecdotal reports from naturalists, Maori people, and early settlers suggest that galaxiids were once more widespread and abundant in New Zealand (McDowall 1980, McDowall 1990c). Deforestation, land use conversion, in-stream modifications (e.g. the construction of dams and weirs) and the introduction of exotic fish species are all likely to have negatively affected galaxiid populations (McDowall 1990a, McDowall 1990b, Townsend and Crowl 1991, Crowl et al. 1992, Jowett et al. 1996, Townsend 1996, Boubée et al. 1997, Rowe et al. 1999, McIntosh 2000). Therefore, it is possible that humans could be responsible for the rare status of shortjaw kokopu.

Documented distribution patterns and taxonomic recognition of species contribute to the classification or mis-classification of rare species. For example, the perceived monotypy of tuatara (*Sphenodon spp*) contributed to the extinction of at least 25 % of 40 populations. Furthermore, the mis-classification of tuatara is thought to have contributed to the extinction of one subspecies (Daugherty et al. 1990). In the past there has been confusion in the taxonomy of New Zealand *Galaxias* species (Clarke 1899, Regan 1905, Whitley and Phillips 1939). Shortjaw kokopu have been confused with giant kokopu (*Galaxias argenteus*) and banded kokopu (*Galaxias fasciatus*) and have been described as *Galaxias charlottae* (Regan 1905, Whitley and Phillips 1939). Taxonomic confusion, the lack of historical data on the distribution and abundance of New Zealand freshwater fish species and uncertainties about the distribution and abundance of shortjaw kokopu are likely to have contributed to the threatened status of shortjaw kokopu. Better knowledge of shortjaw kokopu should allow a more accurate assessment of its rarity.

Sampling techniques

Records of distribution patterns are the main source of information on rarity. The New Zealand Freshwater Fish Database (NZFFD) was set up by Ministry of Agriculture and Fisheries (MAF) in the 1970s and is currently maintained by the National Institute of Water and Atmospheric research (NIWA) (McDowall and Richardson 1983, McDowall 1990a). This database contains records of fish species present in freshwater habitats throughout New Zealand. A wide range of organisations contribute to the database, for example universities, the Department of Conservation, freshwater consultants, regional councils, as well as fish enthusiasts. Over 30 different sampling techniques or combinations of sampling techniques have been used to obtain fish species data for the greater than 18 000 records on the NZFFD.

The efficiency, accuracy and precision of data is influenced by biological characteristics of the population, sampling technique, human error, and the number of samples collected (Johnson 1983, McDowall 1990a, Kritzer et al. 2001). The historical classification of shortjaw kokopu as a 'Category A' threatened species, the highest Department of Conservation category for threatened species, was largely based on NZFFD records (Tisdall 1994). Prior to 1996, records from the NZFFD indicated that shortjaw kokopu were widely but sporadically distributed throughout New Zealand. For example, they were recorded at less than two percent of the greater than 11 000 records (McDowall et al. 1996a). Most records of shortjaw kokopu were of few individuals, usually one or two, sometimes three and very occasionally more (McDowall et al. 1996a).

Electrofishing is an efficient sampling technique, especially for capturing fish species that occupy low to moderate water depths in areas of high velocity, however it is known to have decreased efficiency in deep waters (Reynolds 1983, McDowall 1990a). Shortjaw kokopu adults often occupy deep water (pools and runs) (McDowall et al. 1996a, Caskey 1999, Studholme et al. 1999, Jack and Barrier 2000, Eastwood 2001, Jack et al. 2001). It is possible that historical data on the distribution and abundance of shortjaw kokopu may reflect the bias of electrofishing (Eldon 1983, Studholme et al. 1999). Recently, there has been an increase in the use of spotlighting

methodology for observing nocturnally active fish species (McCullough 1998, Studholme et al. 1999). This technique may be better for detecting nocturnal fish species like shortjaw kokopu. I investigated the distribution and abundance of shortjaw kokopu in the Nelson Marlborough conservancy using spotlighting methodology.

The rationale of research affects the type of information gathered, therefore it is important to define goals and objectives prior to research (Johnson 1983). Prior to this investigation, shortjaw kokopu were recorded in 12 streams in the Nelson Marlborough conservancy. The desired outcome of this research was up-to-date and accurate information on the distribution and abundance of shortjaw kokopu in the Nelson Marlborough conservancy. Moreover, it was hoped that this information would enhance knowledge of the reasons for the apparent rarity of shortjaw kokopu. In this chapter I document the distribution and abundance of shortjaw kokopu in the Nelson Marlborough conservancy and discuss their present distribution in relation to their possible past distribution.

METHODS

Study area

Research was carried out in the Nelson Marlborough Department of Conservation conservancy (Figure 2.1). The Nelson Marlborough conservancy covers 2.33 million hectares of the northern South Island of New Zealand. Of this 2.33 million hectares, 1.22 million hectares is administered by the Department of Conservation (M. Rutledge, *pers. comm.*). This conservancy ends at Kahurangi Point on the West Coast of the South Island and at the mouth of the Conway River on the East Coast of New Zealand (Figure 2.2, Allibone 1995). The Tasman, Nelson, Marlborough and Kaikoura districts, as well as parts of the Buller and Hurunui districts fall within the boundaries of the Nelson Marlborough conservancy (Figure 2.1, Allibone 1995).

A high proportion of the area is covered by native vegetation and a significant proportion is protected within the boundaries of Abel Tasman, Kahurangi and Nelson Lakes National Parks, Mount Richmond Forest Park, and Stephens Island and

Farewell Spit Nature Reserves. Although much of the Nelson Marlborough region is relatively unmodified compared with the rest of New Zealand, lowland areas are highly modified and dominated by urban areas, agriculture, viticulture and horticulture. However, some lowland areas with primary or regenerating forest are protected within Kahurangi and Abel Tasman National Parks. Nevertheless, these areas are not free from modification, for example, prior to the creation of the Abel Tasman National Park, this coastline was subject to modification by European settlers who burnt forest for pasture, logged forest and quarried for granite.

There are a wide range of freshwater habitats in the Nelson Marlborough conservancy and they reflect the complex geology, diverse topography and vegetation within the Nelson Marlborough region (Campbell and Johnston 1992). Lotic habitats range from small steep coastal streams, to medium sized lowland and coastal streams, through to large river systems. The majority of streams outside the boundaries of protected areas and the lower reaches of some streams within protected areas, flowed through agricultural, horticultural, plantation forest, or urban areas. However, the majority of streams surveyed originated in native forest.

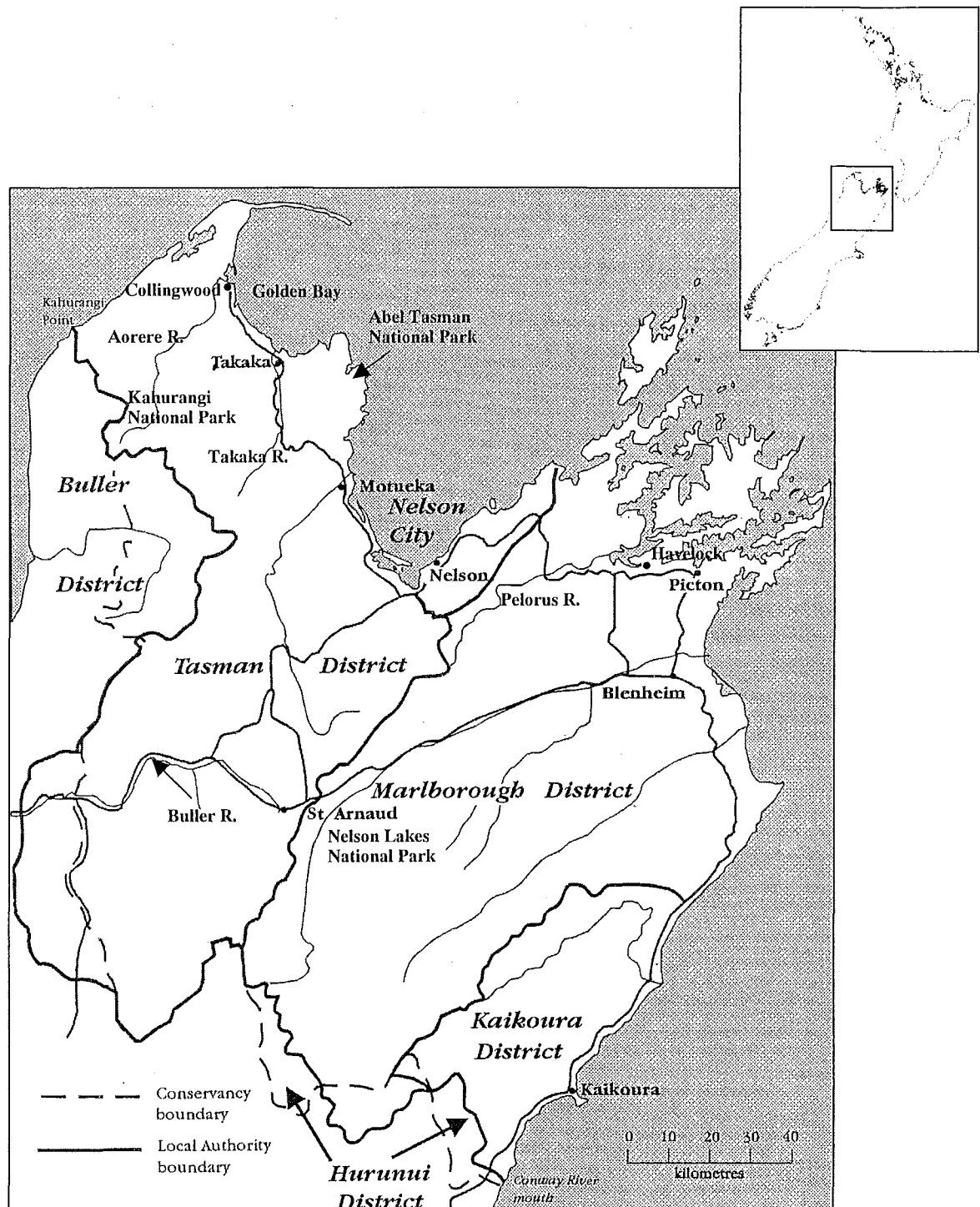


Figure 2.1

Map of the Nelson Marlborough Department of Conservation conservancy boundaries and local authority boundaries within the Nelson Marlborough conservancy (modified from Allibone 1995, with permission of R.M. Allibone)

Survey Methods

Stream selection

The survey to document the presence, absence and abundance of shortjaw kokopu was carried out over a three year period. Streams were surveyed during and including the months of January to May, in 1999, 2000 and 2001. A total of 148 streams were surveyed. Thirty-six streams were surveyed along the Abel Tasman and Golden Bay coastline in 1999 from February through to April, including streams within the Abel Tasman National Park (Studholme et al. 1999). In 2000, the Marlborough Sounds area was surveyed between February and May including 48 streams from Croisilles Harbour, D'Urville Island, Pelorus and Queen Charlotte Sound to Port Underwood. A small number of streams were sampled in the Whangamoia, Pelorus and Wairau Rivers, as well as four streams in the Kaikoura District (Jack and Barrier 2000). In 2001, 64 streams were surveyed from January to May including coastal streams along the West Coast of the South Island to Kahurangi Point and along the Golden Bay coastline to the base of Farewell Spit, tributaries of the Takaka and Aorere Rivers and mid to upper tributaries of the Buller River. Four streams were also surveyed in the Goulard Downs area on the Heaphy track, Kahurangi National Park (Jack et al. 2002).

In the first year of the survey (1999) streams that were likely to contain shortjaw kokopu were selected, largely based on descriptions of habitat characteristics of shortjaw kokopu (McDowall et al. 1996a) and existing records of shortjaw kokopu in the Nelson Marlborough conservancy. In the following two years (2000 and 2001) the results of previous years influenced selection. Topographical maps (NZMS 260, 1:50 000) were used to identify potential sites which were then visited during the day. Landowner permission was required for approximately fifty percent of the streams surveyed.

Survey site selection

In year one (1999) of the survey, Studholme and co-workers (1999) compared the efficiency of electrofishing and spotlighting for capturing shortjaw kokopu in eleven

streams. This investigation was carried out because of uncertainties relating to the capture of small fish (< 100 mm Fork Length, FL) and the accuracy of abundance estimates for all individuals (Studholme et al. 1999). Spotlighting was found to be more effective than electrofishing at detecting the presence of shortjaw kokopu. One individual was captured using electrofishing from the 11 streams surveyed, whereas forty-five individuals were captured from seven of the streams using spotlighting (Studholme et al. 1999). Possible limitations of electrofishing in the area investigated included the ability of shortjaw kokopu to flee to deep cover when disturbed and before they became narcotised, low water conductivity, the presence of large granite boulders disrupting the electric field (i.e. by causing constant removal of the anode from the water) and in some cases areas of deep water (Studholme et al. 1999). Furthermore, electrofishing was time consuming, whereas larger areas could be surveyed using spotlighting in a smaller time frame, therefore increasing the chance of finding shortjaw kokopu. Electrofishing would have been logistically difficult and potentially dangerous in many situations because of access, and the steep gradient of many streams (Studholme et al. 1999, Jack and Barrier 2000, Jack et al. 2001). Spotlighting equipment is lighter and more easily transported than electrofishing equipment. Access to many sites was on foot (up to three hours to reach the survey site) and in some cases a helicopter was used. Thus, spotlighting methodology was used for the remainder of the survey.

Spotlighting methodology

Four hundred metres of stream was measured and marked during the day using flagging tape and rock cairns. Two hours after sunset (2300 hrs in summer and 2100 hrs in autumn) two surveyors used 35 and 50 watt spotlights powered by 12 volt dry cell batteries to observe and identify fish in the water column. Starting two hours after dark allowed fish to move from daytime refugia to night-time feeding positions before survey work began. Each surveyor also wore a head-lamp and used hand-held dip nets to capture fish. Surveyors had varied experience using spotlights and identifying freshwater fish species. However, at least one and usually both surveyors were experienced at identifying fish species and using spotlighting methodology. One surveyor was involved in all three years of the survey.

Surveyors worked methodically upstream spotlighting the entire stream. When shortjaw kokopu were observed they were captured and measured. Capture of small fish (< 100 mm FL) allowed identification to be confirmed. If fish evaded capture and a positive identification was made, an estimate of size was recorded. If a positive identification could not be made fish were recorded as unidentified *Galaxias* species.

Analysis

The known distribution of shortjaw kokopu prior to 1999, and in 2001 were compared using data from the New Zealand Freshwater Fish Database (NZFFD), and data collected in this survey. Maps indicate whether data collected in the current study increased the known spatial distribution of shortjaw kokopu in the Nelson Marlborough conservancy.

The number of individuals captured at each site from NZFFD records prior to 1999 were compared to the number of individuals captured in the Nelson Marlborough conservancy in 1999, 2000, and 2001. The size range of shortjaw kokopu individuals captured in the Nelson Marlborough region were plotted on frequency graphs for each year. Individuals were categorised by size (≤ 100 mm FL, 101 mm - 150 mm FL, 151 mm - 200 mm FL, 201 mm - 250 mm, and > 251 mm) and a chi-square test of independence was performed to establish if size categories were independent of the survey year.

Data were obtained from the NZFFD on the number of records, from throughout New Zealand, of shortjaw kokopu captured using spotlighting and electrofishing methodology, prior to 1996, and from 1996 to 2002. These year groupings were used because all records of shortjaw kokopu were analysed, and targeted surveys for shortjaw kokopu were being carried out in areas other than the Nelson Marlborough conservancy prior to 1999. The number of individuals captured using spotlighting and electrofishing prior to 1996 and between and including the years 1996 to 2002 were tested for differences with a t-test. The average area fished was calculated, and the mean density of shortjaw kokopu captured with electrofishing or spotlighting methodology were also tested for differences with t-tests (SYSTAT version 10).

Spotlighting was not a defined sampling technique on the NZFFD and was categorised under 'observation'. In this analysis records of shortjaw kokopu that were recorded as observations were considered to have been made using spotlights. It is possible that some of these observations were not made with spotlights. However, the 'secretive' nature of shortjaw kokopu during the day and their nocturnal habits mean that almost all contributors probably used spotlights to 'observe' and subsequently capture shortjaw kokopu at night with hand-held dip nets.

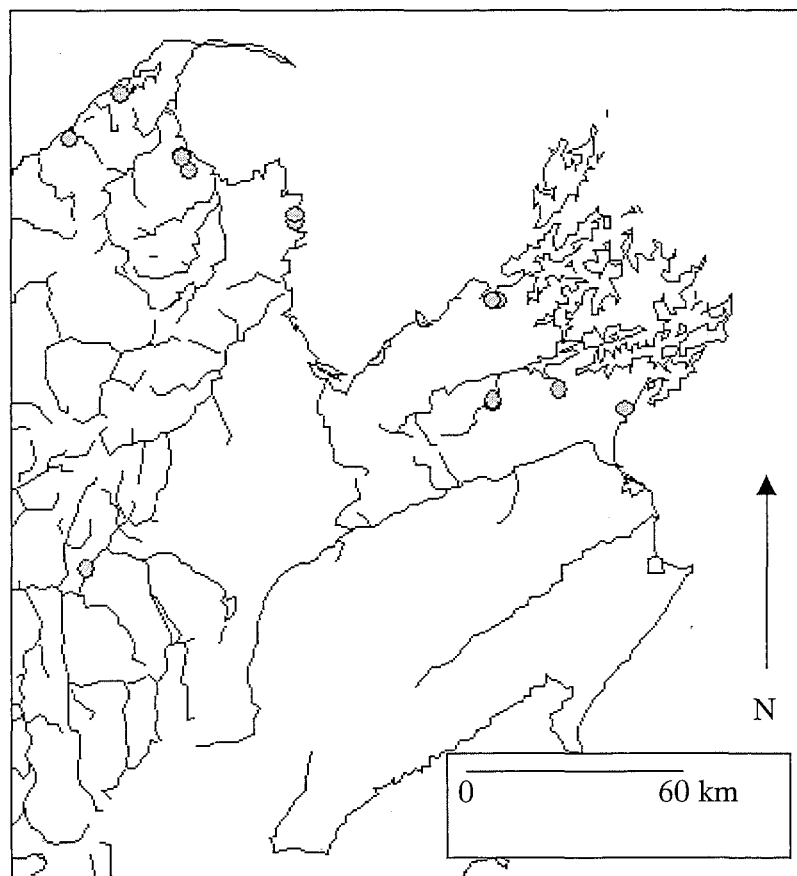
The number of streams in the Nelson Marlborough conservancy that were within the dispersal range of shortjaw kokopu were counted from topographical maps and compared to the total number of streams actually surveyed and the number of streams known to contain shortjaw kokopu. Shortjaw kokopu are known to penetrate greater than 100 km inland, and have been found at altitudes higher than 500 metre asl, but are more commonly found in streams < 100 km inland and below 500 metres asl (McDowall 2000). All streams that were < 100 km inland, and below 500 metres asl, were counted regardless of size or order from topographical maps (L25, M24/N24, M25, M26, N25, N26, N27, O26, O27, O28, O29, O30, O31, O32, P27, P28, P29, P30, Q26, and Q27). Tributaries and mainstem habitat were counted as separate habitat. Data on the actual number of streams surveyed below 500 m asl and < 100 km inland in the Nelson Marlborough conservancy were obtained from the NZFFD. The number of shortjaw kokopu records that were below 500 m asl and < 100 km inland were extracted from this data set.

RESULTS

Distribution and abundance of shortjaw kokopu

This survey substantially increased the known range of shortjaw kokopu in the Nelson Marlborough conservancy (Figure 2.2). Shortjaw kokopu occurred in 77 (52 %) of the 148 surveyed streams in the Nelson Marlborough conservancy.

a Shortjaw kokopu distribution - prior to 1999



b Shortjaw kokopu distribution, 1999 - 2001

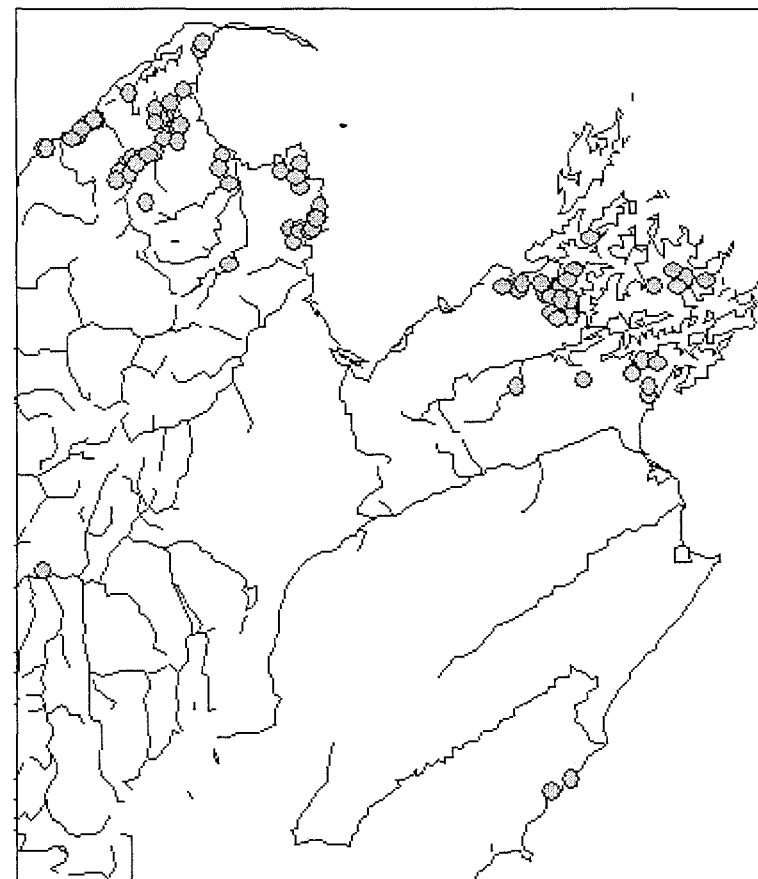


Figure 2.2 Known distribution of shortjaw kokopu in the Nelson Marlborough conservancy prior to 1999 (a) and from 1999 to 2002 (b)

In year one shortjaw kokopu were recorded in 36 % of streams surveyed, in year two they occurred in 58 % of streams and in year three shortjaw kokopu were captured from 56 % of streams (Table 2.1). Six hundred and eight individuals were observed or captured during the three year survey (1999-2001) (Table 2.2).

Table 2.1 The number of streams surveyed, number of streams containing shortjaw kokopu and the percentage of streams shortjaw kokopu were recorded from in year one (1999), year two (2000) and year three (2001) of the survey of streams in the Nelson Marlborough conservancy.

	No. of streams surveyed	No. of streams with shortjaw kokopu	% streams with shortjaw kokopu
Year 1- 1999	36	13	36
Year 2 - 2000	48	28	58
Year 3 - 2001	64	36	56

Table 2.2 The number of shortjaw kokopu individuals captured in year one (1999), year two (2000), and year three (2001) of the survey of streams in the Nelson Marlborough conservancy.

Year of survey	No. of individuals observed or captured
Year 1 – 1999	103
Year 2 – 2000	176
Year 3 – 2001	329
Total	608

Sixty-one percent of the 77 streams where shortjaw kokopu occurred contained more than three individuals, whereas prior to 1999 only 15 percent of all New Zealand streams surveyed recorded more than three shortjaw kokopu individuals (Figure 2.3). Furthermore, in 23 % of streams in the Nelson Marlborough conservancy, more than ten individuals were captured. Thirty-nine percent of streams containing shortjaw kokopu in the Nelson Marlborough conservancy contained between one and three individuals compared to 85 % of streams from throughout New Zealand prior to 1999 (Figure 2.3).

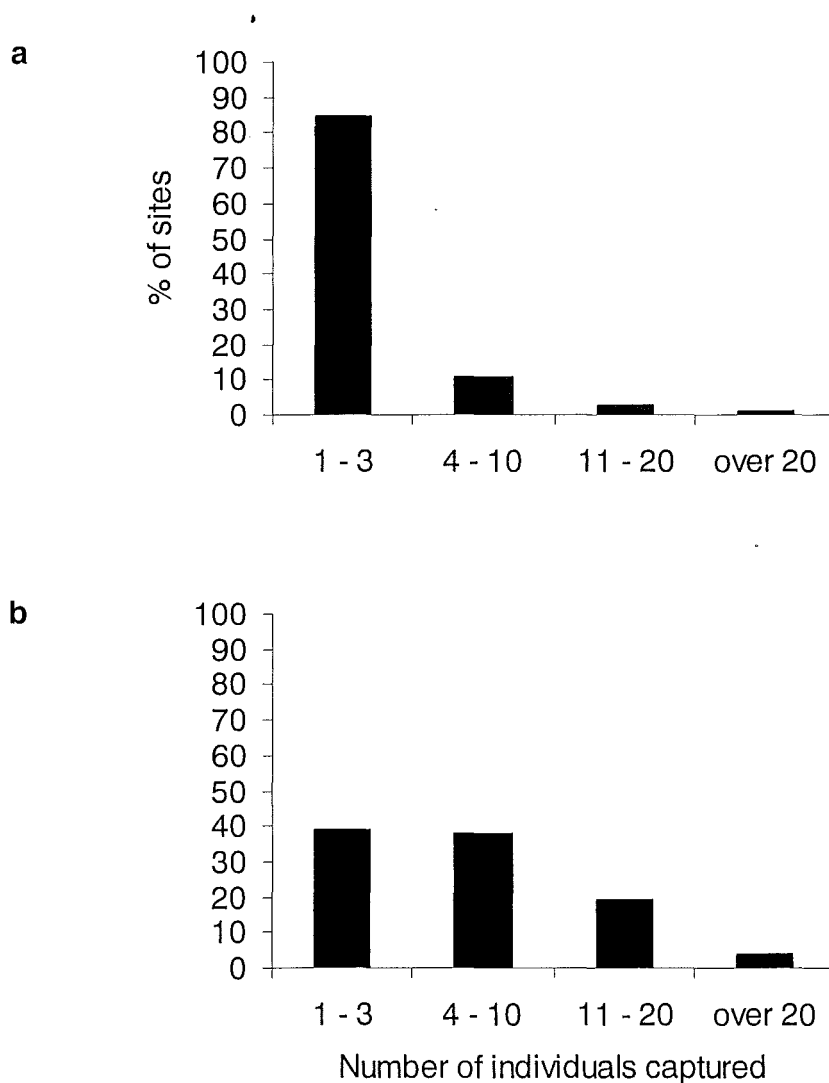


Figure 2.3

The numbers of shortjaw kokopu individuals captured per site prior to 1999 from throughout New Zealand (NZFFD) (a) and in the Nelson Marlborough conservancy from 1999 to 2001 (b).

The upper size limit of shortjaw kokopu was similar in all three years of the survey. In year one (1999) the largest individual captured was 260 mm FL, 280 mm FL in Year two and 270 mm FL in year three (Figure 2.4). However, the number of individuals in different size categories was not independent of the year (chi-square = 60, df = 8, $p < 0.05$). There were more small individuals (≤ 100 mm FL) captured in year three (2001) of the survey, than in other years (Figure 2.4).

Shortjaw kokopu are currently known to occupy 101 (8 %) of the 1302 streams and rivers surveyed in the Nelson Marlborough conservancy below 500 m asl and < 100 km inland. However, only 1302 (21 %) of all 6088 lotic habitats below 500 m asl and < 100 km inland have been surveyed in the Nelson Marlborough conservancy (Table 2.3).

Table 2.3 Total number of streams < 500 m asl, < 100 km inland counted from topographical maps, the total number of streams that have been surveyed in the Nelson Marlborough conservancy and the number streams shortjaw kokopu occur in (< 500 m asl, < 100 km inland) from the NZFFD.

	Topographical map analysis	NZFFD
All streams		
< 500 m asl	6088	1302
< 100 km inland		
Shortjaw kokopu streams		
< 500 m asl	-	101
< 100 km inland		

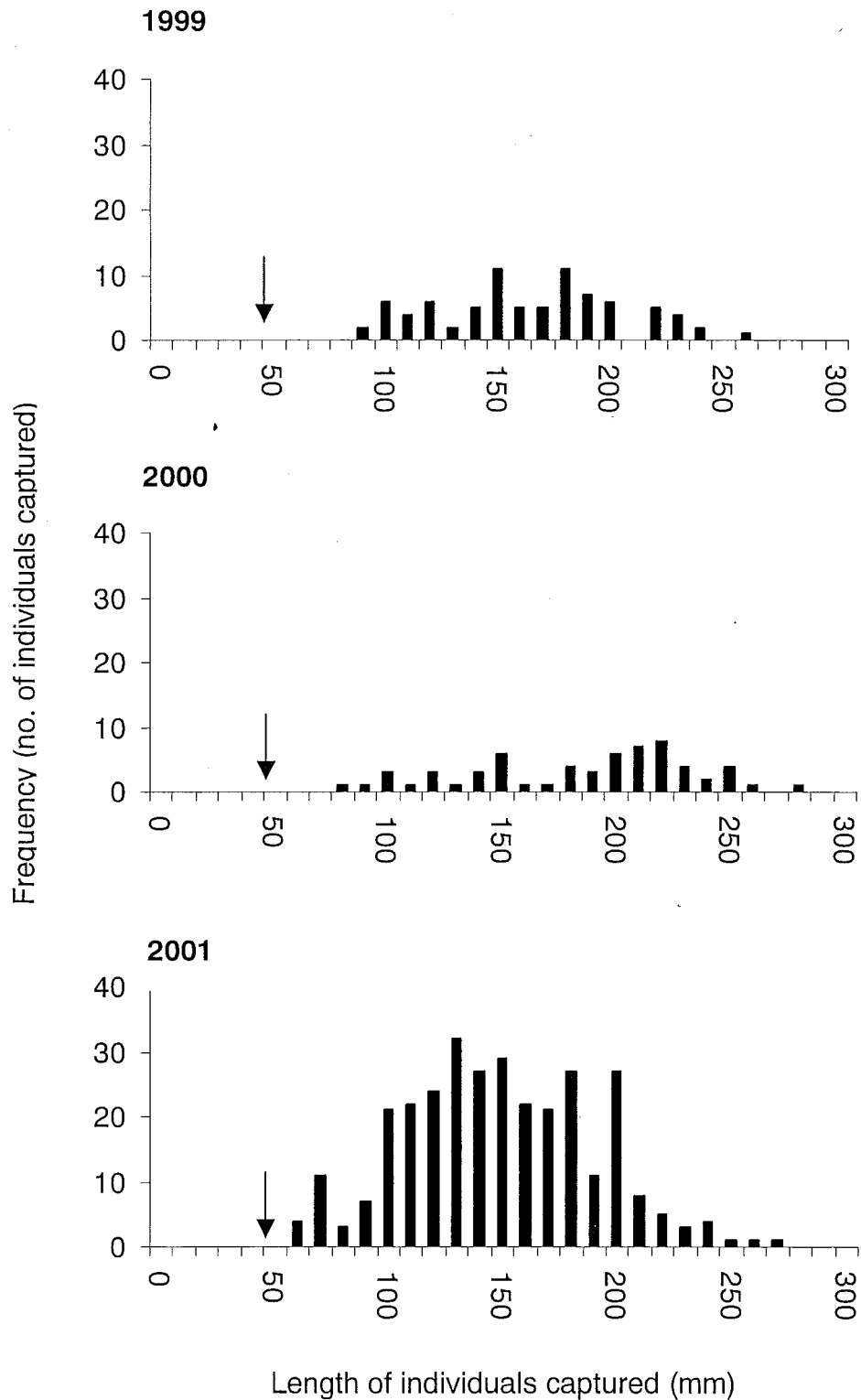


Figure 2.4 Length-frequency distributions of shortjaw kokopu in the Nelson Marlborough conservancy from year one (1999), year two (2000) and year three (2001) of the survey. Arrow indicates approximate size at which juveniles return to freshwater.

Sampling techniques

Spotlighting was an effective sampling technique for finding and observing shortjaw kokopu in still or slow flowing water (pools and runs). However, its effectiveness was limited in fast flowing or broken water (riffles, rapids and cascades). Rain and high flows also reduced the penetration of spotlights into the water column and subsequently the visibility of surveyors was severely reduced. Streams were not surveyed when water levels were high or when it was raining.

There has been an increase in the use of spotlighting methodology and a decrease in the use of electrofishing methodology for capturing shortjaw kokopu. Prior to 1996, two percent (four) of the records on the NZFFD documenting the presence of shortjaw kokopu were obtained using spotlighting, whereas 79 % (179 records) were obtained using electrofishing. From 1996 to 2002, 70 % (196 records) of shortjaw kokopu records were obtained using spotlighting methodology and 23 % (69 records) were obtained using electrofishing. Other methods, for example gee-minnow traps, were used to capture shortjaw kokopu on the remaining NZFFD cards. The total number of individual shortjaw kokopu observed or captured, using either electrofishing or spotlighting, was substantially lower prior to 1996. Three hundred and sixty one shortjaw kokopu individuals were captured using electrofishing or spotlighting prior to 1996, compared to 1322 individuals between and including the years of 1996 to 2002 (Table 2.4). The average number of shortjaw kokopu captured using spotlighting (seven individuals) was significantly higher than the number of shortjaw kokopu captured using electrofishing (three individuals) ($t = 1.97$, $df = 184$, $p < 0.05$). However, the average density of shortjaw kokopu captured using electrofishing methodology was significantly higher than spotlighting methodology ($t = 1.98$, $df = 109$, $p < 0.05$, Table 2.4).

Table 2.4 The number of streams shortjaw kokopu (SJK) were captured from throughout New Zealand (NZFFD) using electrofishing and spotlighting methodology prior to 1996, 1996 - 2002, and all years (a) and the number of shortjaw kokopu individuals captured (b) throughout New Zealand (NZFFD) using electrofishing and spotlighting methodology prior to 1996, 1996 - 2002 and all years. The average area (square metres) fished using spotlighting and electrofishing prior to 1996, 1996 - 2002 and all years (c), the density of shortjaw kokopu per square metre (d) and the average number of individuals captured (e) using spotlighting and electrofishing for all years.

	Prior to 1996	1996 – 2002	All years
a) No. of sites			
Total	228	277	505
Electrofishing	179	69	248
Spotlighting	4	196	200
b) No. of sjk			
Total	361	1334	1695
Electrofishing	349	142	142
Spotlighting	4	1192	1545
c) Ave area fished (m²)			
Electrofishing	340	232	286
Spotlighting	500	1264	882
d) Density (no. sjk/ m²)			
Electrofishing	-	-	0.03
Spotlighting	-	-	0.01
e) Mean no. of sjk captured			
Electrofishing	-	-	3
Spotlighting	-	-	7

DISCUSSION

Distribution, abundance and sampling methodology

Shortjaw kokopu are currently known from more than 100 streams in the Nelson Marlborough conservancy. This is a substantial increase from the 12 streams they were recorded from prior to 1999. Spotlighting methodology was an effective technique for documenting the distribution and abundance of shortjaw kokopu in the Nelson Marlborough conservancy. The findings of this study indicate that spotlighting methodology is a useful technique for rapidly estimating the relative abundance of shortjaw kokopu, whereas electrofishing may give a better overall estimate of fish density in known populations. This is similar to previous research that indicated that electrofishing was a better method for estimating the density of banded kokopu (McCullough 1998). However, electrofishing is time consuming and small areas of stream are usually fished. A larger area can be searched more efficiently using spotlighting. Consequently, the probability of encountering shortjaw kokopu in 'patchy' stream environments (*sensu* Townsend 1989) is higher using spotlighting. McCullough (1998) concluded that spotlighting would provide a more realistic and accurate estimation of abundance because a larger sample could be obtained in a smaller amount of time.

Eastwood (2001) reported that spotlighting was more effective than electrofishing for locating shortjaw kokopu in West Coast streams, however it was not consistently so. In some streams more fish were captured using electrofishing than spotlighting. Furthermore, Eastwood (2001) suggested that neither spotlighting nor electrofishing were reliable enough to quantify the exact number of shortjaw kokopu, and that for accurate data on population sizes, fish should be tagged. McCullough (1998) proposed that a calibration factor could be added to spotlighting data to obtain a more realistic estimate of fish density. Furthermore, current work tagging shortjaw kokopu, indicates that repeated spotlighting effort is needed to gain a good representation of the density of individuals within streams (R. Allibone, *pers. comm.*). In the current study, spotlighting was a more appropriate method because the rationale was to provide accurate and up-to-date data on the distribution and abundance of shortjaw kokopu in the Nelson Marlborough conservancy. It is likely that if electrofishing had

been used, results would have been vastly different because not as much area (within streams and within the conservancy) would have been covered in the time available. Furthermore, surveyors were able to spotlight streams where access was difficult and using an electrofishing machine would have been dangerous. The best way to obtain accurate data is by using a combination of sampling techniques (sensu Brown and Moyle 1997, Chadderton and Allibone 2000). Therefore, using spotlighting and electrofishing for future studies on shortjaw kokopu, depending on the objective of the research, may yield the best results.

Size range of captured shortjaw kokopu

A high number of juvenile fish (< 100 mm FL) relative to past studies (McDowall et al. 1996a, Studholme et al. 1999) were captured or observed in year three (2001) (Jack et al. 2001). However, the proportion of juvenile fish captured is still low compared to the number of adult fish (Chapter Five). One of the reasons for the lack of records of small individuals (> 40 mm FL, i.e. larvae in the marine environment, and < 100 mm FL) has been attributed to identification problems (McDowall 1990a, McDowall et al. 1996a, Studholme et al. 1999). Distinguishing between whitebait of large-bodied *Galaxias* species, especially shortjaw kokopu and koaro is difficult because shortjaw kokopu and koaro have similar morphological features (McDowall 1990a). Whitebait gradually become pigmented in freshwater are more easily identified than recent arrivals from the sea, however confusion still occurs when identifying small individuals (McDowall 1990a). It is also possible that the low rate of capture of juveniles may be attributed to human bias due to large fish being more obvious than small fish. Furthermore, it has been suggested that the lack of small fish observed or captured in the past was related to more specific, or different, habitat requirements to that of adults. (McDowall et al. 1996a). However, in the current study, shortjaw kokopu juveniles were captured from the same stream reaches as adults.

The size of fish, particularly the number of juveniles captured in this study was dependent on the survey year. This could be related to 'good' and 'bad' spawning years influencing the number of recruits (McDowall and Eldon 1980, Charteris 2002). However, it is more likely to be related to spotlighting conditions and surveyor experience (Studholme et al, 1999, Jack and Barrier 2000, Jack et al. 2001).

Weather patterns in all three years provided good spotlighting conditions (low to average stream flows and settled weather). In the third year (2001) an unseasonably long period of dry weather provided good spotlighting conditions for an extended period. Surveyor experience was varied, for example one surveyor was involved in all three years of this study and their experience using spotlighting methodology and identifying small fish increased over time. A second surveyor was always present, but this surveyor differed between survey year and their experience of using spotlighting methodology and identifying small fish varied. Thus, the higher number of small individuals in year three may have been related to the ability of surveyors to identify and find small individuals. The relatively high number of juveniles captured in habitat similar to adults is an important finding for the conservation of shortjaw kokopu.

Rarity

Prior to 2002, shortjaw kokopu were ranked as a 'Category A' threatened species, the Department of Conservation's highest classification for a threatened species. The current study indicates that shortjaw kokopu are more widespread and abundant in the Nelson Marlborough conservancy than previously thought. Furthermore, recent research indicates that shortjaw kokopu are also widespread and abundant in other areas of New Zealand (Caskey 1999, Eastwood 2001, Bowie 2002, Charteris 2002). However, whether this pattern holds true for the rest of New Zealand is unclear. The current distribution of shortjaw kokopu throughout New Zealand indicates that they are locally common, but nationally rare (*sensu* Gaston 1994, deLange and Norton 1998). Shortjaw kokopu are still regarded as threatened. However, with the introduction of a new ranking system for threatened species, they are no longer classified in the highest threat category (Molloy et al. 2001, R. Allibone, *pers. comm.*). Shortjaw kokopu are currently ranked as 'chronically threatened' species in gradual decline. This ranking reflects the Department of Conservation's assessment that shortjaw kokopu are expected to decline by between 5 and 30 % in the next ten years and that this decline will continue into the future. It is also acknowledged that the rate of decline of shortjaw kokopu is not well understood, and that local and national decline rates may be very different (R. Allibone *pers. comm.*).

DeLange and Norton (1998) emphasise that species may be naturally uncommon or uncommon because of human activities. It is likely that the current distribution of shortjaw kokopu has been affected by human modifications to land in the riparian zone and catchment of streams. The extent of this effect is difficult to quantify because of the lack of historical (pre European) information on their distribution and abundance (McDowall 1980, McDowall 1990c). Shortjaw kokopu are currently recorded from only 8 % of sites sampled below 500 m asl and < 100 km inland. Seventy nine percent of streams below 500 m asl, and < 100 km inland in the Nelson Marlborough conservancy have not been surveyed. However, many unsampled streams have been severely degraded by human activities in their surrounding landscape, for example native vegetation has been removed. Shortjaw kokopu are positively associated with native forest (McDowall et al. 1996a), and it is unlikely that adults will occur in stream reaches where the surrounding landscape has been modified (see Chapter Three). Therefore, the probability of finding shortjaw kokopu in 8 % (382) of the remaining 4780 unsampled streams is low. Furthermore, shortjaw kokopu were absent from many (48 % of the 148) streams in this study thought to be 'suitable' for this species. The reasons for this are discussed in the following three chapters.

“We are the front end loaders
we are the movers of earth
wheel deep in drainage odours
assisting at bungalows birth
we are the grim foreboders
of a world without trees or mirth.”

Janet Frame



CHAPTER THREE

Habitat occupancy by shortjaw kokopu

INTRODUCTION

Factors affecting the distribution and abundance of organisms

The distribution and abundance of organisms varies through time and in space (Begon et al. 1996, Boisclair 2001, Krebs 2001). The premise of many ecological studies considering the distribution and abundance of organisms, is that habitat is limiting (e.g. Mills et al. 1984). Considerable effort and resources are devoted to defining habitat requirements, especially for conservation purposes (Gorman and Karr 1978, Gray and Craig 1991, Jowett and Richardson 1995, Hicks and Barrier 1996, Rosenfeld et al. 2000). Habitat is obviously important, but it may not always be the factor limiting population size (Gray and Craig 1991). Many factors contribute to the distribution patterns of organisms. The distribution of shortjaw kokopu may be influenced by their dispersal ability, the nature of the stream environment between larval and adult habitat and possibly by interactions with other species, as well as habitat requirements. In this chapter I describe the habitat occupied by shortjaw kokopu in the Nelson Marlborough conservancy in relation to habitat ‘availability’.

Dispersal

The nature of space within the habitat range of organisms influences their ability to disperse and the ‘choice’ of habitat they occupy (Fraser et al. 1995, Kupferberg 1996, Krebs 2001). The landscape surrounding organisms may be naturally restricting, or may be retriecting because of anthropogenic influences (Pringle 1997, Boisclair 2001, Gilliam and Fraser 2001). Organisms with life-history traits that allow dispersal through a variety of environments are likely to occupy a wide range of habitats

(McDowall 1990a, Krebs 2001). The New Zealand freshwater fish fauna has a high percentage (over 50 %) of diadromous fish species (McDowall 1990a). Diadromous fish species migrate between the freshwater and marine environments and are usually widely distributed (Myers 1949, Gross 1987, McDowall 1987). Shortjaw kokopu (*Galaxias postvectis*), giant kokopu (*Galaxias argenteus*), banded kokopu (*Galaxias fasciatus*), koaro (*Galaxias brevipinnis*) and inanga (*Galaxias maculatus*) have a larval stage that migrates to the marine environment to feed and grow, and returns as a juvenile to freshwater habitat for adult growth and reproduction (McDowall 1990a, McDowall 1997a). Shortjaw kokopu juveniles returning to the freshwater environment are presented with a wide array of river mouths to enter. The precise mechanisms that influence river mouth 'selection' by shortjaw kokopu are unclear. Recent research indicates that juvenile migratory galaxiids may select streams to enter based on the presence of adult conspecifics (i.e. chemical cues), the presence of native vegetation and water quality (Rowe et al. 1992, Baker and Montgomery 2001). Modifications to the land surrounding streams often degrades instream values (for example, water quality) and subsequently the distribution and abundance of freshwater species may be altered (Bruton 1985, Rabeni and Smale 1995, Jowett et al. 1996, Richardson 1997). Given that shortjaw kokopu are diadromous they have the potential to occupy a wide range of habitats.

Habitat associations

The shortjaw kokopu used to be regarded as New Zealand's rarest freshwater fish species (Tisdall 1994, McDowall 1990a). Prior to 1996, shortjaw kokopu were recorded from few (two percent of the greater than 11 000) sites on the New Zealand Freshwater Fish Database (NZFFD) (McDowall et al. 1996a). One of the reasons thought to be contributing to the rarity of shortjaw kokopu was the sparseness of suitable habitats (McDowall et al. 1996a). McDowall and co-workers (1996a) suggested that shortjaw kokopu 'preferred' small streams (3 - 5 m wide) with a high proportion of large cobbles and boulders. They reported that a critical feature for predicting the presence of shortjaw kokopu was the presence of native forest (McDowall et al. 1996a, McDowall 1997b). The destruction of native forest and subsequent conversion of land for intensive anthropogenic practises like agriculture was thought to have reduced and degraded shortjaw kokopu habitat.

The habitat organisms occupy is also influenced by intra- and inter-specific interactions. Large bodied *Galaxias* species (shortjaw kokopu, banded kokopu, giant kokopu, and koaro) are associated with native vegetation (McDowall 1990a, McDowall et al. 1996a, Jowett et al. 1996) and are affected by water quality and downstream modifications (Hanchet 1990, Minns 1990, Pringle 1997, Joy and Death 2000, Rowe et al. 2000). Micro-scale interactions between large bodied galaxiids have not been widely studied in New Zealand. It is possible that large-bodied galaxiids compete for food and space with each other and with other native fish. Some *Galaxias* species may occupy different habitats and display different behaviours in the presence or absence of other fish species (Townsend and Crowl 1991, Hayes 1996, Chadderton and Allibone 2000). The effect of intra- and inter- specific interactions on the distribution of shortjaw kokopu has not been well researched. Interactions with other diadromous fish species and introduced trout (considered in Chapter Four) could affect the habitat shortjaw kokopu occupy.

Given the potential for factors like dispersal and species interactions to also limit shortjaw kokopu populations, it is important to determine how shortjaw kokopu are distributed in relation to habitat availability. In this chapter I document habitat features associated with post whitebait shortjaw kokopu in the Nelson Marlborough conservancy and analyse the distribution of shortjaw kokopu in relation to habitat availability.

METHODS

Study Area

Research was carried out in the Nelson Marlborough Department of Conservation conservancy (Chapter Two, Figure. 2.1). Districts within this conservancy include Tasman, Nelson City, Marlborough and Kaikoura, as well as parts of the Buller and Hurunui districts (Chapter Two, Figure 2.1). A high proportion of land within the Nelson Marlborough conservancy is covered by native vegetation and protected in national parks, forest parks and nature reserves. However, similar to the rest of New Zealand, much of the lowland area within the Nelson Marlborough conservancy has

been modified and is now dominated by human activities (agriculture, viticulture, horticulture, forestry, recreation and urban activities). Nevertheless, some lowland areas are relatively unmodified (e.g. in the Abel Tasman National Park). The Nelson Marlborough conservancy has a wide variety of lotic habitat that reflect the diverse geology, topography and vegetation of the area. Thus, there is a large range of streams that could potentially be occupied by shortjaw kokopu.

Survey methods

Stream selection

Streams were selected for study based on past descriptions (McDowal et al. 1996a) of shortjaw kokopu habitat and knowledge gained throughout this study (Studholme et al. 1999, Jack and Barrier 2000, Jack et al. 2001). Initial stream selection was from topographical maps (NZMS 260 1:50 000), potential streams were then visited during the day and assessed for accessibility. Throughout this study, the aim was to maximise the chance of finding shortjaw kokopu by surveying streams that were considered possible shortjaw kokopu habitat. Random selection of study sites might have resulted in data that allowed stronger conclusions to be made about habitat 'selection', however it would have provided less information on the extent of habitat occupied. This study emphasises the range of streams shortjaw kokopu occupy, and the extent to which 'suitable' habitat is occupied.

Spotlighting methodology

During daylight hours, 400 m of stream was marked using flagging tape and rock cairns for ease of relocation after dark. Two hours after sunset (2300 hours in the summer and 2100 hours in the autumn), two surveyors returned to the marked 400 metre site. This allowed fish to emerge from day time refuge and assume nocturnal feeding positions. Surveyors used spotlights (either 35 or 50 watt) powered by 12 volt dry cell batteries to locate fish. Surveyors wore headlamps for additional illumination of the water column. Headlamps allowed surveyors to switch from a high beam light source (spotlights) to a lower beam light source. This reduced the chance of fish fleeing during capture. It also enabled surveyors the use of both hands,

subsequently allowing greater manoeuvrability of hand-held dip nets used for capturing fish.

Surveyors moved methodically upstream spotlighting all habitats where possible (pool, run, riffle, backwater, rapid, cascade). The effectiveness of spotlighting methodology was reduced in fast flowing or broken water (see Chapter Two). All captured shortjaw kokopu, as well as shortjaw kokopu that were positively identified but evaded capture were recorded. Small fish that evaded capture were recorded as unidentified *Galaxias* species.

Habitat occupancy analysis

Habitat measurements

A range of habitat variables was recorded at each of the 148 streams surveyed, as recommended on NZFFD forms (McDowall and Richardson 1983). This included measurements of instream, riparian zone and catchment variables. Catchment land use types were categorised into the percentage of native forest, exotic forest, farmland, scrub and swampland based on maps and visual observations. Riparian land use types were also visually assessed and categorised into the percentage of native forest, exotic forest, grass/tussock, exposed bed, scrub/willow and raupo/flax. The percentage of the stream bed covered by large cobbles and boulders (substrate), weed/algae, instream woody debris, bank vegetation, undercut banks and overhead shade that provided cover for fish were estimated. Stream flow types were also estimated and categorised (Table 3.1).

Table 3.1 Categories and descriptions of stream flow types

Flow type	Description
Still	no velocity, usually within the main channel of the stream
Backwater	no velocity, usually at stream margins, connected but not directly affecting the main channel
Pool	low to no velocity, moderate to deep water in the main channel
Run	variable velocity, moderate to deep water
Riffle	high velocity, shallow water, with broken surface
Rapid	high velocity, moderate to deep water
Cascade	moderate to high velocity, shallow turbulent water

Land use, vegetation type and stream size

Riparian vegetation types associated with the 148 streams surveyed were recorded (Table 3.2). The vegetation categories were then broadly classified into one of the following groups: pure beech, beech/podocarp/hardwood mixes, hardwood/podocarp/broadleaf mixes, scrub/tussock/willow mixes, and exotic plantation species. Modifications to the stream bed (for example from mining), and modifications to the riparian zone and catchment (for example, agriculture, fire, and plantation forests) were noted. Mean width and depth was calculated by averaging measurements at the lower, mid and upper reaches of each survey site. Maximum depth was measured at the deepest point within the survey reach.

Table 3.2 Vegetation categories and examples of species present in the Nelson Marlborough conservancy.

Vegetation category	Examples of species present
Podocarp	miro, <i>Prumnopitys ferruginea</i> rimu, <i>Dacrydium cupressinum</i> matai, <i>Prumnopitys taxifolia</i>
Beech	black beech, <i>Nothofagus solandri</i> red beech, <i>Nothofagus fusca</i> silver beech, <i>Nothofagus solandri cliffortioides</i>
Hardwood	puriri, <i>Vitex lucens</i> rata, <i>Metrosideros</i> spp.
Broadleaf	papauma, <i>Griselinia littoralis</i>
Scrub	manuka, <i>Leptospermum scoparium</i> gorse, <i>Ulex europaeus</i>
Exotic	pine, <i>Pinus radiata</i>
Willow	cracked willow, <i>Salix fragilis</i>
Tussock	<i>Carex</i> spp.
Pasture	agricultural areas

Multi-variate habitat analysis

Relationships between the presence and absence of shortjaw kokopu and habitat variables were investigated with principal components analysis (PCA) and forward stepwise discriminant functions analysis (DFA). Ryan-Joiner tests of normality were performed on all habitat variables using MINITAB version 13. Habitat variables that did not fit a normal distribution ($p < 0.05$) were transformed. Arcsin square-root transformations were performed on proportion data using SYSTAT version 10. Transformed data were subject to Ryan-Joiner tests of normality. Transformed habitat variables that still did not fit a normal distribution were removed from the analysis.

PCA was performed on sixteen habitat variables (Table 3.3). PCA groups variables into 'factors' so that variables within each factor are more highly correlated than variables between 'factors'. Seven factors with eigenvalues greater than one were

retained from the correlation matrix. DFA was performed on these seven factors to separate sites where shortjaw kokopu were present from sites where shortjaw kokopu were absent. DFA was performed in a forward stepwise manner. Component loadings from PCA accounting for at least 25 percent of a variable's variance (an absolute loading of 0.5) were assumed to be important for predicting the presence or absence of shortjaw kokopu (Table 3.3) (Dillion and Goldstein 1984). PCA and DFA were performed using SYSTAT version 10.

Land use, vegetation type and stream size

A chi-square test of independence was used to test whether the presence and absence of shortjaw kokopu was independent of vegetation categories. Landuse types at sites where shortjaw kokopu were present were categorised and examined. T-tests were performed on average width, average depth and maximum depth data using SYSTAT version 10 to test for a significant difference between streams with and without shortjaw kokopu.

Table 3.3

Normally distributed habitat variables subjected to principal components analysis (PCA) and discriminant functions analysis, (DFA). Positive (+) and negative (-) component loadings are indicated for factors significant in discriminating (DFA) shortjaw kokopu presence and absence: factor one (F1), factor two (F2) and factor 3 (F3). Component loadings that explained less than 0.5 are blank.

Habitat variable	transformation	PCA component loading		
		F1	F2	F3
Instream habitat				
Still	arcsin sqrt			
Riffle				-
Rapid				
Cascade				+
Run	non-normal			
Pool	non-normal			
Backwater	non-normal			
Fish cover				
Substrate	arcsin sqrt		+	
Weed/algae	arcsin sqrt			
Instream debris	arcsin sqrt		-	
Bank vegetation	non-normal			
Overhead shade	non-normal			
Catchment vegetation				
Native forest	arcsin sqrt	+		
Farmland	arcsin sqrt	-		
Scrub	arcsin sqrt	-		
Swampland	non-normal			
Riparian vegetation				
Native forest	arcsin sqrt	+		
Grass/tussock		-		
Exposed bed	arcsin sqrt	-		
Scrub/willow	arcsin sqrt	-		
Raupo/flax				

RESULTS

Multivariate habitat analysis

Three PCA factors that collectively explained 42 % of the variance in the habitat variables measured were identified with DFA (Table 3.3). These three factors correctly classified 65 % of sites where shortjaw kokopu were present and where they were absent. This model was better at predicting the presence (70 % of sites were classified correctly) of shortjaw kokopu than the absence of shortjaw kokopu (65 % of sites were classified correctly). Classifications were determined by the jackknifed classification matrix. This involves allocating each individual to its closest group without using that individual to help determine a group centre, so bias in allocation is avoided (Manly 1986).

DFA indicated that PCA factors one, two and three explained most of the variation in shortjaw kokopu presence or absence. Factor one was negatively associated with the percentage of farmland and scrub in the catchment, and the percentage of grass/tussock and scrub/willow in the riparian zone, and positively associated with the percentage of native forest in the catchment and riparian zone (Table 3.3, Figure 3.1). Factor two was negatively associated with the percentage of instream debris for fish cover; and positively associated with the percentage of substrate for fish cover (Table 3.1, Figure 3.1). Factor three was negatively associated with the percentage of riffle and positively associated with the percentage of cascade (Table 3.3).

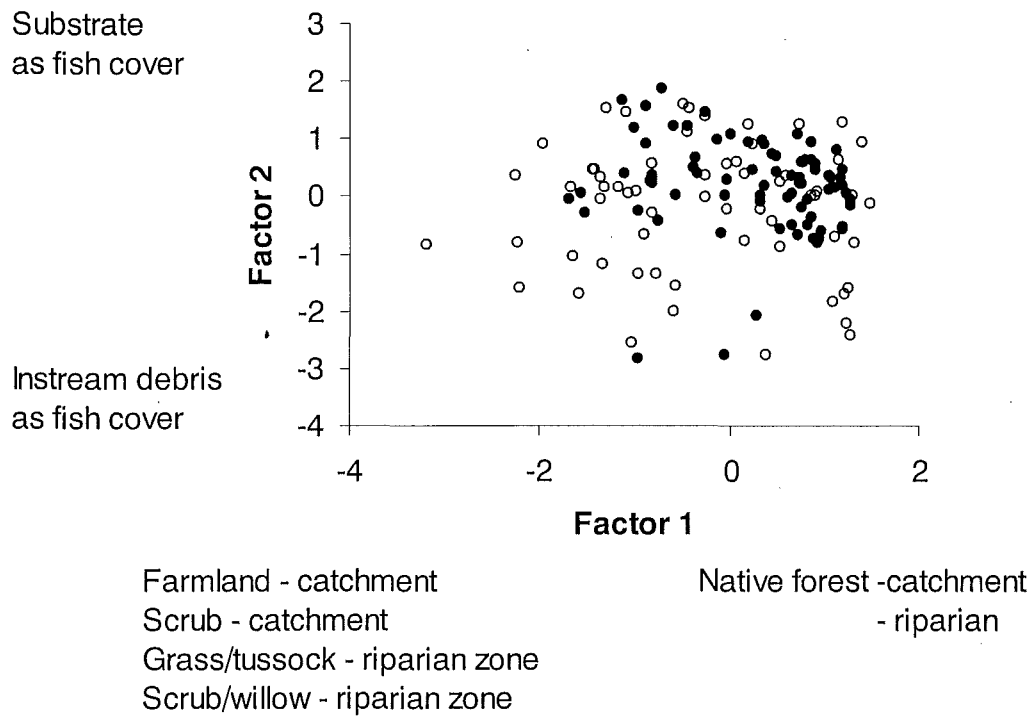


Figure 3.1 Scores for the first two factors (accounting for 21 and 13 % of the variance, respectively) derived from PCA and DFA on habitat variables. Symbols indicate sites with shortjaw kokopu (solid circles) and sites without shortjaw kokopu (open circles). Variables correlated with the factors are shown on the axes.

Land use, vegetation type and stream size

The average depth of streams with shortjaw kokopu was deeper than streams without shortjaw kokopu ($t = -2.14$, $df = 110$ $p < 0.05$, Figure 3.2a). The average maximum depth of streams with and without shortjaw kokopu was not significantly different ($t = -1.45$, $df = 140$ $p = 0.149$, Figure 3.2b). The average width of streams that contained shortjaw kokopu was significantly larger than streams without shortjaw kokopu ($t = -2.75$, $df = 133$, $p < 0.05$, Figure 3.2c). Shortjaw kokopu were predominately found in streams less than 10 m wide (Figure 3.2c). They occurred in streams ranging from two to 24 m wide (Fig. 3.2d). The average width of all streams shortjaw kokopu occurred in was 6 m (Figure 3.2d).

The presence of shortjaw kokopu was not independent of vegetation type (chi-square = 12.51, $df = 4$, $p < 0.05$, Table 3.4). Shortjaw kokopu were more often associated with beech/podocarp/hardwood and hardwood/podocarp/broadleaf mixes than with scrub/tussock/willow mixes. They were absent from sites with pure beech and exotic forest, however sample sizes were too small to draw any statistical conclusions. Shortjaw kokopu occurred in both unmodified and modified streams (Table 3.5).

Table 3.4 Grouped vegetation types indicating the sample size of each vegetation type (column one). The percent of the total number of sites surveyed in each vegetation type and the percent of each vegetation type shortjaw kokopu (SJK) occur in are shown in column two and column three respectively.

Vegetation type	% of sites surveyed in each vegetation type n = 146	% SJK occurrence in vegetation types
Beech, n = 2	1.4	0
Beech/podocarp/hardwood, n = 86	58.9	56
Hardwood/podocarp/broadleaf, n = 34	23.3	62
Scrub/tussock/willow, n = 22	15.1	27
Exotic, n = 2	1.4	0

Table 3.3 Number of unmodified and modified (indicating the type of modification) streams shortjaw kokopu occupied, n = 75.

Unmodified streams [#]	22
Modified streams*	
Pasture/regeneration (scrub) ¹	4
Pasture ²	15
Mined ³	4
Pasture/mined ^{2,3}	1
Burnt ⁴	1
Burnt/mined ^{3,4}	1
Logged ⁵	9
Logged/pasture ^{2,5}	11
Logged/mined ^{3,5}	2
Selective logged ⁶	3
Logged/exotics/pasture ⁷	1
Logged/mined/pasture ^{2,3,5}	1

[#] Unmodified streams contained native vegetation (usually native forest) in their catchment and in the riparian zone, with no modifications in downstream reaches

* All modified streams shortjaw kokopu occupied contained native forest in their upper reaches.

¹Pasture in lower stream reaches with areas of regenerating native vegetation mixed with gorse in the riparian zone.

² Pasture in lower stream reaches

³ Impacted by mining activities

⁴ Vegetation cleared by burning, but regenerating

⁵ Native forest cleared by logging, but regenerating

⁶ Native forest selectively logged

⁷ Areas of logged native forest, with some areas of exotic plantation species and with pasture in the lower reaches

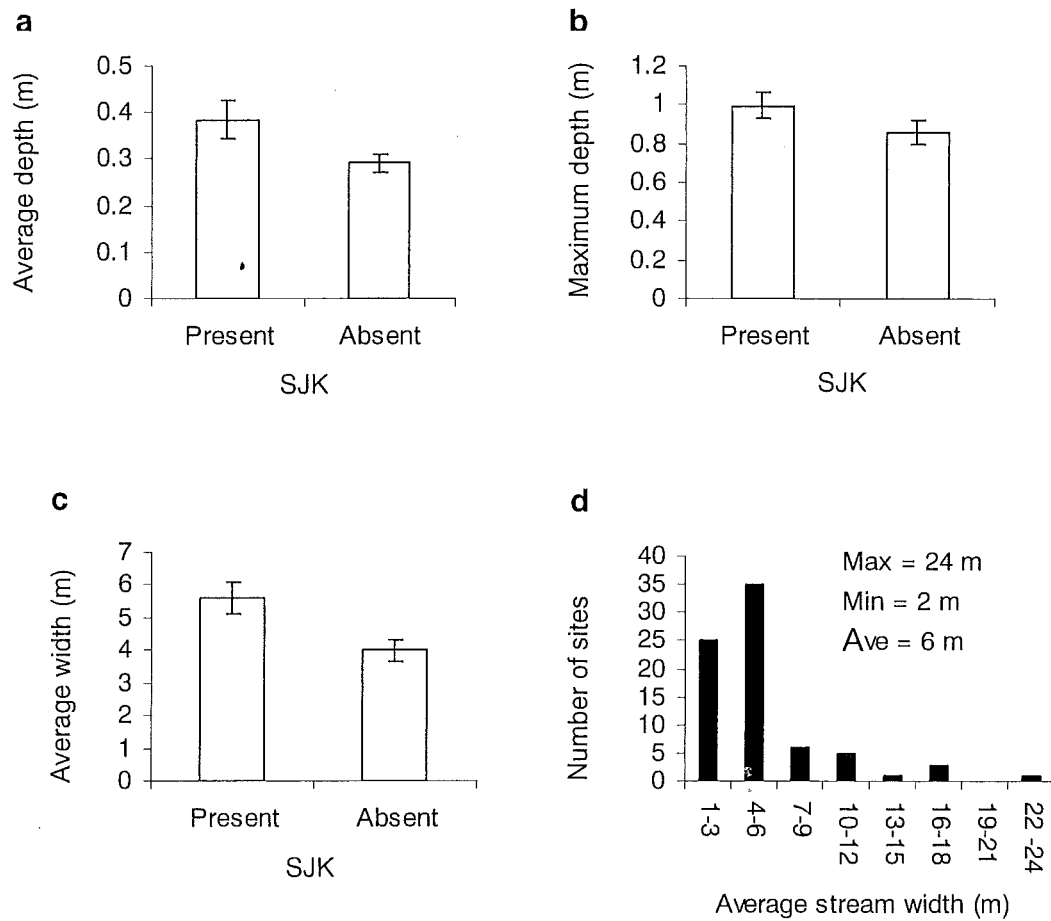


Figure 3.2 Average depth (± 1 se) (a), average maximum depth (± 1 se) (b), average width (± 1 se) (c) of streams with and without shortjaw kokopu (SJK), and the frequency distribution of stream widths of sites with shortjaw kokopu (d). The maximum (max), minimum (min) and average (ave) width of streams containing shortjaw kokopu are also indicated.

DISCUSSION

Features of shortjaw kokopu habitat

The multi-variate analysis of habitat variables in this study was not able to precisely separate streams where shortjaw kokopu were present. Only 65 % of the 148 streams surveyed were classified correctly using DFA and PCA. There are a variety of reasons for the weakness of the habitat selection of shortjaw kokopu. Shortjaw kokopu occupied a relatively wide range of stream habitats in the area studied, and streams likely to contain shortjaw kokopu were targeted. However, 48 % of streams targeted did not contain shortjaw kokopu and streams with shortjaw kokopu were similar to streams without shortjaw kokopu. This implies that local habitat is not the only factor controlling shortjaw kokopu distribution. Nevertheless, forested habitats did appear to be important for shortjaw kokopu.

The importance of native forest

Native forest is important for the persistence of many freshwater fish species (Frissel 1993, Allen et al. 2002). In New Zealand, large-bodied *Galaxias* species (i.e. shortjaw kokopu, giant kokopu, banded kokopu and koaro) are associated with native forest (Main 1988, Hanchet 1990, McDowall et al. 1996a). McDowall and co-workers (1996a) suggested that a critical habitat feature predicting the presence of shortjaw kokopu was the presence of native forest. However, evidence was largely circumstantial and the exact reasons for their forest preference are unclear (McDowall 1997b). In this study, shortjaw kokopu were most often associated with beech/podocarp/hardwood and hardwood/podocarp/broadleaf forest and less often with scrub/regenerating forest. Shortjaw kokopu were absent from sites with pure beech forest and exotic forest, however sample sizes of these forest types were extremely small. Therefore no conclusions can be made about the reasons for the absence of shortjaw kokopu from these sites. McDowall (1997b) reported similar findings to my study and suggested that the association of shortjaw kokopu with native forest (and certain native plant species) could be because forest cover reduces extreme temperature fluctuations, it stabilises stream banks and contributes terrestrial food sources to the stream environment. Main (1988) concluded that the distribution

of large-bodied galaxiids was not limited by temperature. The relationship between terrestrial food items, native forest, and shortjaw kokopu is unclear. Terrestrial foods are important for shortjaw kokopu and numerically comprised between 0.5 % and 45.6 % of the food items in their gut, and contributed gravimetrically between 3.3 % and 94.1 % in diet studies. (Main 1988, McDowall et al. 1996b). However, Main (1988) argued that shortjaw kokopu were probably not dependent on native forest for a riparian food source because the abundance and biomass of terrestrial invertebrates was not consistently greater in forested streams compared to streams flowing through pasture (but see Edwards and Huryn 1996). It is possible that certain terrestrial and aquatic invertebrate species associated with riparian forest are important for shortjaw kokopu.

Habitat modifications

Shortjaw kokopu were found in modified and unmodified streams. Modifications to streams in the study area included direct modifications to the stream bed, as well as degradation associated with the destruction of native forest and landuse conversion. The majority of modified streams originated in native forest, with downstream reaches passing through farmland. The specific microhabitat occupied by shortjaw kokopu within modified streams was not recorded. However, they were almost always observed in stream reaches that contained native forest in the riparian zone. This indicates that shortjaw kokopu juveniles were able to migrate through degraded stream reaches to reach adult habitat. It is unclear to what extent water quality can be degraded or stream beds modified before shortjaw kokopu juveniles are inhibited from moving upstream. However, juveniles of migratory *Galaxias* species have been shown to avoid high suspended sediment loads (Boubee et al. 1997, Rowe et al. 2000) and dams and weirs are known to inhibit upstream movement of migratory species (McDowall 1995).

Instream habitat and stream size

Instream habitat variables (e.g. the type of fish cover) were identified by the DFA but still did not clearly separate streams with shortjaw kokopu from streams without shortjaw kokopu. Shortjaw kokopu were most closely associated with a high

percentage of stream bed covered by substrate (e.g. large cobbles and boulders) that provided fish cover. Previous studies show that shortjaw kokopu occupy streams with a high proportion of large cobbles and boulders (McDowall et al. 1996a). Nevertheless, this research shows that in the absence of large substrate, shortjaw kokopu can utilise other forms of cover like instream debris. Thus, they do not appear to be restricted by the type of fish cover available.

In this study shortjaw kokopu were predominantly associated with streams less than 10 m wide, however, they were found in mainstem rivers up to 24 m wide. Furthermore, shortjaw kokopu were found in streams with an average maximum depth of one metre. This suggests that they are not restricted to the small forested streams that they have been associated with in the past (McDowall et al. 1996a). Shortjaw kokopu may now be less commonly documented from large streams because of sampling bias (see Chapter Two), landuse modifications in lowland areas affecting large mainstem (third order and above) rivers and the possible deleterious effect of introduction of trout (see Chapter Four).

Habitat occupancy

In summary, the distribution of shortjaw kokopu within and between streams in the Nelson Marlborough conservancy is likely to be affected by human modifications to the land surrounding streams, as well as direct instream modifications. However, shortjaw kokopu did occupy a relatively wide range of streams in the Nelson Marlborough conservancy. This can be partially related to the high proportion of native forest in the catchment and riparian zone of streams surveyed in this area. Many streams that did not contain shortjaw kokopu were similar to streams with shortjaw kokopu, thus it appears that habitat is not the only factor limiting the abundance of shortjaw kokopu in this area. If habitat is not limiting shortjaw kokopu, why are they not more widespread and abundant? The multi-variate analysis in this chapter did not include distance inland and altitude measurements because I wanted to assess the importance of local habitat conditions for shortjaw kokopu populations. Distance inland and altitude are important predictors of freshwater fish communities in New Zealand (McDowall 1993, Jowett and Richardson 1996, Joy and Death 2000). The majority of streams (96 %) in this study were within the known habitat range of

shortjaw kokopu (520 m asl and 206 km inland) (McDowall 2000). In the next two chapters I assess the importance of inter-specific interactions and dispersal on shortjaw kokopu distribution.

The current habitat range of shortjaw kokopu may be 'sub-optimal', compared to their habitat range before the arrival of Europeans (McDowall 1980). Therefore, defining the 'habitat requirements' of shortjaw kokopu should be done with caution. Sheldon (1988), and Gray and Craig 1991 recommend that the concept of 'habitat requirements' for conservation of threatened animal species be abandoned for a more all-encompassing approach, taking into account past distribution, behavioural plasticity, and social transmission. Similarly, Norton and Reid (1997) discuss, in relation to mistletoes, that conservation management requires an ecosystem approach that addresses direct and indirect causes of current distribution patterns. It is possible that on a national scale shortjaw kokopu are restricted by their specific habitat requirements. However, at the local scale where environmental conditions are favourable, habitat does not appear to be restricting shortjaw kokopu. The range of forested streams shortjaw kokopu occupy in the Nelson Marlborough conservancy indicates they have relatively broad habitat requirements.

“Man has great power of speech,
but the greater part thereof is empty and deceitful.
The animals have little,
but that little is useful and true;
and better is a small and certain thing
than a great falsehood.”

Leonardo da Vinci



CHAPTER FOUR

Fish assemblages in Nelson and Marlborough

INTRODUCTION

Factors affecting community composition

Community and population structure are influenced by random (stochastic, abiotic) and non-random (deterministic, biotic) processes (Power et al. 1988, Dunston and Travis 1991, Hildrew and Giller 1994). Some models (e.g. the harsh-benign model of community dynamics) suggest that deterministic processes dominate in stable environments, whereas stochastic processes will have a larger influence on community structure in unstable environments (Connell 1975, Menge 1976, Menge and Sutherland 1976, Peckarsky 1983, Ives and Klopfer 1997). However, recent research contradicts the harsh-benign hypothesis. Thomson and co-workers (2002) found that predator induced prey emigration increased during floods. Random and stochastic processes are not necessarily mutually exclusive and may influence community structure to varying degrees (May 1986, Townsend 1989, Dunston and Travis 1991, Allan 1995). In this chapter I examine the potential effect of biotic interactions on the distribution and abundance of shortjaw kokopu. Is it possible, that despite their migratory life cycle and the patchy nature of streams, that biotic interactions affect shortjaw kokopu distribution and abundance?

The longitudinal nature of stream environments and the effect of upstream processes on downstream areas are major factors structuring aquatic communities (Vannote et al. 1980, Ward 1989, Winterbourn and Townsend 1991). However, downstream processes can also affect upstream processes (Fraser et al. 1995, Pringle 1997). In New Zealand, over 50 % of freshwater fish species are diadromous. Not surprisingly then, fish community structure, especially at low elevation sites are affected by

downstream processes (McDowall 1995). The structure of fish communities in the Nelson Marlborough conservancy may be affected by anthropogenic disturbances and influenced by the differential migratory abilities of fish species.

Tropical fish assemblages are to some extent controlled by processes outside of the local habitat (Sale 1988). Sale (1988) showed that assemblages of some tropical fish communities varied greatly through time and suggested that composition was attributed to the proximity of recruits at a time when space was available. McDowall (1996) argues that on a continuum, freshwater fish communities that contain diadromous species are relatively 'open' and are controlled by ecological time events and processes outside of the community itself. In comparison, non-diadromous fish communities in streams and lakes are relatively 'closed' (i.e. community composition is related to evolutionary time events). New Zealand freshwater fish communities, particularly those in low elevation streams that contain a high proportion of diadromous fish species, may be examples of open ecological systems (McDowall 1990a, McDowall 1996). Invasion/reinvasion of freshwater habitat via marine dispersal might have a large influence on community structure at the 'stream scale'. Fish communities in the Nelson Marlborough region may be predominantly structured by diadromy. However, shortjaw kokopu habitat occupancy at a local scale may be influenced by processes within streams, for example interactions with other fish species.

Species interactions

The occupation of specific areas of space by organisms can be influenced by a wide range of variables (Gause 1934, Hardin 1960, Hildrew and Giller 1994, Allan 1995). When species have overlapping habitat ranges, the composition and structure of communities may reflect intra- and inter-specific interactions that take place through time (ecological and evolutionary) and in space (Connell 1980, McDowall 1990b). Detrimental interactions between individuals of the same or different species may involve competition for resources (Wilson et al. 1998, Beggs and Rees 1999, Chadderton and Allibone 2000, Jackson et al. 2001) and predation (Crowl et al. 1992, Wilson et al. 1998, McIntosh 2000, Jackson et al. 2001). Species interactions may also be beneficial to individuals (Greene and Stamps 2001). For example, the use of

chemical cues by individuals to home or to disperse to areas occupied by conspecifics, increases the chances of finding 'suitable' habitat (Nordeng 1971, Nordeng 1977, Stamps 1987, Stamps 1988). Baker and Montgomery (2001) found that banded kokopu juveniles were attracted to pheromones produced by adult conspecifics. Therefore, the dynamics of diadromous fish communities may also be influenced by species that are already established (i.e. they are founder controlled) (sensu Townsend 1989).

In New Zealand, there are few studies on interactions between native fish species in controlled or experimental conditions (but see Glova 1999). However, the longitudinal distribution of freshwater fish species within streams, and the distribution of species of throughout New Zealand, has been well researched (Main 1989, Jowett and Richardson 1996, Allibone and Townsend 1997, Jowett et al. 1998, Chadderton and Allibone 2000, Joy et al. 2000). Some native fish species occupy different habitat and display different behaviour in the presence or absence of other native fish species, but the mechanisms explaining these patterns are unclear (McDowall and Allibone 1994, Hayes 1996, Chadderton and Allibone 2000). Shortjaw kokopu may alter the habitat they occupy, or may affect the habitat occupied by other native fish species.

Exotic organisms

Species may avoid or reduce competition, or the threat of predation from another species by occupying specific habitats that do not overlap with the predator (i.e. mutually exclusive distributions) (Nilsson 1967). Furthermore, where distributions overlap they may evolve morphological features or life history tactics that reduce the chances of being preyed on (e.g. Reznick et al. 1996). Allopatric distributions of predator and prey species or fragmented prey populations (e.g. Fraser et al. 1995) can also be attributed to the removal of prey species by predatory species, especially where the predator is introduced (Townsend and Crowl 1991). In communities where predatory species are introduced, prey species have little time to evolve anti-predator tactics (however, see Edge et al. 1993, McIntosh and Townsend 1995 and 1996) and therefore the effects may be marked (Pracy 1974, Taylor and Thomas 1993). The distribution and abundance of shortjaw kokopu within and between streams may be affected by the presence of introduced trout.

The introduction of exotic organisms can cause changes in species assemblages (Coblentz 1990, Soule 1990, McDowall 1990b, Crowl et al. 1992, Lodge 1993, Taylor and Thomas 1993, Mack et al. 2000). At the extreme, exotic organisms may cause extinctions of native species (Townsend et al. 1997). Rare species or species that have evolved in the absence of a dominant predator have a higher chance of extinction in the presence of an invading species (O'Donnell 1996, Meffe and Carroll 1997). Exotic organisms may reduce the range and cause decreases in the abundance of native species (Wilson et al. 1998). Furthermore, exotic organisms can potentially alter and degrade the physical environment to the detriment of native species (Pracy 1974, Townsend 1991).

Trout in New Zealand

The introduction of brown (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) in the late 1800's and their subsequent rapid colonisation of all accessible habitat is thought to have had a detrimental effect on New Zealand's native fish fauna (McDowall 1990b, Crowl et al. 1992). The effect of trout on large-bodied *Galaxias* species is not well understood. Recent studies indicate that large trout (> 150 mm FL) can prey on galaxiids of a least 120 mm FL (McIntosh 2000) and are associated with declines of small non-migratory galaxiids in Otago and Canterbury (Townsend and Crowl 1991). However, other studies indicate that trout and galaxiids can co-occur (Kusabs and Swales 1991, Glova and Sagar 1993, McIntosh et al. 1994). Predation by trout on shortjaw kokopu may be size related. Trout are gape limited and their growth is influenced by the availability of large areas of holding water (Jowett 1992, Mittelbach and Persson 1998). Thus, because shortjaw kokopu grow up to 350 mm FL and are commonly 150 – 200 mm FL (McDowall 2000), they may have a size refuge from trout predation. Trout are also known to competitively exclude small non-migratory galaxiids from their preferred foraging habitats (McIntosh et al. 1992, Edge et al. 1993). Trout may competitively exclude or displace shortjaw kokopu, where habitat allows them to reach high numbers. Furthermore, the effect of trout predation and competition on shortjaw kokopu may not be obvious because individuals that are eaten or displaced are continually replaced by juveniles returning from the marine environment. In this study I examine the effect of trout presence,

size and abundance on shortjaw kokopu at the tributary scale and the potential for biotic interactions to affect the distribution of shortjaw kokopu.

METHODS

Site selection

Initial site selection was from NZMS 260 1:50 000 topographical maps. Recommendations from McDowall and co-workers (1996a) report, "Critical habitats for the conservation of shortjawed kokopu, *Galaxias postvectis*" and experience gained throughout the survey also helped site selection. Sites were visited prior to spotlighting to ensure accessibility and gain permission from landowners where necessary. Four hundred metres of stream was marked with flagging tape and/or rock cairns to ensure re-location after sunset (see Chapter Two for full details).

Collection of fish data

Spotlighting methodology

Streams were spotlighted two hours after sunset. This allowed fish to move from day time cover and settle into their night time feeding positions before spotlighting began. Two surveyors worked their way methodically upstream spotlighting all habitat types (see Chapter Three). Spotlights had limited effectiveness in fast flowing broken water (for example, riffle habitat). Thirty-five watt and 50 watt spotlights, powered by 12 volt dry cell batteries were used to illuminate water and locate fish. Each surveyor also wore a headlamp to allow spotlights to be turned off after fish were located. This freed both hands and subsequently improved the manoeuvrability of hand held dip nets used to capture fish.

The presence of all fish species was recorded. Fish species, other than shortjaw kokopu and brown trout, were only caught when their identification needed clarification. For shortjaw kokopu, size and abundance were recorded. The size

range of trout were recorded at each site. Trout abundance was classified into the following categories: rare (< 4 individuals/500 m²), occasional (4-9 individuals/500 m²), common (10-19 individuals/ 500 m²) or abundant (< 20 individuals/500 m²). All captured shortjaw kokopu were measured. If fish escaped capture, but a positive identification was made, an estimated size was recorded (± 10 mm).

Analysis

Species richness

Fish species richness for all species, migratory species, non-migratory species and introduced species were calculated for streams with and without shortjaw kokopu. Two sample t-tests assuming unequal variance were performed to test if there was a significance difference between the average number of fish species at sites with and without shortjaw kokopu. The average number of migratory species and the average number of non-migratory species, and exotic species for all sites were tested for differences with t-tests. T-tests were performed in SYSTAT version 10.

Species associations

To distinguish between species that co-occurred with shortjaw kokopu because they are widespread habitat generalists and those species that had similar habitat requirements to shortjaw kokopu, preference ratios were calculated for ten species that occurred at greater than five percent of all sites (Table 4.1, after McDowall et al. 1996a). The preference ratio is a measure of the affinity of fish species co-occurring with shortjaw kokopu for similar habitat. Detrended correspondence analysis (DECORANA) using PCORD was performed on presence/absence data of 11 fish species including shortjaw kokopu and excluding species occurring at less than five percent of sites to determine which species were most closely associated with shortjaw kokopu (Table 4.1).

Trout analysis

The effect of trout size on the presence or absence of shortjaw kokopu was tested using a chi-square test of independence. Sites were categorised according to the presence or absence of small (< 150 mm FL) or large (> 150 mm FL) trout. These categories were used because trout become piscivorous at sizes around 150 mm (Mittelbach and Persson 1998). A chi-square analysis was used to test if the presence or absence of shortjaw kokopu was independent of the categorical abundance of trout. The relationship between the maximum size of trout and the average size of shortjaw kokopu was tested using linear regression and ANOVA (SYSTAT version 10).

Principal component analysis (PCA) and discriminant functions analysis (DFA) were carried out on streams with trout (25 variables) and without trout (17 variables) using habitat and fish variables to predict the presence and absence of shortjaw kokopu (SYSTAT version 10). Ryan-Joiner tests of normality using Minitab 13 were performed on habitat variables. Where necessary, arcsin square root or log transformations were performed on habitat variables to normalise data (Table 4.2). After transformation if variables still did not fit a normal distribution they were removed from the analysis. PCA reduced 25 variables to ten factors with eigenvalues greater than one for 'trout stream data', and 17 variables to seven factors with eigenvalues greater than one for 'trout-less stream data'. These factors were subjected to forward stepwise discriminant functions analysis to identify the variables that best separated sites with and without shortjaw kokopu. PCA component loadings accounting for at least 25 percent of a variable's variance (an absolute loading of 0.5) were assumed to be important for predicting the presence or absence of shortjaw kokopu (Dillion and Goldstein 1984).

RESULTS

Co-occurring species

Sixteen species were recorded from the 148 streams surveyed (Table 4.1). Shortjaw kokopu (*Galaxias postvectis*) (52%), longfin eels (*Anguilla dieffenbachii*) (92%), redfin bully (*Gobiomorphus huttoni*) (74%) and banded kokopu (*Galaxias fasciatus*) (57 %) were recorded in more than 50 % of the 148 streams surveyed. Bluegill bully (*Gobiomorphus hubbsi*), upland bully (*Gobiomorphus breviceps*), smelt (*Retropinna retropinna*) and torrent fish (*Cheimarrichthys fosteri*) occurred at less than five percent of all sites surveyed (Table 4.2).

Table 4.1 The percent occurrence of all species captured or observed in the Nelson Marlborough conservancy.

Variable	% occurrence
Shortjaw kokopu, <i>Galaxias postvectis</i>	52
Giant kokopu, <i>Galaxias argenteus</i>	21
Banded kokopu, <i>Galaxias fasciatus</i>	78
koaro, <i>Galaxias brevipinnis</i>	56
inanga, <i>Galaxias maculatus</i>	62
Dwarf galaxias, <i>Galaxias divergens</i>	16
Giant bully, <i>Gobiomorphus gobioides</i>	14
Redfin bully, <i>Gobiomorphus huttoni</i>	88
Common bully, <i>Gobiomorphus cotidianus</i>	8
Bluegill bully, <i>Gobiomorphus hubbsi</i>	< 5
Upland bully, <i>Gobiomorphus breviceps</i>	< 5
Torrentfish, <i>Cheimarrichthys fosteri</i>	< 5
Smelt, <i>Retropinna retropinna</i>	< 5
Longfin eel, <i>Anguilla dieffenbachii</i>	97
Brown trout, <i>Salmo trutta</i>	30

Species richness

The average number of all species ($t = -9.74$, $df = 138$, $p < 0.05$) and the average number of migratory species ($t = -10.90$, $df = 144$, $p < 0.05$) was significantly higher at sites where shortjaw kokopu were present than where they were absent (Figure

4.1). Non-migratory ($t = 1.52$, $df = 138$, $p = 0.12$) and exotic species ($t = -0.146$, $df = 145$, $p = 0.88$) did not differ significantly in species richness in the presence or absence of shortjaw kokopu (Figure 4.1). However, exotic ($t = 22.28$, $df = 163$, $p < 0.05$) and non-migratory ($t = 22.79$, $t = 162$, $p < 0.05$) species were far less common than migratory species at all sites. Only two non-migratory species, dwarf galaxias (*Galaxias divergens*), upland bully (*Gobiomorphus breviceps*), and one introduced species brown trout (*Salmo trutta*) were recorded in the entire survey.

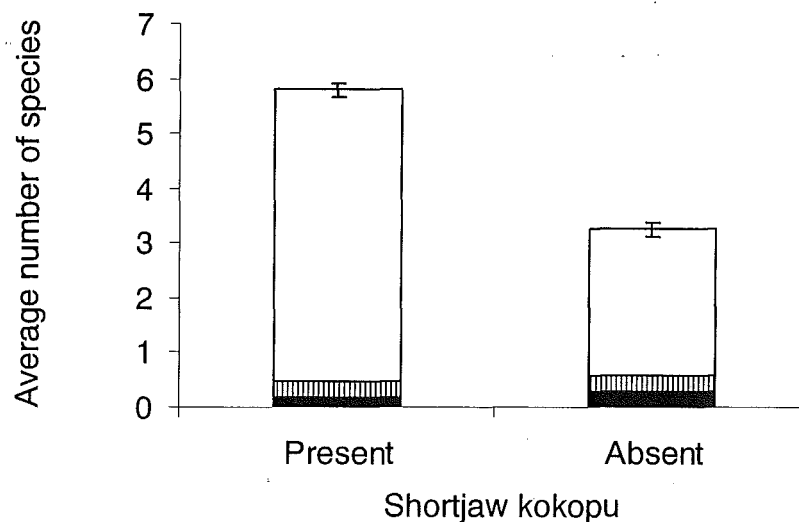


Figure 4.1 Species richness of migratory (unfilled sections), non-migratory (black sections) and introduced species (shaded sections) in the presence ($n = 77$) and absence ($n = 71$) of shortjaw kokopu. Standard error bars (± 1 s.e.) are for total species richness.

Predictive models

DECORANA was performed on 11 fish species (Table 4.1) using PCORD version 4. Species that occurred at less than 5 % of the 148 streams surveyed were removed from the DECORANA because this type of analysis is very sensitive to rare species. Shortjaw kokopu were most closely associated with inanga (*Galaxias maculatus*) and banded kokopu (*Galaxias brevipinnis*) and redfin bully (*Galaxias huttoni*) in the ordination (Figure 4.2). Species with the highest preference ratios (column ten in

Table 4.2) for shortjaw kokopu streams were giant kokopu (*Galaxias argenteus*), inanga, banded kokopu, common bully (*Gobiomorphus cotidianus*) and koaro (*Galaxias brevipinnis*) (Table 4.2). Giant kokopu were not closely associated with shortjaw kokopu on the ordination, however they had a high 'preference ratio' for shortjaw kokopu streams. Shortjaw kokopu were present at 16 of the 21 sites occupied by giant kokopu. Longfin eel (*Anguilla dieffenbachii*), giant bully (*Gobiomorphus gobioides*), redfin bully (*Gobiomorphus huttoni*) and brown trout (*Salmo trutta*) had a low affinity for shortjaw kokopu streams, however they co-occurred with shortjaw kokopu in at least 50 % of the streams surveyed. Dwarf galaxias had the lowest preference ratio for shortjaw kokopu streams. They occurred at only 16 % of the 77 sites with shortjaw kokopu.

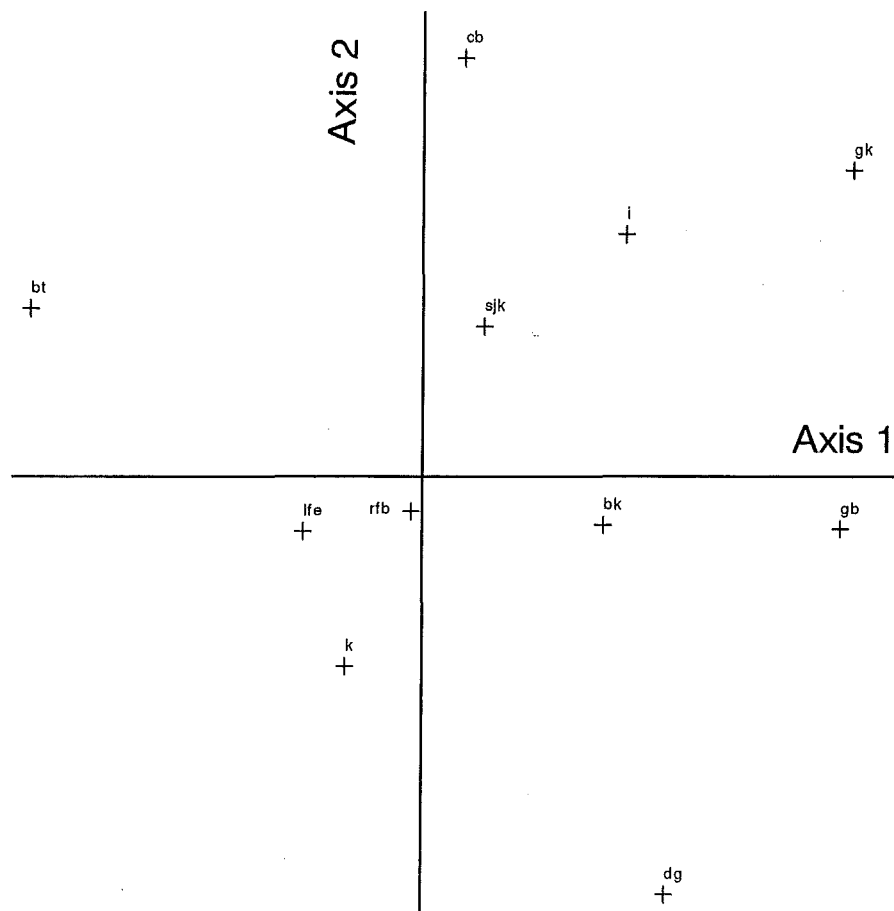


Figure 4.2 The first two axes from detrended correspondence analysis of fish communities (presence/absence) in the Nelson Marlborough conservancy. Abbreviations are, cb, common bully; bt, brown trout; sjk, shortjaw kokopu; i, inanga; gk, giant kokopu; lfe, longfin eel; rfb, redfin bully; bk, banded kokopu; gb, giant bully; k, koaro; and dg, dwarf galaxias.

Table 4.2 'Preference ratios' of fish species that co-occur with shortjaw kokopu (SJK) in the Nelson Marlborough conservancy. More detailed descriptions of columns are given on the next page.

Column number	1	2	3	4	5	6	7	8	9	10
Description	no. sites species co-occur with SJK	rank of column 1	no. sites species occurs at in survey	column 1 as % of no. sites species co-occurs with SJK	no. sites species co-occurs with SJK as % of total	% from column 5 ranked	shift in rank from column 2 to 6	total no. sites species recorded as % of total	ratio of column 4 to column 8	column 9 ranked
Species										
Giant kokopu	16	7	21	21	76	1	6	14	1.5	1
Banded kokopu	60	3	85	78	71	3	0	57	1.37	3
koaro	43	5	66	56	67	4	1	45	1.24	5
inanga	48	4	66	62	73	2	2	45	1.38	2
Dwarf galaxias	12	8	28	16	43	10	-2	19	0.84	10
Giant bully	11	9	18	14	61	6	3	12	1.17	7
Redfin bully	68	2	110	88	62	5	-3	74	1.19	6
Common bully	6	10	9	8	60	7	3	6	1.33	4
Longfin eel	75	1	137	97	55	8	-7	93	1.04	9
Brown trout	23	6	45	30	51	9	-3	30	1.00	8

The following descriptions relate to **Table 4.2**.

- Column 1** The actual number of sites at which each species co-occurs with shortjaw kokopu ($= n$).
- Column 2** Rank of co-occurring species.
- Column 3** The number of sites that each co-occurring species is recorded in the survey (148 sites) ($= w$).
- Column 4** The number of sites a species co-occurs with shortjaw kokopu as a percentage of the 77 sites from which shortjaw kokopu is known ($= n/77$ as a percentage).
- Column 5** The number of sites which each species co-occurs with shortjaw kokopu as a percentage of the total number of records for that species in the survey ($= n/w$ as a percentage).
- Column 6** Percentages from column five are ranked.
- Column 7** Shift in rank from column 2 to column 6 (i.e. column 6 minus column 2). A negative digit indicates that the ranking has increased and the species is more prevalent in shortjaw kokopu sites than in all sites (it shows a preference for shortjaw kokopu sites) and a positive digit means the opposite.
- Column 8** The number of sites from which each co-occurring species is known as a percentage of the total number of site records in the survey (148) ($= w/148$ as a percentage).
- Column 9** The ratio of percentage occurrence of co-occurring species in shortjaw kokopu sites to the percentage occurrence of that co-occurring species in all 148 survey sites, the species "preference ratio" (ratio of column 4 to column 8).
- Column 10** Ratios are ranked.

Trout analysis

The presence of shortjaw kokopu was independent of the presence of small (<150 mm FL) or large (>150 mm FL) trout (chi-square = 2.356, df = 2, $p > 0.05$) (figure 4.3). There was however, a significant relationship between the categorical abundance of trout and the presence or absence of shortjaw kokopu (chi-square = 3.98, df = 1, $p < 0.05$). Shortjaw kokopu were more likely to be present when trout were rare or occasional, than when they were common or abundant (Figure 4.4). There was no relationship between the average length of shortjaw kokopu and the maximum length of trout ($r = -0.247$, $p = 0.256$, Figure 4.5).

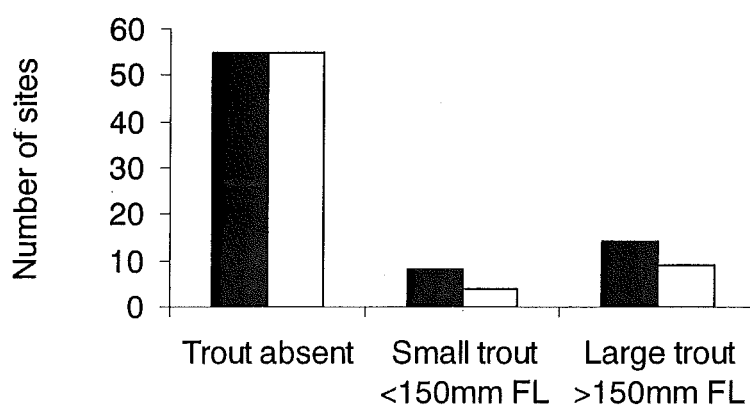


Figure 4.3 The number of sites at which shortjaw kokopu are present (filled bars) or absent (unfilled bars) with or without small or large trout.

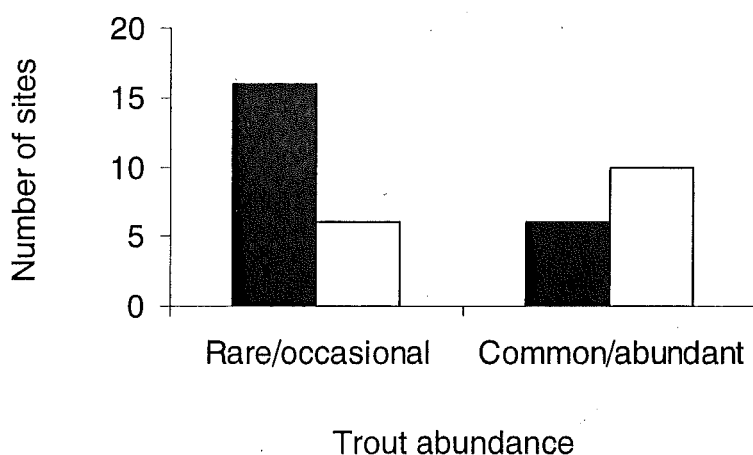


Figure 4.4 Presence (filled bars) and absence (open bars) of shortjaw kokopu at sites where trout were rare or occasional compared to common or abundant

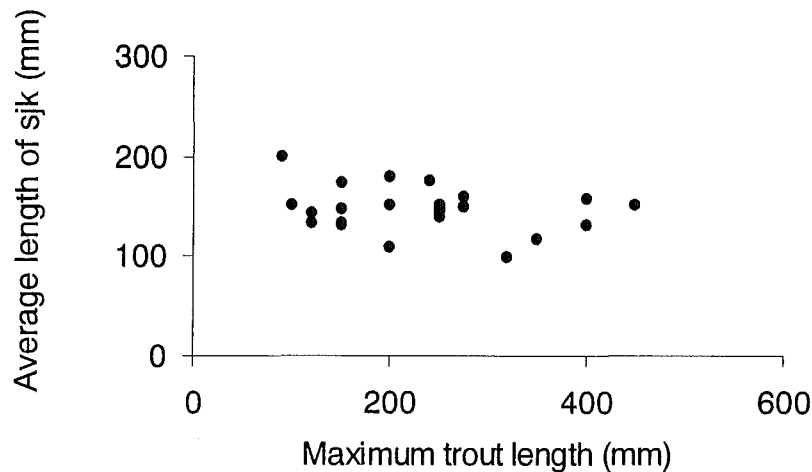


Figure 4.5 Average length of shortjaw kokopu and maximum length of trout in streams where they co-occur.

Multivariate analysis of trout and troutless streams

Three out of ten PCA factors were retained after forward stepwise DFA on habitat and fish variables in streams where trout occurred. These three factors collectively explained 30 % of the variance in shortjaw kokopu presence or absence. Eighty-three percent of sites with and without shortjaw kokopu were correctly classified according to a jackknifed classification matrix (see Chapter Three for more details on this method). In streams with trout, shortjaw kokopu presence was best predicted by giant kokopu, banded kokopu, inanga, high species richness, low trout abundance, low percentages of bank vegetation as a form of fish cover and a low percentage of rapid habitat (Table 4.3, Figure 4.6a). Four out of seven PCA factors were retained after forward stepwise DFA on habitat and fish variables in streams without trout. These four factors collectively explained 47 % of the variance in shortjaw kokopu presence and absence. Seventy-eight percent of sites were classified correctly using these four factors (Jackknifed classification matrix). In streams without trout the best predictors of shortjaw kokopu presence were banded kokopu, inanga, giant bully, redbfin bully, high species richness, high maximum depth, a high percentage of substrate (for fish cover) and low percentages of overhead shade (for fish cover) (Table 4.3, Figure 4.6b).

Table 4.3 Fish and habitat variables used in the ‘trout stream’ and ‘troutless stream’ PCA and DFA analyses. Statistical transformations and factors significant in discriminating shortjaw kokopu presence and absence for trout streams (factors 1, 6 and 5); and for troutless streams (factors 1, 2, 6 and 5). Component loadings that explained greater than 25 % of the variance of factors with positive (+) and negative (-) associations are indicated. Component loadings that explain less than 25 % of the variance are blank. * indicates categorical fish variables used in each analysis.

Variable	Trout streams	F1	F6	F5	Troutless streams	F1	F2	F6	F5
Fish variables									
Giant kokopu	*	+			*				
Banded kokopu	*	+	+		*	+			
Koaro	*				*			+	
Inanga	*	+			*	+			
Dwarf galaxias	*				*				
Giant bully	< 5 % sites				*	+			
Redfin bully	*				*	+			
Common bully	*				*				
Longfin eel	*				*				
Trout abundance	*	-							
Species richness	*	+			*	+			
Depth									
Average depth	log				non-normal				
Maximum depth	log				log		+		
Width									
Average width	non-normal				non-normal				
Habitat									
Still	arcsin sqrt				normal				
Backwater	normal				non-normal				
Pool	arcsin sqrt				non-normal				
Run	arcsin sqrt				non-normal				
Riffle	normal				non-normal				
Rapid	normal	-			normal				
Cascade	normal				normal				
Fish Cover									
Substrate	normal				arcsin sqrt		+		
Weed/algae	arcsin sqrt			-	normal				-
Instream debris	normal				non-normal				
Bank vegetation	normal	-			non-normal				
Undercut banks	normal				non-normal				
Overhead shade	arcsin sqrt				arcsin sqrt		-		

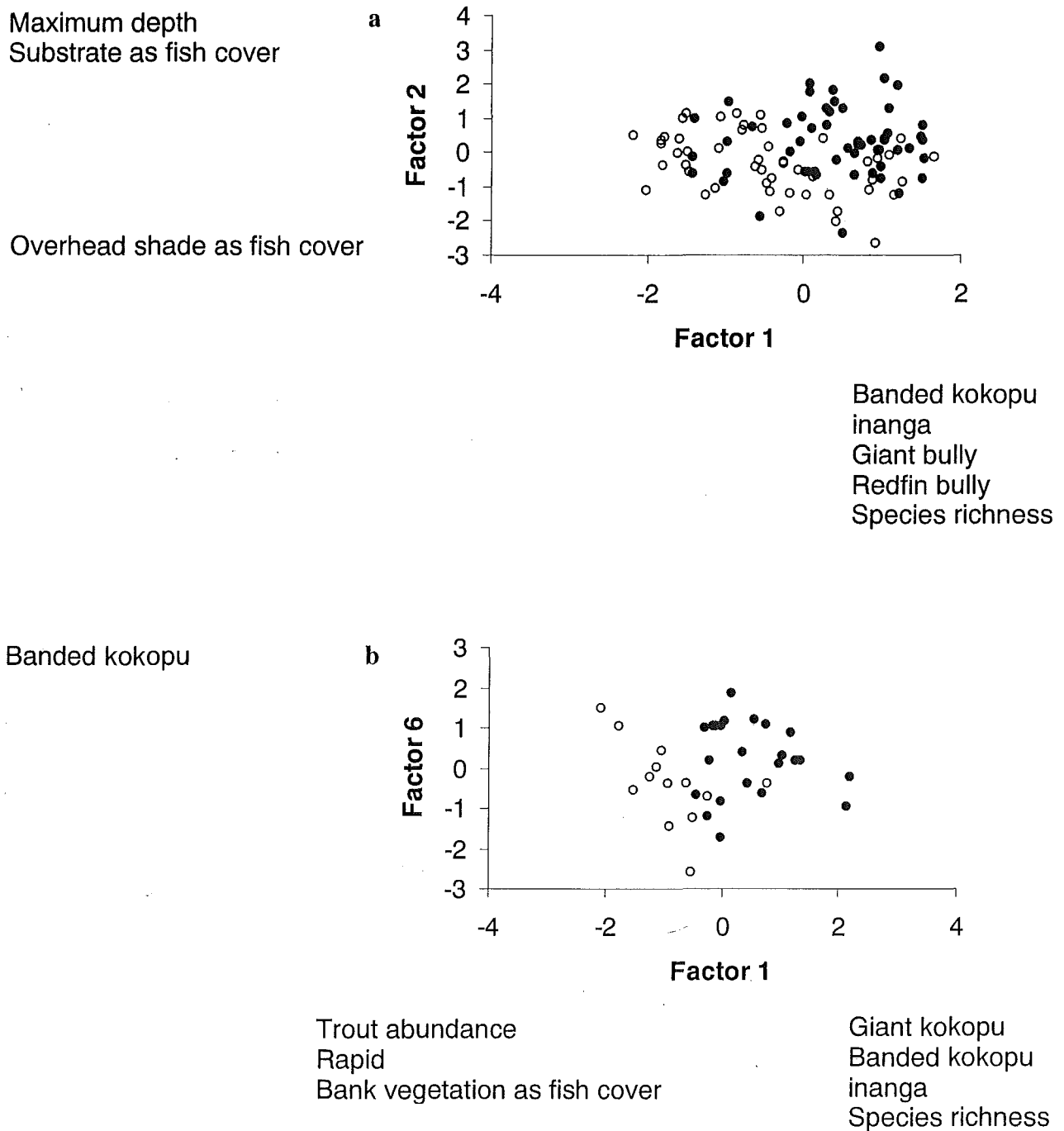


Figure 4.6 Scores for the first two factors (accounting for 22 % and 11 % of the variance, respectively) derived from PCA and DFA on habitat and fish variables in streams without trout (**a**), and scores for the first two factors (accounting for 16 % and 7 % of the variance, respectively) derived from PCA and DFA on habitat and fish variable in streams with trout (**b**). Symbols indicate sites where shortjaw kokopu are present (solid circles) and absence (open circles). Variables correlated with the factors are shown on the axes.

DISCUSSION

Species composition

In this study significantly more fish species, in particular migratory species, were present in streams containing shortjaw kokopu than in streams without shortjaw kokopu. Species that had a high affinity for shortjaw kokopu streams and were closely associated with shortjaw kokopu using ordination, included the four other migratory *Galaxias* species (giant kokopu, banded kokopu, koaro, and inanga). Low species richness in some of the streams that shortjaw kokopu did not occur in may be attributed to elevation and distance to the sea (i.e. they may have been outside the migratory range of most diadromous species) and the species that did occur at these sites were probably non-diadromous. Furthermore, low richness at sites without shortjaw kokopu could also be attributed to low water quality and lack of native vegetation, therefore only species 'tolerant' to habitat degradation may have been present.

The strong correlation between species richness and the presence of migratory species indicates that fish communities in the area studied are highly structured by diadromy. It appears that because the fish communities contain diadromous species they could be largely controlled by processes operating outside the community and are relatively 'open' (Sale 1988, McDowall 1996). However, the role of local processes in structuring communities should not be underestimated. Even though this study examined 'reach scale' (400 m) patterns of community composition there was some evidence that local biotic interactions could be important.

Interactions with trout

The presence of shortjaw kokopu could not be predicted by the absence or presence of small (< 150 mm FL) or large (>150 mm FL) trout. This differs from the relationship between trout and non-migratory galaxiids. McIntosh (2000) found that non-migratory galaxiids were absent from sites with trout greater than 150 mm FL (i.e. piscivorous trout). In the current study, piscivorous trout (the maximum size of trout

ranged from 100 mm FL to 400 mm FL) often co-occurred with shortjaw kokopu. It is possible that trout predate on shortjaw kokopu. However, because trout are gape limited and shortjaw kokopu grow up to 350 mm FL, and are commonly 150 to 200 mm FL, adult shortjaw kokopu may have a size refuge from trout predation. The mechanisms behind the co-occurrence of shortjaw kokopu and brown trout are unclear. However, shortjaw kokopu were more likely to be present at sites where trout were rare or occasional than where they were common or abundant. Thus, the effect of trout on shortjaw kokopu may depend on trout abundance.

This study documented shortjaw kokopu and trout co-occurrence in 400 metre reaches, their co-occurrence at a smaller scale was not quantified. Trout are known to be aggressive competitors, especially for optimum foraging sites, thus native species may find it difficult to compete with trout (McIntosh et al. 1992, Townsend 1996). It is possible that trout and shortjaw kokopu populations may be segregated within streams at small scales. Bohn and Amundsen (2001) found a successive process of competition and interactive segregation in a study on invading vendace and native whitefish in Norway and Russia. This segregation decreased direct competition, however competition was still strong despite the low overlap in the range of vendace and whitefish (Bohn and Amundsen 2001). In the multivariate analysis of habitat and fish variables shortjaw kokopu presence and absence were more clearly separated in trout streams than in troutless streams. Furthermore, trout abundance was one of the factors causing separation of these sites. There are a number of explanations for this finding.

The presence of trout in shortjaw kokopu habitat is regulated by several mechanisms. Trout require stable streams with gravels to spawn in, thus they may be absent or found in low numbers in streams that do not meet this criteria (Jowett 1992). McIntosh (2000) found that large trout were absent from unstable streams, whereas, non-migratory galaxiids were able to occupy these unstable streams. Furthermore, growth and abundance of trout are related to the presence of large areas of holding water (Jowett 1992). The majority of streams where shortjaw kokopu and trout co-occurred in this study were tributaries of the Aorere River. Most of these tributaries lacked large areas of holding water. Moreover, tributaries of the Aorere River are likely to act as spawning sites, and nursery streams for juvenile trout and large trout

eventually migrate into the mainstem (N. Deans, *pers. comm.*). While speculative, the low abundance of trout may allow shortjaw and trout to co-occur in Aorere River tributaries. Whereas in river systems where tributaries contain large areas of holding water, trout may reach high numbers and exclude shortjaw kokopu.

There are no quantitative historical data on the distribution of shortjaw kokopu prior to the introduction of trout. Thus, it is not possible to determine whether shortjaw kokopu used to occupy the mainstem rivers now occupied and dominated by trout. However, this possibility can not be discounted. This study showed that shortjaw kokopu do occupy mainstem rivers (Chapter Three). Furthermore, the predictive model of shortjaw kokopu presence and absence in troutless streams indicated that the shortjaw kokopu were positively associated with the maximum depth of streams. Also supporting this hypothesis is the finding that bank vegetation and overhead shade as forms of fish cover were less important than substrate cover in the predictive models. This implies that although native forest is important, it may not be solely as a source of cover. The typical streams shortjaw kokopu have been documented from in the past are small with dense overhanging vegetation. However, this study demonstrates shortjaw kokopu can occupy sites where native vegetation is intact, but not overhanging. In summary, trout and shortjaw kokopu co-occur in small to medium sized streams, however it is possible that shortjaw kokopu have been displaced from large mainstem rivers by trout. Nonetheless, even if shortjaw kokopu adults have never occupied large mainstem rivers, trout may still affect the population dynamics of shortjaw kokopu by predating on juveniles as they move upstream.

Factors controlling community structure

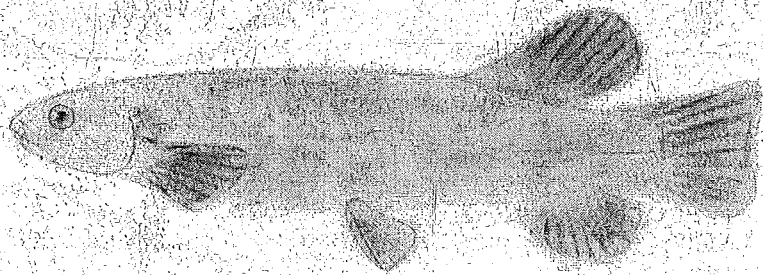
It is difficult to determine if interactions among native fish are also influencing fish community structure. Chadderton and Allibone (2000) found that the micro-habitat of koaro appeared to be influenced by the presence of banded kokopu and longfin eel. In the absence of these two species, koaro occupied a wider range of micro-habitats. Similar findings regarding the micro-habitat occupied by koaro in different species assemblages have been documented by Main (1988) and Hayes (1996). Some species may live in close vicinity of each other without there being any 'direct' interactions (for example, where resources are not limiting or 'preferred' micro-habitats are

different). However, detecting interactions (especially indirect or higher order interactions) is difficult, and not always apparent from pairwise studies on organisms (Masters and Brown 1992, Billick and Case 1994, Kareiva 1994, Berlow et al. 1999). Interactions between shortjaw kokopu and other native and introduced species may not be apparent from large scale field observations. Further research is needed at small scales to find out if interactions between diadromous fish species are important for stream community structure.

The influence of diadromy may offset the possible effects of trout on shortjaw kokopu. For example, shortjaw kokopu individuals eaten or displaced by trout are constantly replaced by recruits returning from the marine environment. Diadromy may also serve to reduce competition between natives if recruitment controls population size.

"Fish are mothers too."

Paul Reps



CHAPTER FIVE

Population dynamics and recruitment

INTRODUCTION

Population processes

Population densities vary in time and space (Krebs 2001). Processes (e.g. natality, mortality, immigration and emigration) that affect the density and structure of populations differentially influence various stages (for example, juveniles and adults) (Krebs 2001). Furthermore, biotic and abiotic factors (extrinsic factors) along with the physiology and genetics of individuals (intrinsic factors) interact with population processes to regulate or limit population density (Power et al. 1988, Dunson & Travis 1991, Krebs 2001). In this chapter I describe an investigation of the possible factors affecting shortjaw kokopu populations.

In unstable environments the composition of species and individual population dynamics may be greatly influenced by stochastic events (Lake 2000), whereas in stable environments, deterministic factors such as interactions between species and the density of species may have a larger influence on community and population structure (Menge 1976, Menge and Sutherland 1987, Peckarsky 1983). However, recent research shows that biotic interactions may be just as strong in unstable environments as they are in stable environments (Thomson et al. 2002). Stochastic and deterministic factors are likely to differentially influence various stages in the life-cycle of shortjaw kokopu. Here I examine possible factors that influence the number of juvenile galaxiids recruiting to the adult population and the subsequent effect on adult population structure.

Factors affecting shortjaw kokopu population dynamics

The structure of populations, or communities of species may be affected to varying degrees by competition (intra- and inter- specific) for resources (i.e. food and space) and threat of predation. Individual 'choice' of an area to 'settle' may be affected by the presence of predators and competitors (Brown 1969, Holt 1987, Ens et al. 1995). The strength of competition, threat from predation and direct predation are influenced by density-dependent processes (Begon et al. 1997). Where resources are limited and populations are near carrying capacity, density-dependent processes may structure communities. There is little evidence that this is the case for shortjaw kokopu populations and diadromous fish communities. Individual habitat selection is often researched in relation to high-density populations and less is known about the processes affecting individual habitat 'choice' in low density populations (Greene & Stamps 2001). For shortjaw kokopu and other diadromous fish species, dispersal and stochastic events could be particularly important.

Downstream – upstream linkages

Diadromy, on a world wide scale is a minority phenomenon (Gross 1987, McDowall 1987, Gross et al. 1988). Less than one percent of fish species are diadromous (Magurran 1993). In New Zealand over 50 % of species are diadromous (McDowall, 1996). Therefore, fish communities in New Zealand, especially in low elevation streams are greatly structured by diadromy and are likely to be affected by downstream processes. The effect of upstream processes on downstream areas have been extensively researched and discussed (Vannote et al. 1980, Ward 1989, Winterbourn & Townsend 1991). Upstream flight of adult stream invertebrates might compensate for larval drift (Hershey et al. 1993), but there are few studies on instream processes and their transfer upstream. McDowall (1998) lists studies on upstream migrations of aquatic benthos (Muller 1982, Williams & Williams 1993) and nutrient transfer by anadromous fish (Cederholm et al. 1989, Garman 1992) as some of the few studies examining downstream-upstream trajectories.

More recently, Pringle (1997) studied the effects of downstream human modifications on upstream processes in a Puerto Rican stream. Pringle (1997) argued that

modifications to downstream reaches could affect the gene pool, the species present, the community structure, population dynamics and ecosystems processes in upstream reaches. Human modifications, instream (e.g. the construction of dams and weirs) and to stream catchments (e.g. agriculture and urbanisation) may reduce water quality and change flows fragmenting continuous habitat and causing disjunct distributions of organisms (Benstead et al. 1999, Boubée et al. 1997). Furthermore, Fraser and co-workers (1995) show that predatory fish in mainstem rivers fragment prey populations in Trinidad streams. It is possible that the number of juveniles of shortjaw kokopu and other diadromous fish species that recruit to adult populations are affected by predatory fish, land use changes, and other human influences in areas downstream of adult habitat:

The objective of this chapter was to determine if the number of juveniles recruiting to adult habitat is limiting the abundance of shortjaw kokopu populations. I investigated some of the mechanisms that may indicate if recruitment is limiting and the factors that potentially affect the number of juveniles making it to adult habitat.

METHODS

Study area

The Aorere River is situated in north-west Nelson, in the northern South Island, New Zealand. It originates in the Tasman Mountains, flowing north-east and entering the sea at Collingwood in Golden Bay (Fig. 2.1). The lower reaches of the Aorere River flow through one of the few areas of low lying topography in north-west Nelson. The majority of this low lying topography has been developed for dairy farming. However, the upper reaches of the Aorere River and many of its tributaries originate in protected native forest managed by the Department of Conservation.

Data collection

Aorere River survey 2001

Twenty-three tributaries of the Aorere River were surveyed in 2001, between and including the months of January to March. Initial site selection was from NZMS 260 1:50 000 topographical maps. Sites were visited during the day to check for accessibility and where necessary obtain permission from landowners. Site selection was based on recommendations from reports on shortjaw kokopu habitat, and experience gained throughout this survey.

A 400 m site was marked using flagging tape and rock cairns for ease of relocation. Spotlighting was used to survey shortjaw kokopu. A period of two hours after sunset was allowed before night time survey work began. This allowed fish to move from day time cover and assume feeding positions. Two surveyors worked their way methodically upstream using a 35 watt or 50 watt spotlight powered by 12 volt dry cell batteries to light the water column. Each surveyor also wore a headlamp and used hand held dip nets to capture fish. Switching from a high beam light source (spotlight) to a lower beam light source (headlamp) created less disturbance to fish. Headlamps also freed both hands and increased manoeuvrability of hand held dip nets used for capturing fish. All shortjaw kokopu captured were measured. When individuals evaded capture and a positive identification was made, length was estimated (± 10 mm). Spotlighting methodology is described in more detail in Chapter Two.

Juvenile galaxiid survey 2002

During the month of January 2002 six tributaries of the Aorere River were spotlighted at differing distances inland (Table 5.1). The six tributaries surveyed were known to contain adult shortjaw kokopu populations. Surveyors looked specifically for juvenile galaxiids. In five of the sites, two 100 m reaches were sampled. At the sixth site only 100 m was sampled due to poor spotlighting conditions. All juveniles were captured, measured and identified. When juveniles could not be identified to species they were recorded as 'unidentified juvenile galaxiid'.

Table 5.1 Tributaries of the Aorere River spotlighted for juveniles in January 2002. Distance inland and altitude were estimated from topographical maps, NZMS 260, 1: 50 000.

Stream	Grid reference	Distance inland (km)	Altitude (m)
Otimataura	M25 764578	6	40
Little Granity	M25 747545	15	50
Kaituna	M25 723558	18	50
Salisbury	M25 706446	26	80
Eliot	M25 647418	34	120
Fossil	M26 633397	36	125

Influence of trout density

Biomass estimates of trout (*Oncorhynchus mykiss* and *Salmo trutta*) in the mainstem of four of the river catchments (the Aorere River, Takaka River, Pelorus River and Buller River) sampled for shortjaw kokopu were obtained from the Nelson Marlborough Fish and Game Council. Data were collected by drift diving. Drift diving is used to rapidly assess population abundance of fish species and is useful technique in large deep river systems (Cochran 1977). In this study estimates were made of fingerlings (< 100 mm, FL), small trout (101 – 180 mm, FL), medium trout (181 – 250 mm, FL) and large trout (> 250 mm, FL). These size classes are only approximate as they were visual estimations. Comparisons of trout biomass among rivers may be limited because of variability within rivers (for example, seasonally, yearly and longitudinally) and the choice of sampling location. Nevertheless, these measurements provide the best available indication of trout biomass in the mainstem of rivers sampled. Trout abundance (kg/km) was worked out using the following formula: (large brown trout, bt + large rainbow trout, rt) x 1.16 + (medium rt x 0.343) + (small rt x 0.043) + (medium bt x 0.31) + (small bt x 0.04) and then worked out in relation to the length of the drift dive (Graynoth and Tierney 1990, N. Deans pers. comm.). To compare rivers of different widths, biomass (g/m²) was then calculated. Biomass data were available for more than one year, therefore I calculated an average biomass for each river.

The number of tributaries containing shortjaw kokopu, at each of the four rivers that trout biomass data were available, were obtained from the New Zealand Freshwater Fish Database (NZFFD).

Analysis

Aorere River survey 2001

Distance inland and altitude for each stream was obtained from NZMS 260 1:50 000 topographical maps. The relationships between shortjaw kokopu density, distance inland and altitude were tested using linear regression and ANOVA. Normality assumptions were assessed and where necessary data were transformed. The length frequency of shortjaw kokopu in tributaries of the Aorere River was analysed. Tributaries where shortjaw kokopu occurred were placed in the following categories: lower Aorere River (< 11 km inland), mid Aorere River (between 12 and 19 km inland) and upper Aorere River (> 20 km inland). A chi-square test of independence was used to determine if the size distribution of shortjaw kokopu was independent of distance inland.

Survey for juvenile galaxiids

The percent of the total number of juveniles captured that were positively identified to species was calculated. To test the relationship between distance inland, altitude and the density of all juvenile galaxias linear regression was performed and tested with ANOVA.

RESULTS

Aorere River survey 2001

The density of shortjaw kokopu decreased with increasing distance inland ($r^2 = 0.313$, $F_{1,16} = 7.280$, $p < 0.05$) (Figure 5.1). Shortjaw kokopu density also decreased with increasing altitude ($r^2 = 0.272$, $F_{1,16} = 5.991$, $p < 0.05$). The length of shortjaw kokopu was independent of distance inland (chi-square = 9.344, $df = 8$, $p > 0.05$, Figure 5.2).

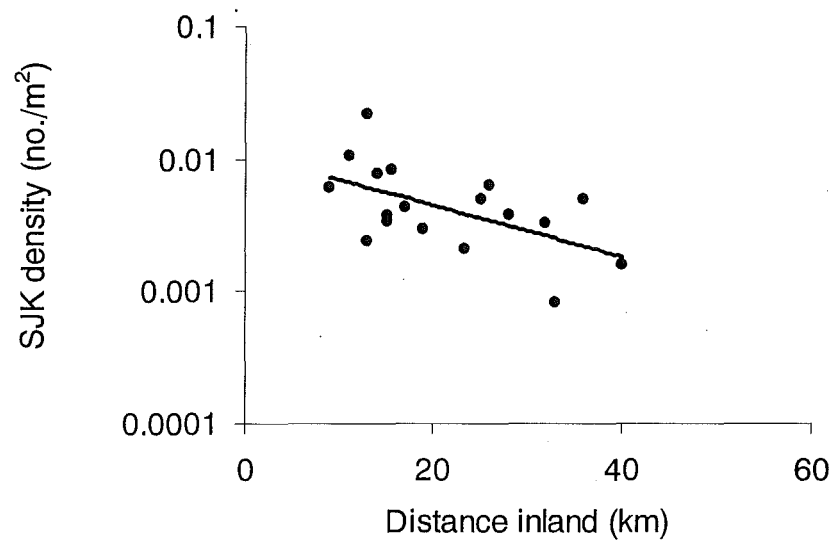


Figure 5.1 Relationship between distance inland (kilometres) and the density of shortjaw kokopu (SJK) individuals per metre squared. Note log scale.

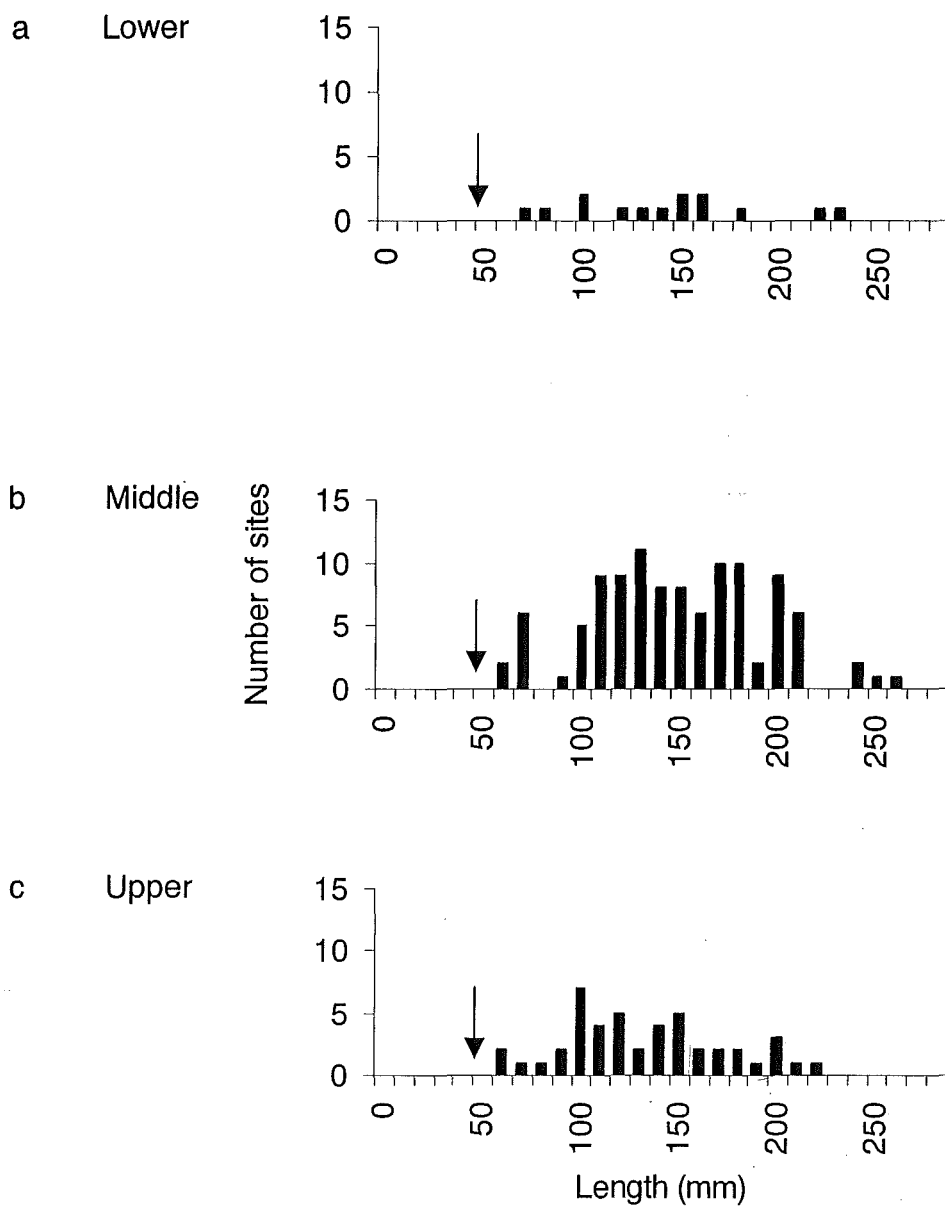


Figure 5.2

Size frequency of shortjaw kokopu in lower (< 11 km inland), middle (12 to 19 km inland) and upper (> 20 km inland) tributaries of the Aorere River. Arrow indicates the approximate size at which juveniles return to freshwater habitat.

Juvenile galaxiid survey

Fifty-nine juvenile *galaxiids* were captured from six tributaries of the Aorere River. Of these, 20 % were identified as shortjaw kokopu, 19 % as banded kokopu and 8 % as koaro. The remaining 53 % were not able to be reliably identified, however they were likely to be one of the above species (i.e. not inanga or giant kokopu). Juveniles ranged from 40 mm FL to 95 mm FL (Figure 5.3). The smallest individuals identified for each species were, 42, 43 and 53 mm FL for shortjaw kokopu, banded kokopu and koaro respectively. All fish > 60 mm were reliably identified. For the following analyses all species were grouped together to generate hypotheses about the possible relationships between altitude, distance inland and the density of juvenile migratory *Galaxias* species.

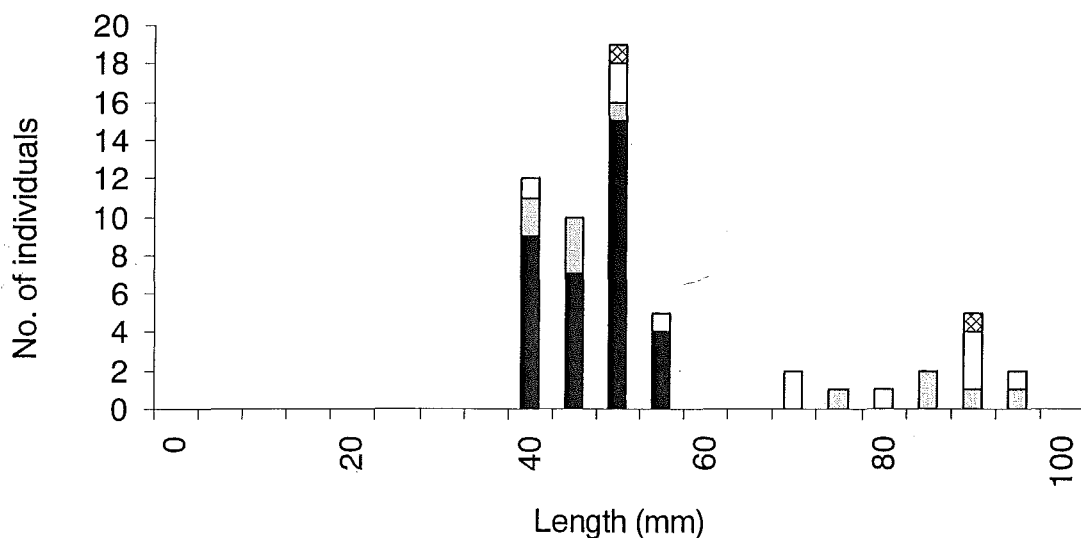


Figure 5.3

Number of juvenile galaxiids captured, showing the proportion of unidentified *Galaxias* species (black sections), banded kokopu (grey sections), shortjaw kokopu (unfilled sections) and koaro (cross-hatched sections).

In the Aorere River system there was a significant relationship ($r^2 = 0.954$, $F_{1,4} = 82.27$, $p < 0.05$) between the density of juvenile *Galaxias* species and distance inland. Density of juveniles decreased with distance from the mouth of the Aorere River (Figure 5.4). There was also a decline in juvenile density with increasing altitude ($r^2 = 0.922$, $F_{1,4} = 47.574$, $p < 0.05$). There was no significant relationship between distance inland and the average size of juveniles captured ($r^2 = 0.006$, $F_{1,4} = 0.025$, $p = 0.88$).

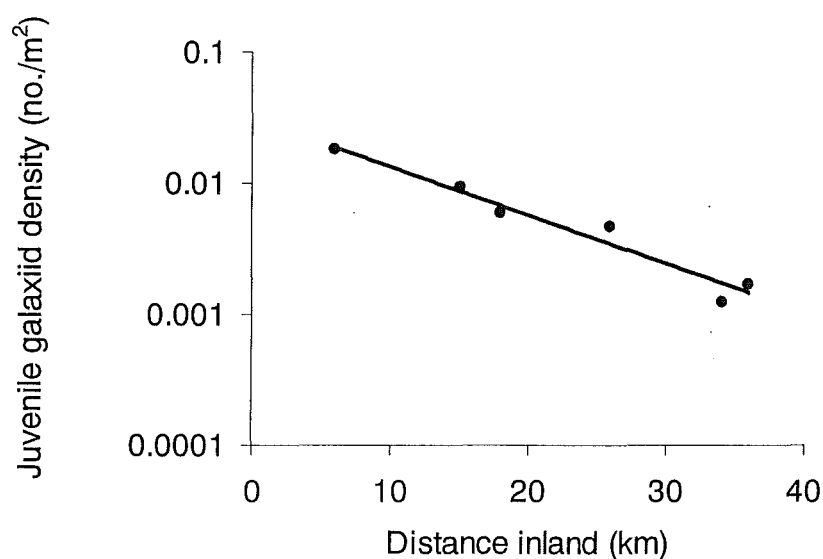


Figure 5.4 The relationship between the density (no./m²) of juvenile galaxiids and distance inland in tributaries of the Aorere River. Note log scale.

Trout density

In the Aorere River there was a low density of trout and a high number of tributaries with shortjaw kokopu, whereas in the Buller River there was a high trout density and a low number of tributaries that contained shortjaw kokopu. However, the Takaka and Pelorus Rivers had low trout densities and a low number of tributaries that contained shortjaw kokopu (Figure 5.5).

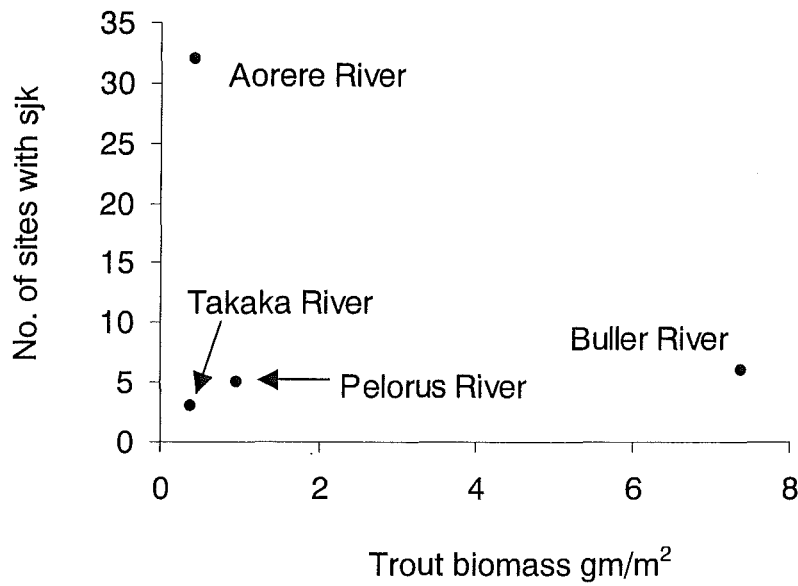


Figure 5.5 Number of sites (tributaries) known to contain shortjaw kokopu (sjk) in the Aorere River, Takaka River, Pelorus River, and Buller River.

DISCUSSION

Juvenile galaxiid density and distance inland

In this study, there was a significant decrease in the density of juvenile migratory galaxiids (< 100 mm, FL) with increasing distance inland and increasing altitude. There are a number of possible explanations for these findings. Juveniles may feed and grow as they move upstream, so when they reach upstream habitat they may be approaching adult size (McDowall and Eldon 1980, McDowall et al. 1996a). Size structure of fish species has been found to shift with increasing inland penetration (McDowall 1965, McDowall 1973). McDowall (1998) pointed out that in large river systems or in coastal streams where habitat is suitable further inland, the size of fish will increase, as they grow while moving upstream. The average size of juveniles in the current study was similar among tributaries. However, in this analysis, all

juvenile *Galaxias* species (*G. brevipinnis*, *G. fasciatus*, and *G. postvectis*) captured were clustered together so the pattern observed may be related to size variation of different species.

The low upstream density of juvenile galaxiids in this study may also reflect fluctuations and surges of juveniles returning from the marine environment, as juveniles may have had insufficient time to reach upstream habitat. Larval galaxiids have been recorded in the marine environment all year round (Hickford, 2000). Thus, juveniles may enter river mouths throughout the year, however peaks occur from August through to December (McDowall and Eldon 1980, Charteris 2002). In the current study, data on juvenile galaxiids were collected in January, therefore juveniles are likely to have had time to reach adult habitat in upstream tributaries. The presence of individuals as small as 55 mm FL in upstream reaches confirms this. The observed pattern of juvenile density indicates that the availability of recruits decreases upstream. Nonetheless, sampling bias needs to be considered. Variability in spotlighting conditions may have affected these results because data were collected over several nights and differences in habitat availability for juveniles within streams were not taken into account. However, it is unlikely that there was a systematic bias leading to a greater chance of detecting fish downstream.

Shortjaw kokopu density and distance inland

The density of shortjaw kokopu (all individuals) also decreased with increasing altitude and distance inland. However, these relationships were not as strong as those for juvenile galaxiids. This is to be expected because as individuals become older, size structure is less likely to reflect recruitment and more likely to be affected by deterministic processes. The size of shortjaw kokopu was not dependent on distance inland in the current study. All tributaries surveyed were less than 50 km inland and well within the migration range of shortjaw kokopu. However, there were fewer shortjaw kokopu individuals in lower tributaries (< 11 km inland). This may be related to the presence of intensive land use practises (agriculture) in downstream tributaries. Furthermore, it is possible that the low numbers of shortjaw kokopu in downstream tributaries may be related to high densities of other fish species that are more tolerant to anthropogenic disturbances.

In summary, it appears that the availability of recruits could limit shortjaw kokopu populations. However, a more detailed investigation distinguishing shortjaw kokopu juveniles from juveniles of other large-bodied *Galaxias* species and accounting for the number of shortjaw kokopu whitebait entering freshwater habitat needs to be carried out before stronger conclusions, can be made. Understanding the factors that contribute to the abundance of juvenile shortjaw kokopu and other diadromous fish species recruiting to adult habitat is important for conservation and management.

Downstream-upstream linkages

Fluctuations in the abundance of juvenile galaxiids may be related to several processes operating in the marine and freshwater environments (McDowall and Eldon 1980). The number of larvae entering the marine habitat is influenced by environmental conditions, affecting spawning and egg development. For example, large-bodied *Galaxias* nests are found above base flow among substrate, therefore eggs may suffer pre-hatching mortality from desiccation (McDowall 1990a, Charteris 2002). In New Zealand, added pressures from whitebaiters, landuse modifications, man-made structures (dams and weirs) and introduced predatory fish are likely to affect recruitment (Joy & Death 2000, Charteris 2002). Pringle (1997) suggested that modification of lower reaches (via water abstraction and channel modification) for example, may cause population and community level changes in native species upstream. In this study, shortjaw kokopu juveniles were able to move through modified areas to reach adult habitat (Chapter Three). However, it is unknown to what extent habitat is modified before juveniles are inhibited (however see Rowe et al. 1992). Furthermore, it is possible that predatory fish species in areas downstream of adult habitat influence the number of juveniles recruiting to the adult population.

At the site scale, shortjaw kokopu co-occurred with small and large trout (Chapter Four). However, this relationship needs to be explored further to understand the mechanisms allowing co-occurrence. Mainstem rivers containing high densities of predatory fish present a high risk environment for prey species (Fraser et al. 1999). At the catchment scale the biomass of predatory brown trout downstream of adult habitat may affect recruitment of juvenile shortjaw kokopu to the adult population. The movement of migratory fish and their selection of habitat may be influenced by

the presence of predators in areas they disperse through. In Trinidad the presence of predatory fish fragmented prey populations and dispersal was blocked by predators killing prey species (Fraser et al. 1999).

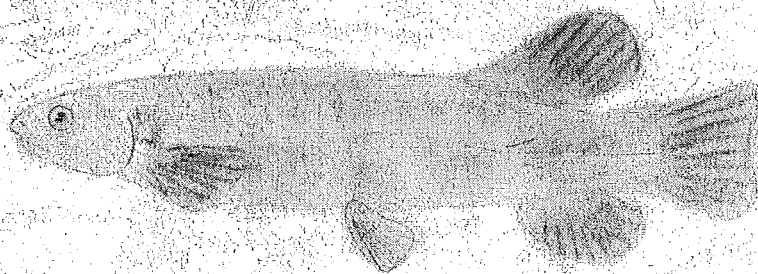
In the Aorere River, the biomass of trout is relatively low compared to the Buller River. The Aorere River has a high number of tributaries containing shortjaw kokopu, compared to the Buller River. These two data points indicate that the biomass of trout downstream could affect shortjaw kokopu populations in tributaries. However, the biomass of trout in the mainstem of the Takaka and Pelorus Rivers are similar to the Aorere River trout biomass and both have few tributaries that contain shortjaw kokopu. Migration by shortjaw kokopu and other diadromous fish species may be impeded in the Takaka River by subterranean drainage and water extraction. It is possible that tributaries of the Pelorus River may have more 'suitable' trout habitat than tributaries of the Aorere River. Therefore, migratory access may be having a larger influence on shortjaw kokopu populations than the biomass of trout in the Takaka River. In the Pelorus River, competition between shortjaw kokopu and trout in tributaries and predation of shortjaw kokopu juveniles in the mainstem may have cumulative affects on shortjaw kokopu populations. It is possible that shortjaw kokopu are found in low numbers in the Buller River because of the lack of 'suitable' habitat. The Buller River catchment is covered by a high proportion of beech forest. McDowall (1997b) found that shortjaw kokopu were largely absent from streams passing through pure beech forest. However, habitat in tributaries of the Buller River are suitable for shortjaw kokopu. Shortjaw kokopu whitebait have been documented from the Buller River (Eldon 1983) and McDowall and co-workers (1996b) suggested that there may be substantial populations of shortjaw kokopu in the tributaries of the Buller River that are undiscovered. Shortjaw kokopu were recorded from two tributaries in the mid reaches of the Buller River in this study.

These explanations are still speculative and further research with a larger data set is required before strong conclusions can be made about the possible affect of trout predation on recruitment of shortjaw kokopu and other diadromous fish species. However, it seems possible that where habitat allows trout to reach high abundances and migratory access for shortjaw kokopu is unimpeded, that trout may influence the number of recruits reaching adult habitats. An interesting experiment would be to

transport shortjaw kokopu juveniles upstream and into streams without adults, and monitor the density of adult populations. My work here indicates that populations could be enhanced if recruitment is increased.

"All art, all education, can be merely a supplement to nature."

Aristotle



CHAPTER SIX

Discussion

The abundance of shortjaw kokopu:

Naturally uncommon or impacted by humans?

Accurate and up-to-date data sets on the distribution and abundance of organisms are important when strategies need to be implemented to conserve and protect threatened species from further decline, and ultimately extinction. Moreover, establishing the reasons for the patterns seen in their distribution and abundance is important to prevent declines (Eldon 1993, Gaston 1994, deLange and Norton 1998, Young and Harig 2001). In 2002 shortjaw kokopu were recorded at 2.7 % of the greater than 18 000 sites on the New Zealand Freshwater Fish Database (NZFFD). This is an increase of 0.7 % from those recorded prior to 1996 when they were recorded as widely, but sparsely distributed throughout New Zealand, with few individuals (usually less than 3) captured at each site (McDowall et al. 1996a). Recent research (1998 to 2002) on shortjaw kokopu indicates that this species is more abundant in some areas of New Zealand than previously thought (Nelson Marlborough: Studholme et al. 1999, Jack and Barrier 2000, Jack et al. 2001; West Coast, South Island: Eastwood 2001; Taranaki: Caskey 1999, Bowie 2002, Charteris 2002). In this study, shortjaw kokopu were found in 77 of the 148 streams surveyed. Twenty five percent of sites had ten or more individuals. More research on shortjaw kokopu is required to establish whether these patterns hold true for the rest of New Zealand. Accurate records of shortjaw kokopu distribution and abundance will assist with the management and conservation of this species. This work indicates that shortjaw kokopu may be nationally rare, but locally common. This pattern may be attributed to natural processes, or to the influence of humans (Gaston 1994, deLange and Norton, 1998). To aid future management it is important to determine which is true.

Naturally uncommon

It is possible that compared with the other large-bodied *Galaxias* species (banded kokopu, giant kokopu and koaro), shortjaw kokopu have always been uncommon. Although identification and taxonomy of large-bodied *Galaxias* species were confused, the first descriptions of banded kokopu Gray 1842, giant kokopu Gmelin 1789 and koaro Gunther 1866 were made over thirty years before shortjaw kokopu (Clarke 1899). By the time Clarke (1899) described shortjaw kokopu, illustrations of giant kokopu, banded kokopu and koaro could be easily recognised. In contrast, illustrations of shortjaw kokopu made by Clarke (1899) and Whitley and Phillips (1939) (drawn from observations of a preserved specimen) provided a much lower basis for their recognition. It becomes clearer after reading Clarke's (1899) description of *Galaxias postvectis* and Whitley and Phillips (1939) description of *Galaxias charlottae*, that these authors are describing what are now commonly known as shortjaw kokopu. In summary, it appears possible that shortjaw kokopu may always have been more uncommon than other large-bodied *Galaxias* species. It is also possible that shortjaw kokopu were nationally rare, but locally common (sensu Gaston 1994). Early naturalists may not have sampled areas where shortjaw kokopu were common. Furthermore, their evasive nature may well have played a role in making them an 'enigmatic' species (Eldon 1983).

Human influences

Sampling methodology

In the past, the most commonly used sampling technique for documenting freshwater fish species in New Zealand streams and rivers was electrofishing. Sixty five percent of the 13396 sites on the NZFFD prior to 1999 were sampled by electrofishing, whereas only 42 % of the 4265 records subsequent to 1999 used electrofishing. The high abundance of shortjaw kokopu captured in this study using spotlighting methodology, suggests that past sampling techniques may have contributed to the apparent rarity of shortjaw kokopu. For example, because distributions of shortjaw kokopu in streams are patchy and electrofishing is usually carried out over a small area, the chance of detecting this species with electrofishing methodology may be

low. Whereas, large areas of stream can be sampled using spotlighting methodology, and thus the probability of finding shortjaw kokopu is higher.

To obtain the best estimate of species distribution, presence and abundance, a combination of methods may yield the best results. Furthermore, when choosing a sampling technique the type of data required and the scale of the study need to be considered. For example, electrofishing may be efficient for determining the density of shortjaw kokopu in a known population, whereas spotlighting may be better for rapidly assessing the abundance of shortjaw kokopu.

Habitat fragmentation

It is possible that shortjaw kokopu were once more common, throughout New Zealand. However, the past distribution and abundance of galaxiids and other freshwater fish species is not well documented and largely anecdotal (McDowall 1990). The widespread distribution of shortjaw kokopu throughout New Zealand, with some areas of high abundance, implies that shortjaw kokopu may have declined in distribution and abundance since the arrival of Europeans. It is likely that deforestation, land conversion, the introduction of exotic species and direct in-stream modifications have contributed to the fragmented distributions and reduced abundance of native fish populations seen today (Main 1988, McDowall 1990a, Townsend and Crowl 1991, McDowall 1995, Boubée et al. 1997, McIntosh 2000).

Past studies indicate that shortjaw kokopu and other large-bodied *Galaxias* species are associated with native forest (Main 1988, McDowall et al. 1996a, McCullough 1998). The relatively high abundance of shortjaw kokopu in the Nelson Marlborough conservancy can be partially attributed to the high proportion of intact native forest. For example, 68 % of streams had 70 % or more of their catchments covered by native forest. No conclusions could be made about the 'preference' of shortjaw kokopu for streams passing through native forest over exotic forest because of the low number of sites that contained greater than 50 % of exotic forest in the riparian zone and catchment. Shortjaw kokopu do show some habitat 'selection' for forested streams. However, habitat is not the only factor limiting shortjaw kokopu. Shortjaw kokopu were absent from nearly 50 % of the streams surveyed.

Habitat fragmentation creates disjunct distributions of organisms (With and Crist 1995). Depending on the extent and type of habitat modification the movement of organisms can be restricted and in some cases completely inhibited (Fraser et al. 1995, Wiens et al. 1997). Some species, or life stages of species, have the ability to move through 'hostile' habitat to reach 'suitable' habitat for growth and reproduction, whereas other organisms may be restricted, therefore inhibiting movement to 'suitable' habitat fragments (Andren 1994). Migratory freshwater fish species can be restricted by water abstraction and the construction of dams and weirs (Pringle 1997, Benstead et al. 1999). Furthermore the quantity of suspended solids in streams and rivers may influence river mouth selection by juvenile migratory *Galaxias* species (Rowe et al. 1992, Boubee et al. 1997). In this study, it appears that shortjaw kokopu juveniles can move through modified (or 'hostile') areas to reach adult habitat. However, the proportion of juveniles (whitebait) entering freshwater habitat that recruit to the adult population is unknown. The extent to which the movement of juveniles is restricted by degraded habitat needs further research (however, see Boubee et al. 1997, Charteris 2002).

Factors affecting community composition

Many theoretical models have been constructed to predict community composition and the distribution and abundance of species in relation to biotic and abiotic factors (Peckarsky 1983, Townsend 1989, Vannote et al. 1980, Ward 1989, Yodzis 1986). Some models appear to be supported by empirical data (Peckarsky 1983, Townsend 1989, Vannote et al. 1980, Ward 1989). However, no single model explains all or even most patterns of species and community dynamics (Townsend 1989, Dunston and Travis 1991). A combination of dispersal and biotic interactions probably determine community structure of freshwater fish communities in the Nelson Marlborough conservancy.

Diadromy could be important in determining the outcome of interaction between large-bodied galaxiids. Greater than 50 percent of New Zealand freshwater fish species migrate between the freshwater and marine environments (McDowall 1990a, McDowall 2000). Therefore, one of the strongest influences on these communities is

diadromy (McDowall 1996, McDowall 1998). McDowall (1996) suggests that the occurrence of diadromy in freshwater fish communities equates to relatively open communities. Diadromy strongly influenced the fish communities in stream reaches surveyed in the Nelson Marlborough area, thus they were relatively 'open'.

Diadromy could be important in determining the outcome of interactions between large-bodied galaxiids. The specific mechanisms that allow large-bodied *Galaxias* species to co-occur were not researched in this study. It may be that competitive interactions between species are not strong, for example because spatial variation, temporal variation and the mobility of species are high, or because strong competition has led to competitive exclusion (i.e. niche controlled communities) (Hardin 1960, Yodzis 1986). A recent study showed that koaro occupied different habitat in the absence of banded kokopu and longfin eel (Chadderton and Allibone 2001). Similar observations have been made by Hayes (1995 and 1996) and Main (1988) regarding the habitat occupancy of koaro. The composition and structure of large bodied *Galaxias* species communities may also be 'founder'- or 'dominance'- controlled (sensu Townsend 1989) because dispersal plays such a large part in determining community composition. Evidence suggesting that interactions between diadromous galaxiids may be affected by 'founder' – or 'dominance' – controlled processes, is the potential for juveniles to home to pheromones from adult conspecifics (Baker and Montgomery 2001). Thus, even though there is the potential for juveniles to repopulate new areas, fish assemblages may be influenced by the presence of adults. Townsend's (1989) theory of patch dynamics explaining community organisation may be the best model to apply to and explain 'open' diadromous fish communities because it envisages different mechanisms operating in different situations (e.g. with varying distances from the sea). This model emphasises temporal variation, the patchiness of streams, the colonisation ability and the life-cycle differences of species, and therefore it encompasses abiotic, biotic, stochastic, and deterministic factors.

Introduced species

Introduced brown trout were found to co-occur with shortjaw kokopu at the site scale. This co-occurrence is interesting because the distribution of non-migratory *Galaxias* species has been negatively affected by trout (Townsend and Crowl 1991, Crowl et al. 1992, McIntosh et al. 1994, Allibone 1999, McIntosh 2000). For example, McIntosh (2000) found that large piscivorous trout (greater than 150 mm Fork Length, FL) excluded non-migratory *Galaxias* species from stable streams in Canterbury. However, non-diadromous *Galaxias* species co-occurred with small non-piscivorous trout in the Canterbury streams (McIntosh 2000). Large trout were able to exclude *Galaxias vulgaris* because they were able to prey on all sizes of individuals (i.e. there was no size refuge). Bed-stability also restricted the distribution of large trout to stable sites and non-migratory *Galaxias* species occupied a wider range of streams than large trout (McIntosh 2000). One of the mechanisms that therefore promoted the persistence of non-migratory *Galaxias* was disturbance.

Inter-specific interactions between shortjaw kokopu and trout were not explored at a micro-habitat scale. However, shortjaw kokopu were more likely to co-occur in streams where trout were rare or occasional, than where they were common or abundant. I can only speculate on the mechanisms behind this observation. It is possible that where the abundance and size of trout is limited by the lack of holding water and stable spawning gravels, that shortjaw kokopu and trout can co-occur. However, in streams where conditions are favourable and trout become abundant, resources (for example, food and space) may become limited and competitive exclusion of shortjaw kokopu may occur leading to interactive segregation (Chapman 1966, Nilsson 1967, Cadwallader 1975, McIntosh et al. 1992, Bohn and Amundsen 2001).

Habitat patchiness within streams and the patchiness of tributary habitats within larger catchments may also allow the co-occurrence of shortjaw kokopu and trout at the site scale (sensu Townsend 1989). Furthermore, it is possible that the relationship between trout and shortjaw kokopu is offset by diadromy. The constant invasion/reinvasion of habitat by shortjaw kokopu juveniles from the marine environment may replace individuals that are eaten or displaced by trout.

The current study did not take into account possible temporal variation in trout abundance within streams. The majority of streams that contained shortjaw kokopu and trout were tributaries of the Aorere River. These tributaries are used by adult trout to spawn in during winter freshes (N. Deans, *pers comm.*). It is possible that the threat posed by trout to shortjaw kokopu in spawning tributaries is greater in high flows. Furthermore, shortjaw kokopu spawn in the months of May and June and may be more vulnerable to predation by piscivorous fish species (Charteris 2002). This hypothesis is contrary to the harsh-benign theory of community structure (Connell 1975, Menge 1976, Menge and Sutherland 1976, Peckarsky 1983) that states that competition and predation are more prevalent in stable environments. However, it is similar to findings that suggest the threat of predation increases in high flows (Thomson et al. 2002). In a study on the effects of a predatory stonefly on a mayfly species, Thomson and co-workers (2002) found that nonlethal predator effects (i.e. predator induced prey emigration) were increased in variable flows.

Gilliam and Fraser (2001) showed that the effects of predators on prey fish species in Trinidad rivers were context dependent (i.e. dependent on abiotic factors, and body size), and that the net movement of prey species was enhanced by the same factor, predation threat, that produced the initial spatial fragmentation of prey species. Similarly, interactions between shortjaw kokopu and trout are probably context dependent. There are obviously many factors that need to be taken into consideration, for example micro-habitat occupancy of trout and shortjaw kokopu, temporal variation in trout abundance and dispersal of juvenile galaxiids, before robust conclusions can be made about the nature of relationships between introduced trout and shortjaw kokopu.

Shortjaw kokopu population structure

Recruitment

Knowledge of the whole life cycle and the factors that limit population size is important for the future conservation of shortjaw kokopu. The density of shortjaw kokopu (all individuals) and the density of juvenile galaxiids decreased with increasing distance inland in Aorere River tributaries. Habitat does not appear to be a

strong factor limiting shortjaw kokopu so the number of recruits could be limited. However, even though the density of juveniles decreases with increasing distance inland, it appears that the few individuals that do reach upper tributaries can sustain low density upstream sub-populations. Nevertheless, an increase in recruitment would be expected to substantially increase population density upstream. An interesting experiment would be to transport juveniles upstream to see if populations could be increased.

Strong conclusions can not be made about the effect of trout on the density of juvenile migratory galaxiids because of the lack of information on trout biomass in downstream reaches of rivers. However, it is likely that trout, eels and possibly giant kokopu predate on whitebait as they move upstream to adult habitat. The biomass of trout in areas downstream of adult shortjaw kokopu habitat may influence the number of juveniles recruiting to the adult population. This issue needs further investigation.

Population dynamics

Shortjaw kokopu are a widespread species (McDowall 1990a). The abundance of widespread species can be characterised by many "cool spots" where a species is rare (few individuals) and a few "hot spots" where a species is particularly abundant (Brown et al. 1995). The current pattern of shortjaw kokopu abundance in the Nelson Marlborough conservancy fits this model. "Hot spots" include the Kaituna River, a tributary of the Aorere River where shortjaw kokopu are abundant (40 individuals), the Awapoto River (29 individuals), a coastal stream on the Abel Tasman coastline, as well as 23 % of all streams surveyed. The remaining 77 % of streams surveyed can be characterised as "cold spots" where there are few individuals.

If the distribution pattern is examined at a national scale, Nelson/Marlborough, the West Coast of the South Island, the Taranaki region and the Bay of Plenty may be "hot spots" while the remainder of New Zealand are "cold spots". It is also possible that both natural and human influences contribute to this analogy. For example, shortjaw kokopu may always have had "cold spots" and "hot spots" of abundance, but the influence of human modifications and the introduction of exotic species may have made this distributional pattern appear more marked. Furthermore, multi-modal

distributions of prey species (i.e. with high densities in some tributaries and low densities in others (Brown 1984)) may result from predation (Fraser et al. 1995). It is also possible that the distribution and density of migratory fish in streams may be influenced by freshwater plumes, specifically their size, and the distance they reach into the marine environment (Allibone 1995). Smith and Smith (1998) found that migratory fish species were strongly attracted to flowing water. Perhaps, the size of freshwater plumes influences the density of diadromous fish migrating up various streams. More research throughout New Zealand is needed to test this hypothesis.

Conservation implications

This study has contributed to the conservation of shortjaw kokopu by increasing knowledge of their known range and factors controlling their abundance. The use of spotlighting methodology provided a breakthrough in shortjaw kokopu research. This study contributed to the knowledge of fish capture techniques and my findings may be useful for studies on other nocturnally active fish species. With experience, surveyors captured a greater number of juveniles (< 100 mm FL). The ability to find and capture juvenile *Galaxias* species allowed further research to be carried out on recruitment in the Aorere River in 2002. Furthermore, the knowledge that post-whitebait juveniles occupy similar areas, albeit different micro-habitat, to adults, has started to fill a major gap in knowledge relating to the life-history and population dynamics of shortjaw kokopu and other migratory *Galaxias* species.

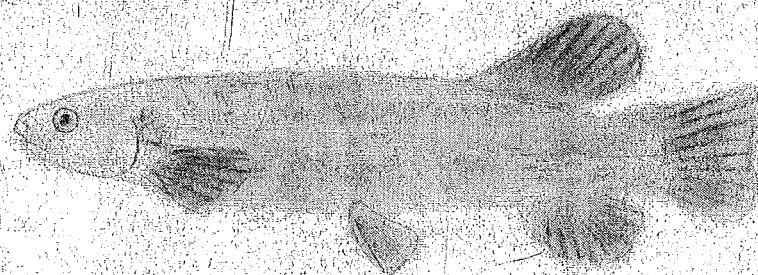
The Nelson Marlborough conservancy is a stronghold for this species. A large number of streams in this region contained shortjaw kokopu, often with more than four individuals. This finding contributed to the re-assessment of the conservation status of shortjaw kokopu (Molloy et al. 2001) and subsequently to the management of this species. Many sub-populations of shortjaw kokopu and other threatened native fish species observed in the study area are protected in national parks (Kahurangi and Abel Tasman). However, lower reaches of many streams flow through land that has been developed for agriculture (e.g. the Aorere River which originates in Kahurangi National Park).

The Aorere River may be a stronghold for shortjaw kokopu, and because recruitment could limit populations, care needs to be taken to ensure that the migratory path of diadromous fish species is not inhibited. Furthermore, it is likely that in the Aorere River shortjaw kokopu juveniles may make up a significant proportion of whitebait captures in some areas (e.g. the Aorere River). Restrictions on whitebaiting may be important for reducing mortality of juveniles, and therefore increasing the pool of recruits making it to adult habitat.

It is extremely unlikely, and it would be logistically very difficult for trout to be eradicated from all New Zealand streams and rivers. Therefore, managers of game fish and native fish should work together to mitigate the deleterious effects of habitat degradation on freshwater fish populations and where possible enhance in-stream and riparian zone values. However, in streams with high native fish values freshwater reserves could be created. Perhaps in these streams, if trout are present they could be eradicated or at least controlled. For example, stocking could be discontinued, or open seasons could be declared for trout fishing. Further research on trout and migratory galaxiid interactions needs to be carried out. Research should be aimed at mechanisms that allow the co-occurrence of trout and shortjaw kokopu at the site scale. Furthermore, it may be especially important to understand the effect of trout predation on juvenile migratory galaxiids, if as my findings suggest, adult populations are recruit limited.

"All night I looked through the dictionary but could not find the words."

Paul Reps



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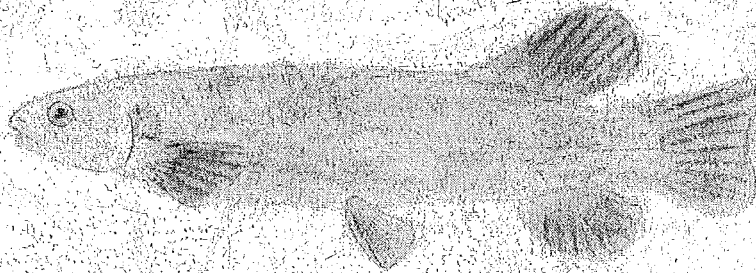
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"By the time it came to the edge of the Forest the stream had grown up, so it was almost a river, and, being grown-up, it did not run and jump and sparkle along as it used to do when it was younger, but moved more slowly.

For it knew now where it was going, and it said to itself, "There is no hurry. We shall get there some day." But all the little streams higher up in the Forest went this way and that, quickly, eagerly, having so much to find out before it was too late."

A.A. Milne



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